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Regional Case Study

Hair Mercury Concentrations among Residents Living Near Artisanal and Small-Scale Gold Mining Activities in Indonesia

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Abstract

Mercury use in artisanal and small-scale gold mining (ASGM) remains a major public health concern in Indonesia. This cross-sectional biomonitoring study examined the factors associated with mercury exposure among 50 adults living near ASGM activities in the Bungo District. The interview data covered sociodemographic, occupational, behavioral, and exposure-related factors, while hair mercury concentrations were measured using inductively coupled plasma mass spectrometry. Descriptive analyses, bivariate logistic screening, and multivariable logistic regression with backward stepwise selection were performed. In the final model, non-mining participants had lower odds of higher mercury exposure than mining-related workers (OR = 0.164; 95% CI: 0.030–0.892; P = 0.036). Adults aged ≥45 years had lower odds than those aged 21–44 years (OR = 0.097; 95% CI: 0.020–0.474; p = 0.004), whereas women had higher odds than men (OR = 8.032; 95% CI: 1.586–40.675; p = 0.012). The model showed moderate explanatory performance (Nagelkerke R^2 = 0.414) and 78.0% accuracy. These findings indicate higher exposure among younger adults, women, and mining-related workers, supporting targeted biomonitoring, occupational risk reduction, and community-based interventions in areas affected by ASGM.

Keywords: Artisanal and small-scale gold mining; hair mercury; human biomonitoring; mercury exposure; public health

1. Introduction

Artisanal and small-scale gold mining (ASGM) is one of the largest global sources of anthropogenic mercury emissions and remains a major environmental and public health concern, particularly in low- and middle-income countries (Soe et al., 2022). Mercury is widely used in ASGM because it is inexpensive and highly effective in gold amalgamation; however, poorly controlled handling and disposal practices often lead to chronic environmental contamination and human exposure (Saim 2021). Communities living near mining sites may be exposed to multiple pathways, including occupational contact, inhalation of mercury vapor, contaminated household environments, and dietary intake of aquatic products (Basu, 2023; Gibb and O'Leary, 2014). Chronic mercury exposure is associated with a range of adverse health outcomes, including neurological, renal, cardiovascular, and developmental effects (Chamoli and Karn, 2024; Wu et al., 2024). In ASGM settings, mercury exposure should be understood not only as an occupational hazard affecting miners but also as a broader environmental health issue affecting surrounding communities.

Previous studies in ASGM areas have largely focused on environmental contamination in sediment, soil, water, and fish, or on biological monitoring among miners using hair, blood, or urine samples (McLagan et al., 2025; Mulenga et al., 2024; Saim, 2021; Basu et al., 2018; Castaño et al., 2019). Hair mercury concentration is widely regarded as a useful marker of long-term exposure because mercury incorporated into keratin reflects the cumulative internal exposure over time (Branco et al., 2017; Warret Rodrigues et al., 2025). Studies on ASGM communities in several countries have reported elevated hair mercury concentrations, particularly among individuals directly involved in amalgamation and gold-processing activities (Gibb and O'Leary, 2014; Harianja et al., 2025; Saim, 2021). Simultaneously, increasing attention has been paid to non-occupational exposure pathways, including fish consumption and indirect environmental exposure among residents not directly engaged in mining.

Despite growing concerns about mercury exposure in ASGM regions, important knowledge gaps remain, particularly in Indonesian mining communities. Much of the existing literature has emphasized either environmental contamination or occupational exposure among miners, with less attention paid to the broader determinants of mercury accumulation among residential populations. Consequently, the interplay among demographic characteristics, occupational activities, behavioral factors, environmental proximity, and exposure awareness remains insufficiently understood. In addition, relatively few studies have attempted to assess the cumulative exposure burden arising from multiple coexisting risk factors within a single human biomonitoring framework. A better understanding of exposure heterogeneity among mining and non-mining populations is essential for identifying vulnerable subgroups and strengthening environmental health surveillance in ASGM settings.

Accordingly, this study examined the factors associated with a binary mercury exposure classification derived from hair mercury measurements among residents living near ASGM activities in the Bungo District, Indonesia, using a human biomonitoring approach. The analysis considered demographic, occupational, behavioral, and exposure-related variables and evaluated their independent contributions using multivariable logistic regression. The findings of this study are intended to inform biomonitoring strategies and public health interventions aimed at reducing mercury exposure in ASGM communities.

2. Literature Review

Recent literature has shown that mercury exposure in ASGM settings is not limited to miners directly handling amalgam but is produced through overlapping occupational, environmental, and dietary pathways. Global and regional syntheses continue to identify ASGM as the largest source of anthropogenic mercury emissions, with releases into air, soil, and water creating persistent exposure risks for workers and nearby residents. More recent reviews have also emphasized that exposure in mining communities is socially patterned: risk is shaped not only by job category but also by task allocation, household processing practices, food systems, informal work arrangements, and limited risk awareness. In practical terms, this means that the mercury burden in ASGM communities should be conceptualized as a community-wide exposure gradient rather than a narrowly occupational problem.

Within this literature, hair mercury remains one of the most practical biomarkers for population-level assessment because it captures cumulative exposure over time and is feasible for field-based human biomonitoring in low-resource settings. However, the interpretation of hair mercury levels in ASGM areas requires caution. While total mercury in hair is strongly informative for chronic methylmercury exposure through diet, ASGM communities may simultaneously experience inhalational exposure to elemental mercury vapor and indirect contamination from dust or household processing residues. Recent biomonitoring work supports the utility of hair mercury for public health surveillance in mining-affected populations, especially when the objective is to characterize exposure heterogeneity across communities rather than diagnose acute intoxication at the individual level. This is particularly important in settings where urine and blood biomarkers are less feasible, more invasive, or capture shorter exposure periods.

However, the evidence base remains uneven. Much of the ASGM literature has either prioritized environmental contamination mapping or focused narrowly on miners, leaving residential populations under-characterized and multivariate analyses of exposure determinants relatively limited. This gap is particularly relevant in Indonesia, where ASGM is geographically widespread, often informal, and frequently embedded in settlements where occupational and domestic exposure zones overlap. Emerging Indonesian studies confirm substantial environmental and health threats, but they also indicate that exposure cannot be inferred from proximity alone and may differ by occupation, gender roles, age structure, and behavioral practices. Therefore, a sharper analytical approach is needed—one that moves beyond descriptive contamination reporting to evaluate which factors independently distinguish higher-exposure subgroups within mining-affected communities. On this basis, the present study used hair mercury biomonitoring and multivariable logistic modelling to identify the demographic, occupational, behavioral, and exposure-related correlates of higher mercury exposure among residents living near ASGM activities in the Bungo District.

3. Materials and Methods

3.1 Study Design and Study Area

This study used a cross-sectional human biomonitoring design to examine mercury exposure among residents living near ASGM activities in the Bungo District of Jambi Province, Indonesia. ASGM has been practiced in this area since the 1990s, and mercury is still used in the amalgamation process. Mining activities are distributed along river systems and near residential areas, creating the potential for chronic occupational and environmental exposure in nearby populations. This study focused on demographic, occupational, behavioral, and environmental factors that may be related to mercury accumulation, as assessed through hair mercury biomonitoring.

3.2 Study Population and Sampling

The study population comprised adult residents living in communities near ASGM activities in the Bungo District. Participants were recruited using purposive sampling based on their residential proximity to mining activities and willingness to participate in the study. Individuals aged ≥ 21 years who had lived in the study area for at least two years were considered eligible for inclusion. Participants with incomplete questionnaire data or insufficient biological samples were excluded from the analysis. A total of 50 participants were included in the final study sample.

3.3 Questionnaire and Exposure Assessment

Sociodemographic and exposure-related information were collected through structured face-to-face interviews using standardized questionnaires administered by trained researchers. The variables assessed in this study included age, sex, educational level, occupation, body mass index (BMI), frequency of fish consumption, residential distance from mining activities, and knowledge of mercury exposure and its health effects. Occupational status was classified as mining-related or non-mining related. Fish consumption frequency was categorized as low (≤2 times/week) or high (>2 times/week), and residential proximity was categorized as <4 km or ≥4 km from the mining areas. Knowledge of mercury exposure was scored based on questionnaire responses and then classified into poor and good knowledge categories. To capture the cumulative exposure burden, a composite exposure-risk score was constructed from four exposure-related factors: mining-related occupation, frequent fish consumption, residential proximity to mining areas, and limited mercury-related knowledge. Each factor contributes one point to the cumulative score.

3.4 Hair Sample Collection and Mercury Analysis

Hair samples were collected from the occipital region of the scalp using stainless-steel scissors. Approximately 1–2 cm of hair closest to the scalp was collected from each participant to reflect recent and chronic mercury exposure. Hair samples were stored in clean polyethylene containers before laboratory analysis. The samples were washed and prepared following standard laboratory procedures to minimize external contamination. The total mercury concentration in hair samples was analyzed using inductively coupled plasma mass spectrometry (ICP-MS). Mercury concentrations were expressed in milligrams per kilogram of hair (mg/kg). Hair mercury concentration was used as a biomarker of long-term mercury exposure because mercury is incorporated into keratin during hair formation and reflects cumulative systemic exposure over time. For descriptive presentation, participants were also summarized according to the World Health Organization (WHO) reference threshold of 2 mg/kg; however, the regression analysis used the binary mercury exposure classification defined in the analytic dataset.

3.5 Statistical Analysis

Data analysis was performed using the IBM SPSS Statistics software. Descriptive statistics were used to summarize the participant characteristics and hair mercury concentrations. Continuous variables are expressed as mean ± standard deviation (SD), whereas categorical variables are presented as frequencies and percentages. For regression modelling, the primary outcome was a binary mercury exposure classification derived from the analytic dataset (merkuri2), coded as 0 = lower-exposure group and 1 = higher-exposure group. To avoid confusion, this modeled outcome is referred to in this manuscript as the higher-exposure classification, whereas the continuous laboratory measurement is referred to as the hair mercury concentration. Based on the uploaded coding file, the principal coded predictors retained in the final model were interpreted as follows: age category (1 = 21–44 years; 2 = ≥45 years), sex (1 = male; 2 = female), and occupational category (1 = mining-related occupation, including miners and panners; 2 = non-mining occupations). Bivariate logistic screening was used to examine candidate predictors, including knowledge, occupation, education, residential distance, body mass index, age, urine findings, blood findings, sex, and fish consumption. The variables were then entered into a multivariable logistic regression model using backward stepwise likelihood ratio selection. The adjusted odds ratios (ORs), 95% confidence intervals (CIs), Wald statistics, model fit indices, and classification performance were extracted from the final model. Statistical significance was set at $p < 0.05$.

3.6 Ethical Considerations

This study was conducted in accordance with the ethical principles of research involving human participants. Ethical approval was obtained from the Health Research Ethics Committee of Rumah Sakit Mohammad Hoesin Palembang (No. DP.04.03/D.XVIII.06.08/ETIK/109/2025. Written informed consent was obtained from all participants prior to data collection, and the confidentiality of participant information was maintained throughout the study.

4. Results and Discussion

4.1 Participant Characteristics

The socio-demographic and exposure-related characteristics of the participants are summarized in Figure 1. Women accounted for a slightly larger proportion of the study population than men (54.0% vs. 46.0%). Although ASGM activities are often dominated by male workers, women living in mining communities may also be exposed to indirect environmental pathways, household-level gold processing, and dietary intake of contaminated aquatic products. Previous studies have shown that mercury exposure in ASGM settings frequently extends beyond occupationally exposed miners to include women and other residents of mining-affected communities (Gibb and O'Leary, 2014; Taux et al., 2022).

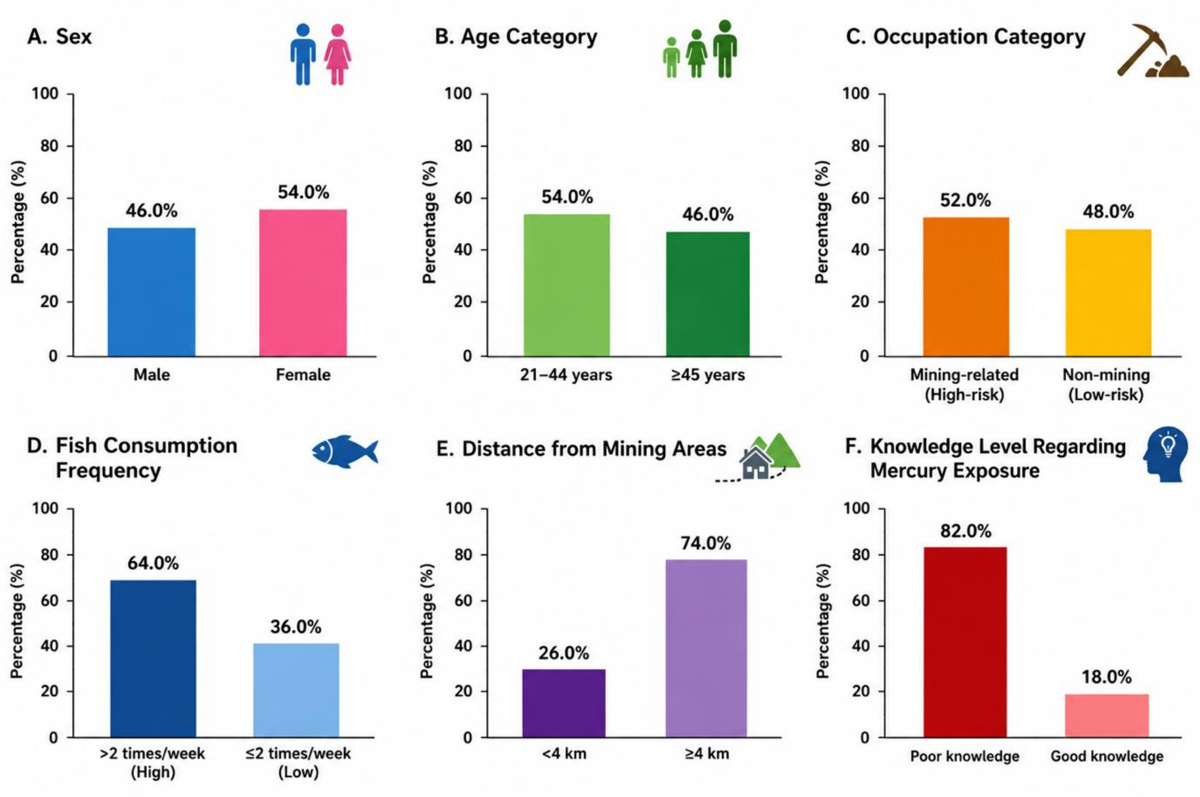

Figure 1. Sociodemographic and exposure characteristics of the study participants

Participants aged 21–44 years represented the largest group (54.0%). The predominance of productive-age adults may reflect greater involvement in mining-related activities, such as ore transport, amalgamation, and gold extraction, all of which may increase opportunities for repeated mercury exposure. Figure 1C shows that more than half of the participants (52.0%) were engaged in mining-related occupations categorized as higher-risk activities. Occupational exposure remains an important pathway for mercury accumulation in mining communities because elemental mercury vapor released during amalgamation and gold burning can be rapidly absorbed through the respiratory system (Bose-O'Reilly et al., 2008). Similar findings have been reported in other ASGM settings, where miners and ore-processing workers tend to have higher mercury biomarker concentrations than non-mining populations (Baeuml et al., 2011; Calao-Ramos et al., 2021).

Dietary exposure characteristics are presented in Figure 1D, which shows that 64.0% of the participants reported frequent fish consumption (>2 times/week). Fish consumption may represent an important non-occupational exposure pathway because mercury entering aquatic systems can be transformed into methylmercury, which subsequently bioaccumulates in fish and biomagnifies through the food chain (Calao-Ramos et al., 2021; Hong et al., 2012). Therefore, repeated consumption of contaminated fish may contribute to chronic low-dose mercury exposure among residents living near mining areas (Bank, 2012; Hong et al., 2012). Figure 1E also shows that 74.0% of the participants lived ≥4 km from active mining areas, whereas 26.0% lived closer. However, exposure-related vulnerabilities remained apparent, suggesting that mercury contamination may extend beyond immediate mining sites through atmospheric transport, contaminated dust, aquatic pathways, and household contamination.

Knowledge of mercury exposure and its potential health effects are shown in Figure 1F. Approximately 82.0% of the respondents were categorized as having poor mercury-related knowledge, indicating limited environmental health awareness in the study population. Limited understanding of mercury toxicity and exposure pathways may reduce the adoption of protective behaviors and increase the likelihood of unsafe occupational or household practices. Overall, Figure 1 suggests that participants may face multiple overlapping vulnerabilities, including occupational exposure, dietary practices, limited awareness of exposure, and environmental contamination associated with ASGM activities. These observations reinforce the importance of integrated biomonitoring and community-based environmental health interventions in mining-affected populations.

4.2 Distribution of Hair Mercury Concentration

Hair mercury analysis confirmed measurable exposure among residents living near ASGM activities in the region. The mercury concentrations in hair ranged from 0.17 to 6.15 mg/kg, with a mean concentration of 1.01 ± 0.98 mg/kg across 50 participants. For the multivariable analysis, the dataset used a binary mercury exposure classification derived from these measurements. This modeled outcome served as the basis for the logistic regression analyses of the factors associated with membership in the higher-exposure group.

Table 1. Summary of hair mercury concentrations among study participants

Parameter	Value
Number of participants	50
Mean Hg concentration (mg/kg)	1.01 ± 0.98
Minimum concentration (mg/kg)	0.17
Maximum concentration (mg/kg)	6.15
Participants with Hg ≥2 mg/kg	5 (10.0%)

The relatively wide range of mercury concentrations observed in this study indicates substantial inter-individual variability in exposure conditions within the community. This variability may reflect differences in occupational activities, environmental proximity to mining areas, dietary habits, and the cumulative duration of exposure. Hair mercury is widely recognized as a useful biomarker of long-term mercury exposure because mercury is incorporated into keratin during hair formation and reflects cumulative internal exposure over time (Kempson and Lombi, 2011; Manceau et al., 2016; Spangler, 2011). Although the mean mercury concentration remained below the WHO reference threshold of 2 mg/kg, identifying individuals with elevated levels remains important from a public health perspective. Similar patterns have been reported in other ASGM communities, where population averages appear moderate despite the presence of highly exposed individuals or subgroups (Gibb and O'Leary, 2014; Rajaee et al., 2015; Weinhouse et al., 2021).

The presence of elevated mercury concentrations in several participants suggests that multiple exposure pathways may coexist in the study area. Residents may be exposed not only through direct occupational contact associated with mining activities but also through indirect environmental and dietary pathways. In mining-affected settings, mercury released during amalgamation can contaminate the surrounding ecosystems and contribute to chronic low-dose exposure over extended periods (Agustiani et al., 2025a; Huisa-Mamani et al., 2025). The findings also indicate that mercury exposure in this community is not evenly distributed across individuals but appears to vary according to occupational, behavioral, and environmental circumstances. This heterogeneity highlights the value of human biomonitoring in identifying vulnerable subgroups and informing exposure surveillance in mining-affected populations.

4.3 Multivariable correlates of membership in the higher-exposure group

Multivariable logistic regression was used to identify participant characteristics that were independently associated with membership in the higher-exposure group. The candidate variables entered into the initial model included knowledge, occupation, education, residential distance, body mass index, age, urine findings, blood findings, sex, and fish consumption. After backward stepwise likelihood ratio selection, three variables remained in the final model: occupational category, age category, and sex. This pattern suggests that within the current dataset, demographic and occupational characteristics captured more of the modeled variation in exposure classification than the other candidate predictors.

Table 2. Final multivariable logistic regression model for membership in the higher-exposure group

Variable (coded comparison)	B	Adjusted OR	95% CI	p-value
Occupational category (2 = non-mining vs 1 = mining-related)	-1.810	0.164	0.030–0.892	0.036
Age category (2 = ≥45 years vs 1 = 21–44 years)	-2.336	0.097	0.020–0.474	0.004
Sex (2 = female vs 1 = male)	2.083	8.032	1.586–40.675	0.012

Participants aged ≥45 years had significantly lower odds of membership in the higher exposure group than those aged 21–44 years (OR = 0.097; 95% CI: 0.020–0.474; p = 0.004). This result indicates that the younger age group was more strongly represented in the modeled higher exposure category after adjusting for sex and occupation. A plausible interpretation is that productive-age adults are more likely to engage in mining-related tasks or spend more time in work environments where mercury exposure is more frequent and sustained.

Sex was also independently associated with membership in the higher-exposure group. Female participants had significantly higher odds than male participants (OR = 8.032; 95% CI: 1.586–40.675; P = 0.012). This finding highlights the importance of exposure pathways beyond direct mining labor. In mining communities, women may experience mercury exposure through domestic contamination, indirect environmental contact, food preparation, and involvement in gold-processing activities. The strength of this association suggests that gendered exposure patterns deserve closer attention in future biomonitoring and intervention research.

4.4 Model performance

The final multivariable logistic regression model showed moderate explanatory performance. A Nagelkerke R^2 of 0.414 indicated that the retained predictors accounted for a meaningful proportion of the variation in the binary mercury exposure classification. The model correctly classified 78.0% of the participants overall, with better discrimination in the higher-exposure group than in the lower-exposure group. Although these results suggest reasonable in-sample performance, the modest sample size and absence of external validation warrant cautious interpretation of the results.

Table 3. Performance characteristics of the final logistic regression model

Model parameter	**Value**
-2 Log likelihood	50.662
Cox & Snell R^2	0.310
Nagelkerke R^2	0.414
Overall classification accuracy	78.0%
Correct classification: lower-mercury category	65.4%
Correct classification: higher-mercury category	91.7%

The occupational category remained significant after adjusting for age and sex. Participants in the non-mining occupational group had lower odds of membership in the higher exposure group than those in mining-related occupations (OR = 0.164; 95% CI: 0.030–0.892; p = 0.036). This finding reinforces the central role of mining-related work in mercury exposure and is consistent with the expectation that ore processing, amalgamation, and related tasks contribute substantially to the cumulative mercury burden.

Several variables entered into the initial model did not remain in the final stepwise solution, including knowledge, education, residential distance, body mass index, urine findings, blood findings, and fish consumption. Their exclusion does not imply that they are unimportant; rather, it indicates that their independent contributions were not retained after simultaneous adjustment of this dataset. Within the final model, demographic and occupational characteristics explained more of the modeled variation in exposure classification than other candidate predictors.

Taken together, the final model indicated that the higher-exposure classification was more common among younger adults, women, and mining-related workers. These findings support the interpretation that mercury exposure in ASGM communities is socially and occupationally patterned rather than uniformly distributed across residents. However, the estimates should be interpreted as sample-specific until confirmed in larger studies with clearer outcome definitions and external validation

4.5 Environmental and Human Health Implications of Mercury Exposure

The implications for human health are equally important and should not be minimized by the apparently moderate community mean. Population averages can obscure clinically and public health-relevant subgroup burdens, especially in small heterogeneous samples, such as mining-affected communities. Mercury is a multisystem toxicant, and repeated exposure in ASGM settings has been linked to neurological dysfunction, renal impairment, and developmental harm, including risks that may emerge gradually under chronic low-dose exposure (Bose-O'Reilly et al., 2008; Gibb and O'Leary, 2014; Taux et al., 2022; WHO Health Organization, 2008). Against this background, the stronger representation of women in the higher-exposure group deserves a more critical reading than a conventional occupational account. This suggests that mercury risk may be reproduced through gendered divisions of labor, household contamination, and indirect participation in ore-processing environments—pathways that are often underrecognized when surveillance is oriented primarily toward male miners (Harianja et al., 2025; Steckling et al., 2017). Similarly, the elevated modeled risk among younger adults implies that the burden of exposure may be concentrated in economically productive groups whose repeated task engagement increases cumulative contact over time (Gibb and O'Leary, 2014; Mambrey et al., 2020; Taux et al., 2022). Taken together, these results challenge any interpretation of mercury in ASGM communities as a problem confined to miners or overtly contaminated locations. Instead, they support a broader environmental health perspective in which vulnerability is structured by everyday work, domestic roles, and unequal capacity to avoid exposure. From a policy standpoint, this argues for moving beyond narrow occupational control toward integrated prevention that includes household risk reduction, food-chain awareness, routine biomonitoring, and earlier identification of vulnerable subgroups before more severe effects become visible in clinical settings (Weinhouse et al., 2021; WHO Health Organization, 2008).

4.6 Public Health Implications and Biomonitoring Perspective

The multivariate findings indicate that mercury exposure in this ASGM-affected population is shaped by a combination of demographic and occupational factors. The final model showed that membership in the higher exposure group was more common among younger adults, women, and participants engaged in mining-related occupations. This pattern is consistent with broader evidence indicating that mercury exposure in mining regions arises through a combination of direct occupational contact and socially patterned environmental interactions.

From a public health perspective, these findings support the use of targeted biomonitoring and intervention strategies that consider demographic and occupational risk profiles of workers. Younger adults, women, and mining-related workers may benefit from prioritized surveillance, risk communication, and protective interventions. In mining-affected settings, such strategies may improve exposure prevention by directing limited public health resources toward groups most strongly represented in the higher exposure classification.

Hair mercury biomonitoring may be a practical, non-invasive tool for environmental health surveillance in mining-affected regions. Because hair mercury reflects cumulative long-term exposure, it may help identify higher-risk population subgroups and support the evaluation of future exposure-reduction programs. Several limitations should be considered when interpreting the findings. The sample size was modest, the regression analysis depended on a binary mercury exposure classification whose operational definition should be reported explicitly in future studies, and some potentially relevant environmental and behavioral variables may not have been captured in sufficient detail. In addition, the cross-sectional design limits the causal interpretation. Future studies involving larger populations, clearer outcome definitions, and longitudinal follow-ups are needed to strengthen causal inferences and improve model generalizability in ASGM communities.

4.7 Recommendations for Public Health Action and Future Research

Based on the findings of this study, several recommendations can be proposed to strengthen public health actions in communities affected by ASGM activities. First, regular community-based mercury biomonitoring may help identify subgroups at greater modeled exposure risk and monitor exposure trends over time. Second, occupational risk reduction remains essential, including safer gold-processing practices, reduced direct Hg handling, improved ventilation, and appropriate protective equipment. Third, risk communication and environmental health education should be strengthened at the community level to improve awareness of mercury toxicity and its exposure pathways. Because younger adults, women, and mining-related workers were more strongly represented in the higher exposure classification, future intervention strategies should consider these groups when designing surveillance and prevention programs. Larger follow-up studies should incorporate more detailed environmental and behavioral predictors and evaluate how community-based interventions modify mercury exposure patterns over time.

5. Conclusion

This study indicates that residents living near ASGM activities in the Bungo District experience measurable mercury exposure and that membership in the higher-exposure group was independently associated with younger age, female sex, and mining-related occupation. In the final multivariable logistic regression model, participants aged ≥45 years had lower odds of belonging to the higher exposure group than those aged 21–44 years (OR = 0.097; 95% CI: 0.020–0.474; p = 0.004), female participants had higher odds than male participants (OR = 8.032; 95% CI: 1.586–40.675; p = 0.012), and non-mining participants had lower odds than mining-related workers (OR = 0.164; 95% CI: 0.030–0.892; p = 0.036). The model demonstrated moderate explanatory performance (Nagelkerke R^2 = 0.414) and an overall classification accuracy of 78.0%. Taken together, these findings suggest that the modeled exposure burden in this setting is more concentrated among younger adults, women, and mining-related workers and support the need for targeted biomonitoring, safer occupational practices, strengthened risk communication, and broader public health interventions in mining-affected communities.

Declaration of Generative AI and AI-assisted Technologies in the Writing Process

During the preparation of this work, the author(s) used ChatGPT to improve the readability and fix grammatical errors. After using this tool/service, the author(s) reviewed and edited the content as needed and take(s) full responsibility for the content of the published article.

CRediT Author Statement

Rini Maya Sari: Idea Development, Investigation, Formal Analysis, Visualization, Manuscript Draft Preparation**. Muhammad Irsan:** Supervision, Research Design, Resources, Result Verification, Manuscript Review and Revision. **Legiran: Sup**ervision, Result Verification, Manuscript Review and Revision**. Poedji Loekitowati Hariani:** Supervision, Manuscript Review and Revision. **Lia Nurbanillah Fujianti**: Supervision, Research Design, Resources, and Result Verification

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