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Correlation Analysis of Water Quality and Microplastic Identification in the North Coast Area of Situbondo

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Abstract: Water pollution occurs when unwanted substances contaminate a body of water, affecting its quality. Rivers, as the main source of water, are particularly vulnerable to pollution from human activities. This study was located in the Situbondo North Coast Area with a focus on 15 sampling points. Water quality was assessed through several parameters. The abundance and characteristics of microplastics were analyzed, revealing the highest abundance at one point, with small fiber-shaped black particles predominant. Canonical Correspondence Analysis (CCA) identified microplastic characteristics, such as color and size, showed strong correlations with water quality. Green and large-sized microplastics were associated with increased ammonia and turbidity, while transparent and fragmentary microplastics correlated with decreased DO and increased BOD. Black microplastics were associated with a decrease in pH. These findings confirm the role of microplastics in worsening the chemical and biological conditions of waters. The study also found that Dissolved Oxygen (DO) and BOD had the strongest influence on the relationship between water quality and microplastics, highlighting the ecological significance of these findings.

Keywords: Biochemical Oxygen Demand (BOD); Canonical correspondence analysis (CCA); Dissolved oxygen (DO); Microplastic, situbondo coastal area; Water pollution; Water quality

Introduction

Water pollution is an increasingly pressing environmental problem caused by human activities, which can damage the quality of water resources and threaten aquatic ecosystems. Rivers, as one of the major water bodies, are highly vulnerable to pollution, especially due to increasing human activities. The continuous exploitation of water resources, coupled with the discharge of industrial waste and plastic waste, causes a significant decline in water quality (Yohannes et al., 2019). Plastic waste, which is often found in water bodies, is a particularly worrisome pollutant due to its non-biodegradable nature, with most of it originating from land and being carried through rivers to the sea (Mani et al., 2015). Microplastics, which are divided into primary microplastics (produced in small sizes) and secondary microplastics (derived from the degradation of large plastics), have become one type of pollutant that is particularly harmful to aquatic ecosystems. Rapidly growing land use and industrial activities often increase the concentration of microplastics in rivers, which in turn contaminate wider water sources.

One of the regions that has great potential in the fisheries industry is Situbondo Regency in East Java, with a pond area of approximately 675.7 hectares and a leading commodity of Vanamei shrimp. However, this fisheries industry also contributes to environmental pollution, especially through liquid waste and plastic waste from product packaging (Situbondo District Fisheries Service). This growing industrial activity

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makes Situbondo a highly relevant location for research on microplastic pollution, especially given its potential impact on water quality.

Research on the relationship between microplastics and water quality is limited. Some studies, such as one conducted in the Rio De La Plata estuary, Argentina, showed no significant correlation between microplastics and environmental factors such as temperature, pH, and salinity (Kye et al., 2024). In contrast, in Fengshan River, Taiwan, a correlation was found between microplastics and several water quality parameters such as COD and SS. Research in shrimp and crab ponds also showed higher abundance of microplastics compared to fish ponds (Huang et al., 2024). The study by Talbot et al. (2022) showed that the distribution of microplastics is influenced by human activities, with higher concentrations in urban and densely populated areas. These findings suggest that there are contextual differences that may influence the correlation between microplastics and water quality, which remain largely unexplored, especially in coastal areas with fishing industries such as Situbondo.

This study aims to fill the knowledge gap on the correlation between microplastics and water quality in areas prone to pollution. By examining the influence of water quality on microplastic pollution, this study will provide important information on the ecological impacts in the area. It is also expected to provide recommendations for more effective waste management policies to minimize microplastic pollution and improve environmental quality in coastal areas.

The novelty of this study lies in its approach of directly linking water quality and microplastics in an area with a large fishing industry, such as Situbondo, which has not been studied much. Therefore, this research is crucial to understand the specific impacts of industrial activities on water quality, as well as to provide a scientific basis for better management of plastic waste in coastal areas.

Method

This study used an explanatory quantitative method, which was to describe water quality and microplastic abundance, as well as analyze the relationship between water quality parameters and microplastic abundance in the Situbondo North Coast area. The explanatory approach was chosen because the research not only aims to describe phenomena, but also test the relationship between variables through inferential statistical analysis. This research examines water quality and microplastics in the Situbondo North Coast area. The research location covers the coastal area of the North Coast of Situbondo Regency with a catchment area of 44,741 hectares. A total of 15 sampling points were selected through representation of various types of human activities around the location (agriculture, settlements, fishing industry), proximity to the river mouth as the main route of waste transportation to the sea, technical considerations such as accessibility and safety in the field. Sampling was carried out following the guidelines of SNI 6989.59:2008 regarding water quality sampling methods, taking into account the ease of sampling in the field. Meanwhile, microplastic sampling was carried out by referring to the Mississippi State University guidelines (Sartain et al., 2018; Masura et al., 2015). Water samples were taken using a glass container with a capacity of 1 liter and filtered using a 5 mm and 0.075 mm stainless steel mesh sieve.

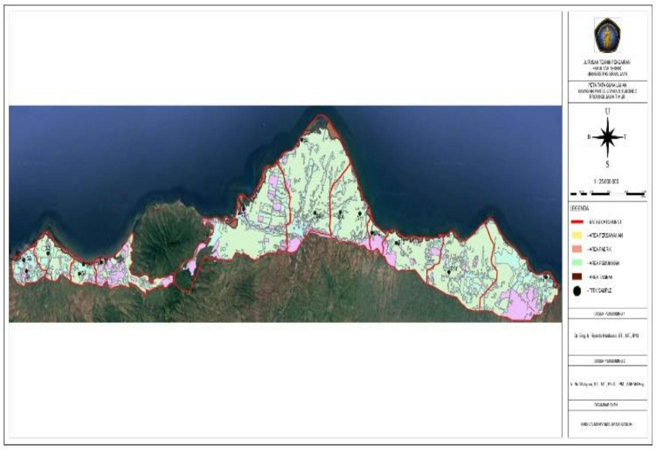

Figure 1. Picture of sample points in Situbondo beach area

Primary data collection was carried out by taking water samples directly in the field, which were then analyzed in the laboratory for water quality and microplastic testing. Water quality testing includes pH, TSS, ammonia, turbidity, and salinity parameters conducted at the Situbondo Regency Brackish Water Aquaculture Center (BPBAP) Laboratory. Microplastic analysis was conducted at the Soil and Groundwater Laboratory, Department of Irrigation Engineering, Universitas Brawijaya, with FTIR testing to identify the type of microplastic polymer at the Instrumentation Unit, Department of Chemistry, Faculty of Mathematics and Natural Sciences, Universitas Brawijaya. The difference in laboratories used is based on each laboratory having specialized facilities and tools that are in accordance with the parameters being tested. After testing water quality samples and microplastics, the data were analyzed through several stages. Microplastic abundance was calculated using the formula (Masura et al., 2015).

After testing water quality samples and microplastics, the data were analyzed through several stages. Microplastic abundance was calculated using the formula (Masura et al., 2015):

$$K = \frac{n}{v} \quad (1)$$

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

To analyze the correlation between water quality and microplastics, normality, homogeneity, and Kruskal-Wallis tests were conducted. Correlations were calculated using Canonical Correlation Analysis (CCA), with plot results analyzed using Past Statistic 4.03 and SPSS applications.

Result and Discussion

Water quality sampling was conducted in the Situbondo North Coast Area, with 15 sample points taken twice (right and left of the river) in accordance with SNI 6989.59:2008. The water collection method uses grab sampling to obtain instantaneous water characteristics. The parameters analyzed include pH, TDS, Ammonia, Salinity, Turbidity, DO, and BOD. Measurements of pH and TDS were conducted directly in the field using a pH meter and TDS meter, while other analyses were conducted in the laboratory. Water quality analysis refers to Government Regulation No. 22 of 2021 which regulates the quality standards of class III river water, which is used because this river is used for agricultural irrigation and fish farming. Below are the results of the water quality analysis:

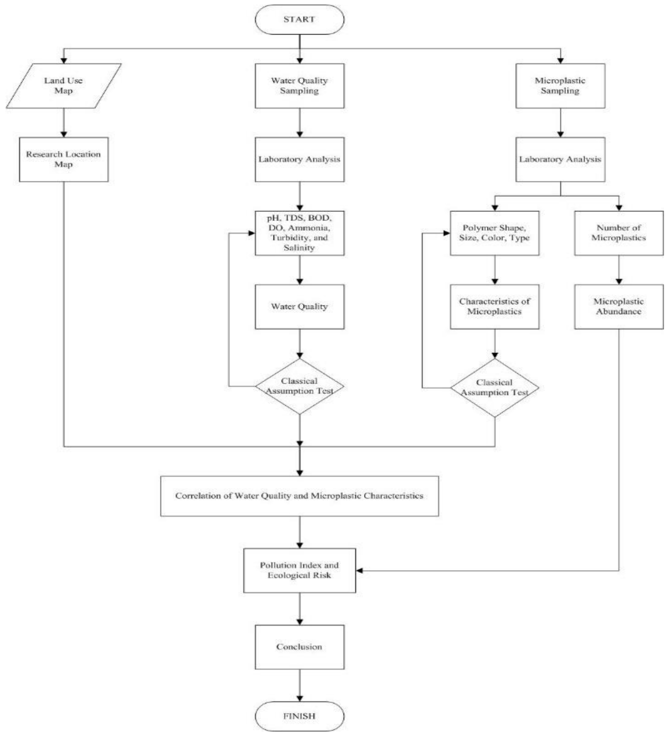

Figure 2. Research flowchart

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

Acidity Level (pH)

Water pollution can change the acidity of water. By measuring the pH of water in the Situbondo North Coast Area, it shows that the pH of water at points 1 to 14 is in normal condition, which is in the range of 6-9, the range is in accordance with PP number 22 of 2021. At point 15 the pH exceeds the normal range of 9.8. The smallest pH value is at point 13 of 7.2 with a value that is in normal conditions. High pH values in water bodies can be produced by lime. This lime can come from agricultural lime (dolomite), domestic waste, and industrial waste (Prayogo & Desmaiani, 2025). This is evidenced at point 15 land use consists of 45.80% agricultural land, followed by 29.84% residential, and 23.18% industry. The high pH value is caused by the use of dolomite lime in agriculture. In addition to the function of dolomite lime to increase pH value levels, it can also neutralize toxic compounds in the soil, increase nutrients in the soil, encourage the release of roots, and spur green color in plants according to the Situbondo Regency Agriculture and Food Security Office. Agricultural waste in the form of liquid silica fertilizer involves the use of detergents or other natural materials containing bases that can increase pH levels (Hasanah et al., 2023).

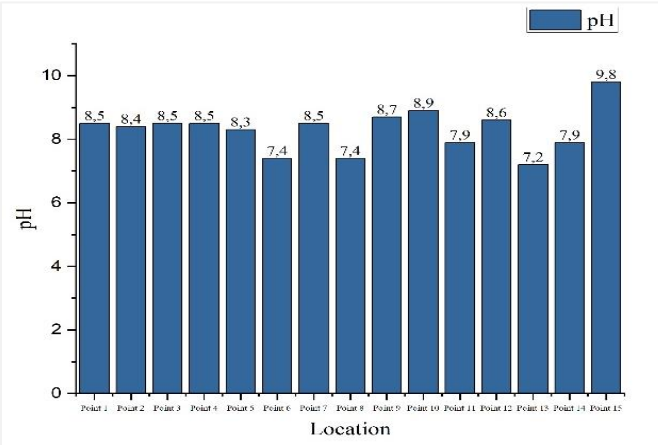

Figure 3. The degree of acidity (pH) at points 1 to 15 in the Situbondo North Coast Area

Total Dissolved Solid (TDS) levels

TDS at all points was below the class III quality standard of 1000 mg/l. Riparian vegetation helps reduce TDS through the absorption of certain minerals and salts by plants (Njurumay et al., 2021). An increase in TDS can increase the conductivity of water, which impacts water quality (Fadhilah & Afdal, 2016).

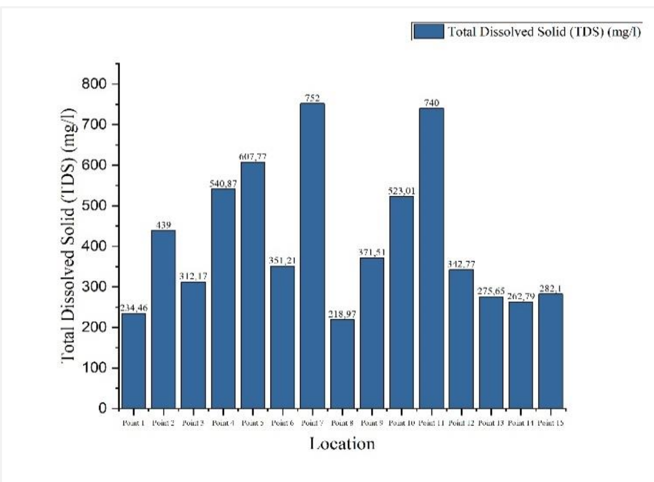

Figure 4. Total Dissolved Solid (TDS) levels at points 1 to 15 in the Situbondo North Coast Area

Ammonia Level (NH3-N)

The results of ammonia analysis in the North Coast Area of Situbondo showed that the highest ammonia levels were at points 8 and 15 with results of 0.35 mg/l and 0.32 mg/l. According to PP no. 22 of 2021, the water quality standard for ammonia levels in class III rivers is 0.5 mg/l. With these results, the ammonia levels in the North Coast Area of Situbondo are below the quality standard. The main source of the highest ammonia levels is in rice fields due to the use of nitrogen fertilizers, decomposition of organic matter, soil microbial activity, and potential pollution from external sources (Ananda, 2022). It is proven at points 8 and 15 that the highest land use is rice fields.

Excessive ammonia can cause eutrophication which damages water bodies and excessive exposure to this pollutant can also be harmful to humans (Hamonangan & Yuniarto, 2022).

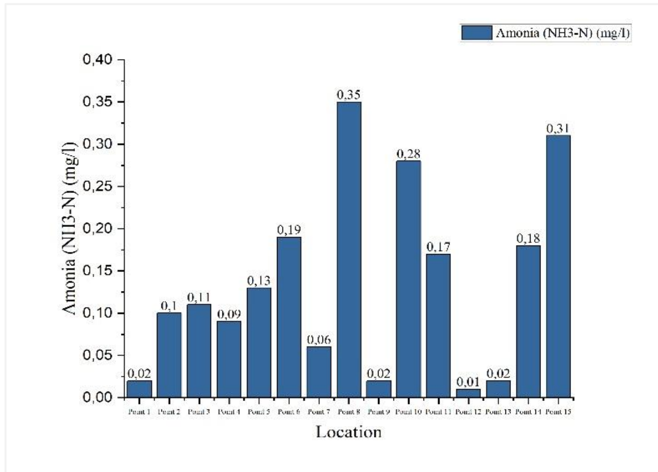

Figure 5. Ammonia (NH3-N) levels at points 1 to 15 in the Situbondo North Coast Area

Salinity Level

Salinity at most points was within the range of 0-0.5‰, which corresponds to freshwater. However, points 5, 6, 7, 9, and 15 showed salinities of 5-30‰, which could be affected by pond effluent discharge and seawater intrusion (Palin et al., 2022; Su'aidah et al., 2021).

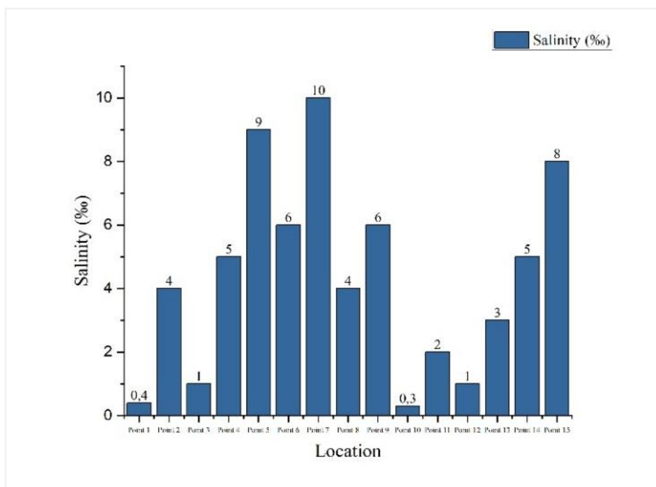

Figure 6. Salinity levels at points 1 to 15 in the Situbondo North Coast Area

Turbidity Level

Water turbidity at all points was below the class III quality standard of 400 mg/l, with point 15 having the highest turbidity (58.85 mg/l). Factors causing turbidity include the use of pesticide fertilizers in agriculture, sedimentation, and domestic and industrial waste (Iqtashada & Febrita, 2023; Hastutiningrum et al., 2020). Turbidity blocks light penetration, which interferes with photosynthesis and reduces the gas exchange capacity of the waterbody (Solo et al., 2023; Wilson, 2013).

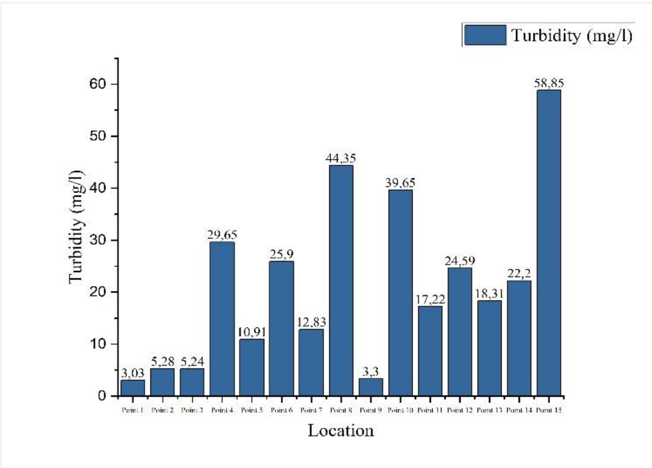

Figure 7. Turbidity levels at points 1 to 15 in the Situbondo North Coast Area

Dissolved Oxygen (DO) Levels

By measuring the Dissolved Oxygen (DO) levels in the North Coast Area of Situbondo, it shows that the Dissolved Oxygen (DO) levels in water at points 1 to 14 are above the standard value for class III river water quality for Dissolved Oxygen (DO) levels which are 3 mg/l. while at point 15 the DO level value was below the standard quality standard of 2.74 mg/l. This standard is in accordance with PP no. 22 of 2021. The low DO level value is at point 15 of 2.74 mg/L. Land use consists of 45.80% agricultural land, followed by 29.84% residential, and 23.18% industrial. Low DO levels are caused by agricultural activity factors whose fertilizers can be carried into rivers and cause waste in the form of organic materials. With evidence that the dominant land use is agriculture with. If the organic material content is too high, the need for dissolved oxygen for bacteria to decompose organic materials will increase, which causes a decrease in the concentration of dissolved oxygen in the water source. If the DO level is low, organisms will not be able to breathe and will weaken or die (Alfionita et al., 2019;Rajwa-Kuligiewicz et al., 2015). The low DO level at point 15 is also caused by the highest turbidity level of 58.85 mg/L. Turbidity levels can reduce DO levels because the photosynthesis process is disrupted, oxygen consumption by microorganisms increases, water temperatures rise, and the aquatic ecosystem is damaged (Pinontoan et al., 2023).

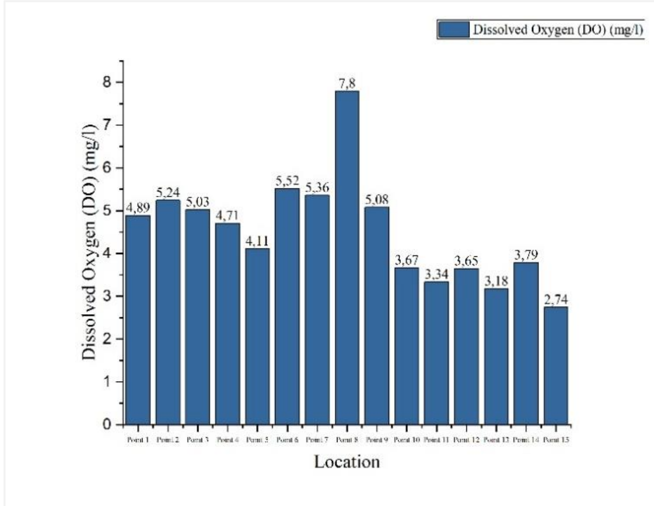

Figure 8. Dissolved Oxygen (DO) levels at points 1 to 15 in the Situbondo North Coast Area

Biochemical Oxygen Demand (BOD) Levels

BOD indicates the amount of oxygen required by microorganisms to decompose organic matter in water. BOD levels in the Situbondo North Coast Area, especially at point 12, are below the quality standard value of class III river water which should be 6 mg/l. The high BOD levels at this point are influenced by organic waste from settlements, factories and farms that are discharged into the river. Excessive fertilizer use in rice fields also contributes to the increase in BOD. An increase in BOD indicates the presence of a lot of decomposing organic matter, which depletes dissolved oxygen (Rahmazywati, 2011).

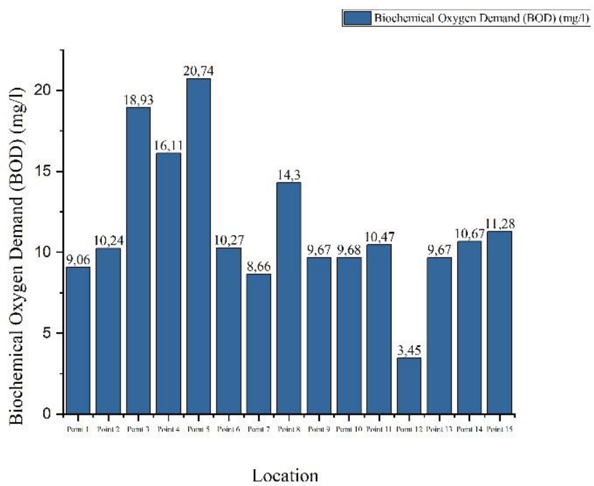

Figure 9. Biochemical Oxygen Demand (BOD) levels at points 1 to 15 in the Situbondo North Coast Area

Microplastic Abundance Analysis

Microplastic analysis was conducted using a binocular microscope to identify the type and number of microplastic particles. Based on the calculation results, Figure 10 shows that all sampling points are contaminated with microplastics in the Situbondo North Coast Area. The highest abundance value was obtained at point 3, namely with the largest land use area for settlements, namely 64.39% of the total area, followed by rice fields, ponds and factories with an abundance value of 85.44 particles/L. The lowest abundance value was obtained at point 4 with a value of 33.00 particles/L. The overall average abundance value for the Situbondo North Coast Area is 58.71 particles/L. In the Situbondo North Coast Area, many water hyacinth plants were found. Water hyacinth plants can play a role in reducing microplastics to sediments. Water hyacinths that inhabit the area can ingest microplastics which are then released back into the aquatic environment in the form of feces or decomposing carcasses, causing microplastics to eventually accumulate in sediments (Kuncoro, 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. Whereas high-density microplastics such as PVC (density: 1.41 g/cm^3) and PET (density: 1.29-1.40 g/cm^3) they will settle to the riverbed or sediment (Zhu et al., 2018; Xu et al., 2018). This is in accordance with the Situbondo North Coast Area samples 1 and 2 obtained PVC polymer type of 63.39% and 64.38% in the FTIR test.

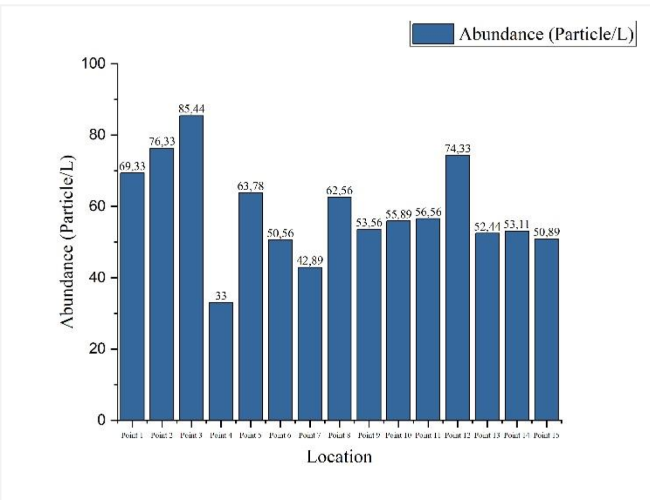

Figure 10. Microplastic Abundance in Situbondo North Beach Area

Characteristic Analysis 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).

Identification of Microplastic Polymers

Testing using Fourier Transform Infrared Spectroscopy (FTIR) showed the dominant types of microplastic polymers in the Situbondo North Coast Area. At points 4, 5, and 12, PVC (63.39%) and PE (36.61%) polymers dominated, while at points 1, 2, and 3, PVC (64.38%) and Polystyrene (PS) (35.17%) were more dominant. At points 6, 7, 8, 9, 10, 11, 13, 14, and 15, polypropylene (PP) dominated (60.11%) along with other polymers (39.89%). These polymers are associated with industrial and agricultural activities in the area (Hossain et al., 2021; Trivantira1 et al., 2023; Budi & Arifin, 2022).

Data Standardization

Data that has different units of measurement needs to be normalized to avoid the influence of outliers or large-scale differences. The normalization process is done by converting the data to a standardized value or z-score, as done by (Harnanto et al., 2017). In SPSS, this procedure is done through the analysis > descriptive statistics > descriptive menu, then check the Save standardized values as variables option.

Normality Test

The normality test was conducted to ensure that the data was normally distributed, which is a requirement in parametric analysis. The Kolmogorov-Smirnov test was used for this test. The results showed that the water quality and microplastic data were normally distributed (p-value > 0.05). The normality test procedure using SPSS was performed through the analyze > descriptive statistics > explore menu and selecting the normality plots with test option. Before analysis, the data were tested for normality to ensure the feasibility of using parametric or non-parametric statistical tests (Wahdaniah et al., 2024).

Homogeneity Test

The homogeneity test tests whether the data comes from a population with the same variance. The homogeneity test results showed that the data was not homogeneous (p-value <0.05), so non-parametric statistical tests such as the Kruskal-Wallis test were performed to continue the analysis. If the data does not meet the assumption of homogeneity, non-parametric tests such as the Kruskal-Wallis test are used to test for significant differences between groups of variables (Wardani et al., 2023).

Kruskal-Wallis Test

The Kruskal-Wallis test was used to test for significant differences between groups of variables. The Kruskal Wallis nonparametric test with a probability value of 0.05 was used to compare the abundance of microplastics obtained between locations (Haribowo et al., 2023). The test results showed a significant difference between water quality and microplastic abundance and characteristics, with a p-value <0.05. These results are similar to research conducted by Kamaruddin et al., (2023) analyzed using the Kruskal-Wallis test. The test results showed a significant difference in color parameters between treatments, with a p value <0.05 while the aroma, taste, and texture parameters did not show significant differences (p>0.05).

Canonical Correspondence Analysis (CCA)

CCA analysis was used to understand the multivariate relationships between the two groups of water quality variables and microplastics. The CCA results revealed that in quadrant I also the color of transparent microplastics and the shape of microplastic fragments had a correlation with the water quality variable Dissolved Oxygen (DO). Transparent microplastic color can occur due to color fading factors by UV light (Hiwari et al., 2019). The shape of microplastic fragments has a rough and irregular surface, making it easier to attract bacterial biofilms. Aerobic bacteria in these biofilms use oxygen for their metabolism, which can reduce DO levels in water (Khatulistiwa et al., 2024). In quadrant III, the black microplastic color has a correlation with the water quality variable pH. The black microplastic color absorbs more heat. Increasing water temperature can accelerate the degradation of organic matter and increase the release of acidic compounds, which can reduce pH levels in water (Sakinah et al., 2022). In quadrant IV, the color of transparent microplastics and the shape of microplastic fragments have a correlation with the water quality variable Biological Oxygen Demand (BOD). Transparent microplastic color can occur due to color fading factors by UV light (Hiwari et al., 2019). Microplastic fragments have a rough and irregular surface, making it easier to attract bacterial biofilms. Microorganisms that live in biofilms in the form of microplastic fragments will use oxygen to break down organic matter, thereby increasing BOD levels in water (Khatulistiwa et al., 2024).

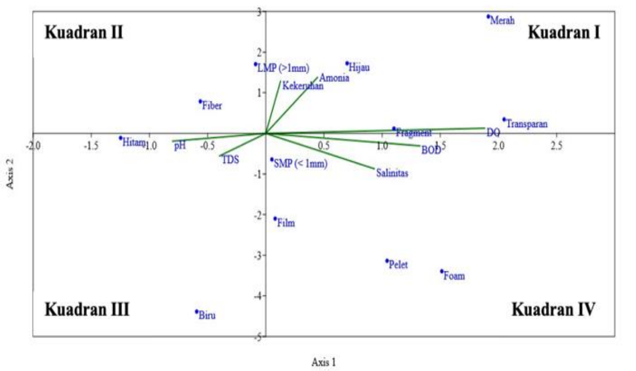

Figure 11. Canonical correlation analysis (CCA) test display for water quality and microplastic variables in the North Coast Area of Situbondo

The Eigenvalue of axis 1 is greater than axis 2, and has a value of 72.76% of the variation of microplastic data and 88.25% of the relationship between microplastics and water quality. And this value is on the axis 1 with an eigenvalue of 72.76%> 70% so that this CCA plot can be interpreted. Significant water quality parameters are indicated by the largest score of the loading variables on the appropriate axis in CCA, namely the DO and BOD variables. With the loading value on the axis for the DO variable is 0.75 and BOD is 0.53.

Table 2. Canonical Correlation Analysis (CCA) Eigenvalue Test Results

Axis	Eigenvalue	Variance Proportion	Accumulation (%)
1	0.727600	72.76	72.760
2	0.154900	15.49	88.250
3	0.070330	7.033	95.283
4	0.030460	3.046	98.329
5	0.010400	1.040	99.369
6	0.006221	0.622	99.991
7	0.000089	0.0089	100.000

Canonical Correspondence Analysis (CCA) Permutation Test Analysis

CCA permutation analysis was used to test the statistical significance of the relationship between species communities and environmental variables. The purpose of this test is to determine whether the relationship found in the data occurs by chance or is based on a strong ecological basis. In this study, permutation analysis was performed using R-Studio, and the results showed a ρ-value of 0.011, which is smaller than 0.05. This indicates that the microplastic variable has a significant effect on the water quality variable, indicating that the relationship between microplastics and water quality is not a coincidence, but is based on a strong ecological relationship.

Conclusion

Based on the research results, the water quality in the North Coast Area of Situbondo generally still meets the water quality standards, except at point 15 which shows a pH value of 9.8 and DO 2.74 mg/L, exceeding and below the established standards. The concentrations of TDS, ammonia, salinity, and turbidity at all sampling points are generally within the appropriate quality standard range. The BOD parameter shows that most observation points exceed the quality standard value of 6 mg/L, except at point 12. The abundance of microplastics was recorded at an average of 58.71 particles/L, with the highest value at point 3 (85.44 particles/L) and the lowest at point 4 (33.00 particles/L). The characteristics of microplastics were dominated by small particles (>1 mm) at 70.88%, fiber shape at 54.69%, and black color at 61.01%. The types of polymers found included PVC, PE, PS, and PP, with varying distributions between sampling points. Canonical Correspondence Analysis (CCA) analysis showed a significant correlation between microplastic characteristics and water quality parameters. Green color and large microplastic size (LMP) are associated with ammonia and turbidity, black color is related to pH, while transparent color and fragment shape are related to BOD. The eigenvalue axis 1 of 72.76% indicates that the relationship between microplastics and water quality can be interpreted strongly, with the most influential water quality variables being DO and BOD.

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Author Contributions

Collecting data, analyzing data, writing original drafts, Y.M.V.M.; methodology, data curation, A.; review writing, visualization, R. Conceptualization, A.M.S.; methodology, A.M.S; formal analysis, A.M.S.; resources, A.M.S.; data curation, A.M.S.; writing—original draft preparation, A.M.S.; writing—review and editing, A.M.S.; visualization, A.M.S.; supervision, validatin, and formal analysis R.H. and S.W.

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Conflicts of Interest

The author declares no conflict of interest.

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