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Arsenic Levels in Drinking Water and Urinary Biomarkers: Implications for Public Health and Nutrition in Poboya Village, Central Sulawesi, Indonesia

Kadar Arsen dalam Air Minum dan Biomarker Urin: Implikasinya terhadap Kesehatan Masyarakat dan Gizi di Kelurahan Poboya, Sulawesi Tengah, Indonesia

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Abstract: Arsenic contamination from artisanal gold mining poses significant public health and nutritional risks. This cross-sectional study assessed arsenic levels in drinking water and urinary biomarkers among 100 residents of Poboya Village, Central Sulawesi. Eight drinking water sources were tested, and all showed arsenic concentrations far above the permissible limit (>10 μg/L), ranging from 40–70 μg/L. Elevated urinary arsenic levels (≥35 μg/L) were found in 75% of participants. Duration of residence was significantly associated with urinary arsenic concentration (p = 0.026), while occupation, nutritional status, and distance from pollutant sources showed no significant associations. These findings indicate widespread arsenic exposure through contaminated drinking water, underscoring the need for improved water safety and integrated public health and nutrition interventions in the community.

Key word: arsenic, drinking water, urinary biomarker, public health, nutritional status

1. INTRODUCTION

Arsenic (As) is a naturally occurring metalloid present in soil, rock, and groundwater, but anthropogenic activities such as mining — especially artisanal and small-scale gold mining (ASGM) — may greatly elevate arsenic concentrations in local water sources (1). Chronic exposure to arsenic through contaminated drinking water poses a serious global health concern, given its association with dermatological lesions, gastrointestinal problems, anemia, nephrotoxicity, peripheral vascular disease, and increased risk of cancers of the skin, bladder, lung, and kidney (2). Despite regulatory guidelines — such as the threshold of 10 μg/L for arsenic in drinking water — many communities worldwide continue to rely on water from wells, springs, or other unregulated sources vulnerable to contamination (3). Beyond these clinical manifestations, arsenic exposure has also been implicated in disruptions to nutritional status, including anemia, micronutrient imbalance, and altered metabolic pathways that influence overall health (4).

Communities living near artisanal and small-scale gold mining (ASGM) sites face heightened risk of arsenic exposure. During ore extraction and processing, arsenic-bearing minerals can leach into soil and groundwater, contaminating drinking water sources used by surrounding households (5). Similar contamination patterns have been reported in South and Southeast Asia, where mining activities contribute significantly to heavy metal pollution (6). In Indonesia, Artisanal and Small Scale Gold Mining operations have expanded in several regions, with documented cases of heavy metal contaminationin local water sources and human biomarkers (7). These environmental hazards may pose additional challenges for community nutrition and health, particularly in vulnerable populations with limited access to safe water and health services.

Poboya Village, located in East Palu District, Central Sulawesi, is one of the most active ASGM sites in the region. Over the past decade, rapid mining expansion has raised concerns regarding contamination of groundwater, streams, and other water sources used for drinking and domestic purposes. Despite reports of declining environmental quality, limited scientific evidence exists on the extent of arsenic exposure in this community based on human biomarker measurements. Furthermore, potential implications for public health and nutrition have not been adequately examined.

Given these gaps, this study aims to evaluate arsenic concentrations in drinking water sources in Poboya Village and assess urinary arsenic levels among residents as a direct biomarker of exposure. Additionally, the study explores demographic and environmental factors associated with arsenic exposure and discusses the potential implications for community health and nutrition. Understanding these relationships is essential for informing public health interventions, improving water safety, and mitigating long-term environmental health risks.

2. METHODS

This study employed a cross-sectional design to assess factors associated with arsenic exposure among residents of Poboya Village, East Palu District, Central Sulawesi, an area characterized by intensive artisanal and small-scale gold mining (ASGM). Cross-sectional studies are widely used in environmental health research to identify exposure patterns and associated determinants within a population at a specific point in time (8). A total of 100 adult residents were recruited using purposive sampling based on their residency in the study area and use of local water sources for drinking. Primary data were collected through structured interviews and direct anthropometric measurements. Body weight and height were measured following standardized anthropometric procedures recommended by the World Health Organization (WHO), after which Body Mass Index (BMI) was calculated to categorize nutritional status (9). Additional information, including age, sex, occupation, duration of residence, and daily water use practices, was obtained through interviewer-administered questionnaires. The distance between each respondent’s home and the nearest pollutant source was measured using a handheld Global Positioning System (GPS) device, a method commonly applied in environmental exposure assessment studies (10).

Water samples were collected from eight drinking water sources commonly used by the community, including springs, shallow wells, storage tanks, and river water. Each sample was collected in sterile polyethylene bottles and transported under cold-chain conditions to the Public Health Laboratory. Arsenic concentrations in drinking water were analyzed using Atomic Absorption Spectrophotometry with a graphite furnace (AAS AA-7000), a technique recognized internationally for accurate measurement of trace metals in environmental samples (11). The threshold of 10 μg/L was used to classify arsenic levels as exceeding the permissible limit, following the WHO guideline for drinking water quality (12). Urine samples were collected from all respondents using sterile containers and analyzed in the same laboratory using AAS with graphite furnace to quantify urinary arsenic levels. Urinary arsenic is considered a reliable biomarker for recent exposure to inorganic arsenic, reflecting internal dose and absorbed contaminants (13). Values ≥35 µg/L were classified as elevated based on established biomarker assessment guidance for population studies. All variables were operationalized using established criteria. The dependent variable was urinary arsenic concentration (normal <35 µg/L; elevated ≥35 µg/L). Independent variables included duration of residence (<5 years; ≥5 years), occupation (mining vs. non-mining), nutritional status based on BMI, and distance to pollutant sources (<500 m; ≥500 m). Data were analyzed using descriptive statistics and Chi-square or Fisher's Exact Test to identify associations between exposure factors and urinary arsenic levels; these tests are commonly used in categorical epidemiological data analysis. Statistical significance was determined at a p-value <0.05 (14,15).

3. RESULTS

A total of 100 respondents were included in this study. Arsenic analysis from eight drinking water sources showed that all samples exceeded the permissible limit (>10 µg/L), with concentrations ranging from 40–70 µg/L (Table 1). Urinary arsenic examination revealed that 75 respondents (75.0%) had elevated levels (≥35 µg/L), while 25 respondents (25.0%) were within normal limits.

Table 1. Arsenic Concentration in Drinking Water Sources

Water Source	Normal (≤10 µg/L)	Not Normal (>10 µg/L)
Spring 1 (Sagu 1)	No	Yes
Spring 2 (Sagu 2)	No	Yes
Well 6 m	No	Yes
Well 9 m	No	Yes
Storage Tank 1	No	Yes
Storage Tank 2	No	Yes
River	No	Yes
Storage Tank 3	No	Yes

Analysis of factors associated with urinary arsenic concentration is presented in Tables 2. Duration of residence showed a significant association with urinary arsenic levels (p = 0.026). Occupation (p = 0.717), nutritional status (p = 0.545), and distance from pollutant sources (p = 0.382) were not significantly associated with urinary arsenic concentration.

Table 2. Factors Associated with Urinary Arsenic Levels

Variable	Category	Normal <35 µg/L (n, %)	Elevated ≥35 µg/L (n, %)	Total (n)	p-value
Duration of Residence	<5 years	6 (54.5%)	5 (45.5%)	11	**0.026***
	≥5 years	19 (21.3%)	70 (78.7%)	89	
Occupation	Mining	15 (23.1%)	50 (76.9%)	65	0.717
	Non-mining	10 (28.6%)	25 (71.4%)	35	

Variable	Category	Normal <35 µg/L (n, %)	Elevated ≥35 µg/L (n, %)	Total (n)	p-value
Nutritional Status (BMI)	Poor	7 (20.0%)	28 (80.0%)	35	0.545
	Normal	18 (27.7%)	47 (72.3%)	65	
Distance to Pollutant Sources	<500 m	10 (32.3%)	21 (67.7%)	31	0.382
	≥500 m	15 (21.7%)	54 (78.3%)	69	

4. DISCUSSION

The findings of this study demonstrate that all drinking water sources used by the residents of Poboya Village contain arsenic levels far exceeding the recommended limit of 10 µg/L, with measured concentrations ranging from 40 to 70 µg/L. This level of contamination is consistent with recent assessments of arsenic pollution in groundwater from mining-affected regions globally, which indicate that artisanal and small-scale gold mining (ASGM) activities are a major contributing factor due to geochemical mobilization and leaching from arsenic-bearing ore deposits (16). The widespread contamination observed in Poboya suggests that the community is chronically exposed to arsenic primarily through drinking water, the most common exposure pathway in environmentally contaminated areas. Consistent with the elevated concentration found in water, urinary arsenic analysis revealed that 75% of respondents had levels ≥35 µg/L, indicating significant internal exposure. Recent epidemiological studies have confirmed urine arsenic as a reliable biomarker for recent inorganic arsenic exposure, showing strong correlations between drinking water arsenic and urinary concentrations even at low to moderate exposure levels (17). Similar results were observed in a 2023 U.S.-based biochemical survey demonstrating that both private well users and public water system users exhibited measurable urinary arsenic, emphasizing that arsenic exposure remains a relevant public health concern in diverse settings (18).

In this study, duration of residence was the only factor significantly associated with elevated urinary arsenic levels. Individuals who had lived in the area for five years or longer had markedly higher exposure compared to newer residents. This finding aligns with the pathophysiology of arsenic, which accumulates in the human body over time despite partial urinary elimination. Studies published in 2024 and 2025 have emphasized the cumulative nature of arsenic exposure and its associations with chronic diseases including cardiovascular dysfunction, metabolic disorders, and impaired immune and endocrine systems, especially among long-term exposed populations (19,20).

Although no statistically significant association was found between nutritional status (BMI) and urinary arsenic levels in this study, existing evidence suggests that arsenic exposure may impair nutritional and metabolic pathways. Arsenic has been shown to interfere with micronutrient absorption, redox balance, and metabolic homeostasis, leading to oxidative stress and potential micronutrient depletion even in individuals with normal BMI (21). Given that BMI alone cannot detect micronutrient deficiencies or metabolic dysregulation, it is possible that arsenic-related nutritional effects in this community remain undetected. Recent metabolomic studies show that arsenic exposure alters urinary metabolic profiles even in asymptomatic individuals, indicating early biochemical disruption before clinical symptoms emerge (21,22). Additionally, arsenic may interfere with essential trace elements such as selenium and zinc—both critical for antioxidant defense and immune function—through competitive binding or disruption of enzyme systems dependent on these micronutrients. Such interactions can exacerbate oxidative stress and weaken metabolic resilience, providing a plausible mechanism by which arsenic contributes to subclinical nutritional deficits, even in individuals without overt malnutrition (23).

The absence of significant association with occupation suggests that arsenic exposure is community-wide rather than limited to those involved in mining. This is expected, as arsenic-contaminated water is shared across households regardless of occupational background. Similar findings were reported in contaminated communities in Asia and Latin America, where arsenic exposure was evenly distributed due to the communal use of groundwater sources (6). Likewise, distance from pollutant sources was not significantly associated with urinary arsenic levels, reinforcing that contamination has likely spread throughout the local aquifer and is not confined to areas near tailings or mining equipment.

The public health implications of these findings are substantial. Chronic exposure to arsenic through drinking water has been associated with increased risks of bladder, skin, and kidney cancers, as supported by a comprehensive 2023 meta-analysis (24). Additionally, arsenic exposure may exacerbate community health vulnerabilities by impairing immune response, increasing oxidative stress, and disrupting metabolic pathways, which collectively contribute to long-term nutritional and health consequences (3). Given that Poboya residents rely heavily on contaminated water sources, mitigation efforts are urgently needed to prevent further accumulation of arsenic in the community.

This study is not without limitations. The cross-sectional design prevents causal interpretation, and nutritional status assessment using BMI does not account for micronutrient status or metabolic impairment, which may be more sensitive indicators of arsenic-related health effects. Furthermore, urinary arsenic reflects short-term exposure and may not fully represent long-term body burden, which could be better assessed using hair or blood arsenic biomarkers. Nonetheless, the consistent pattern of elevated urinary arsenic and contaminated water suggests a clear and ongoing public health threat. Overall, the results highlight the urgent need for interventions to provide safe drinking water, implement regular monitoring of arsenic levels, and integrate environmental health risk mitigation into nutrition and public health programs. Given the global evidence demonstrating that arsenic exposure affects not only disease risk but also nutritional resilience and metabolic function, addressing arsenic contamination should be considered a priority for improving overall community health.

5. CONCLUSION

The findings of this study demonstrate that all drinking water sources used by residents of Poboya Village contain arsenic concentrations substantially exceeding international safety limits, resulting in widespread exposure as reflected by elevated urinary arsenic levels in three-quarters of respondents. Duration of residence was the only factor significantly associated with arsenic burden, suggesting that cumulative exposure plays a central role in internal dose, while occupation, nutritional status, and residential proximity to pollutant sources did not significantly influence exposure levels. These results indicate that arsenic contamination in Poboya is pervasive and community-wide, likely driven by long-standing artisanal gold mining activities and the resulting environmental degradation. Given the established health consequences of chronic arsenic exposure, including its potential impact on metabolic function, micronutrient balance, and long-term disease risk, the situation presents a significant public health concern. Immediate efforts are required to provide safe drinking water alternatives, strengthen environmental monitoring, and integrate arsenic risk mitigation into community health and nutrition programs. Further research using more sensitive biomarkers and broader nutritional assessments is recommended to better understand the long-term health implications for this population.

REFERENCES

1. Sultan MW, Qureshi F, Ahmed S, Kamyab H, Rajendran S, Ibrahim H, et al. A comprehensive review on arsenic contamination in groundwater: Sources, detection, mitigation strategies and cost analysis. Environ Res. 2025;265:120457.
2. Kapaj S, Peterson H, Liber K, Bhattacharya P. Human health effects from chronic arsenic poisoning–a review. J Environ Sci Health Part A. 2006;41(10):2399–428.
3. World Health Organization. Arsenic in drinking-water: background document for development of WHO guidelines for drinking-water quality. World Health Organization; 2003.
4. Flanagan SV, Johnston RB, Zheng Y. Arsenic in tube well water in Bangladesh: health and economic impacts and implications for arsenic mitigation. Bull World Health Organ. 2012;90:839–46.
5. Keita MM, Ogendi GM, Owuor O, Nyamao WN. Impacts of artisanal gold mining on water quality: a case study of tangandougou commune in sikasso region, Mali. J Environ Health Sustain Dev. 2018;621–9.
6. Sagar L, Singh S, Attri M, Maitra S, Shankar T, Sairam M, et al. Arsenic contamination in soil and water across south east Asia: Its impact and mitigation strategies. In: Global arsenic hazard: Ecotoxicology and remediation. Springer; 2022. p. 533–60.
7. Tosepu R, Parman P, Nasaruddin N. Heavy Metal Pollution in the Waters of South Konawe Regency, Southeast Sulawesi Province, Indonesia. WSEAS Trans Environ Dev. 2023;19:820–5.
8. Levin KA. Study design III: Cross-sectional studies. Evid Based Dent. 2006;7(1):24–5.
9. Esparza-Ros F, Vaquero-Cristóbal R. Anthropometry. Springer; 2025.
10. Kiani B, Hashemi Amin F, Bagheri N, Bergquist R, Mohammadi AA, Yousefi M, et al. Association between heavy metals and colon cancer: an ecological study based on geographical information systems in North-Eastern Iran. BMC Cancer. 2021;21(1):414.
11. Shivhare H, Chincholikar P. ANALYTICAL CHEMISTRY: Overview (Techniques & Applications). J Pharm Negat Results. 2022;13.
12. World Health Organization. Guidelines for drinking-water quality: small water supplies. World Health Organization; 2024.
13. Eaves LA, Choi G, Hall E, Sillé FC, Fry RC, Buckley JP, et al. Prenatal exposure to toxic metals and neural tube defects: a systematic review of the epidemiologic evidence. Environ Health Perspect. 2023;131(8):086002.
14. Ganie SY, Javaid D, Hajam YA, Reshi MS. Arsenic toxicity: sources, pathophysiology and mechanism. Toxicol Res. 2024;13(1):tfad111.

15. Mattimoe R, Hayden M, Murphy B, Ballantine J. Approaches to analysis of qualitative research data: A reflection on the manual and technological approaches. Account Finance Gov Rev. 2021;27(1):1–16.
16. Kanel SR, Das TK, Varma RS, Kurwadkar S, Chakraborty S, Joshi TP, et al. Arsenic contamination in groundwater: Geochemical basis of treatment technologies. ACS Environ Au. 2023;3(3):135–52.
17. Domingo-Relloso A, Makhani K, Riffo-Campos AL, Tellez-Plaza M, Klein KO, Subedi P, et al. Arsenic exposure, blood DNA methylation, and cardiovascular disease. Circ Res. 2022;131(2):e51–69.
18. Huang Z, Guo L, Chen X, Sun J, Ye Y, Sheng L, et al. Long-term chronic food-derived arsenic exposure induce the urinary system metabolic dysfunction in mice. Sci Total Environ. 2023;898:165499.
19. Frisbie SH, Mitchell EJ. Arsenic in drinking water: An analysis of global drinking water regulations and recommendations for updates to protect public health. PLoS One. 2022;17(4):e0263505.
20. Sinha D, Prasad P. Health effects inflicted by chronic low-level arsenic contamination in groundwater: A global public health challenge. J Appl Toxicol. 2020;40(1):87–131.
21. Sarkar SD, Swain P, Manna S, Samanta S, Majhi P, Bera A, et al. Arsenic contamination in food chain-a menace to food safety, human nutrition and health. J Environ Biol. 2022;43(3):339–49.
22. Dudka I, Kossowska B, Senhadri H, Latajka R, Hajek J, Andrzejak R, et al. Metabonomic analysis of serum of workers occupationally exposed to arsenic, cadmium and lead for biomarker research: a preliminary study. Environ Int. 2014;68:71–81.
23. Jenkins JA, Musgrove M, White SJO. Outlining potential biomarkers of exposure and effect to critical minerals: Nutritionally essential trace elements and the rare earth elements. Toxics. 2023;11(2):188.
24. Essien EE, Said Abasse K, Côté A, Mohamed KS, Baig MMFA, Habib M, et al. Drinking-water nitrate and cancer risk: A systematic review and meta-analysis. Arch Environ Occup Health. 2022;77(1):51–67.