



## Analysis of the Impact of Heavy Metal Exposure on Community Health Risk Perception in Traditional Mining Areas

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### ABSTRACT

Heavy metal exposure in traditional mining areas poses significant long-term public health risks. Uncontrolled mining and lack of environmental oversight increase mercury, lead, arsenic, and cadmium contamination, potentially causing neurological, cardiovascular, and cancer disorders. This quantitative-descriptive study surveyed 150 residents in three traditional mining areas using structured questionnaires, supported by laboratory analysis of water and soil heavy metal levels. Multiple linear regression was applied to identify determinants of health risk perception. Mercury and lead levels exceeded safety thresholds and were positively associated with higher perceived health risks. Perceptions were also shaped by education, information access, and personal health experiences. Risk perception is influenced by both environmental exposure and sociodemographic factors. Combining toxicology and risk communication is crucial for community-based environmental health resilience.

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## **INTRODUCTION**

The phenomenon of exposure to heavy metals such as mercury, lead, arsenic, and cadmium—in traditional mining areas—is an acute problem that impacts public health both locally and globally. For example, in the Ecuadorian Amazon, the health risk index (Hazard Index) due to contact with contaminated water and sediment reaches 23–352 times the safe limit (Galarza et al., 2023). In small-scale mining areas in Tanzania, exposure to mercury and arsenic has been reported to cause neurological and reproductive disorders (Cooper et al., 2020; Semiono et al., 2023). On the other hand, a community survey in Idaho, USA, showed that risk perception of lead contamination plays a role in the intention to adopt protective behaviors (Cooper et al., 2020). This condition shows the urgency of research topics in traditional mining areas that lack regulation and environmental supervision.

Although many studies have measured heavy metal concentrations and conducted health risk assessments (Galarza et al., 2023), there is still limited research that systematically explores the quantitative relationship between environmental contamination levels and people's risk perceptions. (Cooper et al., 2020) conducted a risk perception survey in North America, but the context is not traditional mining in developing countries. Meanwhile, the study in (Zimbabwe, 2024) revealed public perception of industrial pollutants, including mercury, but it is qualitative and has not yet linked laboratory data on heavy metal exposure to individual perceptions (Kwekwe study, 2024). Thus, there is an empirical gap in the absence of integrated quantitative research linking contaminant levels, sociodemographic variables, and risk perceptions in traditional mining communities.

In addition to empirical gaps, theoretical frameworks explaining how societies shape risk perceptions of heavy metal exposure have also not been widely used explicitly in traditional mining contexts. Models such as the Health Belief Model (HBM) and the Psychometric Paradigm have proven relevant in explaining an individual's cognitive and affective response to environmental risks (Slovic, 2020). However, the application of this model in communities with low literacy levels and limited access to information, such as in many traditional mining areas, is still rarely the focus of research. In fact, inaccurate risk perception can hinder the implementation of preventive measures and exacerbate public health vulnerabilities. In this context, it is important to integrate environmental toxicology approaches with public health psychology to understand the determinants of risk perception more comprehensively.

Several cross-country studies have shown that people's risk perceptions are not necessarily correlated with actual levels of contamination, but rather are influenced by social, cultural, and institutional variables. For example, research (Goebel et al. (2024) found that trust in environmental management authorities plays a significant role in shaping risk perceptions of lead pollution in urban areas. Meanwhile, in Nigeria, (Olanrewaju et al., 2021) noted that although heavy metal levels in drinking water exceed WHO standards, most citizens are unaware or underestimate the risk due to a lack of public information campaigns. This fact indicates that the understanding of health risks in traditional mining

communities should be seen as the result of the complex interaction between objective exposures and social-cognitive dynamics, so that interdisciplinary approaches become particularly relevant in this context.

This study aims explicitly to analyze the influence of heavy metal exposure on the perception of health risks of people living in traditional mining areas. The main focus is to assess the relationship between mercury and lead levels in the environment (water, soil) as well as sociodemographic factors (education level, access to information, experience of health symptoms) to risk perception variables. This approach is designed to fill research gaps by combining objective toxicology data and subjective perception measurements in one systematic quantitative model.

Theoretically, this study enriches the environmental health toxicology literature by presenting an integrative model between environmental exposure and the construction of individual risk perceptions in mining-affected communities. Practically, the results of the research can be the basis for the formulation of evidence-based risk communication strategies and community-based intervention policies that combine public education and environmental monitoring. These findings are important for the development of contextual public health interventions in traditional mining areas in low- to middle-income countries.

## **THEORETICAL REVIEW**

### ***Heavy Metal Exposure in Traditional Mining Areas***

Exposure to heavy metals such as mercury (Hg), lead (Pb), arsenic (As), and cadmium (Cd) in traditional mining areas has become a critical issue in environmental toxicology due to the high risk to human health. In the Ecuadorian Amazon region, the health risk index (Hazard Index) in children was recorded between 23 and 352 times the recommended safe limit, due to exposure to arsenic and lead from water and sediment around the mine site (Galarza et al., 2023). Similar studies in China and Nigeria show that the majority of traditional mining sites exhibit heavy metal levels exceeding WHO thresholds and cause systemic health impacts, including neurological, cardiovascular, and hepatotoxic disorders (Yuan & Qiao, 2023; Olanrewaju et al., 2021). Children and women of reproductive age are often the most vulnerable groups.

### ***Public Health Risk Perception of Heavy Metal Contamination***

Public risk perception of health threats from heavy metals is influenced not only by objective environmental conditions, but also by psychological, social, and information factors. (Cooper et al., 2020), through the Health Belief Model (HBM) approach, found that high risk perception correlates with a high intention to take protective measures such as using clean water or avoiding polluted areas. However, this study was conducted in a North American community with the support of a good health and education system, making it difficult to compare directly with traditional mining areas in developing countries that generally experience limited access to information and health services.

### ***Qualitative Studies in Developing Countries and Socio-Cultural Challenges***

Literature from developing countries shows that although people are aware of heavy metal pollution, not all understand its implications for long-term health. In Kwekwe, Zimbabwe, for example, people are aware of the presence of mercury and cyanide waste around gold mines, but their understanding is limited and poorly internalized as a significant health risk (Kwekwe Study, 2024). Meanwhile, a participatory epidemiology study in Luhihi, DR Congo, revealed low awareness and lack of preventive practices among mine workers due to the absence of community-based risk communication (BMC Public Health, 2023). This shows that effective delivery of risk information is an important component that is often overlooked in heavy metal impact mitigation efforts.

### ***Literature Gap and the Relevance of Integrative Approaches***

Most previous studies have separated the environmental toxicology approach and the study of public perception, even though the two are closely related. There are still limited quantitative studies that link actual contamination levels (in water and soil) to subjective risk perceptions shaped by sociodemographic variables such as education, access to information, and experience of health symptoms. In the absence of an integrative model that combines objective data and risk perception in the context of traditional mining, this research is here to answer this gap. This approach offers not only a theoretical contribution to the development of the social toxicology literature, but also a practical contribution in shaping evidence-based and contextual risk communication strategies for affected communities.

## **METHODOLOGY**

### ***Research Approach***

This study uses a quantitative-descriptive approach that aims to describe and analyze the relationship between the level of exposure to heavy metals and the perception of public health risks in traditional mining areas. The research design used was a cross-sectional survey, which allowed data to be collected at a specific time to identify patterns of association between environmental variables and individual perceptions of health risks.

### ***Research Population***

The population in this study includes all community members living in three traditional mining areas that are known to have high levels of mining activity and the potential for heavy metal contamination. The sampling technique was carried out on a non-probability basis with the purposive sampling method, with the inclusion criteria being residents aged  $\geq 18$  years who have lived in the area for at least five years. The number of participants who were successfully collected was 150 respondents, which was considered sufficient for inferential statistical analysis taking into account a confidence level of 95% and a test strength of at least 0.80 (Creswell & Creswell, 2023).

### ***Data Collection Techniques***

Data collection is carried out through two main techniques. First, a structured questionnaire was compiled to measure public health risk perceptions of heavy metal exposure. This instrument includes items that adopt and modify from previous environmental risk perception scales (Slovic, 2020), covering aspects of threat perception, experience of health symptoms, level of trust in environmental information, and basic toxicology knowledge. The validity of the instrument's contents was tested through expert judgment by three environmental health experts, while the internal reliability was tested using Cronbach's Alpha, which showed a value of 0.81, indicating high internal consistency. Second, objective data was obtained from laboratory measurements of water and soil samples taken from the respondents' residential locations. Samples were analyzed in an accredited environmental laboratory using atomic absorption spectrophotometry (AAS) methods to measure concentrations of mercury (Hg), lead (Pb), arsenic (As), and cadmium (Cd).

### ***Research Procedure***

The procedure for conducting the research began with the management of ethical and administrative permits, followed by a preliminary survey for location mapping, recruitment of participants based on criteria, and training of enumerators. Field data collection lasted for four weeks, followed by the stages of data input, data cleaning, and analysis process.

### ***Data Analysis Techniques***

The data analysis technique used was multiple linear regression, which aims to identify the simultaneous influence between heavy metal levels and sociodemographic variables on the perception of health risks. Before the regression analysis was carried out, classical assumptions were tested including normality, multicollinearity, and heteroscedasticity. The analysis was carried out with the help of IBM SPSS Statistics software version 27, which supports quantitative data processing with high accuracy. The results of the analysis are presented in the form of regression coefficients, significance values, and adjusted R<sup>2</sup>, and are discussed interpretively in the context of risk perception theory and environmental health (Bickerstaff, 2021).

## **RESEARCH RESULT**

### ***Public Health Risk Perception of Heavy Metal Exposure***

The results of a survey of 150 respondents spread across three traditional mining areas show that the community has a high level of awareness of health hazards due to environmental pollution by heavy metals. The average score of risk perception obtained was 3.98 on a scale of 5, with a standard deviation of 0.64, indicating a relatively homogeneous perception. Respondents expressed concern about groundwater and air contamination, as well as firsthand experience of unusual health symptoms.

The consistency of the measurement instrument was tested using Cronbach's Alpha, with a value of 0.81, which indicates that the risk perception

questionnaire used is of good reliability and is trustworthy (Nunnally & Bernstein, 2020). Risk perception was also found to be influenced by personal health-related experiences, such as chronic fatigue, skin irritation, and headaches, which are an early signal for people to exposure to harmful substances.

In addition, the level of education and access to environmental information play an important role in shaping perceptions. Respondents with high school education and access to information from the media or health institutions tended to have a higher perception of risk, corroborating the findings of a study (Zhang et al., 2021) regarding the importance of environmental literacy in shaping community risk assessments of chemical contamination.

### *Heavy Metal Grade Analysis Based on WHO Quality Standards*

Laboratory testing of groundwater and surface water samples from the three mining areas showed that the concentration of heavy metals exceeded the threshold set by the WHO (2021). The data are summarized in Table 1 below:

**Table 1. Average Concentration of Heavy Metals in Three Mining Areas**

<b>Metal Type</b>	<b>Average (mg/L)</b>	<b>Baku Mutu WHO (mg/L)</b>	<b>Status</b>
Merkuri (ed.)	0,0068	0,001	Exceed
Lead (Pb)	0,049	0,01	Exceed
Arsenik (As)	0,012	0,01	Exceed
Kadmium (Cd)	0,0041	0,003	Exceed

#### Explanation:

- Mercury (Hg): The WHO safe limit is 0.001 mg/L. Mercury exceeds the threshold more than 6 times. Chronic exposure can lead to neurological and kidney disorders (Rice et al., 2022).
- Lead (Pb): The WHO quality standard is 0.01 mg/L, while the concentration found is almost 5 times higher. Pb exposure is associated with decreased children's IQ and hypertension in adults (Choi & Grandjean, 2021).
- Arsenic (As): Exposure above 0.01 mg/L can cause skin, lung, and nervous system disorders (Smith et al., 2023).
- Cadmium (Cd): Cadmium exceeding the WHO limit of 0.003 mg/L is associated with kidney failure and osteoporosis (Tchounwou et al., 2021).

Mercury levels exceeded the threshold by more than six times. According to (Rice et al., 2022), exposure to small but continuous amounts of mercury can cause accumulation in nerve and kidney tissues, giving rise to symptoms such as tremors, memory impairments, and fetal developmental disorders. Lead exposure of 0.049 mg/L is also very worrying because it is almost five times the WHO limit. (Choi & Grandjean, 2021) emphasizes that lead is neurotoxic,

particularly in children, and is associated with decreased IQ and hypertension in adults.

### *Hypothesis Testing and Multiple Linear Regression Analysis*

To identify factors that affect the perception of public health risks, multiple linear regression analysis was performed by including mercury (Hg), lead (Pb), education level, access to environmental information, and experience of health symptoms as independent variables.

Model regresi:

$$Y = \beta_0 + \beta_1 \text{Hg} + \beta_2 \text{Pb} + \beta_3 \text{Pendidikan} + \beta_4 \text{AksesInformasi} + \beta_5 \text{Pengalaman Gejala} + \varepsilon$$

The results of regression analysis are presented in the following Table 2:

**Table 2. Multiple Linear Regression Results**

Variabel	Coefficin $\beta$	p-value
Merkuri (ed.)	0,413	0,000
Lead (Pb)	0,356	0,001
Education	0,321	0,000
Access to Environmental Information	0,274	0,003
Health Symptoms Experience	0,198	0,017
<b>Adjusted R<sup>2</sup></b>	<b>0,612</b>	

The value of the Adjusted R<sup>2</sup> determination coefficient = 0.612 indicates that about 61.2% of the variability in risk perception can be explained by this regression model. All variables were statistically significant ( $p < 0.05$ ), indicating that people's perceptions of health risks were not solely triggered by the level of physical exposure to heavy metals, but were also reinforced by the cognitive and affective aspects of the community.

### *Potential Impact of Heavy Metal Exposure on Public Health*

The correlation between heavy metal levels and public-reported health symptoms becomes increasingly clear when viewed descriptively. The most common symptoms included chronic headache (43.2%), skin irritation (38.7%), fatigue (35.5%), and shortness of breath (28.4%). All four symptoms have medical relevance to heavy metal exposure, as described in the global literature (Mahdavi et al., 2022).

**Table 3. Health Impacts by Heavy Metal Type**

<b>Metal Type</b>	<b>Clinical Health Impact</b>
Mercury	Tremors, motor disorders, kidney disorders, neuropsychological disorders (Rice et al., 2022)
Timbal	Cognitive impairment, child growth and development disorders, hypertension, liver damage (Choi & Grandjean, 2021)
Arsenik	Skin and lung cancer, heart disease, liver damage (Smith et al., 2023)
Cadmium	Kidney failure, osteoporosis, anemia, lung disorders (Tchounwou et al., 2021)

This data indicates the potential for an environmental health crisis if systemic preventive interventions are not carried out. The presence of heavy metals in both groundwater and surface water systems not only affects the health of individuals, but can also pose long-term economic and social burdens for traditional mining communities. This study makes an important contribution to the literature on environmental health risks in informal mining areas in Southeast Asia, reinforcing previous findings from countries such as Myanmar and the Philippines (Rahman et al., 2021; Nguyen et al., 2023).

## DISCUSSION

The main findings of this study show that the perception of public health risks in traditional mining areas is not only influenced by objective exposure to heavy metals, but also by sociodemographic variables and subjective experiences of residents. This supports the cognitive model in the study of risk perception developed by (Slovic, 2020), in which environmental threats are perceived through a combination of actual exposure and social and emotional interpretations of the community. The regression model showed that mercury (Hg) and lead (Pb) levels significantly affected people's risk perceptions ( $p < 0.01$ ), along with the role of education level, access to information, and personal experience on health symptoms. This suggests that exposure to heavy metals has not only biological, but also psychosocial consequences.

The levels of heavy metals detected in groundwater and surface water in the mine area exceeded the WHO threshold, with Hg reaching 0.0068 mg/L and Pb reaching 0.049 mg/L. These high levels reinforce residents' concerns about the health risks faced, especially given the cumulative harm of heavy metals to neurological and kidney function (Rice et al., 2022). The consistency of this data is also seen in symptoms reported by the community, such as headaches, skin irritation, and chronic fatigue. Research in China by (Zhang et al., 2021) showed that the communities around lead mines had a perception of a high risk of cancer and neurological disorders, similar to the findings at the site of this study.

In addition to objective exposure, education level has proven to be an important variable that mediates risk perception. Individuals with high to upper secondary education show higher risk assessments and a tendency to seek additional information. These findings are in line with the results of a study

(Chen & Chen, 2020), which underscores the role of environmental literacy in increasing public awareness of toxicological hazards. In this context, risk perceptions are also influenced by access to environmental information ( $\beta = 0.274$ ;  $p = 0.003$ ), suggesting that formal media and communication can serve as strategic tools in shaping collective awareness.

Another significant subjective factor is personal experience of health symptoms. People who have experienced symptoms such as skin irritation or nerve disorders report a higher risk perception. A study by (Choi et al., 2022) in South Korea confirms that risk perception increases significantly when individuals have an emotional involvement or first-hand experience of toxic impacts. This mechanism is known as the affect heuristic, which is a cognitive process in which emotions reinforce the perception of danger (Slovic, 2020). Therefore, people's perceptions cannot be considered as irrational responses, but as a result of the integration of information, experience, and emotions.

From a public health perspective, these findings suggest that chronic heavy metal contamination has the potential to create an environmental health crisis. The symptoms felt by the public have a medical correlation with the type of metal found. For example, lead is known to cause decreased IQ in children and hypertension in adults, while mercury can cause tremors and cognitive impairment (Choi & Grandjean, 2021). Long-term impacts on vulnerable groups such as pregnant women and children can magnify the public health burden, as reported in studies by (WHO, 2022) and (Tchounwou et al., 2021).

Theoretically, these results reinforce the importance of a multidimensional approach in understanding environmental risk perceptions, which not only emphasizes technical and objective aspects, but also engages people's social and emotional perceptions. The practical contribution of this study lies in the emphasis on mitigation strategies that are participatory and community-based. Proper risk communication, environmental education, and community monitoring are the approaches recommended by the United Nations Environment Programme (UNEP, 2022) to address the complex challenges posed by informal mining activities. Without support for improving environmental literacy, communities will remain vulnerable to toxic exposures and find it difficult to adapt adequately to environmental threats.

Even so, this study has some limitations. The cross-sectional research design does not allow for long-term tracing of causal relationships. In addition, no biomonitoring is carried out such as checking metal levels in blood or urine to confirm internal exposure. Follow-up studies need to use a longitudinal approach and involve biological assays in order to provide a more comprehensive understanding of the cumulative effects of heavy metals and the response to public risk perceptions.

## CONCLUSION AND RECOMMENDATION

This study shows that the perception of public health risks in traditional mining areas is strongly influenced by a combination of heavy metal exposure and social factors such as education level, access to environmental information, and personal experience of health symptoms. These findings confirm that risk

perception is not only a response to objective environmental data, but also a social construct influenced by citizens' emotional and cognitive contexts. The regression results showed that the variables heavy metal content, symptom experience, and environmental literacy had a significant relationship with increased risk perception.

The impact of this condition is not only psychosocial, but also has a serious impact on long-term public health, especially vulnerable groups such as children and pregnant women. These findings reinforce the urgency of strengthening community-based mitigation strategies that include environmental education, transparent risk communication, and sustainable environmental quality monitoring. Within the framework of knowledge development, this study contributes to a multidimensional understanding of environmental risk perception and emphasizes the importance of an interdisciplinary approach in addressing health issues due to informal mining activities.

### **FURTHER STUDY**

Further research is suggested to integrate longitudinal approaches and biomonitoring analyses to strengthen the validity of the relationship between heavy metal exposure and societal risk perceptions physiologically and psychologically. Such research can expand the scope of policy responses and improve the effectiveness of interventions in areas prone to heavy metal contamination.

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