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HEAVY METAL CONTAMINATION IN WATER SOURCES IN POHUWATO REGENCY: IMPLICATIONS FOR BIODIVERSITY AND PUBLIC HEALTH IN GOLD MINING AREAS

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Abstract

Artisanal and small-scale gold mining (ASGM) can increase the levels of heavy metals in surface water and groundwater sources. This study was conducted to evaluate water quality in Pohuwato Regency, Gorontalo, Indonesia. Sampling was performed at three sites: a reservoir, an irrigation channel, and a well. The concentrations of lead (Pb), cadmium (Cd), iron (Fe), manganese (Mn), and mercury (Hg) were analyzed using Atomic Absorption Spectrophotometry (AAS). The results indicated that Hg concentrations ranged from 0.00883 to 0.01493 mg/L (≈8.8–14.9× above the WHO guideline value of 0.001 mg/L), Mn concentrations ranged from 0.1309 to 0.543 mg/L (≈1.3–5.4× above the WHO guideline value of 0.1 mg/L), while Pb concentrations ranged from 0.0019 to 0.0048 mg/L, Cd concentrations ranged from 0.0002 to 0.0006 mg/L, and Fe concentrations ranged from 0.0728 to 0.101 mg/L, all of which were below the recommended threshold values for drinking water. The findings emphasize the importance of mitigation strategies based on mining governance, strengthening water safety plans, as well as interventions for household water treatment (adsorption/filtration) and risk communication.

Keywords: ASGM; AAS; mercury; drinking-water quality; Gorontalo; manganese; Pohuwato

INTRODUCTION

Research on mercury is crucial given that Pohuwato Regency, located in the western part of Gorontalo Province, relies on agriculture and fisheries, both of which require surface and groundwater for domestic needs. However, the increase in small-scale gold mining (ASGM) activities over the past two decades has increased the risk of heavy metal contamination, particularly mercury, in water bodies used by local communities. This is further exacerbated by the region's geographical and hydrological conditions, as well as inappropriate ore processing practices. This research is needed to better understand the potential for mercury exposure, which has been shown to affect environmental compartments and pose health risks to humans. As reported by Arifin et al. (2015), approximately 572 Kg of mercury annually contaminates the environment in North Gorontalo Regency, indicating the worsening environmental damage caused by illegal gold mining (PETI). Therefore, this research is crucial for strengthening mercury-free mining governance and supporting public health monitoring and protection.

Further support is found in the study by Metaragakusuma et al. (2023), which highlights the need for continuous educational interventions on risk awareness among mining communities. However, there is still limited specific evidence linking the water quality conditions consumed daily by households in Pohuwato with health reference standards. Therefore, it is necessary to map key parameters at actual water source points used by the community.

In terms of regulations, the global reference framework from the World Health Organization (WHO) sets the guideline values (NAB) for mercury exposure in drinking water. WHO states that the total mercury limit is 0.001 mg/L (WHO, 2003, p. 12). Nationally, drinking water quality standards are regulated by Permenkes No. 2 of 2023 to maintain the quality and governance of community health, ensuring that local measurement results align consistently with international standards and domestic policies.

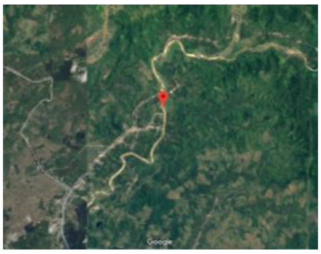
This study aims to measure the concentrations of Pb, Cd, Fe, Mn, and Hg in water sources widely used by the community in Pohuwato, compare them with relevant WHO, 2016 and national guideline values, and discuss the health implications and practical mitigation options at the household and public service levels. The expected results include empirical evidence for village/PDAM water safety plan planning, data-driven risk communication, and technical recommendations aligned with local processing capacities.

RESEARCH METHODS

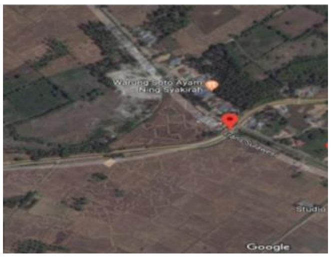
This research was conducted for 1 month (May 2025) with the sampling locations being the dam, irrigation channels and residents' wells. The method used in sampling is the judgment method, namely a sampling or assessment method that relies on subjective assessment based on certain criteria that have been determined by the researcher.

Design & Location

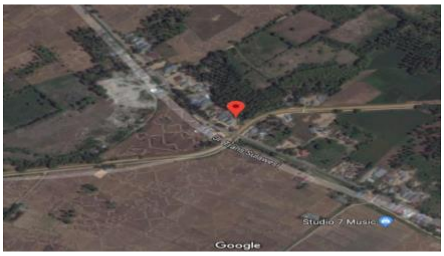
This study was conducted at three sites (a reservoir, an irrigation channel, and a household well) representing water usage by the community in this cross-sectional study. Sampling was conducted during the day at locations affected by artisanal mining activities.



Reservoir



Irigation



well

Figure 1. Sampling location

Field Parameters

Kode Sampel	Lokasi	Lokasi		Suhu	pH	Waktu pengambilan
		North	East			
1	Reservoir	0°31'04.9"N	121°57'18.9"E	27,7	7,5	11.05
2	Irigation	0°30'12.5"N	121°55'53.6"E	27,4	7,4	11.30
3	Well	0°30'17.1"N	121°55'47.9"E	28,6	6,5	11.45

Laboratory Analysis

Sample testing begins with sample preparation in the Chemistry Department laboratory at Gorontalo State University. The samples are then preserved using concentrated nitric acid or other concentrated acid mixtures. Samples of lead (Pb), cadmium (Cd), iron (Fe), manganese (Mn), and mercury (Hg) were analyzed using AAS (U.S. Environmental Protection Agency, 1994; 2007) according to Standard Methods (APHA, 2017). Multi-point calibration, blank methods, sample control, and duplicate analysis were part of the QA/QC procedures, with a minimum RPD of 20%.

RESULTS AND DISCUSSION

Data & Comparison

The results obtained were compared to the WHO guidelines for drinking water (Mn 0.1 mg/L; Hg 0.001 mg/L), and also compared with national regulations (Permenkes No. 2/2023). Descriptive analysis showed changes in concentration and fold differences against reference thresholds.

Table 1. Sample Collection Metadata

Sample Code	Location	Temperature (°C)	pH	Time	Location
1	Reservoir	27.7	7.5	11:05	121°57'18.9"E
2	Irrigation	27.4	7.4	11:30	121°55'53.6"E
3	Well	28.6	6.5	11:45	121°55'47.9"E

Results

Table 2. Heavy Metal Concentrations

Parameter	Reservoir	Irrigation	Well
Lead (Pb)	0.0048 mg/L	0.0047 mg/L	0.0019 mg/L
Cadmium (Cd)	0.0002 mg/L	0.0006 mg/L	0.0004 mg/L
Iron (Fe)	0.0847 mg/L	0.1010 mg/L	0.0728 mg/L
Manganese (Mn)	0.1309 mg/L	0.2802 mg/L	0.5430 mg/L
Mercury (Hg)	0.00883 mg/L	0.01082 mg/L	0.01493 mg/L

Comparison with Guidelines

Comparing with WHO reference values, Hg exceeds the guideline by 8.8× (reservoir), 10.8× (irrigation), and 14.9× (well). Mn exceeds the reference by 1.3× (reservoir), 2.8× (irrigation), and 5.4× (well). Meanwhile, Pb (≤0.0048 mg/L), Cd (≤0.0006 mg/L), and Fe (≤0.101 mg/L) are below the general drinking water threshold.

Table 3. Fold Change Comparison against Guidelines

Parameter	Reference	Reservoir	Irrigation	Well
Hg (mg/L)	0.001	8.83×	10.82×	14.93×
Mn (mg/L)	0.10	1.31×	2.80×	5.43×
Pb (mg/L)	0.010	0.48×	0.47×	0.19×
Cd (mg/L)	0.003	0.07×	0.20×	0.13×
Fe (mg/L)	0.30*	0.28×	0.34×	0.24×

*Note: Fe value based on organoleptic consideration (WHO, 2003; 2011).

Discussion

The high Hg levels at all three sample points suggest that amalgamation and tailings disposal that are poorly managed are the primary causes. This finding is consistent with regional literature indicating that ASGM activities in Gorontalo have high mercury burdens (Arifin et al., 2015), as well as reports of contamination in environmental matrices and human exposure. Manganese concentrations exceeding the guideline value (NAB) were predominantly found in wells.

Impact of Heavy Metal Contamination on Biodiversity

Bioaccumulation in the Food Chain

The ongoing process, often referred to as biomagnification, means that aquatic organisms can accumulate heavy metals such as mercury (Hg), cadmium (Cd), and lead (Pb). Small invertebrates and plankton, for example, are exposed to these heavy metals, which then become food for larger predators like fish and birds. This process causes the concentration of heavy metals to increase at higher trophic levels (Oziegbe, 2025), ultimately leading to long-term damage to aquatic ecosystems. The decline in the population of organisms contaminated by heavy metals can reduce biodiversity in the affected environment

According to Ghannem et al. (2023), the accumulation of heavy metals in organisms' bodies can disrupt biological functions such as reproduction, nervous systems, and kidneys. Furthermore, the accumulation of heavy metals in apex predators can affect their feeding habits and reproductive success, which can lead to population imbalances and ecosystem damage.

Disruption of Survival and Reproduction

Many species, particularly aquatic organisms, have reproductive systems that are vulnerable to heavy metal exposure in water. For instance, cadmium and lead can disrupt larval development and reduce the quality of fish eggs. These effects can lower the number of species in the population, which ultimately reduces the number of individuals that successfully grow into adult organisms. Heavy metal contamination in the environment disrupts the community structure due to the disturbance in reproductive processes.

Furthermore, heavy metal contamination can interfere with metabolism and growth, as well as disrupt organisms' survival. Fish exposed to heavy metals often show reduced growth rates and lower physical endurance. This results in a decline in the species' resistance to environmental pressures, affecting biodiversity across the ecosystem. The reduction in survival and reproduction can lead to the loss of vulnerable species, disrupting ecosystem balance (Hong, 2013) "Heavy pollution can have a significant impact on reproduction, causing population declines and reduced biodiversity, as species vulnerable to pollution fail to reproduce" (Briffa et al., 2020).

Declining Environmental Quality

The physical and chemical structure of water deteriorates due to high levels of heavy metal contamination, which affects the habitats of aquatic species. Chemical changes from heavy metal contamination such as Fe and Mn can alter water quality, including dissolved oxygen, making habitats unsuitable for more sensitive species, ultimately reducing biodiversity in the area, Texas A&M AgriLife Extension (2012)

Heavy metal pollution can also damage natural habitats like coral reefs and underwater vegetation, which are home to many species. Essential resources for the survival of organisms, such as shelter and food, are disrupted when these habitats are destroyed. Research published by Alsherif et al. (2022) states that poor habitat quality leads to the local extinction of species that depend on those environments.

Management Procedures

Heavy metal contamination in biodiversity can be mitigated through several management strategies. The first step is to control pollution sources. This can be done by implementing strict regulations in the agricultural and industrial sectors to reduce heavy metal waste in water bodies, Alsherif, (2022). Regular water quality monitoring can help detect contamination early and correct it. Second, the restoration of contaminated ecosystems can be assisted through environmental engineering, such as habitat rehabilitation. Water quality recovery can be achieved through planting aquatic vegetation that can filter out heavy metals or using bio-adsorption technology to remove heavy metals from water. Efforts to enhance species diversity and habitat quality can be made by restoring coral reefs and other marine ecosystems.

Public education and awareness are crucial in addressing heavy metal contamination in the environment. Briffa et al. (2020) found that local community participation in conservation efforts can accelerate ecosystem recovery and prevent further damage.

Public Health Risks

Heavy metal contamination presents a significant public health risk. With mercury concentrations 9–15 times above the WHO reference value, there is a neurotoxic risk, particularly for children and pregnant women. This occurs through the food chain (freshwater fish) and water consumption. According to WHO (2003), the 0.001 mg/L limit is considered a conservative threshold to reduce exposure.

Policy and Management Implications

Eliminate mercury and promote mercury-free technologies through the establishment and formalization of small-scale gold mining chains in line with national obligations following the Minamata Convention ratification. Implement water safety plans (WSP) at the village or PDAM level, hazard mapping, process supervision, and regular monitoring. Implement household-level treatment for impacted areas, such as carbon or zeolite-based filtration and sulfur adsorbents for mercury. Behavioral interventions and risk communication have been shown to improve risk literacy in mining communities (Metaragakusuma et al., 2023). Selective biological screening involving hair and urine testing for vulnerable groups.

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CONCLUSION

The surveyed water sources in Pohuwato showed mercury (Hg) and manganese (Mn) contamination exceeding guidelines, with Hg levels approximately 9–15× and Mn levels approximately 1.3–5.4× above the WHO reference values. Lead (Pb), cadmium (Cd), and iron (Fe) were below drinking water thresholds at the time of measurement. Policies for mercury-free mining governance, water safety plans, household water treatment, and community-based risk education are required. Further research is needed to map seasonal variations, mercury speciation, and exposure to biota and humans.

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