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Water Pollution Index and Microplastic Ecological Risk in The North Coastal Area of Situbondo

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Abstract: Microplastic pollution in rivers can harm ecosystems and water quality. This study aims to assess water quality and the ecological risk of microplastics in 15 locations in the North Coastal Area of Situbondo, which include rivers and estuaries. Water samples were analyzed based on water quality parameters, such as pH, TDS, ammonia, salinity, turbidity, DO, and BOD. Microplastics were identified using binocular microscopes and FTIR, with characteristics (size, shape, color) recorded. The Water Pollution Index (IP) showed a mild level of pollution with values ranging from 1.322 to 3.897, where IP values 1-3 are considered "mildly polluted." Ecological risk analysis using the Pollution Load Index (PLI), Polymer Hazard Index (PHI), and Potential Ecological Risk Index (PERI) showed that industrial and residential areas had a higher risk of pollution. A significant correlation was found between microplastic color and water quality parameters based on CCA analysis. The results of this study indicate that despite moderate water quality, microplastics pose significant ecological risks, especially in areas with high human activity, emphasizing the need for better environmental management.

Keywords: FTIR; Microplastic correlation; Microplastic pollution; PERI; PHI; PLI; Water Pollution Index (IP); Water quality

Introduction

Water pollution occurs when unwanted substances are released into water bodies, which can affect water quality and aquatic ecosystems (Huang et al., 2013). Rivers are one of the main water bodies that are vulnerable to pollution, especially due to increasing human activities. Uncontrolled exploitation of water resources can lead to significant environmental degradation (Yohannes et al., 2019). Pollutants found in water include cloth, foam, plastic, cork, glass, ceramics, metal, paper, wood, and rubber, with plastic waste being one of the most significant pollutants. It is estimated that 80% of plastic waste found in the sea comes from land, especially through rivers (Mani et al., 2015). Plastic waste that flows from rivers to estuaries and then to the sea has the potential to settle on the seabed, adding to the pollution burden in aquatic ecosystems (Hiwari et al., 2019).

Microplastics, a type of plastic waste, can be categorized into primary microplastics produced in small sizes, and secondary microplastics formed from the degradation of large plastic products into smaller particles. Research shows that land use has an impact on microplastic pollution, especially in areas with intensive industrial and fisheries activities. Situbondo Regency in East Java, which has 675.7 hectares of ponds with Vanamei shrimp as its main product, has the potential to experience environmental pollution due to liquid waste discharged into rivers and plastic waste from product packaging (Situbondo Regency Fisheries Service).

Research on the relationship between microplastics and water quality in rivers is still limited. For example, in the Rio De La Plata estuary, Argentina, no significant correlation was found between microplastics and environmental factors such as temperature, pH, and salinity (Kye et al., 2024). However, in the Fengshan River, Taiwan, microplastics in water were correlated with several water quality parameters, such as COD and SS. Other studies have shown higher abundance of microplastics in shrimp and crab ponds compared to fish ponds (Huang et al., 2024). A study by Talbot & Chang

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(2022) also showed that the distribution of microplastics is influenced by human activities, with higher concentrations in urban areas and areas with high population density.

The novelty of this study lies in the in-depth analysis of the ecological risks posed by microplastics, focusing on the Water Pollution Index (IP) and the correlation between water quality parameters and the abundance and characteristics of microplastics in the River and Estuary of the North Coastal Area of Situbondo. This study also examines how human activities, especially in the fisheries and industrial sectors, can affect the level of microplastic pollution.

This research is important to understand the impact of microplastic pollution on water quality and aquatic ecosystems in areas with great economic potential, such as Situbondo. In addition, the results of this study can provide a stronger basis for better environmental management, as well as policy development to reduce microplastic pollution and improve water quality in coastal and river areas that are vulnerable to the impacts of human activities.

Method

This study uses a quantitative descriptive approach to study water quality and the presence of microplastics in the North Coast of Situbondo, by taking samples at 15 points located in the downstream area of the river. to evaluate water quality and the presence of microplastics. Water sampling follows two specific guidelines: General water sampling refers to the SNI 6989.59:2008 guidelines which are used for water quality sampling in public waters. Water samples are collected using a 1 liter glass container. Sampling for microplastics is based on the procedure from Mississippi State (Sartain et al., 2018), water samples are taken for microplastic analysis, with the volume of water collected for microplastic analysis being 1 liter per sample point.

After sampling, the collected water was filtered using a stainless steel filter to remove large particles. The microplastics remaining on the filter were then processed in the laboratory with the following steps: filtration and drying the filtered water was left to dry to separate the microplastics from the water, wet peroxide oxidation (WPO) this process is carried out to remove organic matter that can interfere with the analysis of microplastics (Masura et al., 2015), separation based on density microplastics were separated using NaCl (sodium chloride) solution with a density of around 1.2 g/cm³ to separate microplastic particles based on differences in density, and identification of microplastics separated microplastics were analyzed using a binocular microscope for visual observation with a magnification of 100x to 400x. Further identification was carried out using FTIR (fourier-transform infrared spectroscopy) to identify the type of microplastic polymer based on the infrared spectrum (Sutanhaji et al., 2021).

Data obtained from water and microplastic samples were analyzed with the following steps: data requirements test before further analysis, normality and homogeneity tests were conducted to ensure data suitability. The Kruskal-Wallis test was used to compare differences between locations, and canonical correlation analysis (CCA) was used to analyze the correlation between water quality parameters and the abundance and characteristics of microplastics. Data were analyzed using SPSS and Past Statistic 4.03 software to produce CCA results.

Figure 1. Picture of sample points in Situbondo Beach Area

To provide an overview of water quality and its pollution level, the pollution index (IP) is calculated using the following water quality parameters: pH, Total Dissolved Solids (TDS), Ammonia, Salinity, Turbidity, Dissolved Oxygen (DO), and Biochemical Oxygen Demand (BOD). The IP formula used is:

$$\mathrm{Lij} = \frac{\mathrm{Ci}}{\mathrm{Cj}} \tag{1}$$

Where:
Lij = The Ratio Value Between the Concentration of Parameter i at the location j
Ci = Value of Parameter i at location j (Laboratory Test Results)
Cj = Quality Standard Parameter i

The IP value is used to classify the level of pollution, where a value of $0 \leq IP \leq 1.0$ indicates that the water quality "meets the quality standards", $1.0 < IP \leq 5.0$ indicates "lightly polluted", $5.0 < IP \leq 10$ indicates "moderately polluted", and $IP > 10.0$ indicates "heavily polluted". To assess the ecological risk of microplastics in river and coastal areas, the following indicators are used.

Pollution Load Index (PLI)

Measuring the level of pollution of water systems based on the abundance of microplastics in rivers. PLI is calculated by comparing the concentration of microplastics found with applicable standards. Pollution Load Index (PLI) formula:

$$\mathrm{CFi} = \frac{\mathrm{Ci}}{\mathrm{C0i}} \tag{2}$$

$$\mathrm{PLIi} = \sqrt{\mathrm{CFi}} \tag{3}$$

Where:
Ci = Abundance of Microplastics in Samples
C0i = Basic abundance of microplastics, based on research (Pan et al., 2021)

Polymer Hazardous Index (PHI)

Measuring the potential risk of chemical toxicity based on the type of microplastic polymer. Each type of microplastic polymer has a different level of toxicity, which is calculated based on the toxicity risk factor established by Lithner et al., 2011). PHI is calculated by multiplying the polymer concentration by the toxicity factor of each polymer.

Potential Ecological Risk Index (PERI)

Used to evaluate the potential ecological risk of microplastics in river and coastal environments. PERI calculates the risk based on the polymer toxicity factor (PHI) and the pollution load index (PLI). The PERI formula is as follows:

$$\mathrm{Ei} = \mathrm{Ti} \times \mathrm{CFi} \tag{4}$$

$$\mathrm{PERI} = \sum_{\mathrm{i}=1}^{\mathrm{n}} \mathrm{Ei} \tag{5}$$

Where:
Ei = Potential ecological risks of Single polymers
Ti = Chemical toxicity coefficient for each polymer according to Lithner et al. (2011).

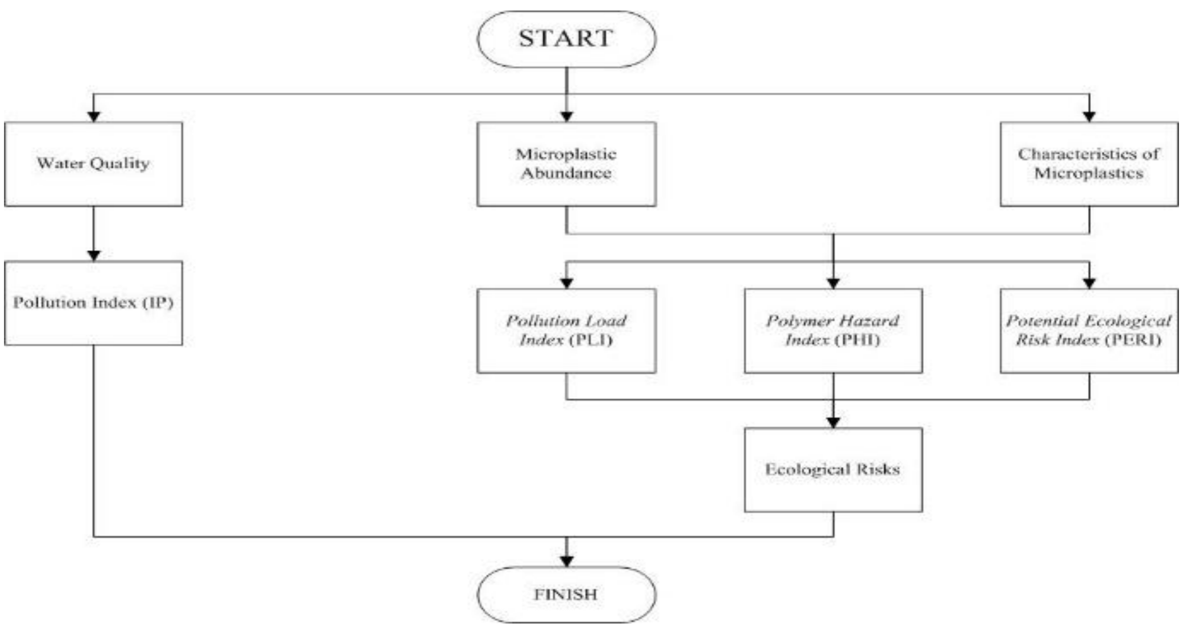

Figure 2. Flowchart of pollution index and ecological risk analysis

Result and Discussion

This study was conducted in the North Coast Area of Situbondo with the aim of analyzing water quality and microplastic abundance in rivers in the area. Sampling was carried out at 15 different points with two water withdrawals at each point (right and left of the river), referring to the purposive sampling method based on accessibility, cost, and time. The parameters analyzed in water quality include pH, TDS, Ammonia, Salinity, Turbidity, DO, and BOD. pH and TDS measurements were carried out directly in the field, while other parameters were analyzed at the Situbondo Regency BPBAP Laboratory using methods according to established specifications. To assess water quality, this study used class III water quality standards in accordance with Government Regulation No. 22 of 2021, considering that the rivers in the area are used for agricultural irrigation and certain fish farming.

Table 1. Results of water quality analysis in the North Coast Area of Situbondo

Location	pH	TDS (mg/L)	Ammonia (mg/L)	Salinity (‰)	Tubidity (mg/L)	DO (mg/L)	BOD (mg/L)
1	8.5	234.5	0.02	0.40	3.03	4.89	9.06
2	8.4	439.0	0.10	4	5.28	5.24	10.24
3	8.5	312.2	0.11	1	5.24	5.03	18.93
4	8.5	540.9	0.09	5	10.91	4.11	20.74
5	8.3	607.8	0.13	9	10.91	4.11	20.74
6	7.4	351.2	0.19	6	25.90	5.52	10.27
7	8.5	752.0	0.06	10	12.83	5.36	8.66
8	7.4	219.0	0.35	4	44.35	7.80	14.30
9	8.7	371.5	0.02	6	3.30	5.08	9.67
10	8.9	523.0	0.28	0.3	39.65	3.67	9.68
11	7.9	740.0	0.17	2	17.22	3.34	10.47
12	8.6	342.8	0.01	1	24.59	3.63	3.45
13	7.2	275.7	0.02	3	18.31	3.18	9.67
14	7.9	262.8	0.18	5	22.20	3.79	10.67
15	9.8	282.1	0.32	8	58.85	2.74	11.28

Source: Analysis result

Microplastic Abundance Analysis

It is done by identifying microplastic particles using a binocular microscope and counting the number of particles found at each sample point. The abundance of microplastics is calculated using the formula (Masura et al., 2015).

$$K = \frac{n}{V} \quad (6)$$

Where:
K = Microplastic abundance (particles per liter)
n = Number of microplastic particles detected
V = Volume of filtered water (in liters)

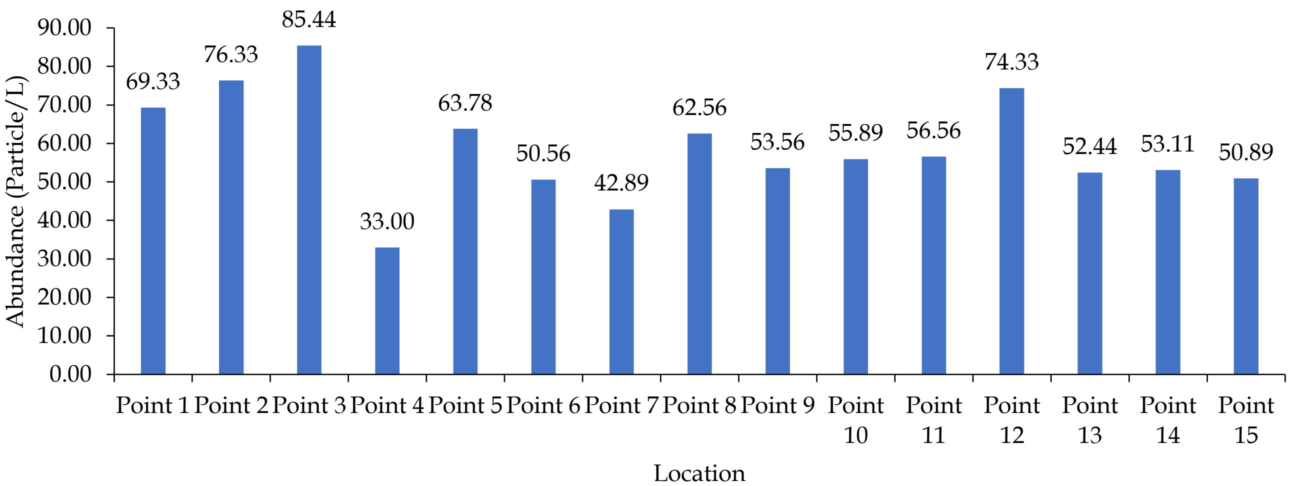

Figure 3. Microplastic abundance in Situbondo North Beach Area

Based on the calculation results, it shows that all sampling points are contaminated with microplastics in the North Coast Area of Situbondo. The highest abundance value was obtained at point 3, namely with the largest land use area for settlements, which is 64.39% of the total area, followed by the area of rice fields, ponds and factories with an abundance value of 85.44 particles/L. The lowest abundance value was obtained at point 4, namely with a value of 33.00 particles/L. The overall average abundance value for the North Coast Area of Situbondo was 58.71 particles/L. In the North Coast Area of Situbondo, many water hyacinth plants were found. Water hyacinth plants can play a role in reducing microplastics into sediments. Water hyacinths that inhabit the area can swallow microplastics which are then released back into the aquatic environment in the form of feces or rotting carcasses, causing microplastics to eventually accumulate in the sediment (Adji et al., 2021). Low-density microplastics consist of polymers such as PE (density: 0.91–0.96 g/cm^3) and PP (density: 0.85–0.94 g/cm^3), with a lower density than seawater (density: 1.02 g/cm^3); thus, they float on the surface of seawater. While high-density microplastics such as PVC (density: 1.41 g/cm^3) and PET (density: 1.29–1.40 g/cm^3) will settle to the bottom of the river or sediment (Zhu et al., 2018; Xu et al., 2018). This is in accordance with the North Coast Area of Situbondo samples 1 and 2, where the PVC polymer type was 63.39% and 64.38% in the FTIR test.

Characteristics of Microplastics

Among all collection points, the size of microplastic particles SMP (small microplastic particles) is the most dominant size, with a total of 70.88% of the total. This is similar to the results of other studies showing that SMP (Small Microplastic Particles) is the dominant microplastic size in research locations, such as in the Ganges River Region, India (Rajan et al., 2023) and the Beijing River Region, China (Tan et al., 2019). Due to their small size and shape, they appear to be food for aquatic species. Excessive inhalation of microplastics causes hypoxia, oxidative stress, decreased growth, and death (Chen et al., 2022). Overall, microplastics in the form of fibers dominate in the North Coast Area of Situbondo (54.69%), followed by films (22.77%), fragments (21.75%), pellets (1.29%), and foam (1.10%). Fibers are usually obtained from washing wastewater, as well as from the disintegration of fishing lines and nets (Li et al., 2023). In accordance with the North Coast Area of Situbondo which is a coastal area where the majority of people's livelihoods are fishermen and shrimp farmers, the most dominant form of microplastics is fiber. And followed by films and fragments originating from plastic bags, food packaging, or plastic bottles due to residential and factory activities in the North Coast Area of Situbondo. The color of the microplastics found was mostly black (60.67%) and transparent (37.39%), which is consistent with the findings of other studies (Hiwari et al., 2019; Buwono et al., 2021). Furthermore, FTIR analysis was used to identify the type of microplastic polymer at each sample point. FTIR results showed the dominance of PVC polymers at sample points located in factory areas, PE and PS polymers in residential areas, and PP polymers in agricultural areas. These results indicate that the sources of microplastics in the North Coast Area of Situbondo are influenced by industrial, residential, and agricultural activities (Frond et al., 2021; Hossain et al., 2021; Trivantira et al., 2023; Budi & Arifin, 2022). Polystyrene (PS) is commonly used to make furniture or wood coatings and storage box containers (Faujiah & Wahyuni, 2022).

Pollution Index (IP)

Table 2. Results of IP pollution index test in the North Coast Area of Situbondo

Location	Total Ci/Lix	Average Ci/Lix	Maximum Value Ci/Lix	Pij	Category
Point 1	4.699	0.671	1.630	1.763	Light Pollution
Point 2	6.816	0.974	1.745	1.998	Light Pollution
Point 3	6.907	0.987	3.154	3.305	Light Pollution
Point 4	8.194	1.171	2.684	2.928	Light Pollution
Point 5	10.437	1.491	3.600	3.897	Light Pollution
Point 6	5.663	0.809	1.838	2.008	Light Pollution
Point 7	5.827	0.832	1.785	1.970	Light Pollution
Point 8	8.595	1.228	2.600	2.875	Light Pollution
Point 9	7.283	1.040	2.400	2.616	Light Pollution
Point 10	5.333	0.762	1.613	1.784	Light Pollution
Point 11	5.830	0.833	1.745	1.934	Light Pollution
Point 12	3.749	0.536	1.208	1.322	Light Pollution
Point 13	5.184	0.741	1.611	1.773	Light Pollution
Point 14	6.777	0.968	2.000	2.222	Light Pollution
Point 15	5.773	0.825	1.880	2.053	Light Pollution

Source: Analysis result

This study used the pollution index (IP) method to determine the water quality status of the North Coast Area of Situbondo based on the Decree of the Minister of Environment Number 115 of 2003 concerning Guidelines for Determining Water Quality Status. The average value of each specified parameter (pH, TDS, Ammonia, Salinity, Turbidity, DO, and BOD) is used to determine the pollution index (IP) value. The aim is to classify the water pollution status based on these parameters. In the North Coast Area of Situbondo, the

Ecological Risk Index is in the light pollution category as seen in Table 2.

The results of the pollution index (IP) in the North Coast Area of Situbondo are in the lightly polluted category. This is evidenced by the dominant land use being rice fields with an average land use area of 63.20%. With the large land use of rice fields than urban areas such as settlements and factories, this affects the index category, namely polluted. Because from urban areas, domestic wastewater and industrial waste are often directly discharged into water channels or rivers without treatment. Meanwhile, in rice fields, human activity is less than in urban areas and pollution is more natural, mostly from fertilizers and pesticides. According to Nugroho et al. (2023) and Hastutiningrum et al. (2020), water quality in rice fields tends to experience light pollution compared to residential areas. And found that changes in land use and population in urban areas cause a decline in water quality.

Ecological Risk

Pollution Load Index (PLI)

Pollution load is used to reflect the amount of pollutants discharged into the environment (Xu et al., 2018). Microplastic pollution load is measured using the Pollution Load Index (PLI) developed by Tomlinson et al. (1980). To assess the level of pollution in the water system. PLI is known as a standard monitoring and assessment method to determine the level of pollution between different stations. The calculation of ecological risk in this study is based on Tomlinson et al. (1980) and Shekoohiyan & Akbarzadeh, 2022). PLI indicates the level of microplastic pollution based on the abundance of measured microplastic particles. Overall, the results of the Pollution Load Index (PLI) in the North Coast Area of Situbondo are in hazard category 1, namely a low level of pollution. PLI is used to measure the level of microplastic contamination (Pan et al., 2021). And the PLI value is calculated based on the ratio between the measured microplastic abundance. Microplastic abundance is influenced by regional human activities, including the rate of industrialization, population density, economic development activities, and marine-based activities (fishing and shipping) (Jang et al., 2020). The low PLI value with a low hazard level in the North Coast Area of Situbondo is evidenced by the majority of land use in this area being rice fields. This is because rice fields that are managed traditionally or organically tend to use natural fertilizers such as manure or compost that do not contain heavy metals, The absence of industrial activity around the rice field area reduces the possibility of contamination, Rice field soil has the ability to fix heavy metals through natural processes such as adsorption and precipitation., Some types of plants, especially rice, are able to stabilize heavy metals in the soil thereby reducing pollution in the surrounding waters. And Irrigation that comes from clean water without significant pollution also maintains soil and water quality, which contributes to low PLI values (Mutia et al., 2023; Lusiyana et al., 2021).

Table 3. Ecological risk analysis results for Pollution Load Index (PLI) values in the North Coast Area of Situbondo

Location	Abundance Particle/L	Ci/Co	PLI	PLI Hazard Category
Point 1	69.333	6.933	2.6	1
Point 2	76.333	7.633	2.8	1
Point 3	85.444	8.544	2.9	1
Point 4	33.000	3.300	1.8	1
Point 5	63.778	6.378	2.5	1
Point 6	50.556	5.056	2.2	1
Point 7	42.889	4.289	2.1	1
Point 8	62.556	6.256	2.5	1
Point 9	53.556	5.356	2.3	1
Point 10	55.889	5.589	2.4	1
Point 11	56.556	5.656	2.4	1
Point 12	74.333	7.433	2.7	1
Point 13	52.444	5.244	2.3	1
Point 14	53.111	5.311	2.3	1
Point 15	50.889	5.089	2.3	1

Source: Analysis result

Polymer Hazard Index (PHI)

The risk of microplastic polymers is assessed using the Polymer Hazard Index (PHI) based on the toxicity coefficient of the identified polymers (Lithner et al., 2011). Overall, the results of the Polymer Hazard Index (PHI) in the North Coast Area of Situbondo for sample 1 representing location points 4, 5, and 12 with hazard category 3 with a moderate hazard level which is a factory area. For sample 2 representing location points 1, 2, and 3 with hazard category 3 with a moderate hazard level which is a residential area. And sample 3 representing location points 6, 7, 8, 9, 10, 11, 13, 14, and 15 with hazard category 2 with a low hazard level which is a rice field area. The polymer index is more dangerous from factories and settlements because microplastic sources are more commonly found in industrial, household, textile, cosmetic and waste disposal systems that are not always effective in filtering microplastics (Damanik & Widada, 2024). Although paddy fields can absorb microplastics from plastic mulch or fertilizer waste, the level of pollution is lower than in urban areas. This is because the bioaccumulation process is slower (Huang et al., 2020). The results of the PHI ecological risk index can be seen in Table 4.

Table 4. Ecological risk analysis results for Polymer Hazard Index (PHI) values in the North Coast Area of Situbondo

PHI	PVC	PS	PP	PE	Nylon	Other	Total	Hazard Category
Sample 1	6.688			4.027			10.715	3
Sample 2	6.793	10.685					17.478	3
Sample 3			9.016				9.06	2

Source: Analysis result

Potential Ecological Risk Index (PERI)

After calculating the PLI and PHI, the Potential Ecological Risk Index (PERI) was calculated based on the Shekoohiyan & Akbarzadeh (2022) method. The most important parameter that is finally used to evaluate the ecological risk caused by microplastics is the PERI index, which considers the sum of the risks of all polymers and the abundance of identified microplastics (Haribowo et al., 2024). In this study, the results of the Potential Ecological Risk Index (PERI) after calculating the Pollution Load Index (PLI) and Polymer Hazard Index (PHI) in the North Coast Area were in various hazard categories. The results of the Potential Ecological Risk Index (PERI) at points 1 and 12 were at a moderate hazard level, points 2 and 3 were at a high hazard level and points 4 to 15 were at a minor hazard level. The results of the Potential Ecological Risk Index (PERI) are influenced by the abundance of microplastics and polymers contained in microplastics which cause the PERI results to differ at each location point. The higher the number of microplastics, the greater the potential ecological risk, which will increase the PERI value. Locations with high human activity such as polluted residential or industrial areas usually show higher abundance of microplastics. Because microplastics are more commonly found in flowing water in urban areas (Gonzalez-Saldias et al., 2024). This is evidenced by the PERI results for moderate and high hazard levels at points 1, 2, and 3 which are in the majority of residential land uses and point 12 is in the majority of industrial land uses. Several types of polymers can release hazardous chemicals that affect aquatic organisms. Such as the types of Polyvinyl chloride (PVC) and Polystyrene (PS) polymers tend to be more dangerous because PS type polymers can cause more severe histological damage and PVC type polymers significantly inhibit the growth of Skeletonema costatum diatoms by 39.7% after 4 days of exposure, indicating a strong toxic effect on phytoplankton (Zhou et al., 2023; Zhang et al., 2017). Proven by the results of PERI with high hazard levels at points 2 and 3 with PVC and PS polymer types. The results of the PERI ecological risk index can be seen in Table 5.

Table 5. Ecological risk analysis results for Potential Ecological Risk Index (PERI) values in the North Coast Area of Situbondo

Location	PVC	PS	PP	PE	Nylon	Other	PERI	Risk Category
Point 1	73.154	208.000	-	-	-	-	281.154	Moderate
Point 2	80.539	229.000	-	-	-	-	309.539	High
Point 3	90.152	256.333	-	-	-	-	346.486	High
Point 4	34.818	-	-	36.300	-	-	71.118	Minor
Point 5	67.292	-	-	70.156	-	-	137.447	Minor
Point 6	-	-	75.833	-	-	-	75.833	Minor
Point 7	-	-	64.333	-	-	-	64.333	Minor
Point 8	-	-	93.833	-	-	-	93.833	Minor
Point 9	-	-	80.333	-	-	-	80.333	Minor
Point 10	-	-	83.833	-	-	-	83.833	Minor
Point 11	-	-	84.833	-	-	-	84.833	Minor
Point 12	78.429	-	-	89.200	-	-	167.629	Moderate
Point 13	-	-	78.667	-	-	-	78.667	Minor
Point 14	-	-	79.667	-	-	-	79.667	Minor
Point 15	-	-	76.333	-	-	-	76.333	Minor

Source: Analysis Result

Conclusion

The Pollution Index (IP) of water quality in the North Coast Area of Situbondo shows a slightly polluted category, with the highest value of 3.897 at point 4 and the lowest value of 1.322 at point 12, based on tests with parameters of pH, TDS, ammonia, salinity, turbidity, DO, and BOD. Based on the ecological risk analysis, for the Pollution Load Index (PLI), all points are in the hazard category 1 with a low level of pollution, with the highest value of 2.9 at point 3 and the lowest value of 1.8 at point 4. The Polymer Hazard Index (PHI) shows that samples 1 and 2 are in the hazard category 3 with values of 10.715 and 17.478, while sample 3 has a value of 9.06 and is also in the hazard category 3. The results of the Potential Ecological Risk Index (PERI) show that points 1 and 12 are at a moderate hazard level, points 2 and 3 at a high hazard level, and points 4 to 15 at a minor hazard level. Although the Pollution Index (IP) shows a low level of pollution, the PHI value which varies from minor, moderate, to high indicates that microplastics detected in water can pose a risk of harm to health and the environment. The presence of microplastics originating from domestic waste, industry, and other human activities is not easily decomposed, so even though water pollution is still in the low category, its impact on the ecosystem and health remains significant.

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