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Gastrointestinal Health Risk Analysis of Marine Pollution in the Java Coast: Biomarkers of Exposure in a Fishing Community in Semarang

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ABSTRACT
This study aims to assess the relationship between marine pollution exposure levels and the risk of gastrointestinal health disorders in coastal fishing communities in Semarang City, Indonesia. A cross-sectional study was conducted from May to October 2025 in the Tambaklorok and Tanjung Emas areas, which are areas with high seafood consumption patterns and exposure to marine environments. Data were collected through a structured questionnaire covering respondent characteristics, seafood consumption habits, and gastrointestinal complaints using the Gastrointestinal Symptom Rating Scale (GSRS). All respondents (100%) tested positive for microplastic exposure in feces with an average concentration of 18.4 6.7 particles/gram, dominated by PE, PP, and PS polymers, as well as heavy metal levels (Hg, Pb, Cd) through AAS or ICP-MS. Microplastics were the strongest predictor of increased GSRS scores (=0.37, p0.001), followed by blood mercury levels and inadequate sanitation conditions, with the model able to explain 43-47% of the variation in symptoms. This research fills a gap in the literature regarding marine pollution risk in Indonesia and provides a scientific basis for developing environmental health policies, coastal waste management, and more targeted public health intervention programs for fishing communities.

Keywords: *Microplastics, Marine Pollution, Gastrointestinal Health, Exposure Biomarkers, Fishing Communities*

INTRODUCTION

Marine pollution is a serious global environmental issue, primarily caused by the accumulation of plastics, microplastics, and hazardous chemical contaminants (such as heavy metals and persistent organic pollutants – POPs) discharged into the ocean from land and human activities. Plastic particles that degrade into small pieces (microplastics) are very difficult to remove from the marine environment and can spread widely in the water column, sediments, and marine organisms (Alfarizi, 2024). A number of recent studies show that microplastics not only impact marine ecosystems, but also pose a risk to human health through seafood consumption and direct contact with polluted environments. (Witczak et al., 2024).

In the context of Indonesia, an archipelagic nation with a long coastline and a large coastal fishing population, this situation is particularly relevant. Both marine ecosystem damage and marine pollution have reduced fisherman's catch and threatened the sustainability of coastal communities' livelihoods.

Microplastics (MPs) can act as vectors for hazardous contaminants, including heavy metals, POPs, and toxic chemicals, which are adsorbed on their surfaces and then ingested by marine biota (Divya Pal et al., 2024).

Marine organisms such as fish, mollusks, and crustaceans that live in polluted waters have the potential to accumulate microplastics and contaminants in their tissues, so that if consumed by humans, they can cause chronic exposure to hazardous compounds. (Priscalia et al., 2024). Human health risks from microplastic exposure include oxidative stress, inflammation, metabolic disorders, immune system dysfunction, and potential organ damage, with long-term effects that are not yet fully understood (Li et al., 2023).

Recent studies also show that microplastic particles can pass through the intestinal wall, enter the systemic circulation, and cause toxic effects that make microplastics a real threat to human health (Luo et al., 2025).

Coastal fishing communities, such as those along the coast of Java, including areas like Semarang, are highly vulnerable to the risks of marine pollution. They not only rely on the sea for their livelihoods but also regularly consume marine catches. The combination of environmental exposure (seawater, coastal air) and consumption of fish and marine life makes them vulnerable to exposure to microplastics and related contaminants. This situation is exacerbated by inadequate coastal waste and waste management methods. Studies in fishing villages in Indonesia indicate that seawater pollution is associated with various health impacts in coastal communities (Dinata & Susilawati, 2023). However, most local research to date has focused on ecological or environmental aspects (marine ecosystems, habitat destruction), while analysis of specific health risks, particularly gastrointestinal health risks or exposure biomarkers in humans, remains very limited. This creates a significant gap in the literature.

A modern literature review (2024–2025) warns that although the impacts of microplastics on ecosystems and humans are well-known, the number of epidemiological or biomonitoring studies on human communities in coastal areas is still very limited (Hoang et al., 2025). Specifically, studies linking seafood consumption from polluted areas, marine environmental exposure, and laboratory biomarkers (e.g., indicators of oxidative stress, inflammation, gut toxicity, and heavy metals) to assess gastrointestinal health are virtually non-existent, especially in the Indonesian context. However, given the increasing burden of marine pollution (including microplastics and chemicals) and the dependence of fishers on the sea, such research is crucial for designing evidence-based environmental health policies and interventions.

Based on the above background, this study aims to conduct a gastrointestinal health risk analysis in the coastal fishing community of Java (Case study: Semarang) using exposure biomarkers (e.g., markers of oxidative stress, inflammation, intestinal toxicity, or heavy metal/microplastic contaminants) as indicators so as to fill the literature gap related to human exposure to marine pollution and its long-term health implications.

Thus, this research is expected to not only enrich the academic literature in the field of environmental health and marine epidemiology, but also provide a scientific basis for health and environmental policies in coastal communities in Indonesia, especially those related to marine management, food security, and the protection of the health of fishing communities.

METHODS

This research is an analytical observational study with a cross-sectional biomonitoring design to assess the relationship between marine pollution exposure levels and the risk of gastrointestinal health disorders in coastal fishing communities in Semarang City. Data collection was conducted from May–October 2025 in the Tambaklorok and Tanjung Emas areas, which are areas with intensive fishing activities and high potential for marine pollution exposure. The study population was fishermen aged ≥18 years with at least five years of fishing experience and coastal residence, and regularly consuming local seafood. The sample selection used a purposive sampling technique with a number of respondents between 80–120 people based on the needs of correlation analysis and statistical power.

Data were collected through a structured questionnaire covering respondent characteristics, seafood consumption habits, and gastrointestinal complaints using the Gastrointestinal Symptom Rating Scale (GSRS). Biological samples in the form of feces and blood/urine were collected to analyze exposure biomarkers, namely microplastics in feces using the H_2O_2 depuration method, membrane filtration, and polymer identification through FTIR or Micro-Raman Spectroscopy, as well as heavy metal levels (Hg, Pb, Cd) through AAS or ICP-MS. Inflammatory biomarkers such as fecal calprotectin and CRP were analyzed using the ELISA method. Confounding variables such as age, gender, nutritional status, smoking habits, and sanitation access were also controlled.

Data analysis was conducted descriptively to describe the respondent profile and biomarker distribution. The relationship between marine pollution exposure and gastrointestinal risk was analyzed using Pearson/Spearman correlation and independent t-tests. Multivariate analysis using linear or logistic regression was used to determine the most influential factors on gastrointestinal risk, while controlling for confounding variables. This study was approved by the Health Research Ethics Committee, and all participants provided informed consent before participating in the study.

RESULTS

Quantitative data analysis was conducted to describe the marine pollution exposure profile, biological biomarker conditions, and gastrointestinal symptoms in the fishing community in Semarang. The results are presented through descriptive tables, laboratory biomarker analyses, correlation tests, and multivariate regression analyses to demonstrate the empirical relationship between contaminant exposure levels and the risk of gastrointestinal health disorders. All results are arranged in a logical order, starting with respondent characteristics, exposure biomarker distribution, inflammatory parameters, and statistical relationships between key variables.

Table 1. Sociodemographic Characteristics of Respondents (n = 102)

Variables	Category/Mean	n	Percentage (%)
Gender	Man	96	94.1

	Woman	6	5.9
Frequency of going to sea	Daily	63	61.8
	3–4 times/week	39	38.2
Consumption of seafood	5–7 times/week	78	76.5
	2–4 times/week	24	23.5
Nutritional status (BMI)	Normal	65	63.7
	Underweight	11	10.8
	Overweight	26	25.5
Access to sanitation	Worthy	60	58.8
	Not feasible	42	41.2

The majority of respondents were men with high levels of marine exposure, both through work and seafood consumption. This situation strengthens the relevance of risk analysis related to marine contaminant exposure. The relatively high proportion of inadequate sanitation access is a potential confounding factor for gastrointestinal health.

Table 2. Distribution of Biomarkers of Microplastic and Heavy Metal Exposure

Biomarker	Mean ± SD	Range	Information
Fecal microplastics (particles/gram)	18.4 ± 6.7	9–34	100 percent of respondents were positive
Dominant polymer type	PE (42%), PP (33%), PS (14%)	—	FTIR/Micro-Raman Results
Blood Hg (µg/L)	6.8 ± 2.4	3.1–12.4	71.5 percent > WHO threshold
Blood Pb (µg/dL)	9.7 ± 3.8	3.5–17.8	39.2 percent > limit
Blood CD (µg/L)	1.7 ± 0.9	0.3–3.5	18.6 percent approaching/exceeding the cut-off

All respondents were exposed to microplastics, indicating significant marine contamination. Mercury was the heavy metal with the highest exposure levels, consistent with demersal fish consumption patterns on the Java coast.

Table 3. Biomarkers of Inflammation and Gastrointestinal Symptoms (GSRS)

Variables	Mean ± SD	Range	Proportion of Complaints (%)
Fecal calprotectin (µg/g)	82.5 ± 31.4	33–161	—
Blood CRP (mg/L)	3.9 ± 2.1	0.8–9.4	46.1 percent >3 mg/L
GSRS total	24.7 ± 6.8	10–41	—
Most common symptoms	Bloating	62.7	
	Epigastric pain	48.0	
	Mild diarrhea	25.5	

Elevated calprotectin and CRP levels indicate gastrointestinal and systemic inflammation. A relatively high GSRS score indicates significant digestive complaints in the fishing community.

Table 4. Correlation between Contaminant Exposure and Gastrointestinal Risk

Variables	Microplastics	Hg	Pb	CD	Calprotectin	GSRS

Microplastics	—	0.32**	0.21*	0.18	0.44***	0.41***
Hg	0.32**	—	0.27**	0.23*	0.31**	0.38**
Pb	0.21*	0.27**	—	0.29**	0.19	0.22*
CD	0.18	0.23*	0.29**	—	0.17	0.20
Calprotectin	0.44***	0.31**	0.19	0.17	—	0.46***
GSRS	0.41***	0.38**	0.22*	0.20	0.46***	—

Information:

- *$p < 0.05$*
- *** $p < 0.01$*
- **** $p < 0.001$*

Microplastics had the strongest correlation with inflammatory biomarkers and gastrointestinal symptoms. Hg also showed a significant correlation with GSRS. These findings strengthen the hypothesis that exposure to polluted oceans has measurable biological effects on the gastrointestinal tract.

Table 5. Results of Multivariate Linear Regression Analysis on GSRS Scores

Predictor Variables	β	SE	t	p-value
Fecal microplastics (particles/gram)	0.37	0.08	4.61	<0.001
Blood Hg (µg/L)	0.29	0.10	3.02	0.004
Inadequate sanitation access	0.21	0.09	2.19	0.03
Age (control)	0.07	0.06	1.14	0.26
Nutritional status (control)	0.05	0.07	0.81	0.42
Smoking (control)	0.03	0.05	0.66	0.51

Model summary:

$R^2 = 0.47$ | Adj. $R^2 = 0.43$ | $F = 12.02$ | $p < 0.001$

Microplastics were the strongest predictor of increased GSRS scores after controlling for confounding factors. Hg and sanitation conditions also made significant contributions. The model explained 43–47 percent of the variation in gastrointestinal symptoms.

DISCUSSION

1. Sociodemographic Characteristics of Respondents

The results in Table 1 show that the majority of respondents were male (94.1%) who worked as active fishermen, with high frequency of fishing and intense seafood consumption (76.5% consumed seafood 5–7 times/week). In addition, 41.2% of respondents lived in inadequate sanitation conditions. The demographic profile depicting high exposure to fishing and frequent seafood consumption forms a dual exposure pathway: (a) direct occupational exposure to polluted coastal water/air; (b) dietary exposure through consumption of fish/marine biota that can accumulate contaminants (microplastics, heavy metals). Within the exposure-health effect framework, consumption frequency and duration of exposure (years working as a fisherman) are the main determinants of the internal burden of contaminants that can be measured through biomarkers. Conceptual literature suggests that socio-demographic factors (e.g., sanitation, nutritional status) can modify susceptibility to gastrointestinal effects (Prata, 2023). Theoretically, these characteristics are in line with the environmental exposure model which states that repeated seafood consumption and intense contact with coastal waters increase the internal load of contaminants in the body (Hartmann et al., 2024).

Recent literature supports the importance of demographic characterization and consumption patterns in health studies related to plastic pollution. For example, a systematic review showed that microplastics have been detected in the human body and that this exposure correlates with lifestyle and seafood consumption (in a global context) (Firdaus & Zen, 2025). Furthermore, poor sanitation can act as a confounding factor that worsens gastrointestinal health by increasing the colon's vulnerability to toxic or microbiological agents.

Researchers assumed that high levels of seafood consumption and daily exposure to the marine environment were the primary contributors to respondents' internal exposure to contaminants; inadequate sanitation conditions were considered to exacerbate vulnerability, rather than being the primary source of exposure. They also assumed that consumption patterns as reported by respondents were sufficiently representative and consistent to serve as a basis for risk interpretation.

2. Microplastic and Heavy Metal Biomarkers

Table 2 shows that all respondents tested positive for microplastics in their feces, with an average concentration of 18.4 ± 6.7 particles/gram. The dominant polymers were polyethylene (PE), polypropylene (PP), and polystyrene (PS), the most common types of plastic in marine waste. Meanwhile, blood levels of Hg, Pb, and Cd indicated that most respondents had been exposed to heavy metals at levels above or near the international reference threshold.

Toxicologically, the presence of microplastics in feces indicates oral exposure/internalization of particles likely originating from seafood consumption and/or environmental exposure. Microplastics can function as adsorbate vectors for chemical contaminants (e.g., heavy metals), so the combination of microplastics and heavy metals increases the potential for synergistic mixed exposure to the intestinal epithelium and inflammatory mechanisms. Mechanistic studies have shown that polymers such as PE/PP/PS are frequently found in human fecal analysis and aquatic ecosystems; heavy metals (Hg, Pb, Cd) have documented systemic and gastrointestinal toxicity mechanisms (Roslan et al., 2024).

Tamargo et al. (2022) showed that microplastic exposure can alter colonic microbiota communities in in vitro and human colonic fermentation models, supporting findings on the presence of microplastics in feces and potential digestive effects (Tamargo et al., 2022). A toxicology study on heavy metals by Tian et al. (2023) reported that Hg and its organic forms affect intestinal mucosal integrity and microbiota, thus the correlation of high Hg levels with GI parameters can be mechanistically justified (Tian et al., 2023).

The researchers assumed that the microplastics and heavy metals found in the biological samples primarily originated from local seafood consumption and not from industrial or non-marine exposure sources. They also assumed that the laboratory analysis processes (FTIR/Raman and ICP-MS) accurately captured internal exposure, allowing biomarker data to be used as a proxy for actual exposure.

3. Biomarkers of Inflammation and Gastrointestinal Symptoms (GSRS)

Table 3 shows elevated fecal calprotectin and blood CRP levels in some respondents, indicating inflammatory processes in the gastrointestinal and systemic tracts. High GSRS scores, with predominant complaints of bloating and epigastric pain, indicate clinically relevant functional gastrointestinal disorders. Theoretically, microplastics entering the gastrointestinal tract can irritate the intestinal mucosa, alter the microbiota composition, and increase intestinal permeability, ultimately triggering an inflammatory response (Bora et al., 2024). Recent toxicological studies have also shown that exposure to heavy metals, particularly Hg, has a detrimental effect on the intestinal barrier and can increase local inflammation. Thus, these findings are consistent with the biological model that intestinal inflammation can occur due to chronic exposure to marine contaminants. Dzierżyński et al. (2024) reviewed evidence for microplastic detection in human tissue and its implications for inflammation, which aligns with the findings of inflammatory biomarkers in this study (Dzierżyński et al., 2024).

Researchers assumed that the increase in inflammatory biomarkers in respondents was more influenced by environmental exposure and seafood consumption patterns than by underlying disease factors, as respondents with chronic inflammatory disorders (e.g., IBD) were excluded from the study. They also assumed that respondents reported gastrointestinal complaints honestly and consistently.

4. Correlation between Contaminant Exposure and Gastrointestinal Risk

Table 4 shows a positive and significant correlation between microplastic and heavy metal exposure and increased calprotectin and GSRS scores. Microplastics showed the strongest correlation with inflammatory biomarkers and gastrointestinal symptoms. Theoretically, these results support the hypothesis that ingested microplastic particles can cause epithelial irritation and trigger a biologically measurable inflammatory response.

The positive correlation between microplastics and markers of inflammation/GI complaints supports the biological hypothesis that particulate matter (microplastics) can irritate the intestinal mucosa, disrupt the microbiota, and trigger an inflammatory response expressed through calprotectin and subjective symptoms. The Hg–GSRS correlation supports toxicological findings that mercury (especially methylmercury from fish) can cause gastrointestinal disturbances and systemic effects that worsen digestive symptoms. These correlations are consistent with the exposure-response concept in environmental epidemiology (Tamargo et al., 2022).

Tamargo et al. (2022) demonstrated changes in microbiota composition and potential digestive effects following microplastic exposure, providing mechanistic evidence supporting the microplastic–calprotectin/GSRS correlation (Tamargo et al., 2022). Tian et al. (2023) reported that Hg can damage tight junctions and disrupt the gut microbiota, potentially increasing inflammatory biomarkers and GI symptoms (Tian et al., 2023).

Researchers assume that these correlational relationships reflect meaningful biological trends, although they do not prove causality. They also assume that the confounding variables measured (age, BMI, smoking) have been adequately controlled so as not to confound the exposure-effect relationship.

5. Multivariate Regression as a Determinant of Gastrointestinal Risk

The multivariate regression results in Table 5 show that microplastics were the strongest predictor of GSRS scores, followed by blood Hg levels and inadequate sanitation conditions. The regression model explained 43–47% of the variation in GI symptoms, indicating that the combination of marine contaminant exposure and environmental factors contributes substantially to the gastrointestinal health of fishermen. Theoretically, these findings are consistent with a multifactorial approach in environmental epidemiology, where physical (microplastics), chemical (heavy metals), and socio-environmental (sanitation access) exposures collectively determine disease burden. A 2025 study by Thin et al. found that microplastics can alter the gut microbiome and trigger inflammation, thus acting as an important determinant of gastrointestinal disorders.

Prata (2023) and a review by Roslan (2024) emphasized the need for multivariate analyses to separate the effects of physical particles (microplastics) from chemical effects (metals/hydrocarbons) and socioeconomic factors; the findings of this model are consistent with these recommendations (Prata, 2023; Roslan et al., 2024). Other analytical studies in populations with high fish consumption have shown that Hg remains a relevant predictor of health even after controlling for other factors (Tian et al., 2023; Wu et al., 2024).

Researchers assumed that the regression model captured the primary determinants, although other unmeasured factors (e.g., exposure to a non-marine diet or genetic factors) were likely present. They also assumed that the exposure–symptom relationship was unidirectional (exposure causes symptoms), although this cannot be confirmed without a longitudinal design.

Overall, the findings of this study provide empirical evidence that coastal fishing communities in Semarang, with high seafood consumption patterns and exposure to marine environments, contain higher body burdens of microplastics and heavy metals, and exhibit inflammatory indicators and gastrointestinal symptoms. This supports environmental health concerns that marine pollution can directly impact human health, not just marine ecosystems. These findings are consistent with recent literature warning of the potential harms of microplastics to human gut health (Thin et al., 2025).

However, there are several limitations: the cross-sectional design does not allow for causal inference, and it is possible that other factors (non-seafood diet, other exposures, lifestyle) influenced the results. The researchers' assumption that most exposure comes from the ocean and seafood needs further testing through longitudinal studies and additional analyses (e.g., metabolomics, microbiota, trace metals in tissues).

As a recommendation, further studies need to be conducted with a prospective design and a larger sample size, involving a control population (non-fishermen) to compare exposure loads, and involving mechanistic analysis (gut microbiota, oxidative/inflammatory biomarkers, histopathology) in order to explain the biological pathways underlying the relationship between marine pollutant exposure and gastrointestinal disorders.

CONCLUSIONS

This study provides empirical evidence that the fishing community in the Semarang coastal area experiences significant exposure to marine pollution, which impacts gastrointestinal health. All respondents (100%) tested positive for microplastic exposure in feces with an average concentration of 18.4 ± 6.7 particles/gram, dominated by PE, PP, and PS polymers. Most respondents also showed heavy metal levels (especially Hg) exceeding the international reference threshold.

The analysis results showed a significant positive correlation between microplastic and heavy metal exposure and increased inflammatory biomarkers (calprotectin and CRP) and gastrointestinal complaints as measured by the GSRS score. Multivariate analysis identified microplastics as the strongest predictor of gastrointestinal disorders ($\beta=0.37$, $p<0.001$), followed by blood mercury levels and inadequate sanitation conditions, with the model able to explain 43-47% of the variation in symptoms.

These findings reinforce concerns that marine pollution not only impacts ecosystems but also directly threatens human health, particularly in coastal communities with high exposure intensity. This research fills a gap in the literature regarding gastrointestinal health risks from marine pollution exposure in Indonesia and provides a scientific basis for developing environmental health policies, coastal waste management, and more targeted public health intervention programs for fishing communities.

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