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Blood Lead Surveillance of Children and Pregnant Women in Tamil Nadu

Vital Strategies

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Acknowledgments

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Acronyms and Abbreviations

ASHA	Accredited social health activist
BLL	Blood lead level
GDP	Gross domestic product
IQ	Intelligence quotient
μg/dL	Micrograms of lead per deciliter of whole blood
SRIHER	Sri Ramachandra Institute of Higher Education and Research
ULAB	Used lead acid battery
WHO	World Health Organization

Executive Summary

Overview

Lead is a widely used toxic metal that causes significant public health problems, especially in low- and middle-income countries. According to estimates from the 2019 Global Burden of Disease Study, India accounted for more than half the total global morbidity and mortality attributable to lead exposure despite having only 18% of the global population. In addition, lead can impair children's brain and neurological development, resulting in lower intelligence quotient and poor academic performance. The cost of such losses of children's IQ and productivity due to lead exposure is estimated to account for nearly 3% of the GDP in India (1).

While a few studies have assessed lead exposure among children in Tamil Nadu, most have been conducted more than a decade ago on small sample sizes. A recent report by the National Institution for Transforming India Aayog and the Council of Scientific and Industrial Research estimated the average blood lead level (BLL) among people living in Tamil Nadu to be above 5 µg/dL, exceeding the WHO-recommended level (2) but limited empirical data are available to validate the estimates. There is thus a need to generate representative statewide exposure profiles for lead exposure in Tamil Nadu, especially among vulnerable groups, including children and pregnant women.

The current project was executed between 2023 and 2024 as a collaborative effort by Vital Strategies, in partnership with Pure Earth and (SRIHER) with due approvals from the Directorate of Public Health, Government of Tamil Nadu to profile the distribution of BLLs in children under the age of 6 and their pregnant mothers in Tamil Nadu, India. Elevated BLLs were common among these children, and higher BLLs were found among children ages 5 and 6 living in urban areas. Several factors related to lead exposure at home were identified, including living near lead-related industries and living in households with chipping paint. Finished household flooring was identified as being protective and related to lower risk of lead exposure.

Findings from this study highlight the urgency to develop a comprehensive strategy to protect children in Tamil Nadu from lead poisoning. Strengthening the local health system's capacity to address lead exposure should include ongoing monitoring of childhood BLLs, integrating lead exposure assessment into routine pediatric care for early prevention and timely treatment, increasing awareness among health professionals and parents, and regulating lead use in consumer products, industry, and manufacturing.

About Lead Poisoning

Lead is a potent toxin that can severely affect the mental functioning and physical health of children and adults. Children are particularly vulnerable to lead poisoning because they absorb significantly more lead from their environments than adults, and their central nervous systems are still developing. Lead exposure can affect children's brain development, even at a low level, resulting in behavioral changes, reduced IQ, reduced educational attainment, and lifetime earnings(3)(4).

Globally, known sources of lead exposure include the use of lead paint, unsafe recycling of lead-acid batteries, mining, manufacturing, and lead in consumer products. While India has tried to regulate lead in gasoline and paint, little is known about the prevalence and extent of exposure from other emerging sources, including spices, metal and ceramic cookware, and the recycling of used lead-acid batteries (ULABs). In addition, recent population-level data on childhood BLLs are limited.

Summary of Approach

The project aims to understand the exposure distribution of BLLs to estimate prevalance of high BLLs among children under the age of 6 and their pregnant mothers in Tamil Nadu. Using a multistage sampling design, we selected a sample of children (n=727) and their pregnant mothers (n=76) from seven districts in Tamil Nadu. We visited homes to mobilize randomly selected eligible participants for blood lead testing at the nearest sample collection centers. Consent administration, blood lead testing using capillary blood, and analysis by a portable analyzer were conducted at a designated sample collection center. We also collected information on factors related to lead exposure (e.g., take-home exposure, home environment, use of consumer products, behavior, and nutrition) and home demographics through interviews with the primary caregivers. We developed statistical models to identify factors that might be associated with elevated BLL among children. The results and recommendations for reducing lead exposure were shared with all participating families. The study received full ethical clearance from the Tamil Nadu Directorate of Public Health review board[1] and a US-based institutional review board[2].

Key Findings

Over 39% of the sampled children in Tamil Nadu had elevated BLLs (≥5 µg/dL), exceeding the level requiring intervention as recommended by WHO. We observed that the average BLL of children in Tamil Nadu (geometric mean = 4.2 µg/dL) is similar to the average estimated for Indian children in previous studies. In all districts except Salem, 1 in 4 children tested had elevated BLLs. Prevalence of elevated BLL was higher in urban areas and in older children, between the ages of 5 and 6. We also observed elevated BLLs among 20% of pregnant women. The average level of pregnant women in Tamil Nadu

1 IEC No. DPHPM/ IEC/ 2023/ 160

2 BRANY Protocol No. 23-089-522

(geometric mean = 3.2 µg/dL) is slightly lower than the average level estimated for pregnant women in previous studies in India.

Multiple factors were associated with high BLLs in children within the sampled households, even after controlling for age, sex, and demographics. These factors include living in a household with chipping paint or recent renovation, living near a lead-related industry, and the type of flooring.

Children with the following factors were likelier to have a BLL ≥5 µg/dL.

Living in a household with chipping paint or a recent renovation.

Living near an industry that may involve lead, such as manufacturing plants and smelting.

Living in households with unfinished flooring (e.g., dirt floor).

Children with the above risk factors were likelier to have elevated BLLs, while those living in households with finished flooring were less likely to exhibit high BLLs, indicating that finished flooring may be a protective factor against lead exposure.

Introduction

Lead Poisoning as a Public Health Issue in India

Lead poisoning is a severe public health problem affecting children in India. Based on the 2019 Global Burden of Disease Study estimates, an estimated 275 million children in India had BLLs that were considered unsafe, exceeding 5 µg/dL (2). India has the highest number of children with elevated BLL estimated in the world. Lead exposure causes harm to several organ systems, which in turn affects behavior, lowers performance in school, stunts physical growth, hinders cerebral development, and eventually lowers productivity(5). Studies have shown that lead exposure is associated with a significant deficit in children's IQ(6). According to an economic model published by the researchers from the World Bank, lead-attributable loss of IQ in children 0-5 years accounts for a loss of 3.3% of India's GDP(1).

Compared to adults, children are at a greater risk for lead toxicity due to hand-to-mouth behavior, ingestion of nonedible items, and also because the proportion of ingested lead that is absorbed is much greater in children than in adults(7). Lead competes and interferes with critical micronutrients such as iron, zinc, and calcium needed for hemoglobin synthesis, mitochondrial function, nerve cell conduction, and muscle activation. Understanding lead exposure also helps inform interventions on malnutrition or health conditions like anemia, as previous studies have found a strong tie between lead exposure and anemia among children(8,9). As per the recent demographic health survey (Fifth National Family Health Survey 2019–21), the anemia rate among children and adults has worsened in India, with more than half of women and children being anemic. Many recent studies in other countries have found elevated BLLs significantly associated with anemia. However, it is unclear how lead exposure contributes to the anemia in India, as the population-level lead exposure has not been adequately profiled.

Why Blood Lead Surveillance Is Needed in Tamil Nadu

According to the report from the National Institution for Transforming India Aayog and the Council of Scientific and Industrial Research, "Assessment of Lead Impact on Human and India's Response," published in 2022, Tamil Nadu's average BLL is estimated to be above 5 µg/dL. However, this estimate was based on modeled data from 36 previous studies. Earlier studies in Tamil Nadu focused on understanding lead exposure in schoolchildren living near formal smelting facilities and other high-risk areas. These studies were highly localized, with small populations known to be at risk of exposure from a particular source. The current state of research and the fact that millions of lives are at risk make it abundantly clear that BLLs in children in Tamil Nadu should be studied to determine their prevalence. This project will address the current knowledge gap by providing relevant information on the severity and distribution of lead exposure and its risk factors in children and pregnant women in Tamil Nadu.

Objectives

Determine the exposure profile of BLLs to estimate the prevalence of elevated BLLs in young children (those under 6 years of age) and pregnant women in Tamil Nadu.

Evaluate personal, behavioral, home environment, and occupational risk factors linked to elevated BLLs.

Demonstrate the feasibility and viability of a future statewide blood lead surveillance system.

Overview of Approach

Study Design and Implementation

Vital Strategies led the design of this surveillance and supported the data collection and analysis in collaboration with the SRIHER. The study was approved by the Institutional Ethical Committee at the Directorate of Public Health and Preventive Medicine, Government of Tamil Nadu, the Institutional Ethical Committee of SRIHER, and the Biomedical Research Alliance of New York (BRANY) in the U.S. The study also complies with the U.S. federal and Indian regulations and laws concerning research on human subjects. Blood lead testing was carried out from November 2023 to June 2024.

Recruitment of Participants

We used multistage sampling to draw a sample of children aged between 13 and 72 months and a convenience sample of pregnant mothers of participating children in seven districts across Tamil Nadu, as shown in Figure 1.

Figure 1: Study area

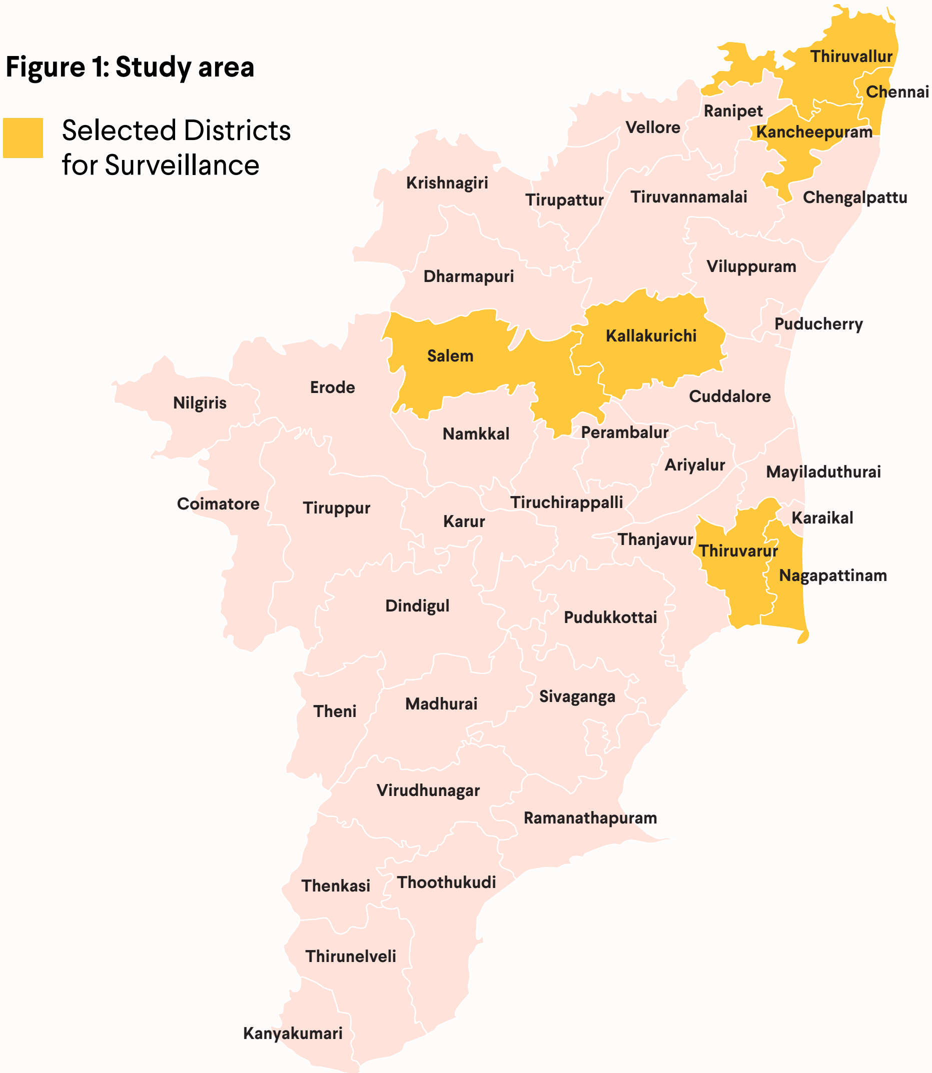


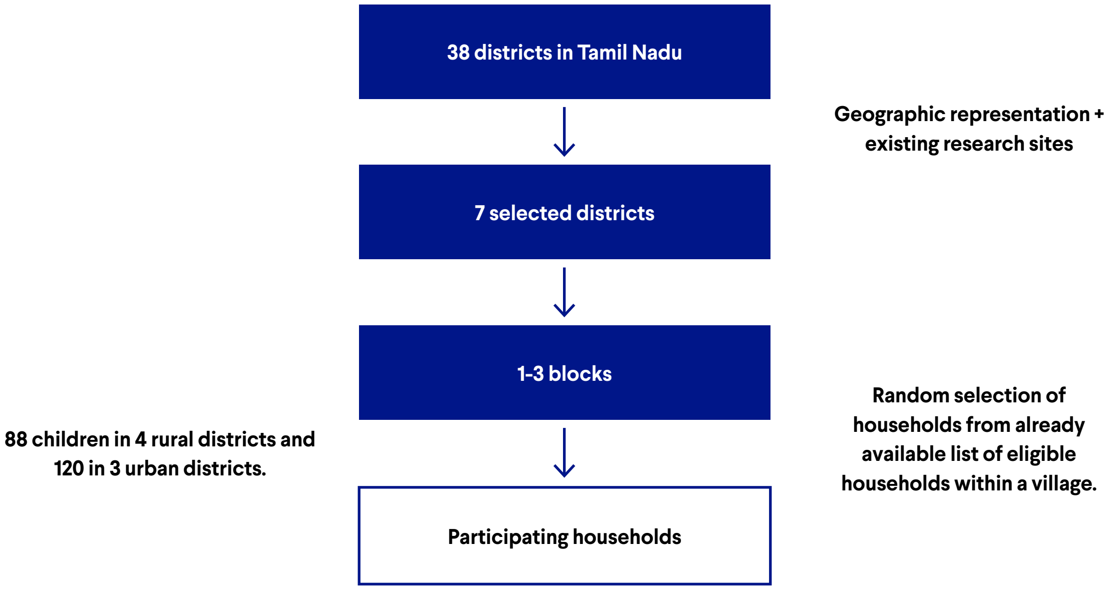
Table 1: Characteristics of seven study districts

Description	Tamil Nadu (selected districts)*						
	Chennai	**Thiruvallur**	**Kancheepuram**	**Kallakurichi**	**Salem**	**Nagapattinam**	**Thiruvarur**
Population	6748026	2721363	1166401	52507	3482056	697069	1264277
Child population by sex (0-6 years)	459324	405669	21879	208	79067	11884	1006482
Sex ratio (females per 1000 males)†	859	991	889	987	900	799	859
Birth registration (%)	98.2	97	97.5	100	97.4	99.1	98.2
Economic Pattern	Auto-mobile, IT, medical tourism, hardware manufac-turing.	Industry, agriculture, fishing	Agriculture, tourism, Silk, Manufacturer, Industry	Agriculture	IT, steel, textile industry, agriculture	Agriculture, tourism, fishing	Agriculture
Anaemia Status (%) Child (6-59 months)	55.3	58.4	68.8	73.4	51.3	60.9	45.0
Under weight Status (%) Child (6-59 months)	21.9	20.6	19.8	20.5	20.8	24.3	21.5

* Data for each district is taken from the National Family Health Survey-5.
† at birth for children born in the last five years; Anaemic (<11.0 g/dl)

First, we selected seven districts in the state and two to three blocks within each district based on geographic representation and existing community engagement through prior projects. Second, villages were randomly selected from the blocks using statistical software. Finally, households were selected from an available list of eligible households/ children using a simple random selection method.

Figure 2: Sampling Procedure



The sampling procedure for surveillance is shown in Figure 2. The list of randomly selected households was shared with a local field team member well in advance, who in turn informed the community health workers to inform the participant's caregiver. Before the sample collection day, the community health worker sought verbal agreement from the caregiver to participate in blood lead testing and communicated the sample collection date and location (often a local health center) to the caregiver. One or two days before the sample collection, a phone call was made to the caregiver as a reminder to increase the response rate and address any difficulty in accessing the sample collection center. On the day of sample collection, the field team member was accompanied by community health workers to selected households and screened the eligibility of participants, explaining the purpose and procedure in the local language (Tamil). Screening questions were used to ensure consistent current residency, to confirm that the subjects' general health allowed their participation, and to determine their willingness to participate in this study. Interviewers obtained written consent from the child's primary caregiver and the pregnant woman at the sample collection center. For participants who were not located within walking distance, the field team organized transportation.

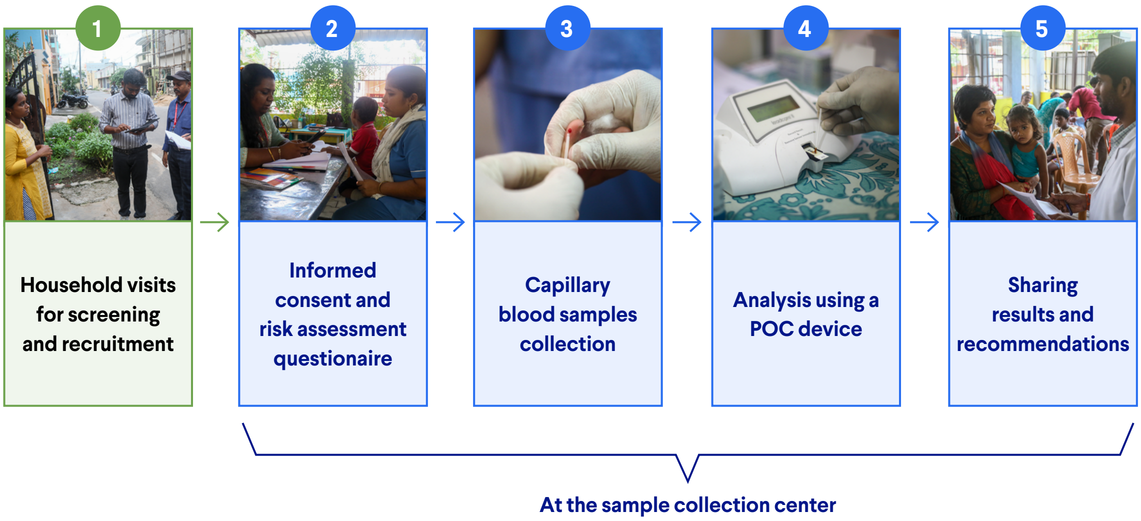
Household Questionnaire

The study team interviewed either the child's primary caregiver or the pregnant woman in Tamil and recorded responses on a tablet. The interview gathered information on the potential take-home lead exposure (e.g., parental lead-related occupation or hobby), home environment (e.g., source of drinking water, chipping paint), use of consumer products that might contain lead (e.g., spices, cosmetics), behavioral and nutritional factors that might modify the exposure (e.g., pica behavior, nutrition, household and personal hygiene), and household demographics (e.g., age, sex, primary caregiver's educational attainment).

Measurement of BLLs

BLLs were determined using capillary blood samples analyzed by a portable point-of-care (POC) analyzer (LeadCare II, Meridian Bioscience, USA). After cleaning the participant's hand and finger, a trained team member drew a few drops of blood by pricking the finger, following WHO guidelines(10). The capillary blood was then analyzed by a LeadCare II analyzer, which was placed in an undisturbed and clean area at the sample collection center. This portable analyzer is certified for clinical use by the United States Food and Drug Administration and measures BLL in three minutes. It is considered a good screening tool and provides comparable results with laboratory methods within its testing range (3.3-65 µg/dL). Test results were shared with the caregivers and pregnant women, along with advice tailored to BLL on how to reduce lead exposure and whether clinician vists were recommended. An overview of the study procedure is shown in Figure 3.

Figure 3: Overview of study procedure



Data Analysis and Dissemination

We calculated the geometric means of BLL, which is preferred when analyzing exposures with a skewed distribution. Spearman correlation coefficients were calculated to assess the correlation between maternal and child BLL. The prevalence of participants with elevated BLLs was also assessed using two different thresholds:

1. BLL ≥5 µg/dL: the threshold that WHO recommends for initiating clinical intervention for children and pregnant women.
2. BLL ≥10 µg/dL: the exposure level thought to contribute to anemia(11).

We used statistical models to assess the associations between each risk factor and the probability of BLL above 5 µg/dL among children. The final model accounted for the influence of demographic factors, including children's age and sex, maternal education, and socioeconomic status (measured by ownership of a below poverty line certification card).

Limitations

- While the portable analyzer is designed to screen for elevated BLL, it cannot detect extremely low levels (below 3.3 μg/dL). We assigned a value of 2.3 μg/dL for BLLs below the detection limit, consistent with recommendations from the literature(12).
- Testing BLLs using capillary blood and the portable analyzer can be more vulnerable to environmental contamination. The performance of the portable analyzer may be affected by temperature and strong airflow. We enforced several quality control procedures to minimize contamination during blood lead testing. We also collected a small subset of venous blood samples to validate the measurements of the portable analyzer, but these blood samples were impaired during transportation and could not be analyzed.
- State and district levels may not be representative since selecting districts and blocks was not random. However, the districts selected were spread across the states with different demographic profiles and economic activities, covering both rural and urban areas. The villages and households were randomly selected within selected blocks.
- Our findings for pregnant women should be seen as indicative rather than definitive since the sample size was fairly small.
- The risk factors associated with higher BLLs are based on analysis of data from self reported questionnaires and a limited number of direct visual observations in the field. It does not include any home based assessments to measure lead in potential sources. However, this aspect was covered in a subsequent study being reported separately.

Summary of Findings

Surveillance Sample

727 children and 76 pregnant women participated in the study. Table 2 and Table 3 summarize the demographics of participants. The average age of the children in our sample was 37.2 months, with almost equal proportions of male (51%) and female (49%) children. An estimated 51% of children were from urban households and 49% from rural households. Less than 20% of primary caregivers had lower than high school education. The average age of pregnant women in the sample was 27.3 years. More women sampled were in the second trimester (53%), and fewer were in the first or third trimester. Most of the sampled pregnant women had completed high school (92.1%).

Table 2: Demographics of child participants

Characteristics	N (Percentage, %)
Age group	
12-24 months	165 (22.7)
25-36 months	207 (28.5)
37-48 months	186 (25.6)
49-60 months	113 (15.5)
61-72 months	56 (7.7)
Sex	
Female	357 (49.1)
Male	370 (50.9)
Urbanicity	
Urban	374 (51.4)
Rural	353 (48.6)
Primary caregiver education level	
Illiterate	14 (1.9)
Primary or less	70 (9.6)
Middle school	72 (9.9)
High school	294 (40.4)
Higher education	276 (38.0)
Missing	1.0 (0.1)
Ownership of BPL card	
Yes	592 (81.4)
No	132 (18.2)
Missing	3.0 (0.4)
District	
Chennai	134 (18.4)
Kallakurichi	89 (12.2)
Kancheepuram	120 (16.5)
Nagappatinam	88 (12.1)
Salem	88 (12.1)
Thiruvarur	88 (12.1)
Thiruvallur	120 (16.5)

Table 3: Demographics of pregnant women participants

Characteristics	N (Percentage, %)
Pregnancy Trimester	
1st	14 (18.4)
2nd	40 (52.6)
3rd	22 (28.9)
Urbanicity	
Urban	44 (57.9)
Rural	32 (42.1)
Education	
Illiterate	2.0 (2.6)
Primary or less	1.0 (1.3)
Middle school	3.0 (3.9)
High school	32 (42.1)
Higher education	38 (50.0)
Missing	1.0 (0.1)
Ownership of BPL card	
Yes	57 (75.0)
No	18 (23.7)
Missing	1.0 (1.3)

BLLs Among Children

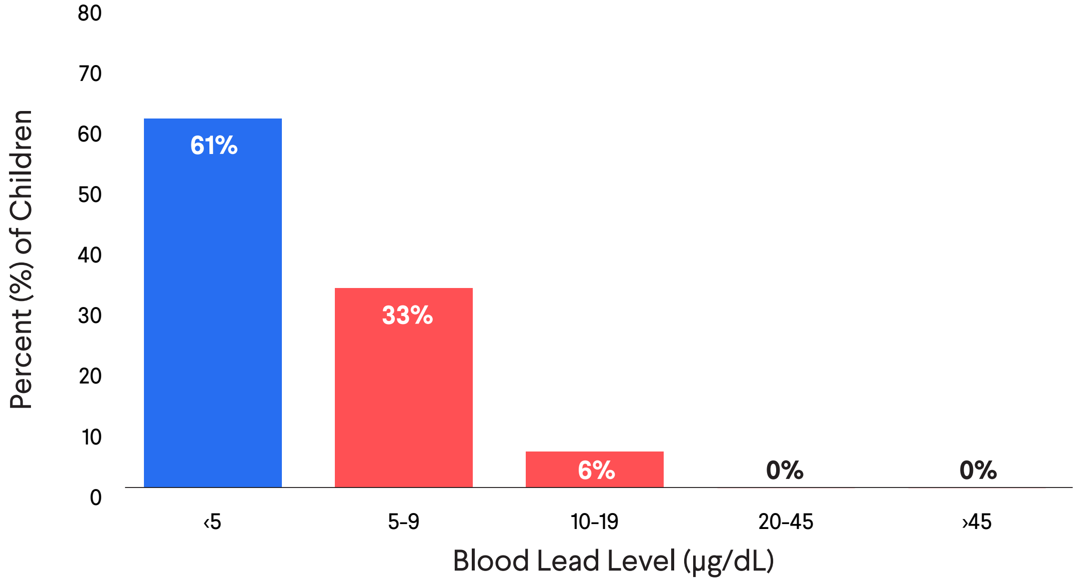
Overview

Almost 39% of the children tested in this study had BLLs exceeding WHO recommendation (≥5 μg/dL) and 6% had BLLs above 10 μg/dL (Figure 4). Table 4 summarizes the BLLs among children in Tamil Nadu. In comparison, fewer than 3% of children under 6 in the USA have BLLs exceeding 5 μg/dL, and less than 0.4% have levels exceeding 10 μg/dL(13).

Table 4: BLLs among sampled children in Tamil Nadu (n=727)

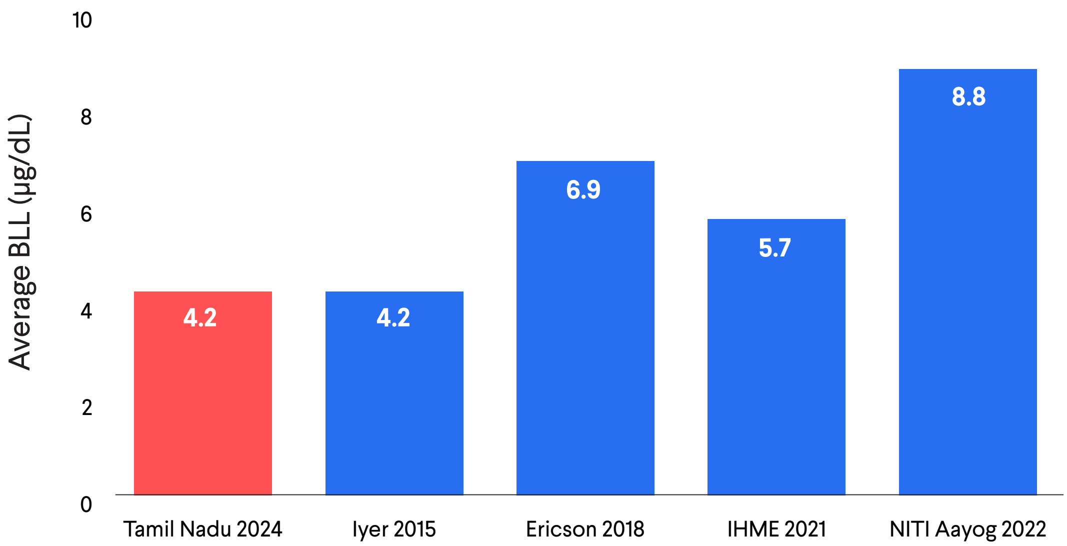
Geometric mean, μg/dL (95% CI)	Minimal BLL measured	Median BLL measured	90th percentile	95th percentile	Maximum BLL measured	Children with BLL ≥ 5 μg/dL, %	Children with BLL ≥ 10 μg/dL, %
4.2 (4.1,4.4)	2.3	4.3	8.0	9.8	31.2	38.6	5.9

Figure 4: Distribution of BLL among sampled children in Tamil Nadu



The average BLL of children living in Tamil Nadu is similar to the average estimated for children in India in previous studies (Figure 5) (14)(15)(16). BLLs of children in Tamil Nadu ranged from 2.3 µg/dL to 31.2 µg/dL with a geometric mean of 4.2 µg/dL.

Figure 5: Comparison of average BLL among children with previous studies in India



The BLLs we observed represent the healthy child population living in Tamil Nadu, while previous studies focused on the children who are unhealthy (e.g., anemic or malnourished) or from high-risk communities (e.g., communities living near a used lead-acid battery recycling site). Figure 6 compares average BLLs with previous studies that measured BLL in children in Tamil Nadu. The average BLL reported in our study is lower than the average BLL (11.8 µg/dL) reported by Mohan et al., which assessed the BLL of children from urban slums with malnutrition (17). Another study by Roy et al. (18) examined BLLs of children attending schools near industries or heavy traffic zones and reported a higher average BLL (11.4 µg/dL) than ours. In our study, healthy children, irrespective of their urbanicity, were assessed. Therefore, our estimate is a better representation of children living in Tamil Nadu after nearly 25 years of lead phase out from petrol.

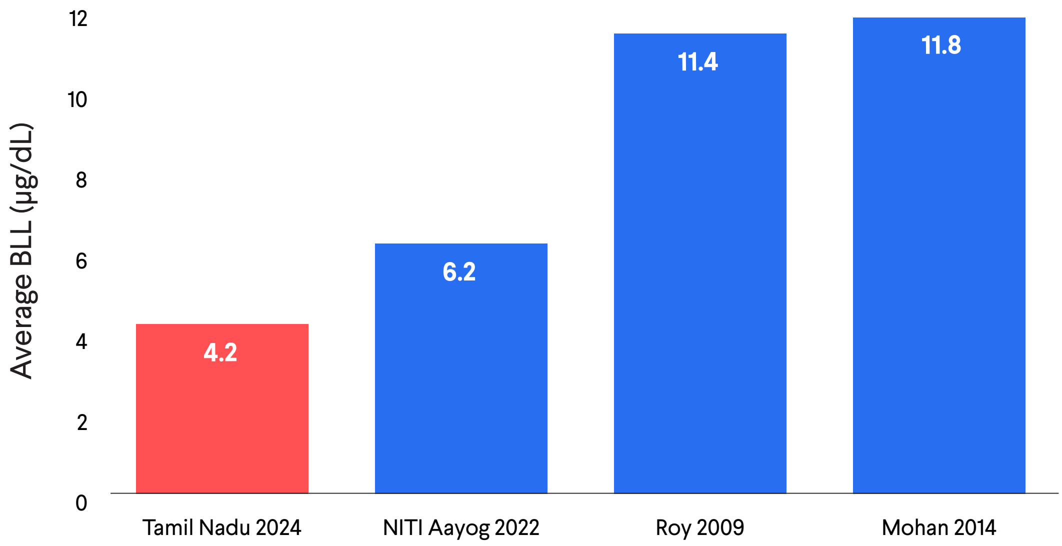


Figure 6: Comparison of average BLLs with previous studies in Tamil Nadu

BLLs by District

Elevated BLL was common among children across all sampled districts but with some geographic variation (Figure 7). Table 5 summarizes the BLLs among children by districts. The highest average levels were observed in children living in Thiruvallur, followed by Chennai and Kancheepuram. In Chennai and Thiruvallur, almost 1 in 2 children had levels ≥ 5 µg/dL. We observed a large variation in children with high BLL (>=5ug/dL) across different districts ranging from 14% to 56%.

Table 5: BLLs among children by district

District	Geometric mean, µg/dL (95% CI)	Children with BLL ≥ 5 µg/dL, %	Children with BLL ≥ 10 µg/dL, %
Chennai	4.7 (4.3, 5.2)	46.3	5.2
Kallakurichi	4.2 (3.8, 4.7)	39.3	4.5
Kancheepuram	4.3 (4.0, 4.6)	41.7	2.5
Nagappatinam	3.7 (3.4, 4.1)	28.4	4.5
Salem	3.0 (2.8, 3.3)	13.6	2.3
Thiruvarur	4.0 (3.6, 4.5)	35.2	3.4
Thiruvallur	5.4 (5.0, 5.9)	55.8	10.8

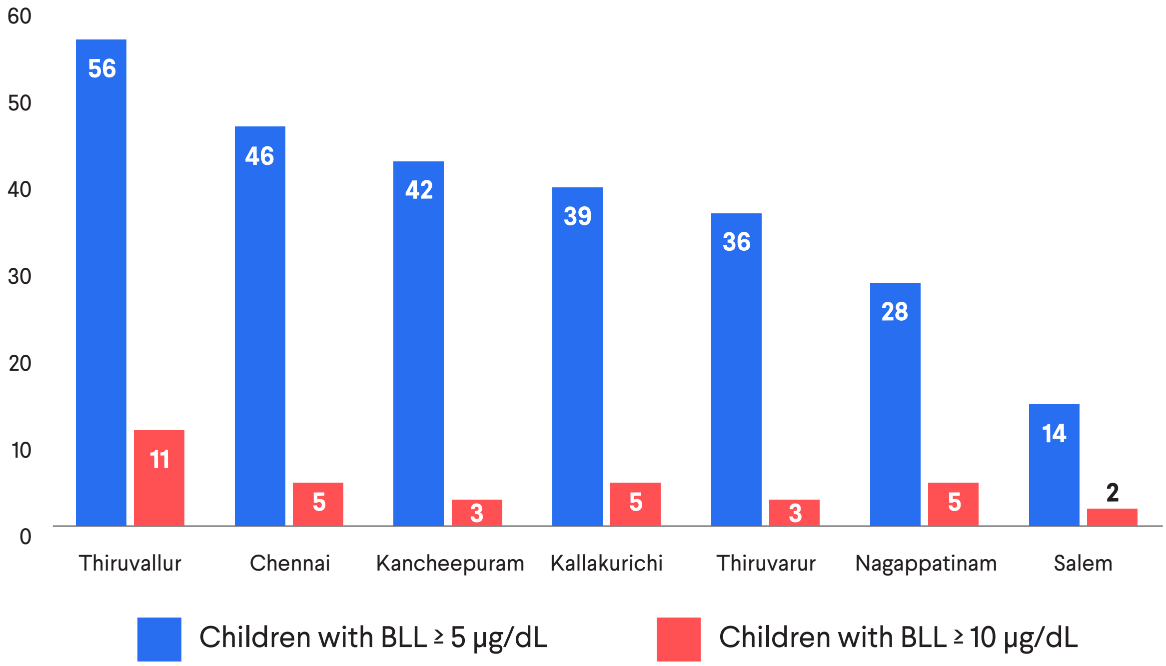


Figure 7: Percentage of children with elevated BLL by district

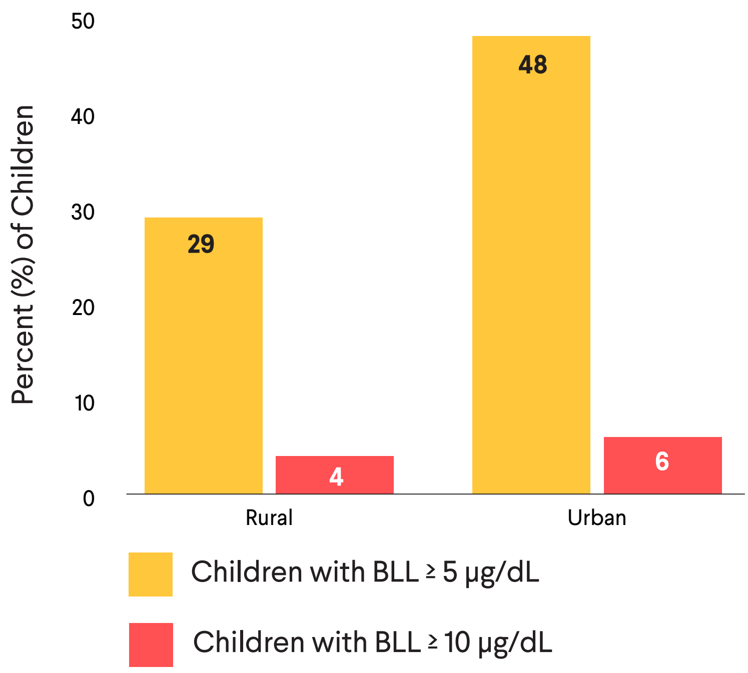
BLLs by Urbanicity

More than half of children living in urban areas had BLLs exceeding the WHO recommendations. Table 6 summarizes levels among children by urbanicity. We observed a slightly higher average BLL among children living in urban areas than those living in rural communities ($p<0.01$) (Figure 8).

Table 6: BLLs among children by urbanicity

Character	Geometric mean, µg/dL (95% CI)	Children with BLL ≥ 5 µg/dL, %	Children with BLL ≥ 10 µg/dL, %
Rural	3.7 (3.5, 3.9)	29.2	3.7
Urban	4.8 (4.6, 5.0)	47.9	6.1

Figure 8: Percentage of children with elevated BLLs by urbanicity



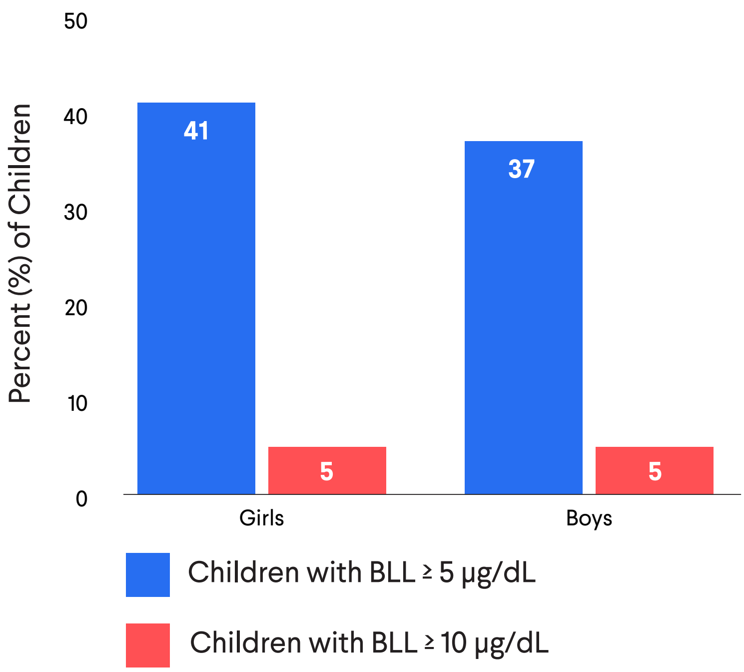
BLLs by Sex

Average BLLs were similar among boys and girls. A slightly higher proportion of girls had elevated blood lead levels at both 5 and 10 μg/dL (Figure 9).

Table 7: BLL among children by sex

Character	Geometric mean, μg/dL (95% CI)	Children with BLL ≥ 5 μg/dL, %	Children with BLL ≥ 10 μg/dL, %
Girls	4.3 (4.1, 4.5)	41.2	5.3
Boys	4.2 (4.0, 4.4)	36.5	4.6

Figure 9: Proportion of Children with Elevated BLLs by Sex



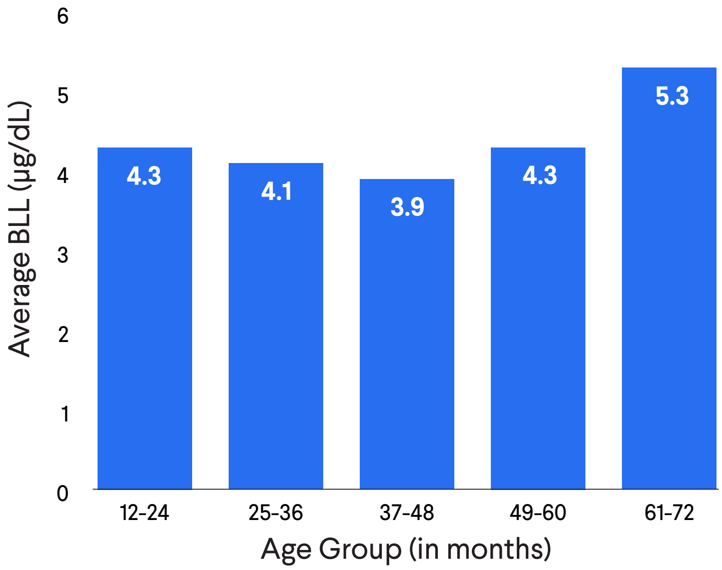
BLLs by Age Group

Elevated BLLs were prevalent across all age groups of young children in Tamil Nadu (Table 8). We observed significant differences in average BLLs among different age groups ($p<0.01$), with the highest among the oldest group (Figure 10). This observation is consistent with what has been observed previously in Indian children and other child populations in Asia(19)(20). This trend is different from what has been observed in the U.S., where BLL tends to peak in children aged 12-24 months and is likely associated with more active hand-to-mouth behavior and ingestion of nonedible items like soil or paint chips(21).

Table 8: BLL among children by age group

Character	Geometric mean, µg/dL (95% CI)	Children with BLL ≥ 5 µg/dL, %	Children with BLL ≥ 10 µg/dL, %
12-24 months	4.3 (4.0, 4.7)	40.6	3.6
25-36 months	4.1 (3.9, 4.4)	36.2	2.4
37-48 months	3.9 (3.7, 4.2)	35.5	4.3
49-60 months	4.3 (3.9, 4.8)	40.7	6.2
61-72 months	5.3 (4.6, 6.1)	50.0	17.9

Figure 10: Average BLL among children by age group



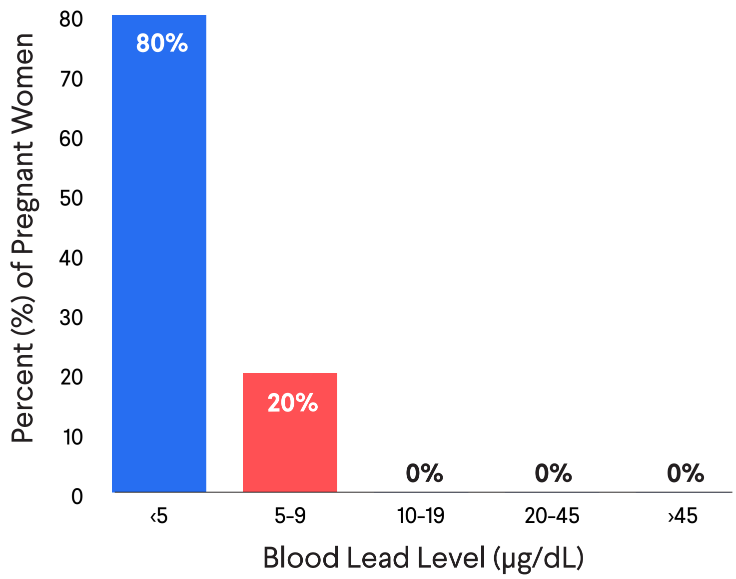
BLLs Among Pregnant Women

Over 20% of pregnant women tested had BLLs exceeding the WHO threshold for clinical response (5 µg/dL). Table 9 summarizes the levels among pregnant women in Tamil Nadu. We found a weak correlation between BLLs of pregnant women and their young children (r=0.35).

Table 9: BLL among pregnant women sampled in Tamil Nadu (n=76)

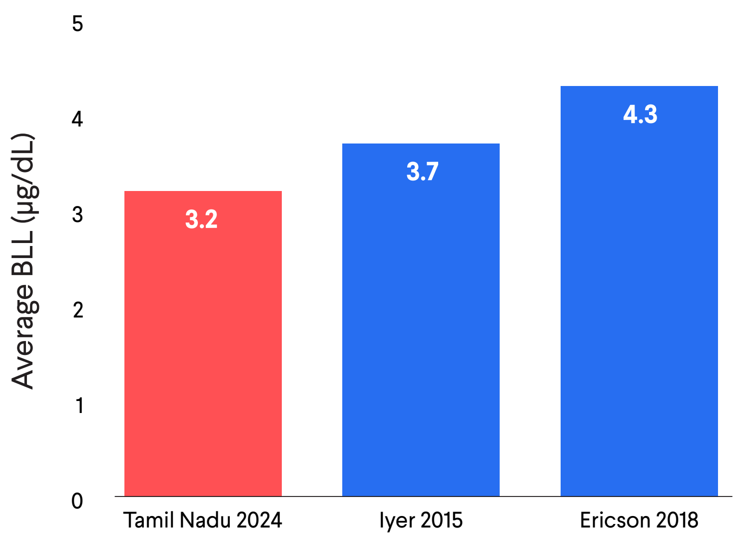
Geometric mean, µg/dL (95% CI)	Minimal BLL measured	Median BLL measured	90th percentile	95th percentile	Maximum BLL measured	Women with BLL ≥ 5 µg/dL, %	Women with BLL ≥ 10 µg/dL, %
3.2 (2.9, 3.5)	2.3	2.3	6.3	7.6	9.3	19.7	0.0

Figure 11: Distribution of BLL among pregnant women (n=76)



The average BLL of pregnant women living in Tamil Nadu is slightly lower than the average levels observed in Indian women (Figure 12). BLLs of pregnant women in Tamil Nadu ranged from 2.3 µg/dL to 9.3 µg/dL with a geometric mean of 3.2 µg/dL.

Figure 12: Comparison of average BLL among pregnant women with previous studies in India



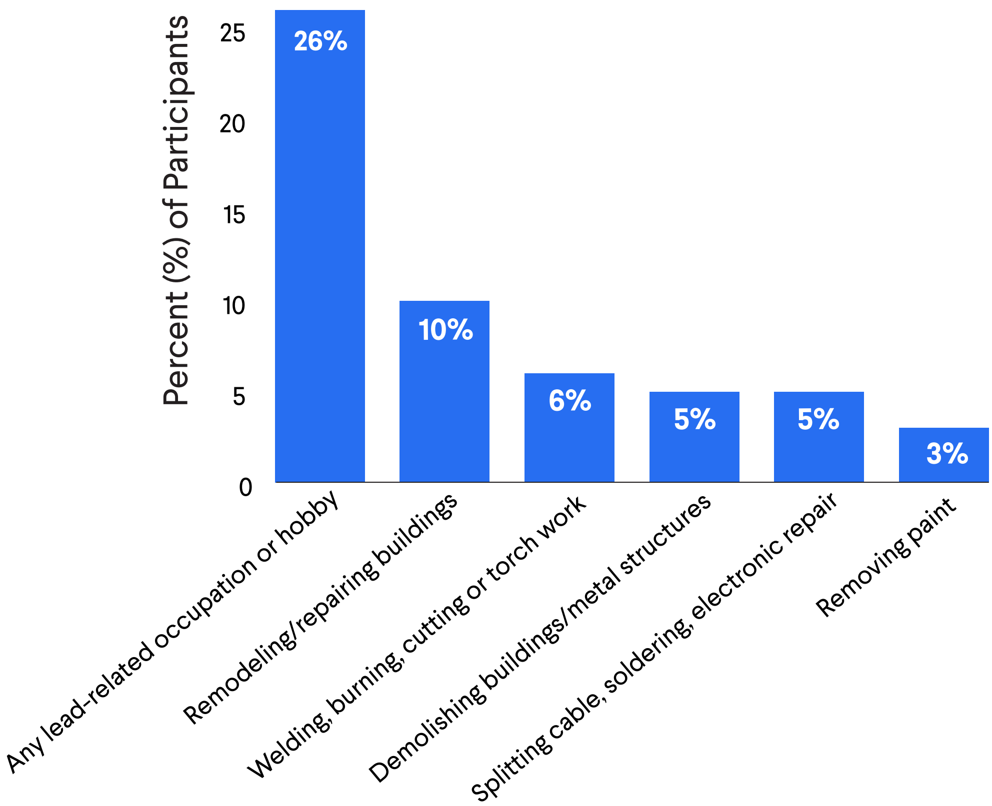
Risk/Protective Factors for Lead Exposure

Prevalence of Potential Risk Factors

Take-Home Exposure

Children can be exposed to lead if their family members carry lead dust home from their workplace or hobby. Occupations that potentially involve the use of or exposure to lead include construction, manufacturing, smelting, and battery recycling. Hobbies may include soldering, applying paints, or glazes. Past research has shown that this can be an important source of lead exposure for children at home (22)(23). In our study, around 26% of children lived with someone involved in lead-related occupations or hobbies. The most common jobs or hobbies with potential lead exposure reported by participating households are remodeling/repairing buildings (10%) and welding, burning, cutting or torch work (6%). Figure 13 shows the prevalence of any lead-related occupation/hobby with the list of the top five responses from the study.

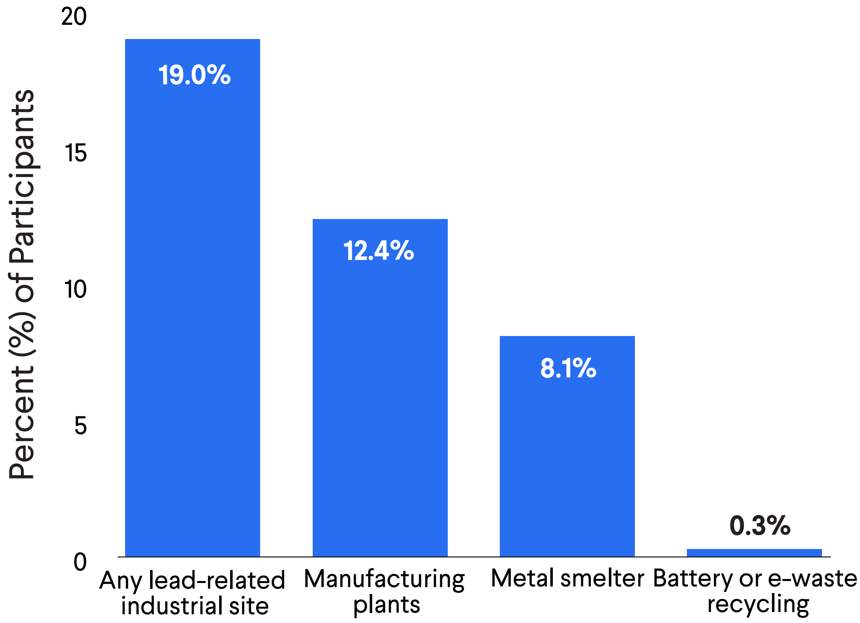
Figure 13: Prevalence of any lead-related occupation/hobby with the top five responses



Home Environment

Industrial activities processing lead may contaminate the soil and result in high concentrations of lead in the soil found in communities near industrial sites. Higher BLLs were observed among Indian children living in highly industrialized areas(24)(25), ULAB sites (26) and smelters(27), likely due to ingestion of contaminated soil and dust. We found that about 19% lived in homes within 1 km of potential lead-related industrial activities. The most common types of potential lead-related industrial sites within 1 km of sampled households were manufacturing plants (12%) and metal smelters (8%). The types of industrial sites varied by district, as metal smelters were most reported in Chennai, while manufacturing plants were most reported in Kancheepuram.

Figure 14: Prevalence of lead-related industrial sites



Drinking water can be another potential source of lead exposure, especially if it is contaminated by leaching lead from pipes or fixtures in the plumbing system. While India has a strict standard for lead usage as an additive in PVC pipes, the PVC pipes manufactured by the informal sector often use lead-based stabilizers in unregulated quantities that compromise the safety of the pipes(28). Most children were from households (69%) that reported water supplied by municipal corporations as the source of drinking water, and about 31% of households used RO-filtered drinking water.

Young children exhibit frequent hand-to-mouth activity and may be exposed to lead by ingesting dust or contaminated soil on their hands. Both the type of floor and cleaning practices may affect a child's exposure to lead-contaminated dust or soil at home. Regularly wet mopping hard floors can reduce lead contamination, while dry sweeping should be avoided as it can stir lead dust up into the air(29). We observed finished floors (e.g., concrete, cement floor, ceramic tiles, granite, marble, and mosaic) in 95% of the homes, and only 29% of these households reported regularly using wet wipes/mopping to clean their floors.

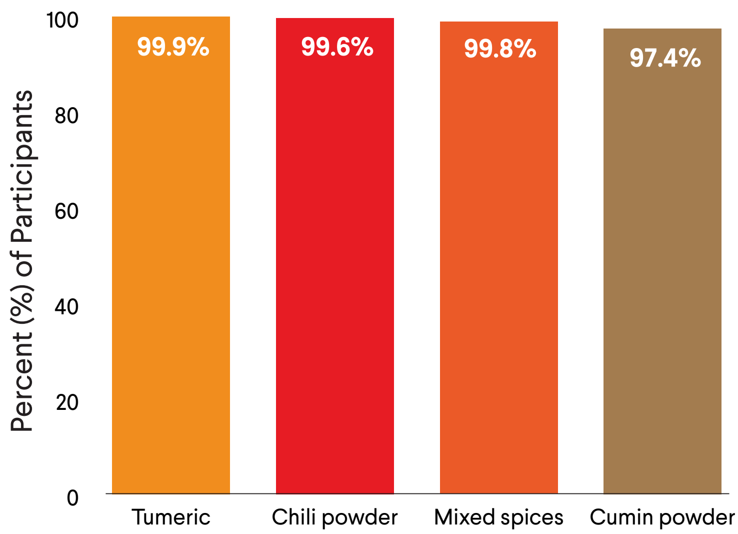
Lead compounds are widely found in paints at unacceptable levels(30). A 2018 review of paint studies in India revealed that paint frequently exceeded 10,000 mg/kg(31). Young children exhibiting hand-to-mouth activity are also exposed to lead through chipping paint(32). In our study, we found that 32% of the households reported the presence of chipping paint on their walls.

Consumer Products

Lead has been found in consumer products worldwide, including metal cookware, spices, toys, cosmetics, and traditional medicines. A recent study that screened lead in consumer products purchased in Indian markets found lead levels exceeding recommended standards in ceramic and metal cookware, toys, cosmetics, and spices(33). In our study, most participating households reported using metal cookware (98%), and many also use ceramic (53%) or plastic cookware (58%).

Spice powders with bright yellow or red color, such as turmeric and red chili, are more likely of concern for lead adulteration. A turmeric testing study in one of the cities in India reported lead levels exceeding 1000 µg/ g with projected BLLs as high as 35 µg/ dL(34). The same study tested 19 turmeric samples in Chennai out of which only one reported lead concentration above 10 µg/g. As expected, almost all households used turmeric, chili, cumin and mixed spices (Figure 15). When asked where they purchased their spices, most households reported purchasing packed spices from nationally known (55%) or regionally known brands (25%) rather than loose spices sold by local shops (15%). The universal use of these spices means that they would not be associated with variations in lead exposure, even if they serve as significant sources of exposure.

Figure 15: Spice use in participating households



High lead concentrations have been detected in some eye cosmetics produced in South Asia, the Middle East, and Africa (33)(35)(36)(37). The use of Kumkum (76%), sacred ash/ Vibhuti (80%), and eye cosmetics such as kajal, kohl, and Surma (59%) were common in sampled households. In addition, WHO highlights traditional medicines as sources of exposure to lead(30), and the use of traditional medicine is very common in South and Southeast Asian countries(38). In our study, the use of traditional medicine was common, as 43% of participating households reported using it.

Pica Behavior

Pica is the craving and eating of nonedible items, commonly observed among children and pregnant women. Children who exhibit pica behavior may eat soil or paint chips or chew on painted material, and they are particularly at risk of lead exposure(39)(40). Pica behavior was found prevalent among participating children, and nonedible items commonly consumed/chewed include toys (58%), jewelry (43%) and soil (29%).

Nutrition

Diets rich in iron, calcium and vitamin C can reduce the absorption of lead in children(41). Overall, we observed notable use of iron (30%), calcium (23%) and multivitamin (27%) supplements in our participants. A child may be exposed through lead passed into the mother's breast milk when the mother has very high BLLs. However, this exposure is generally not significant compared to environmental sources, and breastfeeding is recommended for its overall benefits unless specially advised(42). Around 19% of children in our sample were breastfed.

Factors Associated with Elevated BLLs in Children

We used statistical modeling to identify risk factors that may be related to elevated BLLs. After controlling for demographic and socioeconomic factors, we observed that children living in households with chipping paint near an industrial site are more likely to have BLLs exceeding 5 µg/dL. Children living in households with finished flooring were less likely to have BLLs exceeding 5 µg/dL, indicating that finished flooring may be a protective factor against lead exposure.

Children with the following factors were **more** likely to have BLL above 5 µg/ dL

Presence of chipping paint

1.5 times more likely

Living near lead-related industry

1.7 times more likely

Children with the following factors were **less** likely to have BLL above 5 µg/ dL

Finished flooring

57% less likely

We also did a stratification analysis to understand gender-specific risk factors. Our analysis shows boys living near lead-based industries (1.7 times) and households with chipping paints (1.5 times) are likelier to have BLLs above 5 µg/ dL. Girls with the behavior of eating soil are more likely to have BLLs above 5 µg/ dL. Although specific mechanisms were not assessed in the current study, these findings suggest the need to explore gender-specific risk factors in future studies.

In Table 10, we summarize the average BLLs and prevalence of elevated levels among children with the identified risk factors and protective factors.

Table 10: Distribution of BLL and prevalence of elevated BLL by the status of identified risk factors

Risk factors		Geometric mean, µg/ dL (95% CI)	Children with BLL ≥ 5 µg/dL, %
Living near lead-related industry	Yes	5.0 (4.6,5.5)	55.8
	No	4.1 (3.9,4.2)	34.8
Homes with peeling/ chipping paint	Yes	4.3 (4.0,4.6)	42.9
	No	4.2 (4.0,4.4)	36.8
Finished flooring	Yes	4.2 (4.0, 4.4)	38.3
	No	4.8 (4.1, 5.6)	47.4

Recommendations

> **“Lead exposures are persisting as a threat for child and adult health despite a long history of intervention efforts. The cost of inaction unfortunately can span across multiple generations. The report provides timely guidance for prioritising surveillance strategies that can alter exposure trajectories and minimize future impacts.”**
>
> **Prof. Kalpana Balakrishnan**
> Dean (Research) and Director, WHO Collaborating Centre, Faculty of Public Health, SRIHER

Establish a routine blood lead surveillance system and enable monitoring of risk factors for elevated BLLs among young children

As elevated blood lead levels were observed among children across different regions and demographic groups, it stresses the need for setting up routine blood lead surveillance system to monitor lead exposure among children in Tamil Nadu. This pilot project demonstrated the feasibility of actively monitoring BLLs and the presence of risk factors among young children by conducting a statewide survey. The state health department should consider establishing a similar statewide lead exposure surveillance system by testing blood lead levels at primary health care centres involving ASHAs in community mobilization. Medical officers can add lead exposure risk assessment to routine care for children or integrate lead exposure assessment into recurring statewide health surveys or programs that evaluate children's health or nutrition.

Strengthen laboratory capacity and accessibility to blood lead tests at public health facilities

The number of laboratories that can perform blood lead testing in Tamil Nadu is still limited. It is important to improve the capacity for blood lead tests, especially at public health laboratories and hospitals specializing in heavy metal poisoning care. Subsidizing the testing cost through health insurance plans is also important, as lead poisoning disproportionately affects poorer families. Using screening questions to identify high-risk children with lead exposure history can also help allocate limited testing capacity.

Raise public awareness of the toxic effects and sources of lead

It is important to raise awareness of lead and its health impacts among health professionals and parents. Our local survey showed a very low awareness of lead among ASHAs. Health education and communication programs related to lead exposure and health effects should be organized for the community in plain language to have tangible impacts.

Strengthen health workers' capacity to improve clinical management of lead poisoning

Familiarize health care providers (local health nurses, ASHAs, community health officers, and medical officers) with existing WHO clinical guidelines to facilitate early detection, intervention, and treatment. It is also important to establish India's national guidelines by adapting and adopting the WHO guidelines in line with India's health system, cultural context, and available resources.

Identify and regulate sources of lead exposure affecting children in India

We recommend that the government continue to monitor lead in consumer products such as paint, spices, and cosmetics. Enforcing legally binding standards for lead in these products can be effective in preventing the market circulation of lead-contaminated products and materials.

Monitor and regulate lead pollution from industrial processes

Existing standards should be enforced in industrial and other workplace settings. Monitoring lead in soil can also be important to protect children living in communities near these industrial sites from lead exposure.

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