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Determinant Factors of Children's Blood Lead Levels in Java, Indonesia

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ABSTRACT

Introduction: Lead poisoning contributes to a significant burden of disease as a toxic substance found in air, soil, and water. In Indonesia, the risk of exposure is high due to the inappropriate recycling of used lead batteries. The objective was to investigate the factors that influence lead levels in children's blood.

Methods: This cross-sectional study assessed blood lead levels (BLLs) in children aged 12–59 months in four communities exposed to used lead-acid batteries (ULABs) recycling activities, comparing them to a control area. The study employed a threshold level of 20 μg/dL to identify high BLLs and utilized a sample size of 324 children from exposed sites and 240 from control sites. Questionnaires, blood lead tests and a home-based assessment for environmental exposures were applied.

Results: The study participants comprised 295 boys and 269 girls, with an average age of 35 months. Significant disparities in soil lead concentrations median: Q1-Q3 were found between exposed (6581.7 : 2432.6–16647.1) ppm and control areas (253.5 : 158.8–417.1) ppm. Children in exposed areas had 3.9 times higher odds of BLL $\geq$20 μg/dL. Fathers with BLL $\geq$20 μg/dL had children with similarly elevated BLLs. Multivariate analysis identified socioeconomic status, study areas, environmental factors (cookware, food ware, spices, house cleaning), and children's behavior (breastfeeding duration) as determinants of elevated BLLs. Reported environmental factors had notable impact on BLLs, with aluminum cookware (aOR = 1.4, 95%CI [1.2–1.6]), food ware materials (aOR = 1.15, 95%CI [1.0–1.3]), type of spices (aOR = 2.7, 95%CI [1.7–48.0]), and house cleaning method (aOR = 2.9, 95%CI [1.2–7.1]).

Conclusion: This study highlighted key risk factors affecting children's blood lead levels (BLL) and emphasized the urgency of employing effective strategies to remediate lead-contaminated soils in exposed regions. The findings underscore the need for prompt medical intervention and monitoring for children in these areas, with additional research essential to fully understand lead poisoning pathways in the environment.

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1. Introduction

Lead (Pb) is a toxicant found in air, soil and water. Pregnant women and children being the most vulnerable ones to the effects of lead (Lidsky and Schneider, 2003). A 2020 joint report by UNICEF and Pure Earth estimates that one in three children worldwide (about 800 million) have elevated blood lead levels (BLLs) above 5 μg/dL (Rees N & Fuller R, 2020). Lead exposure has several devastating health consequences and can cause high healthcare costs (Council On Environmental Health et al., 2016). Lead exposure in the human body can cause anemia, affect the brain and the nervous system, slow growth and development, cause learning and behavioral disorders, impair school performance and reduce productivity (Amitai et al., 2010; Tempowski and World Health Organization, 2021). Meanwhile, in maternal health, lead exposure has the potential to cause, among other things, pre-eclampsia during pregnancy and gestational hypertension, spontaneous abortion, premature birth, decreased fetal growth and impaired neurodevelopment (Parhoudeh et al., n.d.; Vigeh et al., 2022; Zhong et al., 2022). Lead exposure is also responsible for 133 to 1096 disability adjusted life years (DALYs) (Ericson et al., 2018).

This study was focused on the lead exposures in children since they are particularly vulnerable to health adverse effect such as developmental issues, including among others learning disabilities, decreased intelligent quotient, and behavioral problem (Córdoba-Gamboa et al., 2023; Dike et al., 2023; Lidsky and Schneider, 2003). WHO guidelines recommend identifying and addressing the source(s) of lead exposure for individuals with blood lead concentrations ≥5 μg/dL (Tempowski and World Health Organization, 2021). Centers for Disease Control and Prevention (CDC) children who have higher levels of lead in their blood than most children. The value is based on the 97.5th percentile of blood lead distribution in US children aged 1–5 years. By updating the BLRV to 3.5 μg/dL, health providers are recommended to eliminate further lead (Pb) exposure by doing primary prevention (WHO, 2023; Centers for Disease Control and Prevention (U.S.). 2022). Children with BLL ≥45 μg/dL require immediate medical attention, physical and instrumental diagnostics to identify potential health effects including neurological disorders. Admitting children to the healthcare facilities if their homes are not lead-safe, and identifying the source and risk of lead exposure. The healthcare provider should consult a medical toxicologist or pediatrician to initiate gastrointestinal decontamination and chelation therapy (Centers for Disease Control and Prevention (U.S.). 2022). Unfortunately, Indonesia has limitations in this gastrointestinal decontamination and chelation therapy. Chelation therapy has been done solely for iron overload in children with thalassemia (Fianza et al., 2021; Subroto et al., 2003).

In Indonesia, lead exposure has been attributed to the haphazard collection and recycling of Used Lead-Acid Batteries (ULABs) (Paddock, C. R., 2016), Pb in paint, artisanal and small-scale gold mining, industrial activities, cigarettes, and few other Pb related activities (Caravanos et al., 2013; Ericson et al., 2019; Prihartono et al., 2019; Santoso et al., 2011; Santoso et al., 2016; Yuyun, 2021). Previous studies conducted in Indonesia, showed that the BLLs of children in Indonesia have increased throughout the years. From a study conducted in 2005 among primary students, 1% of children had BLL above 10 μg/dL, and another study conducted in 2021 reported that average BLL was 17.0 μg/dL (range 4.0–65.0 μg/dL). Moreover, BLL of children living next to used lead-acid battery (ULAB) recycling sites, both in urban and rural areas, also increased. A study from 2018 in three neighborhoods of Greater Jakarta (Java), where ULAB recycling occurs, showed that BLLs from 279 children aged 1–5 years living near to ULAB recycling sites had a geometric mean BLL of 4.7 μg/dL (Prihartono et al., 2019). Another Indonesian study from Samarinda city (Kalimantan) in 2019 assessed BLLs of 39 street children, showing a mean BLLs of 11.7 μg/dL (range 3–24 μg/dL) (Hansen et al., 2019).

Several Indonesian BLL studies were previously conducted on Java due to higher population density and more informal sectors with ULAB recycling and other Pb-related activities (Annashr et al., 2019; Haryanto, 2007; Irawati et al., 2022; Pure Earth, 2023b). ULABs and other industrial and mining activities contribute to a high Pb exposure in the Java population, particularly to low- and middle-income families who live in contaminated areas. Caravanos from Pure Earth and co-authors estimated for Indonesia that approximately 10.000 children (0–4 years) live near Pb contaminated sites (Caravanos et al., 2014). Gao et al. performed a study in China that showed the mother's education level, father's occupation, decorative tableware, exposure to makeup, and the residential floor were all risk factors for elevated blood lead levels (odds ratios of 1.42, 1.21, 1.11, 1.19, and 1.27, respectively (Gao et al., 2017). A study in Cinangka, a village in Indonesia, showed that children with high BLL were associated with parents having low income, low education, living for several years in the contaminated areas (Irawati et al., 2022). Even though many previous studies have been performed in Indonesia (Pure Earth, 2023b; Paddock, 2016), no study has looked at the possibility with multiple factors affecting BLLs. Lead exposure can enter the body through inhalation, ingestion, and absorption, depending on the physical characteristics of exposure to lead (Binh et al., 2021; Kwong et al., 2021; Landrigan et al., 2019).

Considering that previous studies showed high levels of lead contamination in soil, the main possible route is through ingestion as the children often engage in hand-to- mouth behavior (Ko et al., 2007; Kwong et al., 2021). In this case, it is necessary to trace the lead carrier material, which brings it into the child's body. The entry of substances into digestion is related to daily behavior such as personal hygiene, eating habits and culture; it is necessary to study the food materials and ingredients, cooking wares and food wares used (Efanny et al., 2019; Flannery et al., 2020; Kumar et al., 2020; Lin et al., 2010). Therefore, this research aimed to analyze multiple potential factors that could influence BLLs in children.

2. Methods

This study is a comparative cross-sectional study to assess BLLs in children aged 12–59 months.

2.1. Study area

The study was conducted in the neighborhoods of four communities (Cinangka-Bogor, Pesarean-Tegal, Kadu Jaya-Tangerang, and Dupak-Surabaya). The selection criteria for the exposed areas were based on the status of ULABs recycling activities in that location (Pure Earth, 2023b), the results of soil lead concentration, the number of vulnerable populations, and the presence or absence of government support from the national and regional levels. Cinangneng village was selected as the control area because it had similar demographic characteristics to the study areas, was more than 2.7 km away from the hot spots, was at a higher elevation than the hot spots, and with no increased levels of Pb in the soil (Pure Earth, 2023b).

2.2. Ethical clearance

Approval for the study was obtained from the Health Research Ethic Committee of the Universitas Indonesia/Cipto Mangunkusumo National Hospital on May 22nd, 2023, with ethical approval number KET-622/UN2.F1/ETIK/PPM.February 00, 2023. The ethical clearance process was performed in collaboration with national and international partners. The principles of the Declaration of Helsinki with its amendment of Fortaleza were applied in the currently valid versions of October 2013.

Informed consent for this study was obtained from the children's guardians/study and adults subjects after providing an information sheet, explaining the aim of the study and potential risk and benefits. The members of the study team ensured that parents/children's guardians were provided all the essential information required at the household level to enable them to deliver a written informed consent before blood was taken. The personal data as well as the blood samples were encrypted with number codes (pseudonymized) after the removal. Neither name, initials or the exact date of birth participants appeared in the encryption code. The description list as well as the original data were stored securely and were accessible solely by the principal researcher. The data and samples were secured against unauthorized access, the confidentiality of the personal data was guaranteed if results of the study were published. As mentioned above, the information and the consent form were given in written form.

2.3. Study population

The children selected for this study met the inclusion criteria, i.e. they were between 12 and 59 months of age, have lived within the selected study and control areas for the last 12 months, have lived in the area for most of the time (and not spend more than 4 weeks outside the area) during the last 12 months, and their parents/guardians had given their informed consent for the child to participate in the study. Inclusion criteria for parents/guardians were male between 18 and 65 years of age. This study did not include mothers for some reasons. The fathers were workers that can be carriers of lead. While the majority of mothers in this population were the housewives. Technically, we prioritize fathers because in order to do children examinations their mothers should be as caregivers together with their role as respondents for the daily and home related data. Obtained data consists of the variables such as sociodemographic parameters, residential parameters, potential household Pb exposure sources, children's and father's behavior related to potential Pb exposures. These data were collected via questionnaires. The questionnaires were developed based on each component of the potential exposure group. A pilot study was done by collecting data from an Indonesian version of questionnaire using 30 samples of the same population characteristics. The aim of the pilot study was to give an approximation of data collection time and to identify whether there was any confusion in answering the questions.

2.4. Threshold levels

The study resulted in children's BLL in the exposed population. CDC recommended new reference value of children's BLL of 3.5 μg/dL which is lesser than previous BLRV of 5 μg/dL for prompt actions to mitigate the health risk and to prioritize communities for exposure prevention. While, WHO recommends a BLL of 5 μg/dL as a concerning level for further action reducing and ending the lead exposure (Centers for Disease Control and Prevention (U.S.). 2022 ; Tempowski and World Health Organization, 2021). To present children's BLL in this study, BLL was categorized based on recommended actions by CDC. This study used a cut-off point for BLLs at 20 μg/dL, as heme synthesis is known to be disrupted at this level and shows possible clinical manifestations (Lubran, 1980; Yapfrine et al., 2023).

The required sample size for estimating the prevalence with 95% confidence and considering the potential loss of 18% would have been 240 for the margin of error or absolute precision of 7%. With such a sample size, the expected 95% CI was (40%–54%) of the result. The Scalex SP calculator was used to calculate the sample size (Naing et al., 2022). As a result, the sample size was 320 children from the exposed sites and 240 children from the control sites. We expected that 20% of the children (12–59 months) will have BLLs above the threshold (Prihartono et al., 2019); at least 130 of the fathers' BLLs were tested and home-based analysis were conducted. Based on the calculated estimation 20% of the children (12–59 months) had BLLs above this threshold.

2.5. Recruitment and stratification

The recruitment process in selecting children who could potentially participate in this study was done in collaboration with local public health center *(Puskesmas*). The *Puskesmas* holds a monthly monitoring of children's health named *Posyandu* (Integrated Health Service Post) for children below 5 years of age. Through a database collected in each *Puskesmas*, a list of children 12–59 months was split into different age groups (12–23, 24–35, 36–47, 48–59 months) and gender (male/female). A list of children was created for each subgroup. A random number generator was used to make the order proportional for each group. To obtain 320 children, 80 children were selected according to their neighborhood with 8 children serving as reserve respondents. From the first 10 children in each order, the children's caregivers were given an explanation to obtain written informed consent for their children's participation.

Potential respondents who refused to participate were replaced by the reserve respondents in the order specified from the lists, until the desired number of participants was reached.

The assessment of socioeconomic status was collected using questionnaires to get the data on characteristics related to the respondents' homes, including the type of housing (non-permanent, semi-permanent, and permanent), the construction materials used (specifically, the type of flooring), and home ownership. Individuals living in non-permanent or semi-permanent housing with earthen floors and those residing in rented accommodations were categorized as having a low socioeconomic status.

2.6. Environmental data

The risk of lead exposure to children has the potential to increase due to behavioral and environmental factors. Home-Based Assessment (HBA) is one way to identify sources of exposure and pathways in individual children, as well as to identify community-level trends. In this study, HBA was done following a protocol published by Pure Earth (Pure Earth, 2023a). This stage is carried out after the results of children's BLL measurements are known. The homes visited were selected from children who have BLL >20 μg/dL. The environmental team made home visits and conducted in-home environmental sampling.

Before the home visit was conducted, a risk factor questionnaire was administered to the entire study participants. The questionnaire includes inquiries regarding the following: the activities that have been conducted at home in the past six months that may be associated with lead exposure, the daily activities of the father, the types of cookware and food ware materials used, the spices used for cooking (including their type, form, and source), the primary source of drinking water, the smoking habits of the household, the methods employed by respondents for house cleaning, and the frequency with which adults bring and launder their work clothes at home.

Based on the data obtained from the questionnaire and a brief observation of the homes and surroundings, the environmental team determined the sample items that needed to be taken from homes, which included metal cookware, plastic and ceramic food ware, children's and father's clothes, toys, mattresses, water and dust, as well as soil around homes. Before sampling, the environmental team created a sketch of the home layout to mark where particular samples were collected.

2.7. Laboratory method

To determine the BLLs of children and their father/guardian participating in this study, we used 2 units of LeadCare II Analyzer and used the LeadCare II Blood Lead Test Kits produced by Magellan® and distributed by Meridian Biosciences®. Blood samples were withdrawn from the capillary blood (5 ml per subject) and kept at 4 °C. The samples were transferred to a laboratory using freezers for the cool chain. The commercial laboratory was used for quality control, it is DIN ISO 17025 certified. Validation of test results were carried out at Prodia® on 10% of subjects. This involved obtaining 5 ml of blood which was analyzed using an inductively coupled plasma mass spectrometry (ICP-MS) analyzer. The blood samples were prepared for analysis by dilution with

10% of nitric acid (Fisher Scientific®, Loughborough, UK) in deionized water. Quality assurance and control procedures were applied throughout the analysis to demonstrate the accuracy and precision of the results. After every ten sample runs, the working standards, spiked blood and certified reference materials were tested to ensure the accuracy of the results.

The limit of detection for BLLs for LeadCare II was from 3.5 to 65.0 μg/dL. BLL below 3.5 μg/dL was defined as not-detected (ND), and BLLs over 65 μg/dL) defined as the highest level that can be detected by LeadCare II. There were 23 samples below 3.5 μg/dL and 9 samples >65 μg/dL. For levels that <3.5 μg/dL, a midpoint between 0 and 3.5 μg/dL (bottom level of detection) was defined. For levels that were >65 μg/dL (upper level of detection) measurement through an existing protocol for dilution was used (Neri et al., 2014).

During the analysis, a medical recall notice was received from Magellan® regarding the reagent used. Magellan raised concern of falsely elevated results after discovering that <10% of the plastic caps seal failed to pass the dimensional specification of the cap's lip, which could result in HCl leakage or evaporation of the treatment reagent. The data were reviewed by comparing the BLL measured with the LeadCare II to the BLL measured with the ICP-MS using the correlation coefficient (0.87) and accuracy/recovery rate. In fact, throughout the study, none of the measurement controls fell outside of the range of high results. These results confirmed that there were no problems with the Magellan® reagent that was used (LOT number: 022323).

2.8. Statistical methods

The variables of sociodemographic characteristics, environmental exposure factors and behavior of the children and fathers/guardians were presented as a categorical scale using frequency distribution and percentages. These variables were gender, age, study areas, place of residence, occupation, cooking and eating utensils, main source of drinking water at home, spices (including form, type and source), method of house cleaning, work clothes brought and washed at home, duration of breastfeeding, prescription medicines, use of traditional herbs, use of cosmetics, habit of hand washing before eating, habit including frequency and type of things children introduce from hand-to-mouth, and places where they spend most of their time. Continuous scale variables were presented as mean ± SD and median interquartile range (age).

To identify potential variables suitable for inclusion in the multivariable analysis, a preliminary step involved the utilization of simple logistic regression to evaluate *p*-values. Variables exhibiting *p*-values less than 0.3 were subsequently selected for integration into the multiple logistic regression model, aimed at pinpointing the key determining factors influencing the outcome. For normally distributed variables, correlation analysis using Pearson's correlation, while Spearman's Rho correlation was utilized for variables not conforming to normal distribution.

2.9. Health and safety protocols

In terms of the post pandemic era of Covid-19, all study activities were conducted in acceptable and environmentally safe manner, with appropriate health and safety protocols, that ensured all protocols were adopted with particular attention to cross-contamination of fingers and sampling tools (The Decree of Minister of Health No. HK.01.07/MENKES/413/2020 concerning Coronavirus Disease 2019 (Covid-19).

3. Results

3.1. Characteristics of research subjects

The characteristics of the subject in this study were defined by the children's demographic and residential circumstances. The study included 295 boys and 269 girls as participating children. The average age of the children was 35 months. The analysis indicated that 7.8% had low economic status, while 92.2% in the middle economic status. The majority of the children (87.4%) resided in their parents' permanent homes, with permanent housing being the most common type of construction (94.9%). A smaller percentage lived in semi-permanent housing (5%), and an even smaller fraction lived in non-permanent housing (0.2%). When considering the flooring of the respondents' houses, the majority had tile floors (83.3%), followed by concrete floors (12.4%), and a small minority (0.2%) lived in houses with wooden floors (see Table 1).

Based on sociodemographic analysis and economic status, the community study presented a sociodemographic picture of the suburban population in Indonesia. This can be seen in the distribution of the types of work and economic status of the participants. The regional minimum wages in Bogor (IDR 4.600.000), Tegal (IDR 2.145.000), Surabaya (IDR 4.525.000) and Tangerang (IDR 4.584.519). Most of the participants

Table 1
Characteristics of children's and father's/guardian's sociodemographic and residential (N = 564).

Children Sociodemographic and Residential	Frequency n (%)	Mean ± SD	Median (Q1-Q3)
Gender[a]			
Boys	295 (52.3)		
Girls	269 (47.7)		
Age (in months)[a]		35 ± 13	35 (24–47)
Study area[a]			
Exposed Area	324 (57.4)		
Pesarean (Tegal)	80 (24.7)		
Kadu Jaya (Tangerang)	84 (25.9)		
Cinangka (Bogor)	81 (25.0)		
Dupak (Surabaya)	79 (24.4)		
Control area			
Cinangneng	240 (42.6)		
Residential characteristics[a]			
Ownerships			
Rented	71 (12.6)		
Owned	493 (87.4)		
House type			
Non-permanent	1 (0.2)		
Semi-permanent	28 (5.0)		
Permanent	535 (94.9)		
Type of floor			
Soil floor	3 (0.5)		
Soil and concrete floor	3 (0.5)		
Soil and tiles floor	11 (2.0)		
Concrete floor	70 (12.4)		
Concrete and tiles floor	5 (0.9)		
Concrete and woods floor	1 (0.2)		
Tile floor	470 (83.3)		
Wooden floor	1 (0.2)		
Sociodemographic of children's father/guardian			
Age (in years)		39.57 ± 9.8	39 (33–45)
≤30	18 (13.1)		
31-40	61 (44.5)		
41-50	42 (30.7)		
51-60	12 (8.8)		
>60	4 (2.9)		
Occupation			
Freelance	172 (30.5)		
Private employee	144 (25.5)		
Private businessman	133 (23.6)		
Farmer	24 (4.3)		
Professional	11 (2.0)		
Civil servant	6 (1.1)		
Unemployed	3 (0.5)		
Others	71 (12.6)		

[a] Based on variables of gender, age, and residential characteristics there was no proportional difference in exposed group compared to control group ($p > 0.05$).

have monthly income of less than the regional minimum wages 86.1%, 93.6%, 72.8%, 88% in Bogor, Tegal, Surabaya, Tangerang, respectively. Among these, 70.8% children in Cinangka, 37.6% in Tangerang, 42.3% in Tegal, 25.4% in Surabaya, and 47.9% in Cinangneng were not members of the Social Health Insurance Administration Body *(Badan Penyelenggara Jaminan Sosial Kesehatan/BPJS Kesehatan)*.

3.2. Characteristics of environmental exposures

Based on the interviews of the study participants, the materials of aluminum cookware were most frequently used (46.5%), while plastic and glass were used most frequently for food ware (35.8%). The domestic well as a source of drinking water dominated the other sources (48.2%). All three types of spices (yellow, red and white spices) were used for cooking, with participants (31.2%) preferring unpackaged/ground spices (92.6%). These spices were mostly obtained from street vendors (80.9%) and only a few participants grew the spices themselves (2%). The percentage of participants who cleaned their house by sweeping and mopping was 91.5%, and 7.6% of participants cleaned the house only by sweeping. Many fathers/guardians of the children always bring their work clothes home (66.8%) and wash their work clothes daily at home (56%), while only a few of them never wash their clothes at home (19.9%) (see Table 2).

3.3. Characteristics of children's and father's/guardian's behaviors

Of the 564 children surveyed, 86.9% had been breastfed for at least 6 months. In addition, we found that 51.2% of the children washed their hands regularly, while 16.5% never washed their hands before eating. About 14.9% of the children took doctor-prescribed medication during the study, and 12.6% of the respondents took traditional herbs. Cosmetics use in children refers to baby face and body powder, which is used by 72.7%. Children are likely to have more hand-to-mouth activities than adults. Of the 564 children, 20% put their hands in their mouths daily, and the things they put in their mouths included toys (17.9%). Children spend most of their time indoors (53.5%) (see Table 3).

3.4. Children's blood lead levels

This data showed that the mean of children's BLLs in low socioeconomic level (24.1 μg/dL) higher than mean of children's BLLs in middle socioeconomic level (15.0 μg/dL). The proportion of BLL of ≥3.5 μg/dL showed similar proportion (>95%) based on gender and socioeconomic level. Beside that, the percentage of children's BLL of ≥3.5 μg/dL in controlled areas showed proportion of 93.3% which was slightly lower than children's BLL in exposed areas (97.8%) (see details in Table 4).

The data regarding to the BLLs of 564 children participants revealed that only 4.1% had a BLL below 3.5 μg/dL, while 34.9% had BLLs between 10 μg/dL and 20 μg/dL. A total of 3.4% of the children had BLLs of 45 μg/dL or higher, a threshold at which medical intervention may be necessary (refer to Fig. 1).

This study further revealed a notable disparity in the proportion of children with BLL ≥20 μg/dL. The BLLs were higher in the exposed areas compared to the control area ($p < 0.001$). Children residing in exposed areas exhibited 3.9 times the odds of having BLL ≥20 μg/dL (OR = 3.9, 95% CI: 2.5–6.0) compared to those in control areas.

The BLLs in fathers/guardians (N = 137) displayed a median (Q1 – Q3) of 6.63 (4.71–12.23 g/dL). Intriguingly, among fathers with BLL ≥20 μg/dL, 90% of their children also manifested BLL ≥20 μg/dL. Children whose father's/guardian's BLL was ≥20 μg/dL exhibited a sixfold higher risk of having elevated BLL, compared to children with parents whose BLL was lower than 20 μg/dL ($p < 0.01^{CS}$) (see Table 5).

Table 2
Characteristics of potential household lead exposures (N = 564).

Potential household lead exposures	Frequency n (%)
Cookware materials	
Aluminum	262 (46.5)
Enamel	106 (18.8)
Teflon or ceramic	9 (1.6)
Aluminum & enamel	34 (6.0)
Aluminum & teflon	91 (16.1)
Aluminum & combinations with enamel-teflon-glass-ceramic-clay	9 (1.7)
Enamel & teflon	46 (8.2)
Enamel & clay/glass	2 (0.4)
Teflon & ceramic/glass	4 (0.7)
No cookware at all	1 (0.2)
Food ware materials	
Aluminum	6 (1.1)
Plastic	20 (3.5)
Ceramic	41 (7.3)
Glass	160 (28.4)
Aluminum & plastic/glass	10 (1.7)
Ceramic & plastic/glass	54 (9.6)
Plastic & glass	202 (35.8)
Plastic-ceramic-glass	71 (12.6)
Main drinking water source at home	
River	1 (0.2)
Pond	3 (0.5)
Community well	13 (2.3)
House well	272 (48.2)
Refill water	139 (24.7)
Municipal waterwork	136 (24.1)
Potential household lead exposures	Frequency n (%)
Spices used for cooking	
Yellow spices (turmeric)	95 (16.8)
Red spices (chili/pepper)	22 (3.9)
White spices (ginger/coriander)	80 (14.2)
Yellow & red	17 (3.0)
Yellow & white	148 (26.3)
Red & white	10 (1.8)
All spices	176 (31.2)
Not using spices	16 (2.8)
Form of spices	
Ground/unpackaged	522 (92.6)
Home-made	9 (1.6)
Branded packaging	26 (4.6)
Unbranded packaging	7 (1.2)
Source of spices	
Self-planting	11 (2.0)
Traditional market	95 (16.8)
Street vendors	456 (80.9)
Minimarket	2 (0.4)
Cleaning the house	
Sweeping only	43 (7.6)
Mopping only	1 (0.2)
Sweeping & mopping	516 (91.5)
Sweeping - mopping - vacuuming	4 (0.7)
Bring their work clothes to home	
Always	377 (66.8)
Sometimes	42 (7.4)
Never	145 (25.7)
Washing their work clothes at home	
Every day	316 (56)
A few times a week	136 (24.1)
Never	112 (19.9)

3.5. Determinant factors of children's blood lead levels

Candidate variables for multivariate analysis were obtained from the bivariate analysis that has a *p*-value <0.3. The variables chosen for inclusion in the multivariate analysis were socioeconomic status and study areas. Multivariate logistic regression revealed that children with low socioeconomic status housing had an adjusted odds ratio of aOR = 3.11, 95% CI: 1.6–6.1 indicating a higher likelihood of having BLL ≥20 μg/dL compared to those with a more favorable socioeconomic status.

Similarly, children living in exposed areas demonstrated a

Table 3
Characteristics of children and father's/guardian's behavior that potential to lead exposure (N = 564).

Children's behaviors related to potential lead exposures	Frequency n (%)
Duration of breastfeeding	
<6 months	490 (86.9)
≥6 months	74 (13.1)
Use of prescription medicines	
Yes	84 (14.9)
No	480 (85.1)
Use of traditional herbs	
Yes	71 (12.6)
No	493 (87.4)
Use of cosmetics	
Yes	410 (72.7)
No	154 (27.3)
Handwashing habit before eating	
Always	289 (51.2)
Sometimes	127 (22.5)
Seldom	55 (9.8)
Never	93 (16.5)
Frequency children inserted hand to mouth	
Everyday	113 (20)
Few times a week	140 (24.8)
Never	311 (55.1)
Children's habit inserting other things to mouth	
Yes	138 (24.5)
No	426 (75.5)
Type of things inserted in mouth	
Toys	101 (17.9)
Non-toys	37 (6.6)
None	426 (75.5)
Places for spending most of the time	
Inside the house	302 (53.5)
At house yard	211 (37.4)
At school area	6 (1.1)
At public spaces in neighborhood	38 (6.7)
In nearby village	3 (0.6)
Others	4 (0.8)
Potential lead exposures at home	
Father's activities	
Removing paint including sand blasting	38 (6.7)
Renovating house/building	52 (9.2)
Activity of demolishing	32 (5.7)
Activity fixing waterpipe	22 (3.9)
Repairing car/motor	25 (4.4)
Activity of smelting	25 (4.4)
Activity of welding	21 (3.7)
Activity of molding	17 (3.0)
Activity of mixing paint	19 (3.4)
Activity of sorting waste	25 (4.4)
Activity of soldering	18 (3.2)
Activity in industry (chemical, glass, ceramic, jewel)	6 (1.8)
Activity recycling battery	7 (1.2)
Activities at home related to lead exposure in the last six months	
Renovating home	86 (15.2)
Removing paint at home	32 (5.7)
Removing vehicle's paint	5 (5.7)
Welding pipe at home	9 (1.6)
Mechanical repairing work at home	16 (2.8)
Soldering at home	12 (2.1)
Painting at home	9 (1.6)
Recycling battery at home	7 (1.2)
House yard gardening	82 (14.5)
Other lead activity at home	17 (3.0)
Smoking habit	
Smoking inside the house	425 (75.4)
Not smoking	(4.6)

significantly higher adjusted odds ratio (aOR = 3.83, 95% CI: 2.4–6.0), indicating an almost fourfold increase in the likelihood of having BLL ≥20 μg/dL compared to their counterparts in control areas. Spices with yellow and red colors were used as references based on study results showing the addition of lead compounds to enhance weight and color (Rees N & Fuller R, 2020). Lead chromate is added to brighten golden color and lead oxide for rich red hue.

Environmental factors identified as determinants were cookware (aOR = 1.4, 95% CI: 1.2–1.6), food ware materials (aOR = 1.15, 95% CI: 1.0–1.3), type of spices (aOR = 2.7, 95% CI: 1.7–48.0), and the method of house cleaning (aOR = 2.9, 95% CI: 1.2–7.1) all influenced BLL levels. Additionally, children's behavior, specifically duration of breastfeeding, emerged as a determinant factor with an adjusted odds ratio of 2.0 (95% CI: 1.2–3.4) (refer to Table 6 for details).

4. Discussion

In this study, we identified that socioeconomic status, study areas, environmental factors (including cookware and food ware usage, spices, house cleaning) and breastfeeding duration played as determinant factors of high BLLs. The children living in the exposed areas were almost 4 times more likely to have high BLL ≥20 μg/dL. Moreover, children whose father's BLL ≥20 μg/dL had 6 times higher odds to have similar high BLL levels.

This research data showed that the occupation of the respondents' parents was mostly temporary workers (30.5%), the second most were private workers (25.5%), followed by working in their own business (23.6%). Based on socioeconomic status, we found that low economic status (poverty) in this study area was 7.8% while the economy level nationally was 9.36% (Badan Pusat Statisik, 2023). Both economic status in this study were below 10% as a national target.

Analysis of this study showed that children from low socioeconomic background were three times more likely to have high BLL compare to those from middle socioeconomic background. Moreover, children living in an exposed area of Pb had almost fourfold higher odds ratio for higher BLLs compared to children living in the control area. The results were consistent with previous studies by EPA and Aelion CM et al. (Aelion and Davis, 2019; US Environmental Protection Agency, 2017) that for children 1–5 years of age and with high BLLs, there was an association between BLLs and poverty indices. In addition, many previous studies have shown that children living in socioeconomically disadvantaged households and in rural areas near Pb acid battery recycling sites, or near to smelters are more susceptible to environmental Pb exposure (Córdoba-Gamboa et al., 2023; Leech et al., 2016; Rees N & Fuller R, 2020).

The environmental measurements and analysis revealed that father's BLL, cookware-, non-plastic food ware-, children's clothes-, adults' (fathers/guardians) clothes were the sources of potential lead Pb exposure for children in exposed areas. The study found that when the BLL of the adults (fathers/guardians of children) were above 20 μg/dL the BLL level of the children were six times higher compared to the group below 20 μg/dL. However, the event of father's BLL ≥20 μg/dL among children whose BLL <20 μg/dL was only two cases that made the 95%CI of its odd ratio a bit wide. Nevertheless, the significant level was high (p-value <0.01). It showed the power was still high. The contamination of lead from fathers to their children could be through the contaminated adults' clothing and their personal hygiene practices after work.

A previous study by Haryanto B in the urban area of Jakarta (Haryanto B, 2016), found that the Pb related activities (ULAB recycling; processing and smelting in metal mining areas) deposited in the soil and accumulated on the surface. The deposition of Pb in soil occurred over decades because Pb moves slowly through the soil due to its strong tendency to be absorbed by organic matter and clay particles, making it immobile and biologically inert (Aelion and Davis, 2019; Henry Abadin et al., 2007). The mobility of Pb in soil depends on several factors, including soil type, pH, soil moisture content, and water infiltration (Binh et al., 2021).

Toddlers are more exposed to Pb contaminated soils and dust as a result of their high hand-to-mouth behavior and increased time spent close to the ground through crawling and play activities (Aelion and Davis, 2019; Henry Abadin et al., 2007). In addition, children who play barefoot, frequently put their hands or toys in their mouths and live in poor hygienic conditions at home are high risk factors for increased BLL

Table 4
BLL distribution and proportion of children with BLL level category, gender, study areas and socioeconomic level.

Characteristics	Frequency (%)	Mean (95% CI) in μg/dL	Median (Min-Max)	P90	P95	% ≥3.5 μg/dL	% ≥5 μg/dL	% ≥20 μg/dL
Gender								
Boys	295 (52.3)	15.75 (14.24–17.27)	11.7 (1.9–69.0)	31.7	42.3	95.9	88.5	24.4
Girls	269 (47.7)	15.63 (14.22–17.03)	12.1 (1.9–69.0)	32.4	40.1	95.9	88.8	27.1
Study areas								
Exposed	324 (57.4)	19.12 (17.62–20.65)	15.40 (1.9–69.0)	38.15	48.9	97.8	95.1	35.5
Pesarean	80 (24.7)	25.9 (22.1–29.8)	20.3 (1.9–69.0)	52.1	69	98.8	98.8	53.8
Kadu Jaya	84 (25.9)	17.9 (15.7–20.3)	15.3 (4.9–69.0)	30.5	41.8	100	98.8	31
Cinangka	81 (25.0)	19.5 (16.6–22.5)	15.7 (4.9–69.0)	39	53.7	100	98.8	37
Dupak	79 (24.4)	13.05 (10.8–15.3)	10.9 (1.9–50.5)	29.7	32.4	92.4	83.5	20.3
Controlled (Cinangneng)	240 (42.6)	11.04 (9.98–12.11)	8.25 (1.90–47.80)	21.3	29.69	93.3	80	12.5
Socioeconomic level								
Low	44 (7.8)	24.12 (18.58–29.66)	19.5 (1.9–69.0)	53.2	69	95.5	95.5	50
Middle	520 (92.2)	14.98 (13.97–15.98)	11.6 (1.9–69.0)	29.2	39.5	96	88.1	23.7

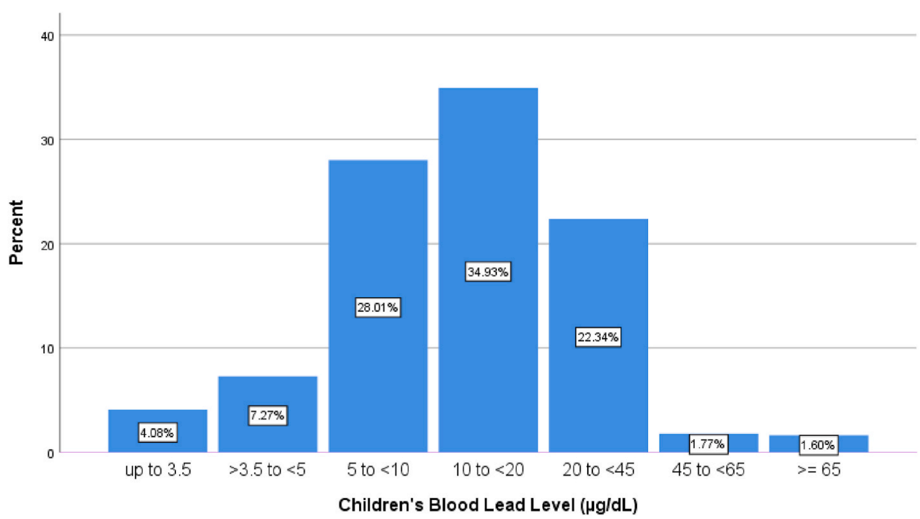

Fig. 1. Children's BLL in categories (N = 564).

Table 5
The proportion comparison of BLL levels based on exposure area as children's and fathers' BLL category.

	Children's BLL ≥20 μg/dL	Children's BLL <20 μg/dL	OR (CI 95%)	*p*
	n (%)	n (%)		
Study Areas				
Exposed Areas	115 (35.5)	209 (64.5)	3.9 (2.5–6.0)	<0.001[CS]
Control Area	30 (12.5)	210 (87.5)		
Fathers' BLL				
BLL ≥20 μg/dL	18 (90)	2 (10)	6.0 (1.3–27.3)	0.009[CS]
BLL<20 μg/dL	70 (59.8)	47 (40.2)		

levels (Kwong et al., 2021), analyzed that direct soil ingestion accounted for nearly 40% of soil consumed by children age 6–23 months. It is important to avoid exposure to soil and dust contaminated with Pb. The Ministry of Environment and Forestry needs to take a role primarily in controlling contaminated land. Soil remediation efforts need to continue to improve their effectiveness and expand their reach. Apart from that, control of pollution sources from industry needs to continue to be strengthened.

Numerous investigations into the impact of lead (Pb) and other hazardous metals on health have been undertaken in the preceding years. Jarup (Järup, 2003) noted that the gastrointestinal absorption of Pb in children can reach up to 50%, whereas adults only absorb 10–15% of Pb from their meals. The diminished protective capacity of the blood-brain barrier in children, compared to adults, renders children's neurological systems more susceptible to harm from Pb exposure. This heightened vulnerability is attributed to the permeable nature of the blood-brain barrier and the elevated absorption of Pb in the gastrointestinal tract, particularly in newborns and infants (Järup, 2003). A rise of 10 μg/dL in blood lead levels (BLLs) corresponds to a five-point reduction in language test scores for children(Lewis et al., 2018). The Indonesian Health Ministry reports a correlation between dietary exposure and a decrease in intelligence, indicating that each 12 g ingestion of lead a day leads to a one-point reduction in IQ (Efanny et al., 2019; Flannery et al., 2020). Furthermore, Pb accumulates in the skeleton and is gradually excreted from the body through urine. The half-life of Pb in blood is approximately one month, with around 90% of the total body Pb deposits residing in the skeleton for two to three decades (Kaji and Nishi, 2006). Thus, the effect of Pb exposure in children may exist for a long time and along their growth periods. Consequently, the impact of Pb exposure in children may persist over an extended period, spanning their growth stages.

4.1. The strength and limitation of the study

One of the strengths of this study is that it was conducted both in exposed and controlled areas using a home-based assessment to determine the risk of lead exposure from households that are present in the child's daily life and also to explore their habits and lifestyle. The blood

Table 6
Multivariate analysis of determinant factors of children's blood lead level (N = 564).

Children demographic and socioeconomic status	Children's BLL ≥20 μg/dL n (%)	Children's BLL <20 μg/dL n (%)	cOR (95% CI)	aOR (95% CI)
Socioeconomic				
Low	22 (50.0)	22 (50.0)	3.2 (1.7–6.0)	3.11 (1.6–6.1)
Middle	123 (23.7)	397 (76.3)		
Study area				
Exposed area	115 (35.5)	209 (64.5)	3.8 (2.5–6.0)	3.83 (2.4–6.0)
Control area	30 (12.5)	210 (87.5)		
Environmental Exposure				
Cookware materials				
Aluminum	132 (33.3%)	264 (66.7%)	6.0 (3.3–10.9)	1.4 (1.2–1.6)
Enamel/teflon/ceramics/clay/glass	13 (7.7%)	155 (92.3%)		
Food ware materials				
Aluminum/ceramic/clay/glass	81 (33.8%)	159 (66%)	2.1 (1.4–3.0)	1.15 (1.0–1.3)
Plastic	64 (19.8%)	260 (80.2%)		
Types of spices used for cooking				
Other than yellow/red spices	46 (31.7)	50 (11.9)	3.4 (2.2–5.4)	2.7 (1.7–48.0)
Yellow/red spices	99 (68.3)	369 (88.1)		
Cleaning the house				
Sweep and mop/vacuum (not daily)	138 (26.5%)	383 (73.5%)	1.8 (0.8–4.2)	2.9 (1.2–7.1)
Sweeping only (daily)	7 (16.3%)	36 (83.7%)		
Children's behavior related to lead exposure				
Breastfeeding duration				
<6 months	29 (39.2%)	45 (60.8%)	1.1 (0.7–1.8)	2.0 (1.2–3.4)
≥6 months	116 (23.7%)	374 (76.3%)		
Taking regular/traditional medicines				
Yes	41 (29.7%)	97 (70.3)	1.3 (0.8–2.00)	1.2 (0.8–1.9)
No	104 (24.4%)	322 (75.6%)		
Frequency of inserting hand-to-mouth				
Everyday	23 (20.4)	90 (79.6)	1.3 (0.8–2.3)	1.4 (0.9–2.5)
Few times a week	42 (30.0)	98 (70.0)	0.8 (0.5–1.3)	0.8 (0.5–1.3)
Never	80 (25.7)	231 (74.3)	Ref	
Type of things inserted in mouth				
Toys	25 (24.8%)	76 (75.2%)	1.0 (0.6–1.7)	1.0 (0.6–1.7)
Non-toys	14 (37.8%)	23 (62.2%)	0.5 (0.3–1.1)	0.6 (0.3–1.3)
Not inserting things to mouth	106 (24.9%)	320 (75.1%)	Ref	
Places for spending most of the time				
Outside the house	75 (29%)	186 (71%)	1.4 (0.9–2.0)	1.4 (0.9–2.0)
Inside the house	69 (22.8%)	233 (77.2%)		

aOR - adjusted OR; cOR -crude OR.

samples required to be analyzed using LeadCare II were relatively small and instant results (within 3 min), making the measurement of BLL more feasible for the children. Moreover, the instant result could be immediately followed up with HBA for participants with relatively high BLL.

Indonesia as an archipelago has various geography and demography which might not be represented by this study setting that limit in Java Island. Therefore, further study in the other setting should be conducted to explore different patterns of lead exposures.

5. Conclusions

This investigation unveiled noteworthy risk factors impacting children's blood lead levels (BLL). In regions of exposure, it is imperative to remediate Pb-contaminated soils employing the most suitable methods and strategies, with a continuous assessment of the remediation process. Children residing in these exposed areas should promptly receive access to appropriate medical intervention, coupled with vigilant health monitoring, particularly if they exhibit symptoms and are experiencing delays in their growth and developmental milestones. Consequently, additional research endeavors are warranted to comprehensively investigate and elucidate the pathways of Pb poisoning within the environment.

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Availability of data and materials

The datasets used and/or analyzed during the current study are available by request to the corresponding author.

CRediT authorship contribution statement

Muchtaruddin Mansyur: Writing – review & editing, Writing – original draft, Validation, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Dewi Yunia Fitriani:** Writing – review & editing, Validation, Resources, Project administration, Formal analysis, Data curation. **Ari Prayogo:** Methodology, Data curation. **Ade Mutiara:** Data curation. **Asep:** Data curation. **Ratih Fadhillah:** Data curation. **Rifka Aini:** Data curation. **Winda Widyaning Putri:** Data curation. **Sarah Edna Fadilah Ramadhani:** Writing – review & editing, Writing – original draft, Data curation. **Agus Kharmayana Rubaya:** Data curation. **Sarjito Eko Windarso:** Data curation. **Herman Santjoko:** Data curation. **Sigid Sudaryanto:** Data curation. **Haryono:** Data curation. **Budi Susilorini:** Writing – review & editing, Resources, Project administration, Methodology, Funding acquisition, Data curation. **Nickolaus Hariojati:** Visualization, Validation, Software, Resources, Methodology, Formal analysis, Data curation. **Alfonso Rodriguez:**

Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Methodology, Data curation, Conceptualization. **Stephan Bose-O'Reilly:** Writing – review & editing, Validation, Supervision, Methodology, Formal analysis, Conceptualization.

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

aOR	adjusted odds ratio
BLL	lood lead level
BLRV	Blood Lead Level Reference
CDC	Centers for Disease Control and Prevention
CI	confidence interval
cOR	crude odds ratio
DALY	Disability Adjusted Life Years
HBA	home based assessment
HCl	hydrogen chloride
ICP-MS	inductively coupled plasma mass spectromet
IDR	Indonesian Rupiah
LMIC	low and middle-income country
LOD	limit of detection
OR	odds ratio
Pb	Plumbum/lead
PE	Pure Earth
ppb	parts per billion
ppm	parts per million
WHO	World Health Organization
XRF	X-ray fluorescence
ULAB	Used Lead-Acid Battery
UN	United Nations

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