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Risks of arsenic-contaminated fish consumption in Manado: Intervention implications from an environmental health risk assessment

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ABSTRACT

Heavy metal contamination in coastal ecosystems continues to be a critical yet under-addressed public health issue, particularly in developing countries where environmental monitoring and risk communication remain limited. Previous studies have insufficiently linked seafood-borne arsenic exposure with targeted health interventions for coastal populations. This study aimed to assess public health risks associated with arsenic (As) exposure from fish and shellfish consumption in Manado Bay, Indonesia, using an Environmental Health Risk Assessment (EHRA) approach. Conducted from April to October 2025, this cross-sectional study combined laboratory analysis of seafood samples with exposure assessment among 50 coastal residents selected via cluster sampling. The highest arsenic concentration was identified in Yellowstripe Red Snapper (*Lutjanus kasmira*) at 1.61 mg/kg, exceeding FAO/WHO safety thresholds. The estimated daily intake and risk quotient (RQ) for *L. kasmira* consumption surpassed the reference dose, with an average RQ of 4.92 over a 30-year exposure duration, indicating significant chronic health risks. These findings underscore the urgent need for integrated public health interventions, including consumption advisories, environmental risk communication, seafood safety regulations, and pollution mitigation strategies. Addressing these gaps is critical to protect vulnerable populations and inform policy actions for sustainable coastal health management in Indonesia and similar settings.

ABSTRAK

Kontaminasi logam berat di ekosistem pesisir terus menjadi masalah kesehatan masyarakat yang kritis namun kurang ditangani, terutama di negara berkembang yang memiliki keterbatasan dalam pemantauan lingkungan dan komunikasi risiko. Studi sebelumnya belum secara memadai mengaitkan paparan arsen (As) dari konsumsi hasil laut dengan intervensi kesehatan yang terarah bagi masyarakat pesisir. Penelitian ini bertujuan untuk menilai risiko kesehatan masyarakat akibat paparan arsen melalui konsumsi ikan dan kerang di Teluk Manado, Indonesia, dengan pendekatan Environmental Health Risk Assessment (EHRA). Penelitian potong lintang ini dilaksanakan pada April hingga Oktober 2025, dengan mengombinasikan analisis laboratorium terhadap sampel hasil laut dan penilaian paparan pada 50 warga pesisir yang dipilih menggunakan teknik cluster sampling. Konsentrasi arsen tertinggi ditemukan pada ikan kakap merah garis kuning (*Lutjanus kasmira*) sebesar 1,61 mg/kg, melebihi ambang batas aman FAO/WHO. Estimasi asupan harian dan nilai risk quotient (RQ) untuk konsumsi *L. kasmira* melampaui dosis referensi, dengan rata-rata RQ sebesar 4,92 untuk durasi paparan selama 30 tahun, yang menunjukkan potensi risiko kesehatan kronis. Temuan ini menegaskan perlunya intervensi kesehatan masyarakat yang terintegrasi, termasuk imbauan konsumsi, komunikasi risiko lingkungan, regulasi keamanan pangan laut, dan strategi mitigasi pencemaran. Penanganan terhadap kesenjangan ini sangat penting untuk melindungi populasi rentan dan mendorong kebijakan pengelolaan kesehatan pesisir yang berkelanjutan di Indonesia maupun wilayah serupa.

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INTRODUCTION

The Heavy metal contamination in coastal environments is a global environmental issue with serious implications for ecosystem integrity and human health. Coastal zones and river estuaries often act as sinks for pollutants derived from anthropogenic activities, including industrial discharge, urban runoff, mining, agriculture, and improper waste management. Numerous studies have documented the accumulation and spatial distribution of toxic metals such as arsenic (As), lead (Pb), and cadmium (Cd) in coastal sediments and aquatic biota, highlighting their persistence and potential to cause long-term ecological damage (Zhao et al., 2016; Zhao et al., 2018; Makokha et al., 2016; Zhang et al., 2017a; Zhang et al., 2017b; Zheng et al., 2016; Salvador et al., 2018). These contaminants not only degrade water quality but also threaten the sustainability of coastal resources that support local livelihoods and food security.

Arsenic is of particular concern due to its high toxicity, carcinogenicity, and ability to bioaccumulate and biomagnify along aquatic food webs. Previous research has shown that arsenic can be transferred from sediments to benthic organisms and subsequently to higher trophic levels, eventually reaching humans through the consumption of contaminated fish and shellfish (Ghosh et al., 2022; Visciano, 2025). Exposure to arsenic-contaminated seafood has been associated with adverse ecological effects, including reduced biodiversity and physiological stress in aquatic organisms, as well as significant health risks to humans, such as neurological disorders, gastrointestinal diseases, reproductive toxicity, cancer, and increased mortality (Gulati et al., 2022; Zahran et al., 2025; World Health Organization [WHO], 2022; Nyarko et al., 2023; Wang et al., 2022).

Despite growing global evidence on the health risks posed by arsenic contamination in coastal ecosystems, site-specific assessments linking arsenic exposure from seafood consumption to human health risks remain limited, particularly in developing coastal regions. The lack of integrated studies combining environmental contamination data with health risk assessment hampers effective risk management and policy formulation. A comprehensive evaluation using an Environmental Health Risk Assessment (EHRA) framework is therefore essential to quantify potential health risks associated with arsenic exposure through dietary intake of marine biota and to support evidence-based interventions for coastal pollution management (WHO, 2022; Nyarko et al., 2023).

Scientific literature emphasizes the importance of using bioindicator species, such as fish, oysters, and various shellfish, to assess heavy metal contamination and associated health risks in coastal environments. These organisms are known to accumulate arsenic in their tissues due to their feeding habits, sedentary nature, and close interaction with contaminated sediments and water columns. Studies have demonstrated that shellfish, including oysters (Saccostrea glomerata) and other bivalves, are particularly effective indicators of arsenic bioavailability and human exposure pathways (Dang et al., 2022; Musfirah, 2016; Martínez López et al., 2023). Monitoring arsenic concentrations in these biota provides critical insight into contamination levels and potential dietary risks for coastal communities.

In addition, the application of Environmental Health Risk Assessment approaches has been widely recommended to estimate both non-carcinogenic and carcinogenic risks associated with heavy metal exposure. EHRA integrates contaminant concentration data, consumption rates, exposure frequency, and toxicological reference values to produce quantitative risk estimates, enabling comparisons with international safety thresholds (Zhang et al., 2023; Kato et al., 2022). This approach has been successfully applied in various coastal and estuarine settings to inform public health protection strategies and environmental management policies.

Previous studies on arsenic contamination in coastal environments have predominantly emphasized environmental monitoring and ecological impacts, with limited translation of findings into actionable public health interventions. Although the presence of arsenic in marine sediments and biota has been well documented, fewer studies have assessed how such evidence can be systematically used to inform health-based interventions, risk communication, and preventive strategies for exposed coastal populations. In Indonesia and other developing coastal regions, research rarely integrates environmental exposure data with intervention-oriented frameworks, such as community risk management, dietary exposure control, and health surveillance, particularly in areas experiencing rapid urbanization and increasing anthropogenic pressures (Lagerström et al., 2022; WHO, 2022).

Moreover, reports of increasing gastrointestinal disorders, including diarrhea and gastritis, among coastal communities consuming fish and shellfish highlight the urgent need for health-focused responses rather than solely environmental assessments. However, the absence of site-specific health risk quantification limits the design and prioritization of effective interventions, such as consumption advisories, community education programs, and policy-driven pollution control measures. Therefore, this study addresses a critical research gap by applying an Environmental Health Risk Assessment approach to generate evidence directly relevant to health interventions. The novelty of this research lies in its emphasis on translating arsenic exposure assessment into practical public health actions, providing a scientific basis for targeted intervention strategies, risk mitigation, and protection of vulnerable coastal populations in Manado Bay.

METHODS

This study employed a quantitative approach using the Environmental Health Risk Assessment (EHRA) method to evaluate potential public health risks associated with arsenic (As) exposure through fish consumption in Manado Bay (US-EPA, 2021). The study area was selected due to its high potential for heavy metal contamination originating from domestic waste, industrial activities, and coastal economic activities. The research was conducted from April to October 2025, while laboratory analysis of environmental samples was performed at the Manado Industrial Research and Standardization Center (BARISTAND).

Sampling was conducted on two main objects: marine biota (fish) and human respondents. Fish samples were collected from several locations within Manado Bay representing areas with relatively high and low pollution levels, determined by their proximity to potential pollution sources. Human sampling targeted coastal communities that regularly consumed fish harvested from Manado Bay. A cluster sampling technique was applied, resulting in a total of 50 respondents, with sample size determined using the Lemeshow formula. Inclusion criteria included permanent residence in the coastal area and voluntary participation after receiving adequate information and providing informed consent (see Figure 1).

The EHRA consisted of exposure assessment, dose–response assessment, and risk characterization. Arsenic concentrations in fish samples were determined using standard laboratory analytical procedures and expressed in mg/kg wet weight. Exposure assessment was conducted by estimating the daily intake (Intake) of arsenic using the following Equation (1).

$$Intake = (C \times IR \times EF \times ED) / (BW \times AT) \quad (1)$$

where:

Intake : daily arsenic intake (mg/kg/day);
C : arsenic concentration in fish (mg/kg);
IR : ingestion rate of fish (kg/day);
EF : exposure frequency (days/year);
ED : exposure duration (years);
BW : body weight of respondent (kg);
AT : averaging time (days), calculated as ED × 365 for non-carcinogenic risk assessment.

Two exposure scenarios were evaluated to represent medium-term (30 years) and long-term (70 years) exposure durations, reflecting realistic consumption patterns in coastal communities.

Dose–response assessment utilized the reference dose (RfD) for arsenic established by the US Environmental Protection Agency, set at 0.0003 mg/kg/day. Risk characterization was performed by calculating the Risk Quotient (RQ) using the following Equation (2).

RQ = Intake / RfD .... (2)

An RQ value greater than 1 indicates a potential non-carcinogenic health risk, whereas an RQ value less than or equal to 1 suggests that adverse health effects are unlikely to occur under the assessed exposure conditions.

Risk management analysis was conducted to identify feasible intervention strategies aimed at reducing health risks associated with arsenic exposure. These strategies included reducing arsenic concentrations in marine environments through pollution control, modifying fish consumption patterns—particularly for high-risk species—and limiting exposure duration through targeted public health advisories. The outcomes of this analysis were oriented toward practical health interventions applicable to coastal populations.

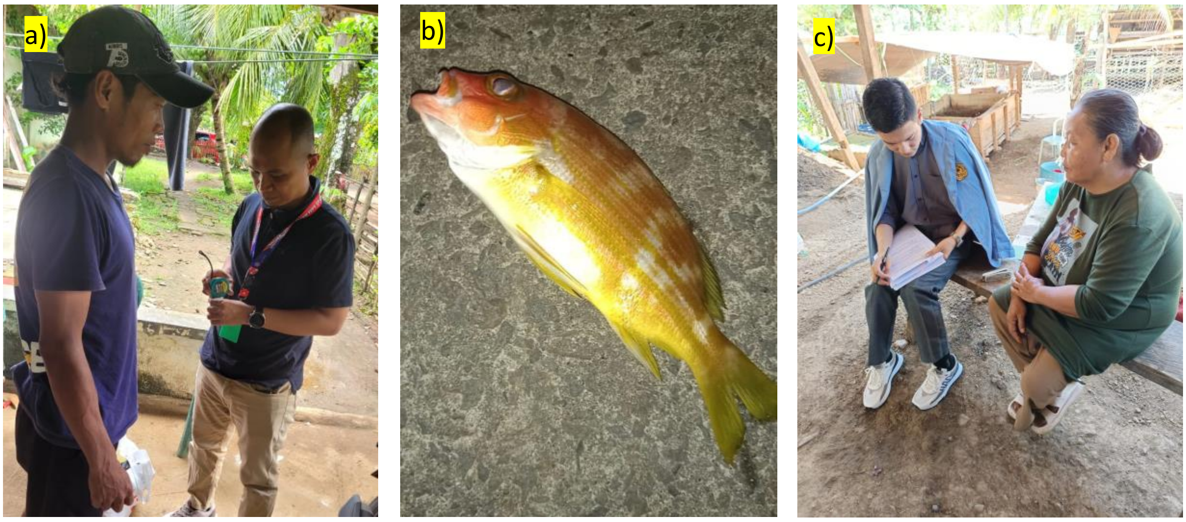
Ethical principles were strictly observed throughout the study. All participants were informed about the study objectives, procedures, potential risks, and benefits prior to participation. Written informed consent was obtained from each respondent, confidentiality of personal data was ensured, and participation was entirely voluntary. The study adhered to established ethical standards for human subject research.

RESULTS AND DISCUSSION

The analysis of arsenic (As) concentrations in marine biota collected from Manado Bay demonstrated clear interspecies variability. Table 1 illustrates that among the three fish species examined, *Lutjanus kasmira* exhibited the highest total arsenic concentration (1.61 mg/kg), exceeding the commonly referenced safety threshold of 1.0 mg/kg for total arsenic in fishery products established by FAO and WHO (2020). In contrast, arsenic concentrations in *Carangidae* (Kuwe) and *Parastromateus niger* (black pomfret) were 0.03 mg/kg and 0.13 mg/kg, respectively, both well below the permissible limit and therefore considered relatively safe based on total arsenic standards. These findings indicate that arsenic contamination in Manado Bay is not uniform across species and is strongly influenced by biological and ecological characteristics.

Table 2 summarizes the dose–response relationship and critical health effects associated with arsenic exposure. The reference dose (RfD) of 0.0003 mg/kg/day reflects the threshold below which adverse health effects are unlikely to occur. Chronic exposure to arsenic above this level has been associated with a wide range of serious health outcomes, including neurological and reproductive impairments, metabolic disorders, and multiple forms of cancer, underscoring the importance of controlling long-term dietary exposure through contaminated seafood.

Figure 1
Field data collection process



Note: (a) preparation of materials and equipment; (b) *Lutjanus kasmira* sample; (c) community data collection

Table 1
Arsenic (As) content in fish in Manado Bay

Species Name	Scientific Name	As Concentration (mg/kg)	Maximum Permissible Limit (mg/kg)	Remarks
Yellow-lined Red Snapper	*Lutjanus kasmira*	1.61	1	Exceeds the limit
Trevally	*Carangidae*	0.03	1	Safe
Black Pomfret	*Parastromateus niger*	0.13	1	Safe

The elevated arsenic concentration observed in *L. kasmira* is consistent with findings from previous studies reporting higher heavy metal accumulation in demersal and benthopelagic carnivorous fish species (Javanshi, 2023; Monteiro et al., 2021). Benthic and benthopelagic organisms are more likely to be exposed to sediment-associated contaminants, as sediments act as major sinks for arsenic in coastal environments. Conversely, pelagic species such as *Carangidae* typically show lower metal accumulation due to their feeding on planktonic organisms and reduced interaction with contaminated sediments (Rosa et al., 2024). The intermediate arsenic concentration detected in P. niger aligns with its omnivorous feeding behavior and mid-water habitat, which may result in exposure from both the water column and resuspended sediments (Tabezar et al., 2023). Compared to similar studies in other coastal regions, the arsenic level in *L. kasmira* from Manado Bay is relatively high, highlighting a localized contamination issue that warrants targeted health risk evaluation.

These findings underscore the importance of species-specific assessment in environmental health studies, as reliance on generalized seafood safety data may underestimate risks associated with particular fish species. From a public health perspective, the identification of L. kasmira as a high-risk species provides a critical evidence base for designing targeted health interventions, such as selective consumption advisories and community education programs. Scientifically, the results reinforce the role of trophic level and habitat preference in arsenic bioaccumulation, contributing to a more nuanced understanding of exposure pathways in coastal ecosystems.

Table 3 presents the estimated arsenic intake resulting from the consumption of selected fish species under two exposure scenarios, representing 30-year and 70-year durations. Using the US Environmental Protection Agency reference dose (RfD) of 0.0003 mg/kg/day (US-EPA, 2001), exposure assessment revealed substantial differences in arsenic intake depending on fish species consumed. For an adult weighing 58 kg with a daily fish consumption rate of 0.18 kg, arsenic intake from *L. kasmira* reached 0.003285 mg/kg/day for a 30-year exposure scenario and 0.000704 mg/kg/day for a 70-year exposure scenario. Both values exceeded the RfD, indicating a high potential for adverse health effects. In contrast, arsenic intake from *Carangidae* remained far below the RfD across both exposure durations, while intake from *P. niger* approached the RfD under long-term consumption scenarios.

The estimated intake values and exposure patterns observed in this study are comparable to those reported in other arsenic risk assessments involving contaminated seafood consumption in coastal populations (Mishra et al., 2019; Monteiro et al., 2021). Similar studies have shown that long-term consumption of arsenic-contaminated fish can lead to cumulative exposure exceeding safe thresholds, even when contamination levels are moderately elevated. Compared with studies that assessed generalized seafood consumption, the present research offers a more refined exposure estimate by incorporating local body weight and consumption rates, thereby providing a more accurate reflection of community-specific risk conditions.

Table 2
Dose–response (RfD) relationship and critical health effects of arsenic (As)

Agent	RfD	Critical Effects and References
Arsenic (As)	0.0003 mg/kg/day	Neurological and reproductive disorders, cancer, and mortality (Mishra et al., 2019; Kasmi et al., 2023); intestinal diseases, type 2 diabetes, and cancers of the bladder, kidney, lung, and liver (Monteiro et al., 2021).

Table 3
Estimated arsenic intake from fish consumption over 30-year and 70-year exposure durations

Fish Species	Concentration (mg/kg)	RfD (mg/kg/day)	Intake (30 years)	Intake (70 years)
Yellowstripe Red Snapper (*L. kasmira*)	1.61	0.0003	0.003285	0.000704
Kuwe Fish (*Carangidae*)	0.03	0.0003	6.12×10^{-5}	1.3118×10^{-5}
Black Pomfret (*P. niger*)	0.13	0.0003	0.000265	5.68459×10^{-5}

The exposure assessment highlights the critical role of dietary habits in shaping health risks associated with arsenic contamination. From an intervention standpoint, these results emphasize the need for risk-based dietary guidance that considers both species type and consumption frequency. Public health interventions such as nutritional counseling, promotion of lower-risk fish species, and dissemination of consumption limits for high-risk species could significantly reduce arsenic exposure among coastal residents. Scientifically, the findings support the integration of local exposure parameters into EHRA to improve the relevance and effectiveness of health risk evaluations.

Risk characterization further confirmed the potential chronic health risks associated with arsenic exposure through fish consumption. Table 4 summarizes the risk quotient (RQ) values for arsenic exposure associated with the consumption of three fish species under 30-year and 70-year exposure scenarios. For a 30-year exposure period, risk quotient (RQ) values ranged from 1.21 to 8.73, with a mean RQ of 4.92, exceeding the acceptable safety threshold (RQ > 1) and indicating significant non-carcinogenic health risk. Although RQ values declined for the 70-year exposure scenario (mean RQ = 2.16), both mean and maximum values remained above 1, suggesting persistent chronic risk over a lifetime. The relative contribution of each species to overall risk followed the order *L. kasmira* > *P. niger* > *Carangidae*.

These RQ values are consistent with prior studies reporting elevated health risks associated with chronic arsenic exposure from contaminated seafood (Nyarko et al., 2023; Wang et al., 2022). Similar patterns of decreasing RQ with longer exposure duration have been attributed to dose averaging over time; however, the persistence of RQ values above unity confirms that prolonged exposure does not eliminate health risk. Compared with studies conducted in less urbanized coastal settings, the higher RQ values observed in Manado Bay suggest stronger anthropogenic influence and greater urgency for intervention.

The persistence of RQ values above safe thresholds has important implications for environmental health intervention and policy. These findings provide strong justification for implementing routine monitoring of total and speciated arsenic in marine biota, issuing evidence-based consumption advisories, particularly for vulnerable groups such as children, pregnant women, and high-frequency fish consumers, and strengthening pollution control measures targeting industrial, agricultural, and domestic waste sources. Collectively, this study demonstrates how EHRA can serve as a critical tool for translating environmental contamination data into actionable public health interventions aimed at reducing chronic arsenic exposure in coastal communities.

Table 4
Risk quotient (RQ) values for arsenic exposure from fish consumption

Respondent	*L. kasmira*	*Carangidae*	*P. niger*	Total
RQ (30 years)				
Max	7.9397	0.1479	0.6411	8.7287
Min	1.1027	0.0205	0.089	1.2122
Mean	4.479	0.0835	0.3617	4.9242
RQ (70 years)				
Max	3.402	0.063	0.274	3.739
Min	0.472	0.008	0.038	0.518
Mean	1.972	0.035	0.154	2.161

CONCLUSION

This study concludes that arsenic contamination in marine fish from Manado Bay poses a species-specific health risk, with Lutjanus kasmira identified as the primary contributor to potential chronic arsenic exposure among coastal communities. The significantly higher arsenic concentration detected in this demersal carnivorous species, exceeding the FAO/WHO safety threshold, reflects the influence of habitat preference, feeding behavior, and trophic position on metal bioaccumulation. Environmental Health Risk Assessment further demonstrated that frequent consumption of L. kasmira may result in non-carcinogenic health risks, as indicated by Risk Quotient values exceeding unity for both medium- and long-term exposure scenarios, while Carangidae and Parastromateus niger were associated with comparatively low health risk.

The findings contribute novel, site-specific evidence linking ecological characteristics of fish species with human health risk, thereby strengthening the scientific basis for intervention-oriented coastal food safety management. From a public health perspective, the results support the implementation of targeted health interventions, including species-specific consumption advisories, routine monitoring of arsenic levels in high-risk fish, and risk communication strategies for vulnerable populations in coastal areas. Although this study was limited to total arsenic analysis and a restricted number of species, it provides a critical foundation for future research incorporating arsenic speciation, broader dietary assessments, and intervention effectiveness evaluation. Overall, this research reinforces the value of Environmental Health Risk Assessment as a practical framework for translating environmental contamination data into actionable, preventive health interventions in coastal communities.

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AUTHORS' CONTRIBUTION

Sri Seprianto Maddusa conceptualized and designed the study, supervised field data collection, and led the manuscript preparation. Afnal Asrifuddin contributed to the study methodology, performed data analysis, and assisted in interpreting the epidemiological findings. Eva M. Mantjoro contributed to data collection, supported statistical analysis, and reviewed and revised the manuscript critically for important intellectual content. All authors have read and approved the final manuscript.

COMPETING INTEREST

The author(s) declare no potential conflict of interest with respect to the research, authorship, or publication

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