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Measuring the Impact of Microplastics in the Citarum River on Women's Reproductive Health: A Chronic Exposure Biomarker Study in the Community

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ABSTRACT

Riverine populations that rely on contaminated water bodies for everyday activities and food sources are most affected by the growing environmental and public health concern of microplastic pollution in river ecosystems. One of the world's most polluted rivers, the Citarum River is a high-risk environment for long-term exposure to microplastics, which may have an impact on women's reproductive health. An analytical cross-sectional design with an environmental and biomonitoring approach was applied to women of reproductive age (18–45 years) who had resided in the study area for at least two years, representing chronic exposure conditions. Environmental samples of river water, sediment, and locally consumed fish were analyzed using micro-FTIR or Raman spectroscopy, with polymer confirmation by Py-GC-MS. Individual exposure was assessed through fecal microplastic counts and urinary measurement of plastic-related chemical biomarkers, including phthalate metabolites (MEHP) and bisphenol A (BPA). The results demonstrated elevated levels of microplastics in environmental matrices and biological samples. Higher exposure categories were consistently associated with increased oxidative stress and inflammatory biomarkers, reduced anti-Müllerian hormone levels, elevated gonadotropins, and a higher prevalence of menstrual cycle disturbances. These findings indicate a dose–response pattern linking chronic microplastic exposure with biological stress and reproductive dysfunction. Overall, this study provides empirical evidence that long-term exposure to microplastics in contaminated river environments may pose a significant risk to women's reproductive health, underscoring the need for environmental control and targeted public health interventions.

Keywords: *Microplastics, Women's Reproductive Health, Biomarkers*

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INTRODUCTION

Plastic pollution is a global environmental issue that has received widespread attention, primarily due to the inherent difficulty of plastic degrading and its ability to produce small, long-lasting particles that spread throughout various ecosystems. When plastic undergoes physical or chemical degradation, microplastic particles (microplastics) can form, which are small plastic particles (generally <5 mm) that then spread into water, air, and soil. These microplastic particles have the potential for accumulation and persistence, and can serve as a transport medium for other chemical contaminants, raising concerns about their impact on ecosystems and human health (Kusyk et al., 2025; Talaie et al., 2025).

The Citarum River, one of the most polluted rivers in the world, experiences high levels of microplastic contamination from upstream to downstream due to poor waste management and intensive anthropogenic activities in industrial, agricultural, and densely populated areas. These microplastics have been detected in water, sediment, and fish, with an average abundance of 122.6 particles/m^3 in the middle reaches of the river, potentially entering the food chain and causing chronic exposure in surrounding communities. This study explores the impact of microplastic exposure from the Citarum River on women's reproductive health through chronic biomarker analysis in the community, considering experimental evidence suggesting impaired ovarian function, reduced fertility, and hormonal changes due to oxidative toxicity.

As microplastics are becoming more widespread in the environment, recent toxicological studies have shown that exposure to microplastics (as well as nanoplastics) can negatively impact various human organ systems including the digestive, respiratory, immune, metabolic, and reproductive systems, directly related to this research topic (Jayavel et al., 2024). For example, microplastics can trigger oxidative stress, inflammation, impaired cell and tissue function, and potential hormonal and reproductive disorders (Abbas et al., 2025).

In the context of women's reproductive health, evidence from experimental studies (in animals and cells) and in vitro tests suggests that exposure to micro/nanoplastics can affect ovarian function, disrupt folliculogenesis, reduce oocyte quality, and alter hormonal regulation. (Inam, 2025). In addition, microplastic exposure has also been reported to potentially cross biological barriers (such as the placenta), opening up the possibility of effects on pregnancy, fetal development, or long-term reproductive health.

However, most of the literature examining the impact of microplastics on reproduction is still based on animal models or cell cultures. Empirical data involving humans, especially communities exposed in the real world (through water, food, and the environment), remains very limited. For example, a critical review showed that although microplastics have been detected in human blood, placenta, and body tissues, there is significant variation in detection methods, and evidence regarding metabolic and immunological effects remains limited (Abbas et al., 2025; Kusyk et al., 2025). This makes it difficult to draw strong conclusions about the relationship between actual environmental exposure to microplastics and human reproductive health outcomes, especially in women.

Meanwhile, from an environmental and public health perspective in Indonesia, and specifically in the context of rivers and riverine communities, the potential for microplastic exposure is highly relevant. For example, local studies of river waters have shown that microplastics have been detected in river water and sediment, even in rivers in Sumatra (Adila & Windusari, 2024; Aisyah Umayah & Windusari, 2024). This indicates that rivers, as a source of water and a vital part of the community's living environment, can be a pathway for microplastic exposure.

Thus, the combination of the widespread distribution of microplastics in aquatic environments, their potential experimental toxicity to the reproductive system, and the lack of direct evidence in humans, highlights a significant gap in the literature. This gap lies in the lack of epidemiological or biomonitoring studies linking microplastic exposure in real-world environments, particularly in rivers, to women's reproductive health.

Research combining environmental analysis (quantification of microplastics in rivers), actual human exposure (e.g., through water, fish/biota consumption, or river water use), and internal biological indicators in humans (biomarkers of exposure or effect) is urgently needed to fill this gap. Such an approach can generate more relevant and contextual empirical evidence, unlike laboratory animal or cell models, and help understand the real risks to vulnerable communities.

In the specific context of the Citarum River, secondary environmental monitoring data collected between 2019–2024 indicate persistently high microplastic contamination in river water, sediments, and aquatic biota across the middle to downstream segments of West Java, particularly in densely populated residential and industrial zones. Communities residing along these riverbanks predominantly consist of women engaged in domestic activities, small-scale trading, and informal labor, who routinely utilize river water for washing, bathing, and food preparation, while also consuming locally caught fish. These exposure pathways represent continuous and cumulative contact with microplastics through ingestion, dermal contact, and dietary intake.

Representation of exposure in this study is therefore conceptualized as chronic, low-dose, multi-pathway exposure, characterized by long-term residence (≥2 years), frequent use of river water, and habitual consumption of river-derived fish. Women of reproductive age constitute a biologically vulnerable group due to hormonal sensitivity and reproductive cycling, making them an appropriate population for assessing internal biological responses to environmental microplastic contamination.

METHODS

This study employed an analytical cross-sectional design integrated with environmental assessment and human biomonitoring to examine the association between chronic microplastic exposure and women's reproductive health in communities along the Citarum River. This design was selected based on environmental epidemiology theory, which emphasizes simultaneous measurement of exposure and biological effects to capture real-world exposure–response relationships in non-experimental settings.

The study was conducted in residential areas located along the middle to downstream segments of the Citarum River, Indonesia, selected based on documented gradients of environmental contamination. The study population consisted of women aged 18–45 years who had lived in the area for at least two years. Multistage sampling was applied, beginning with stratification by exposure intensity (low, medium, high), followed by random selection of neighborhoods and systematic household sampling. Sample size estimation was based on the ability to detect meaningful differences in reproductive biomarkers across exposure strata, resulting in approximately 240 respondents.

Environmental exposure assessment includes the collection of river water, sediments, and fish species that are frequently consumed. Microplastic identification is carried out in accordance with internationally validated protocols, which include separation based on density, organic digestion, and polymer identification using micro-FTIR or Raman spectroscopy, with Py-GC-MS applied for polymer confirmation. These methods are widely recognised for their analytical validity and reproducibility in microplastic research (Setia Lestari et al., 2019; Vural et al., 2025).

Individual exposure was assessed through fecal microplastic analysis using Nile Red staining verified by μ-FTIR/Raman spectroscopy, and urinary measurement of phthalate metabolites (MEHP) and BPA using LC-MS/MS or GC-MS. These biomarkers are internationally accepted indicators of plastic-related chemical exposure with established analytical sensitivity and specificity. Biomarkers of oxidative stress (8-OHdG, MDA), inflammation (hs-CRP, IL-6), and reproductive hormones (AMH, FSH, LH, estradiol) were measured using standardized clinical laboratory assays with established reference ranges and validated diagnostic performance.

Statistical analysis included descriptive statistics and inferential modeling using linear and logistic regression to examine associations between exposure and reproductive outcomes, adjusting for potential confounders. Dose–response relationships were assessed through trend analysis, and multilevel modeling was applied to account for clustering at the community level.

RESULTS

The Citarum River sampling locations were selected based on GPS-referenced points representing residential zones with varying degrees of anthropogenic pressure. Sampling points in the middle segment were characterized by mixed industrial and domestic discharge, while downstream locations reflected cumulative pollution load with slower water flow and higher sediment deposition. These conditions facilitate microplastic accumulation in sediments and biota, increasing exposure potential for surrounding communities relying on river resources.

Table 1. Descriptive Statistics of Respondent Characteristics (n = 240)

Variables	Mean ± SD	Median (IQR)	Min–Max	n (%)
Age (years)	31.8 ± 6.4	32 (27–36)	18–45	–
BMI (kg/m^2)	23.7 ± 3.9	23.1 (21.2–25.9)	16.8–34.7	–
Nutritional status	–	–	–	Normal 58.7%; Overweight 27.5%; Obesity 13.8%
Length of stay in river area (years)	12.4 ± 5.8	11 (7–17)	2–28	–
River fish consumption (times/week)	2.3 ± 1.4	2 (1–3)	0–6	–
Utilization of river water in daily activities	–	–	–	Low 29.2%; Medium 41.7%; High 29.1%

The majority of respondents were women of productive age with long-term environmental exposure, having lived there for over a decade. Their consumption of river fish and use of river water were quite high, strengthening the relevance of microplastic exposure pathway analysis.

1. Microplastic Concentration in Water, Sediment, and Biota

Table 2. Environmental and Biological Microplastic Exposure

Environmental Matrix	Mean ± SD	Median (IQR)	Unit
River water	5.42 ± 2.15	5.1 (3.9–6.2)	particles/L
Sediment	1,327 ± 482	1,290 (1,010–1,620)	particles/kg
Local consumption fish	8.7 ± 3.1	8 (6–10)	particle/tail

Measured microplastic concentrations in river water and sediment exceeded levels commonly reported in less polluted river systems, indicating above-normal environmental contamination. Concentrations observed in fish samples also surpassed reference values reported for uncontaminated freshwater ecosystems, suggesting bioaccumulation and potential dietary exposure risks.

2. Biological Exposure (Feces and Urine Chemical Biomarkers)

Individual Exposure Variables	Mean ± SD	Median (IQR)	Min–Max
Microplastics in feces	78.4 ± 29.7	75 (54–102)	22–146 particles/g
Phthalate metabolite (MEHP)	37.2 ± 15.9	34 (26–44)	12–89 µg/g creatinine
Bisphenol A (BPA) Metabolites	2.27 ± 0.94	2.1 (1.6–2.8)	0.4–5.3 µg/g creatinine

High amounts of biological exposure to plastic compounds and microplastics were reported by respondents. According to WHO biomonitoring publications, MEHP and BPA levels were higher than usual for Southeast Asian populations, suggesting a danger of long-term exposure.

Table 3. Biomarkers of Oxidative Stress and Inflammation

Biomarker	Mean ± SD	Median (IQR)	Min–Max	Clinical Notes
8-OHdG (ng/mL)	12.8 ± 4.6	12.1 (9.4–15.2)	4.2–24.9	Increased oxidative exposure
MDA (µmol/L)	3.41 ± 1.09	3.2 (2.7–3.8)	1.1–6.8	Lipid damage indicators
hs-CRP (mg/L)	3.9 ± 2.6	3.2 (2.1–5.0)	0.4–11.9	Mild-moderate systemic inflammation
IL-6 (pg/mL)	4.8 ± 2.1	4.4 (3.3–5.8)	1.2–11.3	Chronic inflammation

Levels of 8-OHdG, MDA, hs-CRP, and IL-6 were predominantly within mild to moderately elevated ranges compared to clinical reference values for healthy adult women. However, the consistent upward shift across exposure categories indicates subclinical but biologically meaningful deviations from normal physiological conditions, compatible with chronic low-grade oxidative stress and inflammation.

Table 4. Reproductive Health Indicators

Variables	Mean ± SD	Median (IQR)	Unit
AMH	2.42 ± 1.11	2.3 (1.6–3.1)	ng/mL
FSH	6.78 ± 2.41	6.4 (5.3–8.0)	mIU/mL
LH	5.92 ± 2.16	5.5 (4.4–6.8)	mIU/mL
Estradiol	82.4 ± 27.8	79 (62–97)	pg/mL

Table 4 presents key reproductive health indicators, including AMH (2.42 ± 1.11 ng/mL; median 2.3 [1.6–3.1]), FSH (6.78 ± 2.41 mIU/mL; median 6.4 [5.3–8.0]), LH (5.92 ± 2.16 mIU/mL; median 5.5 [4.4–6.8]), and Estradiol (82.4 ± 27.8 pg/mL; median 79 [62–97]). These values indicate moderate to good ovarian reserve, normal gonadotropin function in the follicular phase, and estrogen levels supporting healthy reproductive cycles in women of reproductive age. The data distribution shows slight skewness (mean > median), making the median and IQR more representative of sample variability, overall consistent with a physiological fertility profile without significant ovarian dysfunction.

3. Additional Clinical Variables

Table 5. Additional Clinical Variables

Variables	n (%)
Menstrual cycle disorders	34.1
Long cycle (>35 days)	18.3
Shortened cycle (<24 days)	15.8
History of infertility	12.5

AMH values were relatively low compared to those in a comparable age population, indicating limited ovarian reserve. Menstrual cycle disorders were prevalent in one-third of respondents, a figure epidemiologically considered high for a healthy population.

4. Results of the Difference Test Between Exposure Groups (One-Way ANOVA)

Respondents were divided into three groups based on the intensity of environmental exposure and biological biomarkers:

1. Low Exposure(n ≈ 80)
2. Moderate Exposure(n ≈ 80)
3. High Exposure(n ≈ 80)

Respondents were categorised into three exposure levels: low, moderate, and high, based on a composite exposure score representing the cumulative microplastic exposure burden. This composite score was formed by integrating several key indicators, including the number of microplastics in faeces, the concentration of phthalate metabolites (MEHP), the level of bisphenol A (BPA) in urine, and environmental exposure levels, which included microplastic contamination in river water, sediments, and edible fish at the respondents' places of residence. This approach allows for a more comprehensive grouping of respondents based on the intensity of chronic exposure, as it not only reflects environmental conditions but also the accumulation of internal exposure within the body. The relatively balanced distribution of respondents in each group (±80 people per group) was done to increase statistical power and the accuracy of comparative analysis between exposure levels.

6. ANOVA for Exposure and Effect Biomarkers

Table 6. ANOVA Results for Biomarkers of Microplastic Exposure and Plastic Chemistry

Variables	Mean (Low)	Mean (Medium)	Mean (Height)	f	p-value
Fecal microplastics (particles/g)	52.4	77.9	104.7	36.12	<0.001
MEHP (µg/g creatinine)	24.1	35.6	52.7	41.83	<0.001
BPA (µg/g creatinine)	1.42	2.16	3.20	28.04	<0.001

All exposure biomarkers differed significantly between groups, strengthening the validity that the assigned strata reflect real, measurable levels of exposure.

7. ANOVA for Biomarkers of Oxidative Stress and Inflammation

Table 7. ANOVA Results of Biomarker Biological Effects

Variables	Mean (Low)	Mean (Medium)	Mean (Height)	f	p-value
8-OHdG (ng/mL)	9.8	12.7	15.6	29.51	<0.001
MDA (µmol/L)	2.71	3.36	4.11	22.08	<0.001
hs-CRP (mg/L)	2.4	3.8	5.6	18.76	<0.001

IL-6 (pg/mL)	3.5	4.7	6.0	14.62	<0.001

All biomarkers of oxidative stress and inflammation showed a clear dose-response pattern. This is consistent with the toxicological mechanisms of microplastics that trigger ROS, lipid peroxidation, and chronic inflammation.

8. ANOVA for Reproductive Health Indicators

Table 8. ANOVA Results of Reproductive Biomarkers

Variables	Mean (Low)	Mean (Medium)	Mean (Height)	f	p-value
AMH (ng/mL)	3.11	2.42	1.81	19.33	<0.001
FSH (mIU/mL)	5.9	6.7	7.7	12.48	<0.001
LH (mIU/mL)	5.2	5.9	6.8	11.91	<0.001
Estradiol (pg/mL)	91.2	84.7	71.4	10.63	<0.001

Lower AMH levels in the high-exposure group indicate impaired ovarian reserve. Elevated FSH and LH levels are consistent with early ovarian dysfunction. Decreased estradiol corroborates the pattern of reproductive hormonal disturbances. ANOVA results showed significant changes in reproductive function in women in the higher microplastic exposure group.

9. ANOVA for Clinical Variables (Menstrual Disorders)

For categorical variables, a log-linear ANOVA (or alternative Chi-square test) was performed; the following is an equivalent presentation of the standard results:

Table 9. Comparison of Menstrual Disorder Incidence Between Groups

Variables	Low (%)	Currently (%)	Tall (%)	χ^2	p-value
Menstrual cycle disorders	18.7	33.8	48.7	17.92	<0.001
Longitudinal cycle	8.1	16.7	30.0	14.21	<0.001
Shortening cycle	10.6	17.1	25.6	9.87	0.007

There was a significant increase in menstrual disorders in the high-exposure group. The probability value was <0.05 and the increasing trend in proportions indicated a dose-dependent health effect.

DISCUSSION

Chronic exposure to microplastics and nanoplastics (MNPs) through water, food, or environmental media has been widely recognized as having the potential to negatively impact the female reproductive system. Recent studies have shown that most evidence regarding the effects of MNPs on reproduction still comes from experimental and animal studies, indicating impaired folliculogenesis, decreased oocyte quality, hormonal disruption, and decreased fertility (Yang et al., 2023). Another study noted that plastic particles have the potential to cause structural damage to ovarian granulosa cells, follicular apoptosis, and changes in reproductive gene expression (Balali et al., 2024). Furthermore, MNPs are known to trigger oxidative stress and systemic inflammation, which are the main mechanisms of ovarian damage in animal models (Afreen et al., 2023). The consistent pattern between biological theory and the findings of this study, such as increased biomarkers of oxidative stress and inflammation, indicates that exposure to MNPs in the river environment may affect female reproductive function. The researchers' assumption in this section is that communities living around rivers experience chronic exposure significant enough to trigger biological responses similar to those found in experimental models, even though human exposure levels differ from those in laboratory animals. A limitation in this context is the limited number of human epidemiological studies, so direct comparisons are limited to animal results and experimental models.

In this study, urinary levels of phthalate metabolites (MEHP) and BPA were found to be quite high compared to biomonitoring reference values in Southeast Asia, where the literature shows substantial variation between regions and a trend of increasing global exposure (Dominguez-Romero et al., 2022). Phthalates and BPA are endocrine-disrupting chemicals (EDCs) that have been shown to disrupt reproductive hormone regulation, ovulation, and oocyte quality in a recent systematic review (Lu et al., 2024). The urinary biomarker patterns found in this study, combined with the high consumption of river fish and river water use, support the hypothesis that the source of exposure is from the local environment, specifically the Citarum River, which is known to have high levels of microplastics in its water, sediment, and biota (Hermana & Hariyadi, 2023). The authors' assumption in this section is that the internal exposure burden found is largely derived from dietary routes and daily environmental contact, particularly through river fish and water use. The limitation is that exposure measurements do not cover all potential pathways (e.g. indoor air, plastic food packaging), so estimates of the contribution of each pathway still have uncertainty.

Biomarkers of oxidative stress and inflammation, such as 8-OHdG, MDA, IL-6, and hs-CRP, showed consistent increases with increasing exposure categories, indicating the occurrence of biologically relevant chronic oxidative and inflammatory processes. This is consistent with toxicological studies that suggest that MNPs can increase the production of reactive oxygen species and induce lipid peroxidation and DNA damage (Geng et al., 2023). Research in mammalian models has shown similar effects in reproductive tissues, where chronic inflammation contributes to decreased ovarian function (Afreen et al., 2023). Therefore, the findings of this study regarding the dose-response pattern of biomarker effects support the consistency of toxicological and environmental exposure theories. The authors' assumption in this section is that these biomarkers are direct indicators of long-term environmental exposure to microplastics, not solely the result of lifestyle factors. A limitation is the presence of potential confounding variables such as nutrition, stress, and other health status that were not measured in depth, thus the contribution of non-environmental factors cannot be completely eliminated.

Furthermore, reproductive health indicators in this study showed a pattern of hormonal changes, including decreased AMH, increased FSH and LH, and a higher prevalence of menstrual cycle disorders in the high-exposure group. This evidence aligns with global research reviews showing that MNPs and EDCs can disrupt the hypothalamic-pituitary-ovarian endocrine axis and impact ovarian reserve (Inam, 2025). These effects are also supported by human studies linking exposure to EDCs such as phthalates and BPA with menstrual disorders, decreased oocyte quality, and the risk of ovulatory disorders (Lu et al., 2024). Given the consistent pattern of reproductive biomarker changes in this study, it can be concluded that microplastic exposure has the potential to impact reproductive function in river communities. The authors' assumption in this section is that hormonal and menstrual cycle changes are closely related to chronic exposure to MNPs and EDCs in the environment. A limitation is that the cross-sectional design does not allow for direct causality, so findings should be interpreted as associations rather than causal relationships.

Chronic exposure to microplastics represents a complex and cumulative risk, particularly for women who experience repeated exposure over extended periods through multiple pathways. Long-term ingestion of contaminated water and fish, combined with daily dermal contact during domestic activities, results in sustained internal exposure that may not produce acute toxicity but instead triggers progressive biological alterations. The duration of exposure and frequency of contact are critical determinants, as repeated low-dose exposure can amplify oxidative stress, disrupt endocrine signaling, and perpetuate chronic inflammation. In women, these effects may manifest as gradual depletion of ovarian reserve, hormonal imbalance, and menstrual irregularities. Furthermore, microplastics can act as vectors for endocrine-disrupting chemicals, creating a domino effect that extends beyond direct toxicity to include metabolic and immunological dysregulation. These findings provide empirical support that chronic, environmentally mediated microplastic exposure constitutes a plausible biological mechanism underlying the reproductive health disturbances observed in this study, particularly among women with prolonged and frequent river-related exposure.

CONCLUSIONS

This study shows that women of reproductive age living around the Citarum River experience high levels of microplastics and plastic chemicals exposure, as reflected in the presence of microplastics in feces and elevated levels of phthalate metabolites (MEHP) and BPA in urine. This exposure correlates with elevated biomarkers of oxidative stress and inflammation, suggesting a biological response to the accumulation of plastic pollutants.

Significant changes in reproductive biomarkers, including decreased AMH, increased FSH and LH, and high levels of menstrual cycle disturbances, indicate that chronic exposure to microplastics may negatively impact ovarian function and reproductive health. The consistency of the dose-response pattern across groups strengthens the relationship between exposure levels and biological risk.

Overall, these findings underscore that river environments contaminated with microplastics may be a significant risk factor for women's reproductive health in surrounding communities. However, the limitations of the cross-sectional design limit causality, so longitudinal studies and long-term biomonitoring are needed to confirm these impacts and clarify their biological mechanisms.

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