ANALYSIS OF AIRBORNE MI CROPLASTICS IN SCHOOL INDOOR ENVIRONMENTS IN JEMBER REGENCY

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Abstract

Plastic can degrade into smaller particles ranging from 1 μm to 5 mm, known as microplastics. Due to their small size, microplastics can be easily inhaled and enter the human respiratory system. The high respiratory rate and underdeveloped immune systems of children make them more vulnerable to exposure to airborne microplastics. This study aimed to determine the characteristics and abundance of airborne microplastics in school indoor environments in urban areas of Jember Regency. The study was conducted in four schools representing different educational levels, namely kindergartens and junior high schools, selected using stratified random sampling. Sampling was carried out using a passive sampling method by placing stainless-steel boxes at a height of 1.2 m for 24 hours. Sample pre-treatment included filtration using 1.2 μm filter paper, density separation using $ZnCl_2$ (1.6 g/cm³), and organic matter digestion using 30% H_2O_2. Microplastic abundance and characteristics were then analyzed using microscopy and Fourier Transform Infrared Spectroscopy (FTIR). The highest microplastic density was found in Kindergarten A, reaching 2,239 particles/m²/day, followed by Junior High School C (1,143 particles/m²/day), Junior High School D (1,109 particles/m²/day), and Kindergarten B (603 particles/m²/day). Fiber-shaped microplastics were the dominant form, followed by fragments. Black-colored particles with sizes ranging from 0.2 to 2 mm were most frequently observed, polyethylene terephthalate (PET) and Polyvinyl Alcohol (PVA) were identified in the sample.

Keywords: airborne microplastics; FTIR; indoor microplastics; plastic pollution.

1. INTRODUCTION

The extremely small size of airborne microplastics allows them to be easily inhaled and deposited within the human respiratory tract (Amato-Lourenço et al., 2020). The accumulation of microplastics in the human body may result in a range of adverse health effects due to the hazardous chemicals associated with these particles, including persistent, bioaccumulative, and toxic substances (PBTs) and persistent organic pollutants (POPs), many of which exhibit carcinogenic properties. Potential health impacts include organ inflammation, tissue injury, gastrointestinal disorders, physiological stress, altered feeding behavior, impaired growth and development, and reduced fertility (Faujiah & Wahyuni, 2022).

Research on airborne microplastics, particularly in indoor environments, remains limited even though approximately 89% of human activities occur indoors (Uddin et al., 2022). One important indoor environment that warrants attention is the school classroom, especially at educational levels attended by children and adolescents, such as kindergartens and junior high schools. Students at these levels spend a substantial portion of their time indoors, where they may be exposed to microplastics through inhalation, dermal contact, and resuspended dust particles. Furthermore, children are more susceptible to airborne microplastic exposure because of their higher breathing rates and incompletely developed immune systems. According to Nematollahi et al. (2022), children are more vulnerable to air pollution than adults and exhibit higher rates of inadvertent dust ingestion through hand-to-mouth activities.

Airborne microplastics in classrooms may originate from a variety of sources, including synthetic school uniforms and clothing, plastic stationery and toys, plastic-based furniture, carpets, and dust entering classrooms through doors, windows, and shoe soles. Bhat (2023) reported that fiber-shaped microplastics were the most prevalent type found in classrooms, with black, transparent, blue, and red particles being the dominant colors. Similarly, Vianello et al. (2019) found that polyester accounted for approximately 81% of indoor microplastic particles. The high proportion of polyester was attributed to the widespread use of polyester-based textiles, compounded by the presence of furniture and carpeting.

Scientific investigations concerning the occurrence of microplastics in classroom environments, particularly in kindergartens and secondary schools in Indonesia, remain scarce. Therefore, this study is important for assessing the extent of microplastic contamination in kindergarten and junior high school classrooms, identifying potential sources, and evaluating its implications for student health. The findings are expected to provide a scientific basis for developing policies aimed at creating healthier school environments.

2. MATERIALS AND METHODS

Study Area

The study locations were selected using a stratified random sampling approach implemented in RStudio. Data on all kindergartens and junior high schools located within the urban districts of Jember Regency (Sumbersari, Kaliwates, and Patrang Districts) were compiled in Google Sheets. Schools were then randomly selected according to district strata, resulting in four study locations: Kindergarten A, Kindergarten B, Junior High School C, and Junior High School D (Figure 1).

Airborne Microplstic Sampling

Airborne microplastic samples were collected using a passive sampling method. Stainless-steel collection boxes measuring 26.5 × 16.2 × 10 cm were positioned at a height of 1.2 m above the floor and exposed for 24 hours. This sampling height was selected to represent the human breathing zone, particularly that of children (Fiyanda, 2020). Sampling was conducted once at each school during a regular school day (Thursday). After the 24-hour exposure period, the samples were covered with aluminum foil and transported to the laboratory for further pre-treatment and analysis.

Sample pre-treatment

Sample pre-treatment began by rinsing each collection container three times with distilled water to minimize the loss of microplastic particles adhering to the container surfaces. The resulting sample suspension was filtered through Whatman filter paper with a pore size of 1.2 µm using a vacuum filtration system.

The retained material on the filter paper was subsequently immersed in 50 mL of $ZnCl_2$ solution ($\rho = 1.6$ g/cm^3) and covered with aluminum foil. Density separation was performed by allowing the samples to remain submerged for 24 hours. $ZnCl_2$ was selected because its efficiency for plastic density separation exceeds 95% (Rodrigues et al., 2020).

Following density separation, the samples were transferred to Erlenmeyer flasks and treated with 20 mL of 30% H_2O_2 for 30 minutes. The samples were then heated to 75°C using a magnetic stirrer to digest organic matter that might be present in the samples (Dyachenko et al., 2017).

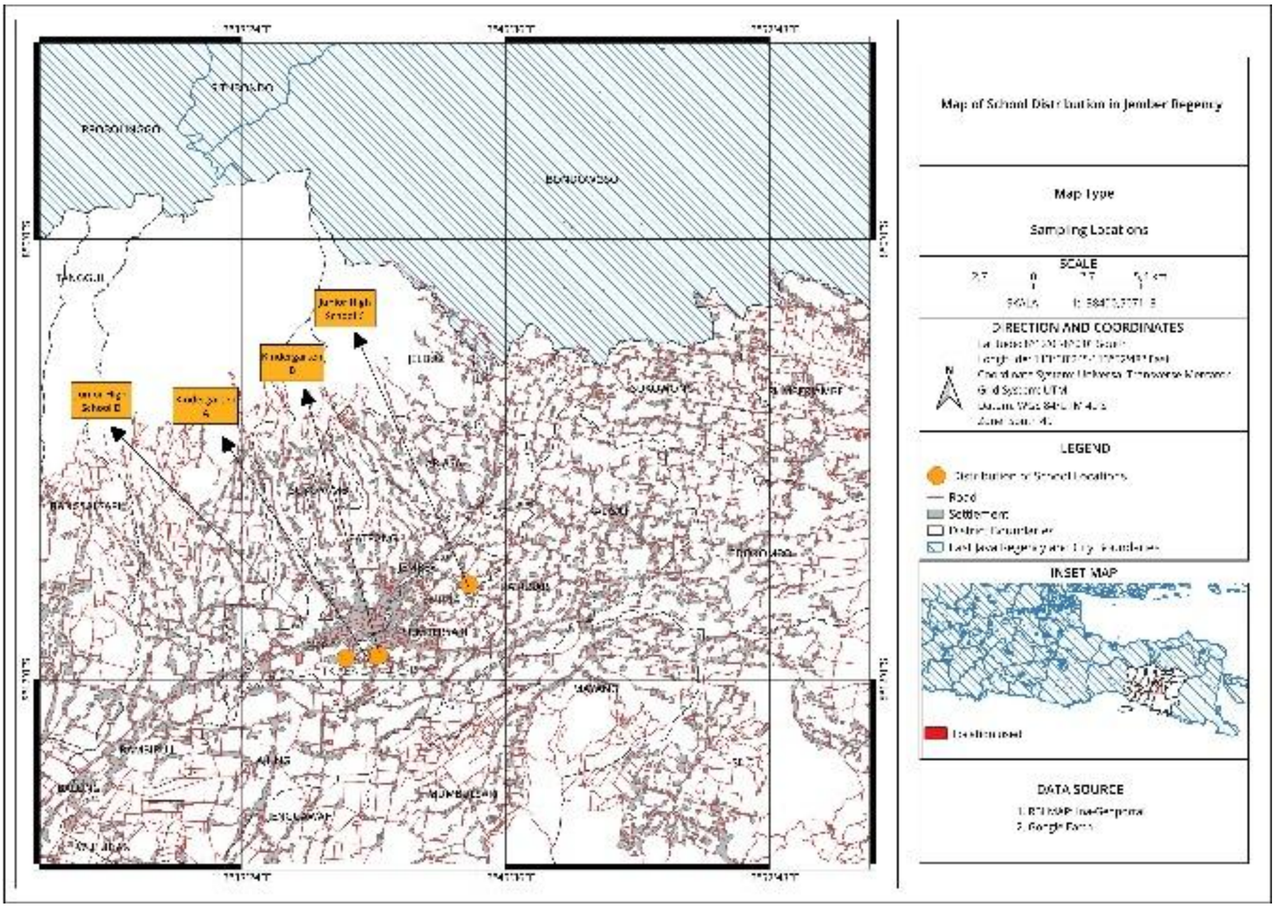


Figure 1. Sampling Location

Microscopic Analysis

Samples that had undergone pre-treatment were examined using a digital microscope to determine the number, shape, size, and color of microplastic particles. Microplastic abundance was calculated using the following equation (Pratiwi, 2020):

$$\textbf{Microplastic Abundance} = \frac{\text{Number of Microplastic Particles (particles)}}{\text{Sampling area (m}^2\text{).days}} \quad (1)$$

FTIR Analysis

Spectral interpretation was performed digitally using specialized software. Polymer identification was conducted using a Thermo Fisher Scientific Nicolet iS10 Fourier Transform Infrared Spectrometer (FTIR). FTIR analysis was used to determine the polymer types of microplastics detected in each school.

3. RESULTS AND DISCUSSION

Characteristics of the Study Sites

The study was conducted sequentially at four different schools over a four-week period. Sampling was carried out on regular school days, specifically on Thursdays, with a sampling duration of 24 hours. The initial characteristics of the study sites are presented in Table 1.

Table 1. Characteristics of the Study Sites

Characteristic	Kindergarten A	Kindergarten B	JHS C	JHS D
Number of occupants (persons)	30	14	26	32
Number of ventilation openings	5	10	17	14
Number of fans	3	2	1	3
Cleaning frequency (times/day)	1	1	2	1
Number of tablecloths	1 (black-white)	1 (pink)	1 (purple)	1 (green)
School Time (WIB)	07.30	08.00	07.00	07.00
First break (WIB)	09.00	09.00	10.00	10.00
Second Break (WIB)	-	-	11.30	11.30
Dismissal Time (WIB)	11.30	11.00	14.30	14.30
Uniform color	Green	White-Green	Cream	Cream
Belt color	-	-	Black	Black
Carpet color	Green-White	-	-	-

Table 1 presents an inventory of items found within the classrooms during the study period. This inventory served as a preliminary identification of materials that could potentially act as sources of indoor microplastics. In addition, the inventory provided information regarding the duration of classroom activities at each school included in the study.

Microplastic Abundance

Microplastic abundance was calculated by considering the surface area of the sampling container used. The total number of microplastic particles identified at each school is presented in Table 2.

Table 2. Total Number of Microplastic Particles

School	Number of Microplastics (particles)
Kindergarten A	862
Kindergarten B	232
JHS C	440
JHS D	427

The total number of microplastic particles obtained was subsequently used to calculate microplastic abundance, as illustrated in Figure 1.

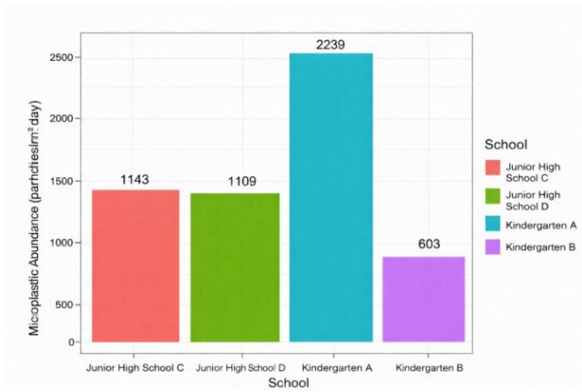
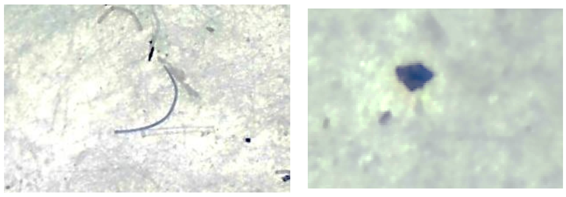


Figure 1. Microplastic Abundance

Based on Figure 1, the results indicate that Kindergarten A exhibited the highest microplastic abundance, reaching 2,239 particles/m²/day, whereas Kindergarten B showed the lowest abundance at 603 particles/m²/day. This difference may be attributed to the higher number of occupants in Kindergarten A compared with Kindergarten B. These findings are consistent with those reported by Ageel et al. (2022), who found that higher indoor occupancy levels contribute to increased microplastic concentrations due to intensified human activities.

Morphological Characteristics of Microplastics

Two morphological forms of microplastics were identified at the study sites, namely fibers (Figure 2a) and fragments (Figure 2b).



(a) (b)

Figure 2. Morphological Forms of Indoor Microplastics in Schools in Jember Regency

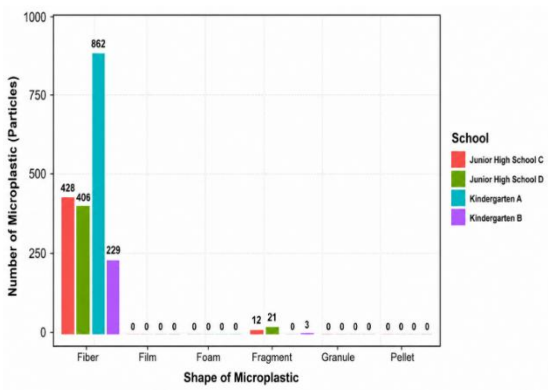


Figure 3. Number of Indoor Microplastic Particles in Schools in Jember Regency by Shape

Figure 3 the microplastics identified at all study sites were predominantly fibers, with 862 particles recorded in Kindergarten A, 229 particles in Kindergarten B, 428 particles in Junior High School C, and 406 particles in Junior High School D.

The dominance of fiber-shaped microplastics may be associated with the presence of carpets, school uniforms, and tablecloths within the classrooms. Synthetic fibers are highly susceptible to tearing and shedding from their sources, including clothing and other soft furnishings such as carpets and curtains (Nematollahi et al., 2021). Similarly, Hussayni et al. (2023) reported that fibers are the most abundant and frequently detected form of microplastics, followed by fragments.

In addition to fibers and fragments, other microplastic morphologies include films, pellets, foams, and granules. However, none of these forms were detected at any of the study locations. Films are thinner than fragments and exhibit irregular shapes. Granules are spherical microplastics ranging from approximately 100 µm to 1 mm in size, whereas pellets are generally larger, measuring approximately 3–5 mm (Lusher et al., 2020). Pellets are classified as primary microplastics commonly used as raw materials in cosmetic products. Foam particles are typically composed of polystyrene and are characterized by a white, porous, sponge-like structure (Rosal, 2021).

Color Characteristics of Microplastics

Six microplastic colors were identified across all study sites, namely black, red, blue, green, yellow, and transparent, as shown in the following figure.

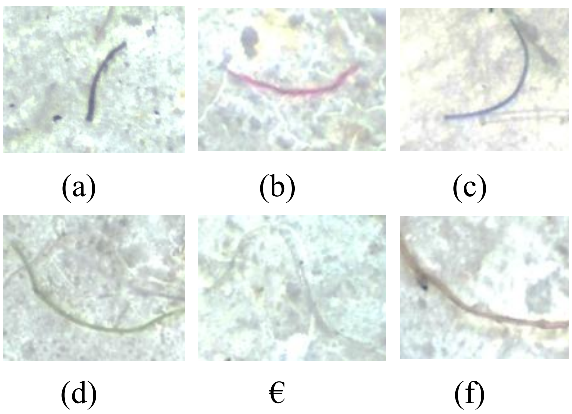


Figure 4. Fiber-shaped microplastics with colors of (a) black, (b) red, (c) blue, (d) green, (e) transparent, and (f) yellow

Black was the dominant microplastic color observed at all study sites, particularly in Kindergarten A. Detailed information regarding the number of indoor microplastic particles in schools based on color is presented in the following figure.

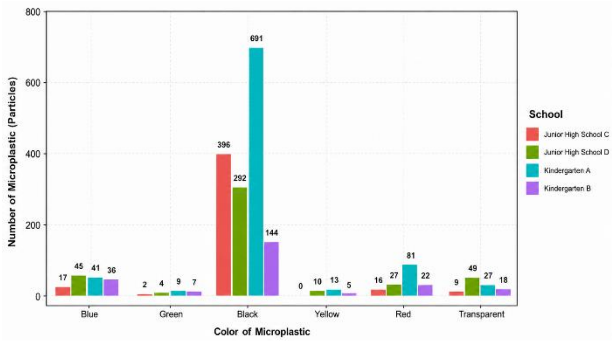


Figure 5. Number of Indoor Microplastic Particles in Schools in Jember Regency by Color

The colors identified in the four schools are consistent with the findings of Bhat (2024), who reported black, transparent, blue, and red as the dominant colors of microplastics detected in classroom environments. The presence of black-colored microplastics may indicate that the particles have undergone contamination or environmental weathering (Adawiyah et al., 2024). Furthermore, the observed colors may differ from the original colors of the source materials, as polymer oxidation and degradation processes can alter the appearance of plastic materials over time (Hernández-Fernández et al., 2023).

Size Characteristics of Microplastics

The lengths of the identified microplastic particles were classified into four size categories. According to Yee et al. (2023), microplastic lengths are categorized as <20 µm, 20–200 µm, 200–2000 µm, and >2000 µm. These size ranges were converted into millimeters (mm) and classified as <0.02 mm, 0.02–0.2 mm, 0.2–2 mm, and >2 mm, as shown in the following figure.

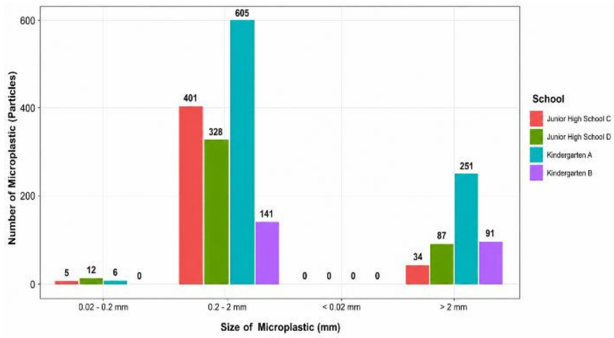


Figure 5. Number of Indoor Microplastic Particles in Schools in Jember Regency by Size

Microplastics within the size range of 0.2–2 mm was the most abundant in all four schools. This finding is consistent with the study conducted by Wang et al. (2018), which reported that fiber-shaped microplastics ranged from 0.1 to 12 mm in length, with the majority occurring within the 0.2–2 mm size range. No microplastic particles smaller than 0.02 mm were detected at any of the study sites. Similarly, particles within the 0.02–0.2 mm size category were not detected in Kindergarten B and were present only in small quantities at the other schools. Based on all identified particles, the average length of fiber-shaped microplastics was 1.78 mm, whereas the average length of fragment-shaped microplastics was 0.35 mm.

Polymer Identification of Microplastics

Polymer identification was conducted using FTIR analysis, which generated infrared spectra characterized by specific wavenumbers. The obtained spectra were subsequently interpreted to determine the polymeric functional groups present in the samples. Each characteristic absorption band corresponds to specific polymer bonds and structures.

For the microplastic sample collected from Kindergarten A, the FTIR spectrum exhibited a strong absorption peak at 1712 cm^{-1}, indicating the presence of a carbonyl (C=O) functional group (Diblan et al., 2018). Peaks within the range of 1240–1100 cm^{-1} corresponded to C–O stretching vibrations associated with carboxylate groups, supporting the presence of ester functionalities, while peaks between 2950 and 2850 cm^{-1} were attributed to aliphatic C–H stretching vibrations (Khoiriyah et al., 2026). In addition, an absorption peak at 872 cm^{-1} indicated the presence of aromatic C–H bonds (Epure et al., 2023), as shown in the FTIR spectrum below.

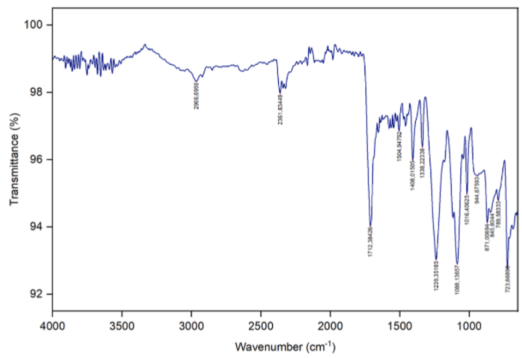


Figure 6. FTIR Spectrum of Kindergarten A Sample

Based on these spectral characteristics, the microplastic sample from Kindergarten A was identified as polyethylene terephthalate (PET). This finding is consistent with the characteristics of the study site, where various recycled craft materials made from plastic bottles and cups were present within the classroom.

For the Kindergarten B sample, the FTIR spectrum showed absorption peaks between 3273 and 3325 cm^{-1}, indicating the presence of hydroxyl (O–H) functional groups (Sari et al., 2019). Peaks within the range of 2850–2916 cm^{-1} corresponded to C–H stretching vibrations (Chaudhari et al., 2026), while strong absorption bands observed between 1100 and 1300 cm^{-1} indicated the presence of C–O bonds.

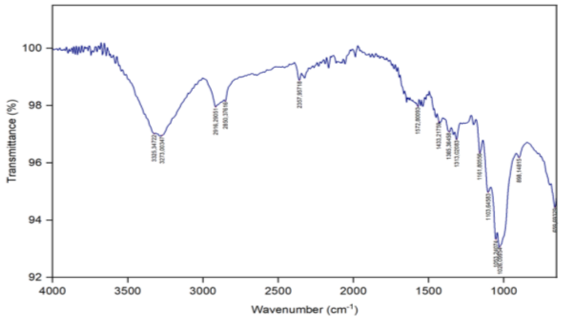


Figure 7. FTIR Spectrum of the Kindergarten B Sample

Based on these spectral characteristics, the microplastic sample from Kindergarten B was identified as polyvinyl alcohol (PVA) (El-Sayed et al., 2017). This finding is consistent with the characteristics of the study site, where craft adhesives, slime materials, and food packaging products were commonly present in the classroom environment (Oun et al., 2022).

Similarly, the polymer samples collected from Junior High School C and Junior High School D were also identified as polyvinyl alcohol (PVA), as shown in Figures 8 and 9.

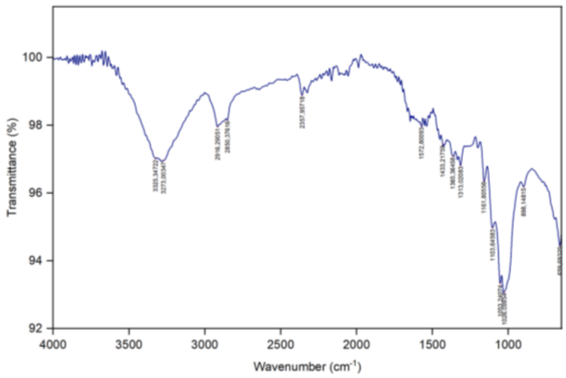


Figure 8. FTIR Spectrum of the Junior High School C Sample

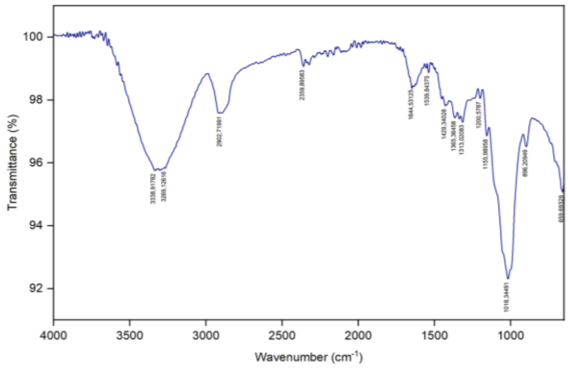


Figure 9. FTIR Spectrum of the Junior High School D Sample

The FTIR spectra obtained from Junior High School C and Junior High School D exhibited absorption peaks between 3269 and 3338 cm^{-1}, indicating the presence of O–H functional groups. The absorption band at approximately 2901 cm^{-1} corresponded to aliphatic C–H stretching vibrations, whereas several strong bands in the region of 1240–1000 cm^{-1} indicated C–O stretching vibrations. Based on these spectral characteristics, the samples were identified as polyvinyl alcohol (PVA) (El-Sayed et al., 2017).

PVA is a synthetic polymer commonly used in a variety of products, including adhesives, paper coatings, and water-soluble films, all of which may serve as potential sources of microplastic particles in school indoor environments (Salthammer, 2022).

4. CONCLUSION

Various sources within school environments in Jember Regency have the potential to generate indoor microplastics. The results of this study indicate that both kindergarten and junior high school classrooms were dominated by black-colored fiber-shaped microplastics with an average length of 1.78 mm, followed by fragment-shaped microplastics with an average length of 0.35 mm. The identified particles were predominantly composed of synthetic polymer materials.

Higher occupancy levels within classrooms contributed to increased microplastic abundance through intensified human activities. In addition, plastic-based products and materials, including furniture, school uniforms, toys, eating utensils, stationery, carpets, craft materials, cleaning frequency, and ventilation characteristics, may also contribute to the presence of indoor microplastics.

Therefore, further research is needed to identify the specific types of microplastics generated from the various sources present within school environments and to better understand their potential impacts on indoor environmental quality and human health.

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