

FTIR-Based Identification of Microplastics in Commercial Bottled Drinking Water

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Abstract. The presence of microplastics in drinking water has raised serious concerns regarding environmental pollution and human health risks. This study aims to identify microplastics in 10 samples of bottled drinking water (BDW) using Fourier Transform Infrared (FTIR) spectroscopy. Water samples from several commercial brands were filtered, and the retained particles were analyzed to determine their polymer composition. FTIR results revealed the presence of various polymer types commonly associated with packaging materials, such as polyethylene (PE), polypropylene (PP), and polyethylene terephthalate (PET). The obtained FTIR spectra exhibited several characteristic peaks, including a broad aliphatic C–H stretching at 2900 cm⁻¹, and a strong C=O stretching band from ester groups at 1715 cm⁻¹. These peaks are consistent with the presence of PET, PE, and PP polymers that are widely used in plastic packaging materials. The findings indicate that microplastic contamination exists in bottled drinking water, potentially originating from packaging and bottling processes. This study emphasizes the importance of monitoring microplastic pollution in drinking water and highlights the need for stricter quality control to ensure public health safety.

1 Introduction

Microplastics have become an urgent global environmental and health issue. Microplastics can originate from the degradation of plastic waste, synthetic fibers from clothing, and particles from pharmaceutical and cosmetic products. Currently, microplastics are widely dispersed in various ecosystems. Microplastics (MPs) are plastic particles ranging in diameter from a few microns to several millimeters, resulting from the breakdown of larger molecular plastics. MPs pose a significant threat to the environment and marine organisms (Kalutharage, 2019). Their presence is not only limited to oceans and soil but has also been detected in the food chain and drinking water supply. This increasing concentration of microplastics raises serious concerns about the toxicological impacts they cause.

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MPs exist in various forms and are found in diverse environments, including remote areas (Serra et al., 2024). MPs pollute aquatic ecosystems, causing harm to species and potentially affecting human health through consumption or inhalation (Senthilkumar et al., 2025). The consumption of food and beverages in daily life cannot be separated from the surrounding environment. If packaged beverages are readily available, people tend to use them.

Bottled drinking water (BDW) has become a primary choice for many modern societies, driven by convenience of access and the belief that these products are safer and of higher quality. However, with the increasing global volume of BDW production and consumption, concerns about microplastic contamination have emerged. Many studies have revealed that microplastics can enter packaged beverages through various points, such as the release of particles from plastic bottle materials and caps during storage, as well as cross-contamination during production and bottling. Therefore, identifying and analyzing the characteristics of microplastics in BDW is crucial to ensure that these products are safe for consumption and meet public health standards.

Microplastic particles smaller than 5 millimeters are now a serious global concern due to their impact on human health and the environment. This phenomenon is no longer limited to marine ecosystems or wildlife; microplastics have now been detected in various daily consumer products, including bottled drinking water (BDW). While BDW is generally chosen for its convenience and perceived safety, several studies suggest a risk of microplastic contamination. Sources of contamination can include the plastic packaging material itself or uncontrolled production and distribution processes.

With increasing public awareness of the microplastic problem, education and socialization about the origins and types of microplastics in drinking water have become very important. The data from this research is expected to provide a strong basis for formulating stricter supervision policies, as well as improving product quality standards. Overall, this research serves as an important step in strengthening public health protection and sustainably minimizing microplastic pollution.

This research specifically focuses on the detection of microplastics in commercial Bottled drinking water (BDW) samples available in the market. Furthermore, this study aims to describe the characteristics of microplastic polymer types identified using Fourier Transform Infrared (FTIR) spectroscopy. To determine the type of polymer composing microplastics, Fourier Transform Infrared (FTIR) spectroscopy is highly effective because it can identify the chemical composition based on the characteristic infrared spectrum of each polymer. In this study, the FTIR method is used to detect and analyze microplastics in various brands of BDW circulating in the market. This research highlights the presence of microplastics (MP) in bottled drinking water (BDW) as a growing issue in environmental pollution and public health. Over the past decade, microplastics have been detected in almost all environmental compartments—water, soil, and air—as well as in the tissues of organisms including humans (Hidalgo-Ruz et al., 2012) (Wright et al., 2013). Although research on tap water has developed quite a bit, data on packaged drinking water is still relatively limited, especially regarding polymer identification using FTIR spectrum techniques.

The novelty of this research is to present a transparent and scientific overview of the types of polymer pollutants, contamination levels, and their relevance to consumer safety. The results of this study provide initial evidence that the packaging process is a major source of MP contamination in the final product, adding urgency to strengthen quality control in the BDW supply chain.

2 Methods

FTIR testing research on packaged drinking water samples was conducted using various brands. The methodology includes sample quantity, sample preparation, FTIR spectroscopic analysis, and contamination control. This research required a total of 10 samples of Bottled drinking water (BDW) from various commercial brands circulating in the Indonesian market, randomly selected. Samples were collected under sterile conditions, stored in clean glass containers, and kept at 4°C until further analysis to avoid additional contamination and particle degradation.

Sample Preparation: Samples were taken using a pipette and placed directly onto the sample holder of the ATR-FTIR instrument.

FTIR Spectroscopic Analysis: This involves the use of Fourier Transform Infrared (FTIR) spectroscopy technique to identify chemical composition and polymer types of microplastics. The equipment used was an FTIR spectrometer with ATR (Attenuated Total Reflectance) mode, allowing direct analysis of particles without complicated extraction processes.

Measurement Conditions: Y axis: transmittance, wavelength range: 4000–650 cm^{-1} , resolution: 4 cm^{-1} , and number of sample scans: 48.

Spectrum Interpretation: Identification of characteristic spectral peaks includes three main peaks: O–H stretching at 3400 cm^{-1} : indicative of water or hydroxyl groups (possibly from contaminants or dissolved organic compounds).

Aliphatic C–H stretching at 2900 cm^{-1} : characteristic of hydrocarbon compounds such as PE (polyethylene) and PP (polypropylene).

C=O stretching from ester groups at 1715 cm^{-1} : typical for PET (polyethylene terephthalate), commonly used in beverage bottle packaging.

Polymer Classification: The resulting spectra were compared with standard FTIR databases (such as Polymer Database (PDB) or FTIR Spectra Library) to identify the presence of polymers like polyethylene (PE), polypropylene (PP), and polyethylene terephthalate (PET).

Contamination Control and Validation:

Negative Control: Performed using ultra-pure water that underwent the entire filtration and analysis process without added particles, to ensure positive results were not due to laboratory contamination.

Replication: Each analysis was performed at least in duplicates to ensure data reliability.

Data Quality: Only particles producing high-quality FTIR spectra (signal-to-noise ratio ≥ 5) and matching standard polymers were classified as microplastics.

3 Results and Discussions

The results of the Fourier Transform Infrared (FTIR) analysis applied to ten Bottled drinking water (BDW) samples show the presence of various types of polymers, used to identify the presence and types of microplastics. Each FTIR spectrum from the samples exhibits characteristic absorption peaks, indicating the presence of specific functional groups from different polymers. Laboratory test results on 10 BDW samples from various commercial brands available in the market yielded the following data:

Table 1. FTIR test results on 10 BDW samples

No.	Kode sampel	Wavenumber (cm^{-1}), Gugus fungsi	Indikasi	Intensitas Puncak
1.	Kode 1	~3400, -OH / N-H ~2900, -CH ₂ / -CH ₃ ~1700, C=O ~1500 – 1600, C=C aromatik ~1100 – 1300, C-O / C-N <1000, -CH (out of plane)	Polimer alami atau protein; PE, PP, PS; PET, Nylon, PU; PS, PET; PET, Nylon, PU;	Sangat kuat Sedang Kuat Sedang-kuat Sedang Lemah-sedang

			PS	
2.	Kode 2	~3400, O–H (air/kelembaban) ~2900, –CH ₂ / –CH ₃ (alifatik) ~1710–1730, C=O (karbonil ester) ~1500–1600, C=C aromatik ~1250–1100, C–O (ester) / C–N (amida) ~900–700, Bending aromatik (oop)	Bukan penentu polimer PET, PE, PP PET, PU, Nylon PET, PS PET, PU, Nylon PS, PET	Sangat kuat & lebar Sedang Tajam & kuat Sedang – kuat Sedang
3.	Kode 3	~3400, O–H ~2950, C–H alifatik ~1715, C=O (ester) ~1600, C=C aromatik ~1240, C–O ~1100, C–O ~870 dan 730, C–H aromatik	Kelembaban, alkohol Rantai polimer PET PET PET PET PET	Sangat kuat & lebar Lemah Sangat kuat Sedang Sedang Sedang Lemah
4.	Kode 4	~3400, O–H ~2900, C–H alifatik ~1715, C=O (ester) ~1600, C=C aromatik ~1100, C–O ~870 dan 730, C–O	Air/alkohol/fenol Polimer alifatik PET PET PET PET	Sangat kuat & lebar Lemah Sangat kuat Sedang Sedang Sedang
5.	Kode 5	~3400, O–H ~2900, C–H alifatik ~1715, C=O (ester) ~1600, C=C aromatik ~1100, C–O ~870 dan 730, C–O	Air, alkohol, atau fenol Umum pada rantai polimer PET PET PET PET	Lemah – sedang Lemah Sangat kuat Sedang Sedang Sedang
6.	Kode 6	~3350, O–H (hidroksil) ~2900, C–H alifatik ~1715, C=O (karbonil ester) ~1410–1450, C–H bending ~1240–1100, C–O (ester) <1000, Fingerprint region	PET, Air, Alkohol PET, PE, PP PET PET, PE PET PET	Sangat kuat, lebar Sedang Kuat, tajam Sedang Kompleks, kuat Kompleks
7.	Kode 7	~3300–3400, O–H (hidroksil) ~2900, C–H alifatik ~1715, C=O (karbonil ester) ~1400–1450, C–H bending ~1250–1100, C–O (ester) <1000, Fingerprint region	Umum: PET, kelembapan PET, PE, PP PET PET, PE PET PET	Sangat kuat Sedang–kuat Sangat kuat, tajam Sedang Kompleks, kuat Kompleks
8	Kode 8	~3400, O–H (hidroksil) ~2900, C–H alifatik ~1715, C=O (karbonil ester)	Umum pada PET dan kelembaban PET, PE, PP	Kuat, lebar Sedang–kuat

		~1400–1450, C–H bending ~1250–1100, C–O (ester) <1000, Fingerprint region	PET (Polyester) PET, PE PET PET	Sangat kuat, tajam Sedang Kompleks, kuat Kompleks
9.	Kode 9	~3400, O–H / N–H ~2900, C–H alifatik ~1710, C=O (karbonil) ~1450, C–H bending ~1100-1300, C–O	PET, PVA, atau kontaminan Polietilena, PET PET, PVC, akrilik Umum di semua plastik PET, PVA, PLA	Lebar & kuat Sedang–kuat Sangat tajam Sedang Sedang
10.	Kode 10	~3400–3500, O–H ~2900–2950, C–H ~1715–1740, C=O ~1450–1500, C–H bending ~1100–1300, C–O stretching	PET, PLA, air PET, PE, PP PET, PLA, poliester Umum PET, PLA	Sangat kuat, lebar Sedang Kuat Sedang Sedang

The Fourier Transform Infrared (FTIR) analysis applied to ten samples of Bottled drinking water (BDW) revealed the dominant presence of Polyethylene Terephthalate (PET) polymer in almost all samples. This is evidenced by characteristic absorption bands in the 1700-1740 cm^{-1} range, which are a strong indicator of the carbonyl group (C=O ester), a common feature of PET ((Andrady & Neal, 2009). Additionally, absorption bands related to the C-O ester group in the 1100-1300 cm^{-1} range were also detected with varying intensities in many samples. The dominance of PET is highly plausible, as PET is the primary material commonly used for bottled drinking water due to its good mechanical properties and chemical resistance. The degradation of PET bottles into microplastics can occur through several mechanisms, such as physical abrasion, degradation due to ultraviolet light, and interaction with chemicals during distribution and storage processes (Andrady, 2011).

Generally, the research results show a dominance of peaks in the 1700-1740 cm^{-1} range, which indicates the presence of the carbonyl group (C=O ester)—a characteristic of Polyethylene Terephthalate (PET) (Andrady & Neal, 2009). These peaks were detected very strongly in almost all samples (Codes 1 to 10), consistent with the widespread use of PET as a raw material for BDW bottles. Furthermore, C-O ester functional groups in the 1100-1300 cm^{-1} range were also detected with varying intensities in most samples, further supporting the identification of PET.

The strong characteristic PET signal in all samples suggests that microplastics from PET are the main contaminant in packaged drinking water. This finding aligns with various previous studies that also found the dominance of PET as the primary microplastic in bottled drinking water products and in aquatic environments in general ((Kosuth et al., 2018) (Mason et al., 2018).

3.1. Identification of Other Microplastic Polymers

In addition to PET, FTIR analysis also successfully identified the presence of other polymers with the potential to be microplastics in BDW samples. Polyethylene (PE) and Polypropylene (PP) were detected through characteristic absorptions around 2900 cm^{-1} , representing aliphatic $-\text{CH}_2$ and $-\text{CH}_3$ groups. Generally, PE and PP are used as materials for bottle caps or secondary packaging. Therefore, the presence of these polymers indicates that microplastic fragments could originate from these packaging components. The detection of PE and PP in several samples (Codes 1, 2, 6, 7, 8, 9, 10) confirms that microplastic sources are not only from the main bottle but also from other packaging elements (Hidalgo-Ruz et al., 2012).

Polystyrene (PS) was also identified in some samples, characterized by aromatic C=C absorption bands at $\sim 1500\text{--}1600\text{ cm}^{-1}$ and aromatic bending vibrations in the $900\text{--}700\text{ cm}^{-1}$ range, which are characteristic of the aromatic ring structure of PS. Given that PS is often used in disposable food packaging, its detection in drinking water may originate from packaging contamination or the production environment (Andrady, 2011).

Furthermore, functional groups related to Nylon and Polyurethane (PU)—such as C-N and C-O amide groups ($1100\text{--}1300\text{ cm}^{-1}$) and -OH and N-H groups (around 3400 cm^{-1})—were also detected in some samples (Codes 1 and 2). Since Nylon and PU are not commonly used as primary materials for drinking water bottles, their presence is most likely from other sources, such as equipment during the production process or cross-contamination.

There was an interesting finding in samples Code 9 and 10, which indicated the presence of polylactic acid (PLA). PLA is a bioplastic that is becoming increasingly popular as an environmentally friendly alternative due to its biodegradable properties. Characteristic features of PLA are seen from the C=O ester absorption peak at $1715\text{--}1740\text{ cm}^{-1}$ and C-O stretching at $1100\text{--}1300\text{ cm}^{-1}$. This discovery of PLA shows the diversity of microplastic sources and provides a new perspective that not all microplastics originate from conventional petroleum-based plastics, but also from bioplastics that are increasingly used (Adhikari et al., 2016).

In addition to PET, several other polymers were also identified as potential microplastics based on their unique functional groups and wavenumbers. The presence of Polyethylene (PE) and Polypropylene (PP) was based on the existence of aliphatic $-\text{CH}_2 / -\text{CH}_3$ groups in the $\sim 2900\text{ cm}^{-1}$ range with medium to strong intensity detected in many samples (Codes 1, 2, 6, 7, 8, 9, 10). These are characteristics of PE and PP, often found in bottle caps or secondary packaging, indicating the possibility of these fragments as microplastics (Hidalgo-Ruz et al., 2012). Polystyrene (PS) was detected at the aromatic C=C peak in the $\sim 1500\text{--}1600\text{ cm}^{-1}$ range, as well as aromatic (oop) bending around $900\text{--}700\text{ cm}^{-1}$, observed in some samples (Codes 1, 2). This indicates the potential for PS contamination, which is commonly used in single-use food packaging. Nylon and Polyurethane (PU) were detected in C-N / C-O (amide) groups in the $\sim 1100\text{--}1300\text{ cm}^{-1}$ range and -OH / N-H at $\sim 3400\text{ cm}^{-1}$ were also found in some samples (Codes 1, 2). This detection may indicate the presence of Nylon or PU, although perhaps in lower concentrations compared to PET.

In sample Code 10, as well as Code 9, an indication of PLA in addition to PET was identified at the C=O peak ($1715\text{--}1740\text{ cm}^{-1}$) and C-O stretching ($1100\text{--}1300\text{ cm}^{-1}$). PLA is an increasingly used bioplastic, and its discovery shows the diversification of microplastic sources [Frère et al., 2016].

PET polymer appeared in almost all samples without exception, while the presence of other polymers such as PE, PP, PS, Nylon, PU, and PLA showed variation among samples without specific patterns related to their respective codes or brands.

This indicates that the source of microplastic contamination in packaged drinking water does not originate from a single source, but rather is a result of a combination of various complex factors. Microplastic contamination likely involves various stages, from the production process, distribution, packaging, to potential environmental pollution. This study supports the view that microplastic contamination in BDW products is a multifactorial phenomenon requiring an interdisciplinary approach for effective understanding and handling (Pivokonsky et al., 2018).

The correlation between individual Bottled drinking water (BDW) sample codes and the specific types of microplastics found did not show any exclusive pattern. Instead, the more dominant finding was the consistent detection of PET in almost every sample. This fact indicates that PET microplastics are the most widespread contaminant in BDW, most likely originating from the packaging bottles themselves. The variation in the detection of other polymers such as PE, PP, and PS in different samples may indicate different secondary

contamination sources, which could come from handling, production processes, or storage environments. For example, PE and PP, frequently used in bottle caps, can potentially detach and become microplastics during the opening or usage process.

This research highlights the presence of microplastics (MP) in bottled drinking water (BDW) as an increasingly prominent issue in environmental pollution and public health. Over the past decade, microplastics have been detected in almost all environmental compartments—water, soil, and air—as well as in the tissues of organisms, including humans (Hidalgo-Ruz et al., 2012) (Wright et al., 2013). Although research on tap drinking water is quite developed, data on packaged drinking water is still relatively limited, especially regarding polymer identification using FTIR spectrum techniques. The results of this study provide initial evidence that packaging and bottling processes can be a major source of MP contamination in the final product, adding urgency to strengthen quality control in the BDW supply chain.

3.2. Comparison with Previous Research

The results of this study are consistent with findings in previous microplastic studies, both those conducted on packaged drinking water and in aquatic environments. Mason et al., (2018) reported the dominance of PET microplastic particles in commercial bottled water brands, while Kosuth et al., (2018) also affirmed that PET is the primary polymer found in bottled mineral water samples.

Furthermore, a review by Hidalgo-Ruz et al., (2012) described the presence of PE, PP, and PS as common microplastic types found in marine environments and everyday consumer products. The identification of bioplastic polymers, such as PLA, in microplastics is relatively new but is gaining attention as an important topic in research by (Adhikari et al., 2016) and (Haider et al., 2019).

Implications of Findings

The results of this study have several important implications, including the dominance of PET. The consistent detection of PET as the primary microplastic in Bottled drinking water (BDW) confirms that the bottle packaging itself is a major source of contamination (Käppler et al., 2016). This highlights the need for innovation in PET bottle design to reduce the release of microplastic particles or the development of alternative packaging materials that are more resistant to degradation.

The discovery of various polymer types besides PET, such as PE, PP, PS, Nylon, and PLA, indicates that microplastic contamination in BDW is a complex problem originating from multiple sources, including plastic materials in the supply chain and the broader environment. The health and environmental impacts include concerns that even small amounts of microplastics pose risks to human health and the environment. Microplastic particles can carry other contaminants and potentially enter the human food chain, leading to adverse toxic effects (Wright et al., 2013).

The FTIR method has proven effective and reliable for rapidly identifying microplastics and characterizing polymer types in BDW samples. The development of stricter standards and testing protocols would be very helpful in monitoring and ensuring the quality of packaged drinking water.

3.3. Limitations of FTIR and Suggestions for Future Research

FTIR spectroscopy is effective for classifying microplastic polymer types based on their chemical functional groups, but this technique has weaknesses, especially in detecting very small particles (less than 20 μm) and in accurately quantifying the number of microplastic particles. Therefore, separation between water samples and microplastics is needed before the FTIR test stage, as FTIR testing is highly sensitive to hydrogen. In addition, for more specific and detailed results, it is necessary to combine FTIR with other methods such as Raman microscopy, electron microscopy, or particle size separation techniques to enable more comprehensive analysis (Renner et al., 2018).

This study also has limitations in terms of polymer identification without quantifying the amount of microplastics or their particle sizes specifically. Further studies focusing on the quantification and dynamics of microplastic transfer from packaging to water are highly needed to understand the actual risks.

Furthermore, research on the toxicology and bioaccumulation of microplastics from plastic packaging materials such as PET and other polymers is also very important to assess the long-term health impacts on consumers of packaged drinking water.

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4 Conclusion

Research using FTIR spectroscopy on ten bottled drinking water (BDW) samples revealed the dominance of PET-based microplastics consistently found in all samples. In addition, other polymers such as PE, PP, PS, Nylon, PU, and PLA were also identified. These results indicate that microplastic contamination in BDW products is a complex issue. For future research, there is significant opportunity for the development of more advanced and comprehensive analytical methods.

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