Health Risk Assessment of Microplastic Contamination in Kamoning River Sampang, Madura

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Abstract

Microplastics are now widespread contaminants in riverine and coastal waters. They may affect both ecosystems and communities that depend on these resources. This study assesses microplastic contamination and associated risks in the Kamoning River, Sampang District, Madura, Indonesia. Residential, agricultural and port activities contribute to substantial plastic inputs to this system. Surface water was sampled at six stations representing upstream, midstream, urban, port and estuarine reaches. Samples were analysed for microplastic abundance and morphology using sieving, chemical digestion and microscopic identification. Particles were classified as fragments, fibres and films. Total abundances were expressed as particles per litre. A screening-level risk quotient (RQ) approach was applied by comparing measured exposure concentrations with literature-based reference values for ecological and human health endpoints. Mean abundances were on the order of 10^2 particles per litre. Values increased from upstream to estuarine stations, with fragments as the dominant form at all locations. Calculated RQ values for short-term exposure via water use and local fish consumption ranged from 0.23 to 0.51. These values indicate screening-level risks below commonly used thresholds but with increasing concern toward the estuary. Results show that the Kamoning River functions as a conduit and accumulation zone for microplastics. The study provides a reproducible framework linking microplastic abundance data to risk indicators. This framework can support targeted plastic waste management and future monitoring in Indonesian rivers.

Keywords: *Health risk; Kamoning River; Microplastics; Risk quotient; Sampang*

1. Introduction

The worldwide increase in microplastic pollution is a serious concern in Indonesian riverine systems [1], [2], [3]. Evidence is emerging of impacts on local biodiversity and human health. Microplastics originate from the fragmentation of larger plastic items as well as from primary microplastics released directly into the environment. They can persist for decades to centuries due to their resistance to degradation. Indonesia plays a leading global role as one of the biggest plastic waste contributors to the oceans. Domestic rivers and estuaries serve as important pathways for the transport of microplastics from land-based activities to marine ecosystems. River systems like the Kamoning watershed in Sampang District act as significant conduits of land-based plastic pollution from inland areas to coastal waters and the wider marine environment [4].

Extensive research in the Kamoning watershed has indicated that poorly managed plastic debris in densely populated riparian regions significantly enhances microplastic surface contamination [4]. Recent field surveys on microplastics in the river waters of Sampang have reported abundant microplastic particles [4]. These are mainly fragments, fibres and films. Mean concentrations have reached up to 10^2 particles per litre at several sampling points. Such patterns indicate high anthropogenic pressures from domestic refuse, agriculture, fisheries and port-related activities along the river corridor.

However, most studies have concentrated on occurrence and spatial distribution. The ecological and human health risks of these contaminants have not been explored at the local scale.

From a toxicological standpoint, microplastics may pose health risks not only through physical effects such as ingestion and tissue damage to aquatic organisms, but also through their ability to transport adsorbed pollutants and associated additives [5]. Humans are exposed through contaminated fish and shellfish, drinking water and occupational contact with contaminated waters. Recent studies have shown that microplastic ingestion might induce inflammation, metabolic disruption and carcinogenic behaviour [1], [6]. Microplastics also function as carriers of persistent organic pollutants and heavy metals [1]. These findings highlight the importance of quantitative models to analyse the environmental concentrations of microplastics and their potential adverse health and ecological effects.

The risk quotient (RQ) framework assesses potential hazards as the relationship between observed environmental levels and approved toxicological reference standards [6], [7]. For deterministic assessments, RQ is derived by dividing a measured environmental concentration or dose by a reference dose or effect value. Risk is judged to be acceptable when RQ is below predefined levels of concern [8]. This approach has been widely used to forecast ecological hazards of pesticides and heavy metals. It has also been applied in several environmental studies to assess the impact of microplastic toxicity on fish and aquatic systems. The integration of the RQ approach with empirical microplastic abundance data from Sampang offers a way to move from a descriptive analysis of contamination to a more policy-relevant measure of risks to local communities and aquatic biota.

Given reported high levels of microplastics in the Kamoning River and substantial human activity in the catchment, there is a pressing need to move from a descriptive assessment of contamination to a more explicit assessment of potential risk. In this research, we quantify the abundance of microplastics at six distinct sites on the Kamoning River. We use a screening-level risk quotient (RQ) that links measured fragment, fibre and film levels to literature-based exposure scenarios and toxicological references [9]. By determining whether present-day contamination in Sampang waters is at negligible, intermediate or high-risk levels for ecological receptors and human populations, this research aims to generate data that can be used for targeted plastic waste management. It also provides evidence to inform future investigations of microplastic contamination and potential toxicity in Indonesian riverine and coastal settings.

2. Method

2.1. Study Area and Design

The Kamoning River, Sampang District, Madura, Indonesia served as a focus area for this study, which drains a densely populated and agriculturally active catchment before discharging into the Madura Strait [4], as shown in Figure 1. The study had a quantitative descriptive design that helped to characterize microplastic abundance and to derive risk quotients (RQ) for specific exposure scenarios [10]. Sampling sites were defined with purposive sampling which focused on the river reaches of upstream residential areas, agricultural zones, urban and port activities, and the river mouth. Geographic coordinates of each sampling point (S1 to S6) were recorded using a Global Positioning System (GPS) receiver to permit precise location referencing and reproducibility.

2.2. Water Sampling and Sample Handling

Surface water samples were collected from six fixed stations (S1 to S6) along the Kamoning River during September 2023, with three replicate grabs taken at each station using a horizontal water sampler. Replicate samples were combined by station to obtain a representative composite, then transferred into pre-cleaned high-density polyethylene (HDPE) bottles, stored in a cool box, and transported to the laboratory for analysis. The exact volume of water filtered at each station was recorded to allow calculation of microplastic abundance per unit volume.

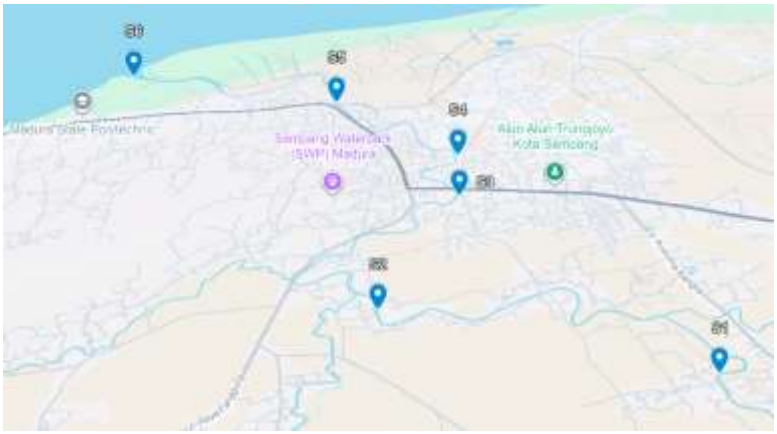


Figure 1. Sampling Point Map

2.3. Microplastic Isolation and Identification

Microplastic isolation was performed according to the laboratory protocol recommended by the U.S. National Oceanic and Atmospheric Administration (NOAA) for microplastic analysis in waters and with minor modifications to local conditions [10], [11]. In brief, samples were wet-sieved through stacked stainless-steel meshes of 5 mm and 0.3 mm to retain particles in the microplastic size range (<5 mm). To eliminate organic interferences from the dried residue (90°C for a minimum of 24 h), wet peroxide oxidation with H_2O_2 and an iron (II) catalyst was performed according to the modified NOAA protocol. Sodium chloride solution was added to achieve a density high enough for microplastics to float in the suspension, before it was processed by a density separator to enhance density separation. Supernatant containing buoyant particles were decanted and filtered carefully, and the putative microplastic particles were visually identified and classified as fragments, fibres or films under a light microscope based on morphology and surface characteristics. Only particles exhibiting typical plastic features (uniform colour, lack of cellular structures, and resistance to crushing) were counted as microplastics.

2.4. Quantification of Microplastic Abundance

Microplastic abundance at each station was calculated as the number of particles per unit volume of filtered water for microplastic quantification in aquatic samples [12]. The abundance (A) was obtained as:

$$A = \frac{N}{V} \quad (1)$$

where N is the total number of microplastic particles (10^2 particles/L) and V is the volume of water filtered (L). Abundance values were expressed as 10^2 particles per litre and summarized for each microplastic category (fragment, fibre, film) and sampling station.

2.5. Risk Quotient (RQ) Calculation

Health and ecological risk were characterized using the risk quotient approach. This approach expresses risk as the ratio between an exposure estimate and a relevant reference or effect value [7]. For each exposure scenario, the risk quotient was calculated as:

$$RQ = \frac{E}{RV} \quad (2)$$

where E denotes the estimated exposure concentration or intake of microplastics (10^2 particles/L), and RV is the corresponding reference value. Reference values represent no-effect or benchmark doses derived from toxicological or epidemiological studies. Exposure estimates were obtained by combining measured microplastic abundances from the Kamoning River with literature-based transfer and

ingestion factors. Reference values were taken from published health risk assessments of microplastic ingestion.

Risk characterization categories followed conventional thresholds used in chemical risk assessment. RQ less than 1 is interpreted as low or acceptable risk. RQ between 1 and 10 indicates moderate concern. RQ of 10 or greater indicates high concern that may warrant management intervention. Where necessary, uncertainty in both exposure and reference values was addressed through conservative (worst-case) assumptions and comparison across multiple reference benchmarks reported in recent microplastic risk studies.

2.6. Data Processing and Statistical Analysis

All microplastic count data were arranged into spreadsheets and analyzed using IBM SPSS Statistics 25 to investigate differences in abundance among stations and microplastic types. One-way ANOVA at a significance level of 0.05 was applied to test differences in total and category-specific abundance among sampling stations and microplastic types. F-values and exact p-values were reported to clarify statistical significance. Abundance and RQ values were summarized using descriptive statistics (mean, standard deviation and range). These statistics provided a basis for interpreting spatial trends of contamination and corresponding risk levels in the Kamoning River.

3. Results and Discussion

3.1. Results

The analysis confirmed that the Kamoning River is heavily contaminated with microplastics, with mean abundances on the order of 10^2 particles/L across the six sampling stations, as shown in Table 1.

Table 1. Microplastic Abundance (10^2 particles/L) and Dominant Particle Type at Each Sampling Station In The Kamoning River.

Station	Land-use/ Activity Context	Total Microplastics (10^2 particles/L)	Dominant Type
S1	Upstream residential and agricultural area	11.26	Fragments
S2	Upstream residential–agricultural transition	12.08	Fragments
S3	Midstream, mixed settlement and cropland	14.19	Fragments
S4	Urban centre, flood-pump infrastructure	21.13	Fragments
S5	Port area with intense shipping and loading activities	20.52	Fragments
S6	Estuary, near salt-farming and fishing activities	25.36	Fragments

Total microplastic concentrations increased from upstream residential–agricultural reaches (S1 to S3) towards urban, port, and estuarine locations (S4 to S6), reflecting a cumulative influence of anthropogenic activities along the river course. The highest abundance was recorded at the river mouth station (S6), where intensive shipping and salt-farming activities coincide with inputs from the entire upstream catchment. Fragments dominated the morphology, followed by fibres and (to a lesser extent) films at all stations. Fragment abundance averaged over 9.5×10^2 particles/L, and fibres and films made up approximately 5.0×10^2 and 2.8×10^2 particles/L, respectively. Both sampling location and particle type significantly affected microplastic abundance ($F= 10.64$; $p<0.05$) through one-way ANOVA, indicating strong spatial variability and form-specific loading patterns along the river.

Risk quotient calculations, which combined measured microplastic concentrations with conservative exposure scenarios and literature-based reference values, indicated that most estimated RQ values for short-term human exposure through water use and local fish consumption remained below 1, as shown in Table 2.

Table 2. Screening-level Risk Quotient (RQ) for Microplastic Exposure at Each sampling station in the Kamoning River, based on total microplastic abundance

Station	Total Microplastics (10^2 particles/L)	RV (10^2 particles/L)	RQ	Risk Category*

S1	11.26	50	0.23	Low
S2	12.08	50	0.24	Low
S3	14.19	50	0.28	Low
S4	21.13	50	0.42	Low-moderate
S5	20.52	50	0.41	Low-moderate
S6	25.36	50	0.51	Moderate

*Risk categories follow commonly used thresholds in chemical risk assessment, where RQ < 1 indicates acceptable or low to moderate concern, and RQ ≥ 1 suggests potential risk requiring attention.

The risk quotient analysis at screening-level, integrating the measured microplastic abundances with a conservative value, suggested RQ values below 1 at all sampling stations in the Kamoning River, as shown in Table 2. In this study, a reference value (RV) of 50×10^2 particles/L was adopted as a screening-level benchmark rather than a formal toxicological limit [13]. This value was derived by combining three lines of evidence: (i) typical ranges of microplastic abundance reported in polluted rivers and estuaries, which often fall within the order of magnitude of 10^2–10^3 particles/L [14], [15]; (ii) intake estimates for drinking water and seafood consumption reported in global exposure studies [5], [16], [17]; and (iii) the order of magnitude of provisional mass-based reference doses proposed in recent quantitative microplastic risk assessments [14], [15].

Estimated RQ values ranged from 0.23 at the upstream residential–agricultural station (S1) to 0.51 at the estuarine station (S6), following the downstream increase in total microplastic concentrations. According to conventional risk assessment thresholds, RQ values below 1 indicate that, under the assumed exposure conditions, risks remain within an acceptable or low-to-moderate range of concerns. Nevertheless, the higher RQ values observed at the lower reaches suggest that these areas are emerging hotspots of microplastic accumulation where precautionary management and closer monitoring would be warranted, even though current estimates do not exceed screening benchmarks. Overall, the present assessment should be interpreted as a screening-level evaluation that identifies relative risk patterns along the river rather than providing definitive toxicity thresholds for specific health outcomes.

3.2. Discussion

The high microplastic loads in the Kamoning River confirm that the system acts as a major pathway for mismanaged plastic waste from densely populated, agricultural and port areas in Sampang District [4]. Fragments dominate the particle assemblage, consistent with the breakdown of packaging, bottles, household plastics and agricultural materials as primary sources [18]. The clear upstream–downstream gradient, with maximum abundance and RQ values at the estuarine station, indicates that microplastics are transported and retained toward the river mouth. Lower reaches turn into accumulation zones and potential ecological stress hotspots. This result is consistent with previous research that has demonstrated the role estuaries generally play as microplastic deposit hotspots and important transmission gateways for plastic particles in streams to the surface of shorelines [19]. For Sampang, this accumulation not only means greater ecological stress on the Kamoning River's lower reaches, but also more pressure on adjacent coastal ecosystems and fisheries that feed local communities.

Similar dominance of fragment and fibre-type microplastics has been reported for other Indonesian rivers and estuaries, such as the Musi and Siak systems, where land-based activities and poor waste management drive plastic inputs [20], [21], [22]. In those systems, land-based activities and poor waste management drive plastic inputs. Reported RQ values in many freshwater and estuarine environments also frequently remain below 1, even where microplastic abundances are high, reflecting both conservative exposure assumptions and the current uncertainties in dose–response relationships. The pattern observed in the Kamoning River, with higher RQ values at downstream and estuarine sites, is consistent with studies that identify estuaries as important filters and deposition zones for river-borne microplastics. Overall, the present assessment should be interpreted as a screening-level evaluation that identifies relative risk patterns along the river rather than providing definitive toxicity thresholds for specific health outcomes.

Although all RQ values in this study are below 1, the elevated abundances and risk indices at the urban, port and estuarine stations indicate that these reaches are priority targets for plastic waste reduction measures and improved solid waste management. Integrating microplastic indicators into routine river and coastal monitoring programmes would help track future changes in contamination and evaluate the effectiveness of management interventions. Given the remaining uncertainties regarding microplastic toxicity, adopting precautionary measures in the watershed—such as reducing single-use plastics, strengthening collection systems and focusing clean-up efforts at downstream hotspots—can help prevent RQ values from approaching or exceeding risk thresholds in the future.

4. Conclusion

This study shows that the Kamoning River currently functions as a critical conduit and accumulation zone for microplastic pollution. Fragment-dominated microplastic contamination intensifies from upstream residential–agricultural areas to the estuarine reach in Sampang District. The study goes beyond descriptive pollution surveys by quantifying microplastic abundance at six sampled stations and developing a screening-level risk quotient (RQ) framework. This framework connects measured concentrations to literature-based exposure scenarios and toxicological benchmarks. It offers an initial, locally based estimation of environmental and human health risks in Sampang waters. Reported RQ values at all sites fall within low to moderate risk regions. These findings indicate current potential for targeted management of plastic waste and highlight the importance of further studies on microplastic toxicity and exposure in Indonesian riverine and coastal conditions.

The study's main contribution is that it provides a replicable bridge from microplastic abundances recorded using field-based measurements to risk-based indicators that are immediately relevant to local policy and management. Results provide a basis for upstream waste management, tighter monitoring of plastic use in residential, agricultural and port settings, and for the inclusion of microplastic indicators in regional water quality and public health monitoring priorities.

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