







Occupational Cadmium Exposure in Landfill Waste Pickers: Evidence from Urinary Biomonitoring and Implications for Occupational Health

Yunita Panca Putri¹, Daniel Saputra², Suheryanto³, Irfannuddin^{4*}

¹ Doctoral Program of Environmental Science, Postgraduate Program, Sriwijaya University, Palembang 30139, Indonesia

² Department of Agricultural Engineering, Faculty of Agriculture, Sriwijaya University, Ogan Ilir 30662, Indonesia

³ Department of Chemistry, Faculty of Mathematics and Natural Sciences, Sriwijaya University, Ogan Ilir 30662, Indonesia

⁴ Department of Physiology, Faculty of Medicine, Sriwijaya University, Palembang 30139, Indonesia

Corresponding Author Email: irfan.md@unsri.ac.id

Copyright: ©2026 The authors. This article is published by IETA and is licensed under the CC BY 4.0 license (<http://creativecommons.org/licenses/by/4.0/>).

<https://doi.org/10.18280/ijse.160117>

ABSTRACT

Received: 10 November 2025

Revised: 12 January 2026

Accepted: 24 January 2026

Available online: 31 January 2026

Keywords:

cadmium biomonitoring, informal waste workers, heavy metal exposure, urinary biomarkers, occupational exposure assessment, landfill contamination

Waste pickers represent a highly vulnerable group of informal workers who are frequently exposed to hazardous substances in landfill environments, including cadmium (Cd), a persistent toxic metal with a long biological half-life and strong renal accumulation. This cross-sectional study assessed urinary cadmium levels and speciation among waste pickers working at the Sukawinatan landfill in Palembang, Indonesia, and examined sociodemographic, occupational, and behavioral factors associated with exposure. A total of 46 waste pickers participated in the study. Information on personal characteristics, work history, hygiene practices, and use of personal protective equipment was collected through structured questionnaires and physical examination. Spot urine samples were analyzed for total cadmium using atomic absorption spectrophotometry (AAS), while inorganic and organic cadmium fractions were determined spectrophotometrically. The results indicated that 47.8% of participants had urinary cadmium concentrations exceeding the recommended reference value of $\leq 0.05 \text{ mg L}^{-1}$ established by the Agency for Toxic Substances and Disease Registry (ATSDR). Speciation analysis showed that inorganic cadmium (Cd^{2+}) accounted for a mean proportion of 39.8% of total urinary cadmium, with substantial inter-individual variability (range: 9.53–86.58%). Notably, 28.3% of waste pickers exhibited an inorganic cadmium fraction equal to or greater than 50% of total urinary cadmium, suggesting considerable differences in internal exposure profiles that are not reflected by total cadmium levels alone. Although no statistically significant associations were identified, longer work duration (≥ 10 years) was associated with a lower likelihood of elevated urinary Cd levels (OR = 0.33; 95% CI: 0.08–1.35), whereas poor hygiene practices (OR = 3.23; 95% CI: 0.48–21.74) and inconsistent use of personal protective equipment (OR = 1.75; 95% CI: 0.31–9.88) were associated with increased exposure risk. These findings highlight the need for improved occupational safety measures, routine biomonitoring programs, and targeted health surveillance to reduce long-term toxic metal exposure among informal waste workers.

1. INTRODUCTION

Occupational exposure to heavy metals remains a critical concern in environmental and occupational health, particularly in informal work settings where regulatory oversight and protective measures are limited. Cadmium (Cd) is recognized as a priority occupational pollutant due to its environmental persistence, strong bioaccumulative properties, and high toxicity at relatively low exposure levels [1]. Chronic Cd exposure has been consistently associated with adverse health outcomes, including renal dysfunction, bone demineralization, hypertension, and increased cancer risk [2–4]. Accordingly, the World Health Organization (WHO) has classified Cd as a human carcinogen, emphasizing the importance of monitoring occupational exposure and implementing effective risk control measures [5, 6].

Occupational activities constitute one of the primary pathways of Cd exposure in humans [7]. Existing biomonitoring studies using urinary Cd have predominantly focused on formal workers in well-recognized high-risk industries such as battery manufacturing, metal processing, mining, and welding [8, 9]. However, informal workers, particularly waste pickers operating at municipal landfill sites, may experience comparable or even greater exposure risks due to continuous contact with mixed solid waste, contaminated soil, leachate, and airborne particulates. These conditions facilitate multiple routes of Cd entry, including ingestion, inhalation, and dermal absorption [3, 4, 10, 11]. Despite this vulnerability, waste pickers are often excluded from occupational health surveillance programs, resulting in limited evidence regarding their exposure burden and occupational health risks.

In the Indonesian context, urban waste management is still predominantly based on landfill systems, including open dumping practices, which may increase environmental exposure to hazardous substances [12]. Waste pickers play a significant role in material recovery and waste reduction; however, most of them work within the informal sector without adequate occupational health protection. This condition, combined with limited regulatory oversight and environmental monitoring, increases the risk of exposure to heavy metals such as cadmium [13]. To date, biomonitoring data regarding metal exposure among this population remain very limited. Therefore, investigating internal cadmium exposure and its associated risk factors is essential to strengthen the scientific basis for occupational health policy development and to enhance preventive strategies in landfill environments.

Urinary cadmium concentration is widely accepted as a reliable biomarker for assessing cumulative occupational Cd exposure and long-term body burden, reflecting renal accumulation over time [14-16]. Previous studies have demonstrated that prolonged occupational exposure to Cd contributes to the progressive decline of kidney function, even at relatively low environmental concentrations [17]. Nevertheless, most occupational biomonitoring studies rely solely on total urinary Cd measurements, which do not distinguish between different chemical forms of Cd that vary in toxicity and exposure origin.

Analysis of urinary Cd that differentiates between its inorganic and organic fractions provides a more comprehensive approach to evaluating exposure. The inorganic fraction is generally associated with occupational exposure and exhibits higher toxicological potency, whereas the organic fraction is predominantly linked to dietary intake [3]. Despite its relevance for occupational risk assessment, urinary Cd speciation has rarely been applied in studies involving informal workers, including waste pickers, whose exposure pathways differ substantially from those of industrial workers. To date, biomonitoring data on metal exposure among this population remain scarce.

Therefore, this study aimed to evaluate occupational Cd exposure among waste pickers at a municipal landfill in Palembang, Indonesia, using urinary biomonitoring. Specifically, the objectives were to (i) quantify total urinary Cd concentrations, (ii) characterize the distribution of inorganic and organic Cd fractions in urine, and (iii) examine the association between urinary Cd levels and selected sociodemographic, clinical, behavioral, and occupational factors. By integrating urinary biomonitoring with occupational health indicators, this study provides novel insights into Cd exposure patterns and their potential health implications among waste pickers, contributing to evidence-based occupational health risk assessment and prevention strategies in informal work environments.

2. MATERIALS AND METHODS

2.1 Study design and setting

This study employed a quantitative descriptive approach with a cross-sectional design. The research was conducted at the Sukawinatan Landfill in Palembang, Indonesia, which operates under an open dumping system without waste segregation. Data collection took place from August to

2.2 Population and sample

The study population comprised all waste pickers working at the Sukawinatan Landfill, Palembang, Indonesia. Eligible participants were waste pickers who were actively working at the landfill during the study period and who agreed to participate by providing written informed consent, completing interviews and questionnaires, and submitting a urine sample. Waste pickers with a history of kidney disease and pregnant female waste pickers were excluded from the study to minimize potential confounding related to renal function and physiological conditions.

2.3 Sample size considerations

Sample size determination was based on a prevalence-based calculation using an estimated prevalence of impaired kidney function of 12.5% and a 95% confidence level. To account for potential nonresponse, an additional 10% was added to the calculated sample size. Based on this estimation, a minimum of 46 respondents was required. Purposive sampling was employed to recruit participants who met the inclusion criteria and were available during the data collection period. This non-probabilistic approach was chosen to ensure inclusion of individuals actively engaged in waste picking activities at the Sukawinatan landfill, who were most likely to be exposed to cadmium. Although this method may limit the generalizability of the findings to the broader population of waste pickers, it enabled a focused assessment of occupational exposure in high-risk subgroups while maintaining study feasibility and relevance.

2.4 Data collection

Data were collected in September 2024 to support occupational risk assessment of cadmium exposure at the landfill. Structured questionnaires were used to obtain information on sociodemographic characteristics, occupational conditions (work duration and use of personal protective equipment (PPE)), and safety-related behaviors, including smoking and personal hygiene, to identify determinants of exposure risk.

2.5 Urine sample collection and preparation

First morning urine samples (50–100 mL) were collected using sterile, clean, and tightly sealed polypropylene containers to minimize external contamination. Each container was labeled with a unique identification code containing the participant's age, sex, and sample type to ensure traceability and prevent misidentification. First morning urine was selected because it is more stable and concentrated, thereby reducing diurnal variation [18].

Immediately after collection, the samples were preserved by adding 10 drops of concentrated nitric acid (HNO₃) to each 50–100 mL sample, followed by gentle homogenization. Acidification was performed to prevent metal adsorption onto the container walls and to inhibit microbial activity that could affect metal stability. The samples were then transported to the laboratory under controlled conditions and stored at 4°C until analysis, following standard procedures [19].

2.6 Measurement of inorganic and organic cadmium in urine

Total cadmium determination in urine was conducted using a Shimadzu AA7000 atomic absorption spectrophotometry (AAS) at a resonance line of 228.8 nm. This method has been validated with a recovery rate of 103.44%, a limit of detection (LOD) of 0.0029 mg L⁻¹, a linear range (LR) of 0.50–2.00 mg L⁻¹, and a relative standard deviation (RSD) of 0.84% (Horwitz CV). Urinary cadmium levels were interpreted in reference to the toxicological guidance provided by the Agency for Toxic Substances and Disease Registry (ATSDR, 2012), which reports urinary concentrations of approximately ≤ 0.05 mg L⁻¹ as indicative of low-level exposure.

Inorganic cadmium in urine was determined using the Concentration Cell Potentiometry method. Two half-cell units containing CdSO₄·8H₂O standard solution and the sample were connected by a salt bridge filled with saturated KCl solution. Pure cadmium metal (99.95% purity, JT brand, ½” Round 9” Long Ingot, 9 oz) was used as both the indicator and reference electrodes. The electrodes were connected to a Hantek 365F multimeter for potential measurement. The Concentration Cell Potentiometry method has been validated with a recovery rate of 91.21%, a LOD of 0.0052 mg L⁻¹, a LR of 0.15 – 7.50 mg L⁻¹, and an RSD of 2.15% (Horwitz CV). Organic cadmium in urine samples was determined by calculating the difference between the total cadmium result from AAS and the inorganic cadmium result from the Concentration Cell Potentiometry method.

2.7 Data analysis

Data were processed and analyzed using Statistical Package for the Social Sciences (SPSS) version 22. Descriptive statistics were applied to summarize respondents’ characteristics and occupational exposure profiles, with categorical variables expressed as frequencies and percentages and numerical variables summarized using appropriate descriptive measures. Bivariate analysis using the Chi-square test was performed to examine the associations between urinary cadmium levels and occupational, behavioral, and work environment–related risk factors. A p-value of < 0.05 was considered statistically significant. This analytical approach aimed to identify key determinants of cadmium exposure and to support risk-based evaluation for the development of occupational safety and health control strategies in the landfill setting.

3. RESULTS

3.1 Sociodemographic and occupational characteristics

A total of 46 waste pickers were included in the analysis. Most waste pickers were of productive age (25–64 years, 87%) and predominantly female (58.7%). Educational attainment was generally low, with more than half of respondents having completed only primary school, while nearly one-fifth had no formal education.

In terms of occupational history, prolonged occupational exposure was common, as 76.1% of respondents had worked at the landfill for more than ten years. Although the majority reported Daily working hours of ≤ 8 hours, a considerable proportion (39.1%) worked for more than 8 hours per day.

Detailed characteristics of the waste pickers are summarized in Table 1.

Table 1. Sociodemographic, occupational, clinical, and behavioral characteristics of respondents (n = 46)

Variables and Categories	Frequency (n)	Percentage (%)
Age		
10–19 years	1	2
15–24 years	3	7
25–64 years	40	87
> 65 years	2	4
Sex		
Male	19	41.3
Female	27	58.7
Working duration		
≤ 10 years	11	23.9
> 10 years	35	76.1
Daily working duration		
≤ 8 hours	28	60.9
> 8 hours	18	39.1
Smoking history		
Yes	17	37
No	26	56.5
Former	3	6.5
Body weight		
≤ 40 kg	3	6.5
> 40 kg	43	93.5
Blood pressure		
Normal	32	69.6
High	11	23.9
Low	3	6.5
Blood glucose		
Normal	46	100
High	0	0
Educational level		
No formal education	9	19.6
Primary school	28	60.9
Junior school	4	8.7
Senior high school	5	10.9
Use of personal protective equipment (PPE)		
Complete	8	17.4
Incomplete	38	82.6
Personal hygiene		
Yes	41	89.1
No	5	10.9
Medication consumption		
Yes	11	23.9
No	35	76.1

Note: Percentages are based on the total sample (n = 46); age categories follow the WHO (2020) classification.

3.2 Clinical characteristics

Most waste pickers had a body weight above 40 kg (93.5%). Normal blood pressure was observed in the majority of waste pickers (69.6%), while elevated and low blood pressure were found in 23.9% and 6.5%, respectively. All waste pickers had normal blood glucose levels at the time of assessment. Regular medication use was reported by approximately one-quarter of respondents (23.9%) (Table 1).

3.3 Behavioral and occupational safety practices

From an occupational safety perspective, incomplete use of PPE was highly prevalent, affecting more than 80% of waste

pickers. Despite this, most waste pickers reported maintaining good personal hygiene practices (89.1%). Regarding behavioral factors, 37.0% of waste pickers reported a history of smoking, while 56.5% were non-smokers and 6.5% were former smokers. Regular medication consumption was reported by 23.9% of waste pickers (Table 1).

3.4 Urinary cadmium levels

Analysis of urine samples collected from 46 waste pickers showed that nearly half of the waste pickers had urinary Cd concentrations exceeding the recommended threshold value ($\leq 0.05 \text{ mg L}^{-1}$). Specifically, 47.8% of samples were above the guideline level, while the remaining 52.2% were below this threshold. The distribution of urinary Cd concentrations indicated considerable variability among respondents, with several samples exhibiting markedly elevated levels (Figure 1).

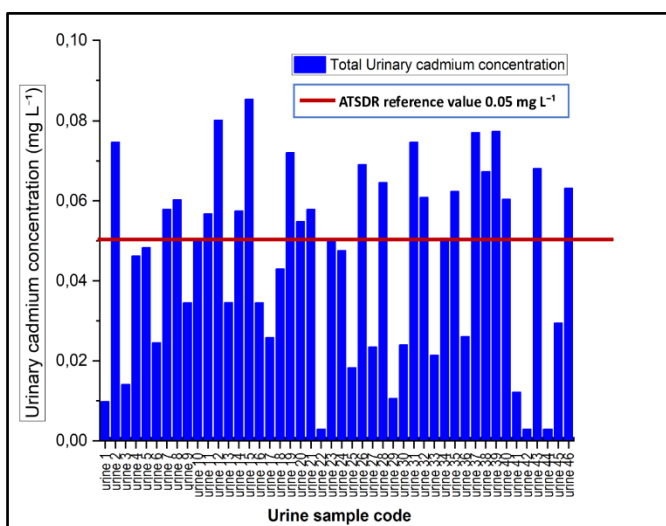


Figure 1. Total urinary cadmium (Cd) concentrations in urine samples collected from waste pickers at the Sukawinatan Landfill, Palembang, Indonesia. Concentrations are expressed in mg L^{-1}

3.5 Measurement of inorganic and organic cadmium in respondents' urine

Analysis of inorganic and organic cadmium measurements in urine demonstrated considerable variation in the relative proportions of these fractions across samples. The inorganic Cd fraction ranged from less than 10% to more than 80% of total urinary Cd. The mean proportion of inorganic Cd was 39.8%, with a median of 34.5% and an interquartile range (IQR) of 23.1%–58.6%. The overall distribution ranged from 9.53% to 86.58%, reflecting substantial inter-individual variability. The moderate difference between the mean and median suggests a slightly right-skewed distribution, indicating the presence of individuals with relatively high inorganic Cd proportions. Although the organic fraction predominated in most samples, although the organic fraction predominated in most samples, 28.3% of waste pickers exhibited elevated proportions of inorganic Cd, which is commonly associated with occupational exposure. The observed heterogeneity in Cd fraction distribution suggests the presence of multiple exposure pathways among waste pickers and underscores that the proportion of inorganic Cd

may have relevance in occupational health risk assessment beyond total cadmium concentration alone (Figure 2). Error bars in Figure 2 represent the SD and IQR for each fraction, providing a visual summary of the distribution of urinary cadmium among waste pickers.

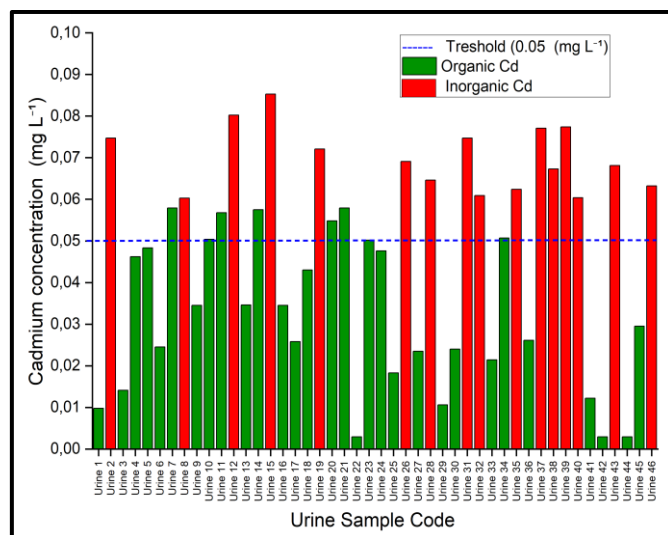


Figure 2. Measurement of inorganic and organic cadmium in waste pickers urine ($n = 46$). Mean \pm SD and interquartile range (IQR) are shown for each fraction

Table 2. Factors associated with urinary cadmium levels

Variable	Odds Ratio (95% CI)	P-Value
Age (10–19 / 15–24 years)	–	0.400
Sex (Male / Female)	1.28 (0.37–4.42)	0.702
Years of work (≤ 10 / > 10 years)	0.33 (0.08–1.35)	0.115
Daily work duration (≤ 8 / > 8 hours)	0.59 (0.17–2.14)	0.424
Smoking history (Yes / No)	–	0.829
Body weight (≤ 40 / > 40 kg)	1.07 (0.09–12.81)	0.957
Blood pressure (Normal / High)	–	0.402
Blood glucose	–	–
Education (No formal education / Primary School)	–	0.823
Use of PPE (Complete / Incomplete)	1.75 (0.31–9.88)	0.523
Personal hygiene (Good / Poor)	3.23 (0.48–21.74)	0.210
Medication use (Yes / No)	0.91 (0.22–3.75)	0.900

Note: CI = confidence interval; PPE = personal protective equipment. (odds ratio not estimated).

3.6 Factors associated with urinary cadmium levels

Bivariate analysis was conducted to examine the associations between waste pickers characteristics and urinary cadmium levels. Overall, no statistically significant associations were observed between urinary cadmium concentration and the examined sociodemographic, occupational, clinical, or behavioral variables ($p > 0.05$).

Nevertheless, several factors demonstrated notable trends. Waste pickers with longer working duration (> 10 years) showed a quantified lower likelihood of elevated urinary

cadmium levels (OR = 0.33; 95% CI: 0.08–1.35). In contrast, poor personal hygiene was associated with quantified higher odds of increased urinary cadmium concentration (OR = 3.23; 95% CI: 0.48–21.74), and incomplete use of PPE was also associated with quantified increased risk (OR = 1.75; 95% CI: 0.31–9.88).

Other variables, including sex, Daily working duration, smoking history, body weight, blood pressure, educational level, and medication use, did not show statistically significant associations with urinary cadmium levels in the bivariate analysis. Although no statistically significant associations were observed, the relatively small sample size may have limited the statistical power to detect modest but potentially meaningful effects. A summary of the associations is presented in Table 2.

4. DISCUSSION

This study provides a comprehensive assessment of Cd exposure among waste pickers at the Sukawinatan landfill using urinary biomarkers and evaluates the contribution of sociodemographic, occupational, clinical, and behavioral factors. The findings confirm that waste pickers constitute a vulnerable occupational group, characterized by prolonged exposure duration, limited protective measures, and measurable internal Cd burdens that are relevant to occupational health risk.

Most waste pickers were of productive age (25–64 years), indicating sustained engagement in informal waste-picking activities that may lead to cumulative Cd exposure over time [11, 20]. The higher participation of female workers aligns with evidence from informal waste sectors in developing countries, where economic necessity drives women's involvement in waste recovery activities [21]. However, the absence of a significant association between sex and urinary Cd levels suggests that exposure patterns are primarily determined by shared work tasks and environmental contact rather than sex-specific biological differences. Interestingly, longer working duration showed a tendency toward lower odds of elevated urinary Cd levels (OR = 0.33; 95% CI: 0.08–1.35), although the association was not statistically significant. This pattern may reflect a healthy worker effect, whereby individuals who remain in physically demanding informal occupations are generally healthier or more physiologically resilient. Poor personal hygiene was associated with increased odds of elevated urinary cadmium concentration (OR = 3.23; 95% CI: 0.48–21.74), and incomplete use of PPE was associated with increased risk (OR = 1.75; 95% CI: 0.31–9.88), highlighting occupational and behavioral factors that may contribute to Cd exposure despite the absence of statistically significant associations. Long-term exposure may also induce adaptive responses, including increased antioxidant enzyme activity and metallothionein synthesis, which can bind Cd and reduce its bioavailability [22]. In addition, experienced workers may gradually adopt informal protective behaviors that reduce direct contact with contaminated materials.

From a clinical perspective, most waste pickers had body weight above 40 kg, and nearly one-quarter were hypertensive. Chronic Cd exposure has been linked to elevated blood pressure through mechanisms involving oxidative stress, endothelial dysfunction, and renal impairment [23, 24]. Although no statistically significant association was observed

between blood pressure and urinary Cd levels in this study, nutritional status and adipose tissue may influence Cd distribution and retention, particularly in populations consuming high-fat diets [25, 26]. The absence of hyperglycemia among waste pickers suggests that Cd-related disturbances in glucose metabolism have not yet manifested, despite evidence linking chronic Cd exposure to diabetes risk [27–29]. This may also reflect selection bias, as individuals with severe chronic illness are less likely to remain active in waste-picking activities.

Low educational attainment was common among waste pickers, potentially limiting awareness of Cd-related hazards and appropriate preventive measures [30]. Although education level was not directly associated with urinary Cd concentration, it plays an important role in shaping risk perception, hygiene practices, and compliance with protective behaviors. Improving environmental health literacy among waste pickers may therefore contribute to reducing long-term exposure and associated health risks [31]. Biomonitoring results showed that nearly half of the respondents exceeded the recommended urinary Cd reference value, indicating substantial internal exposure and potential long-term health implications. Urinary Cd is a well-established biomarker of cumulative exposure and renal Cd burden due to its long biological half-life of 10–30 years [32, 33]. Given the daily contact of waste pickers with contaminated soil, leachate, and waste materials, these findings underscore the importance of regular health surveillance to detect early signs of Cd-related toxicity, particularly kidney dysfunction.

Further insight was obtained by differentiating inorganic and organic Cd fractions in urine, which revealed marked variability in the proportions of inorganic and organic Cd fractions. Although organic Cd predominated in most samples, suggesting dietary intake as an important exposure pathway, substantial inorganic Cd fractions were detected in a considerable number of waste pickers. Inorganic Cd is typically associated with occupational exposure and exhibits higher toxicity, as documented in high-risk industries such as battery manufacturing, welding, and electronic waste recycling [7, 11, 34]. The wide range of inorganic Cd proportions (< 10% to > 80%) highlights heterogeneous exposure pathways among waste pickers and emphasizes the importance of incorporating chemical speciation into occupational risk assessment and biomonitoring strategies [3, 35, 36].

Behavioral and occupational safety practices further contextualize these findings. Incomplete use of PPE was highly prevalent, consistent with reports from informal work settings where limited availability, discomfort, and low risk awareness reduce compliance [37]. Although most waste pickers reported good personal hygiene practices, a subset exhibited poor hygiene that may facilitate Cd intake through hand-to-mouth contact or contaminated food and water [38]. Medication use reported by some respondents suggests the presence of comorbidities that may modify individual susceptibility to Cd toxicity.

Daily working duration and smoking history were not significantly associated with urinary Cd levels. While prolonged working hours and tobacco use are recognized contributors to Cd exposure [39, 40], their effects in this population appear secondary to dominant exposure pathways such as contaminated food, soil, and leachate contact. This interpretation is supported by previous studies showing that Cd concentrations in landfill soil and leachate exceed

regulatory limits [41], whereas other measurements indicate that heavy metal concentrations in ambient air around the landfill are relatively low. These findings suggest that ingestion and dermal contact represent more influential exposure routes than inhalation in this setting.

The absence of statistically significant associations between urinary Cd levels and most examined variables should be interpreted with caution. The relatively small sample size may have reduced the statistical power of the study, limiting the ability to detect modest but potentially meaningful associations. In studies with limited sample sizes, non-significant findings do not necessarily indicate the absence of a true relationship, but may instead reflect insufficient power to reach statistical significance. Therefore, the observed trends, particularly those related to personal hygiene and PPE use, remain epidemiologically relevant and warrant further investigation in larger populations.

Overall, Cd exposure among waste pickers at the Sukawinatan landfill appears to be shaped by a combination of occupational practices, environmental contamination, and behavioral factors rather than by a single determinant. Although the cross-sectional design limits causal inference, the convergence of biomonitoring results, speciation data, and environmental measurements strengthens the relevance of the findings. The results highlight the urgent need for integrated occupational health interventions, including targeted education on Cd hazards, improved access to and use of PPE, and routine health monitoring with a focus on renal function, to reduce long-term health risks among waste pickers in landfill environments.

5. CONCLUSIONS

Urinary biomonitoring indicates that waste pickers at the Sukawinatan landfill experience measurable Cd exposure, with nearly half of the respondents exceeding the recommended urinary threshold. The cadmium fractions in urine were predominantly organic, indicating that dietary intake is likely the main source of exposure. However, the presence of relatively high proportions of inorganic Cd in some individuals also suggests a contribution from occupational activities. No strong evidence was found for an association between urinary Cd levels and most of the examined characteristics, possibly due to the limited sample size. Nevertheless, exposure patterns appear to be more strongly influenced by the level of environmental contamination and occupational practices rather than by individual factors alone. The high prevalence of incomplete use of PPE highlights a critical gap in occupational safety practices. These findings support the integration of biomonitoring, Cd speciation, and targeted occupational health interventions to reduce long-term Cd-related risks in landfill environments. In particular, practical measures such as ensuring access to and proper use of PPE, improving hygiene practices, and including waste pickers in routine occupational health surveillance are recommended to mitigate health risks effectively.

CONTRIBUTIONS

The first author conceptualized and designed the study, performed data analysis, and drafted the manuscript. The

second and third authors contributed to the development of the research protocol, supervised data collection, and critically reviewed the methodology and analytical results, and independently verified the entire data chain to ensure internal consistency of the manuscript. All authors participated in revising the manuscript, approved the final version, and take full responsibility for the accuracy and integrity of the data and content presented.

ACKNOWLEDGMENT

We would like to express our sincere gratitude to all parties involved in this research, including Palembang City Environmental Agency, Sukawinatan Landfill Office, Mohammad Hoesin Hospital Palembang, and the Chemical Analysis and Instrumentation Testing Laboratory, Faculty of Mathematics and Natural Sciences, University Sriwijaya, and our academic supervisor from University Sriwijaya, for their valuable support and contributions throughout the study.

ETHICAL CONSIDERATIONS

This study was approved by the Research Ethics Committee of the Ministry of Health, Mohammad Hoesin General Hospital, Palembang, Indonesia (No. DP.04.03/D.XVIII.06.08/ETIK/235/2024). Written informed consent was obtained from all participants prior to data collection. The confidentiality of participants identities was strictly maintained throughout the study.

REFERENCES

- [1] Qu, F., Zheng, W. (2024). Cadmium exposure: Mechanisms and pathways of toxicity and implications for human health. *Toxics*, 12(6): 388. <https://doi.org/10.3390/toxics12060388>
- [2] Charkiewicz, A.E., Omeljaniuk, W.J., Nowak, K., Garley, M., Nikliński, J. (2023). Cadmium toxicity and health effects—A brief summary. *Molecules*, 28(18): 6620. <https://doi.org/10.3390/molecules28186620>
- [3] Peana, M., Pelucelli, A., Chasapis, C.T., Perlepes, S.P., Bekiari, V., Medici, S., Zoroddu, M.A. (2022). Biological effects of human exposure to environmental cadmium. *Biomolecules*, 13(1): 36. <https://doi.org/10.3390/biom13010036>
- [4] Genchi, G., Sinicropi, M.S., Lauria, G., Carocci, A., Catalano, A. (2020). The effects of cadmium toxicity. *International Journal of Environmental Research and Public Health*, 17(11): 3782. <https://doi.org/10.3390/ijerph17113782>
- [5] Cirovic, A., Satarug, S. (2024). Toxicity tolerance in the carcinogenesis of environmental cadmium. *International Journal of Molecular Sciences*, 25(3): 1851. <https://doi.org/10.3390/ijms25031851>
- [6] Wang, M., Chen, Z., Song, W., Hong, D., Huang, L., Li, Y. (2021). A review on cadmium exposure in the population and intervention strategies against cadmium toxicity. *Bulletin of Environmental Contamination and Toxicology*, 106(1): 65-74. <https://doi.org/10.1007/s00128-020-03088-1>
- [7] Baloch, S., Kazi, T.G., Baig, J.A., Afridi, H.I., Arain,

- M.B. (2020). Occupational exposure of lead and cadmium on adolescent and adult workers of battery recycling and welding workshops: Adverse impact on health. *Science of the Total Environment*, 720: 137549. <https://doi.org/10.1016/j.scitotenv.2020.137549>
- [8] Zhang, X., Bold, T., Zhang, W., Zhao, Q., et al. (2024). Spatio-temporal distribution of cadmium levels in Chinese population and its potential risk factors. *Heliyon*, 10(7): e28879. <https://doi.org/10.1016/j.heliyon.2024.e28879>
- [9] Ferron, M.M., Kuno, R., Campos, A.E.M.D., Castro, F.J.V.D., Gouveia, N. (2020). Cadmio, plomo y mercurio en sangre de trabajadores de plantas de reciclaje en São Paulo, Brasil. *Cadernos de Saúde Pública*, 36: e00072119. <https://doi.org/10.1590/0102-311X00072119>
- [10] Schenck, C.J., Blaauw, P.F., Viljoen, J.M., Swart, E.C. (2019). Exploring the potential health risks faced by waste pickers on landfills in South Africa: A socio-ecological perspective. *International Journal of Environmental Research and Public Health*, 16(11): 2059. <https://doi.org/10.3390/ijerph16112059>
- [11] Putri, Y.P., Saputra, D. (2024). Preliminary study on the measurement of cadmium levels in scavenger hair at Sukawinatan landfill, Palembang. *Sainmatika: Jurnal Ilmiah Matematika dan Ilmu Pengetahuan Alam*, 21(2): 185-192. <https://doi.org/10.31851/sainmatika.v21i2.17058>
- [12] Ghosh, R., Hazra, T., Mukherjee, I., Ushcats, S., et al. (2024). Evaluating the environmental effects of open dumps and waste farming: A case study: Effects of open dumping. *Ecological Questions*, 35(4): 39-51. <https://doi.org/10.12775/EQ.2024.046>
- [13] Boudia, L., Rafatullah, M., Kerrouche, A., Qutob, M., Alosaimi, A.M., Alorfi, H.S., Hussein, M.A. (2022). A review on cadmium and lead contamination: Sources, fate, mechanism, health effects and remediation methods. *Water*, 14(21): 3432. <https://doi.org/10.3390/w14213432>
- [14] Luo, J., Hendryx, M. (2020). Metal mixtures and kidney function: An application of machine learning to NHANES data. *Environmental Research*, 191: 110126. <https://doi.org/10.1016/j.envres.2020.110126>
- [15] Filippini, T., Torres, D., Lopes, C., Carvalho, C., et al. (2020). Cadmium exposure and risk of breast cancer: A dose-response meta-analysis of cohort studies. *Environment International*, 142: 105879. <https://doi.org/10.1016/j.envint.2020.105879>
- [16] Zhao, D., Wang, P., Zhao, F.J. (2023). Dietary cadmium exposure, risks to human health and mitigation strategies. *Critical Reviews in Environmental Science and Technology*, 53(8): 939-963. <https://doi.org/10.1080/10643389.2022.2099192>
- [17] Abbasabadi, M.K., Shirkhanloo, H. (2020). Speciation of cadmium in human blood samples based on Fe₃O₄-supported naphthalene-1-thiol-functionalized graphene oxide nanocomposite by ultrasound-assisted dispersive magnetic micro solid phase extraction. *Journal of Pharmaceutical and Biomedical Analysis*, 189: 113455. <https://doi.org/10.1016/j.jpba.2020.113455>
- [18] Sallsten, G., Barregard, L. (2021). Variability of urinary creatinine in healthy individuals. *International Journal of Environmental Research and Public Health*, 18(6): 3166. <https://doi.org/10.3390/ijerph18063166>
- [19] Wang, X., Gu, H., Palma-Duran, S.A., Fierro, A., et al. (2019). Influence of storage conditions and preservatives on metabolite fingerprints in urine. *Metabolites*, 9(10): 203. <https://doi.org/10.3390/metabo9100203>
- [20] Godwin, A.S., Brown, H., Nwachuku, E.O. (2020). Assessment of some heavy metals and iron parameters amongst dumpsite scavengers in Port Harcourt, Nigeria. *Journal of Advances in Medical and Pharmaceutical Sciences*, 22(11): 31-41. <https://doi.org/10.9734/JAMPS/2020/v22i1130203>
- [21] HO, S. (2024). The impact of gender-inclusive practices on solid waste management in household economic. *Asian Journal of Advanced Research and Reports Учредители: Sciencedomain International*, 18(12): 34-43. <https://doi.org/10.9734/ajarr/2024/v18i12804>
- [22] Paithankar, J.G., Saini, S., Dwivedi, S., Sharma, A., Chowdhuri, D.K. (2021). Heavy metal associated health hazards: An interplay of oxidative stress and signal transduction. *Chemosphere*, 262: 128350. <https://doi.org/10.1016/j.chemosphere.2020.128350>
- [23] Verzelloni, P., Giuliano, V., Wise, L.A., Urbano, T., Baraldi, C., Vinceti, M., Filippini, T. (2024). Cadmium exposure and risk of hypertension: A systematic review and dose-response meta-analysis. *Environmental research*, 263: 120014. <https://doi.org/10.1016/j.envres.2024.120014>
- [24] Martins, A.C., Lopes, A.C.B.A., Urbano, M.R., Carvalho, M.D.F.H., et al. (2021). An updated systematic review on the association between Cd exposure, blood pressure and hypertension. *Ecotoxicology and Environmental Safety*, 208: 111636. <https://doi.org/10.1016/j.ecoenv.2020.111636>
- [25] Mazzocco, J.C., Jagadapillai, R., Gozal, E., Kong, M., Xu, Q., Barnes, G.N., Freedman, J.H. (2020). Disruption of essential metal homeostasis in the brain by cadmium and high-fat diet. *Toxicology Reports*, 7: 1164-1169. <https://doi.org/10.1016/j.toxrep.2020.08.005>
- [26] Satarug, S. (2025). Urinary β 2-microglobulin predicts the risk of hypertension in populations chronically exposed to environmental cadmium. *Journal of Xenobiotics*, 15(2): 49. <https://doi.org/10.3390/jox15020049>
- [27] Xiao, L., Li, W., Zhu, C., Yang, S., et al. (2021). Cadmium exposure, fasting blood glucose changes, and type 2 diabetes mellitus: A longitudinal prospective study in China. *Environmental Research*, 192: 110259. <https://doi.org/10.1016/j.envres.2020.110259>
- [28] Wang, Z., Sun, Y., Yao, W., Ba, Q., Wang, H. (2021). Effects of cadmium exposure on the immune system and immunoregulation. *Frontiers in Immunology*, 12: 695484. <https://doi.org/10.3389/fimmu.2021.695484>
- [29] Buha, A., Đukić-Ćosić, D., Čurčić, M., Bulat, Z., et al. (2020). Emerging links between cadmium exposure and insulin resistance: Human, animal, and cell study data. *Toxics*, 8(3): 63. <https://doi.org/10.3390/toxics8030063>
- [30] Maghchiche, A., Meghchiche, N. (2024). Current awareness and knowledge of heavy metals: A short review. *African Journal of Environmental Sciences and Renewable Energy*, 16(1): 17-29. <https://doi.org/10.62154/ajesre.2024.016.010373>
- [31] Gray, K.M., Triana, V., Lindsey, M., Richmond, B., Hoover, A.G., Wiesen, C. (2021). Knowledge and beliefs associated with environmental health literacy: A case study focused on toxic metals contamination of well

- water. *International Journal of Environmental Research and Public Health*, 18(17): 9298. <https://doi.org/10.3390/ijerph18179298>
- [32] Zeng, T., Liang, Y., Chen, J., Cao, G., et al. (2021). Urinary metabolic characterization with nephrotoxicity for residents under cadmium exposure. *Environment International*, 154: 106646. <https://doi.org/10.1016/j.envint.2021.106646>
- [33] Parvez, S.M., Jahan, F., Abedin, J., Rahman, M., et al. (2024). Blood lead, cadmium and hair mercury concentrations and association with soil, dust and occupational factors in e-waste recycling workers in Bangladesh. *International Journal of Hygiene and Environmental Health*, 257: 114340. <https://doi.org/10.1016/j.ijheh.2024.114340>
- [34] Martinez-Morata, I., Sobel, M., Tellez-Plaza, M., Navas-Acien, A., Howe, C.G., Sanchez, T.R. (2023). A state-of-the-science review on metal biomarkers. *Current Environmental Health Reports*, 10(3): 215-249. <https://doi.org/10.1007/s40572-023-00402-x>
- [35] Ebekozien, A., Aigbavboa, C., Ahmed, M.A.H., Thwala, W.D., et al. (2025). Investigating personal protective equipment awareness of artisans in the informal sector: Issues and measures to improve achieving SDG 3. *International Journal of Building Pathology and Adaptation*, 43(8): 59-74. <https://doi.org/10.1108/IJBPA-04-2024-0083>
- [36] Lompo, P., Heroes, A.S., Ouédraogo, K., Okitale, P., et al. (2024). Knowledge, awareness, and risk practices related to bacterial contamination of antiseptics, disinfectants, and hand hygiene products among healthcare workers in sub-saharan Africa: A cross-sectional survey in three tertiary care hospitals (Benin, Burkina Faso, and DR Congo). *Antimicrobial Resistance & Infection Control*, 13(1): 44. <https://doi.org/10.1186/s13756-024-01396-3>
- [37] Li, X., Yu, Y., Zheng, N., Wang, S., et al. (2021). Exposure of street sweepers to cadmium, lead, and arsenic in dust based on variable exposure duration in zinc smelting district, Northeast China. *Chemosphere*, 272: 129850. <https://doi.org/10.1016/j.chemosphere.2021.129850>
- [38] Wróblewski, K., Wojnicka, J., Tutka, P., Szmagara, A., Błażewicz, A. (2024). Measurements of cadmium levels in relation to tobacco dependence and as a function of cytosine administration. *Scientific Reports*, 14(1): 1883. <https://doi.org/10.1038/s41598-024-52234-w>
- [39] Fatmawati, F., Muhlis, M., Larekeng, S.H., Ibrahim, R., Rahim, I. (2025). Analysis of heavy metal content and isolation of indigenous bacteria with potential as bioremediation agents in leachate at Tamangapa landfill, Makassar City. *BIO Web of Conferences*, 180: 02005. <https://doi.org/10.1051/bioconf/202518002005>
- [40] Hussein, M., Yoneda, K., Mohd-Zaki, Z., Amir, A., Othman, N. (2021). Heavy metals in leachate, impacted soils and natural soils of different landfills in Malaysia: An alarming threat. *Chemosphere*, 267: 128874. <https://doi.org/10.1016/j.chemosphere.2020.128874>
- [41] Budihardjo, M.A., Noveandra, K., Samadikun, B.P. (2018). Characteristic of total suspended particulate (TSP) containing Pb and Zn at solid waste landfill. *Journal of Physics: Conference Series*, 102(1): 012030. <https://doi.org/10.1088/1742-6596/1022/1/012030>