2022

ASSESSMENT OF LEAD IMPACT ON HUMAN AND INDIA'S RESPONSE

सत्यमेव जयते

NITI Aayog

Council of Scientific and Industrial Research (CSIR)

Chief Coordinator

Dr Rakesh Kumar

Editor

Dr Sunil Kumar

Contributing Authors

Dr Atya Kapley

Er Ankit Gupta

Design Credits

Mr. Himanshu Kumbhare

Suggested citation:

Rakesh Kumar et al., 2022 Assessment of Lead Impact on Human and India's Response

Disclaimer

All views, analyses and findings in this work are those of the authors and are based on the information available in public domain The purpose of this report is to understand the need of the problems associated with lead contamination and present views with regard to future steps. This does not in any form indicate the position of Government.

Table of Contents

Abbreviations

ALAD	=	*Aminolaevulinic Acid Dehydratase*
ALT	=	*Alanine Aminotransferase*
AP	=	*Arithmetic Mean*
BLL	=	*Blood Lead Levels*
CDC	=	*Disease Control and Prevention*
CPCB	=	*Central Pollution Control Board*
CSIR	=	*Council of Scientific & Industrial Research*
DALYs	=	*Disability-Adjusted Life Years*
E-waste	=	*Electronic Waste*
GBD	=	*Global Burden of Disease*
GDP	=	*Gross Domestic Product*
GM	=	*Geometric Mean*
HZL	=	*Hindustan Zinc Ltd*
IHME	=	*Institute for Health Metrics and Evaluation*
ILL	=	*India Lead Ltd.*
IQ	=	*Intelligence Quotient*
MoEF&CC	=	*Ministry of Environment, Forest and Climate Change*
MSW	=	*Municipal Solid Waste*
NEERI	=	*National Environmental Engineering Research Institute*
NITI	=	*National Institution for Transforming India*
Pb	=	*Lead*
PCBs	=	*Printed Circuit Boards*
PICA	=	*Persistent and Compulsive Cravings to Eat Non-food Items*
PPE	=	*Personal Protective Equipment*
SPCB	=	*State Pollution Control Board*
ST-GPR	=	*Spatiotemporal Gaussian Process Regression*
ULAB	=	*Used Lead-Acid Battery*
UNICEF	=	*United Nations International Children's Emergency Fund*
WHO	=	*World Health Organization*
XRF	=	*X-ray Fluorescence*

Acknowledgement

I would like to acknowledge all the researchers and authors who have carried out research and published papers on lead toxicity in various parts of India. The subject being so complex needs special efforts to reach out to the population which is affected from multiple sources.

All authors would like to express sincere gratitude to Shri Rajiv Kumar, Former Vice Chairman of NITI Aayog, who initiated this work after a comprehensive consultation with experts. We are extremely thankful to Dr. Karti Sandilya Senior Adviser, Pure Earth and Global Alliance on Health and Pollution (GAHP) Washington for his meticulous suggestions, sharing of useful information and connecting us with IHME and others in India and elsewhere. Special thanks to his colleague Ms. Promila Sharma for coordinating with him and some resources. We would like to acknowledge the assistance provided by Er. Roshan Wathore, Scientist at CSIR NEERI from time to time.

We also acknowledge all the reviewers including Dr. B. Sengupta Ex. Member Secretary, CPCB, Dr. Meena Sehgal, TERI, New Delhi, Dr. Rajiv Bhirud, Industries expert and Dr. A. Shariff, Professor & Head, Department of Anatomy Founder Professor In-charge, Clinical Ecotoxicology Facility, All India Institute of Medical Sciences, New Delhi for reviewing the report and giving very useful suggestions in improving the quality of the report.

We are very much thankful to DG CSIR for his support. I, on behalf of all authors, am grateful to each one who helped us to carry out this work. This work is entirely based on open source information and interpretation which necessitates reaching out to many through formal and informal routes. We would like to acknowledge all such personnel who have been very supportive.

- *Dr. Rakesh Kumar*
  CSIR

Executive Summary

Lead (Pb) exposures in India are significant. A 2020 report from UNICEF and Pure Earth found that approximately 800 million children's globally are Pb poisoned - over 5 µg/dl in blood. This is about one half of all children in India. At this level, they suffer from reduced intelligence (3 to 5 IQ points), more delinquent and violent behavior and lower educational attainment. According to that report, the effects are permanent, lasting throughout adulthood, thus, one half of the Indian population is significantly impaired from Pb exposures. This amount of Pb poisoning causes significant number of deaths from cardiovascular disease (about 2.3 lakh deaths annually in India).

We examined data from Indian studies to review the findings. A total of 89 data sets from 36 studies carried out between 1970 and 2014 were derived and used in the model. A total of sample size for the model study was 234,678. We found that in 23 states, average Blood Pb Levels (BLL) is well above 5 µg/dl. Averages for the country are high - averaging 4.9 µg/dl for children less than 2 years old. These results corroborate with the findings of UNICEF/Pure Earth report and hence it is likely to be reliable.

There are various sources of Pb exposure in India. Pb from battery recycling contaminates neighborhoods with high levels of Pb. Other occupational sources of Pb contamination include Pb mining and smelting, welding and soldering, and automobile repairing. Pb has been banned from gasoline, yet traces of the element remain along roads and around gas stations. Pb has also been phased out from paint, but a 2015 test found enamel paint cans containing Pb far in excess of mandated limits. Pb-based paint remains on the walls and woodwork in many older homes and apartments, and children are prone to eating paint chips.

Pb is also found in pottery glazes, metallic cookware, adulterated spices (e.g., to enhance the yellow color of turmeric), cosmetics (such as sindoor), and in some traditional medicines (used in Ayurveda).

The health implications of Pb poisoning are majorly consequential, and often irreversible. Pb affects the central nervous, hematopoietic, hepatic and renal systems, producing serious disorders. Youngsters are particularly vulnerable because they absorb 4-5 times as much ingested Pb as adults from a given source of exposure. Depending on the quantity and length of the contamination, the symptoms of Pb poisoning can be mild. But the WHO and US Centers for Disease Control and Prevention have declared that there is no safe level of Pb in blood and 5 µg/dl is the threshold for intervention. Though other metal contaminations are also of concern at few places, however, Pb is of major health concern due to its prevalence and occurrences amongst young.

The way forward for minimizing the negative impacts of Pb poisoning must comprise a series of steps at National and State levels.

- Monitoring of BLLs to identify populations at risk;
- Investigations to trace the source of elevated BLLs (e.g., informal battery recyclers, foodstuffs, paint, etc.,);
- Interventions to (i) close down Pb polluting activities and (ii) physically remediate contaminated sites;
- Training of healthcare personnel to monitor, detect and treat Pb poisoning;
- Educate the public on the seriousness of Pb exposures;
- Undertaking targeted research and intervention study to identify newer sources, if any, and bring new knowledge in the domain of policy makers and scientific community;
- Strict enforcement of regulations intended to control and mitigates Pb pollution (e.g., Battery Handling and Management Rules).

Clearly, our research and the UNICEF/Pure Earth report highlight a major and massive public health crisis in India. This review shows the scale and intensity of Pb poisoning in India, particularly of children, is indeed serious and cannot be ignored any longer. This is an appropriate time for a national mission to effectively and comprehensively tackle Pb contamination in India from multiple sources.

Introduction

In 2020, UNICEF and Pure Earth released a report entitled "The Toxic Truth: Children's Exposure to Pb Pollution Undermines a Generation of Future Potential". It indicated that Pb pollution was related to 230,000 annual premature adult deaths in India (out of 900,000 worldwide). In addition, 275 million children in India (out of 800 million globally or 1 in 3) had BLL that were abnormally high i.e., greater than 5 micrograms per deciliter. In view of the massive scale of the problem, NITI-Aayog requested CSIR/NEERI to undertake an in-depth review of the UNICEF/Pure Earth report, and the underlying data from Institute of Health Metrics and Evaluation (IHME). The objective was to confirm the findings and suggest recommendations for reducing and mitigating Pb exposures in India. This report responds to the request of NITI-Aayog.

This report reviews exposures to Pb in light of that report, reviewing journal articles that include data related to BLLs in India. These are compared against the UNICEF report. Exposures have been evaluated at a broad national level, and occupationally. Sources of Pb are also reviewed and presented. This is done to determine the causes of elevated blood Pb levels. A detailed analysis of the health impact of elevated blood Pb levels is presented along with the recommendations for the way forward and follows up. Details of sources and research in India are outlined in **Annexes**.

Chapter 1

Background and Exposures

1.1. Background and Exposure

Lead (Pb) poisoning occurs due to the intake of lead. Lead is a normal element of the earth's crust, present in soil, plants and water. It is practically an immobile element; however, during the process of mining, it gets scattered and spreads rapidly in the environment, persisting for long periods of time in the ecosystem. Anthropogenic activities also spread Pb through paint, gasoline, water, etc. Pb toxicity is highly hazardous, causing potentially irreversible health effects. It interferes with various body functions, affecting the central nervous system, the reproductive system and the renal system resulting in severe disorders. Inhalation and ingestion of Pb lead to Pb poisoning in employees working as painters, auto mechanics, electric accumulator producers, smelters, and miners, according to Sharma et al. (2021).

According to a WHO report dated 11 October 2021, children are mainly susceptible to Pb poisoning because they absorb 4-5 times more Pb than adults (WHO, 2021). Moreover, infants may swallow Pb-coated substances during the oral phase of child development, when the children tend to put all objects in their mouth. This is the main route of Pb intake in children with a psychological disorder called pica (persistent and compulsive cravings to eat non-food items) (WHO, 2021).

1.2. Lead Exposures in India

The report from the UNICEF and Pure Earth dated 29th July 2020, titled "The Toxic Truth: Children's exposure to Pb pollution undermines a generation of potential", says that India has over 275 million children (about one half of all children in India) with BLLs more than considered safe (five micrograms per deciliter). This is the uppermost level of Pb poisoning cases in children in any country. This report, the first of its kind, says that around 1 in 3 children, up to 800 million globally, have BLL at or above 5 micrograms per deciliter (µg/dL). The effect of Pb on adults is so huge that over 900,000 early deaths per year universally are attributed to Pb exposure.

In 2016, the Institute for Health Metrics and Evaluation (IHME) conducted a study called injuries and risk factors that found that Pb exposure caused 13.9 million Disability-Adjusted Life Years (DALYs) and 540,000 deaths globally. The DALY measure is being used to assess the burden of diseases and also is meant to represent mortality rates in a population related to a particular condition or risk factor (WHO, 2016). IHME discovered 4.6 million Pb-attributable DALYs and roughly 165,000 fatalities in India (IHME, 2017a).

1.3. Study Teams and their Methodology

Data Sources

Data from various studies carried out in India were collated to look at BLL. 89 data points from 36 studies were derived and used in the model. It included both males and females through the age groups from neonatal to old age. The data sets were derived from various studies carried out during the period from 1970 to 2014. The total of sample size for the model study was 234678 (IHME, 2017a).

The state-wise average BLL has been analyzed and presented in **Table 1**. It concludes that 23 states exceed 5 µg/dL limits and Bihar exceeds 10 µg/dL limits.

Table 1: Average BLL prevalence across various States in India (IHME, 2017a)

STATES	BLL (µg/dL)
Bihar	10.42
Uttar Pradesh	8.67
Madhya Pradesh	8.32
Jharkhand	8.15
Chhattisgarh	7.46
Andhra Pradesh	7.14

Odisha	6.94
Assam	6.72
Karnataka	6.62
Telangana	6.61
Tripura	6.55
Tamil Nadu	6.23
Meghalaya	6.12
Rajasthan	5.94
Arunachal Pradesh	5.74

These numbers are in line with the IHME data, which indicates that about one-half of all children in India are over 5 μg/dL (Noting that if the average BLL is 5 μg/dL or more, then one half or more of that population is over that level).

Pb exposure is particularly harmful to children. **Fig. 1** shows the number of children (0-14 years) with > 5 μg/dL and > 10 μg/dL BLL for the top 15 States. Child exposure is particularly high in Uttar Pradesh, Bihar and Madhya Pradesh. Also, in these states, more male children are associated with higher BLL than female children.

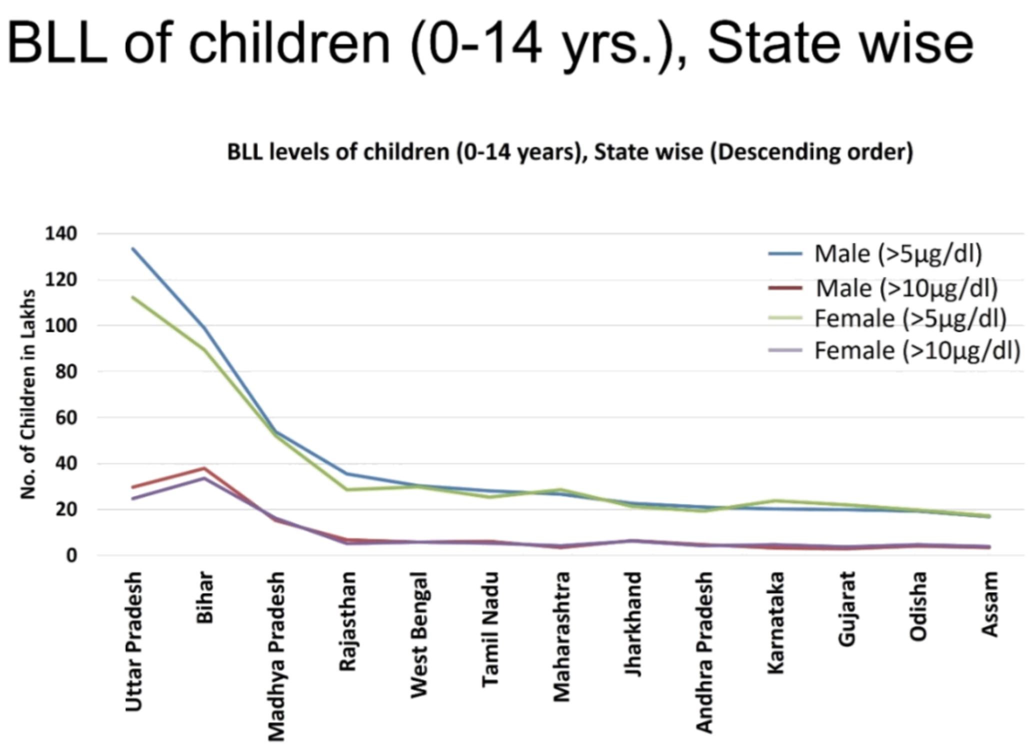

Fig. 1 State wise BLL of Children (0-14 yrs.) (Lyer et al., 2015)

Similarly, **Fig. 2** shows the male vs. female exposures of Pb for all age groups across India. All BLLs are above 5 μg/dL. Generally, across all age groups, females tend to have higher BLLs compared to males.

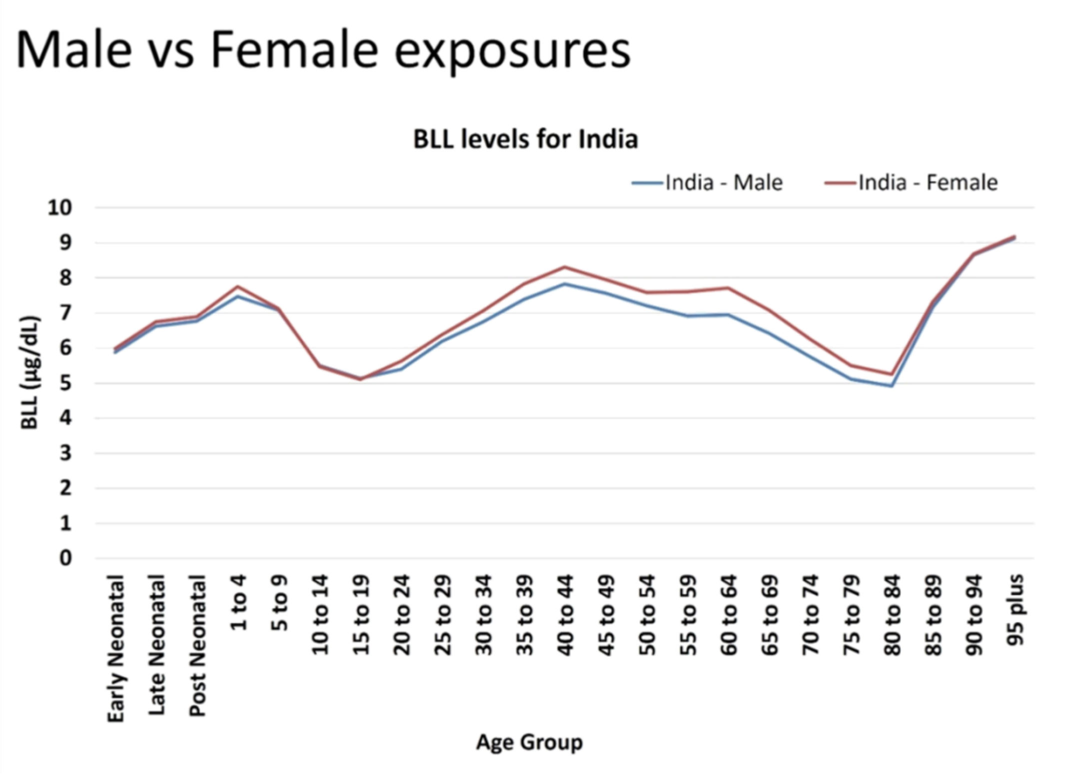

Fig. 2 Male vs. Female Exposures (Lyer et al., 2015)

Chapter 2

Sources and Patterns of Lead Exposure in India

2.1. Sources and Patterns of Lead Exposure in India

Pb is found naturally in the earth's crust, but it has become much more common due to activities, such as mining, burning petroleum products, and industrialization. People may get exposed to Pb over occupational and environmental sources, and that result from the following:

- The particles generated from burning materials containing Pb are inhaled by human beings, such as smelting, recycling activities, leaded paint, and gasoline.
- Ingestion of Pb from contaminated dust, water and food.

Generally, Pb is used in paint, pottery, batteries, cookware etc., India was wholly and slowly gotten rid of leaded gasoline since 2000 (Xu et al., 2012). However, the exposure to Pb continues due to the use of cosmetics and several types of traditional medicines. Vorvolakos et al. (2016) have reported that higher levels of Pb are found in traditional medicines in several cities in Mexico, India, and Vietnam. Hence, the consumers should be cautious about purchasing such medicines and instead use regulated products (Patil et al., 2007).

Other sources of lead also include the following:

- Pb particles from leaded gasoline and paint that settle down on soil which may last for a long time;
- Household dust contains Pb from paint;
- The pottery items like ceramic plates, porcelain, etc. also include Pb;
- Many cosmetic products have Pb like sindoor, bindis, eye make ups, etc., are also significant sources of Pb exposure;
- The clothing of the personnel working in mining areas, battery recycling sites, painting etc., may be contaminated and bring Pb directly home, which can be a source Pb poisoning (Xu et al., 2012).

2.2. Industries

The generation of hazardous and toxic metals is inevitable in processing industries. The most predominant metals thus generated include arsenic (As), cadmium (Cd), nickel (Ni), mercury (Hg), copper (Cu), lead (Pb) and zinc (Zn) (US Department of Health, Education and Welfare, Public Health Service, 2015). These compounds surpassing the prescribed limit can harm the biotic species residing within the ecosystem. However, the metal and toxic compounds produced depend upon the raw materials used and the treatment methods. Pb is primarily used in batteries, nuclear power plants, antioxidants for oils, antivibration pads for buildings and machinery etc. In 2002, automotive, battery and railway sectors utilized 70% of Pb, with an overall demand of 161 metric tonnes of Pb (Sahu et al., 2000). It is estimated that the industrial application of Pb in India might surpass 81000 metric tonnes by 2020 (US Department of Health, Education and Welfare, Public Health Service, 2015). Mining, smelting and refining industries are the primary sectors contributing to the Pb diffusion into the environment. These sectors are equipped with pollution control facilities but have failed to manage their solid waste generation comprising Pb. The major Pb producing industries in India are Hindustan Zinc Ltd. (HZL) and India Lead Ltd. (ILL), with an annual Pb production of 65,000 metric tonnes and 28,000 metric tonnes, respectively (Sahu et al., 2000).

The secondary source of Pb production is through unorganized sectors, such as scrap dealers, recycling vendors and cottage industries. It is estimated that the unorganized sectors contribute 15000 to 20000 metric tonnes per year of Pb (Roy et al., 2009). The

Pb mines in India have failed to cater to the needs of the industries, which has enforced the Pb recovery from acid batteries via the unorganized sectors. Similarly, the unorganized sectors contributing to E-waste recycling facilities have also partly contributed to Pb diffusion into the environment through soil and water contamination. This exposure to Pb has caused health issues in residents belonging to the lower-middle-income group. In 2006, a study was conducted in Chennai to determine BLLs in 814 school children near industrial arena and traffic zones (Roy et al., 2009). It was found that 756 children had BLL of 11.4±5.3 µG/BLL, leading to health issues like higher anxiety levels. In 2002, 37% of children working in small-scale cottage industries in Mumbai were reported to have >10 µg/dL BLLs. This study revealed that 16.67% of paints used in houses have the potential to emit ~5000 ppm of Pb annually. Apart from this case study, multiple reports have also suggested that industries are the major contributors to the Pb diffusion into the environment (Thatte et al., 1993).

2.3. Household products

The application of cosmetic products, such as facewash, face packs, hair oils, face creams, shampoos, conditioners, body soaps, etc. to the body parts leads to the absorption of lead into the body. The concentration of Pb in the blood of the users of the cosmetics was higher (12.9 µg/dL) compared to the non-users of the cosmetics (4.3 µg/dL) (Sprinkle, 1995). A similar study conducted by Ying et al. (2018) found lead tetroxide (Pb_3O_4) in 33.8% and lead monoxide (PbO) in 23.9% of cases following application of talcum powder directly on the skin following bath (Patil et al., 2007). In the western region of Maharashtra, workers at jewellery shops, battery manufacturing workshops and spray painters have increased BLL level of 267% compared to ordinary people (control sample) (Patil et al., 2007). Another source of Pb in adults is from Ayurveda medicines. About 80% of the population used Pb containing formulations for several purposes like prevention of diseases, herbal remedies etc. (Patil et al., 2007). The Ayurveda medicine "Naga bhasmas" are used by patients suffering from conditions such as diabetes mellitus and disorders related to the liver. Apart from these daily household products, other products may cause Pb accumulation in the human blood cells. Therefore, the presence of Pb in natural biota and ecosystems has become persistent.

2.4. Recycling

India produces 960 million tonnes of waste per year, out of which 30% is recycled by rag pickers, local vendors and recyclers. It is estimated that more than 50% of scrap is recovered through informal sectors of rag pickers and vendors. These wastes comprise of both hazardous and non-hazardous materials. These hazardous waste's non-reactive nature and non-scientific handling methods result in rag pickers and vendors being exposed to toxic compounds, such as Pb. Subsequently, these heavy metals end up in soil, air and water. Two soil samples collected from a battery recycling site in Karnataka revealed significantly high Pb levels, i.e., 3920 ppm and 8970 ppm, respectively. The samples collected from the actual workplace of the recycling site contain very high levels of Pb, i.e., 21,200 ppm (Clark et al., 2005). Discarded electronic goods are a major source of these toxic metals in municipal solid waste (MSW) from schools, offices, industries, etc. (Needhidasan et al., 2014). Pb present in printed circuit boards (PCBs) and batteries poses the most serious challenge to mitigating contaminants from leaching into the environment.

2.5. Potteries and Others

Pb has long been used in making utensils and glazed ceramic wares etc., to create attractive designs. Several cooking wares are used for storing, serving and cooking purposes. Some dishes, such as glazed terra cotta (clay) and traditional ceramic dishes are more likely to contain Pb, than plain white ceramic dishes. Some water bodies, too, may be contaminated with Pb. There are multiple sources and media through which Pb enters the small and large water bodies. However, the actual process of Pb contamination of the water bodies may differ depending upon the infrastructure development and mining activities and the natural ecosystem (Surface runoff erosion etc.) in their vicinity. It has been observed that anthropogenic activities are the primary cause of Pb deposition in the soil strata. Subsequently, these compounds are naturally transported to the nearby water bodies through surface run-off, causing long-term accumulation in the river sediments. Even at low concentrations, Pb tends to bioaccumulate in the plants, animals, microbes and other marine species, resulting in chronic health-hazardous (Sindiku et al., 2015). The inorganic Pb is carcinogenic and causes disturbance in behaviour, growth, metabolism, learning ability, and life span. Besides this, bioaccumulation of Pb in the internal organs of aquatic species (such as fishes) causes scoliosis. It is also reported that the bio-magnification of Pb occurs in the marine ecosystem via the continuous discharge of industrial effluent into the local water bodies. In the case of algae, the dissolved Pb (>500 ppb) can cause a reduction in enzyme release, resulting in reduced photosynthesis (Rioboo et al., 2009). This process may hamper the growth of algae in the water bodies, resulting in the decline of food availability for the aquatic animals. Apart from this, exposure to aqueous Pb^{2+} causes failure of internal organs, such as male gonads, liver, heart, and kidney (Ebrahimi, 2010). Continuous exposure to Pb^{2+} (>100 ppb) may also hamper the functioning of the fish gills. The exposure of aquatic fishes to high concentrations of Pb causes muscular dysfunction, paralysis, damage to reproductive organs, and an increase in mortality. An average concentration of 100 to 100,000 µg/L of Pb has been reported in the marine food chain (Pandey and Madhuri, 2014).

Chapter 3

Health Impacts of Lead

3.1. Symptoms

The symptoms of Pb poisoning are difficult to detect. Higher levels of Pb may be found in the blood of apparently asymptomatic people. Symptoms usually may not occur unless dangerous levels of the substance have built up in the blood.

3.1.1. Lead poisoning symptoms in children

Signs and symptoms of Pb poisoning in children include the following:

- Delay in development.
- Learning difficulties
- Loss of appetite
- Sluggishness and fatigue
- Abdominal pain
- Vomiting
- Hearing loss

3.1.2. Lead poisoning symptoms in newly-borns

Babies exposed to Pb before birth might lead to the following:

- Prematurely birth
- Reduced birth weight
- Slow growth of the infant

Table 2 present the effects of BLLs on children and adults.

Table 2: Effects of BLLs on children and adults

BLLs (µg/dL)	Effects on children and adults
<5	Decreased IQ level, increased incidence of behavioral problems and reduced attention span; impaired renal function; deficit/hyperactivity disorders; reduced fetal growth; decreased synthesis of aminolaevulinic acid dehydratase (ALAD), anemia etc.
<10	Developmental disorders and delayed puberty
<20	Reduced vitamin D metabolism; higher level of erythrocyte protoporphyrin; reduced calcium homeostasis
>20	Anemia
>30	Increased vitamin D metabolism; reduced nerve conduction velocity.

3.1.3. Lead poisoning symptoms in Adults

Pb poisoning affects adults as well as children. The symptoms in adults are as follows:

- Muscular pain
- Loss of memory or concentration
- Headaches
- Abdominal pain
- Mood swings
- Male infertility
- Premature deliveries

3.2. Lead Poisoning

Pb is an inessential element which is highly toxic for the human health and environment. It is one of the most common toxic elements in nature. Its toxicity has been known since very long, even before 360 BC., Lead is commonly used in general applications due to its functional properties, which leads to chronic exposure of humans to Pb resulting in infinite cases of Pb toxicity. It can cause significant harm to humans by affecting the nervous system, heart, bones, and kidneys, creating hearing and learning problems (Campbell and Auinger, 2007; Chen et al., 2007; Fenga et al., 2016; Ibeh et al., 2016; Magzamen et al., 2013; Nakade et al., 2015; Rastogi, 2008; Saleh et al., 2009; Wani et al., 2015). Pb poisoning affects definite groups, mostly pregnant women and children. Notably, children soak up four to five times as much ingested Pb as old people (ATSDR, 2017).

3.3.1. Occupational Pb toxicity

Pb exposure from various working industries, such as Pb smelting processes in the industry, battery manufacturing companies and recycling sites, automobile repairing centres, welding, press and printing, etc., are harmful to humans and the environment.

3.3.2. Non-Occupational Pb toxicity

Pb is an inessential element which is harmful to human health. It is widely used because of its various valuable properties as shown in **Fig. 3.** Numerous cases of Pb poisoning are due to chronic Pb exposure.

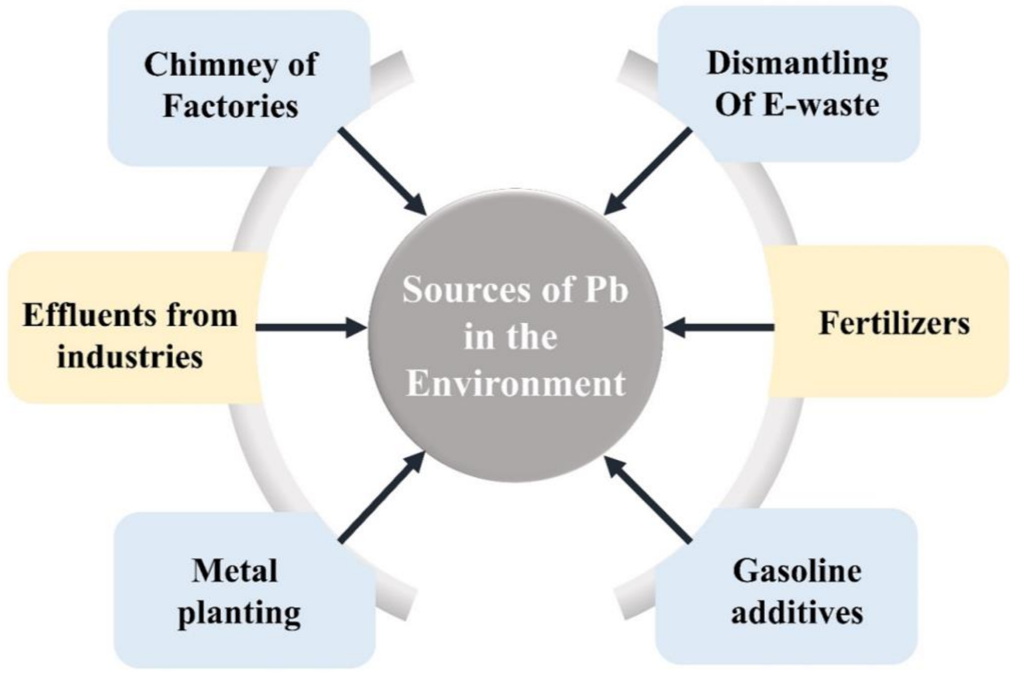

Fig 3. Usage of Pb for multiple applications

Different sources can cause Pb poisoning. There are numerous industrial and non-occupational sources which are presented in **Table 3.**

Table 3: Occupational and Non-occupational sources of Pb poisoning

Occupational	Non-occupational
Battery work (Rabin, 2008)	Traditional medicines
Mining	Vehicular exhaust
Glass manufacturing	Pb contaminated cosmetics and sindoor
Automobile repair	Household storage batteries
Ceramic work	Household paints
Painting	Pb-contaminated spices
Making pottery	Effluent from Pb-based industries
Smelting	Pb-contaminated soil, dust, and water
Printing work	Food grown in Pb-contaminated area
Plumbing(Iwegbue et al., 2008)	Retained bullets
Soldering (Clark et al., 2005)	Food stored/cooked in Pb-coated vessels (Kumar and Pastore, 2007)
Manufacturing Pb pipes and plastic (Dongre et al., 2013)	Painted toys

In India, children living in the vicinity of Pb-acid battery recycling centres have higher BLL i.e. 190 µG/dL. Pb exposure can have serious concerns for the health of children. The higher level of Pb exposure directly attacks the human brain and nervous system, and sometimes even death. Children affected by primary poisoning may have an intellectual disability. Exposure to small quantities of lead may be asymptomatic initially, but cumulative toxicity over a while leads to damage to multiple organs in the body. Chronic Pb poisoning may reduce brain development and IQ levels and result in abnormal behaviour in children. It may also lead to several conditions such as anaemia, hypertension and renal impairment.

Chapter 4

Way Forward

4.1. Steps to strengthen the lead inventory

Over the past few years, anthropogenic activities, such as mining and usage of Pb in several materials have been the leading causes of Pb exposure to a harmful level (Tong et al., 2000). Research on Pb pollution shows that Pb in the human body is now 500-1,000 times higher than pre-industrial ones (Rees and Fuller, 2020). Metallic Pb has distinctive properties, such as high malleability for ease of casting and fabrication, high density, acid resistance, chemical stability, resistance to water and corrosion which can be coiled and uncoiled easily, etc., owing to which it is the preferred metal across various industrial applications (Cheng et al., 2011). In the industrial sector, Pb is a raw material widely used in the production of batteries, machinery manufacturing, shipbuilding, cable sheaths, light industry, paint industry, etc. (Rubesinghe, 2020). However, there are various products containing Pb and Pb compounds, which are used in cosmetics, solder, gasoline as an anti-knocking agent, and batteries (Rees and Fuller, 2020, Vijayakumar et al., 2012).

Around 85 per cent of Pb is consumed worldwide in the production of Pb-acid batteries, which are also recovered from dead Pb acid batteries (Rees & Fuller, 2020). In developed countries like the USA, and Europe; where strict environmental regulations are implemented, 95 per cent of Pb is recovered from used Pb-acid batteries (Prengaman & Mirza, 2017). Many developing and under-developing countries have a lack of stringent laws and poor policy implementation, resulting in poor government control over informal recycling sectors (Patil and Ramakrishna, 2020). As a result, enormous quantities of Pb-acid batteries are recovered without using scientific techniques in an unregulated and uncontrolled way (Rees and Fuller, 2020).

In the paint manufacturing industry, Pb-based paint was incorporated for more than a decade due to its high shielding properties to make paint more durable, maintain a fresh appearance, and resist moisture (Gooch, 2006). Due to their sweet taste, flakes of Pb-based paints are consumed by children leading to kidney damage, stunted growth and damage to the nervous system. In India, the usage of Pb-based paint was not prohibited until 2016. A study conducted in 2015 revealed that around 31 per cent of household paints in India had a Pb concentration of more than 10000 ppm, while the BIS limit for Pb paint is 90 ppm (Clark et al., 2014).

Following is a summary of legislations and policies required to reduce and control the exposure to Pb:

- To develop and implement the environmental safety standards for Pb-acid batteries manufacturers and recyclers, enforcing these policies will help confirm industrial hygiene and occupational measures and reduce exposure from harmful substances that may affect human health.

- Enforce legislation regulating E-waste recycling and proper formal recycling is necessary to mitigate environmental hazards.

- Develop and implement policies to exclude the use of Pb in gasoline and paint, ceramic potteries, cosmetics, and medicines. Proper monitoring activities should do this.

- Implement regulations for air quality parameters for smelting operations. If Pb is eliminated from the gasoline, there is still a chance for Pb exposure through the smelting process. Thus, air quality regulation will help to reduce Pb emissions.

- Pb parameters are to be included in national drinking water quality standards, which will provide water safety management reducing the risk of health hazards.

4.2. Management, Treatment and Remediation

To minimize the negative impact of Pb, different steps, such as scientific management, treatment and remediation of Pb are essential. Following are the essential steps for effective management.

- Education and awareness among the public are essential to understand Pb toxicity and its impact on human health.
- Remediation of Pb-contaminated areas/sites by removing contaminated waste, soil, installing cloth barriers.
- Encourage the usage of non-Pb composites in paint production by promoting alternative paint manufacturing techniques.
- Assessments at the local level like households, schools and communities are essential to identify the source of Pb exposure. Various researchers have conducted many studies to combat Pb pollution. Physical, chemical and thermal are used for remediation techniques (Zulfiqar et al., 2019, Dobrescu et al., 2022). Interventions that treat the soil to reduce Pb poisoning in humans, include physical remediation, chemical remediation, biological remediation, and thermal remediation (Dobrescu et al., 2022). Various Pb remediation techniques are illustrated in Fig. 4.

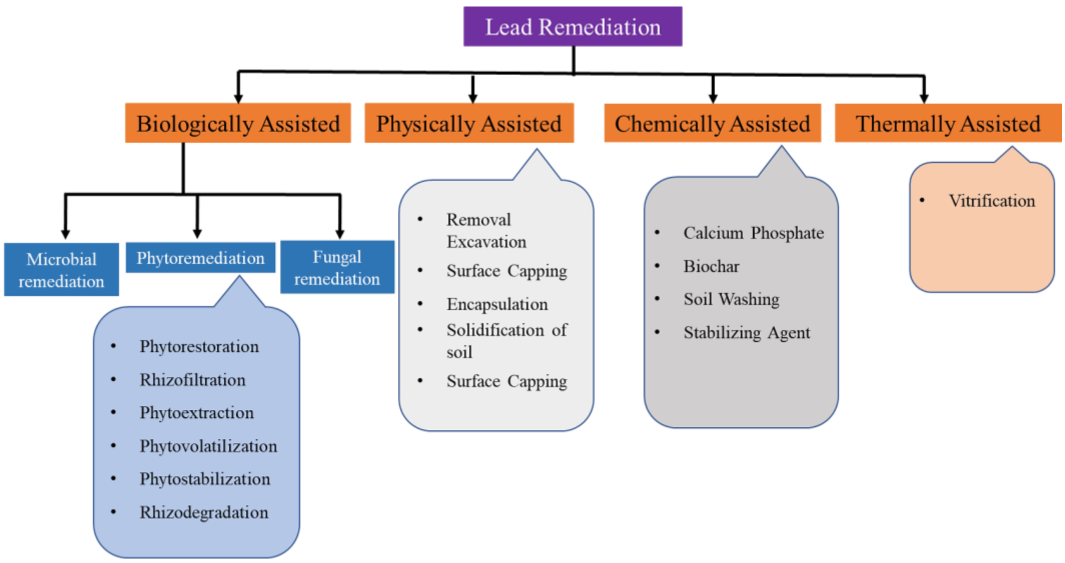

Fig. 4 Pb Remediation Techniques

Lead poisoning can be prevented in children before any ill effects are noticed. There are different ways in which the parent can reduce lead poisoning to children. The important steps for effective management are explained i.e.,

i. Pregnant women should avoid residing in living space undergoing renovation

ii. To avoid penetration of clogged or accumulated Pb through skin tissues, it is essential to perform regular hand wash

iii. Drinking water pipelines may cause Pb exposure, it is essential to flush it for 15-20 seconds.

These will help to reduce Pb contamination as well as exposures, specially children (Prevention and Treatment Report, 2020).

4.3. Study of Sources and their Linkages to Exposure

Pb is present in the environment due to activities associated with smelting, mining, pigments, batteries, pesticides etc. (Liu et al., 2013). Those metals enter the human body through soil, dust (air), cosmetic products, food and drinking water (Qian et al., 2010) as shown in **Fig. 5**. It causes severe health problems like damage to the nervous, endocrine, circulatory, immune and musculoskeletal systems.

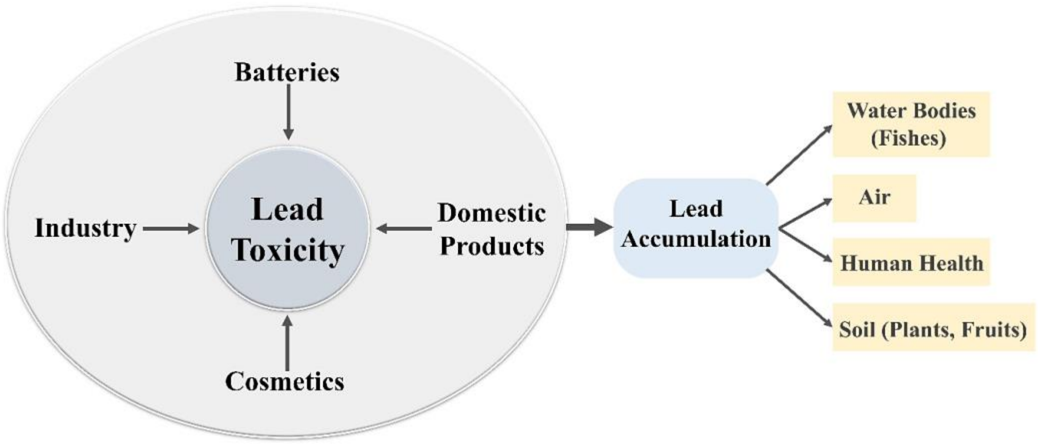

Fig. 5 Pb Exposure Linkage

Pb is one of the most environmental severe poisons among all heavy metals across the globe. It has been seen in all age groups. It is one of the most significant matters of concern for the present as well for future generations. In Mumbai, 172 out of 733 students were affected due to Pb's presence in commercially packed noodles.

4.4. Final Recommendations and Conclusions

Data is critical, and there is an urgent need to monitor Pb levels in children and pregnant women. This data in turn, can be used to determine the main sources of Pb causing high exposures, and this analysis is also needed in many states. This, in turn, can be used to make sure that the sources of Pb are being properly managed to avoid exposure risks.

In the Indian scenario, there is an urgent need to develop mechanisms for collecting Pb scrap for scientific reprocessing in an eco-friendly manner to achieve a pre-eminent quantity of recovered Pb. Developing cost-effective and long-lasting technologies for recycling activity is essential. Central Pollution Control Board (CPCB) and State Pollution Control Board (SPCBs) should organize awareness programs for Pb recyclers to handle, collect, and scientifically recover the Pb scrap. The organized Pb recycling sectors have pollution controlling equipment in practice and use environmentally pleasant processes.

It is vital to use effectual control measures in Pb recycling plants, like workers' health, environmental hazards, high-quality plant design, etc. Nowadays, developing advanced novel smelting processes is eco-friendly and much more efficient than open furnaces.

Overall pollution control measures and treatment options need to be applied thoroughly, predominantly for those where these are retained mostly within the plants. To avoid occupational Pb exposure, it is necessary to take other control measures like air quality improvement methods, health inspection, protecting the equipment, and excellent hygienic practices. The informal recycling sector, with a lack of knowledge about the toxicity of Pb is mainly responsible for Pb poisoning in many countries (Gupta, 2014).

Manufacturing industries are the foremost user of Pb based byproducts which cause Pb penetration into the environment. The major sources include Pb traces during the manufacturing process, and final products. Therefore, the policy maker must introduce the concept of life cycle assessment (cradle to grave) prior to the implementation of the project to understand the long-term impact of Pb on natural biota. Beside this, field-scale mitigation and precautionary measures have to be taken into consideration for Telecom industries manufacturing Pb acid batteries (Matte et al., 1991). It will be vital that Government and Private sectors work together on the possibility of Pb exposure reduction, which creates a considerable disease burden. A growing country like India cannot afford such high levels of morbidity and mortality. All stakeholders starting from Government to private sectors/community need to be aware of the looming danger of Lead contamination related health impacts and work together to address it holistically.

References

- Ahamed, M., Verma, S., Kumar, A., & Siddiqui, M. K. (2010). Blood lead levels in children of Lucknow, India. Environmental Toxicology: An International Journal, 25(1), 48-54.
- Alengebawy, A., Abdelkhalek, S. T., Qureshi, S. R., & Wang, M. Q. (2021). Heavy metals and pesticides toxicity in agricultural soil and plants: Ecological risks and human health implications. Toxics, 9(3), 42.
- Al-Saleh, I., Nester, M., Mashhour, A., Moncari, L., Shinwari, N., Mohamed, G. E. D., & Rabah, A. (2009). Prenatal and postnatal lead exposure and early cognitive development: longitudinal study in Saudi Arabia. Journal of Environmental Pathology, Toxicology and Oncology, 28(4).
- ATSDR, 2017. Lead Toxicity: What is the biological Fate of Lead in the Body? Environmental Health and Medicine Education. Available at: https://www.atsdr.cdc.gov/csem/csem.asp?csem=34&po=9 (accessed on 12 February 2022).
- Balasubramanian, B., Meyyazhagan, A., Chinnappan, A. J., Alagamuthu, K. K., Shanmugam, S., Al-Dhabi, N. A., Ghilan, A. K. M., & Arasu, M. V. (2020). Occupational health hazards on workers exposure to lead (Pb): A genotoxicity analysis. Journal of infection and public health, 13(4), 527-531.
- Barbosa Jr, F., Tanus-Santos, J. E., Gerlach, R. F., & Parsons, P. J. (2005). A critical review of biomarkers used for monitoring human exposure to lead: advantages, limitations, and future needs. Environmental health perspectives, 113(12), 1669-1674.
- Belliniger, D. C., Hu, H., Kalaniti, K., Thomas, N., Rajan, P., Sambandam, S., Ramaswamy, P., & Balakrishnan, K. (2005). A pilot study of blood lead levels and neurobehavioral function in children living in Chennai, India. International journal of occupational and environmental health, 11(2), 138-143.
- Bollhöfer, A., & Rosman, K. J. R. (2000). Isotopic source signatures for atmospheric lead: the Southern Hemisphere. Geochimica et Cosmochimica Acta, 64(19), 3251-3262.
- Bollhöfer, A., & Rosman, K. J. R. (2001). Isotopic source signatures for atmospheric lead: the Northern Hemisphere. Geochimica et Cosmochimica Acta, 65(11), 1727-1740.
- Borah, K. K., Bhuyan, B., & Sarma, H. P. (2010). Lead, arsenic, fluoride, and iron contamination of drinking water in the tea garden belt of Darrang district, Assam, India. Environmental monitoring and assessment, 169(1), 347-352.
- Campbell, J. R., & Auinger, P. (2007). The association between blood lead levels and osteoporosis among adults—results from the third national health and nutrition examination survey (NHANES III). Environmental health perspectives, 115(7), 1018-1022.
- Cao, S., Duan, X., Zhao, X., Wang, B., Ma, J., Fan, D., Sun, C., He, B., & Jiang, G. (2015). Health risk assessment of various metal (loid) s via multiple exposure pathways on children living near a typical lead-acid battery plant, China. Environmental Pollution, 200, 16-23.

- Charkiewicz, A. E., & Backstrand, J. R. (2020). Lead toxicity and pollution in Poland. International Journal of Environmental Research and Public Health, 17(12), 4385.

- Chambial, S., Shukla, K. K., Dwivedi, S., Bhardwaj, P., & Sharma, P. (2015). Blood lead level (BLL) in the adult population of Jodhpur: a pilot study. Indian Journal of Clinical Biochemistry, 30(3), 357-35.

- Chen, T., Hevi, S., Gay, F., Tsujimoto, N., He, T., Zhang, B., Ueda Y., & Li, E. (2007). Complete inactivation of DNMT1 leads to mitotic catastrophe in human cancer cells. Nature genetics, 39(3), 391-396.

- Cheng, F., Liang, J., Tao, Z., & Chen, J. (2011). Functional materials for rechargeable batteries. Advanced materials, 23(15), 1695-1715.

- Clark, C. S., Kumar, A., Mohapatra, P., Rajankar, P., Nycz, Z., Hambartsumyan, A., Astanina, L., Roda, S., Lind, C., Manrath, W., & Peng, H. (2014). Examination of lead concentrations in new decorative enamel paints in four countries with different histories of activity in lead paint regulation. Environmental research, 132, 233-243.

- Clark, C. S., Thuppil, V., Clark, R., Sinha, S., Menezes, G., D'Souza, H., Dav, P., & Shah, S. (2005). Lead in paint and soil in Karnataka and Gujarat, India. Journal of Occupational and Environmental Hygiene, 2(1), 38-44.

- Daniell, W. E., Van Tung, L., Wallace, R. M., Havens, D. J., Karr, C. J., Bich Diep, N., Croteau, G. A., Beaudet, N., & Duy Bao, N. (2015). Childhood lead exposure from battery recycling in Vietnam. BioMed Research International, 2015.

- Das, S., Nath, M., Laskar, A. K., DebRoy, S., Deb, S., Barhai, A., & Choudhury, A. P. (2021). Lead and cadmium exposure network in children in a periurban area in India: susceptibility and health risk. Environmental Science and Pollution Research, 28(22), 28133-28145.

- Dobrescu, A. I., Ebenberger, A., Harlfinger, J., Griebler, U., Klerings, I., Nußbaumer-Streit, B., Chanpman, A., Affengruber, L., & Gartlehner, G. (2022). Effectiveness of interventions for the remediation of lead-contaminated soil to prevent or reduce lead exposure-A systematic review. Science of The Total Environment, 806, 150480.

- Dongre, N. N., Suryakar, A. N., Patil, A. J., Hundekari, I. A., & Devarnavadagi, B. B. (2013). Biochemical effects of lead exposure on battery manufacture workers with reference to blood pressure, calcium metabolism and bone mineral density. Indian Journal of Clinical Biochemistry, 28(1), 65-70.

- Drop, B., Janiszewska, M., Barańska, A., Kanecki, K., Nitsch-Osuch, A., & Bogdan, M. (2018). Satisfaction with life and adaptive reactions in people treated for chronic obstructive pulmonary disease. In Clinical Pulmonary Research (pp. 41-47). Springer, Cham.

- DTE., 2020. Down to Earth: A third of world's children are poisoned by lead, says UNICEF report. Available at: https://www. downtoearth.org.in/news/health/a-third-of-world-s- children-are-poisoned-by-lead-says-unicef-report-72560 (accessed on 12 April 2022)

- Ebrahimi, M., & Taherianfard, M. (2010). Concentration of four heavy metals (cadmium, lead, mercury, and arsenic) in organs of two cyprinid fish (Cyprinus carpio and Capoeta sp.) from the Kor River (Iran). Environmental monitoring and assessment, 168(1), 575-585.

- Ericson, B., Landrigan, P., Taylor, M. P., Frostad, J., Caravanos, J., Keith, J., & Fuller, R. (2016). The global burden of lead toxicity attributable to informal used lead-acid battery sites. Annals of global health, 82(5), 686-699.

- Ericson, B., Dowling, R., Dey, S., Caravanos, J., Mishra, N., Fisher, S., Ramirez, M., McCartor, A., Guin, P., & Fuller, R. (2018). A meta-analysis of blood lead levels in India and the attributable burden of disease. Environment international, 121, 461-470.

- Ericson, B., Caravanos, J., Depratt, C., Santos, C., Cabral, M. G., Fuller, R., & Taylor, M. P. (2018a). Cost Effectiveness of Environmental Lead Risk Mitigation in Low-and Middle-Income Countries. GeoHealth, 2(2), 87-101.

- Ericson, B., Duong, T. T., Keith, J., Nguyen, T. C., Havens, D., Daniell, W., Karr J. C., Gai, N. B., Wilson, B.,& Taylor, M. P. (2018b). Improving human health outcomes with a low-cost intervention to reduce exposures from lead acid battery recycling: Dong Mai, Vietnam. Environmental Research, 161, 181-187.

- Fenga, C., Gangemi, S., Alibrandi, A., Costa, C., & Micali, E. (2016). Relationship between lead exposure and mild cognitive impairment. Journal of preventive medicine and hygiene, 57(4), E205.

- Flegal, A. R., Schaule, B. K., & Patterson, C. C. (1984). Stable isotopic ratios of lead in surface waters of the Central Pacific. Marine chemistry, 14(3), 281-287.

- Fralick, M., Thomspson, A., & Mourad, O. (2016). Lead toxicity from glazed ceramic cookware. CMAJ, 188(17-18), E521-E524.

- Geraldine, M., & Venkatesh, T. (2007). Lead poisoning as a result of infertility treatment using herbal remedies. Archives of Gynecology and Obstetrics, 275(4), 279-281.

- Ghose, M. K., Paul, R., & Banerjee, R. K. (2005). Assessment of the status of urban air pollution and its impact on human health in the city of Kolkata. Environmental Monitoring and Assessment, 108(1), 151-167.

- Ghanwat, G., Patil, A. J., Patil, J., Kshirsagar, M., Sontakke, A., & Ayachit, R. K. (2016). Effect of vitamin C supplementation on blood Lead level, oxidative stress and antioxidant status of battery manufacturing Workers of Western Maharashtra, India. Journal of clinical and diagnostic research: JCDR, 10(4), BC08.

- Gooch, J. W. (2006). Lead-based paint handbook. Springer Science & Business Media.

- Giel-Pietraszuk, M., Hybza, K., Chełchowska, M., Barciszewski, J., 2012. Mechanisms of lead toxicity. Adv. Cell Biol., 39, 17–248.

- Goswami, K. (2013). Eye cosmetic 'surma': hidden threats of lead poisoning. Indian Journal of Clinical Biochemistry, 28(1), 71-73.

- Granata, F., De Marinis, G., Gargano, R., & Hager, W. H. (2011). Hydraulics of circular drop manholes. Journal of Irrigation and Drainage Engineering, 137(2), 102-111.

- Gulson, B. L., Mahaffey, K. R., Jameson, C. W., Mizon, K. J., Korsch, M. J., Cameron, M. A., & Eisman, J. A. (1998). Mobilization of lead from the skeleton during the postnatal period is larger than during pregnancy. Journal of Laboratory and Clinical Medicine, 131(4), 324-329.

- Gupta, M. (2014). Environmental Effects of Growing E Waste. International Journal of Science and Research, 3(11), 204-206.

- Haefliger, P., Mathieu-Nolf, M., Lociciro, S., Ndiaye, C., Coly, M., Diouf, A., Pronczuk, Jenny., Bertollini, R., & Neira, M. (2009). Mass lead intoxication from informal used lead-acid battery recycling in Dakar, Senegal. Environmental health perspectives, 117(10), 1535-1540.

- Ibeh, N., Aneke, J., Okocha, C., Okeke, C., & Nwachukwuma, J. (2016). The influence of occupational lead exposure on haematological indices among petrol station attendants and automobile mechanics in Nnewi, South-East Nigeria???. Journal of Environmental and Occupational Health, 5(1), 1-6.

- Global, regional, and national disability-adjusted life years (DALYs) for 333 diseases and injuries and healthy life expectancy (HALE) for 195 countries and territories (IHME, 2017a), 1990–2016: a systematic analysis for the Global Burden of Disease Study 2016. Lancet, 390, 1260–1344.

- Global burden of disease study, 2016 (IHME, GBD 2016) results URL http://ghdx.healthdata.org/gbd-results-tool (IHME, 2017b), (Accessed 8th March 2022).

- Iwegbue, C., Nwajei, G. E., & Iyoha, E. H. (2008). Heavy metal residues of chicken meat and gizzard and turkey meat consumed in southern Nigeria. Bulgarian. Journal of Veterinary Medicine, 11, 275-280.

- Jangid, A. P., John, P. J., Yadav, D., Mishra, S., & Sharma, P. (2012). Impact of chronic lead exposure on selected biological markers. Indian journal of clinical biochemistry, 27(1), 83-89.

- Karri, S. K., Saper, R. B., & Kales, S. N. (2008). Lead encephalopathy due to traditional medicines. Current drug safety, 3(1), 54-59.

- Kalaivanan, D., & Ganeshamurthy, A. N. (2016). Mechanisms of heavy metal toxicity in plants. In Abiotic stress physiology of horticultural crops (pp. 85-102). Springer, New Delhi.

- Khan, M. I., Ahmad, I., Mahdi, A. A., Akhtar, M. J., Islam, N., Ashquin, M., & Venkatesh, T. (2010). Elevated blood lead levels and cytogenetic markers in buccal epithelial cells of painters in India. Environmental Science and Pollution Research, 17(7), 1347-1354.

- Kumar, A., & Pastore, P. (2007). Lead and cadmium in soft plastic toys. Current Science, 818-822.

- Kumar, A., MMS, C. P., Chaturvedi, A. K., Shabnam, A. A., Subrahmanyam, G., Mondal, R., ... & Yadav, K. K. (2020). Lead toxicity: health hazards, influence on food chain, and sustainable remediation approaches. International journal of environmental research and public health, 17(7), 2179.

- Kuruvilla, A., Pillay, V. V., Adhikari, P., Venkatesh, T., Chakrapani, M., Jayaprakash Rao, H. T., Rao, J., Bastia, K. B., Rajeev, A., & Rai, M. (2006). Clinical manifestations of lead workers of Mangalore, India. Toxicology and industrial health, 22(9), 405-413.

- Kute, V. B., Shrimali, J. D., Balwani, M. R., Godhani, U. R., Vanikar, A. V., Shah, P. R., Gumber, M. R., Patel, V. H., & Trivedi, H. L. (2013). Lead nephropathy due to Sindoor in India. Renal failure, 35(6), 885-887.
- Lal, N. (2010). Molecular mechanisms and genetic basis of heavy metal toxicity and tolerance in plants. In Plant adaptation and phytoremediation (pp. 35-58). Springer, Dordrecht.
- Lal, K., Sehgal, M., Gupta, V., Sharma, A., & Kumari, A. (2020). Assessment of groundwater quality of CKDu affected Uddanam region in Srikakulam district and across Andhra Pradesh, India. Groundwater for Sustainable Development, 11, 100432.
- Lee, J. W., Choi, H., Hwang, U. K., Kang, J. C., Kang, Y. J., Kim, K. I., & Kim, J. H. (2019). Toxic effects of lead exposure on bioaccumulation, oxidative stress, neurotoxicity, and immune responses in fish: A review. Environmental toxicology and pharmacology, 68, 101-108.
- Leeder, M. R. (2009). Sedimentology and sedimentary basins: from turbulence to tectonics. John Wiley & Sons.
- Levin, R., Brown, M. J., Kashtock, M. E., Jacobs, D. E., Whelan, E. A., Rodman, J., Schock, R, M., Padilla, A., & Sinks, T. (2008). Lead exposures in US children, 2008: implications for prevention. Environmental health perspectives, 116(10), 1285-1293.
- Lin, C. G., Schaider, L. A., Brabander, D. J., & Woolf, A. D. (2010). Pediatric lead exposure from imported Indian spices and cultural powders. Pediatrics, 125(4), e828-e835.
- Liu, X., Song, Q., Tang, Y., Li, W., Xu, J., Wu, J., Wang, F., & Brookes, P. C. (2013). Human health risk assessment of heavy metals in soil–vegetable system: a multi-medium analysis. Science of the total environment, 463, 530-540.
- Lokhande, R. S., Singare, P. U., & Pimple, D. S. (2011). Pollution in water of Kasardi River flowing along Taloja industrial area of Mumbai, India. World Environment, 1(1), 6-13.
- Lovei, M. (1999). Eliminating a silent threat. World Bank support for the global. Phaseout of lead from gasoline. The George Foundation, India.
- Lyer, S., Sengupta, C., & Velumani, A. (2015). Lead toxicity: An overview of prevalence in Indians. Clinica Chimica Acta, 451, 161-164.
- Magzamen, S., Imm, P., Amato, M. S., Havlena, J. A., Anderson, H. A., Moore, C. F., & Kanarek, M. S. (2013). Moderate lead exposure and elementary school end-of-grade examination performance. Annals of Epidemiology, 23(11), 700-707.
- Matte, T. D., Figueroa, J. P., Ostrowski, S., Burr, G., Jackson-Hunt, L., & Baker, E. L. (1991). Lead exposure from conventional and cottage lead smelting in Jamaica. Archives of environmental contamination and toxicology, 21(1), 65-71.
- McMichael, J. R., & Stoff, B. K. (2018). Surma eye cosmetic in Afghanistan: a potential source of lead toxicity in children. European journal of pediatrics, 177(2),

265-268.

• McConnell, J. R., Maselli, O. J., Sigl, M., Vallelonga, P., Neumann, T., Anschütz, H., Padilla, A., & Thomas, E. R. (2014). Antarctic-wide array of high-resolution ice core records reveals pervasive lead pollution began in 1889 and persists today. Scientific Reports, 4(1), 1-5

• Menezes, G., D'souza, H. S., & Venkatesh, T. (2003). Chronic lead poisoning in an adult battery worker. Occupational Medicine, 53(7), 476-478.

• Mohanty, A., Budhwani, N., Ghosh, B., Tarafdar, M., & Chakravarty, S. (2013). Lead content in new decorative paints in India. Environment, development and sustainability, 15(6), 1653-1661.

• Mohammad, I. K., Mahdi, A. A., Raviraja, A., Najmul, I., Iqbal, A., & Thuppil, V. (2008). oxidative stress in painters exposed to low lead levels, 59(3), 161-169.

• Nakade, U. P., Garg, S. K., Sharma, A., Choudhury, S., Yadav, R. S., Gupta, K., & Sood, N. (2015). Lead-induced adverse effects on the reproductive system of rats with particular reference to histopathological changes in uterus. Indian Journal of Pharmacology, 47(1), 22.

• Needhidasan, S., Samuel, M., & Chidambaram, R. (2014). Electronic waste–an emerging threat to the environment of urban India. Journal of Environmental Health Science and Engineering, 12(1), 1-9.

• Needleman, H. (2004). Lead poisoning Annual Review of Medicine 55: 209–222.

• Nichani, V., Li, W. I., Smith, M. A., Noonan, G., Kulkarni, M., Kodavor, M., & Naeher, L. P. (2006). Blood lead levels in children after phase-out of leaded gasoline in Bombay, India. Science of the Total Environment, 363(1-3), 95-106.

• Noguchi, T., Itai, T., Tue, N. M., Agusa, T., Ha, N. N., Horai, S., Trang, K. T., Viet, H. P., & Tanabe, S. (2014). Exposure assessment of lead to workers and children in the battery recycling craft village, Dong Mai, Vietnam. Journal of Material Cycles and Waste Management, 16(1), 46-51.

• Palaniappan, K., Roy, A., Balakrishnan, K., Gopalakrishnan, L., Mukherjee, B., Hu, H., & Bellinger, D. C. (2011). Lead exposure and visual-motor abilities in children from Chennai, India. Neurotoxicology, 32(4), 465-470.

• Pandey, G., & Madhuri, S. (2014). Heavy metals causing toxicity in animals and fishes. Research Journal of Animal, Veterinary and Fishery Sciences, 2(2), 17-23.

• Patil, R. A., & Ramakrishna, S. (2020). A comprehensive analysis of e-waste legislation worldwide. Environmental Science and Pollution Research, 27(13), 14412-14431.

• Patil, A. J., Bhagwat, V. R., Patil, J. A., Dongre, N. N., Ambekar, J. G., & Das, K. K. (2007). Occupational lead exposure in battery manufacturing workers, silver jewelry workers, and spray painters in western Maharashtra (India): effect on liver and kidney function. Journal of basic and clinical physiology and pharmacology, 18(2), 87-100.

• Prengaman, R. D., & Mirza, A. H. (2017). Recycling concepts for lead–acid batteries. In Lead-Acid Batteries for Future Automobiles Eds.Garche, J., Karden, E., Rand, D., (pp. 575-598). Elsevier.

- Prevention and treatment report (2020). Available at URL: https://health.mo.gov/living/environment/lead/prevent-treat.php. Accessed on 24th May 2022.

- Prajapati, S. (2016). Lead acid battery recycling in India. IOSR Journal of Electrical and Electronics Engineering, 11, 99-101.

- Qian, Y., Chen, C., Zhang, Q., Li, Y., Chen, Z., & Li, M. (2010). Concentrations of cadmium, lead, mercury and arsenic in Chinese market milled rice and associated population health risk. Food control, 21(12), 1757-1763.

- Rabin, R. (2008). The lead industry and lead water pipes "A Modest Campaign". American journal of public health, 98(9), 1584-1592.

- Rastogi, S. K. (2008). Renal effects of environmental and occupational lead exposure. Indian journal of occupational and environmental medicine, 12(3), 103.

- Rashid, A., Bhat, R. A., Qadri, H., & Mehmood, M. A. (2019). Environmental and socioeconomic factors induced blood lead in children: an investigation from Kashmir, India. Environmental monitoring and assessment, 191(2), 1-10.

- Raviraja, A., Vishal Babu, G. N., Sehgal, A., Saper, R. B., Jayawardene, I., Amarasiriwardena, C. J., & Venkatesh, T. (2010). Three cases of lead toxicity associated with consumption of ayurvedic medicines. Indian Journal of Clinical Biochemistry, 25(3), 326-329.

- Rees, N., & Fuller, R. (2020). The toxic truth: children's exposure to lead pollution undermines a generation of future potential. UNICEF.

- Renner, R. (2010). Exposure on tap: drinking water as an overlooked source of lead available on: https://ehp.niehs.nih.gov/doi/full/10.1289/ehp.118-a68 (Accessed on: 5th March, 2022).

- Rioboo, C., O'Connor, J. E., Prado, R., Herrero, C., & Cid, Á. (2009). Cell proliferation alterations in Chlorella cells under stress conditions. Aquatic toxicology, 94(3), 229-237.

- Roussel, H., Waterlot, C., Pelfrêne, A., Pruvot, C., Mazzuca, M., & Douay, F. (2010). Cd, Pb and Zn oral bioaccessibility of urban soils contaminated in the past by atmospheric emissions from two lead and zinc smelters. Archives of Environmental Contamination and Toxicology, 58(4), 945-954.

- 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.

- Rubesinghe, C. H. (2020). 18 Sustainable use of chemicals in practice. Storytelling for Sustainability in Higher Education: An Educator's Handbook, Eds Petra Molthan-Hill, Heather Luna, Tony Wall.

- Sahu, K. K., Agarwal, A., Pandey, B. D., Premchand., 2000. Lead Industries and Environmental Pollution in India. Proceeding of International Conference on Environmental Management in Metallurgical Industries. 14-16.

- Schneider, F., Buehn, A., & Montenegro, C. E. (2010). New estimates for the shadow economies all over the world. International Economic Journal, 24(4), 443-461.

- Schwikowski, M., Barbante, C., Doering, T., Gaeggeler, H. W., Boutron, C., Schotterer, U., Tobler, L., Ferrari, C., & Cescon, P. (2004). Post-17th century changes of European lead emissions recorded in high-altitude alpine snow and ice. Environmental science & technology, 38(4), 957-964.

- Sehgal, M., Garg, A., Suresh, R., & Dagar, P. (2012). Heavy metal contamination in the Delhi segment of Yamuna basin. Environmental monitoring and assessment, 184(2), 1181-1196.

- Sharma, A., Katnoria, J. K., & Nagpal, A. K. (2016). Heavy metals in vegetables: screening health risks involved in cultivation along wastewater drain and irrigating with wastewater. SpringerPlus, 5(1), 1-16.

- Sharma, S., Mitra, P., Bhardwaj, P., & Sharma, P. (2021). Blood lead level in school going children of Jodhpur, Rajasthan, India. Turkish Journal of Biochemistry, 46(4), 393-398.

- Shen, Z., Hou, D., Zhang, P., Wang, Y., Zhang, Y., Shi, P., & O'Connor, D. (2018). Lead-based paint in children's toys sold on China's major online shopping platforms. Environmental pollution, 241, 311-318.

- Shukla, P. R., Garg, A., & Dholakia, H. H. (2015). Energy-emissions trends and policy landscape for India (Vol. 1). AlliedPublishers.

- Sindiku, O., Babayemi, J. O., Tysklind, M., Osibanjo, O., Weber, R., Watson, A., & Lundstedt, S. (2015). Polybrominated dibenzo-p-dioxins and dibenzofurans (PBDD/Fs) in e-waste plastic in Nigeria. Environmental Science and Pollution Research, 22(19), 14515-14529.

- Singh, A. K., & Singh, M. (2006). Lead decline in the Indian environment resulting from the petrol-lead phase-out programme. Science of the Total Environment, 368(2-3), 686-694.

- Singh, A., Sharma, R. K., Agrawal, M., & Marshall, F. M. (2010). Risk assessment of heavy metal toxicity through contaminated vegetables from waste water irrigated area of Varanasi, India. Tropical ecology, 51(2), 375-387.

- Singhal, K. (2016). Food Safety and Standards: The Maggi Episode. Available at SSRN 2759772.

- Sipahi, H., Eken, A., Aydın, A., Şahin, G., & Baydar, T. (2014). Safety assessment of essential and toxic metals in infant formulas. Turkish Journal of Pediatrics, 56(4).

- Spivey, A., 2007. The Weight of Lead: Ejects Add Up in Adults. Environmental Health Perspectives, 115, 30–36.

- Sprinkle, R. V., 1995. Leaded eye cosmetics: a cultural cause of elevated lead levels in children. Journal of Family Practice., 40, 358–63.

- Stafilov, T., Šajn, R., Pančevski, Z., Boev, B., Frontasyeva, M. V., & Strelkova, L. P. (2010). Heavy metal contamination of topsoils around a lead and zinc smelter in the Republic of Macedonia. Journal of hazardous materials, 175(1-3), 896-914.

- Thatte, U. M., Rege, N. N., Phatak, S. D., & Dahanukar, S. A. (1993). The flip side of Ayurveda. Journal of postgraduate medicine, 39(4), 179.

- TOI., 2015. Times of India: Lead exposure available on: https://timesofindia.indiatimes.com/city/mumbai/172-out-of-733-people-test-ve-for-lead- poisoning-in-mumbai/articleshow/47619815.cms (accessed on 12 April 2022).

- Tong, S., Schirnding, Y. E. V., & Prapamontol, T. (2000). Environmental lead exposure: a public health problem of global dimensions. Bulletin of the world health organization, 78(9), 1068-1077.

- Toxicology and Industrial Health (2004). Vol. 22, Issue 9, 2006, https://doi.org/10.1177/0748233706074174

- Toxics Link, 2015. A Follow-up Study on Lead Levels in Paint Analyzed in 2013. (New Delhi).

- Turner, A. (2019). Cadmium pigments in consumer products and their health risks. Science of the Total Environment, 657, 1409-1418.

- UNEP, 2017. Update on the Global Status of Legal Limits on Lead in Paint: September 2017.

- Véron, A., Flament, P., Bertho, M. L., Alleman, L., Flegal, R., & Hamelin, B. (1999). Isotopic evidence of pollutant lead sources in Northwestern France. Atmospheric Environment, 33(20), 3377-3388.

- Vijayakumar, S., Sasikala, M., & Ramesh, R. (2012). Lead poisoning–an overview. International Journal of Pharmacology & Toxicology, 2(2), 70-82.

- Vorvolakos, T., Arseniou, S., & Samakouri, M. (2016). There is no safe threshold for lead exposure: alpha literature review. Psychiatriki, 27(3), 204-214.

- Wani, A. L., Ara, A., & Usmani, J. A. (2015). Lead toxicity: a review. Interdiscip Toxicol 8 (2): 55–64.

- World Health Organization (WHO)., 2021. Lead Poisoning. Available at: https://www. who.int/news-room/fact-sheets/detail/lead-poisoning-and-health (accessed on 12 April 2022).

- World Health Organization (WHO), 2016. Available on: on:https://apps.who.int/iris/bitstream/10665/206498/1/9789241565264_eng.pdf (Accessed on 28 March 2022).

- Xu, H. M., Cao, J. J., Ho, K. F., Ding, H., Han, Y. M., Wang, G. H., & Li, W. T. (2012). Lead concentrations in fine particulate matter after the phasing out of leaded gasoline in Xi'an, China. Atmospheric Environment, 46, 217-224.

- Ying, X. L., Gao, Z. Y., Yan, J., Zhang, M., Wang, J., Xu, J., & Yan, C. H. (2018). Sources, symptoms and characteristics of childhood lead poisoning: experience from a lead specialty clinic in China. Clinical Toxicology, 56(6), 397-403.

- Zhang, C., & Zhou, X. (2016). Does foreign direct investment lead to lower CO2 emissions? Evidence from a regional analysis in China. Renewable and Sustainable Energy Reviews, 58, 943-951.

- Zulfiqar, U., Farooq, M., Hussain, S., Maqsood, M., Hussain, M., Ishfaq, M., Ahmad, M., Anjum, Z. M., & Anjum, M. Z. (2019). Lead toxicity in plants: Impacts and remediation. Journal of Environmental Management, 250, 109557.

ANNEXURE A

BACKGROUND INFORMATION AND EXPOSURES

1. Introduction

Lead (Pb) is a naturally occurring toxic metal, bluish-grey in colour. It is found in the Earth's crust (0.002%) and formed due to geochemical weathering and endothermic reactions (volcanic eruptions) (Leeder, 2009). The different forms of Pb found in the Earth's crust are lead sulphide (PbS), lead carbonate ($PbCO_3$), lead chloroarsenate ($PbHAsO_4$), lead sulphate ($PbSO_4$) and lead chlorophosphate ($Pb_5(PO_4)_3Cl$), which are found in mineral ores, such as cerussite, galena, and anglesite etc. The direct pathway of Pb poisoning is through the manufacturing of industries using chemical reagents, metals from manufacturing daily household products and electronic appliances. It includes mining, recycling activities, smelting and other manufacturing industries. This causes diffusion of Pb in daily household products like paint, solders, pigments, glass wears, cosmetics, ceramics etc. (Wani et al., 2015; Spivey et al., 2007; Giel-Pietraszuk et al., 2012) that enters in the body via breathing process. The continuous or partial exposure to Pb causes human health hazards, like sudden impairment of the nervous system and blood-related disorders results in long-term bioaccumulation and biomagnification of Pb into the human body parts (liver, blood, kidney, brain etc.) (Drop et al., 2018; ATSDR, 2017; Charkiewicz et al., 2020). The short-term exposure may cause headache, memory loss, weakness, constipation, anaemia, irritation, abdominal pain and tingling in body parts. The industrial application of toxic compounds in the manufacturing process is also responsible for the fatal transportation of Pb and other metals into the ecosystem. Due to these, the presence of Pb is predominant in air, water and soil, i.e., through suspended particulates, water pipes and weathering of rocks etc., as shown in **Fig. 6.**

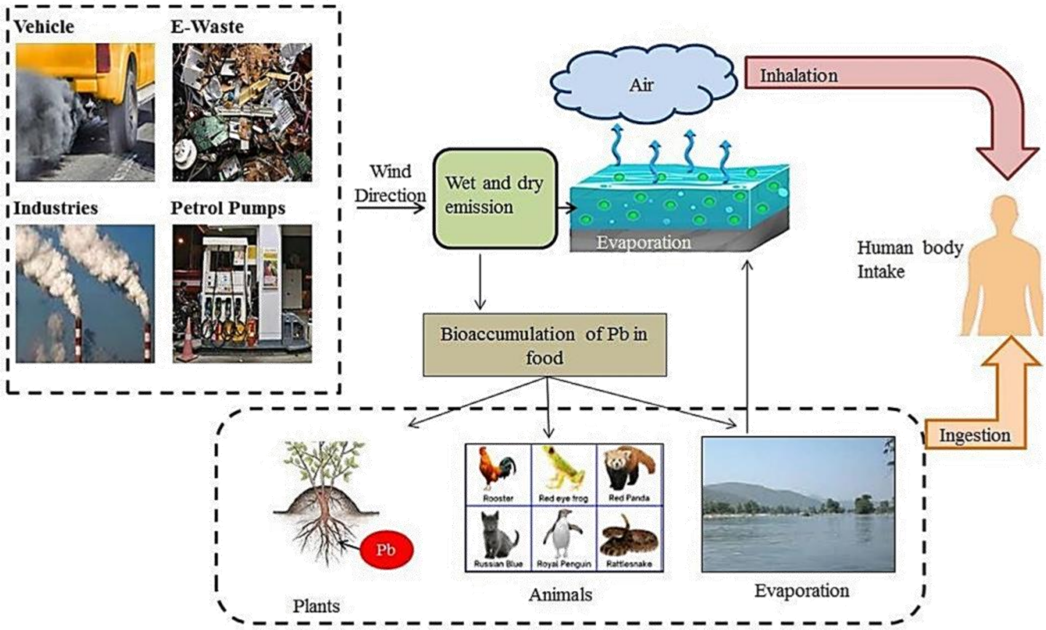

Fig. 6 Pb Exposure to the environment

Because of its helpful qualities, Pb can be used in a wide range of products, including plastics, paints, ceramic glazes, and batteries. For soldering, ceramic glazes, paints, and batteries, this metal is employed in businesses and household appliances (Clark et al., 2005; Dongre et al., 2013; Iwegbue et al., 2008; Kumar and Pastore, 2007; Rabin, 2008). Workers in Pb-based sectors are frequently poisoned by Pb as a result of prolonged contact with the hazardous element. Many of the workers are unaware of the harmful effects of Pb, and so they handle Pb without taking proper precautions, leading to acute or chronic Pb poisoning.

In addition to occupational Pb exposure, non-occupational sources and pathways include Pb contaminated water, food, and air. The acute toxicity of Pb is caused by inhaling its high levels in a short period of time, and the chronic toxicity is a result of long-term exposure (Levin et al., 2008; Renner, 2010; Zhang et al., 2016). Once Pb is absorbed into the body, it is distributed into blood, soft tissues including liver, kidney, lung, spleen, heart, and mineralizing tissues including bone and teeth. The majority of Pb is excreted in urine or by biliary clearance through the faeces.

Pb in blood has a half-life of 28-36 days, while it has a half-life of 40 days in soft tissues, whereas its half-life is approximately 25-30 years in bones. For chronic Pb poisoning, Pb deposits in the bones over a lifetime and hence bone Pb is considered a biomarker of cumulative Pb exposure (Barbosa et al., 2005, Gulson et al., 1998).

Various processes, such as smelting, recycling, processing, and mining, may release Pb and its component into the environment at any time. In minerals, the main Pb-containing compounds are lead sulphide (galena), lead carbonate (cerussite), and lead sulphite (anglesite) (Granata et al., 2011). Agricultural plants and crops cultivated near Pb-related industries have accumulated elevated levels of Pb, resulting in its elevated levels in meat and milk. The soil near smelting, mining, and other Pb-based industries contains high levels of Pb, resulting in elevated levels of Pb in the soil (Kumar et al., 2020). Paints and inks often contain Pb as it holds pigments firmly; thus, it is frequently used. Some painted toys expose infants to Pb due to their hand-to-mouth activities (Noguchi, 2014). House paint also contains Pb, which is ingested through house dust by children, who frequently swallow it. Pb is found in medications that are not branded. It is because of these unbranded medications that Pb poisoning occurs. Religious powders, sindoor, and surma can also Pb. In addition to these, there are several reported incidents of Pb poisoning due to the use of these religious powders (McMichael and Stoff, 2018). There is evidence that Pb can be detectable in spices of India, causing Pb poisoning. Pb might be added either as an adulterant to make spices heavier or accidentally during processing, grinding or packaging. Adulteration of turmeric powder with Pb chromate, which is a yellow colour, is also believed to be the cause of Pb poisoning. Pb is also used for soldering, welding, and in some products of bronze and brass in India. Tinnin is applied to the interior of brass vessels to prevent sour and acidic food from damaging them (Fralick et al., 2016). Ceramic cookware, earthenware, and crystal decanters are also sources of Pb exposure (Turner, 2019). A certain amount of Pb is added to brass and bronze alloys to increase their machinability. Pb poisoning can also result from oil painting and artwork, gasoline huffing, and gunshot wounds with Pb bullets. Pb is a toxic metal that competes with many essential metals, such as calcium, iron, and zinc, interfering with the activities of key heme-synthetic enzymes - aminolevulinate dehydrase, coproporphyrinogen III oxidase, and ferrochelatase - that are required for the formation of haemoglobin (Jangid et al., 2012). In several circumstances, determining the source of Pb poisoning is challenging since patients may not disclose their history of Pb exposure, resulting in a late diagnosis. In addition, these situations often go unreported and untreated, or they are merely medicated symptomatically.

2. Contemporary sources of lead exposure

Pb contamination as a food safety issue has recently come to the frontward since supplies of a popular noodle product, Maggi, had elevated Pb concentrations (Goswami, 2013; Raviraja et al., 2010; Singh et al., 2010). There are a number of sources of Pb exposure in India, including ayurvedic medicine, contaminated food and cosmetics (Goswami, 2013; Raviraja et al., 2010; Singhal, 2016). Additionally, Pb-based enamel paint evidently remains widely available (Toxics Link, 2015).

In India, around 700-775,000 metric tonnes of Pb are recycled each year, perhaps half of which is recycled in the informal sector (Ericson et al., 2016), which is attributable to a large informal economy combined with an increase in car ownership. In India, the informal sector generates 21% of the Gross domestic product (GDP), while the number of cars has nearly tripled since 2001, from 55 million to 159.5 million (Schneider et al., 2010; Shukla et al., 2015). As the result of informal used Pb-acid battery (ULAB) recycling in areas with substandard health systems, Pb exposure from unregulated backyard smelters is a prominent source of illness in low- and middle-income countries (Daniell et al., 2015; Ericson et al., 2018a, Ericson et al., 2018b, Ericson et al., 2016; Haefliger et al., 2009; Prajapati, 2016). One well-recorded case of Pb poisoning in Senegal was due to informal battery smelting, where 18 children were dead. Due to their illegal status, informal smelters are particularly subject to regulatory intervention. They operate intermittently in different areas of a neighbourhood, creating new hotspots of contamination without being mitigated.

There is a limited number of studies that explore how to mitigate the health risks associated with informal ULAB sites. One example from Vietnam describes the construction of an industrial zone 1 km away from residential areas that were contaminated with Pb and other toxic trace metals (Roussel et al., 2010; Stafilov et al., 2010). As a result of the relocation and community education, median BLL in children (6 years of age) declined by 67% after one year (Ericson et al., 2018b).

Important sources of Pb exposure include mining, smelting, leaded petrol and aviation fuel, manufacturing and recycling activities, ammunition, ceramic glaze, toys, cosmetics, traditional medicines, and drinking water delivered through Pb pipes or pipes joined through Pb solder. Principal sources and routes of Pb exposure are the inhalations of Pb particles generated by the burning of Pb-containing materials and ingestion of food, water and dust contaminated with Pb (Rees and Fuller, 2020).

Children are more susceptible to the toxic effects of Pb exposure as it adversely affects the development of the brain and nervous system along with permanent adverse health impacts. Long-term exposure to Pb damages the kidneys and increases the risk of high blood pressure in adults, while in pregnant women, a high level of the Pb causes miscarriage, premature birth, stillbirth and low birth weight (Vorvolakos et al., 2016).

Moreover, Sehgal et al. (2012) analyzed the samples besides the Yamuna River. The study area was selected from the Wazirabad barrage to the Okhla barrage of the Yamuna stretch. The result shows the presence of heavy metals in the water sample in the order of Fe>Cr>Mn>Zn>Pb>Cu>Ni>Hg>As>Cd. Likewise, in agriculture fields, soil contamination has been found out with a higher amount of heavy metal due to longer time of adsorption and absorption processes with varied heavy metal concentrations like Fe>Mn>Zn>Cr>Pb>Ni>Hg>Cu>As>Cd (Sehgal et al., 2012). The author studied the ground water quality and development of chronic kidney disease from drinking water contamination in the Uddanam region, Andhra Pradesh. From August 2018 to May 2019, samples were collected from 40 villages in the Uddanam region and 100 other villages from different districts of Andhra Pradesh. During the pre-monsoon period, 55% of villages have higher lead and silica concentrations, and 35% of villages have acidic groundwater. In the water sample, the concentration of lead is found out to be 0.2/38.9 (Lal et al., 2020).

Pb can be found in soil and dust, primarily near industrial places and recycling units (batteries and E-waste recycling units). The traces of Pb have also been found in marine species, surface water, sediments etc. In some cases, Pb has been formed due to unknowing phenomena, such as corrosion of tap water pipes and many others. This has caused Pb contamination in drinking water. In terms of health perspective, WHO has suggested that Pb should be <10μg/L in drinking water (WHO, 2021). Apart from this, E-waste is one of the most significant rising wastes across the globe, contributing to Pb contamination. As it is a complex and expensive process to recycle E-waste, local vendors and rag picker have adopted non-scientific methods to manage this. However, this has caused direct exposure of Pb and other metals into the human blood cells and skin tissues. During the process of incineration and dismantling, labourers and children working on recycling sites get exposed to these toxic compounds. The staff deployed on such sites inhale the polluted air. Roy et al. (2009) studies and experimental evidence reported that exposure to Pb at a minimum level could cause harmful effects, especially at the stage of brain development. This poisoning of Pb affects the nervous system of young children, reduces IQ levels, and produces hyperactivity and reduced attention.

ANNEXURE B

RESEARCH ON EXPOSURE DATA RELATED TO LEAD

The usage of tetraethyl Pb in gasoline in the twentieth century was a very important historical origin of universal Pb exposure (Bollhöfer and Rosman, 2001, Bollhöfer and Rosman, 2000; Flegal et al., 1984; McConnell et al., 2014; Schwikowski et al., 2004; Véron et al., 1999). In cities, around 80-90% of leaded gasoline is utilized, which causes aerial Pb contamination (Lovei, 1999). In the 1970s, greater-income nations initiated prohibiting the usage of Pb in paints, resulting in considerable reductions in public blood lead levels (BLLs) (Needleman, 2004). In India, slowly getting rid of leaded gasoline was completed at the end of 2000. It was also observed in studies that reported a decrease in BLL (Singh and Singh, 2006). Singh and Singh (2006) discovered a 33 percent reduction in BLL in the city centres of Mumbai, Amritsar, and Lucknow following the phase-out of leaded gasoline.

Despite these significant reductions in exposure studies showed greater than a decade following India's slowly getting rid of leaded gasoline discovered increased BLLs, which are generally linked to closeness to Pb smelting operations (Bellinger et al., 2005; Ghose et al., 2005). Ayurveda medication, cosmetics, and infected foods have all been causes of Pb exposure for the Indian people (Goswami, 2013; Raviraja et al., 2010; Singh et al., 2010; Singhal, 2016). These exposures have resulted in harshly increased levels in both occupational settings in some cases (Ghanwat et al., 2016; Goswami, 2013). Increased Pb concentrations have been found in lakes and sediment according to the studies of Borah et al., 2010; Lokhande et al., 2011. India presently has one of the strictest worldwide Pb-based paint standards of 90 ppm (UNEP, 2017), which is on the decrease level. However, a 2015 research of store-bought glossy paint cans discovered that 46% of those tested contained >10,000 ppm Pb (Toxics Link, 2015). Furthermore, several researchers have suggested that leaded paint could be a substantial origin of exposure (Ahamed et al., 20010; Khan et al., 2010).

1. Lead poisoning in occupational workers

Pyrometallurgical and generating Pb, as well as manufacturing and recycling batteries, vehicle mending, ammunition manufacturing, radiator manufacturing and repair, decoration, welding, electroplating, printing, and plumbing, all require Pb usage and provide a high danger of Pb exposure to employees. The amount of consumption is regulated by the length of exposure, the usage of personal protective equipment (PPE), and having personal cleanliness, as well as the person's nutritional health. Menezes et al., 2003 described a 44-year-old man who had been working in a battery recycling facility in Bangalore, Karnataka, India, since the age of ten years and had been experiencing pain in the epigastrium and knees for the previous five years. The person in this scenario was working on molten Pb without wearing protective equipment and also had poor hygiene practices, like consuming food, without handwashing in a Pb-filled worksite. The patient exhibited a low haemoglobin level and a high alanine aminotransferase (ALT) level, duodenitis, antrum gastritis, and hepatic steatosis, as well as moderate hepatomegaly. Over a 30-year period, the patient was fully unaware of the negative impacts of Pb exposure, which resulted in chronic Pb poisoning and Pb accumulation inside the bones, resulting in an indigenous route of contamination. Multiple sessions of chelation therapy, as well as ecological remediation, are required to treat persistent cases of Pb exposure.

In addition to the paints used in toys, pencils, and other home products, contamination from removing wall paints adds to the indoor dust and becomes a cause of risk. In a research of 35 painters aged 20-50 years, Mohammad et al. (2008) found a BLL of 40 mg/dL, which was about seven times greater than the control group, and a clear link between BLL and oxidative stress in the individuals. Pb-based paints are a route of contamination for both highly exposed and non-exposed people (Mohanty et al., 2013). Pb-based paints have already been found in kids' toys, playground stuffs, and park tools, according to the studies by Kuruvilla et al., 2006; Shen et al., 2018. Due to frequent hand-to-mouth actions, which include consuming non-food things, such as old paint, mud, and cardboard, young children are more vulnerable to Pb poisoning than grownups, and the growing bodies take more Pb than grownups.

2. Lead poisoning in non-occupational exposure

According to Karri et al. (2008), there have been a few cases of Pb poisoning from unconventional sources. They observed a 41-year-old man with anorexia, memory loss, convulsions, moderate disorientation and vomiting, anhedonia, limb weakness, stiffness, and an upgoing plantar response who had no occupational Pb exposure. The patient showed anaemia with basophilic stippling and bilateral focal hyperintensity, as well as lesions in the frontal, temporal, and parietal regions of the brain. The presence of Pb poisoning was suspected, and further testing revealed a dangerously high BLL of 161 mg/dL. Following the discontinuation of the medication, the patient underwent many rounds of chelation therapy, which helped him recover clinically. The same team of experts also documented a case of Pb poisoning in a 9-month-old boy who had taken Ghasard, a traditional Indian remedy for relaxing digestion and reducing constipation in newborns. The fact that the boy had been provided with this medicine by his parents since he was two months old was concerning in this case. Researcher Karri noted that the infant began to lose awareness at the age of eight months, got more sluggish, was unable to crawl, and gradually refused food supplements. At the age of nine months, the child had a seizure, became apneic, and died two days later. An autopsy revealed a severe case of Pb poisoning, with significant amounts of Pb in the blood and other tissues. The traditional remedy Ghasard, which contained 1.6 percent Pb by weight and resulted in the infant's death, was discovered to be the source of Pb poisoning. According to these case studies, high Pb levels in traditional medicine can bring life-threatening consequences, including death.

Geraldine et al. (2007) reported a case of Pb poisoning in a 27-year-old woman from Bangalore, Karnataka, India, who had symptoms such as constipation, sleeplessness, nausea, and abdominal discomfort within five weeks of taking three unbranded herbal drugs indicated for infertility issues. Blood testing 13 weeks after starting herbal drugs revealed lower haemoglobin and higher ALT and BLL levels. The patient's ultrasound scan and endoscopy report revealed damage to the liver and antrum gastritis, according to the report. Except for using herbal supplements, the patient, in this case, had no additional sources of exposure. X-Ray fluorescence (XRF) analysis of three herbal medications revealed Pb levels of 160 mg/g, 2300 mg/g, and 35 mg/g, respectively. The BLL was lowered after a month of chelation therapy with D-penicillamine. There have been multiple examples of people taking herbal/traditional/unbranded medicine that included high levels of Pb, resulting in major health problems; however, epidemiological studies in India are insufficient. To address this issue, strict regulatory measures, as well as public awareness and precautions, are essential.

Several incidences of Pb poisoning have been documented as a result of Surma use. Surma, also known as Kohl or Kajal, is a traditional eye cosmetic intended to ward off the evil eye, especially in young children. It's made with certain other substances and an ultrafine type of specially processed galena. Goswami, 2013 reported a case of Pb poisoning caused by the usage of Surma in Kolkata, West Bengal, India. They measured children's BLL and haemoglobin levels, as well as Pb content, in Surma brands collected from local markets in a variety of shades, including black, brown, orange, grey, and white. According to the study, 69 students used Surma the most regularly, while the remaining children served as study controls because they never used Surma. The study found that Pb poisoning was caused by inappropriate Surma processing, with higher Pb amounts in all the samples except white. According to the study, high Pb content in the eye cosmetic "Surma" is a cause of Pb exposure, and it can enter the body through a variety of routes, including the conjunctiva of the eye and the mouth, which is the main route of ingestion (Goswami, 2013).

Sindoor is a red powder that Hindu women put on their foreheads and hair to indicate their marital status. Men and children may also wear it for religious reasons. Kute et al. (2013) described a 35-year-old male from Ahmedabad, Gujarat, India, who suffered from face puffiness, constipation, nausea, vomiting, abdominal pain, irritability, and insomnia as a result of Pb poisoning. The patient used 5-10 g of Sindoor annually for religious purposes over an 11-year period, and the diagnosis indicated a small bluish-grey line around the gums of the teeth, Pb nephropathy, and abnormal kidney function, and a BLL of 95.9 mg/dL. This is an uncommon case of Pb poisoning and points to Sindoor as a possible source of Pb toxicity in Indians. The BLL dropped to 42 mg/dL after a month of D-penicillamine chelation therapy.

Mohanty et al., (2013) found out the Pb level in Indian decorative paint where 148 paint samples were analyzed from companies. The Bureau of Indian Standards (BIS) has set the limit for Pb, i.e. 300 ppm in paint and 90 ppm for US limit. The results showed that 39% of paints contain>300 ppm. Among 148 samples, 93% of paint was manufactured by the unorganized sector and 5% of paint from the organized sector. The study indicated that companies have more limits that BIS standard for leading in to paint and leads to Pb exposure.

The Pb contaminated food, drinking water, and any other sources can become the path for Pb poisoning. There is a chance to enter Pb while packaging food, cooking, and storage of food material. Greater amount of Pb is found in glassware, cookware, etc. (Fralick et al., 2016). Those plants which grow in soil having more Pb levels contain elevated Pb in fruits or crops (Sharma et al., 2016). Chambial et al. (2015) reported that drinking water is also the source of Pb exposure. The study described that the usage of metal piping for plumbing is a major concern.

Lin et al. (2010) reported a few cases of Pb poisoning due to the usage of cultural powders. The study observed that 9 months of the baby was affected by Pb poisoning with BLL of 21 mg/dL because the parents used to put orange powder on the forehead as a part of the tradition. Similarly, the same case was found in a 3-year girl with 18 mg/dL BLL due to religious powder, and that powder contained 4800 mg/g of Pb. This is also a source of Pb exposure.

ANNEXURE C

RESEARCH ON HEALTH IMPACTS

1. Lead Related Studies in India

According to National Health Portal (2022), Pb poisoning accounts 0.6% of the global burden of disease (GBD) (Ericson, 2018). In 2019, IHME estimated an average annual death rate of 0.9 million. However, till date, the reported cases are ~800 million worldwide (Down to Earth, 2020). Globally, it contributes 62.5% to intellectual disability, 8.2% to hypertension, 7.2% to heart disease and 5.2% to sudden stroke (WHO, 2021). It was also found that middle- and low-income countries have reported majority of these cases compared to high-income countries (Down to Earth, 2020).

In 2016, according to DALYs, Pb exposure was found to be 13.5 million, which is a metric used to determine its morbidity and mortality rate. As per the UNICEF report, India has reported 275 million cases suffering from mild and severe effects of Pb poisoning (Down to Earth, 2020). IHME report (2017a) has also found India alone has a Pb attributable of 4.6 million DALYs. The application of tetraethyl lead ($C_8H_{20}Pb$) as an anti-clock agent in gasoline fuel and petrol was the most significant source of Pb contamination in 20th century. This led to 80% to 90% airborne transmission of $C_8H_{20}Pb$ into the atmosphere. Later in 1970, the awareness among the high-income societies with respect to $C_8H_{20}Pb$ petrol resulted in the banning of such fuel. It was found that there was a significant decline in BLL among the citizens. In 1996 to 2000, the application of $C_8H_{20}Pb$ in petrol was phased out from India, and this caused 60% decline in BLL of citizens residing in Mumbai (Nichani et al., 2006; Ericson, 2018). Similarly, there was 33% decline in BLL in cities, such as Chennai, Bangalore, Amritsar and Lucknow (Singh and Singh, 2006; Ericson, 2018). Studies have also proven that Pb based paints are a significant source of Pb poisoning and exposure in the modern era. Therefore, India maintains a strict permissible limit (90 ppm) for soluble Pb in paints (UNEP, 2017). However, a study conducted on 46 paints cans found to have >10,000 ppm of Pb (Toxics Link, 2015; Ericson, 2018). Despite multiple precautionary measures and stringent laws, most of the developing countries have failed to avoid Pb diffusion into the environment. For policymakers, it is essential to remodify the laws for industries which are engaged in manufacturing commodities affiliated to some form of Pb based compound. After overviewing a complete life-cycle of a product, the researchers and scientists need to develop an efficient framework of handling and manufacturing process leading to minimal exposure to Pb.

2. Impacts and Possible Causes

2.1. Pb Toxicity in Plants

In most developing countries, technological advancement has played a significant role in promoting industrial up-gradation. However, this advancement has also led to environmental hazards caused due to the emission of harmful metals (lead, mercury, copper, etc.). The overall development of industrial infrastructure and agricultural activities has caused metals transmission into the soil strata, water bodies, air etc. (Liu et al., 2013; Cao et al., 2015). Lal, 2010, reported that the Pb is one of the most toxic elements for plant species, as it causes bioaccumulation in leaves, roots, and other parts, resulting in shorter life span. The study reveals that Pb accumulation is higher in roots than in the leaves; the decreasing order of the assembly is in the form of roots>leaves>stem>inflorescence>seeds. A high concentration of Pb in plants causes the blackening of the root, stunted growth, and chlorosis. The fruit-bearing plants are classified as dicots (single seed plants) and monocots (multiple seeds plants). It is observed that dicots accumulate more Pb compared to monocots. Pb contaminated soil reduced crop productivity, leading to a decline in the photosynthesis process by deforming chloroplast, reducing chlorophyll synthesis, and blocking electron transport. It also causes inequity proportioning of minerals (Mg, Mn, K, Ca, Zn, Cu, Fe) inside the plant tissues (Kalaivanan et al., 2016).

2.2. Pb Toxicity on Human Health and Environment

Bioaccumulation of Pb in the human body is mainly caused during inhalation via skin tissues (Lee et al., 2019). The two major pathways are the alimentary canal and respiratory tract. The reported ingestion of Pb through the respiratory tract and oral pathway is 10-20 µg/day and 150- 300 µg/day, respectively. It causes kidney damage, and sterility in males by damaging germinal epithelium and spermatocytes, menstrual irregularities in females, preterm deliveries, and sudden death of infants. Sipahi (2014) have also reported that infants are more prone to Pb contamination compared to adults and children. It has been observed that the local environment plays a vital role in Pb contamination. The population residing near petrol pumps has reported high

Pb concentration (35 µg/dl) levels in their blood cells. At the same time, the children working in the bangle industry have also reported 30 µg/dl of Pb. **Table 4** represents the source of Pb reported in India. Alengebawy et al. 2021 have reported a higher concentration of Pb in paints used in residential buildings and housing infrastructures. The Pb is peeled from this paint into the environment, i.e., soil, resulting in the accumulation of Pb in the upper layer (1 to 2 inches) of soil substrate. It sticks to the skin while working in the soil and later forms airborne oil dust. Agriculture activity performed on these soil strata may further cause Pb accumulation into the crops, resulting in Pb poisoning and sudden death (Alengebawy et al., 2021). The availability of Pb in the soil is checked using soil solubility under acidic conditions (pH < 5). Pb retains less tightly and is more soluble, but at neutral or basic conditions (pH> 6.5), Pb holds tightly to soil particles and is significantly less soluble.

Table 4: Case studies on Pb contamination in India

Author	Location	Source	Methodology	Observation	Health effects
Sharma et al., 2021	Jodhpur, Rajasthan, India	soil, water, and air around highways and traffic, vehicular emission	The blood sample 4-8 years age group children were collected from the school	Pb (>5 µg/dL) was found out in blood sample	Neurologic damage and behavioural problems
Das, 2020	Southern Assam, India	Food, water, and micro-environmental sources like school courtyard soil and paint dust	The Multivariate statistical analysis was carried out to understand the health risk assessments (carcinogenic and non-carcinogenic) as well as the complex data matrices.	Authors found the median values between 0.9- 4.0mg Pb/kg in different food stuffs. Groundwater Pb level has (0.13-0.48 mg/L).	Cancer risk
Kumar et al., 2020	NA	Volcanic activities, sea spray emissions and remobilization of soil, sediment, and water from mining arena	The data has been collected from a literature survey and Pb contamination in soil, crops and water resources find out	The reason behind Bioaccumulation and health hazards of Pb agricultural activities and industrial	Causes anemia, Insomnia, Memory loss, Pregnancy complication, Fatigue and loss of appetite
Balamuralikrishnan et al., 2019	NA	Discarding of gasoline, contaminated landfills pesticides, smelting, fossil	Total 144 samples collected were subjected to chromosomal analysis, micronuclei	Strict regulations should be imposed in India for labelling the hazardous metals in paint container	Dizziness, nausea to Irritation, headaches, eye burn, vomiting, diarrhea,

		fuels, manufacturing units, mining	assessment and comet assay		dizziness, fatigue, nausea to serious complication such as allergic dermatitis, pulmonary irritation, Painters syndrome, lung cancer, reproductive system damage, damage of kidney and liver
Rashid et al., 2020	Kashmir, India	Vehicle	The methodology concentrated on impacts of environmental and socio-economic factors on the concentration of blood Pb levels (BLL) in children.	It is observed that the age group of 4-8 years (5.46 µg/dl) has highest BLL. Moreover, the children belonging to families with incomes higher than 100,000 showed the highest blood Pb levels (5.52 µg/dl)	Damage to bones and central nervous system.
Palaniappan et.al., 2011	Chennai, India	Gasoline	Wide Range of Visual Motor Abilities Test (WRAVMA) and Lead Care Analyzer and is used to measure Pb in blood samples	In Mumbai the 37% of children's Pb concentration level exceeded up to 10 mg/dL	The higher Pb level urban Indian children was suffered from, decreased visual-motor abilities
Roy et al., 2009	Chennai, India	Gasoline and residential paint	Studied the children population of Chennai. Blood was collected from the cubital vein of every child to measure Pb. After that Neurobehavior assessment has been carried out and analysis of variance is used for data analysis	ADHD-type behaviors are observed in children having higher blood Pb levels	Reduces IQ level in young children

3. Data validation and Modelling

Fig. 7 shows a sample of the output of the spatiotemporal Gaussian process regression (ST-GPR) model for females in Delhi, India. The trend across all the age groups is similar, with decreasing BLL levels from 1970 to 2019. A sharp decrease in exposure can be observed just before the year 2000, which is likely due to the phasing out of leaded petrol in India from 1996 to 2000 (Ericsen et al., 2018). The black markers indicate actual data points.

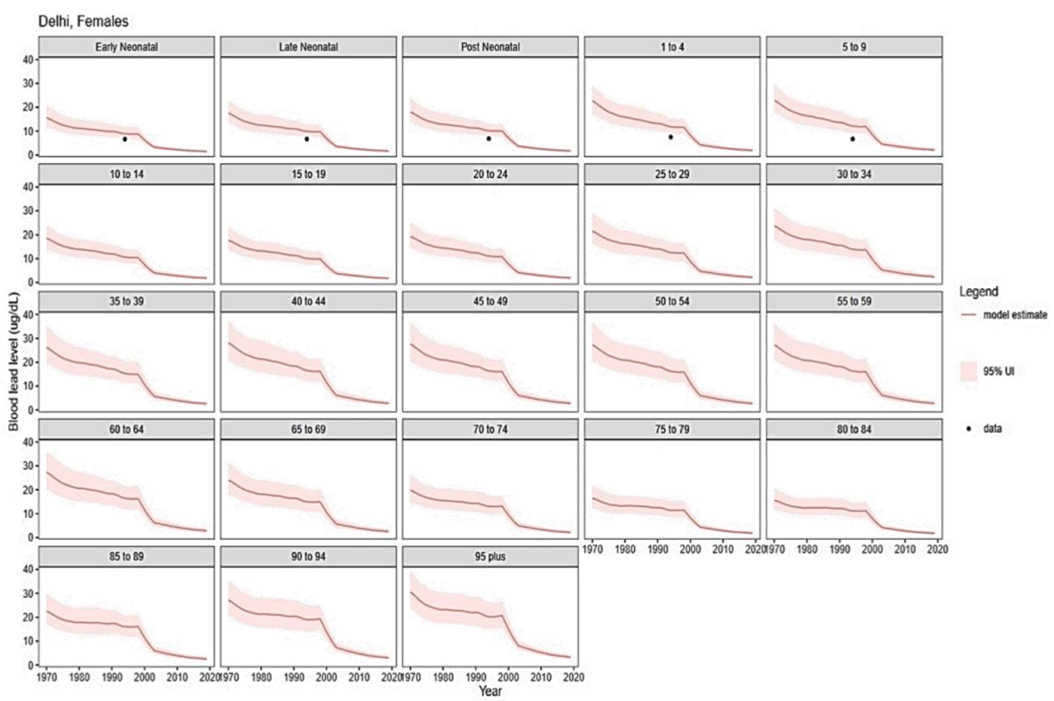

Fig. 7 Sample of the ST-GPR model output for females in Delhi. The black markers indicate data sources with actual measurements of BLL in the year which the study was conducted.

ANNEXURE D

STUDY TEAMS AND THEIR METHODOLOGY

1. Data Sources

Data from various studies carried out in India were collated to look at BLL. A total of 89 data points from 36 studies were derived and used in the model. It included both males and females through the age groups from neonatal to old age. The data sets were derived through various studies carried out during the period of 1970 to 2014. The total of sample size for the model study was 234678.

The GBD study of 2019 has an extensive compilation of Pb exposure studies across the world. The blood samples were analyzed using various methods to find out BLL. In India, a total of 36 studies looking at BLL across various age ranges, genders and locations (rural/urban) were considered from 1970 to 2014. These led to a total of 89 data points with a total sample size of

2, 34,678. **Table 5** summarizes the studies carried out in India:

Table 5: No. of studies in different states of India used as input for the GBD model

Location/State	No. of Studies	No. of Data points
India	3	14
Maharashtra	15	30
Tamil Nadu	5	12
Uttar Pradesh	2	7
Telangana	3	6
Delhi	4	4
Karnataka	2	4
Punjab	3	3
Haryana	1	3
J&K	1	2
Gujarat	1	1

The studies experimented above reported the BLL in terms of the arithmetic mean (AP), geometric mean (GM) or median. To standardize the data, almost all the values have been reported in geometric mean or median. Moreover, the data collected from different locations of urban city (proportion of individuals in a given location living in an urban area) were also adjusted. These values are provided in Table 2 and Table 3 of the GDB appendix: https://ars.els-cdn.com/content/image/1-s2.0-S0140673620307522-mmc1.pdf)

After adjustment of the factors, a Spatiotemporal Gaussian Process Regression methodology (ST-GPR) was applied to the numbers (data). ST-GPR borrows strength across space and time to improve estimates for locations and years with no or limited data. The goal of ST- GPR is used to estimate the mean blood Pb levels for each GBD location and year. Complete methodological details can be found in the GBD risk factors methods appendix (pg. 34-39): https://ars.els-cdn.com/content/image/1-s2.0-S0140673620307522-mmc1.pdf. The socio-demographic index (SDI), urbanicity, the combined number of two- and four-wheeled vehicles per capita, and a covariate indicating whether leaded gasoline had been phased out in a given country year were determined to have the predictive capacity for blood Pb exposure. From 1970 to 2019, ST-GPR was used to calculate the mean and standard deviation of blood Pb in each Indian state.

Using the results of the ST-GPR and individual blood Pb measurements from select locations, density estimates the individual-level distribution of the blood Pb levels within each state and year i.e. across all age groups for both genders. The Pb exposure methodology is in **Fig. 8.**

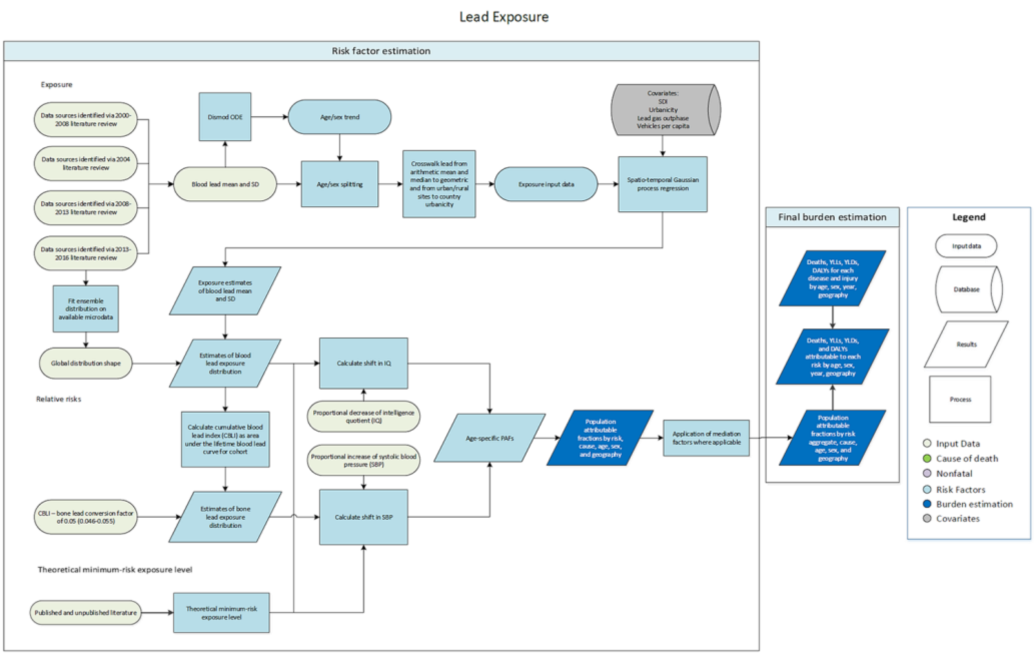

Fig. 8 Pb Exposure Methodology

2. Limitations of the GBD Model

Estimates from the GBD model are the most thorough attempt to date in determining epidemic levels and trends over the world. However, the models will only be as good as the data which is fed into these models. As mentioned previously, in India, a total of 36 studies looking at BLL across various age ranges, genders and locations (rural/urban) were considered from 1970 to 2014. These led to a total of 89 data points with a total sample size of 2,34,678. This sample size is minuscule for a large country like India, which exhibits significant variation in climate and geographies. This also fails to accurately account for district-level variations within the states.

The lack of primary data is a major disadvantage of the GBD analysis. When data isn't available, the results are based on the modelling efforts' out-of-sample predictive validity. While enhancements in data processing and modelling can Pb to a modest increase in estimate accuracy, more and better primary data collected is required for fundamental improvements. Greater consistency in data adjustments has resulted from the more clear designation of the preferred and alternative measurement methods for each outcome, as well as the bias mapping from alternative to reference methods done as part of GBD 2019.

3. Modelling Challenges

Model estimates are always based on multiple assumptions wherein the data from multiple locations and age groups are collated and further derived based on interpolation and ST-GPR methods. Modelling such data sets is always very challenging as the data points are derived from multiple publications, which may have different approaches to survey sampling, analysis tools and interpretation. These estimates are the best estimates one can drive based on available information. India will need more comprehensive exposure data collection and studies which will be able to correlate the information with higher confidence in up to date databases of the exposed population, more so due to the dynamic demographic profile of the country and exposure pathways.

4. Methodology of Studies

4.1. Detection of Lead Poisoning

Elevated BLL can be detected using a variety of ways. Changes in blood cells seen under a microscope or the disappearance of thick lines in the bones of children shown on X-rays are both indicators of Pb poisoning. However, measuring the amount of Pb in blood samples is the most common way to detect excessive levels of body Pb. This test, on the other hand, only shows how much Pb is present in circulating blood and not how much is stored in the body. The Centers for Disease Control and Prevention (CDC) established a standard increased blood Pb level of 10 g/dL for adults and 5 g/dL for children in 2012 (CDC, 2012). The normal Pb level for children used to be 10 g/dL. Clinical symptoms differ from person to person and are influenced by other environmental factors. Some people show clinical symptoms even at low levels of Pb, while others are asymptomatic even at high levels of Pb in their body fluids (IHME, 2017b). The available analytical methods for assessing Pb in the blood are shown in **Table 6**.

Table 6: Available analytical methods for measuring Pb in blood

Method	Strengths	Limitations
Flame atomic absorption spectrometry (FAAS)	• Requires only basic laboratory expertise • Rapid analysis • Minor trial size (50-100 µl) • Low purchase and running costs • Relatively few interferences • Robust interface	• Relatively high detection limit (~10 µg/dl) • Time duration required for sample digestion/pre-concentration if not using Delves cup
Graphite furnace atomic absorption spectrometry (GFAAS)	• Good detection limit (<1-2µg /dl) • Small sample size • Moderate purchase and running costs • Some multi-element capacity • Relatively few interferences (although more than with FAAS) • Widely used, available from multiple vendors	Longer analysis time • Requires some laboratory expertise (more than FAAS) • Greater potential spectral interference than with FAAS
Laboratory anodic stripping voltammetry (ASV)	• Good detection limit (2-3 µg/dl) • Reduced buying and running costs.	• Requires some laboratory expertise (similar to GFAAS) Sample pretreatment

	• Quick Minor trial size (~100 µl) • Relative simplicity of equipment	needed • Few elements might affect measurement (e.g. occurrence of copper) Less available.
Portable ASV	• Easy to handle; does not require skilled laboratory personnel • Very low purchase and running costs • Reasonably good detection limit for a portable device (3.3 µg/dl)	• Not as accurate as other methods • Up to 65 µg/dl level, find out • Levels beyond 8 µg/dl should be confirmed by a laboratory method
Inductively coupled plasma mass spectrometry (ICPMS)	• Best method finding limit (~0.1 µg/dl) Fast • Minor trial size (50-100 µl) • Comparatively less, well-understood • Isotopic measurements possible • Financial method if very greater number of samples • Multi-element ability	• High purchase and running costs • Highly skilled laboratory operator required

Source: WHO, 2021

सत्यमेव जयते

NITI Aayog

Sansad Marg,
New Delhi – 110001

Council of Scientific and Industrial Research (CSIR)

Anusandhan Bhawan, 2 Rafi Marg,
New Delhi – 110001