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Research Article

A Preliminary Assessment of Mercury and Cadmium Concentration in Coastal Fish of Island Garden City of Samal, Davao del Norte

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Abstract
Heavy metal contamination in marine ecosystems poses potential risks to fisheries resources, seafood safety, and public health because of the persistence and bioaccumulative properties of toxic metals. This study aimed to determine the concentrations of mercury (Hg) and cadmium (Cd) in selected reef fish species collected from the Island Garden City of Samal (IGACOS), Davao del Norte, Philippines, compare the concentrations between the Babak and Kaputian districts, and evaluate the results against international food safety standards. A quantitative, cross-sectional research design was employed using field sampling and laboratory analysis. Fish muscle tissues were collected from twenty sampling stations and analyzed for mercury and cadmium concentrations using Atomic Absorption Spectrophotometry following standardized analytical procedures. Mercury concentrations ranged from 0.0177 to 0.0536 $mg \cdot kg^{-1}$, while cadmium concentrations ranged from non-detectable levels to 0.0200 $mg \cdot kg^{-1}$. All measured concentrations remained below the maximum permissible limits established by international standards. Independent samples t-test results indicated no statistically significant differences in mercury ($p = 0.276$) and cadmium ($p = 0.295$) concentrations between the two districts. The findings indicate generally low levels of heavy metal contamination in the sampled fishery resources and provide baseline information for environmental monitoring and fisheries management. Continuous monitoring and expanded assessments involving additional contaminants and fish species are recommended to support sustainable coastal resource management and ensure long-term seafood safety.

Keywords
heavy metals, mercury, cadmium, reef fish, fisheries management

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Author Contributions
The authors contributed to conceptualization, methodology, investigation, writing—original draft preparation, writing—review and editing, and supervision. The authors approved the final manuscript.
Ethics Statement
This study was conducted in accordance with ethical standards.

INTRODUCTION
Heavy metals are naturally occurring elements that become environmental contaminants when released into aquatic ecosystems through both natural processes and anthropogenic activities. Rapid urbanization, industrialization, agriculture,

maritime transportation, and improper waste disposal have contributed to increasing concentrations of toxic metals in marine environments worldwide. Among these contaminants, mercury (Hg) and cadmium (Cd) are of particular concern because of their persistence, toxicity, and ability to bioaccumulate in aquatic organisms and biomagnify through food webs. Fish readily accumulate these metals from surrounding waters, sediments, and dietary sources, making them important indicators of marine environmental quality and potential pathways of human exposure through seafood consumption (Wang & Fisher, 1999; Lavoie et al., 2013). Chronic exposure to mercury and cadmium has been associated with neurological, renal, developmental, and skeletal disorders, emphasizing the need for continuous monitoring of heavy metals in fishery resources to protect both ecosystem and public health (European Food Safety Authority, 2012; World Health Organization, 2024). Consequently, regular assessment of heavy metal contamination supports sustainable fisheries management and contributes to global food security by ensuring the safety and quality of aquatic food resources (Food and Agriculture Organization of the United Nations, 2018, 2020).

The Island Garden City of Samal (IGACOS), located within the Davao Gulf, is one of the major coastal tourism and fishing destinations in Southern Philippines. Fisheries provide an important source of livelihood for coastal communities and contribute significantly to local food security. However, increasing tourism, coastal development, maritime transportation, and expanding human settlements have intensified environmental pressures on the island's coastal ecosystems. Records from the City Investment and Tourism Office indicate a substantial increase in both domestic and international tourist arrivals in 2025, reflecting the continuing expansion of tourism-related activities in the area (City Investment and Tourism Office of the Island Garden City of Samal, 2025). At the same time, the Waste Analysis and Characterization Study reported that approximately 3.2 tons of solid waste remain uncollected daily, increasing the likelihood of waste entering coastal waters through runoff (World Wide Fund for Nature Philippines, 2021). Previous studies have likewise shown that heavy metal contamination has become an emerging concern in Philippine coastal ecosystems because contaminants originating from domestic, agricultural, and maritime activities may accumulate in fishery resources intended for human consumption (Perelonia et al., 2017). These environmental conditions highlight the importance of monitoring heavy metal contamination in coastal fish species harvested from IGACOS.

Although numerous investigations have evaluated heavy metal contamination in aquatic environments, many studies have focused primarily on water and sediment quality rather than on fish species directly consumed by local communities. Existing studies have also concentrated on heavily urbanized or industrialized coastal areas, leaving limited baseline information on mercury and cadmium accumulation in reef fish from IGACOS. Furthermore, few local studies have compared heavy metal concentrations between the northern and southern fishing grounds of the island, despite differences in tourism activities, coastal development, and fishing intensity. This empirical and contextual gap limits the availability of scientific evidence needed to support fisheries management, environmental monitoring, and seafood safety assessment within the locality. Establishing baseline information on heavy metal concentrations in commercially important reef fishes is therefore necessary to strengthen local environmental management and provide reference data for future monitoring programs.

This study aimed to conduct a preliminary assessment of mercury and cadmium concentrations in selected reef fish species collected from the Babak and Kaputian districts of the Island Garden City of Samal, Davao del Norte. Specifically, the study determined the concentrations of mercury and cadmium in fish muscle tissues, compared contaminant levels between the two districts, and evaluated the results against internationally accepted food safety standards. The findings are expected to provide baseline scientific evidence that will support fisheries resource management, environmental protection initiatives, and public health decision-making in the locality. Although the study was limited to selected reef fish species collected during a single sampling period, it contributes new local data on heavy metal contamination and establishes a foundation for future long-term monitoring and ecological risk assessment in the coastal waters of IGACOS.

METHODOLOGY

Design

This study employed a quantitative research design to determine the concentrations of mercury (Hg) and cadmium (Cd) in selected reef fish species collected from the coastal waters of the Island Garden City of Samal (IGACOS), Davao del Norte. A quantitative approach was considered appropriate because it allows the systematic measurement and objective analysis of heavy metal concentrations using standardized laboratory procedures. The study adopted a cross-sectional environmental assessment in which fish samples were collected once from selected sampling stations and analyzed to determine the existing levels of mercury and cadmium. The findings were subsequently compared with internationally recognized food safety standards to evaluate the safety of fishery resources for human consumption.

Sampling

A multistage sampling approach was employed to ensure representative coverage of the study area. The Babak and Kaputian districts were purposively selected because they are among the major fishing areas in IGACOS and represent the northern and southern coastal sections of the island. Within each district, ten sampling stations were selected through simple random sampling from identified fishing grounds, resulting in a total of twenty sampling stations. Fish samples were obtained directly from local fishermen during actual fishing operations. The study focused on commonly available reef fish species, particularly *Cephalopholis miniata* and *Scarus margaritiferus*, because these species are frequently harvested for human consumption and represent different trophic levels within the marine food web. The selection of reef fishes provides ecologically relevant information on heavy metal accumulation in commercially important fishery resources.

Collection

Fish sample collection was conducted following internationally accepted procedures for contaminant monitoring in food and aquatic organisms. Freshly caught fish were collected immediately after capture to minimize contamination during handling and transportation. The researcher accompanied local fisherfolk during fishing activities to ensure that all samples originated from the identified sampling stations. The edible muscle tissue of each fish was carefully separated because it represents the primary portion consumed by humans and is the recommended tissue for evaluating food safety. Samples were properly labeled, stored in clean containers, maintained under appropriate temperature conditions, and transported to the analytical laboratory for examination. Sample handling and preservation followed recommended procedures for environmental contaminant analysis to maintain sample integrity and prevent contamination during transport and storage (U.S. Environmental Protection Agency, 2001).

Analysis

Laboratory analysis was conducted to determine the concentrations of mercury (Hg) and cadmium (Cd) in fish muscle tissues. Mercury concentrations were analyzed using Cold Vapor Atomic Absorption Spectrophotometry (CV-AAS), whereas cadmium concentrations were determined using the Dry Ashing Atomic Absorption Spectrophotometry method. Both analytical procedures followed the Official Methods of Analysis of the Association of Official Analytical Chemists to ensure analytical accuracy, precision, and reliability (Association of Official Analytical Chemists, 2000). Analytical replicates were performed, and the mean concentration obtained from replicate analyses was reported as the final value for each sample. The measured concentrations were evaluated against the maximum permissible limits established by the European Commission (2006) and the Heavy Metals Regulations of the Government of Eritrea (2003), which specify maximum allowable concentrations of 0.50 $mg \cdot kg^{-1}$ for mercury and 0.05 $mg \cdot kg^{-1}$ for cadmium in fish intended for human consumption. Descriptive statistics were used to summarize mercury and cadmium concentrations across sampling stations. An independent samples t-test was performed to determine whether significant differences existed between the Babak and Kaputian districts. Statistical analysis was conducted using appropriate statistical software, with the level of significance set at $\alpha = 0.05$. A p-value less than .05 was interpreted as statistically significant, whereas a p-value greater than .05 indicated no significant difference between districts.

Ethical Considerations

Administrative permission was obtained from the concerned local government units before the commencement of field sampling. Fish collection was conducted in coordination with local fisherfolk to ensure that sampling activities complied with existing fisheries regulations and did not interfere with normal fishing operations. The study adhered to the provisions of the Philippine Fisheries Code of 1998, as amended by Republic Act No. 10654, which promotes the sustainable utilization, conservation, and management of fishery resources (Bureau of Fisheries and Aquatic Resources, 2019). To ensure responsible reporting, laboratory results were validated before interpretation and dissemination. Any findings with potential implications for public health or fisheries management were intended to be communicated first to the appropriate local government authorities through formal technical reporting. All laboratory records, field data, and electronic files were securely stored using password-protected devices, and access was limited to the researcher and academic adviser to maintain data confidentiality and research integrity.

Limitations and Rigor

This study was limited to the determination of mercury and cadmium concentrations in selected reef fish species collected from twenty sampling stations in the Babak and Kaputian districts of IGACOS. Other potentially hazardous heavy metals, such as lead, arsenic, and chromium, were not included because of laboratory and financial constraints. Sampling was conducted only once; therefore, seasonal variations in heavy metal concentrations were not evaluated. Consequently, the findings represent the environmental conditions during the sampling period and should be interpreted as preliminary baseline information rather than comprehensive long-term environmental trends. Despite these limitations, methodological rigor was maintained through the use of standardized field sampling procedures, internationally recognized laboratory methods, analytical replicates, and internationally accepted food safety standards for data interpretation. The systematic sampling design and adherence to established analytical protocols enhanced the reliability and validity of the findings, providing credible baseline information for future environmental monitoring and fisheries management initiatives in the Island Garden City of Samal.

RESULTS AND DISCUSSION

Table 1 presents the maximum permissible concentrations of mercury (Hg) and cadmium (Cd) in fish used as reference standards for evaluating the laboratory results. The allowable limits are 0.50 $mg \cdot kg^{-1}$ for mercury and 0.05 $mg \cdot kg^{-1}$ for cadmium, which serve as internationally accepted benchmarks for assessing seafood safety. These regulatory thresholds provide an objective basis for determining whether the measured concentrations of heavy metals pose potential health risks to consumers. Using internationally recognized standards also strengthens the validity of contaminant assessment and ensures consistency with global food safety regulations. Maximum permissible limits for heavy metals in fish were established to protect consumers from chronic exposure through dietary intake and to promote food safety in fisheries products (European Commission, 2006; Government of Eritrea, 2003). Mercury and cadmium are recognized as priority contaminants because of their persistence, toxicity, and ability to accumulate in aquatic organisms and subsequently enter the human food chain (European Food Safety Authority, 2012; World Health Organization, 2007). The use of these standards provides a reliable framework for evaluating the safety of fish harvested from the Island Garden City of Samal. Consequently, all laboratory results in this study were interpreted against these permissible limits to determine whether the measured concentrations remain within acceptable levels for human consumption.

Table 1
Maximum Permissible Limits of Mercury (Hg) and Cadmium (Cd) in Fish

Sample	Mercury (Hg) ($mg \cdot kg^{-1}$)	Cadmium (Cd) ($mg \cdot kg^{-1}$)
Fish	<0.50	<0.05

Note. The maximum permissible concentrations for mercury and cadmium in fish were adopted from Commission Regulation (EC) No. 1881/2006 (European Commission, 2006) and Heavy Metals Regulations, Legal Notice No. 66/2003 (Government of Eritrea, 2003).

Table 2 presents the distribution of the sampling stations established across the Babak and Kaputian districts of the Island Garden City of Samal. A total of twenty sampling stations, equally distributed between the two districts, were selected to provide representative coverage of the study area. The balanced distribution of sampling locations enhances the representativeness of the assessment and allows reliable comparison of heavy metal concentrations between districts. Sampling from multiple fishing grounds also reduces site-specific bias and provides a more comprehensive evaluation of contaminant occurrence within the coastal environment. Representative environmental sampling is fundamental in contaminant monitoring because heavy metal concentrations may vary according to local environmental conditions and anthropogenic activities (U.S. Environmental Protection Agency, 2001). Likewise, systematic sampling across representative fishing grounds supports sustainable fisheries assessment by providing reliable baseline information for environmental management and resource conservation (Food and Agriculture Organization of the United Nations, 2018). The sampling design adopted in this study therefore strengthens the reliability of the findings and provides baseline information that may support future environmental monitoring and fisheries management programs in the Island Garden City of Samal.

Table 2
Description of the Twenty Fish Sampling Stations in Babak and Kaputian Districts

District	Station Numbers	Number of Sampling Stations
Babak	Stations 1–10	10
Kaputian	Stations 11–20	10
Total	Stations 1–20	20

Note. Ten representative sampling stations were established in each district using a multistage sampling approach. Fish samples were collected from actual fishing grounds in the Island Garden City of Samal for mercury and cadmium analysis.

Table 3 summarizes the analytical methods used to determine mercury and cadmium concentrations in the collected fish samples. Mercury was analyzed using Cold Vapor Atomic Absorption Spectrophotometry, whereas cadmium was determined using the Dry Ashing Atomic Absorption Spectrophotometry method following internationally recognized laboratory procedures. The application of standardized analytical methods enhances the accuracy, precision, and reliability of laboratory measurements. It also ensures that the generated data are comparable with findings from previous investigations and international monitoring programs. The Official Methods of Analysis recommend these analytical procedures because of their sensitivity and reliability in determining heavy metal concentrations in biological samples (Association of Official Analytical Chemists, 2000). Similarly, standardized laboratory protocols are essential for producing high-quality environmental data and minimizing analytical errors during contaminant assessment (U.S. Environmental Protection Agency, 2001). The use of internationally accepted analytical procedures therefore increases confidence that the reported mercury and cadmium concentrations accurately represent contaminant levels in the collected fish samples and provide reliable information for environmental assessment.

Table 3
Analytical Methods Used for the Determination of Heavy Metals in Fish Samples

Heavy Metal	Analytical Method	Instrument	Reference
Mercury (Hg)	Cold Vapor Atomic Absorption Spectrophotometry (CV-AAS)	Atomic Absorption Spectrophotometer	Association of Official Analytical Chemists (2000)
Cadmium (Cd)	Dry Ashing Atomic Absorption Spectrophotometry	Atomic Absorption Spectrophotometer	Association of Official Analytical Chemists (2000)

Note. Heavy metal analyses were conducted following the Official Methods of Analysis (17th ed.) of the Association of Official Analytical Chemists (2000). Analytical replicates were performed, and the mean concentration was reported for each sample.

Table 4 shows that mercury concentrations in the collected fish samples ranged from 0.0177 to 0.0536 $mg \cdot kg^{-1}$. The highest mercury concentration was detected in *Cephalopholis miniata*, whereas the lowest concentration was observed in *Scarus margaritiferus*. All measured concentrations remained considerably lower than the international permissible limit of 0.50 $mg \cdot kg^{-1}$. The observed variation indicates that mercury accumulation differs among fish species, with relatively higher concentrations occurring in the carnivorous species. This pattern suggests that feeding behavior and trophic position influence mercury accumulation in marine organisms. Mercury is known to biomagnify through aquatic food webs, causing predatory fish occupying higher trophic levels to accumulate greater concentrations than herbivorous species (Lavoie et al., 2013). The accumulation of trace elements in aquatic organisms is also influenced by dietary uptake, assimilation efficiency, and contaminant retention within tissues (Wang & Fisher, 1999). Similar observations have been reported in studies identifying predatory fish as effective biological indicators of mercury contamination because of their tendency to accumulate higher concentrations throughout their lifespan (Storelli & Marcotrigiano, 2001). Although mercury was detected in all fish samples, the measured concentrations remained well below international food safety limits, indicating a low level of contamination in the sampled coastal waters. Nevertheless, mercury is a persistent contaminant capable of bioaccumulating over time; therefore, continued environmental monitoring is necessary to ensure that increasing coastal development and human activities do not compromise seafood safety (World Health Organization, 2024; Food and Agriculture Organization of the United Nations, 2020).

Table 4
Mercury (Hg) Concentrations in Fish Samples Collected from Babak and Kaputian Districts

Location	Station	Fish Species	Mercury ($mg \cdot kg^{-1}$)	Permissible Limit ($mg \cdot kg^{-1}$)
Babak	1	Scarus margaritiferus	0.0283	<0.50
	2	Scarus margaritiferus	0.0345	
	3	Cephalopholis miniata	0.0473	
	4	Cephalopholis miniata	0.0244	
	5	Scarus margaritiferus	0.0345	
	6	Scarus margaritiferus	0.0333	
	7	Cephalopholis miniata	0.0400	
	8	Scarus margaritiferus	0.0182	
	9	Scarus margaritiferus	0.0247	
	10	Cephalopholis miniata	0.0477	
Kaputian	11	Cephalopholis miniata	0.0469	<0.50
	12	Cephalopholis miniata	0.0446	
	13	Scarus margaritiferus	0.0177	
	14	Scarus margaritiferus	0.0225	
	15	Scarus margaritiferus	0.0382	
	16	Scarus margaritiferus	0.0380	
	17	Scarus margaritiferus	0.0469	
	18	Scarus margaritiferus	0.0385	
	19	Cephalopholis miniata	0.0536	
	20	Cephalopholis miniata	0.0383	

Note. The maximum permissible mercury concentration is 0.50 $mg \cdot kg^{-1}$ (European Commission, 2006; Government of Eritrea, 2003).

Table 5 presents cadmium concentrations ranging from non-detectable levels to 0.0200 $mg \cdot kg^{-1}$. Several fish samples contained no detectable cadmium, while the highest concentration was recorded in selected samples collected from Babak District. All measured concentrations remained below the international permissible limit of 0.05 $mg \cdot kg^{-1}$. These findings indicate limited cadmium accumulation in the edible muscle tissues of the sampled fishes. Compared with mercury, cadmium exhibited lower concentrations and greater variability among sampling stations, suggesting relatively low environmental bioavailability. Previous studies have likewise reported that cadmium generally accumulates at lower concentrations in marine fish because its uptake is influenced primarily by environmental availability rather than trophic biomagnification (Yi et al., 2011). Heavy metal accumulation is further affected by environmental transfer processes and physicochemical conditions that regulate contaminant mobility and biological uptake (Tong et al., 2022). The mechanisms governing trace element accumulation in aquatic organisms also limit cadmium retention in muscle tissues under normal environmental conditions (Wang & Fisher, 1999). Since all measured concentrations were below internationally accepted food safety limits, the sampled fish may be considered safe for human consumption with respect to cadmium contamination (European Commission, 2006; Government of Eritrea, 2003). However, continuous monitoring remains essential because cadmium persists in aquatic ecosystems and prolonged exposure may result in adverse effects on human health (European Food Safety Authority, 2012; U.S. Environmental Protection Agency, 2006).

Table 5
Cadmium (Cd) Concentrations in Fish Samples Collected from Babak and Kaputian Districts

Location	Station	Fish Species	Cadmium ($mg \cdot kg^{-1}$)	Permissible Limit ($mg \cdot kg^{-1}$)
Babak	1	Scarus margaritiferus	0.020	<0.05
	2	Scarus margaritiferus	0.020	
	3	Cephalopholis miniata	ND	
	4	Cephalopholis miniata	0.000	
	5	Scarus margaritiferus	0.020	
	6	Scarus margaritiferus	0.010	
	7	Cephalopholis miniata	0.020	
	8	Scarus margaritiferus	ND	
	9	Scarus margaritiferus	0.010	
	10	Cephalopholis miniata	0.011	
Kaputian	11	Cephalopholis miniata	ND	<0.05
	12	Cephalopholis miniata	0.020	
	13	Scarus margaritiferus	0.010	
	14	Scarus margaritiferus	ND	
	15	Scarus margaritiferus	0.020	
	16	Scarus margaritiferus	ND	
	17	Scarus margaritiferus	ND	
	18	Scarus margaritiferus	0.010	
	19	Cephalopholis miniata	ND	
	20	Cephalopholis miniata	0.010	

Note. ND = Not detected. The maximum permissible cadmium concentration is 0.05 $mg \cdot kg^{-1}$ (European Commission, 2006; Government of Eritrea, 2003).

Table 6 presents the comparison of mercury and cadmium concentrations between Babak and Kaputian districts. Statistical analysis revealed no significant differences in mercury (p = 0.276) and cadmium (p = 0.295) concentrations between the two sampling areas. The absence of statistically significant variation suggests that both districts experience relatively similar environmental conditions and contaminant exposure pathways. Although slight numerical differences were observed, these were insufficient to indicate distinct spatial patterns of heavy metal contamination. Diffuse sources of heavy metals, including domestic wastewater, coastal runoff, maritime transportation, tourism, and other anthropogenic activities, commonly produce relatively homogeneous contaminant distributions in interconnected coastal environments (Perelonia et al., 2017). Similar ecological assessments have reported that the absence of significant spatial variation often reflects widespread low-level contamination rather than localized pollution sources (Yi et al., 2011). Increasing tourism activities and coastal development in the Island Garden City of Samal, together with the generation of unmanaged solid waste, may contribute diffuse contaminant inputs that are dispersed throughout the coastal environment by tidal circulation and water movement (City Investment and Tourism Office of the Island Garden City of Samal, 2025; World Wide Fund for Nature Philippines, 2021). These findings indicate that current fisheries management and environmental monitoring programs may be implemented uniformly across both districts. Nevertheless, regular monitoring remains essential to detect future changes in heavy metal concentrations associated with expanding coastal development and increasing anthropogenic activities, thereby supporting the sustainable management of fisheries resources and the protection of public health (Food and Agriculture Organization of the United Nations, 2018; Bureau of Fisheries and Aquatic Resources, 2019).

Table 6
Independent Samples t-Test Comparing Mercury (Hg) and Cadmium (Cd) Concentrations Between Babak and Kaputian Districts

Heavy Metal	District	Mean ($mg \cdot kg^{-1}$)	p-value	Interpretation
Mercury (Hg)	Babak	0.03329	0.276	Not Significant
	Kaputian	0.03852		
Cadmium (Cd)	Babak	0.01110	0.295	Not Significant
	Kaputian	0.00700		

Note. An independent samples t-test was conducted at a 0.05 level of significance. Since p > .05 for both mercury and cadmium, there were no statistically significant differences in heavy metal concentrations between Babak and Kaputian Districts.

Conclusion and Recommendations

This study conducted a preliminary assessment of mercury (Hg) and cadmium (Cd) concentrations in selected reef fish species collected from the Babak and Kaputian districts of the Island Garden City of Samal (IGACOS), Davao del Norte. The findings revealed that mercury concentrations ranged from 0.0177 to 0.0536 $mg \cdot kg^{-1}$, while cadmium concentrations ranged from non-detectable levels to 0.0200 $mg \cdot kg^{-1}$. All measured concentrations were below the maximum permissible limits established by international food safety standards, indicating that the analyzed fish samples are safe for human consumption with respect to mercury and cadmium contamination. Furthermore, independent samples t-test results showed no statistically significant differences in mercury and cadmium concentrations between the two districts, suggesting relatively uniform environmental exposure across the sampled coastal waters. The study contributes baseline information on heavy metal contamination in reef fish from IGACOS, addressing the limited local evidence regarding mercury and cadmium accumulation in fishery resources. The findings further demonstrate that species occupying higher trophic levels exhibited relatively higher mercury concentrations, supporting the influence of feeding ecology on contaminant accumulation. Overall, the results indicate that the current levels of mercury and cadmium do not pose an immediate public health concern; however, the consistent detection of mercury across all samples confirms the presence of ongoing low-level environmental exposure. These findings provide valuable scientific evidence that can support fisheries management, environmental monitoring, and local policy development aimed at protecting marine ecosystem health and ensuring seafood safety.

Based on the findings, the City Government of the Island Garden City of Samal, the Bureau of Fisheries and Aquatic Resources, and other concerned environmental agencies should strengthen routine monitoring of mercury and cadmium concentrations in fishery resources and adjacent coastal environments. Regular monitoring of fish, water, and sediments will facilitate the early detection of changes in contaminant levels and support evidence-based management decisions. Local government units should also strengthen solid waste management, regulate coastal development activities, and promote environmentally responsible tourism and fishing practices to minimize anthropogenic sources of heavy metal contamination. Public information campaigns on seafood safety and environmental conservation may likewise increase community awareness and encourage sustainable utilization of marine resources. Future studies should expand the geographical coverage and include a greater diversity of fish species representing different trophic levels to obtain a more comprehensive assessment of heavy metal bioaccumulation in the marine ecosystem. Long-term monitoring across different seasons is also recommended to evaluate temporal variations in contaminant concentrations and their relationship with environmental conditions. Moreover, future investigations may include additional priority contaminants, such as lead, arsenic, and chromium, together with human health risk assessments based on fish consumption patterns. These initiatives will strengthen the scientific basis for environmental management, fisheries conservation, and public health protection in the Island Garden City of Samal and other coastal communities in the Philippines.

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