ORIGINAL RESEARCH ARTICLE

Analysis of cadmium (Cd) and lead (Pb) concentration in the blood of street children in high traffic areas of Makassar City, Eastern Indonesia

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ABSTRACT

Background: Air pollution in urban high-traffic areas contributes to exposure to heavy metals, such as cadmium (Cd) and lead (Pb), posing health risks to vulnerable populations, particularly street children. This study aimed to assess the relationship between Cd and Pb concentrations in ambient air and their levels in the blood of street children in Makassar City, Eastern Indonesia, and to evaluate the influence of age and sex.
Methods: A cross-sectional study was conducted on 80 street children aged 3–12 years living within 700 m of six high-traffic sites. Ambient air samples were collected using a high-volume sampler and analyzed by Atomic Absorption Spectrophotometry, while blood samples were examined using Inductively Coupled Plasma Mass Spectrometry.
Results: The mean blood Pb concentration was 0.32 ng/mL (range 0.05–0.87 ng/mL), which is below the WHO reference threshold of 5 µg/dL, although approximately 10% of the children exceeded this level. The mean blood Cd concentration was 0.68 ng/mL (range 0.12–1.23 ng/mL), which is close to or slightly above the WHO recommended

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threshold of 1 μg/L in some participants, indicating potential health concern. The correlation between ambient and blood Pb levels was very weak (r = 0.041; 95% CI: –0.180 to 0.258), and the correlation between ambient and blood Cd levels was weak and imprecise (r = –0.172; 95% CI: –0.377 to 0.050). A moderate negative correlation was observed between age and blood Cd (r = –0.460; 95% CI: –0.617 to –0.267), indicating higher Cd accumulation in younger children than in older children. Sex had little effect on blood Cd and Pb levels.

Discussion: These findings highlight that multiple exposure pathways, beyond ambient air, contribute to the heavy metal body burden among street children. Public health interventions addressing environmental sources, nutritional support, and healthcare access are essential to reduce the risk of chronic Cd and Pb exposure in this vulnerable group.

Key words: cadmium, lead, street children, blood biomonitoring, high traffic areas

Introduction

Air pollution from motor vehicle emissions is a major environmental health challenge in densely populated urban areas. Makassar City in Indonesia has a high traffic density, contributing to elevated levels of air pollutants, including heavy metals such as cadmium (Cd) and lead (Pb). These metals are of particular concern because they can accumulate in the human body and are associated with a wide range of adverse health effects, including renal dysfunction, impaired cognition, immune suppression, and growth retardation (1). The World Health Organization (WHO) and the United States Environmental Protection Agency (US-EPA) have established threshold limits for heavy metal exposure. WHO recommends that Pb concentrations in ambient air should not exceed 0.5 μg/m³, while Cd should remain below 0.005 μg/m³ (2). For biological markers, blood Pb levels in children should not exceed 5 μg/dL, and blood Cd levels should remain below 1 μg/L (3). These threshold values highlight that even low-level chronic exposure to heavy metals poses a significant health risk to child health. Children are more vulnerable to the toxic effects of heavy metals than adults for several reasons. Physiologically, they have a higher minute ventilation per kilogram of body weight, leading to greater inhaled doses of polluted air (4). Their biological defense mechanisms, including detoxification pathways and renal excretion, are still immature, resulting in less efficient metabolism and elimination of toxic substances (5). Behaviorally, children spend more time engaging in outdoor activities at ground level, where pollutant concentrations are higher. Moreover, socioeconomic vulnerabilities, such as limited access to healthcare, poor nutrition, and inadequate living conditions particularly among street children further exacerbate susceptibility to Cd and Pb toxicity (6). Street children in Makassar often spend long hours in high-traffic environments, such as intersections, markets, and bus terminals, increasing their exposure to airborne contaminants. Previous studies have shown that traffic-related pollution is associated with an increased risk of stunting, respiratory diseases, and impaired cognitive development in vulnerable child populations (7,8). However, direct evidence linking environmental concentrations of Cd and Pb with internal biomarkers of exposure, such as blood concentrations, remains limited in Indonesia, especially among street children. This study aimed to address this knowledge gap by analyzing the relationship between the ambient air concentrations of Cd and Pb and their corresponding levels in the blood of street children in high-traffic areas of Makassar City. Furthermore, it examines the influence of demographic factors, including age and sex, on the accumulation of these metals. The findings are expected to provide a stronger scientific basis for public health strategies aimed at protecting vulnerable children from the health risks associated with heavy metal exposure.

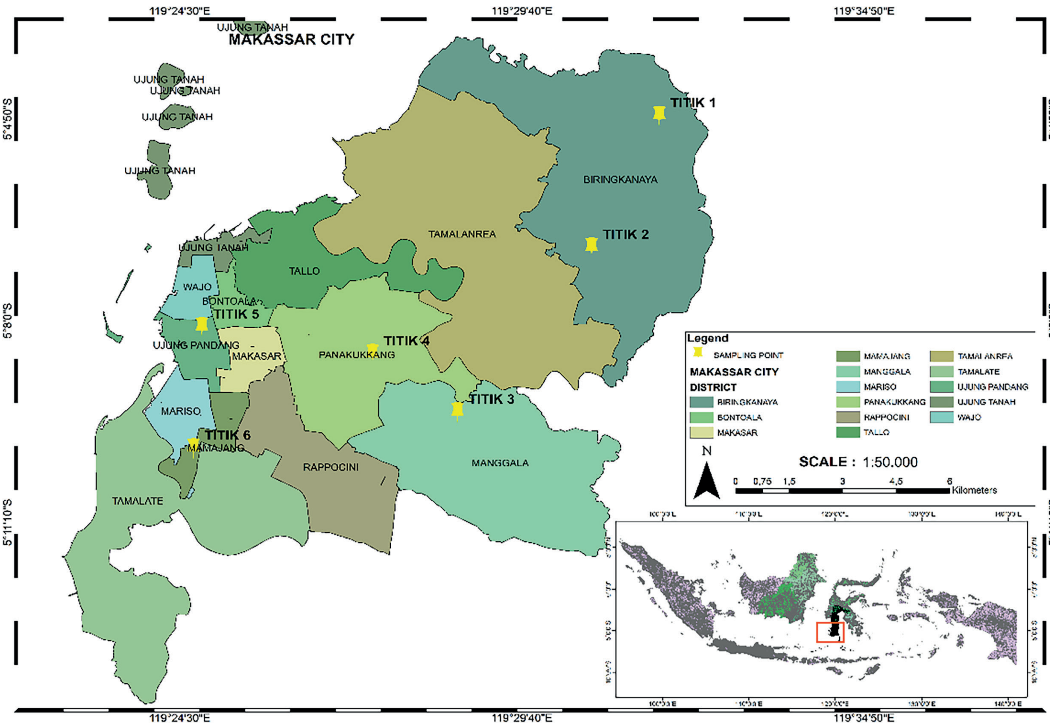

Figure 1. Geographical location of the study area along with the ambient air sampling in Makassar City, Indonesia (GIS.2024).

Materials and Methods

Study design and population

This study employed an analytical design using a cross-sectional approach. The target population consisted of street children aged 3–12 years who lived or carried out daily activities within 700 m of six high-traffic locations in Makassar City (Figure 1). Site selection was based on traffic density, urban zoning data, and accessibility for environmental sampling purposes. A total of 92 children were approached, and 80 consented to participate, yielding a response rate of 87.0%. The inclusion criteria were residence or daily activity within the designated study area, willingness to participate with informed consent from parents or guardians, and absence of acute illness during sampling. The exclusion criteria were refusal of blood sampling and incomplete questionnaires. Baseline data collected included age, sex, and nutritional status.

Air sampling and analysis

Ambient air samples were collected at six high-traffic sites using a High Volume Sampler (HVS Hg-300), positioned 1.25 m above ground level to approximate the breathing height of the children. Sampling was conducted over 24-hour periods on non-rainy days and included both morning and afternoon sessions to capture diurnal variation. Meteorological parameters (temperature, relative humidity, and wind speed) were recorded using portable environmental-monitoring devices. Dust samples were then analyzed for Cd and Pb content using Atomic Absorption Spectrophotometry (AAS, PerkinElmer Analyst series). Calibration curves were prepared using certified standard solutions, and blank samples were analyzed to ensure the absence of background contamination.

Blood sampling and analysis

Venous blood samples (1 mL) were collected from each participant by trained phlebotomists in accordance with biosafety and ethical guidelines. The samples were stored at 4°C, digested with concentrated nitric acid and hydrogen peroxide, and diluted with deionized water. Analysis was performed using Inductively Coupled Plasma Mass Spectrometry (ICP-MS, Thermo iCAP RQ). Analytical quality assurance procedures included the use of certified reference material (Seronorm™ Trace Elements Whole Blood), addition of internal standards (Indium and Yttrium) to correct for matrix effects and method blanks, and triplicate analyses to ensure reproducibility. The limits of detection (LOD) were 0.001 ng/mL for Cd and 0.003 ng/mL for Pb. The recovery rates ranged from 92% to 105%, indicating acceptable analytical accuracy.

Data analysis

Descriptive statistics were used to summarize the respondent characteristics (age, sex, nutritional status, and exposure to secondhand tobacco smoke) and the distribution of Cd and Pb concentrations in both air and blood samples. Data normality was assessed using the Kolmogorov–Smirnov test because the sample size exceeded 50. Differences in Cd and Pb concentrations based on age groups (Early Childhood: 3–6 years and Middle Childhood: 7–12 years) and sex were examined using the Mann–Whitney U test or Kruskal–Wallis test, as appropriate. The relationship between Cd and Pb concentrations in ambient air and their blood concentrations was analyzed using the Spearman correlation test, as most variables were not normally distributed. Correlation coefficients (r) were interpreted as follows: 0–0.25 = very weak, 0.26–0.50 = weak, and 0.51–0.75 = moderate. 0.76–1.00 = strong. Statistical significance was set at $p < 0.05$.

Results and Discussion

The correlation analysis indicated a very weak association between ambient Pb and blood Pb levels (r = 0.041; 95% CI: –0.180 to 0.258) and a weak negative association between ambient Cd and blood Cd levels (r = –0.172; 95% CI: –0.377 to 0.050). These wide confidence intervals suggest considerable uncertainty, indicating that ambient air concentrations alone may not substantially influence the blood Cd and Pb levels in street children. A moderate negative correlation was observed between age and blood Cd (r = –0.460; 95% CI –0.617 to –0.267), reflecting higher Cd accumulation in younger children than in older children. In contrast, age showed little effect on blood Pb (r = –0.103; 95% CI –0.316 to 0.119). Sex also had little effect on both Cd and Pb levels in blood

The results showed that lead (Pb) concentrations in the air were consistently higher than cadmium (Cd) concentrations across all sampling locations (Figure 2). Cadmium levels ranged from 0.0009 μg/m³ in Daya to 0.0092 μg/m³ in Cendrawasih, indicating relatively low values overall, with the highest concentration found in Cendrawasih. In contrast, lead concentrations were much higher, ranging from 0.0573 μg/m³ in Daya to 0.337 μg/m³ in Cendrawasih. The highest Pb concentration was observed in Cendrawasih, which was nearly three times greater than the levels recorded in medium-range locations such as Sudiang (0.1291 μg/m³) and Sudirman (0.133 μg/m³). Daya had the lowest Pb level among all the sites.

Table 1 indicates that a total of 80 street children aged 3–12 years were included in this study, with a mean age of 8.75 years. Of these, 32.5% (n=26) were in early childhood (3–6 years), and 67.5% (n=54) were in middle childhood (7–12 years). The majority of the participants were male (67.5%, n=54), and 32.5% (n=26) were female. Regarding pubertal status, 32.5% (n=26) were classified as pre-pubertal and 67.5% (n=54) as early pubertal status.

Table 1. Characteristics of research samples on street children in densely populated areas of Makassar city

Variabel	n (%) Mean
Age (years) 3-12	80 8,75
Early Childhood (3-6 years)	26 (32.5)
Middle Childhood (7-12 years)	54 (67.5)
Gender (M/F)	
Male	54 (32,5%)
Female	26 (67,5 %)
Pubertal Status	
Pre-pubertal (3-6 years)	26 (32.5)
Early pubertas (7-12 years)	54 (67.5)

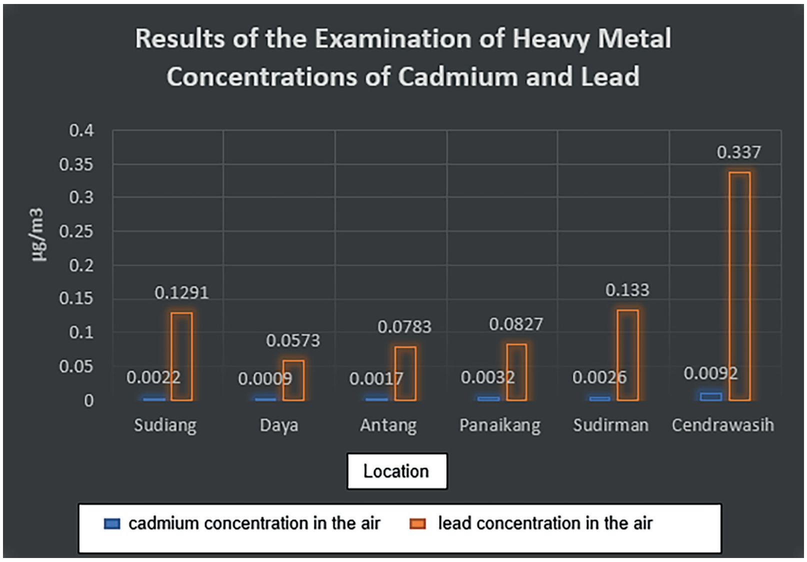

Figure 2. Concentrations of Cadmium (Cd) and Lead (Pb) in the Air at High-Traffic Locations in Makassar City.

Table 2 shows that age had little effect on blood Pb concentrations (r = –0.103; 95% CI, –0.316 to 0.119), indicating a very weak association. In contrast, a moderate negative correlation was observed between age and blood Cd concentrations (r = –0.460; 95% CI –0.617 to –0.267), suggesting that younger children exhibited higher Cd levels than to older children.

Table 3 shows that the correlation between ambient Pb concentrations and blood Pb levels was very weak (r = 0.041; 95% CI: –0.180 to 0.258), indicating little to no meaningful association. The correlation between ambient Cd concentrations and blood Cd levels was weak and imprecise (r = –0.172; 95% CI –0.377 to 0.050), suggesting that the contribution of airborne Cd to blood Cd levels is likely limited.

Discussion

This study assessed cadmium (Cd) and lead (Pb) exposure among street children living in high-traffic areas of Makassar City by measuring ambient air concentrations and blood biomarkers. The results revealed that although Cd and Pb were consistently detected in both air and blood samples, no significant correlation was found between the environmental and biological concentrations. However, a significant negative association was observed between age and blood Cd levels, indicating higher Cd concentrations in younger children. The absence of a strong correlation between ambient air and blood Cd and Pb concentrations (r-values close to zero with wide CIs) suggests that ambient air is not the sole exposure pathway. Previous research has highlighted that diet, ingestion of contaminated dust or soil, and exposure to secondhand tobacco smoke contribute significantly to the body burden of heavy metals in children. The moderate age-related effect observed for blood Cd (r = –0.460; 95% CI –0.617 to –0.267) underscores that younger children are more vulnerable, consistent with toxicokinetic immaturity and behavioral factors. Previous research has highlighted that diet, ingestion of contaminated dust or soil, and exposure to secondhand tobacco smoke contribute significantly to children's body burden of heavy metals (9,10). Street children are particularly vulnerable due to limited access to clean food and water, poor housing conditions, and continuous proximity to polluted traffic environments. These multiple exposure pathways may mask the direct contribution of ambient air pollutants. The significant negative correlation between age and blood Cd concentration is consistent with toxicokinetic principles. Younger children (3–6 years) exhibited higher

Table 2. Analysis of the relationship between age and cadmium (Cd) and lead (Pb) levels in blood biomonitoring of street children in high-traffic areas of Makassar City

Variable	Blood Biomarker	r value	95% CI	Strength of Correlation	Information
Age	Blood Pb	–0.103	–0.316 to 0.119	Very weak	Age had little effect on blood Pb
	Blood Cd	–0.460	–0.617 to –0.267	Moderate	Younger children had higher Cd levels

Table 3. Analysis of the relationship between airborne concentrations of cadmium (Cd) and lead (Pb) and their levels in the blood of street children in high-traffic areas of Makassar City

Heavy metal	concentration in Air → Blood	Direction of Relationship (r)	Strength of Correlation	95% CI	Information
Lead (Pb)	concentration in Air → Blood	0,041	Very weak	-0.180 to 0.258	Little to no association
Cadmium (Cd)	concentration in Air → Blood	-0,172	Weak	–0.377 to 0.050	Weak, imprecise association

Source: Primary Data, 2024 (Statistical Test Results using the Mann-Whitney Test).

blood Cd levels than older children (7–12 years). This may be explained by immature detoxification mechanisms, such as reduced metallothionein-binding capacity and limited renal, excretion in early life (11). In addition, younger children are more likely to engage in hand-to-mouth behaviors and spend longer periods close to the ground level, where resuspended road dust is concentrated. Over time, Cd is redistributed and accumulates in tissues such as the kidney and liver, resulting in declining blood concentrations with age, despite an increasing cumulative body burden. The measured blood Pb concentrations in this study (mean 0.32 ng/mL, range 0.05–0.87 ng/mL) were below the WHO reference threshold of 5 μg/dL, but approximately 10% of the children exceeded this level. This is concerning given that no safe threshold exists for Pb in children, and even low levels of exposure have been associated with impaired neurocognitive development, reduced IQ, and behavioral problems (2). Cd blood concentrations were also within the range reported in other low- and middle-income countries; however, their presence in all participants underscores the widespread nature of environmental exposure. The lack of significant sex differences is consistent with prior studies, suggesting that toxicokinetic differences between boys and girls are minimal before puberty (12). The inclusion of pubertal status in our analysis further supports the finding that age, rather than sex or pubertal stage, is a stronger determinant of heavy metal burden in this population.

Strengths and Limitations

This study is among the first in Indonesia to investigate heavy metal exposure in street children, a highly vulnerable population. The combined measurement of air and blood samples provides a more comprehensive assessment of exposure. However, several limitations of this study should be noted. Air sampling was limited to six sites and may not represent the long-term exposure variability. Blood biomarkers reflect recent exposure rather than cumulative exposure, potentially underestimating the total body burden. Moreover, detailed dietary intake data, soil ingestion, and household exposure factors were not collected, which may have introduced unmeasured confounding factors.

Public Health Implications

Despite these limitations, our findings highlight the need for urgent public health interventions. Strategies should include reducing traffic-related emissions, providing nutritional support to reduce susceptibility to heavy metal absorption, and improving healthcare access for street children.

Conclusion

This study demonstrated that street children living in high-traffic areas of Makassar City, Indonesia, are consistently exposed to cadmium (Cd) and lead (Pb). Although the correlations between air and blood concentrations were weak, younger children showed moderately higher blood Cd levels, indicating increased vulnerability. While most blood Cd and Pb levels remained within the international reference ranges, the presence of elevated concentrations in some children highlights potential health risks. These findings emphasize the urgent need for public health interventions, including traffic emission control, nutritional support, and improved healthcare access to protect this highly vulnerable population.

Acknowledgments: Further studies should incorporate long-term biomarkers (e.g., hair, urine, or bone), detailed dietary surveys, and multivariate analyses to better elucidate the contributions of multiple exposure pathways.

Ethic Approval: The authors thank all parties who have participated in the research. This study was conducted by ethical recommendations and with approval, with financial support number: [1474/UN4.14.1/TP.01.02/2024].

Conflict of Interest: The author declares that there is no conflict of interests regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancy have been completely observed by the authors.

Author's Contribution: AD: Conceptualization; Formal analysis; Investigation; Writing Original draft; Writing Review and Editing; Visualization. AM: Supervision; Methodology; Data curation; Writing Review and Editing. NJ and AZ : Methodology; Supervision; Writing Review and Editing. AW: Supervision; Writing Review and Editing. AS and AJ: Supervision; Writing Review and Editing. KD: Investigation ang Formal analysis. KP and AA: Resources.

Declaration on the Use of AI: The author employed an artificial intelligence (AI) tool, namely ChatGPT, solely for the purposes of translation and linguistic refinement. No AI tools were utilised in the generation of original scientific content, data analysis, or interpretation of findings.

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