Lead exposure at homes as modifying factors of blood lead levels among young children in Bihar, India

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Abstract

Background: Over 275 million children in India have elevated blood lead levels (BLLs). With few exceptions, previous studies focused on children living in highly polluted areas. Potential sources of exposure include lead-based paints, lead-contaminated spices, and other consumer products. This study aims to identify sources of lead exposure among children living in Bihar by assessing the lead concentrations in environmental samples collected in and around the children's homes and their association with children's BLLs.

Methods: The study used a subset of a state-wide study in Bihar. The blood lead study was performed after obtaining ethical clearances. From the larger representative sample, 153 children were selected, including all children with BLL ≥ 20 μg/dL and a random sample of those below this level. Blood samples from children aged 12 to 60 months were analyzed using LeadCare II® between December 2022 and March 2023. All children with blood lead levels (BLLs) ≥20 ug/dL and a subset of children with BLL below this level received a home-based assessment (HBA) to evaluate the lead concentrations in soil, drinking water, paint, metal and ceramic cookware, spices, cosmetics, and toys. Lead concentrations were determined using a portable X-ray fluorescence analyzer and laboratory-based analyses. The HBA results were compared to local regulatory limits where available and international thresholds.

Results: Environmental sampling showed that metal cookware, spices and painted walls were the main sources of lead in households. The odds of elevated BLL are only significantly associated with lead in spices (aOR=1.35, 95%CI: 1.16, 1.59) after adjustment for age, sex and demographic factors of the child.

Conclusion: Lead in metal cookware, spices and painted surfaces are common in households in Bihar/India. To protect children, measures are needed to protect them from lead exposure, including health, legal and political measures.

Keywords: lead, child, home-based assessment, blood lead level, India, home-environment

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1. Introduction

Exposure to lead can pose severe health risks, particularly for children. The impacts of lead on children's brain development include a reduction in intelligence quotient (IQ) and behavioral impacts such as diminished attention span and increased antisocial behavior, as well as lower educational and lifetime earnings achievement. Additionally, lead exposure can lead to anemia, hypertension, renal impairment, seizures, immunotoxicity, and toxicity to reproductive organs. It is widely believed that the neurological and behavioral effects of lead are irreversible (Amitai et al., 2010; Bose-O'Reilly and Landrigan, 2021).

Young children are especially vulnerable to lead poisoning for various reasons. Firstly, behaviors like hand-to-mouth actions, ingestion of non-food items, and crawling increase the likelihood of contact with and ingestion of environmental lead (Bellinger, 2004). Secondly, the proportion of ingested lead that is absorbed is significantly higher in children compared to adults (Bellinger, 2004). Household dust, contaminated soil, and polluted drinking water, especially relevant due to hand-to-mouth behavior and crawling, are significant sources of exposure for young children (World Health Organization, 2021), but the sources of relevance vary between, and within countries (Bose-O'Reilly and Landrigan, 2021). Therefore, identifying potential sources of lead exposure, particularly within the home environment where children spend the majority of their time, is crucial.

In India, an estimated nearly 7 million disability-adjusted life years (DALYs) were lost in 2019 due to lead exposure, resulting in over 232,500 deaths (Murray et al., 2020). Lead exposure in India accounts for an annual loss of US$236 billion, equivalent to 5% of the country's gross domestic product (GDP) (Attina Teresa and Trasande, 2013). It is also estimated that over 275 million children in India have blood lead levels (BLLs) exceeding 5 µg/dL (Rees and Fuller, 2020), a globally recognized threshold requiring intervention (World Health Organization, 2021). The associated disease burden is substantial, particularly concerning intellectual disability outcomes in children (Ericson et al., 2018). A recent report on BLLs of school children in India reported that the children in Patna, Bihar had high median BLLs of 9.7 µg/dL (Kumar et al., 2023).

A pilot study of BLLs in children close to an informal lead battery recycling workshop in Patna showed a median BLL of 19.2 µg/dL for children (Ansari et al., 2020). A larger follow-up of 135 children in Patna, revealed a high prevalence of elevated BLLs both near battery recycling operations and in control areas, with a combined median 13 µg/dL (Brown et al., 2022).

Various sources contribute to lead exposure for children in India, including toxic hotspots such as elevated lead levels in soil and dust from industrial sites (e.g., lead-acid battery manufacturing and recycling), lead-based paint, and lead-contaminated spices, consumer products, food, or water (Ansari et al., 2020; Brown et al., 2022; Ferraro et al., 2023; Keosaian et al., 2019; Kharkwal et al., 2023; Kumar et al., 2022; Mahdi et al., 2020; Mawari et al., 2022; Rashid et al., 2019).

Despite localized studies on small populations at risk from specific sources, there is limited data, aside from modeled estimates, on the extent of exposure, the demographics affected, predictive risk factors, and the current trend in lead poisoning (Ericson et al., 2018; Parween et al., 2018; Rees and Fuller, 2020).

Therefore, this study aims to fill this gap by addressing lead exposure sources in and around homes and assessing the potential contribution of these exposure sources to blood lead levels among young children in Bihar, India.

2. Methods

2.1. Study area and population

Between December 2022 and March 2023, Vital Strategies and Pure Earth assessed BLLs among children under the age of five and their pregnant mothers in eight districts in Bihar, India (Lu et al., 2024). The primary investigation was carried out as a cross-sectional study in Bihar (see Figure 1) to understand the distribution of BLL among the children population in Bihar using a state-representative sample. A subset of participating households was referred for home visits to gather information on potential environmental sources contributing to elevated BLLs.

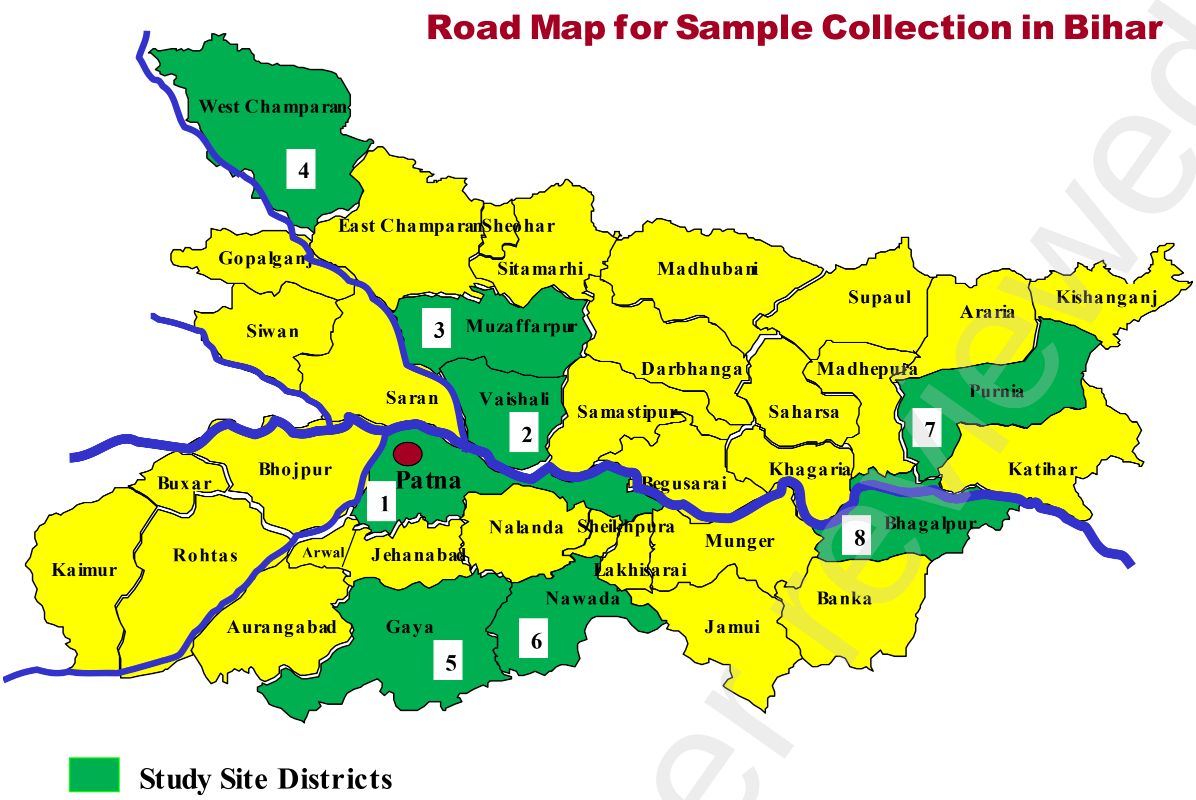

Figure 1: Eight selected districts in Bihar region for the current study

All households with a child with blood lead levels (BLLs) equal to or greater than 20 µg/dL or with both a child and pregnant mother participants underwent a comprehensive home-based assessment (HBA) to identify potential lead sources within their homes, with informed written consent from the caregiver. Additionally, a 30% random sample of children with BLLs below 20 µg/dL was selected to create a comparison group. In total, assessments were conducted at 153 households, and 1,218 items were analyzed.

2.2. Health related data

Capillary blood was collected from the participating child and analyzed by LeadCare II, a portable analyzer during a home visit. Information on household characteristics was collected through computer-assisted personal interviews with primary caregivers. More details on the method and results are reported elsewhere (Lu et al., 2024).

2.3. Environment related data

Within the selected households, a standardized approach was applied by a Pure Earth field team to select among and measure lead levels in environmental samples (for more details, see (Brown et al., 2022)). The field crew comprised of two teams of six investigators each with backgrounds in environmental health and social work; it included one leader who would administer the survey, 1 investigator each for handling the XRF, for environmental sample collection, for data recording, spice sample collection and XRF data recording. These HBAs aimed to identify the primary routes of lead exposure among children and included data collection on lead in:

- soil(sol)
- paint on walls (lpt)
- metal cookware (mcw)
- spices (spc)
- toys (toy)
- ceramic cookware
- cosmetics
- snacks
- drinking water

Generally, one or more samples were collected for each sample type from a household. Except for drinking water, all elements of the assessments were carried out using a portable X-Ray Fluorescence analyzer (XRF) (Thermofisher Niton XL3t 700s), providing real-time readings in the field. When using XRF, three readings were taken for each sample and the average readings were used. The limit of detection of the XRF varies depending on the sample medium being analyzed and selected mode for each sample type. In total, 1,762 XRF tests were conducted. Drinking water was analyzed in a commercial laboratory, using ICP-MS technology (Envirochem Research & Test Labs, Lucknow, India).

2.4. Reference levels

To provide context to the concentrations of lead found in the various environmental samples, a “reference level” for each sample type was selected (see Table 1). Existing Indian standards were used where possible. Where such national standards do not exist, standards from the United States were applied. In general, standards are set at levels below which significant health effects are unlikely to occur in populations. While standards for leachable lead from ceramic and metal foodware do exist in some countries, field testing of leachable lead in foodware was not possible. Based on ongoing work of Pure Earth on leaching of lead from cookware, for this assessment a reference level of 100 ppm for all types of foodware was applied. The following reference levels are used in this study (Food Safety and Standards Authority of India, 2011):

Product	**Reference level [ppm]**	**Comment**
Ceramic foodware	100	*
Cosmetics	20	(Government of India, 1940)
Metal cookware	100	*
Paint (wall)	90	Indian Central Pollution Control Board
Soil	400	(U.S. Environmental Protection Agency, 2014)
Spices	10	(Food Safety and Standards Authority of India, 2011)
Toys	100	(United States Consumer Product Safety Commission, 2023)

Table 1: Reference Levels (in ppm);
* A reference level of 100 ppm was applied for ceramic and metal cookware based on on-going leachability research, performed by Pure Earth.

2.5. Ethical clearance, data management and data protection

The blood lead tests were conducted after obtaining approval by the BRANY (Biomedical Research Alliance of New York) Institutional review board (Protocol Number: 22-176-522) and the ethics committee of the Indian Council of Medical Research- Rajendra Memorial Research Institute of Medical Sciences situated in Patna, Bihar (Approval letter no. RMRI/EC/54/2022, dated 21/09/2022).

For testing BLL of the child, parents or legal guardians of the eligible child provided informed consent to complete the interview and carry out blood sampling and consent to be contacted for a home-based assessment. A separate consent form was used for seeking consent for the HBA and an assigned team member explained the purpose of the study to the head of household/guardian including the risks and benefits of the study before seeking consent.

Any data collected on paper was stored in a locked file cabinet in a locked office. The questionnaire data entered and saved in the tablet were exported to the computer and linked with the blood lead level data using a unique ID and saved in a password-protected database and kept safeguarded. Participants and households in this linked database were identified and referred to by the unique ID only to protect confidentiality. A master list that contains unique ID and name/address/contact information was kept separate from the linked database. The name, address, and contact information collected during blood testing were provided to Pure Earth to refer the participant for a home inspection if selected for HBA. All data sets and reports were stripped of personal identifying information. All field personnel, including local staff, were trained on proper interviewing techniques and obtained human subjects' ethical clearance.

2.6. Variables

The dependent variable in our model is elevated BLL (Yes/No) using the cut point of 10 μg/dL. Independent variables included in the model are lead concentrations measured in different environmental samples collected from the home. Among the nine types of environmental samples tested, we selected four types with considerable sample size (number of measured households ≥ 80), more uniform materials (excluded furniture), and without large percentage of samples below detection limits including metal cookware, paint on wall, spices, and soil. An average value is calculated for a subject across all readings if it was tested more than once. If multiple subjects of the same type (e.g., two metal cookwares) were tested in one household, the maximum value is used for this household. Lead in environmental samples were log transformed using a base of 2 before use in the model due to its skewed distribution and for the ease of interpretation.

2.7. Statistical methods

Data were analyzed using Excel®, SPSS 27®, and R. Both geometric and arithmetic means were reported due to the skewed distribution of lead in blood and environment and the common use of arithmetic means in producing pooled estimates in systematic reviews. Samples reported lead levels below the limit of detection (LOD) were assigned the value of DL/√2. Generalized logistic regression analyses were used to calculate odds ratios (ORs) and 95% confidence intervals (CIs) for associations between lead in each environmental sample and elevated blood lead levels (BLL≥10 μg/dL). The final model for each environmental sample adjusted for important confounders identified from literature including children's age in months (continuous), sex (male/female), primary caregivers' education (illiterate (1), school education (2-7), higher education (8-10)), socioeconomic status (having BPL card Y/N), and urbanicity (urban/rural).

3. Results and Discussion

In total, 153 children were assessed for both BLLs and Pb in their home environment. Characteristics of sampled children and households are presented in Table 2, grouping the children with BLLs below and above 10 ug/dL.

Characteristics	**BLL < 10 ug/dL (n=99)**	**BLL ≥ 10 ug/dL (n=54)**
Average age in months (range)	38 (25-52)	53 (31-59)
Gender		
Male	48 (48%)	32 (59%)
Female	51 (52%)	22 (41%)
Caregiver's education		
Illiterate	15 (15%)	7 (13%)
School education	70 (71%)	42 (78%)
Higher education	13 (13%)	5 (9.3%)
Unknown	1	0
Has BPL card	60 (61%)	22 (41%)
Area type		
Rural	84 (85%)	28 (52%)
Urban	15 (15%)	26 (48%)

Table 2 Characteristics of participants by BLL

3.1. Results of the e*nvironmental samples*

For each sample type, we calculated how many households had an item of this type above reference level (see Table 3) using household level data. When helpful, we also presented the percentage of samples with lead levels above reference level among all subjects tested in all households under a specific sample type (see supplement Figure S2).

Environmental sample	# Above reference level (%)
Metal cookware	135 (95%)
Paint (wall)	97 (71%)
Spice	99 (75%)
Soil	1 (1%)

Table 3: Percentage of households with environmental samples above reference level

Cookware made of metal, especially low-cost, locally manufactured items, has been identified as containing lead that may seep into the food during cooking (Brown et al., 2022; Fellows et al., 2022; Weidenhamer et al., 2023; Weidenhamer et al., 2017). Predicting the amount of lead leaching from a specific pot is challenging without dedicated testing (Ali Sultan et al., 2023). There are currently no established international standards for the total lead content in metal cookware. In 95% of the examined households, metal cookware was found to contain lead above the reference level of 100 ppm, indicating the potential for a hazardous leaching of lead.

The levels of lead in extensive **painted surfaces** exhibited notable variations (see Figure 2). This variability was particularly evident in doors, gates, and windows. When paint is applied to a metal surface, the XRF may not discern whether lead is present in the paint (or in which layer) or in the underlying material. Concerning the potential for exposure , our primary focus is on lead paint rather than lead in the underlying metal material. Lead paint has the potential to chip off or generate lead dust, which a child may ingest through hand-to-mouth behaviors. Consequently, these findings require careful interpretation. In 71% of the homes tested, paint on the walls was found to be above the reference level of 90 ppm.

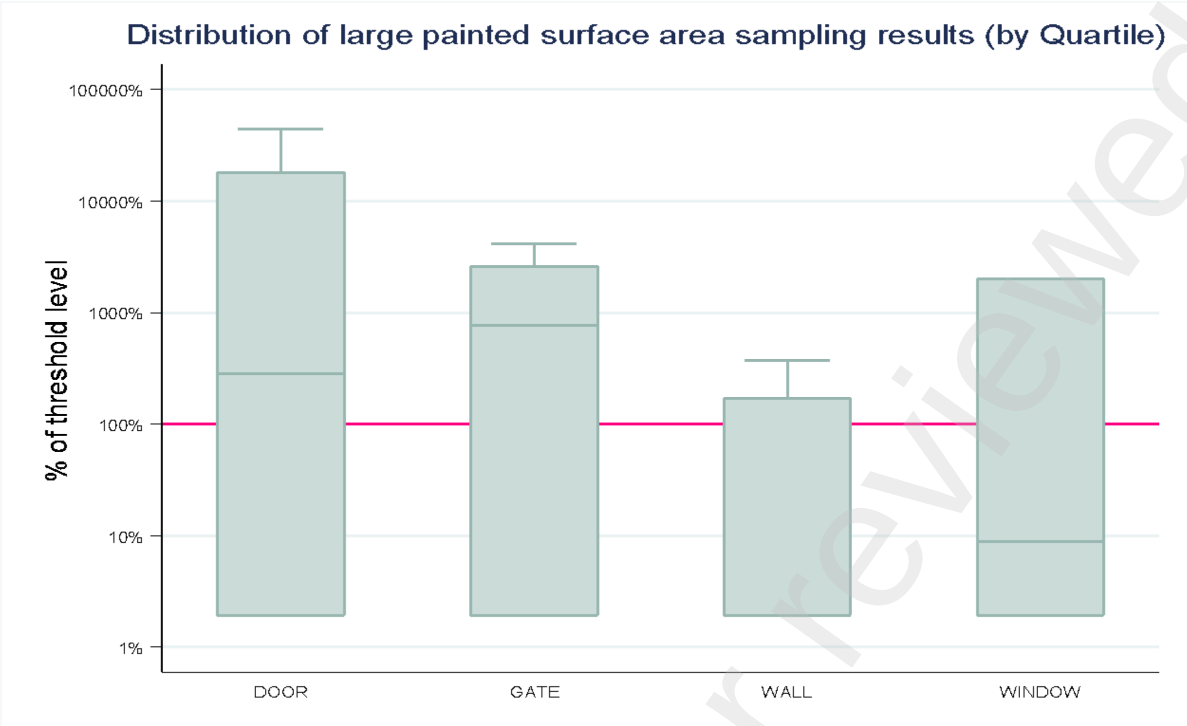

Figure 2: Distribution of lead by different type of painted surface among all tested paint samples (N=406), compared to threshold level (red line). Y-axis log-scale.

Spices in South Asia have been discovered to be tainted with lead chromate to enhance their color (Baig et al., 2019; Brown et al., 2022; Forsyth et al., 2023; Gleason et al., 2014; Nordin and Selamat, 2013; Senanayake et al., 2013). This issue was previously identified in Patna, Bihar (Brown et al., 2022). In the current study, elevated lead levels were detected in all four spice types assessed—chili, coriander, turmeric, or mixed spices (see Figure 3). The India Food Safety Authority has established a lead content limit in spices of 10 ppm (Food Safety and Standards Authority of India, 2011). Turmeric exhibited the highest lead levels, with a median of 30 ppm and a maximum of 4,139 ppm, surpassing the regulatory standard of 10 ppm by more than 400 times (Food Safety and Standards Authority of India, 2011). In 75% of the households surveyed, at least one spice was found to exceed the reference level of 10 ppm (see supplement Figure S3). This means that household members were exposed to adulterated spices.

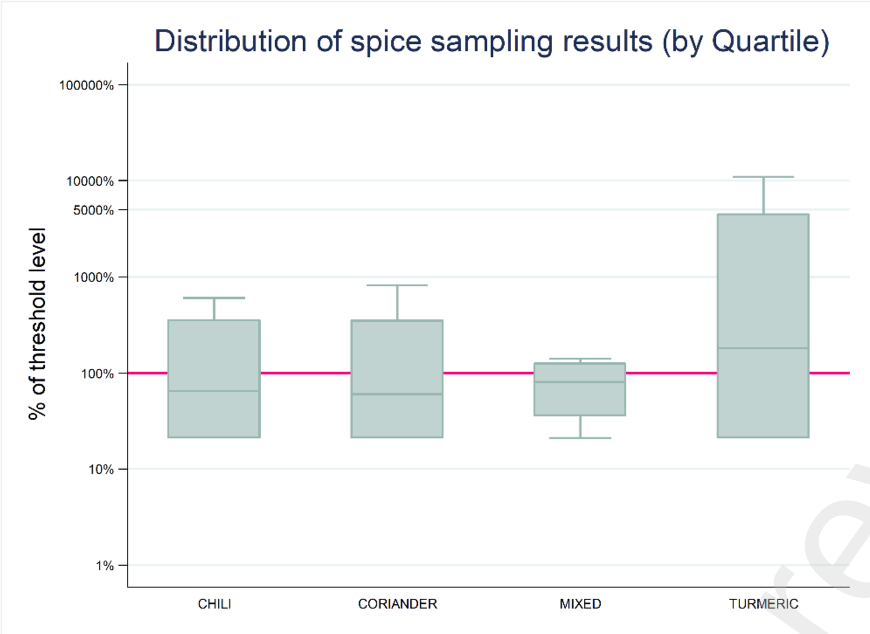

Figure 3: Distribution of lead by different spice sample among all tested spice samples (n=306)), compared to threshold level (red line). Y-axis log-scale.

Readings of **soil** were obtained from an area directly outside the residence. Out of 79 households tested, all but one were above the 400 ppm US-EPA threshold value, and its proposed revision of 200 ppm (U.S. Environmental Protection Agency, 2024). This sample had an exceptionally high value of 1,990 ppm. The median soil lead levels of household with children with elevated BLL is 21 ppm while the median levels of households with children lower BLLs is 17 ppm, both indicative of background levels (Table 4).

A total of 149 **toys** underwent XRF analysis. Some readings were exceptionally high, with a maximum of 124,510 ppm. In 68% of the households the maximum toy lead levels were below the limit of detection. For this reason toys were excluded from further statistical analysis.

Thirty-five local **snack items** were screened with the XRF, and all results were below the XRF's limit of detection of 3 ppm.

Nine out of all 16 tested **ceramic** samples exceeded 100 ppm. Similar to metal cookware, there are no recommended limits for total lead in ceramics, so the 100-ppm threshold is based on our current research applying leaching tests. However, it should be noted that the sample size was only 16 for this category, potentially limiting the representativeness of the results.

Out of the 10 **cosmetic** samples identified, all were below 20 ppm, which aligns with the Bureau of Indian Standard's limit for lead in cosmetics (Government of India, 1940). Nevertheless, caution is warranted in interpreting these results due to the small sample size.

Lead content in **drinking water** was sampled from a representative subset of homes, encompassing various sources such as hand pumps, government supply, and borewells. Out of 25 samples, only one exceeded India's drinking water standard for lead of 10 ppb (Government of India, 2011), with half of all samples falling below 3.4 ppb (see supplement Table S1).

The analysis of the environmental samples showed that metal cookware, spices and painted walls were the main sources of lead in sampled houses. The next step in the statistical analysis was to divide the children into two groups, using a BLL of 10 µg/dL as the cut-off. The characteristics of the lead levels in the household environmental samples according to the BLL of the children are presented in Table 4.

		BLL <10 µg/dL					BLL ≥10 µg/dL				
Environmental sample	% Below LOD	N	Median (min-max)	GM (SD)	AM (SD)	% above reference level	N	Median (min-max)	GM (SD)	AM (SD)	% above reference level
Metal cookware	4 %	91	1670 (1.7-12100)	1409.3 (4.6)	2410.6 (2242.8)	96%	51	1790 (1.7-17400)	1237.4 (6.9)	2755.4 (3159.5)	94%
Paint (wall)	24%	85	1180 (1.7-344410)	396.5 (55.8)	21956.7 (57330.5)	67%	51	1396 (1.7-183422)	1056.7 (48.5)	29007.1 (49879.3)	78%
Spice	25%	87	8 (1.7-2378)	13.9 (7.8)	134,0 (367.2)	67%	45	472 (1.7-4139)	194.4 (10.8)	842.4 (1008)	91%
Soil	1%	62	17 (1.7-52)	16.7 (1.6)	18.2 (7.5)	0%	17	21 (14-1990)	29.5 (3.2)	140.2 (476.8)	6%

Table 4: Lead levels in household environmental samples by BLL among children (N=number, LOD=limit of detection, GM=geometric mean, AM=arithmetic mean, SD=standard deviation)

3.2. *Association between environmental sources and elevated BLL*

Table 5 presents the association between lead in different environmental samples and the odds of a child having BLL ≥10 µg/dL. In the crude analysis, odds of elevated BLL are significantly associated with lead concentration in spice (crude OR=1.4, 95%CI: 1.24 - 1.60) and in soil (crude OR=4.15, 95%CI: 1.53 - 14.01). After adjusting for the child's age, sex, and demographic factors, the odds of elevated BLL are only significantly associated with lead in spice (aOR=1.35, 95%CI: 1.16 - 1.59). This means when the lead concentration in spice doubles, the odds of a child having elevated BLL will be 1.4 times higher. Our finding is similar to findings from an earlier study in Bihar by Brown et al (Brown et al., 2022)which also observed significant associations between high levels of lead in turmeric and soil collected from the household and higher BLL among children living in communities distant from a contaminated site.

Variable	Unadjusted OR (95% CI)	p-value	Adjusted OR (95% CI)	p-value
Pb in metal cookware	0.97 (0.84 - 1.12)	0.66	1.08 (0.92 - 1.23)	0.35
Pb in large surface paint	1.05 (0.98 - 1.11)	0.17	1.03 (0.95 - 1.10)	0.56
Pb in spice	**1.40 (1.24 – 1.60)**	**<0.01**	**1.35 (1.16 – 1.59)**	**<0.01**
Pb in soil	**4.15 (1.53 - 14.01)**	**0.01**	2.15 (1.09 – 9.14)	0.13

Table 5: Associations between environmental sources and elevated BLL (OR=odds ratio, Pb=lead)

3.3. *Lead concentration in rural versus urban homes*

In Table 6 we compared lead concentrations in environmental samples collected from homes located in urban and rural areas. Applying a Wilcoxon rank sum test shows that lead levels in metal cookware used in rural households were significantly higher than those used in urban households (67% higher median level), potentially reflecting a greater dependence on informally produced cookware. In contrast, urban households reported significantly higher lead levels in paint (43 times higher), spices (33 times higher), and soil (50% higher) than rural households (see Figure 4). These urban disadvantages may reflect greater availability of commercial paints, bulk-sale spice markets and the historic deposition of lead particles in soil from decades of spatially dense combustion of gasoline containing tetra-ethyl lead.

Characteristic	**Rural**	**Urban**	**p-value***
	Median (IQR)	Median (IQR)	
Metal cookware	1,860 (1,235-3,640)	1,110 (260-2,015)	**<0.001**
Paint (wall)	456 (2-3,638)	15,247 (484-78,555)	**0.001**
Spice	8 (2-43)	344 (60-1,072)	**<0.001**
Soil	17 (14-20)	26 (2- 31)	**<0.001**

*Wilcoxon rank sum test

Table 6: Lead concentrations in environmental samples by household urbanicity

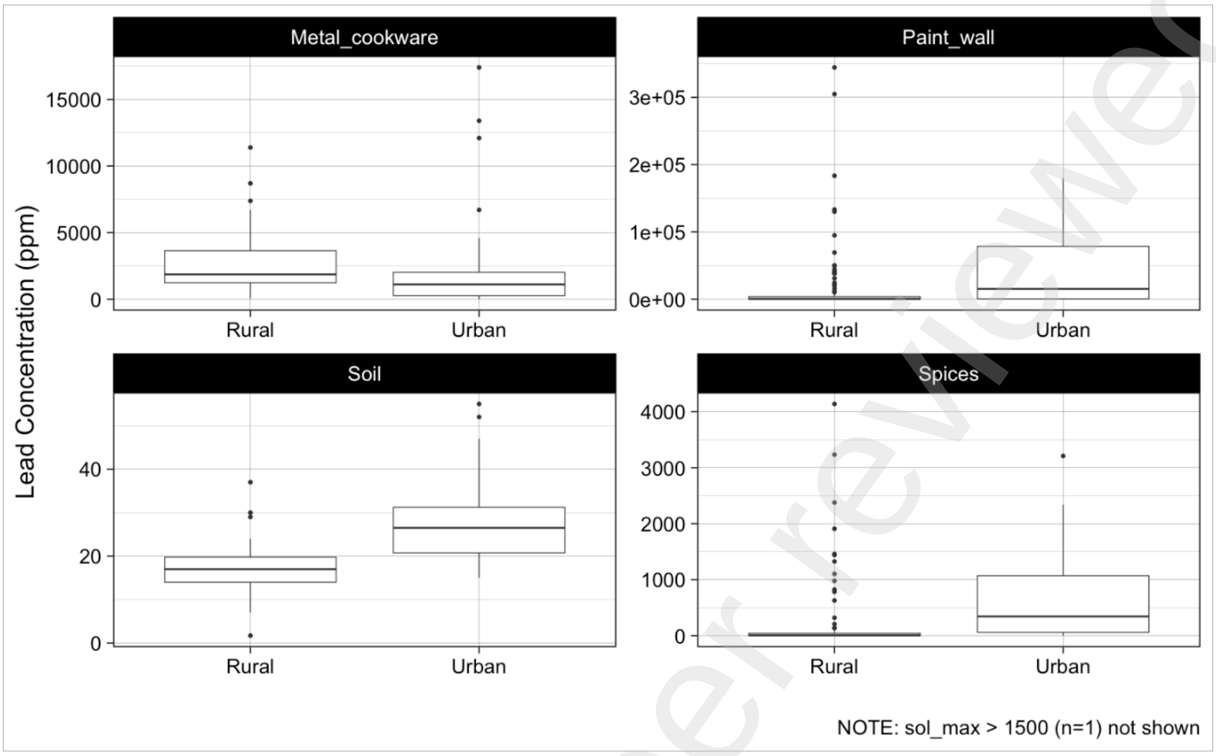

Figure 4. Box plot of lead in environmental samples by urbanicity

3.4. Impact

In summary, our assessments conducted in households identified high prevalence of elevated lead levels in metal cookware, spices, and painted walls among tested Bihar households. We also found a positive association between lead levels in spices collected in homes and elevated BLL among Bihar children. The concern regarding lead in spices has been previously highlighted in this region of India (Brown et al., 2022). While a minimal amount of lead can naturally occur in spices due to varying lead concentrations in soil, the levels observed in this study suggest intentional adulteration. Research from Bangladesh suggests that this practice aims to enhance color for greater appeal in the market (Forsyth et al., 2019) and to add weight for pricing advantages. The issue of lead in metal cookware, though not widely recognized today (Brown et al., 2022), emerges as a significant concern from our data. Lead may be found in cookware that is manufactured from recycled and waste metals. Metal cookware that contains lead presents risks as studies indicate that lead can leach into cooked food. Predicting the extent of lead transfer from a specific pot to food is challenging, and there are currently no international standards for total lead content in metal cookware. Lead in paint is a well-known source of exposure in India (Kumar et al., 2022; Vishwanath et al., 2012), with lead in house dust posing a serious risk, especially for young children who frequently touch their hands to their mouths or teethe painted surfaces. Our results indicate elevated lead levels in doors, windows, gates, and certain painted walls in many houses in Bihar. While less widespread, high lead levels were also identified in specific toys, posing a risk to individual children.

3.5. Strengths and limitations

Strengths. This study assessed lead levels in a wide range of environmental samples collected from households in Bihar, India. This study was able to pair biologic samples with home environmental testing. Both households of children with high BLL and a random subset of households with low to moderate BLL were evaluated. The random selection of households for the original blood lead testing studies provided a good representation of the population and not only of the high-risk communities with known environmental lead contamination. Site selection focused on non-contaminated areas, and results may not be representative of hotspot areas with expected higher lead levels in soil, house dust, and locally sourced food or water (Brown et al., 2022).

Limitations should be acknowledged, including the XRF's suitability for screening lead content, with some items like toys having multiple components with varying lead concentrations that may be overlooked. The XRF's limit of detection, around 3 ppm, may not be ideal for food items. Additionally, the limited sample size in certain categories, such as cosmetics and ceramics, precludes definitive conclusions.

Several factors may play a role in limiting our power to detect associations between several environmental lead sources and elevated BLL. Although high BLLs and lead levels exceeding standards were observed in several products, the sample size is fairly small and may have limited the study's power to detect effects with small or moderate effect sizes. For some environmental samples such as lead in paint on large surfaces, the percentage of samples with levels under detection limits was also high and limited the variation in exposure level among sampled children. Moreover, contribution of lead exposure from home environment to blood lead levels is likely modified by the child's behavior (e.g., handwashing, frequency of spice intake, time spent indoor), home condition (e.g., chipping paint, frequency of mopping the floor), and children's exposure outside of home (e.g., playing outside or in kindergarten). BLLs in children are indicative of relatively recent exposures, while actual exposure to household lead sources may not be temporally correlated. The lead levels in the various environmental samples might not be independent, as the weak correlation observed between lead in soil and spice and moderate correlation observed between lead in soil and toy indicates (see supplement Figure S1).

4. Conclusions

The home-based assessment in Bihar underscores the prevalence of high lead levels in various common household items, particularly cookware, spices, and painted surfaces, necessitating interventions to protect residents, especially children, from avoidable lead exposure. Health education to raise awareness about lead hazards and promote protective measures, along with regulatory and policy interventions, is imperative to address lead in cookware, spices, and paint.

Availability of data and materials

The datasets used and/or analyzed during the current study are available on specific request only.

CRediT authorship contribution statement

Emily Nash, conceptualization, data curation, formal analysis, methodology, validation, visualization, writing - original draft, writing - review & editing final draft

Yi Lu, conceptualization, data curation, formal analysis, methodology, project administration, validation, visualization, writing - original draft, writing - review & editing final draft

Stephan Bose-O'Reilly, conceptualization, methodology, writing - original draft, writing - review & editing final draft

Ambrish Kumar Chandan, conceptualization, data curation, formal analysis, investigation, project administration, writing - review & editing final draft

Lavanya Nambiar, conceptualization, data curation, funding acquisition, investigation, methodology, project administration, visualization, writing - review & editing final draft

Meenakshi Kushwaha, data curation, formal analysis, visualization, writing - original draft, writing - review & editing final draft

Given Moonga, formal analysis, , writing - review & editing final draft

Kumar Bhaskar, data curation, investigation, writing - review & editing final draft

Promila Sharma Malik, conceptualization, data curation, investigation, project administration, writing - review & editing final draft

Sumi Mehta, conceptualization, funding acquisition, methodology, project administration, supervision, writing - review & editing final draft

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Gabriel Sanchez Ibarra, conceptualization, funding acquisition, project administration, supervision, writing - review & editing final draft

Daniel Kass, conceptualization, funding acquisition, methodology, project administration, supervision, writing - review & editing final draft

<u>All authors read and approved the final manuscript.</u>

Declaration of competing interest

The authors declare no conflict of interest. The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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List of abbreviations

BLL	Blood lead level
BPL	below-poverty-line (BPL) certificate
BRANY	Biomedical Research Alliance of New York
HBA	Home based assessment
ICP-MS	inductively coupled plasma mass spectrometry
LMIC	low- and middle-income country
LOD	limit of detection
lpt	lead in paint on walls
mcw	lead in metal cookware
ND	“non-detect”
OR	odds ratio
PB	lead
PE	Pure Earth
ppb	parts per billion
ppm	parts per million
SD	standard deviation
sol	lead in soil
spc	lead in spices
toy	lead in toys
UN	United Nations
US	US Consumer Product Safety Commission
VS	Vital Strategies

WHO	World Health Organization
XRF	X-ray fluorescence

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