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Ecological Risk Assessment of Microplastic Pollution in Surface Water of the Kranji River Basin

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Abstract

Microplastics are defined as small plastic particles with a diameter of less than 5 mm. The formation of microplastics occurs as a result of the degradation and fragmentation of microplastics within the environment. The present study was conducted over the course of two months, from August to September 2025. The present study was conducted in the Kranji River basin, which is in Banyumas Regency, specifically in Baturraden Subdistrict and East Purwokerto Subdistrict, which are the upstream and downstream points of the river, respectively. The present study measured the abundance of microplastics and the polymers they contain. The present study measured the abundance of microplastics and the polymers they contain and calculated the polymer load index and polymer hazard index in order to determine the potential for contamination and the hazards posed by microplastic pollution in the Kranji River. The analysis employed the SmartPLS methodology to examine the direct and indirect effects of total MPs pollution, the Pollution Load Index (PLI), and the Polymer Hazard Index (PHI). The study revealed that microplastic levels are higher upstream than downstream. The microplastics identified were fibers, films, and fragments. On average, they measure 0.5 mm and come in many colors, with most being black. FTIR tests identified a polymer called polyethylene in all the samples. The risk assessment indicates medium pollution levels and a 97.6% increase in risk due to microplastics in the Kranji River. This indicates contamination of surface water in the river basin.

Introduction

Microplastics are defined as small plastic particles with a diameter of less than 5 mm. The formation of microplastics occurs as a result of the degradation and fragmentation of microplastics within the environment (Daud, 2020). One such cause of microplastic formation is ultraviolet radiation from the sun, which has been demonstrated to cause microplastics to degrade into micro- or nano-sized plastics (Burrows *et al.*, 2024). Indonesia is a country with a relatively high population density, distributed across several provinces from Sabang to Merauke. It is located in the tropics (Azizah *et al.*, 2021), meaning it experiences a high level of exposure to sunlight, which has the potential to cause the formation of microplastics.

A significant proportion of the extant literature concerning the distribution of microplastics in the environment is derived from studies conducted in the open sea

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and oceans. These studies demonstrate that microplastics are widely distributed in aquatic areas (Collignon *et al.*, 2014; Doyle *et al.*, 2011; Law *et al.*, 2010; Moore *et al.*, 2001). The presence of microplastic particles in seawater or oceans can be attributed to various sources, with one significant cause being the contamination of rivers that drain into the sea. A significant proportion of research has been dedicated to the marine environment, with approximately 80% of microplastic pollution in the sea being attributed to transport from rivers to the marine environment (He *et al.*, 2025; Rochman, 2020). The sources of microplastic pollution can be traced back to human anthropogenic activities, industry, wastewater disposal, or household activities that flow into rivers (Liu *et al.*, 2024).

As demonstrated by data obtained from the Indonesian waste management information system, plastic waste is the second most prevalent type of waste, exceeded only by household waste, accounting for 19.55% of the total waste recorded in Indonesia. Central Java Province has been identified as a region with a high rate of waste production, with Banyumas Regency being ranked as the fifth-highest producer of waste within the province (Kementerian Lingkungan Hidup, 2024). Despite the presence of adequate waste management infrastructure in Banyumas Regency, both nationally and within the ASEAN framework, there remains a possibility that some waste may not be adequately managed, thereby contributing to environmental degradation, particularly in river basins. The Kranji River is located in Banyumas Regency. The Kranji River extends from its upper reaches to its lower reaches. The lower reaches of the Kranji River pass through urban areas, rendering it highly susceptible to microplastic contamination. Furthermore, the upper reaches of the Kranji River have gained popularity as a tourist destination and are in proximity to residential areas. This proximity renders them vulnerable to microplastic contamination from anthropogenic activities.

The distribution of microplastics in water bodies poses a potential hazard to the environment and aquatic organisms (Xu *et al.*, 2018), as previous studies have shown that microplastic particles can be ingested by aquatic organisms if they resemble the color of their prey (Cera *et al.*, 2025; Laurier & Mason, 2007; Xu *et al.*, 2018). Our preceding investigations have demonstrated that microplastics have the capacity to contaminate the food chain, encompassing fish, squid, bivalves, and other marine biota (Rizaldi *et al.*, 2025; Sulistyorini *et al.*, 2024). Furthermore, other studies have demonstrated that MPs have the capacity to readily contaminate organisms inhabiting rivers (Rahman *et al.*, 2025). Consequently, it is imperative to monitor microplastic pollution in river waters to mitigate microplastic contamination of aquatic organisms, which can adversely impact the health of aquatic environments and the health of communities that consume aquatic organisms. In response to the issue of microplastic pollution in surface water, the present study aims to assess the risk of microplastic pollution in the Kranji River Basin and identify microplastics in the Kranji River Basin, including the distribution of microplastic abundance, shape, size, color, and type of polymer contained in microplastics. Moreover, the undertaking of a multi-index risk assessment is to be pursued, encompassing the calculation of both the Pollution Load Index (PLI) and the Polymer Hazard Index (PHI). It is recommended that, in the future, this study be utilized as a point of reference in the mitigation of microplastic pollution in the river basin.

Method

The present study was conducted in the Kranji River basin in Banyumas Regency, with a focus on the Baturraden and East Purwokerto sub-districts, which are located at the river's upstream and downstream points, respectively. The study encompassed a total of six sampling points, with three located upstream and three downstream from the point of interest. The study was conducted from August to September 2025. Equipment and materials used included a 300-mesh plankton net, a 10-L bucket, glass jars, and distilled water. Preparation and analysis of microplastic samples followed a modified NOAA protocol, implemented by Ecoton Laboratory (Indonesia). Each water sample was treated with 20 mL of 30% hydrogen peroxide (H2O2) to digest organic matter. Five drops of 30% ferrous sulfate (FeSO4) were added as a catalyst. The samples were then incubated for

24 hours to ensure complete degradation of the organic components.

A binocular stereo microscope (40× magnification) with a digital camera was used for the microscopic examination. The identification and classification of microplastic particles were based on their shape, color, and size. The suspected particles were then subjected to visual inspection under consistent illumination to distinguish them from natural debris or organic fragments. The chemical composition of the isolated microplastic particles was determined by means of a Fourier transform infrared (FTIR) spectrometer. The present analysis was carried out by the Division of Material Characterization, Department of Materials Engineering and Metallurgy, Faculty of Industrial Technology and Systems Engineering, Sepuluh Nopember Institute of Technology (ITS), Surabaya, Indonesia. The risk assessment of microplastic pollution was conducted utilizing the Pollution Load Index (PLI) and the Polymer Hazard Index (PHI). This approach enabled the estimation of the magnitude of microplastic contamination in the aquatic ecosystem and the potential ecological risks to flora and fauna. The PLI was utilized as a metric to ascertain the overall level of environmental pollution in the designated study area. In this research, the PLI method was employed to quantify the degree of microplastic contamination in the surface water of the Kranji River. The PLI was calculated using the following equation (Rahman *et al*., 2025):

$$PLI = \sqrt{CF_i} \quad (1)$$

The PLI value >1 indicates that the environment is polluted, whereas a value <1 denotes an unpolluted condition. This index is of particular value in understanding the cumulative impact of microplastic pollution within the study area (Rahman *et al*., 2025). In order to evaluate the prospective environmental risk pertaining to differing polymer types, the Polymer Hazard Index (PHI) was determined (Lithner *et al*., 2011; Ranjani *et al*., 2021). The PHI is defined as the product of the proportion of a specific polymer type identified at each sampling site (Pn) and its corresponding hazard score (Sn). The index was computed using the following equation:

$$PHI=\sum(Pn \times Sn) \quad (2)$$

Where Pn is the percentage of each polymer type identified in the samples, and Sn is the hazard score for that polymer type, as derived from Lithner *et al*. (Lithner *et al*., 2011). The total PHI value reflects the overall hazard level of microplastic contamination in the study area and can be used to classify the area into different risk categories based on the magnitude of the index. These polymers are categorized into four distinct hazard levels based on their PHI values: Level I (0–10): Low hazard level; Level II (10–100): Medium hazard level; Level III (100–1000): High hazard level; Level IV (>1000): Extremely high hazard level (Md. R. Ali *et al*., 2025). The data analysis in this study was conducted systematically and rigorously to ensure the accuracy and reliability of the results. Descriptive statistical methods were employed to calculate the mean, range, and standard deviation of microplastic (MP) abundance in surface water. Additionally, Smart PLS software was used to examine direct and indirect effects of total MPs pollution, the Pollution Load Index (PLI), and the Polymer Hazard Index (PHI). Integrating statistical and spatial analytical techniques provided a comprehensive understanding of MP distribution patterns, supporting the subsequent environmental risk assessment.

Result nd Discussion

The research was conducted in two distinct locations: the upper and lower reaches of the river. The upper segment of the river is representative of areas with low density, operating under the assumption that these areas do not contain significant levels of microplastic. In contrast, the lower segment is representative of areas with high density. The geographical area under investigation comprises two distinct sections: the upper section is in the Rempoah region, while the lower section is situated in the Kranji district. The findings of the research are illustrated in Table 1.

The findings of the study indicated that the upstream section exhibited lower results in comparison to the downstream section.

Table 1. Abundance of Microplastics in the Kranji River Basin

No	Location	Abundance of MPs (Particle/Litre)	Abundance MPs (Particle/Litre)
1	Kranji Village 1 (Downstream)	1.9	
2	Kranji Village 2 (Downstream)	4.9	10.4
3	Kranji Village 3 (Downstream)	3.6	
4	Rempoah Village 1 (Upstream)	1.4	
5	Rempoah Village 2 (Upstream)	5.1	7.7
6	Rempoah Village 3 (Upstream)	1.2	
	Average abundance of MPs (Particle/Litre)	3.01	

The table illustrates that the abundance of microplastics in the upstream section was 7.7 particles/liter, while in the downstream section it was 10.4 particles/liter. The mean microplastic concentration in the upstream and downstream sections was found to be 3.01 particles/liter. This study also identified the characteristics of microplastics, namely their shape, size, and color. The results of the microplastic identification process revealed that microplastics detected manifested as fibers, films, and fragments. The results of the study are illustrated in Figure 1. Fiber-shaped MPs have been detected at a higher frequency than other shapes. The total number of fiber-shaped MPs detected in the upstream and downstream sections of the river is 150 particles. The illustration of the shape of microplastics is presented in Figure 1.

Furthermore, the study determined the size of microplastics. The microplastics detected exhibited an average size of 0.28 mm. The colors of microplastics detected included blue, yellow, green, black, red, orange, brown, and transparent. The majority of microplastics identified were black. Microplastics are defined

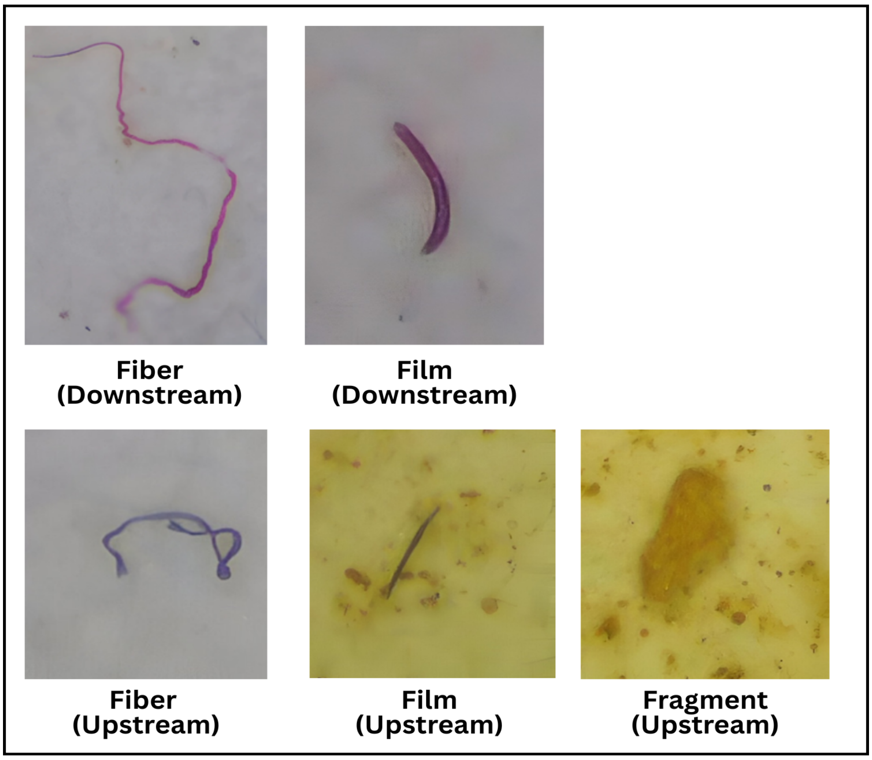


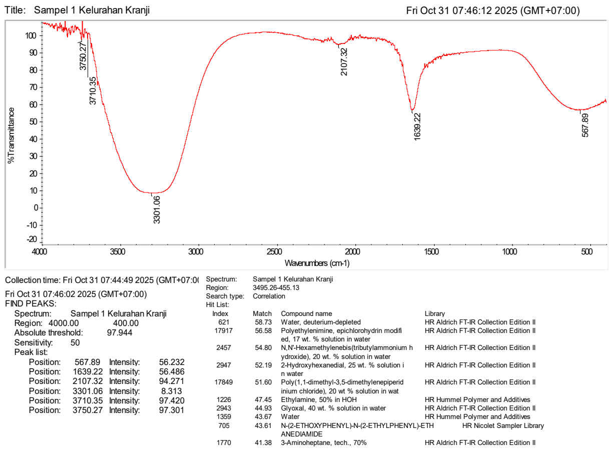
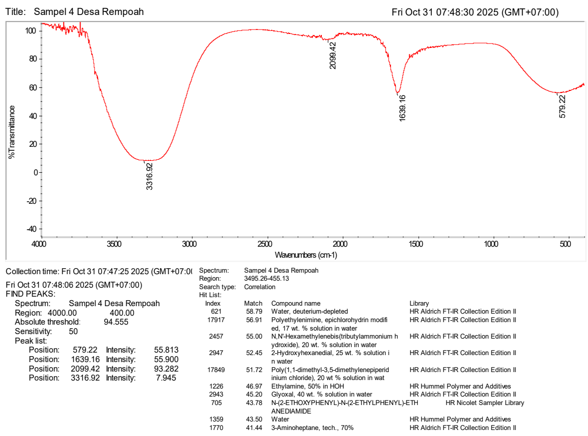
Figure 1. Visualization of Microplastics from the Downstream and Upstream Areas

as small plastic particles with a diameter of less than 5 mm (Aulia *et al*., 2023). The presence of microplastics has been detected in all environments, including waterways. The presence of microplastics in marine waters can be attributed to the contamination of rivers by microplastics. The presence of microplastic particles in fluvial environments can be attributed to anthropogenic influences, including population density, urbanization, and land use (Kunz *et al*., 2023). The findings of the study demonstrate that the mean abundance of microplastics identified in the upstream and downstream areas is 3.01 particles/liter. The results of this study demonstrate that the downstream area of the Kranji River exhibits a higher abundance of species than the upstream area, which is characterized by its densely populated urban nature. This study corroborates earlier research that identified a correlation between microplastic abundance and rural-urban population density. It has been demonstrated by further studies that urbanization is a contributing factor to microplastic pollution in rivers. A correlation has been identified between population density and microplastic pollution (Kunz *et al*., 2023). Other studies also show that urbanization is a cause of microplastic pollution in rivers, where population density is related to microplastic pollution (Gutiérrez-Rial *et al*., 2024). In addition, there are several sources of microplastic pollution in rivers, such as industry, agriculture, domestic sewage, and water deposition (Li *et al*., 2023).

This study also succeeded in identifying the characteristics of microplastics. The results of the study demonstrated that the majority of microplastics identified were fibers (Figure 3A). A further study conducted on rivers in China also demonstrated that the most prevalent form of microplastic identified was fiber (Akdogan *et al*., 2023). However, a contradictory study was conducted in Japan, which indicated that fragment-shaped microplastics were more frequently identified, while fibers were more commonly identified in mesoplastics (5-25 mm) (Nihei *et al*., 2024). However, the majority of microplastics detected in the environment were fibers (A. A. M. Ali *et al*., 2024). Furthermore, the study determined the size of the microplastics detected. The majority of the microplastics identified were of a small size, with a diameter of less than 0.5 mm (see Figure 3B). As demonstrated in other studies, the size of microplastics identified in water ranges from 0.002 to 0.249 millimeters, with a percentage of 99.81% being small microplastics (Kerubo *et al*., 2022; Nyaga *et al*., 2024). The utilization of Plankton Nets in the filtration of microplastics from water has been demonstrated to exert an influence on the morphology of the microplastics identified (Nyaga *et al*., 2024). Nets with smaller mesh sizes have been shown to filter more fiber-shaped microplastic particles, while more fragment-shaped microplastics are able to pass through (Razeghi *et al*., 2021). A further study demonstrated that nets with a mesh size of 80 micrometers exhibited a higher capacity for filtering fiber-shaped microplastics in comparison to nets with a mesh size of 330 micrometers (Wagner & Lambert, 2018). The microplastic samples that were identified were then subjected to analysis of their polymer content by means of FTIR. The FTIR test results can be found in Table 2.

The findings of the FTIR test indicated that all the microplastic samples that were successfully identified were composed of a polymer known as polyethylene (PE). This polymer is ubiquitous in the environment due to its extensive use as a constituent of plastic bags and myriad other plastic materials that are utilized on a daily basis. The majority of microplastics identified in this study were black, specifically 122 particles, constituting 67% of the total particles identified. This finding aligns with the conclusions of previous studies, which identified a predominance of black microplastics, accounting for 45% of the total particles identified (Flores-Cortés & Armstrong-Altrin, 2022). The black color of the microplastics found is indicative of the degradation of plastic bags commonly used by the community in their daily activities. The community in the study location predominantly utilizes plastic bags in their quotidian activities, such as when shopping, where the bags most commonly employed are black plastic bags. Furthermore, the presence of black microplastics in rivers has been attributed to the friction of motor vehicle tires entering or being

Table 2. The Result of Microplastics Polymer by FTIR

<table>
<tr><th>No</th><th>Location</th><th>Microplastic polymer</th><th>FTIR Result</th></tr>
<tr><td>1</td><td>Downstream</td><td>Polyethylene (PE)</td><td>
</td></tr>
<tr><td>2</td><td>Upstream</td><td>Polyethylene (PE)</td><td>
</td></tr>
</table>

discarded into these water bodies. The presence of black microplastics has been observed in various sources, including food packaging, toys, electronic goods, motor vehicle tires, and other potential sources (Y. Huang & Xu, 2022).

The microplastics identified in this study were subjected to polymer content analysis using FTIR. The results indicated that all microplastic samples, both upstream and downstream, were identified as polyethylene (PE). As demonstrated by other studies, microplastics identified in surface water and sediment consist of polypropylene, polyethylene, polyvinyl chloride, and polyethylene terephthalate (D. Huang *et al.*, 2021). It has been demonstrated by other studies that the types of microplastics that have been identified are generally polyethylene (PE) and polypropylene (PP) microplastics. This is because these microplastic polymers are commonly used by the public (D. Huang *et al.*, 2021; Liu *et al.*, 2024). Polyethylene is one of the most prevalent polymers (Bouadil *et al.*, 2024). The results of the study demonstrate that microplastic pollution risk analysis indicates a location that is both polluted and at medium risk. The results of the study are presented in Table 3.

As demonstrated in Table 3, a medium PLI score (i.e.,>1) indicates that the location is contaminated by microplastics. In contrast, the PHI scores 25.63 and 18.92, which place them within the medium hazard category (Level 2:

Table 3. The results of the Pollution Load Index (PLI) and Polymer Hazard Index (PHI) were Calculated and Categorized

Risk Category	Location	
	Downstream	Upstream
PLI	1.526	1.311
Category	Polluted	Polluted
PHI	25.63	18.92
Category	Medium	Medium

Table 4. The result of the correlation and the direct and indirect effects of total MPs, PLI, and PHI

	Original Sample (O)	Sample Mean (M)	Standard Deviation (STDEV)	T Statistics (|O/ STDEV|)	P Values
Total of MPs → PLI	0,997	0,998	0,001	766,956	**0,000**
PLI → PHI	0,979	0,975	T0,057	17,084	**0,000**
Total of MPs → PLI → PHI	0,976	0,973	0,057	17,086	**0,000**

10-100 medium hazard level). The presence of microplastic contamination can be attributed to a variety of factors, including anthropogenic and industrial activities. As demonstrated in previous studies, water contamination can be attributed to industrial and domestic waste (Musfirah & Rangkuti, 2019; Widiyanto *et al.*, 2015). Furthermore, the issue of illegally disposed-of waste accumulating in specific locations along riverbanks can result in environmental concerns, such as river water contamination with microplastics (Maliga *et al.*, 2025; Mulasari & Sulistyawati, 2014). Furthermore, microplastic contamination in rivers can act as a vector for heavy metals such as lead, which can be introduced to water bodies through industrial activities like the batik industry. Once ingested, lead has the potential to cause various health concerns, including antisocial behavior (Susilowati *et al.*, 2025). Measures must be implemented to prevent water pollution through effective waste management. One such measure could be the establishment of waste management, which has been shown to increase community income while simultaneously preventing environmental pollution (Astuti *et al.*, 2024; Bhattacharjee *et al.*, 2025)

The PLS algorithm analysis demonstrates that the model exhibits adequate fit, as evidenced by SRMR values falling below 0.08 and NFI scores exceeding 0.90. This finding signifies that the model is both fit and feasible for utilization. The composite reliability score and Cronbach alpha are indicative of data validity and reliability for advanced analysis, with scores greater than 0.7 indicating such validity and reliability. Table 4 shows the results of the direct and indirect effect analysis.

The findings of the direct effect analysis demonstrate a substantial relationship between elevated microplastic pollution levels and PLI values (see Table 4). The analysis results demonstrate a positive correlation between microplastic pollution levels in the Kranji River and the impact on PLI values, with a 99.7% increase observed in the PLI values. The analysis further demonstrates a significant relationship between the PLI score and the PHI score, indicating that an increase in the PLI score results in a corresponding rise in the PHI value, with a 97.9% direct effect.

The indirect effect analysis demonstrates a substantial relationship between microplastic pollution, PLI value, and PHI value. The results of the indirect effect analysis demonstrate a significant association between microplastic contamination levels in the Kranji River and the PHI value. This finding indicates that a PLI can be a mediator to increase PHI values. (see Table 4).

Consequently, the analysis results indicate that elevated microplastic pollution levels in the Kranji River may potentially contribute to an escalation in the risk of microplastic-contaminated aquatic environments by 97.6%.

The results of the microplastic pollution risk analysis demonstrate that the Pollution Load Index (PLI) values in the upstream and downstream areas exceed 1, indicating that the upstream and downstream locations of the Kranji watershed are contaminated by microplastics. The findings of this study are consistent with the results of a study conducted in India, which demonstrated that the PLI value of microplastics in river surface water was >1, indicating that the river was contaminated with microplastics (Rahman *et al*., 2025). The presence of microplastics in a water environment has been demonstrated to cause disruption to the ecosystem inhabiting that water body (Jaikumar *et al*., 2025). The presence of microplastics in the aquatic environment poses a significant threat to the biota inhabiting these ecosystems, as microplastics themselves become a contaminant in the water, potentially affecting the health and well-being of aquatic organisms. In addition to contaminating biota living in aquatic ecosystems, microplastics have been shown to act as vectors for other pollutants, including heavy metals. These pollutants can be harmful if consumed by living creatures (Sharma *et al*., 2024).

The findings of the polymer hazard index (PHI) analysis indicate that the PHI value remains in the medium category. This outcome is inconsistent with the results of other studies, which have categorized PHI values as 'very dangerous'. The hazard score of the polymer in question, Polyvinyl chloride (PVC), is a critical factor in this regard. With a hazard score of 10001 (Islam *et al*., 2025), PVC exemplifies the influence of polymer type on the overall assessment. In this study, the PHI was found to be low, a phenomenon that can be attributed to the presence of microplastic polymers, specifically polyethylene, which had a hazard score of 11. It is well-documented that microplastics can have detrimental effects on the environment and human health (Karami *et al*., 2017).

To ascertain the existence of a relationship between the amount of microplastics, PLI score, and PHI, an analysis was conducted using Partial Least Squares (PLS). The findings of the analysis demonstrate a substantial correlation between the quantity of microplastics detected in the water area and the PLI score. Furthermore, a significant relationship is observed between PLI and PHI (p-value = 0.000). Furthermore, an indirect effect analysis was conducted to ascertain the indirect effects that influence PHI. The findings indicated that the presence of microplastics in water bodies can exert a significant influence on the PHI value through the PLI mechanism of up to 97.6%, thereby underscoring the indirect impact of MPs on the escalation of PHI values or PHI levels in contaminated environments. However, other research results have indicated that the type of polymer is a determining factor for high PHI values. In this regard, PE, PP, PS, and PET polymers, despite having a higher proportion or quantity, have lower PHI scores (Yang *et al*., 2023). The types of microplastic polymers identified in water bodies have been shown to play a role in the level of danger of exposure to humans. Several studies have demonstrated that PE and PET MPs have the capacity to augment reactive oxidative stress (ROS), which can result in health complications including dementia and immune system disorders (Gecegelen *et al*., 2025; Nihart *et al*., 2025; Yu *et al*., 2023). As demonstrated in another study, exposure to polyethylene has been shown to have a detrimental effect on the digestive system, kidneys, and liver of male Rattus norvegicus (Inaku *et al*., 2024). It has been demonstrated that the presence of microparticles in river water has the potential to engender a heightened public health risk for human life within the confines of the river basin. The present study is subject to certain limitations; it is only able to identify microplastics and calculate the potential for microplastic pollution and the associated dangers. Moreover, in order to accurately calculate surface water pollution, it is imperative that water samples are collected from the centre of the river basin, rather than merely from specific points downstream or upstream. The present study has highlighted the necessity for further research in order to fully elucidate the potential dangers of microplastic pollution. In order to ascertain the full extent of the threat to the environment, aquatic ecosystems, and public health, further research is required.

Conclusion

A recent study has revealed the presence of microplastics in surface water samples collected from the Kranji River, indicating potential contamination in both the upstream and downstream areas of the river basin. The Pollution Load Index (PLI) calculation results indicated that the PLI value obtained was greater than 1, thereby suggesting that the river basin had been contaminated with microplastics. In addition, the PHI calculation results demonstrated that the river basin was assigned to a medium or level 2 hazard category. The high PLI and PHI can be influenced by the large concentration of microplastics detected in river basins, so if the river flow is contaminated by microplastics, it will potentially disrupt the aquatic ecosystem. Furthermore, the contamination of water resources has the potential to enter residents' wells, thereby endangering public health if the water is consumed due to its accumulation in the human body. Another study has demonstrated that microplastic contamination in the human body can induce oxidative stress reactions, which have the potential to result in various long-term health complications, particularly in cases of continuous and substantial exposure.

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