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Evaluation of Microbiological Indicator Contamination (Escherichia coli) and Heavy Metal Levels in Edible Fish from Situ Bambon, Ciracas: A Health Risk Assessment

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Abstract

Situ Bambon in Ciracas, East Jakarta, is utilized by the local community for daily activities ranging from recreation, angling, to net fishing. The community frequently utilizes the areas around the inlet, midstream, and outlet to catch fish. This study aims to evaluate the content of the microbiological indicator E. coli and heavy metal levels in edible fish from Situ Bambon Ciracas to obtain a comprehensive Health Risk Assessment. The results showed that the microbiological contamination levels through the Escherichia coli indicator in edible fish ranged from <1.8 to 13.9 MPN/g, indicating that fish samples in the inlet 1 and outlet 2 areas failed to meet food safety standards (< 3 APM/g). The worst concentrations of Cadmium (Cd) and Lead (Pb) in edible fish from Situ Bambon were found in the inlet 2 area, with a Cd value of 0.83 mg/kg and a Pb value of 0.80 mg/kg. The obtained Cd and Pb contamination levels exceeded the Maximum Contaminant Limits (MCL) established by PerBPOM Number 9 of 2022, where Cd was approximately 8.3 times higher, while Pb exceeded the limit by about 2.7 times. The Health Risk Assessment (HRA) indicated that the Hazard Index (HI) value of 1.489 exceeded the allowable tolerance threshold of 1.0. Risk contribution analysis showed that Cd accounted for 51.0% of the total HI risk, while Hg contributed 35.0%. Furthermore, the carcinogenic risk (cancer) was evaluated through the Total Risk (TR) for Cadmium (Cd) because it possesses the highest Slope Factor (SF) of 0.38 $(mg/kg\text{-}day)^{-1}$, calculated based on the Lifetime Average Daily Dose (LADD) and SF, yielding a result of 3.37×10^{-7}. This value remains below the internationally acceptable carcinogenic risk threshold of TR < 10^{-6}. The environment-fish-human exposure cycle in Situ Bambon has reached a hazardous threshold and demands top-priority intervention to protect public health.

Keywords: biomonitoring, phytoplankton, macrozoobenthos, community structure, water quality

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INTRODUCTION

Situ Bambon Ciracas in East Jakarta has experienced ecological degradation caused by complex pollution that threatens both ecological and social functions. From a regulatory perspective, the water quality of Situ Bambon is targeted to meet Class II standards, which establish strict threshold values to support recreational activities and aquatic ecosystem protection (DIKPLHD, 2024). However, the relationship between water quality and human health risks is inseparable from the role of fish as a primary human exposure pathway through consumption, where fish serve as a biological matrix that transfers pollutants directly from the environment into the human food chain (Dippong et al., 2024). Massive anthropogenic pressures from densely populated residential areas and industries in the Ciracas region have driven water quality degradation beyond the pollution load capacity. The aquatic quality of Situ Bambon Ciracas indicates that heavy metal contamination is in a light to moderately polluted status (DPR RI, 2021), with BOD (5–34.67 mg/L) and COD (17.05–193.56 mg/L) values consistently exceeding Class II water quality standards (Cundaningsih et al., 2025). KLHK (2023) notes that 68% of Indonesian urban lakes undergo eutrophication, including Situ Bambon (KLHK, 2023). Within this contaminated ecosystem, fish are chronically exposed to pollutants that possess a high capacity for bioaccumulation within muscle tissues, which are subsequently consumed by the public (Dippong et al., 2024).

The government has made efforts to maintain and improve lake water quality, one of which is by enacting the Regulation of the Government of the Republic of Indonesia Number 22 of 2021 concerning the Implementation of Environmental Protection and Management (DPR RI, 2021). Pollutants in lake water are inherently hazardous to humans, particularly bioaccumulative substances such as heavy metals (Ahyar et al., 2018). A study by Dippong et al. (2024) aimed to examine metal transfer from water to fish tissues and assess the associated health risks; the results demonstrated that despite the water quality being physically deemed good, the fish muscle tissues contained accumulated Fe, Zn, and Mn exceeding safe limits for human consumption (Dippong et al., 2024). Furthermore, another high-risk lake water pollutant to human health is bacteria or viruses, notably Escherichia coli (Mokodompit et al., 2020). Pathogenic bacteria dominating urban lake ecosystems are predominantly E. coli (Ferdana et al., 2021). The presence of Escherichia coli in lake waters indicates the discharge of fecal waste from humans or warm-blooded animals into the water body. The high level of E. coli contamination in domestic wastewater warrants vigilance, given that E. coli serves as an indicator of pathogenic bacteria. This aligns with a study conducted by Widiyanti et al., which stated that if the E. coli content reaches 1,000 cells/100 mL, it is highly probable that pathogenic bacteria are present in the water, thereby threatening human health (Widiyanti et al., 2017). Beyond standard bacteriological risks, Sohidullah et al. (2025) explored aquatic commodities with the objective of detecting antibiotic resistance genes and assessing heavy metal risks; their findings revealed that 51.28% of the bacterial isolates exhibited multidrug-resistant (MDR) properties, which could endanger consumer health through the food chain Sohidullah et al. (2025).

Palgunadi and Purnama conducted a study to determine the bioaccumulation and public health risk assessment of Pb and Cd heavy metal pollution in fish caught in Tukad Badung, Denpasar; their findings indicated that the average lead level in both fish species exceeded the maximum limit for Pb established by the Indonesian FDA (PerBPOM) Regulation Number 23 of 2017. Regarding the health risk assessment results, the Estimated Daily Intake (EDI) values indicated a high-risk daily intake of Pb, while the Target Hazard Quotients (THQ) for Pb showed a low-level non-carcinogenic risk, and the Target Cancer Risk (TR) for Pb indicated a low-level carcinogenic risk (Palgunadi & Purnama, 2022). A similar condition was evaluated by Birie et al. (2024) with the objective of assessing the microbiological quality and metal accumulation in tilapia fish fillets; their results demonstrated a high microbiological load and Chromium (Cr) concentrations exceeding safety standards, potentially triggering long-term health risks such as cancer (Birie et al., 2024). A study aimed at analyzing the relationship between total organic matter concentrations and E. coli abundance was carried out by Ning Asih et al. (2024), showing that chemical and physical parameters heavily influence the abundance of E. coli bacteria, namely total salinity, pH, temperature, and Dissolved Oxygen (DO) (Asih, Ramadhanti, & Wicaksono, 2024b). Fish have also been proven to act as reservoirs for resistance genes, as demonstrated by a study by Yalcin & Cebeci (2026) which aimed to evaluate the heavy metal resistance characteristics of bacterial isolates from fish; their findings successfully identified the pcoD gene encoding copper (Cu) resistance, confirming the role of fish in transferring resistance factors from the environment to humans (Yalcin & Cebeci, 2026).

Based on the monitoring results by the Environmental Agency (Dinas Lingkungan Hidup - DLH) of East Jakarta City in 2024, E. coli bacteria were the highest contributor to pollution in Situ Bambon Ciracas, reaching 500,000 MPN/100 mL, indicating a moderate to severe pollution level. Water quality tests indicated that bioaccumulative heavy metal parameters were in a lightly polluted status (DIKPLHD, 2024). Fishing and netting activities raise concerns regarding the toxicological effects of fishery products from Situ Bambon Ciracas, given the water quality monitoring by the DLH of East Jakarta Administrative City, which shows that the lake waters are lightly to moderately polluted, and during certain periods, such as the dry season, the status degrades to severely polluted. Although mitigation strategies, such as the use of probiotics, have been investigated by Giri et al. (2024) with the objective of remediating heavy metal toxicity in aquaculture to reduce its bioavailability, the threat of exposure through direct consumption from public waters still demands profound attention (Giri et al., 2024). Currently, studies examining heavy metal content and E. coli bacteria in fish associated with potential health risks due to consuming fish from Situ Bambon Ciracas have not yet been conducted. In fact, it is critical to determine the microbiological indicators of E. coli and heavy metal levels to obtain a comprehensive Health Risk Assessment. This study will analyze the microbiological indicators of E. coli and heavy metal levels in fish commonly caught by the local community as the primary exposure pathway for humans.

METHOD

The methodology describes in detail the steps taken in this research. The explanation of these steps starts from the preparation stage, field activities, to field data analysis, and then ends with the results following the research objectives.

Research Location and Time

The research location is Situ Bambon Ciracas at Jalan Raya PKP 6°20'19.99"LS 106°53'8.57"BT as shown in **Figure 1**. The research was conducted from January to March 2023.

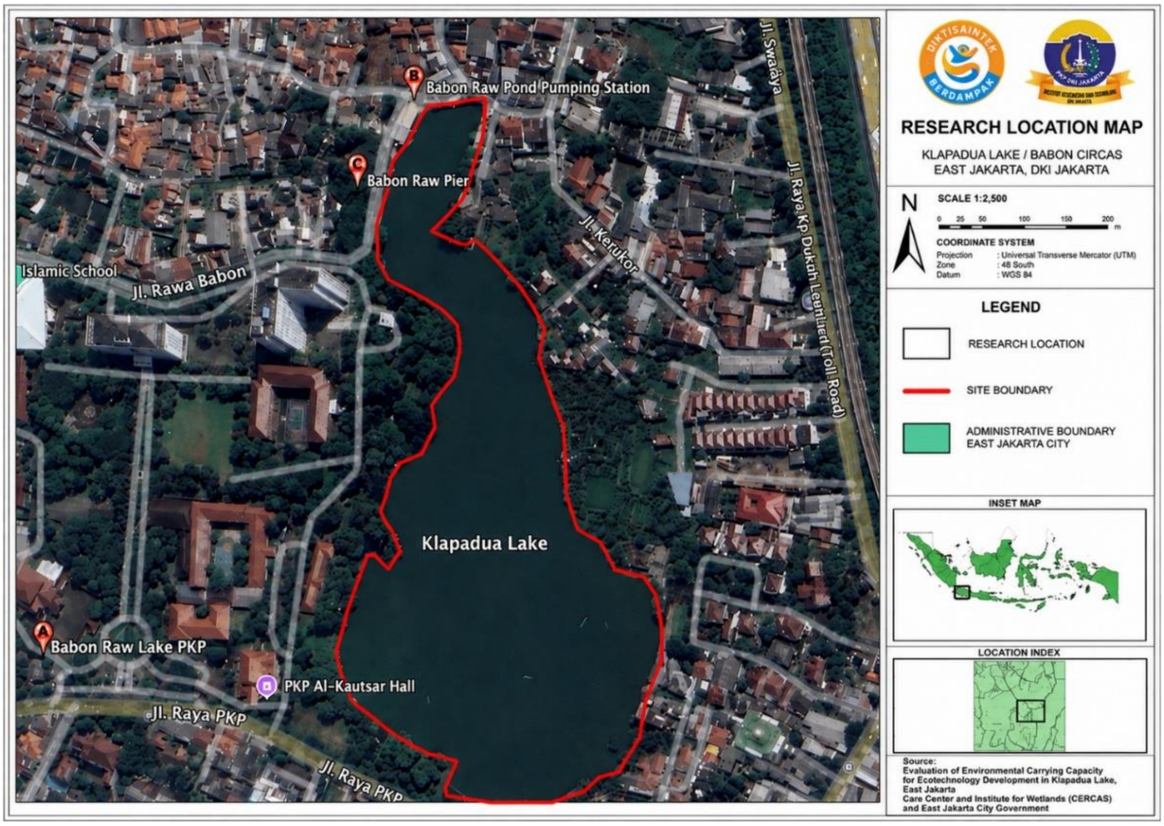

Figure 1. Research Site Map

Research Equipment

This study utilized a series of specific tools and materials to analyze multi-sector contamination in edible fish from Situ Bambon Ciracas, including a GPS device for coordinate positioning, fish storage buckets, and a cooler box for sample preservation. Laboratory analysis involved two primary sets of equipment: (1) for the heavy metals Pb, Cd, and Hg, Inductively Coupled Plasma Mass Spectrometry (ICP-MS) was employed following a sample digestion process with concentrated nitric acid (HNO_3), with sample preparation utilizing drying ovens and muffle furnaces; (2) additionally, E. coli bacterial contamination was analyzed using the Most Probable Number (MPN) method based on SNI 2332.1:2015. The final concentration data from all parameters were subsequently processed to calculate the Health Risk Assessment (HRA), including the HI and TR parameters, utilizing toxicity equations adopted from the US EPA guidelines.

Data Acquisition, Data Processing, and Data Interpretation

The research method consisted of several stages including field sampling and laboratory analysis (**Figure 2**). Laboratory tests were conducted at the Environmental Quality Laboratory, Faculty of Civil Engineering and Planning, Universitas Islam Indonesia, Yogyakarta.

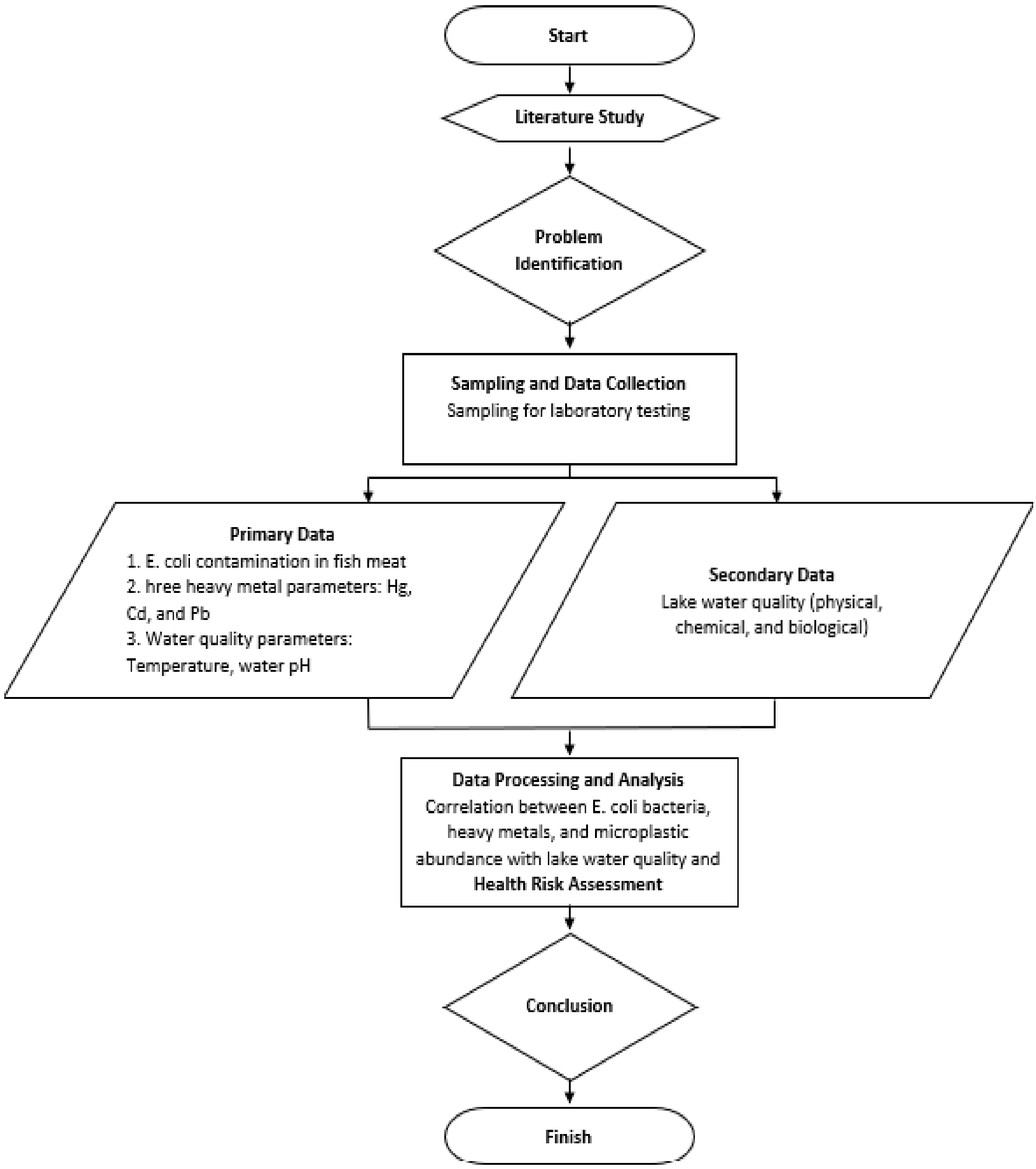

Figure 2. Research Flowchart

Fish Sampling and Microbiological Analysis

Fish sampling was conducted on fish caught by the local community within the inlet, midstream, and outlet areas of the lake, yielding a total of 6 samples, which were subsequently tested in the laboratory based on SNI 2332.1:2015 for Microbiological Test Methods - Part 1: Determination of Total Coliform and Escherichia coli in Fishery Products (BSN, 2015). The outputs of this activity consisted of the fish samples and the microbiological indicator data for E. coli bacteria. The performance indicator was defined as the availability of 6 fish samples suitable for laboratory testing along with the corresponding E. coli microbiological indicator data from those 6 samples. The information and characteristics of the edible fish samples from Situ Bambon, Kelapa Dua Wetan, East Jakarta, are as follows **Table 1**:

Table 1. The information and characteristics of the edible fish

Fish Species	Tilapia (*Oreochromis niloticus*)
Number of Samples per Research Point	Inlet: 3 fish; Midstream: 3 fish; and Outlet: 3 fish
Fish Size or Weight	±3-5 kg per sampling point
Bagian ikan yang diuji	Heavy metals: Muscle tissue (flesh) *E. coli* bacteria: Digestive tract (viscera/intestines)
Sample Analysis Method	Individual
Preservation Procedure	Samples were grouped into zip-lock plastic bags based on the sampling points, then transported using a cooler box equipped with ice packs and additional ice cubes to maintain the temperature.
Sample Transportation	Biosafety Transport (cooler box)

Heavy Metal Analysis

Heavy metal content testing was performed using Inductively Coupled Plasma-Mass Spectrometry (ICP-MS) (Pirdaus et al., 2018). The outputs of this procedure consisted of heavy metal concentration data from the fish. The performance indicator was defined as the availability of heavy metal concentration data (Pb, Cd, and Hg) from the 6 fish samples. The sample mass utilized for digestion was 0.5 grams using an acid digestion procedure, with the digestion temperature and duration complying with SNI 8910:2021; SM Ed. 24, 3125B: 2023. Concentrations were reported on a wet-weight basis. The instrument detection limit for the analysis was ICP: 0.01 μg/mL. Quality control procedures for heavy metals were conducted using an instrument calibrated with validated and internationally recognized Certified Reference Material (CRM) standards (ISO/IEC 17025 and ISO 17034) (PerkinElmer, 2025).

Water Quality Testing

Water quality testing involved chemical parameters including temperature, pH, and dissolved oxygen (DO) based on SNI 8995:2021 concerning water sampling methods for physical and chemical analysis (BSN, 2021). The output of this stage consisted of lake water quality data. Sampling was conducted in the inlet and outlet areas and compared with monitoring data from the Environmental Agency of DKI Jakarta which conducts routine monitoring twice annually.

Health Risk Assessment

Health Risk Assessment analysis included the calculation of Estimated Daily Intake (EDI), Target Hazard Quotient (THQ), Hazard Index (HI), and Total Risk (TR) to evaluate the relationship between environmental contamination and potential human health impacts. The output consisted of calculated EDI, THQ, HI, and TR values.

$$EDI = \frac{C\ x\ IR}{BW} \tag{1}$$

$$THQ = \frac{EDI}{RfD} \tag{2}$$

$$HI = \sum THQ \tag{3}$$

$$LADD = \frac{C\ x\ IR\ x\ ED\ x\ EF}{BW\ x\ AT} \tag{4}$$

$$TR = LADD \ x \ SF \tag{5}$$

where;

LADD	:	Estimated Daily Intake (mg/kg/day)	RfD	:	Reference Dose
C	:	Consentration (mg/kg)	HI	:	Hazard Index
IR	:	Intake Rate (kg/day)	AT	:	Averaging Time (day)
ED	:	Exposure Duration (years)	EF	:	Exposure Frequency (day/years)
BW	:	Body weigth (kg)	TR	:	Target Cancer Risk
THQ	:	Target Hazard Quotient	SF	:	Slope factor $(mg/kg/day)^{-1}$

Source: (U.S. Environmental Protection Agency,1989)

RESULTS AND DISCUSSION

Water Quality of Situ Bambon Ciracas

Water quality testing in this study included microbiological analysis to determine the presence of *E. coli* and total coliform indicators, ICP-MS analysis to measure heavy metal concentrations including Pb, Cd, and Hg, chemical parameter analysis including temperature, pH, Chemical Oxygen Demand (COD), and Dissolved Oxygen (DO), and physical parameter analysis including Total Suspended Solids (TSS) and Total Dissolved Solids (TDS). The microbiological analysis revealed that water in Situ Bambon Ciracas contained *E. coli* concentrations of 920,000 MPN/100 mL and fecal coliform concentrations of 920,000 MPN/100 mL in the inlet area. In the middle section, *E. coli*concentrations reached 350,000 MPN/100 mL with fecal coliform values of 350,000 MPN/100 mL. In the outlet section, *E. coli* contamination reached 1,300 MPN/100 mL with fecal coliform values of 5,400 MPN/100 mL. These bioindicator contamination values exceed the water quality standards established by Government Regulation No. 22 of 2021. Heavy metal analysis indicated that Pb concentrations were below the quality standard (<0.031 mg/L), Cd concentrations were 0.001 mg/L and still below the standard, while Mn concentrations reached 0.464 mg/L and exceeded the permissible limit. Physical parameters showed Total Dissolved Solids (TDS) values of 242 mg/L and Total Suspended Solids (TSS) values of 20.5 mg/L, both below the established water quality standards. Chemical parameter analysis indicated water temperature of 27.07°C, pH of 7.04 within acceptable limits, COD concentration of 15.5 mg/L below the quality standard, and DO concentration of 5.07 mg/L slightly above the standard threshold (**Table 2, 3, 4** and **5**).

Table 2. Results of Biological Parameter Testing of Water Quality in Situ Bambon Ciracas

Sampling Location	Sampling Date/Time / Examination Date/Time	Test result MPN Index/100 mL		Water Quality Standart			
		Fecal Coliform	E. coli	Class I		Class II	
Situ Bambon Inlet Channel	19-09-2025/09.40 19-09-2025/13.00	920.000	920.000	TCF	FCF	TCF	FCF
				1000	100	5000	1000
				Class III		Class IV	
				10000	2000	10000	2000
Situ Bambon Middle Channel	19-09-2025/10.20 19-09-2025/13.09	350.000	350.000	TCF	FCF	TCF	FCF
				1000	100	5000	1000
				Class III		Class IV	
				10000	2000	10000	2000
Situ Bambon Outlet Channel	19-09-2025/10.58 19-09-2025/13.18	5400	5400	TCF	FCF	TCF	FCF
				1000	100	5000	1000
				Class III		Class IV	
				10000	2000	10000	2000

Notes :

- Water and wastewater sampling methods for microbiological parameters: SNI 9063:2022.
- Total Coliform bacterial testing method: APHA Standard Methods, 24th Edition (2023), Methods 9221 B and C.
- *E. coli* bacterial testing method: APHA Standard Methods, 24th Edition (2023), Methods 9221 B, C, E, and G.
- Water quality standards refer to Government Regulation of the Republic of Indonesia No. 22 of 2021.
- Test results < 1.8 MPN Index/mL are considered approximately equal to 0.
- Testing parameters were determined based on client request and the collected samples.
- TCF = Total Coliform; FCF = Fecal Coliform.

Table 3. Results of Chemical Water Quality Parameters in Situ Bambon Ciracas

No.	Parameter	Unit	Submission Method	Result		
				Inlet	Midlet	Outlet
1	pH	-	SNI 6989.11-2019	7.04	6.69	8.06
2	BOD5	mg/L	APHA 5210 B-2017	10.2	4.78	10.4
3	COD	mg/L	SNI-6989.2:2009	15.2	<6.118	15.2
4	DO	mg/L	APHA 4500 O.C-2017	5.07	5,37	10,1
5	Sulfate	mg/L	SNI 6989.20-2019	19.9	20.3	23.0
6	Chlorida	mg/L	SNI 6989.19-2009	15	14.5	15
7	Nitrite as N	mg/L	SNI-06-6989.9-2004	<0.031	0,153	0.056
8	NH-N	mg/L	SNI-06-6989.30.2005	0.975	7.08	0,775
9	Total Fosfat	mg/L	SNI 6989.13-2021	0.262	0.283	0,329
10	Fluoride	mg/L	SNI-06-6989.29.2005	1.24	0.561	< 0.055
11	Cyanide	mg/L	EPA 335.2, ISO 6703	<0.010	<0.010	<0.010
12	Khlorin free	mg/L	APHA 4500-CI, 2017	0.16	0.2	0.16

Table 4. Results of Dissolved Metals and Organic Chemical Parameters of Water Quality in Situ Bambon Ciracas arsen

No.	Parameter	Unit	Submission Method	Result		
				Inlet	Midlet	Outlet
1	Arsen	mg/L	SNI-06-6989.54-2005	0.011	0.011	0.012
2	Selenium	mg/L	SNI 6989.84-2019, SNI-06-2475-1991/APHA 22ND 3111.B ed 2017	0.008	0.013	0.015
3	Iron	mg/L	SNI 6989.84-2019	0.331	0.135	0.182
4	Cadmium	mg/L	SNI-6989.84-2019	0.001	<0,001	<0.001
5	Manganese	mg/L	SNI 6989.84-2019	0.464	5.17	0.411
6	Nikel (Ni)	mg/L	SNI 6989.84-2019	<0,031	< 0,031	< 0,031
7	Seng (Zn)	mg/L	SNI 6989.84-2019	< 0,031	<0,031	< 0.031
8	Copper (Cu)	mg/L	SNI 6989.84-2019	< 0,033	< 0.033	<0,033
9	Lead	mg/L	SNI 6989.84-2019	<0,003	<0,003	<0.003
10	Khrom (VI)	mg/L	APHA 3500-Cr-B, 2017	0.040	0.011	0.08
11	Oil and grease*	mg/L	SNI 6989.10-2011	6.5	<5	<5
12	Surfaktan Anionik	mg/L	SNI-06-6989.51-2005	0.510	0.142	0.135
13	Fenol*	mg/L	SNI-06-2469-1991	0.049	< 0,004	0.066

Tabel 5. Results of Physical Parameter Testing of Water Quality in Situ Bambon Ciracas

No.	Parameter	Unit	Submission Method	Result		
				Inlet	Midlet	Outlet
1	Total Dissolved Solids	mg/L	SNI 6989.27-2019	242	312	252
2	Total Suspended Solids	mg/L	SNI 6989.3-2019 / SNI-6989.3-2019	20.5	22	26.5

Microbiological Contamination in Edible Fish

Further analysis evaluated microbiological indicators of *E. coli*, heavy metal concentrations, and microplastic abundance in edible fish collected from Situ Bambon Ciracas. Heavy metals and *E. coli* indicators were measured using ICP-MS, while microplastic identification followed the NOAA standard method. Health Risk Assessment parameters including EDI, THQ, HI, and TR were also calculated (**Table 6**).

Microbiological contamination through *Escherichia coli* indicators in edible fish ranged from 7–170 MPN/100 mL, indicating that all fish samples exceeded the safe food consumption standard (<3 APM/g). These elevated levels directly reflect the degraded water quality conditions of Situ Bambon which are categorized as heavily polluted (**Figure 3**). These findings position Situ Bambon among water bodies heavily contaminated by domestic waste inputs, similar to conditions reported in the Bengawan Solo River where fecal bacteria accumulation in fish serves as an indicator of pathogen risk. In the context of food safety, high *E. coli* contamination in freshwater organisms acts as a biological indicator of the presence of other fecal-derived pathogens that may cause acute foodborne illnesses.

Table 6. Escherichia coli Contamination in Edible Fish from Situ Bambon Ciracas

Test Parameters	Location	Unit	Result	Quality Standart (BMC)	Source of Quality Standarts	Notes
E. coli	Inlet 1	MPN/g	13.9	< 3 APM/g	SNI 2332.1:2015	Exceeds the Limit
	Inlet 2	MPN/g	<1.8	< 3 APM/g	SNI 2332.1:2015	Complies
	Midlet 1	MPN/g	<1.8	< 3 APM/g	SNI 2332.1:2015	Complies
	Midlet 2	MPN/g	<1.8	< 3 APM/g	SNI 2332.1:2015	Exceeds the Limit
	Outlet 1	MPN/g	<1.8	< 3 APM/g	SNI 2332.1:2015	Complies
	Outlet 2	MPN/g	4.3	< 3 APM/g	SNI 2332.1:2015	Exceeds the Limit

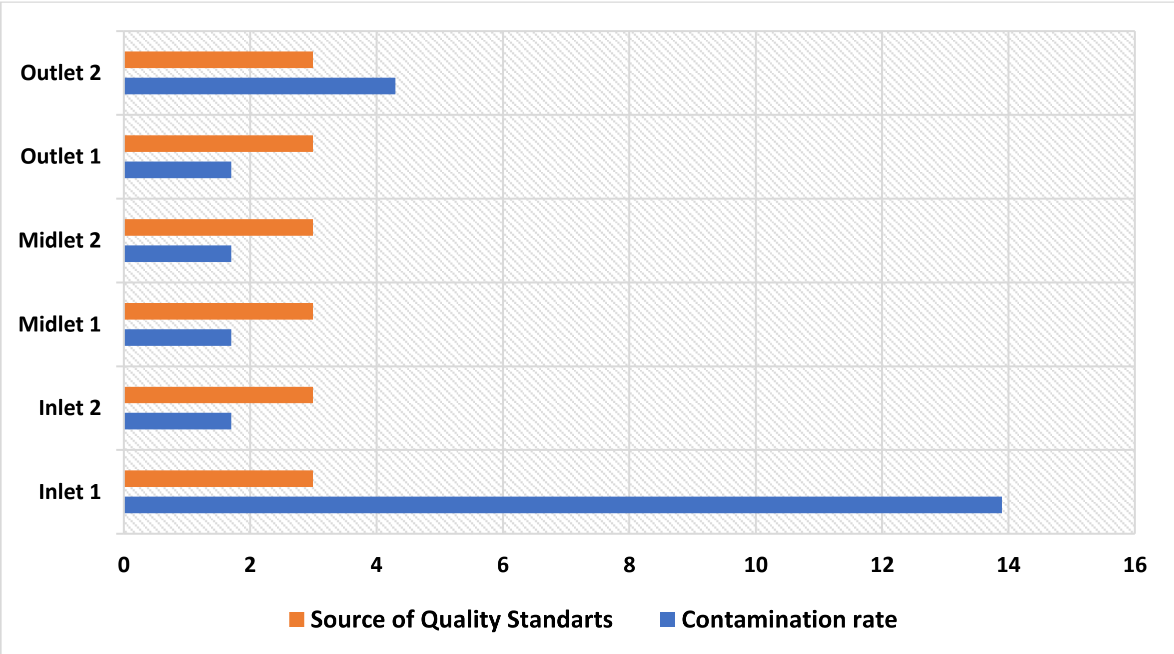

Figure 3. Levels of *E. coli* Microbiological Indicator Contamination in Edible Fish from Situ Bambon Ciracas

Chemical Contamination in Edible Fish

Heavy metal bioaccumulation analysis revealed highly concerning findings. The concentrations of Cadmium (Cd) and Lead (Pb) in fish from Situ Bambon, particularly in Sample Inlet

2, reached 0.83 mg/kg for Cd and 0.80 mg/kg for Pb, far exceeding the Maximum Contaminant Limit (BMC) established by PerBPOM No. 9 of 2022. These values are comparatively very high when compared with findings from fish in other urban water bodies, such as the lower concentrations reported in Wader fish from the Cikaniki River, Bogor (Azizah & Maslahat, 2021). This contrast indicates that the Inlet 2 area of Situ Bambon is not only generally polluted but also exposed to acute and localized heavy metal inputs (**Table 7**).

Table 7. Results of Heavy Metal Contamination Levels in Edible Fish from Situ Bambon Ciracas

Test Parameters	Location	Unit	Result	Quality Standart (BMC)	Source of Quality Standarts	Notes
Timbal (Pb)	Inlet 1	mg/kg	0,07±0,002	0,3	PerBPOM No. 9/2022	Complies
	Inlet 2	mg/kg	0,80±0,02	0,3	PerBPOM No. 9/2022	Exceeds the Limit
	Midlet 1	mg/kg	0,04±0,001	0,3	PerBPOM No. 9/2022	Complies
	Midlet 2	mg/kg	0,05±0,002	0,3	PerBPOM No. 9/2022	Complies
	Outlet 1	mg/kg	0,04±0,001	0,3	PerBPOM No. 9/2022	Complies
	Outlet 2	mg/kg	0,11±0,003	0,3	PerBPOM No. 9/2022	Complies
Kadmium (Cd)	Inlet 1	mg/kg	0,08±0,003	0,1	PerBPOM No. 9/2022	Complies
	Inlet 2	mg/kg	0,83±0,03	0,1	PerBPOM No. 9/2022	Exceeds the Limit
	Midlet 1	mg/kg	0,04±0,002	0,1	PerBPOM No. 9/2022	Complies
	Midlet 2	mg/kg	0,06±0,002	0,1	PerBPOM No. 9/2022	Complies
	Outlet 1	mg/kg	0,04±0,002	0,1	PerBPOM No. 9/2022	Complies
	Outlet 2	mg/kg	0,11±0,05	0,1	PerBPOM No. 9/2022	Exceeds the Limit
Raksa (Hg)	Inlet 1	mg/kg	0,16±0,006	0,5	PerBPOM No. 9/2022	Complies
	Inlet 2	mg/kg	0,17±0,006	0,5	PerBPOM No. 9/2022	Complies
	Midlet 1	mg/kg	0,19±0,007	0,5	PerBPOM No. 9/2022	Complies
	Midlet 2	mg/kg	0,18±0,006	0,5	PerBPOM No. 9/2022	Complies
	Outlet 1	mg/kg	0,12±0,004	0,5	PerBPOM No. 9/2022	Complies
	Outlet 2	mg/kg	0,11±0,004	0,5	PerBPOM No. 9/2022	Complies

Cd and Pb are non-essential metals known for their chronic and cumulative toxicity. Cadmium is classified as a human carcinogen, while lead is a strong neurotoxin. Such extreme accumulation levels indicate serious deficiencies in waste management around the inlet area and confirm significant health risks for communities consuming fish from the Ciracas region (Nag & Cummins, 2022). In contrast, mercury (Hg) concentrations in this study remain within acceptable limits and are relatively comparable to levels observed in highly active coastal waters such as Jakarta Bay, which range from 0.10 to 0.30 mg/kg (DLH DKI Jakarta, 2024). This finding suggests that although contamination exists, Hg accumulation in Situ Bambon is not as severe nor as rapid as the input of Pb and Cd.

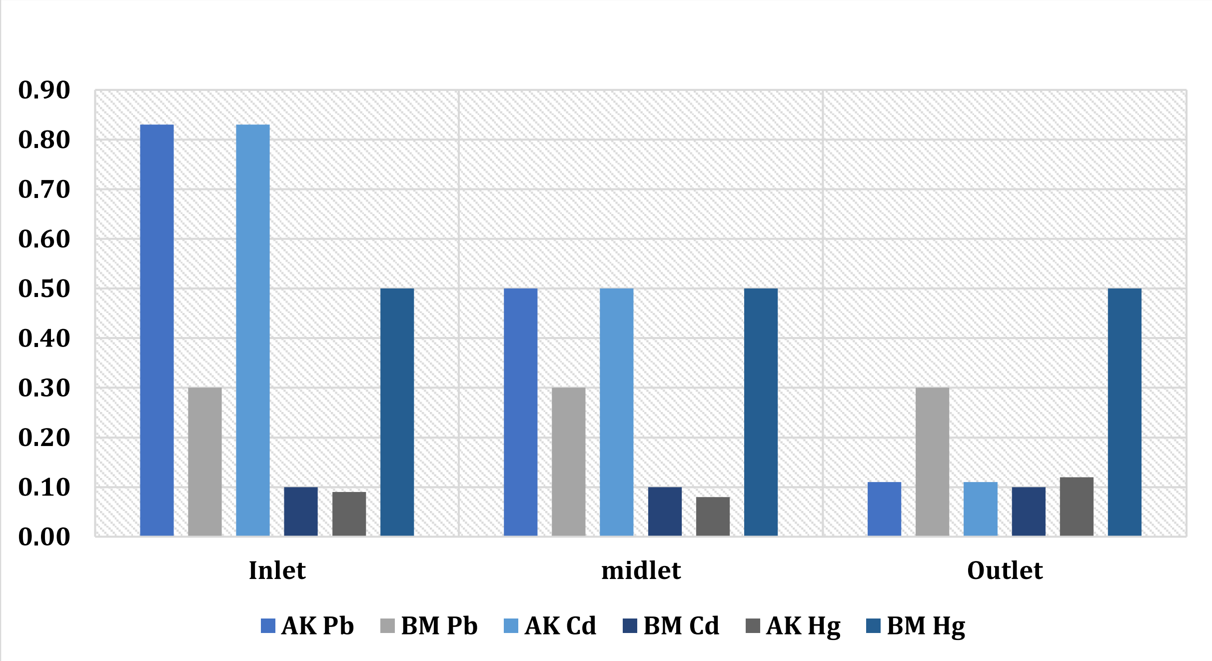

Figure 4. Heavy Metal Contamination Levels in Edible Fish from Situ Bambon Ciracas

Health Risk Assessment

Health Risk Assessment (HRA) was conducted to evaluate the potential health impacts of exposure to heavy metals Lead (Pb), Cadmium (Cd), and Mercury (Hg) accumulated in fish tissue from Situ Bambon on adult consumers. The analysis applied a worst-case scenario approach using the maximum concentration (Cmax) detected at the highest pollution point (Inlet 2/PA.329) to represent the maximum possible risk faced by the local population. The key input parameters used in the assessment were the adult fish consumption rate (IR) of 0.064 kg/day and an average body weight (BW) of 70 kg. The Estimated Daily Intake (EDI) was calculated using the basic equation: EDI = (C × IR) / BW (**Table 8**). The results show that the highest daily exposure was observed for Cd at 7.60×10^{-4} mg/kg-day, followed by Pb at 7.31×10^{-4} mg/kg-day and Hg at 1.56×10^{-4} mg/kg-day. The next stage involved evaluating individual non-carcinogenic risks using the Target Hazard Quotient (THQ), defined as the ratio between EDI and the Reference Dose (RfD). The RfD value for Hg is 0.0003 mg/kg-day, the lowest among the three metals, reflecting its high neurotoxicity and strict safety threshold. The calculated individual THQ values were 0.209 for Pb, 0.760 for Cd, and 0.520 for Hg. Although each THQ value remains below the safety threshold of 1.0, the Cd and Hg values approaching this limit indicate that the current daily exposure levels already represent a concerning condition.

Table 8. Input Data for Metal Concentrations, Toxicity Parameters, and Estimated Daily Intake (EDI)

Metals	Cmax (mg/kg)	RfD (mg/kg-hari)	SF $(mg/kg\text{-}dayi)^{-1}$	Worst-Case EDI (mg/kg-day)
Pb	0,8	0,0035	0,0085	$7{,}31\times10^{-4}$
Cd	0,83	0,001	0,38	$7{,}60\times10^{-4}$
Hg	0,17	0,0003	N/A	$1{,}56\times10^{-4}$

Cumulative non-carcinogenic health risk was validated through the calculation of the Hazard Index (HI), obtained from the sum of all metal Target Hazard Quotient values (HI = ΣTHQ). The worst-case calculation at Inlet 2 produced the following result: HI = 0.209 + 0.760 + 0.520 = 1.489. This HI value exceeds the tolerance threshold of 1.0 and represents a critical finding that quantitatively confirms the presence of unacceptable non-carcinogenic health risks for consumers who regularly consume fish from this contaminated location. Risk contribution analysis indicates that Cd contributes 51.0% of the total HI value, while Hg contributes 35.0%. In addition, carcinogenic risk was evaluated using Total Risk (TR), calculated only for Cadmium (Cd), which has a Slope Factor (SF) of 0.38 $(mg/kg\text{-}day)^{-1}$. TR was calculated using the Lifetime Average Daily Dose (LADD) multiplied by the SF. The calculated TR value is 3.37×10^{-7}. This value remains below the internationally acceptable carcinogenic risk threshold of $TR < 10^{-6}$. Although the cancer risk remains within acceptable limits, the elevated HI value shifts the primary focus of environmental health intervention from carcinogenic risk toward the risk of acute non-carcinogenic organ damage dominated by Cadmium and Mercury exposure.

Table 10. Results of Target Hazard Quotient (THQ), Hazard Index (HI), and Total Risk (TR) Calculations

Metal	Worst-Case THQ	Risk Contribution (%)	Total HI (∑THQ)	Carcinogenic TR (Cd)
Pb	0,209	14,00%		
Cd	0,76	51,00%	1,489	$3{,}37\times10^{-7}$
Hg	0,52	35,00%		
Risk Status	THQ<1,0 (safe)		HI>1,0 (unsafe)	$TR<10^{-6}$ (safe)

The elevated HI indicates a potential non-carcinogenic health risk, particularly related to chronic exposure to Cd and Hg through fish consumption. Comparatively, the non-carcinogenic risk identified in Situ Bambon is higher than that reported in several Health Risk Assessment (HRA) studies conducted in Indonesian waters during the last five years (2020–2025). Fahimah et al. (2023) conducted a study in the Citarum River, which is widely recognized for its severe industrial pollution, and reported HI values for fish consumption below 1.0, indicating that the risk remained within acceptable limits (Fahimah et al., 2023). Similarly, research conducted in the coastal waters of Badung Bay, Bali, which are exposed to domestic and tourism-related waste inputs, also reported HI values in fish that remained within safe limits. In contrast, Situ Bambon now shows conditions comparable to highly specific and acutely contaminated environments such as the waters of Kao Bay affected by illegal gold mining activities (Amqam et al., 2020), as well as heavy industrial estuaries such as the Musi River Estuary where HI values consistently reach or exceed 1.0 (Diansyah et al., 2025). The environmental implications of these findings are clear. Pollution sources located at Inlet 2, likely originating from domestic waste and small-scale industrial activities, appear to possess specific toxic characteristics that promote rapid bioaccumulation of Cd and Pb in fish.

CONCLUSION

The results indicate that edible fish from Situ Bambon Ciracas are contaminated by Escherichia coli and selected heavy metals at levels that may pose health risks to consumers. Escherichia coli contamination was detected in all fish samples and exceeded the microbiological safety standard for fishery products. The highest concentrations of Cd and Pb were found in the inlet area, reaching 0.83 mg/kg and 0.80 mg/kg, respectively, exceeding the maximum contaminant limits established by PerBPOM No. 9 of 2022. The Health Risk Assessment showed that although the individual THQ values for Pb, Cd, and Hg were below 1.0, the cumulative Hazard Index reached 1.489, indicating an unacceptable non-carcinogenic risk for regular fish consumers. Cd was the dominant contributor to the total risk, followed by Hg. The carcinogenic risk for Cd remained below the internationally acceptable threshold; however, the elevated HI suggests that non-carcinogenic health risks should be prioritized. These findings confirm that the water–fish–human exposure pathway in Situ Bambon requires immediate pollution control, restriction of fish consumption, and continuous monitoring to protect public health.

AUTHOR CONTRIBUTIONS

Conceptualization, HA and FMJ; methodology, HA, N, and FMJ; software, BAS and AM; validation, FMJ, CVA, and AM; formal analysis, HA, N, and BAS; investigation, HA, N, and FMJ; resources, HA and FMJ;

data curation, HA, N, and BAS; writing—original draft preparation, HA and N; writing—review and editing, FMJ, CVA, and AM; visualization, BAS and AM; supervision, FMJ and CVA; project administration, HA; funding acquisition, HA and FMJ.

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CONFLICTS OF INTEREST

The authors declare no conflict of interest concerning the publication of this article. The authors also confirm that the data and the article are free of plagiarism.

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