Article

Not peer-reviewed version

Childhood Lead Exposure in Primary Health Care Settings in Indonesia: A Cross-Sectional Study in Bogor City and Bogor Regency

Anna Suraya * , Maryuni Maryuni , Desi Aryanie , Lelitasari Lelitasari , Uci Sulandari , Maya Setyawati , Sari Narulita , Renan Prasta Jenie , Sri Utami Ningsih , Eni Kusrini , Agung Cahyono Triwibowo , Then Suyanti , Rooswanti Soeharno , Mrunel Shetye

Posted Date: 21 May 2026

doi: 10.20944/preprints202605.1311.v1

Keywords: lead exposure; blood lead level; geographic mapping; public health screening

Article

Childhood Lead Exposure in Primary Health Care Settings in Indonesia: A Cross-Sectional Study in Bogor City and Bogor Regency

Anna Suraya [1,*], Maryuni [1], Desi Aryanie [1], Lelitasari [1], Uci Sulandari [1], Maya Setyawati [1], Sari Narulita [1], Renan Prasta Jenie [2], Sri Utami Ningsih [1], Eni Kusrini [1], Agung Cahyono Triwibowo [1], Then Suyanti [3], Rooswanti Soeharno [4] and Mrunel Shetye [4]

[1] Faculty of Health Science and Technology, Binawan University, Jakarta, Indonesia
[2] Faculty of Business and Management Science, Binawan University, Jakarta, Indonesia
[3] Ministry of Health of Republic Indonesia
[4] Unicef Indonesia
* Correspondence: anna.suraya@binawan.ac.id

Highlights

Public health relevance

- Childhood lead exposure remains an important environmental health concern in Indonesia, with 21.9% of children aged 1–5 years in this study having elevated blood lead levels ≥5 μg/dL.
- The study identifies clear geographic clustering of elevated blood lead levels, particularly in Bogor Regency and among children living near lead-processing activities, indicating localized environmental exposure risks.

Public health significance

- This study provides evidence from routine primary health care settings, addressing an important gap in Indonesia where most previous studies focused on selected high-risk communities or environmental hotspots.
- The findings show that primary health care–based screening can help detect vulnerable children and generate actionable data for targeted environmental and public health responses.

Public health implications

- Lead exposure management should be integrated into routine child health services, supported by strengthened laboratory capacity, referral pathways, caregiver counselling, and follow-up mechanisms.
- Future programs and studies should combine health facility screening with environmental investigation to confirm exposure sources and guide cross-sectoral interventions involving health and environmental authorities.

Abstract

(1) Background: Lead exposure is an important preventable environmental health concern among children, especially in low- and middle-income countries. In Indonesia, evidence from routine health service settings remains limited; (2) Methods: This cross-sectional study assessed blood lead levels (BLLs) and associated factors among children aged 1–5 years attending 12 primary health care facilities in Bogor City and Bogor Regency between December 2025 and January 2026. A total of 420 children were recruited consecutively during routine services. Environmental and household risk factors were collected using structured questionnaires, and venous blood samples were analyzed using inductively coupled plasma mass spectrometry. Elevated BLL was defined as ≥5 μg/dL; (3) Results: The mean BLL was 2.01 μg/dL, and 21.9% of children had elevated BLLs. Marked geographic disparities were observed, with higher prevalence in Bogor Regency than Bogor City (41.2% vs. 2.4%; $p<0.001$). Children living near lead-processing activities also had higher prevalence than those living

farther away (44.2% vs. 16.2%; p<0.001). In multivariable analysis, residence in Bogor Regency and proximity to lead-processing activities were significant predictors of elevated BLL. No significant associations were found with anemia or wasting; (4) Conclusions: Primary health care–based screening may help identify vulnerable children and guide targeted public health and environmental responses.

Keywords: lead exposure; blood lead level; geographic mapping; public health screening

1. Introduction

Lead exposure remains a major global environmental health concern, particularly among children, for whom no safe blood lead level (BLL) has been identified. Even low-level exposure is associated with adverse neurodevelopmental, behavioral, and physical health outcomes [1–4]. Globally, lead exposure continues to disproportionately affect children in low- and middle-income countries (LMICs), where rapid urbanization, informal industries, and weak environmental regulation contribute to persistent exposure risks [1,5].

In Indonesia, the burden of lead exposure is substantial and increasingly recognized as a critical public health issue. Recent estimates suggest that more than 8 million children have BLLs exceeding 5 μg/dL, the threshold requiring clinical and environmental intervention [6,7]. Earlier studies have consistently documented elevated BLLs in Indonesian children since the 1990s, with particularly high levels observed in areas near informal used lead–acid battery (ULAB) recycling, mining, and other environmentally hazardous activities [8–12]. For example, children living near ULAB recycling sites in Bogor Regency have shown markedly elevated BLLs, while studies in mining areas have demonstrated associations between lead exposure and impaired growth outcomes [8,13].

Despite growing evidence, important gaps remain in understanding the distribution, determinants, and health correlates of lead exposure within routine health system settings. Most prior studies in Indonesia have focused on specific high-risk populations or environmental hotspots, with limited integration of clinical, environmental, and health outcome data.

Within this context, the present study—conducted within a broader implementation research program—examines blood lead levels among children aged 1-5 years attending primary health care facilities in Bogor City and Bogor Regency. By combining facility-based quantitative data with contextual environmental observations across two contrasting settings, the study describes the distribution, correlates and geographic concentration of lead exposure in routine service settings. The findings are intended to inform health system–integrated strategies for childhood lead exposure detection and response in Indonesia and similar LMIC settings.

2. Materials and Methods

This study was initiated, designed and funded by UNICEF, with strategic support from the Ministry of Health of Indonesia. Implementation was conducted in collaboration with local health authorities and the primary health care facility network, ensuring integration within routine service delivery. Binawan University served as the lead academic institution, coordinating the overall implementation, data management and analysis.

2.1. Study Design and Setting

This study was conducted as part of Phase 1 of a phased implementation research program designed to evaluate the integration of the National Guideline on Clinical Management of Lead Exposure in Children and Pregnant Women into routine health services in Indonesia. Within this framework, the present study specifically aimed to describe blood lead level (BLL) distribution in relation to environmental exposure sources across different geographic contexts, namely Bogor City and Bogor Regency. These two areas were selected due to their contrasting exposure profiles, with

 doi:10.20944/preprints202605.1311.v1

Bogor Regency characterized by the presence of informal lead-related activities, and Bogor City representing a relatively lower-exposure urban setting.

A cross-sectional study design was employed across 12 primary health centers (PHCs)—six in Bogor City and six in Bogor Regency—selected to represent diverse environmental exposure contexts and support comparative analysis between settings. In addition, environmental field observations were conducted to provide contextual information supporting the interpretation of facility-level and geographic patterns of blood lead levels, although these observations were not analyzed as formal qualitative data.

2.2. Participants and Recruitment

The study population included children aged 1–5 years attending participating primary health care facilities for routine services, including immunization, growth monitoring, and outpatient care, between December 2025 and January 2026. Participating facilities were located within the designated study areas and provided maternal and child health services, with the capacity and commitment to implement study standard operating procedures, participate in training and supervision activities, and conduct specimen storage and transport. Facilities undergoing major renovation, lacking minimum infrastructure for screening and specimen collection, or involved in other intensive implementation research projects were excluded.

Each facility recruited approximately 35 children, resulting in a total sample of 420 participants. The target sample size per facility was determined based on recruitment feasibility during the pilot implementation period, facility service volume, staff availability, and laboratory and logistical capacity.

Participants were recruited consecutively during routine service delivery. Inclusion criteria were children aged 1–5 years whose caregivers provided informed consent for participation, including blood sample collection. Children whose caregivers declined participation or blood collection were excluded from the study.

2.3. Capacity Building

Prior to implementation, health care workers received training based on the Ministry of Health (MoH) Training Curriculum and module on lead exposure management for children and pregnant women. The training covered risk screening, safe blood collection, clinical management pathways, and reporting procedures.

2.4. Data Collection

Data collection was conducted by health facility staff who had participated in prior training on the implementation of the national guideline.

Exposure source information was obtained using structured questionnaires adapted from the National Guideline on Clinical Management of Lead Exposure in Children and Pregnant Women, capturing household, environmental, and occupational risk factors (e.g., proximity to informal recycling, industrial activities, mining, use of lead-containing materials, and environmental dust exposure).

Anthropometric measurements and hemoglobin levels (as an indicator of anemia) were assessed using standard procedures routinely applied in child health services. Other health-related data were collected based on the existing capacity of each facility, reflecting routine service delivery practices within primary health care settings.

2.5. Blood Lead Level Measurement

Blood lead level (BLL) testing was performed using venous blood samples collected by trained personnel following contamination-minimizing procedures. Samples were transported under controlled conditions using a rapid courier service capable of delivering specimens within hours,

 doi:10.20944/preprints202605.1311.v1

ensuring sample integrity. All samples were analyzed at the DKI Jakarta Regional Health Laboratory using inductively coupled plasma mass spectrometry (ICP-MS). Laboratory analyses adhered to established quality assurance and quality control (QA/QC) protocols. BLL results were reported in micrograms per deciliter (μg/dL). Values below the laboratory detection limit were treated as non-detectable and retained in the <5 μg/dL category for descriptive analyses.

2.6. Data Analysis

Data were analyzed using descriptive and inferential statistics. Continuous variables were summarized using means, standard deviations, medians, and ranges, while categorical variables were presented as frequencies and percentages. Missing data for anemia and wasting were handled using available-case analysis, and no imputation was performed.

BLL distribution was analyzed overall and by facility. The proportion of children with elevated BLLs (≥5 μg/dL) was calculated. Associations between elevated BLLs and exposure risk factors were assessed using chi-square or Fisher's exact test, as appropriate. Multivariable logistic regression was conducted to identify adjusted associations with elevated BLL. Formal collinearity diagnostics and facility-clustered sensitivity analyses were not performed in this Phase 1 analysis and should be considered in interpreting adjusted estimates.

2.7. Ethical Considerations

Ethical approval for this study was obtained from the Ethics Committee of Binawan University (No: 629/KEPK-UBN/XI/2025). Written informed consent was obtained from parents or caregivers prior to participation, including consent for blood sample collection. All data were anonymized prior to analysis to ensure confidentiality.

2.8. Artificial Intelligence (AI) Use Disclosure

The authors used AI-based tools (ChatGPT, OpenAI) to assist in drafting sections of the manuscript, improving English grammar, and enhancing clarity of expression. All content was critically reviewed, revised, and approved by the authors, who take full responsibility for the accuracy and integrity of the manuscript.

3. Results

3.1. Distribution, Determinants, and Health Correlates of Childhood Blood Lead Levels

3.1.1. Participant Characteristics

A total of 420 children under five years of age were included in the main analysis. Slightly more than half of the children were male (52.6%), while 46.9% were female. Regarding socioeconomic status, the majority of participants' parents reported a monthly income below IDR 3 million (59.0%). In terms of environmental risk factors, 20.5% of participants resided near lead-processing activities, including informal used lead–acid battery (ULAB) recycling. Most participants lived in generally adequate housing conditions (90.2%); however, 45% reported peeling paint within the household. With regard to consumer product use, most parents (97.4%) reported not using cosmetics that were unlabeled or not confirmed as safe. Aluminum cookware was commonly used in households, with 34.8% reporting its use. Additionally, 12.4% had household members engaged in lead-related occupations (Table 1).

Table 1. Participant characteristics.

Variables		Number	Percent
Gender	Female	198	46,9
	Male	222	52,6
Parents' monthly income (IDR)	<3 million	248	59,0
	3-10 million	158	37,6
	>10 million	8	1,9
	N/A	6	1,4
Resided near lead-processing activities, including (ULAB) recycling	No	334	79,5
	Yes	86	20,5
Housing conditions	Adequate	379	90,2
	Limited access to clean water	26	6,2
	Dirt floors	13	3,1
	Dirt floors and limited access to clean water	2	0,5
Peeling paint within the household (wall, furniture, etc.)	No	231	55
	Yes	189	45
Household members engaged in lead-related occupations	No	368	87,6
	Yes	52	12,4
Parents use cosmetics that are not labelled safe	No	409	97.4
	Yes	11	2.6
Parents use aluminium cookware	No	274	65.2
	Yes	146	34.8

3.1.2. Blood Lead Level

BLL distribution was strongly right-skewed, with most children having non-detectable or very low values and a smaller subgroup showing substantially elevated exposure (Figure 1).

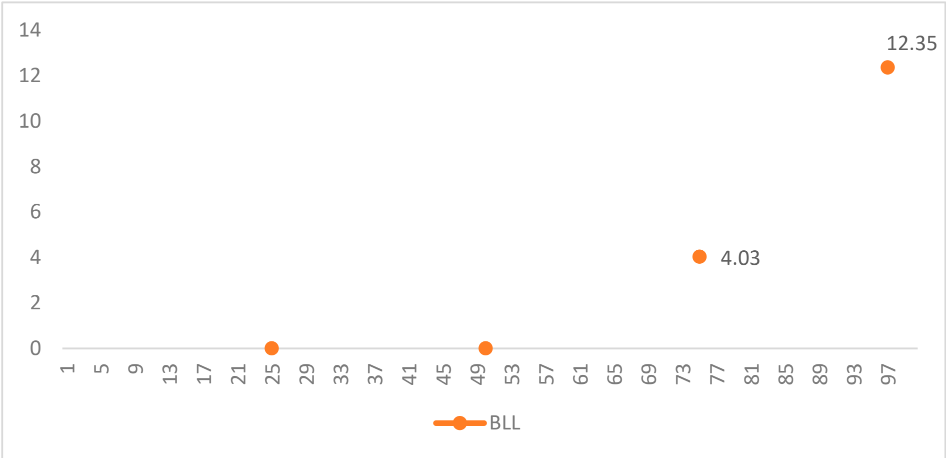

Figure 1. Percentile Pattern of Blood Lead Levels in Children Aged 1–5 Years.

The prevalence of elevated BLL (≥5 μg/dL) was 21.9%. Specifically, 5% had BLL between >0 and <5 μg/dL, 21.7% had BLL within the 5–45 μg/dL range, and a very small proportion (0.2%) exhibited

 doi:10.20944/preprints202605.1311.v1

BLL >45 μg/dL (Figure 2). Notably, the child with the highest recorded BLL (66.82 μg/dL) was reported to have a history of recurrent anemia, highlighting a potential clinical manifestation associated with severe lead exposure (Figure 2).

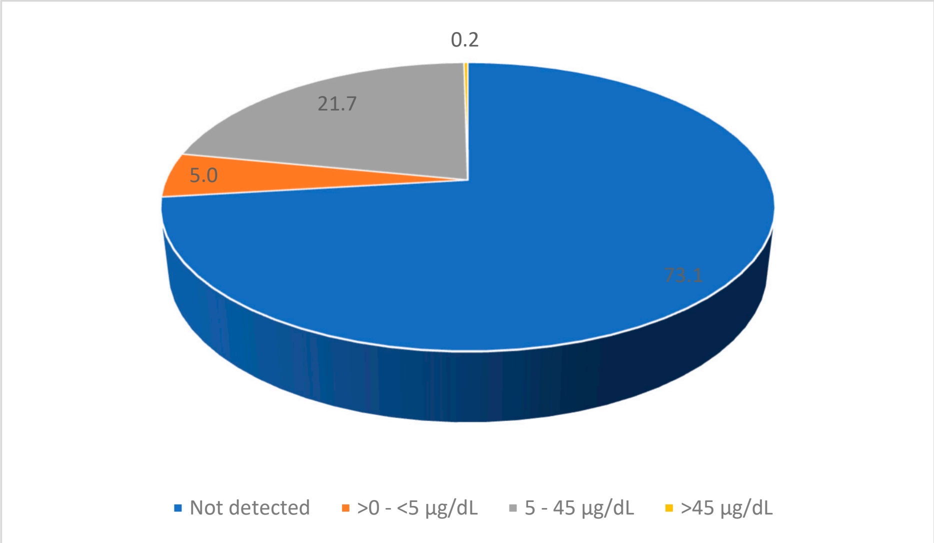

Figure 2. Prevalence of blood lead level categories among children aged 1-5 years.

3.1.3. Geographic/Facility Distribution

The Table 2 presents the distribution of blood lead levels (BLL) among children across primary health centers (PHCs) highlighting substantial geographic disparities. Facilities in Bogor Regency consistently show higher BLL levels compared to those in Bogor City. The highest burden was observed in: PHC Pasar Rebo, with a mean BLL of 6.93 μg/dL, median 6.74 μg/dL, and 82.9% of children exceeding 5 μg/dL, indicating a severe exposure cluster. PHC Tenjo and PHC Pasir also demonstrated high mean BLLs (5.65 and 6.42 μg/dL, respectively) and high proportions of elevated BLL (77.1% and 58.6%). Moderate levels were observed in PHC Rumpin and PHC Klapa Nunggal, while PHC Citeureup showed relatively low exposure (mean 0.39 μg/dL; 5.7% ≥5 μg/dL).

By contrast, facilities in Bogor City generally reported low BLL.: Most centers had mean BLLs below 1μg/dL and 5.7% of children exceeding 5μg/dL. An exceptions was PHC Pulo Armyn, which had a relatively higher mean BLL (2.03 μg/dL) and an extreme maximum value (66.82 μg/dL), suggesting a localized outlier case rather than widespread exposure.

Table 2. Facility-level summary (ranked by % BLL≥5 μg/dL).

City/Area	Facility (PHC)	Mean BLL	Median BLL	% BLL≥5	Max BLL
Kab. Bogor	Pasar Rebo	6.93	6.74	82.9	32.56
Kab. Bogor	Tenjo	5.65	6.52	77.1	13.94
Kab. Bogor	Pasir	6.42	6.6	58.6	18.66
Kab. Bogor	Rumpin	2.72	0.0	38.9	13.51
Kab. Bogor	Klapa Nunggal	1.84	0.0	31.4	9.57
Kab. Bogor	Citereup	0.39	0.0	5.7	8.03
Kota Bogor	Kedung Badak	0.34	0.0	5.7	6.34
Kota Bogor	Lawang Gintung	0.18	0.0	2.9	6.47
Kota Bogor	Pulo Armyn	2.03	0.0	5.7	66.82
Kota Bogor	Warung Jambu	0.17	0.0	2.9	5.96
Kota Bogor	Bogor Selatan	0.10	0.0	2.9	3.8
Kota Bogor	Pondok Rumput	0.0	0.0	0.0	0.0

 doi:10.20944/preprints202605.1311.v1

The spatial distribution map illustrates the geographic clustering of blood lead level (BLL) risk across Bogor Regency and Bogor City. Areas shaded in darker red indicate higher relative risk, while lighter shades represent lower risk. The figure demonstrates a clear concentration of elevated BLL risk in western and northwestern parts of Bogor Regency, particularly around Pasar Rebo, Tenjo, and Pasir, which correspond to known or suspected exposure sources such as informal lead-acid battery (ULAB) recycling and mining-related activities. In contrast, no ULAB recycling activities were observed in Rumpin. However, extensive stone and sand mining operations were present throughout the area (Figure 3).

The observed geographic clustering suggests that local environmental sources may contribute to elevated BLL. However, because environmental observations were not analyzed as formal qualitative or exposure-measurement data, source attribution should be interpreted cautiously and requires confirmation through environmental sampling.

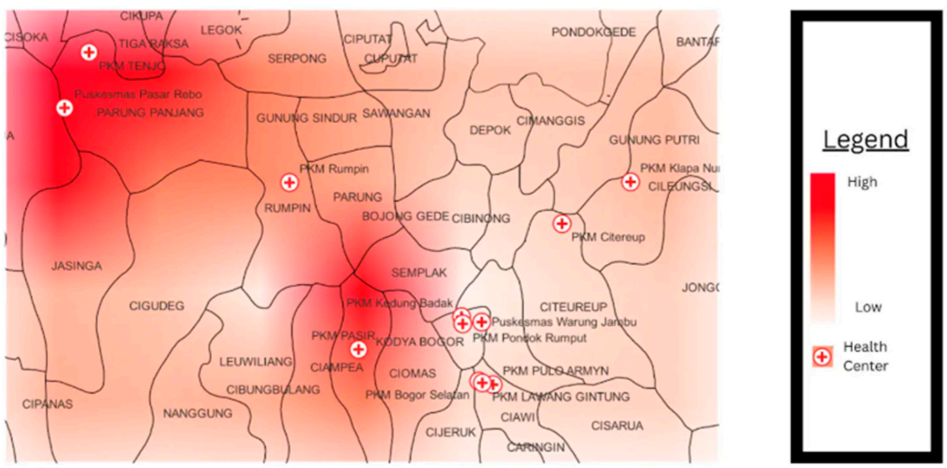

Figure 3. Geographic distribution of elevated blood lead levels (BLL ≥5 µg/dL) among children aged 1–5 years in Bogor City and Bogor Regency.

3.1.4. Risk Factors for Elevated Blood Lead Levels

Bivariate analysis assessed associations between selected risk factors and elevated blood lead levels (BLL ≥5 µg/dL). No significant associations were found for gender (p=0.746), parental income (p=0.744), peeling paint or household lead materials (p=0.740), parental cosmetic use (p=0.978), or aluminum cookware (p=0.056).

In contrast, several factors were significantly associated with elevated BLL. Poor housing conditions, particularly limited access to clean water, were linked to higher BLL (p=0.009). Children living with household members engaged in lead-related occupations also had higher prevalence (32.7% vs. 20.4%; p=0.045).

The strongest associations were observed for environmental proximity and geographic location. Children living near lead-processing activities had substantially higher prevalence of elevated BLL (44.2% vs. 16.2%; p<0.001). Similarly, prevalence was markedly higher in Bogor Regency compared with Bogor City (41.2% vs. 2.4%; p<0.001) (Table 3).

Table 3. Bivariate Analysis of Risk Factors for Elevated Blood Lead Levels (BLL ≥5 µg/dL).

Risk Factors	Blood Lead Level		P Value
	<5µg/dL	≥5 µg/dL	
Gender			
Female	154 (77,7)	44 (23.3)	0.746

doi:10.20944/preprints202605.1311.v1

Male	174 (78.3)	48 (21.7)	
Parents' monthly income (IDR)			
<3 million	190 (76.6)	58 (23.4)	0.744
3-10 million	124 (78.5)	34 (21.5)	
>10 million	8 (100)	0 (0)	
N/A	6 (100)	0 (0)	
Housing Condition			
Adequate	301 (79.4)	78 (20.6)	0.009
Limited access to clean water	15 (57.7)	11 (42.3)	
Dirt floors	11 (84.6)	2 (15.4)	
Dirt floors and limited access to clean water	1 (50)	1 (50)	
Household members engaged in lead-related occupations			
No	293 (79.6)	75 (20.4)	0.045
Yes	35 (67.3)	17 (32.7)	
Peeling paint within the household (wall, furniture, etc)			
No	179(77.5)	52 (22.5)	0.740
Yes	149 (78.8)	40 (21.2)	
Resided near lead-processing activities, including (ULAB) recycling			
No	280 (83.8)	54 (16.2)	<0.001
Yes	48 (55.8)	38 (44.2)	
Area			
Bogor City	204 (97.6)	5 (2.4)	<0.001
Bogor Regency	124 (58.8)	87 (41.2)	
Parents use cosmetics that are not labelled safe			
No	299 (97.4)	8 (2.6)	0.978
Yes	110 (97.3)	3 (2.7)	
Parents use aluminium cookware			
No	192 (62.8)	115 (37.5)	0.056
Yes	82 (72.6)	31 (27.4)	

Multivariable logistic regression analysis was conducted to identify independent predictors of elevated blood lead levels (BLL). After adjustment for proximity to lead-processing activities, housing conditions, and the presence of household members engaged in lead-related occupations, geographic location emerged as the strongest independent determinant of elevated BLL. Children residing in Bogor Regency had substantially higher odds of elevated BLL compared with those in Bogor City (adjusted OR 25.124; 95% CI 9.713–64.989; p<0.001), indicating marked spatial disparities in exposure risk. In addition, proximity to lead-processing activities remained a significant predictor, with children living near such sites having more than twice the odds of elevated BLL compared with those living farther away (adjusted OR 2.522; 95% CI 1.385–4.345; p=0.002). In contrast, housing conditions and the presence of household members engaged in lead-related occupations were not statistically significant after adjustment, suggesting that their effects may be mediated through broader environmental exposure contexts (Table 4).

 doi:10.20944/preprints202605.1311.v1

Table 4. Adjusted Odds Ratios for Risk Factors of Elevated Blood Lead Levels.

Risk Factors	Blood Lead Level		
	Adjusted OR	**95% CI**	**P Value**
Housing Condition			
Adequate	1		0.798
Limited access to clean water	0.920	0.420-2.762	
Dirt floors	1.278	0.140-5.345	
Dirt floors and limited access to clean water	10.429	0.240-453.268	
Household members engaged in lead-related occupations			
No	1		0.612
Yes	0.945	0.440-2.029	
Resided near lead-processing activities, including (ULAB) recycling			
No	1		0.002
Yes	2.522	1.385-4.345	
Area			
Bogor City	1		<0.01
Bogor Regency	25.124	9.713-64.989	

3.2. Association Between Blood Lead Levels and Health Outcomes

Among 356 children assessed for anemia, prevalence was similar between those with BLL <5 µg/dL (22.1%) and ≥5 µg/dL (22.5%), with no significant association (OR = 1.025; 95% CI: 0.550–1.911; p = 0.938). Among 411 children evaluated for wasting, prevalence was higher in the ≥5 µg/dL group (36.7%) compared to <5 µg/dL (30.6%), but this difference was not statistically significant (OR = 1.311; 95% CI: 0.803–2.141; p = 0.278) (Table 5).

Table 5. Odds Ratios for Anemia and Wasting According to Blood Lead Level Category.

	Anemia (n=356)		**OR**	**95%CI**	**P Value**
BLL	No	Yes			0.938
<5µg/dL	222 (77.9)	63 (22.1)	1		
≥5 µg/dL	55 (77.5)	16 (22.5)	1.025	0.550-1.911	
		Wasting (n=411)			
BLL	No	Yes			
<5µg/dL	222 (69.4)	98 (30.6)	1		
≥5 µg/dL	57 (63.3)	33 (36.7)	1.311	0.803-2.141	0.278

4. Discussion

This study provides a comprehensive assessment of childhood lead exposure within a primary health care–based implementation setting in Indonesia, using quantitative screening data supported by contextual environmental observations. The findings confirm that lead exposure remains a

 doi:10.20944/preprints202605.1311.v1

significant public health concern, with 21.9% of children presenting elevated blood lead levels (BLL ≥5 μg/dL), despite a relatively low mean BLL. The observed right-skewed distribution, characterized by a small proportion of highly exposed individuals, is consistent with global evidence showing that localized environmental sources often contribute to high exposure clusters within otherwise lower-exposure populations [3,6].

4.1. Comparison with Global and Indonesian Evidence

The prevalence of elevated BLL observed in this study aligns with estimates from LMICs, where approximately one-third of children globally are estimated to have BLL ≥5 μg/dL [6]. In Indonesia, recent national and subnational data similarly indicate a substantial burden of exposure, particularly in areas with informal industrial activities such as used lead–acid battery (ULAB) recycling and small-scale mining [8,9,14]. Previous studies in Indonesia have reported elevated BLLs among children living near ULAB recycling sites and industrial zones, with prevalence often exceeding 30–50% in high-risk areas [9,13,15].

The markedly higher prevalence observed in Bogor Regency compared with Bogor City is consistent with these findings and reflects the uneven distribution of environmental risk factors. This geographic disparity supports the growing body of evidence indicating that lead exposure in LMICs is highly context-specific, driven by proximity to pollution sources rather than broad socioeconomic indicators alone [1].

4.2. Environmental and Household Determinants

The study identified environmental proximity as a key determinant of elevated BLL. Children living near lead-processing activities had significantly higher odds of exposure, consistent with extensive literature demonstrating the impact of ULAB recycling, industrial emissions, and contaminated environments on childhood lead burden [5,16,17]. The multivariable analysis further highlighted geographic location as the strongest predictor, reinforcing the importance of spatial clustering and localized exposure sources.

An important observation from this study was the presence of mining-related activities in a high-prevalence area, suggesting a potential additional pathway for lead exposure. While informal ULAB recycling is widely recognized as a major source of lead contamination globally, the contribution of small-scale stone and sand mining has been less frequently reported [6]. Emerging evidence indicates that mining activities can mobilize naturally occurring heavy metals, generate contaminated dust, and increase environmental dispersion, potentially contributing to chronic exposure among nearby communities [18,19]. Although environmental observations in this study were used only as contextual information and not analyzed as formal exposure data, these findings highlight the need for broader environmental surveillance beyond traditional industrial sources in Indonesia.

Household-level factors also showed mixed associations. Limited access to clean water was significantly associated with elevated BLL, potentially reflecting broader environmental and infrastructural vulnerabilities that increase exposure risk. Similarly, children living with household members engaged in lead-related occupations showed higher exposure in bivariate analysis, consistent with the "take-home exposure" pathway described in occupational health literature [20]. However, these factors were not significant in multivariable models, suggesting that their effects may be mediated through environmental proximity and broader contextual exposures.

4.3. Non-Significant Findings and Interpretation

Several expected risk factors—including peeling paint, household lead-containing materials, parental cosmetic use, and aluminum cookware—were not significantly associated with elevated BLL in this study. These findings should be interpreted cautiously, particularly for peeling paint, as exposure assessment was based only on caregiver report without laboratory confirmation of lead

 doi:10.20944/preprints202605.1311.v1

content. Consequently, exposure misclassification may have occurred because not all peeling paint contains lead, and the presence of lead-based paint could not be objectively verified [20,21]. This may partly explain the absence of a significant association despite strong evidence from high-income settings identifying lead-based paint as an important exposure source. Similarly, the lack of association with cosmetics and cookware may reflect the low prevalence of unsafe product use or limitations of self-reported exposure measures. These findings underscore the importance of incorporating objective environmental and product testing in future studies to better characterize exposure pathways [22,23].

4.4. Health Outcomes

The study did not find significant associations between elevated BLL and anemia or wasting. While lead exposure has been linked to anemia through interference with heme synthesis and iron metabolism, evidence from epidemiological studies is mixed, particularly at lower exposure levels [12]. The relatively low mean BLL in this study may partly explain the absence of detectable associations. Additionally, anemia and wasting are multifactorial conditions influenced by nutritional status, infections, and socioeconomic factors, which may dilute the observable effect of lead exposure in cross-sectional analyses [12,24].

4.5. Implications for Health System Integration

A key strength of this study lies is its implementation within routine primary health care services. The ability to conduct BLL screening through primary health centers suggests operational feasibility for embedding environmental health within existing health systems in LMICs. However, future studies should report more explicit implementation indicators—such as turnaround time, referral completion, fidelity, and acceptability—to better assess scalability and sustainability [25].

Furthermore, linking contextual environmental observations with clinical screening data provides a more comprehensive understanding of possible exposure pathways and may support more targeted, context-specific interventions. This approach is particularly relevant in settings such as Indonesia, where environmental monitoring systems are limited and fragmented.

4.6. Strengths and Limitations

This study benefits from implementation within routine health services and inclusion of diverse geographic contexts. However, several limitations should be acknowledged. First, the study was conducted in purposively selected implementation sites, limiting generalizability. Second, exposure assessment relied partly on self-report and contextual observation, introducing potential misclassification. Third, the cross-sectional nature of quantitative data limits causal inference. Fourth, formal collinearity diagnostics and facility-clustered sensitivity analyses were not per-formed. Fifth, health outcome data were limited and may not fully capture long-term effects of exposure.

4.7. Future Directions

Future research should incorporate longitudinal designs, expanded environmental sampling, and biomarker validation to better characterize exposure pathways and health impacts. From a programmatic perspective, findings support scaling up integrated screening, strengthening environmental surveillance, and expanding cross-sectoral collaboration to address both industrial and domestic sources of lead exposure.

5. Conclusions

This study shows that childhood lead exposure remains an important public health concern in Indonesia, with 21.9% of children aged 1–5 years showing elevated blood lead levels (BLL ≥5 μg/dL). Significant geographic disparities were identified, particularly in Bogor Regency and among children

 doi:10.20944/preprints202605.1311.v1

living near lead-processing activities, underscoring the importance of environmental proximity in shaping exposure risk.

The findings also suggests that blood lead screening can be integrated into routine primary health care services through the existing system, although stronger implementation measures are needed to assess its scalability and sustainability.

Overall, this study provides useful evidence to inform expansion of health system–integrated lead exposure management, including strengthened health screening, laboratory capacity, environmental follow up, and cross-sectoral collaboration in Indonesia and other LMIC settings.

Author Contributions: Conceptualization, A.S., M.S, and R.S.; methodology, A.S., R.S; software, R.P., S.U., E.K.; validation, M., A.C. and M.S.; formal analysis, A.S., R.P.; investigation, M., D.A., S.N., L, U.S.,; resources, T.S.; data curation, A.S.; writing—original draft preparation, A.S.; writing—review and editing, R.S., M.S.; visualization, M.S.; supervision, T.S.; project administration, D.A.; funding acquisition, A.C. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by UNICEF, grant number SC200470.The APC was funded by UNICEF.

Institutional Review Board Statement: The study was conducted in accordance with the Declaration of Helsinki and approved by the Ethics Committee of Binawan University (No: 629/KEPK-UBN/XI/2025 and date of approval: 17 November 2025).

Informed Consent Statement: Informed consent was obtained from all caregivers of subjects involved in the study. Written informed consent has been obtained from the caregivers to publication of this paper.

Data Availability Statement: The data presented in this study are not publicly available due to ethical and institutional restrictions, including agreements with collaborating institutions and protection of participant confidentiality. Requests for access to de-identified data may be considered by the corresponding author in consultation with the Ministry of Health of Indonesia and UNICEF.

Acknowledgments: The authors would like to express their sincere appreciation to all public primary health care staff in Bogor City and Bogor Regency for their valuable support and active participation in the implementation of this study. We also gratefully acknowledge the Bogor City Health Office and Bogor Regency Health Office for their coordination, technical support, and facilitation throughout the study process. We extend our gratitude to UNICEF for initiating and funding this study, final editing of the paper, and to the Ministry of Health of Indonesia for its strategic support and guidance in the implementation of the National Guideline on Clinical Management of Lead Exposure in Children and Pregnant Women. The authors also acknowledge Binawan University for its leadership and support in study coordination, data management, and analysis. The authors also acknowledge the use of ChatGPT (OpenAI) for assistance with English language editing and improving clarity of expression during manuscript preparation. All content was critically reviewed and approved by the authors. Finally, we thank all participating children and their caregivers for their cooperation and contribution to this study.

Conflicts of Interest: UNICEF funded the study and provided strategic support for study implementation. The authors declare no conflicts of interest.

Abbreviations

The following abbreviations are used in this manuscript:

ATSDR	Agency for Toxic Substances and Disease Registry
BLL	Blood Lead Level
ICP-MS	Inductively Coupled Plasma Mass Spectrometry
LMICs	Low- and Middle-Income Countries
PHC	Primary Health Center
QA/QC	Quality Assurance and Quality Control
ULAB	Used Lead–Acid Battery

 doi:10.20944/preprints202605.1311.v1

References

1. Ericson, B.; Hu, H.; Nash, E.; Ferraro, G.; Sinitsky, J.; Taylor, M.P. Blood Lead Levels in Low-Income and Middle-Income Countries: A Systematic Review. *Lancet Planet Health* **2021**, *5*, e145–e153, doi:10.1016/S2542-5196(20)30278-3.
2. Exposure to Lead: A Major Public Health Concern: Preventing Disease through Healthy Environments, 4th Ed Available online: https://www.who.int/publications/i/item/9789240112384?utm_source=chatgpt.com (accessed on 20 April 2026).
3. Lanphear, B.P.; Rauch, S.; Auinger, P.; Allen, R.W.; Hornung, R.W. Low-Level Lead Exposure and Mortality in US Adults: A Population-Based Cohort Study. *Lancet Public Health* **2018**, *3*, e177–e184, doi:10.1016/S2468-2667(18)30025-2.
4. Suraya, A.; Soriton, J.N.; Hakiem, S.; Nedra, W.; Shetye, M.; Soeharno, R.; Makruf, A.; Darunndiyah, K.; Bose-O'Reilly, S. Association between Potential Lead Exposure Assessed Using a Screening Questionnaire and Aggressive Behaviour among Adolescents in Jakarta, Indonesia: A Cross-Sectional Study. *bmjph* **2026**, *4*, doi:10.1136/bmjph-2025-003239.
5. Kordas, K.; Ravenscroft, J.; Cao, Y.; McLean, E.V. Lead Exposure in Low and Middle-Income Countries: Perspectives and Lessons on Patterns, Injustices, Economics, and Politics. *Int J Environ Res Public Health* **2018**, *15*, 2351, doi:10.3390/ijerph15112351.
6. The Toxic Thruth: Children's Exposure to Lead Pollution Undermines a Generation of Potential.
7. Guideline for Clinical Management of Exposure to Lead Available online: https://www.who.int/publications-detail-redirect/9789240037045 (accessed on 14 October 2022).
8. Irawati, Y.; Kusnoputranto, H.; Achmadi, U.F.; Safrudin, A.; Sitorus, A.; Risandi, R.; Wangsamuda, S.; Setia Asih, P.B.; Syafruddin, D. Blood Lead Levels and Lead Toxicity in Children Aged 1-5 Years of Cinangka Village, Bogor Regency. *PLoS One* **2022**, *17*, e0264209, doi:10.1371/journal.pone.0264209.
9. Prihartono, N.A.; Djuwita, R.; Mahmud, P.B.; Haryanto, B.; Helda, H.; Wahyono, T.Y.M.; Dignam, T. Prevalence of Blood Lead among Children Living in Battery Recycling Communities in Greater Jakarta, Indonesia. *International Journal of Environmental Research and Public Health* **2019**, *16*, 1276, doi:10.3390/ijerph16071276.
10. Albalak, R.; Noonan, G.; Buchanan, S.; Flanders, W.D.; Gotway-Crawford, C.; Kim, D.; Jones, R.L.; Sulaiman, R.; Blumenthal, W.; Tan, R.; et al. Blood Lead Levels and Risk Factors for Lead Poisoning among Children in Jakarta, Indonesia. *Sci Total Environ* **2003**, *301*, 75–85, doi:10.1016/s0048-9697(02)00297-8.
11. Haryanto, B. Blood-Lead Monitoring Exposure to Leaded-Gasoline among School Children in Jakarta, Indonesia 2005. *Kesmas: Jurnal Kesehatan Masyarakat Nasional (National Public Health Journal)* **2007**, *1*, 214–218, doi:10.21109/kesmas.v1i5.293.g293.
12. Suraya, A.; Yuliana, E.; Triwibowo, A.C.; Rahmawati, A.; Zakiyah; Aryani, D.; Yunetti; Jenie, R.P.; Trimawanti, W.; Soeharno, R.; et al. Blood Lead Levels in Children From a Non-Industrial Urban Area in Indonesia. *Asia Pac J Public Health* **2026**, 10105395261435158, doi:10.1177/10105395261435158.
13. Zarmawi, R.; Haryanto, B. The Association of Children's Blood Lead Levels and Prevalence of Stunting in Tin Mining Area in Indonesia. *Ann Glob Health* **2023**, *89*, 55, doi:10.5334/aogh.4119.
14. Haryanto, B. Lead Exposure from Battery Recycling in Indonesia. *Reviews on Environmental Health* **2016**, *31*, doi:10.1515/reveh-2015-0036.
15. Mansyur, M.; Fitriani, D.Y.; Prayogo, A.; Mutiara, A.; Asep; Fadhillah, R.; Aini, R.; Putri, W.W.; Ramadhani, S.E.F.; Rubaya, A.K.; et al. Determinant Factors of Children's Blood Lead Levels in Java, Indonesia. *International Journal of Hygiene and Environmental Health* **2024**, *261*, 114426, doi:10.1016/j.ijheh.2024.114426.
16. Ondayo, M.A.; Simiyu, G.M.; Raburu, P.O.; Were, F.H. Child Exposure to Lead in the Vicinities of Informal Used Lead-Acid Battery Recycling Operations in Nairobi Slums, Kenya. *J Health Pollut* **2016**, *6*, 15–25, doi:10.5696/2156-9614-6.12.15.
17. Chen, M.; Gazze, L.; DiTraglia, F.J.; Das, R.; Nriagu, J.; Erel, Y.; Boyle, E.A.; Taylor, C.M.; Weiss, D. Environmental Lead Risk in the 21st Century. *Commun Earth Environ* **2025**, *6*, 776, doi:10.1038/s43247-025-02735-x.

 doi:10.20944/preprints202605.1311.v1

18. Urrutia-Goyes, R.; Argyraki, A.; Ornelas-Soto, N. Assessing Lead, Nickel, and Zinc Pollution in Topsoil from a Historic Shooting Range Rehabilitated into a Public Urban Park. *International Journal of Environmental Research and Public Health* **2017**, *14*, 698, doi:10.3390/ijerph14070698.
19. Ionita, M.-F.; Radu, S.M.; Dunca, E.-C.; Ionita, M.-F.; Radu, S.M.; Dunca, E.-C. Mining Activities–Mediated Soil Contamination with Heavy Metals: Insights into Mobility, Bioaccumulation, and Ecological Impacts; IntechOpen, 2025; ISBN 978-1-80631-072-2.
20. Rinsky, J.L.; Higgins, S.; Angelon-Gaetz, K.; Hogan, D.; Lauffer, P.; Davies, M.; Fleischauer, A.; Musolin, K.; Gibbins, J.; MacFarquhar, J.; et al. Occupational and Take-Home Lead Exposure Among Lead Oxide Manufacturing Employees, North Carolina, 2016. *Public Health Rep* **2018**, *133*, 700–706, doi:10.1177/0033354918795442.
21. Sargsyan, A.; Nash, E.; Binkhorst, G.; Forsyth, J.E.; Jones, B.; Sanchez Ibarra, G.; Berg, S.; McCartor, A.; Fuller, R.; Bose-O'Reilly, S. Rapid Market Screening to Assess Lead Concentrations in Consumer Products across 25 Low- and Middle-Income Countries. *Sci Rep* **2024**, *14*, 9713, doi:10.1038/s41598-024-59519-0.
22. Lead (Pb) Toxicty: What Is Lead? | Environmental Medicine | ATSDR Available online: https://www.atsdr.cdc.gov/csem/leadtoxicity/what_lead.html (accessed on 17 November 2022).
23. Lead (Pb) Toxicity: Initial Check | Environmental Medicine | ATSDR Available online: https://www.atsdr.cdc.gov/csem/leadtoxicity/initial_check.html (accessed on 8 February 2023).
24. Hegazy, A.A.; Zaher, M.M.; Abd el-hafez, M.A.; Morsy, A.A.; Saleh, R.A. Relation between Anemia and Blood Levels of Lead, Copper, Zinc and Iron among Children. *BMC Res Notes* **2010**, *3*, 133, doi:10.1186/1756-0500-3-133.
25. Aisyah, D.N.; Setiawan, A.H.; Mayadewi, C.A.; Lokopessy, A.F.; Kozlakidis, Z.; Manikam, L. Understanding Health Information Systems Utilization Across Public Health Centers in Indonesia: Cross-Sectional Study. *JMIR Med Inform* **2025**, *13*, e68613, doi:10.2196/68613.