Research

Microplastics in indoor deposition samples in university classrooms

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Abstract

The pollution caused by microplastics (MPs) is a growing concern on a global scale, especially considering the significant proportion of time that individuals spend indoors. The contamination in question has the potential to directly impact the human population through exposure to indoor dust and air. This research undertook a comprehensive analysis of the indoor deposition of MPs in university classrooms, employing various investigative tools. The present study aimed to comprehensively analyze the physical and chemical properties of MPs found in university classrooms. Analyzing samples under a stereomicroscope, the predominant MPs were identified as fibers of varied colors, mainly attributed to clothing. Sizes of these MPs varied significantly across different classrooms, with a general average size range of 120–2222 µm. The observed morphological changes in MPs, including cracks and grooves, hint at potential degradation into nanosized plastics over time. This observation raises concerns about increased concentrations of nanoplastics in indoor environments. Using µRaman analysis, eleven types of MPs were identified, potentially originating from clothing, shoes, and stationery. The majority of MPs were polyamide 6, polypropylene, and polyamide 12. The scanning electron microscope and energy-dispersive X-ray spectroscopy (SEM–EDX) technique unveiled the elemental composition of the MPs, with carbon, fluorine, and oxygen being dominant. The findings align with past studies but highlight the need to understand MPs' structural components and any possible contaminants. Compared to existing literature, this study adopts a comprehensive methodological approach combining optical microscopy, µRaman, and SEM–EDX, enriching the knowledge on indoor MP deposition and aiding future research directions.

Highlights

- Fiber was the dominant type of MP identified.
- The primary source of fibers is believed to be the clothing worn by students and teachers.
- The dominant colors were black, transparent, blue, and red.
- The average range size of MPs is 120–2222 µm.
- The majority of MPs were identified as polyamide 6, polypropylene, and polyamide 12.
- Common elements across samples were carbon, fluorine, silicon, and oxygen.

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1 Introduction

Plastic pollution is a global threat to human health and the environment. This is primarily due to plastics' tendency to accumulate in diverse environmental components due to their resistance to chemical and/or biological breakdowns [1–3]. Based on their size, plastics can be classified into five major categories: nanoplastics (< 0.3 mm), microplastics (MPs) (< 5 mm), mesoplastics (5–50 mm), macroplastics (5–500 mm), and mega-plastics (> 500 mm) [4–6]. Due to their pervasive pollution in the natural environment, MPs have become significant environmental problems in ocean ecosystems; they affect fish, seabirds, and marine mammals [7]. Various agricultural regions contain MPs. Research shows MPs in soil and crops/plants. Studies have found MPs in agricultural soils, indicating they may enter via plastic-based mulches, polluted irrigation water, or the decomposition of bigger plastic detritus [8, 9]. MPs have been found in crops, indicating roots may absorb them. MPs may go from soil to crops and into the food chain. MPs in the air represent serious health concerns in metropolitan environments, highlighting their many issues. Inhaling airborne MPs in cities underlines the need for extensive study and effective methods to reduce health risks to inhabitants and the urban environment [10, 11]. However, indoor spaces, including houses, businesses, classrooms, and public buildings, are highly susceptible to MP contamination. The sources of these MPs are often the everyday items found within these spaces, including furniture, materials used in construction, carpets, and clothing. These materials shed tiny plastic particles that can become airborne or settle into indoor dust, contributing to the overall presence of MPs in these indoor environments [12–14]. Given the potential hazards to human health and the environment that MPs pose (respiratory issues, digestive problems, environmental pollution, biodiversity impact, contamination of food and water), their presence in indoor environments is particularly concerning [3, 10, 15]. Due to the significant amount of time that individuals spend inside (up to 90% or more), the indoor environment is crucial to modern human life (e.g., homes, offices, markets, transport, etc.) [16–18]. In indoor environments, primarily where microfiber products are extensively used, there is a need to consider the potential impact of MPs. Microfiber is a synthetic fiber made from polyesters, polyamides (such as nylon), or a combination of these substances. Microfiber shedding from synthetic textiles, microbeads in personal care products, plastic debris from home goods, and dust from outside air pollution are just a few examples of the many sources of indoor MPs [13, 19, 20]. These MPs can infiltrate indoor spaces through various entry points, such as ventilation systems, interior activities like cleaning and cooking, and outside air infiltration [12, 18]. MPs may gather inside on various surfaces, including floors, carpets, and furniture, and they can also be breathed or ingested by humans [10, 21]. Another source of indoor MPs is the deterioration of all surface finishes, including wall and ceiling paints, PVC and PUR flooring, wallpapers, other plastic goods, kitchen plastic utensils like scouring pads, brushes, and towels, and basic multipurpose hygiene products [13, 20]. MPs are frequently released from these surfaces when used, cleaned, rubbed, cut, scratched, or maintained [14, 22]. The degree of MP pollution within a building depends on many factors, including the building's location and kind, its ventilation system, and the activities that occur inside. Indoor environments, however, have been repeatedly identified as significant contributors to the problem of MP contamination [23, 24].

Despite the limited evidence regarding the detrimental impact of MP pollution, it is imperative to acknowledge their potential as a viable threat, given the ongoing increase in their concentration. Numerous investigations have established the existence of MP in aquatic ecosystems; however, a restricted amount of research has been conducted on the occurrence of airborne MPs in terrestrial environments, particularly in indoor air environments [10, 20]. Currently, more than 96% of MP studies are on marine/aquatic ecosystems, and it is clearly stated that most MPs in these environments originate from land [25]. However, there is not enough focus on MP research in terrestrial ecosystems [12, 26]. The concentration of MP pollutants in the indoor environment is contingent upon various factors such as the spatial arrangement, utilization, purpose, and interior decoration of the given space. Despite the lack of extensive research or data about the evaluation of MP prevalence and quantity within indoor settings, certain air and dust samples obtained from various indoor environments have demonstrated markedly elevated levels of MP content compared to outdoor environments [20, 27].

Although indoor MPs' possible health impacts on people are not entirely known, there are worries that they might endanger people's health [2, 7, 10]. For instance, MPs may result in lung issues if breathed, and they may build up in the digestive tract and result in gastrointestinal problems [10, 28, 29]. Furthermore, it has been shown that MPs include dangerous chemicals like phthalates and bisphenol A (BPA), which have been linked to various health issues, including difficulties with development and reproduction [30, 31]. It is critical to understand the origins and pathways of MP contamination in indoor environments before addressing the issue of indoor MPs. This may be accomplished by sampling and analyzing indoor air, dust, and deposition. Once the pathways and sources have been identified, actions to decrease

MP pollution can be undertaken. Numerous studies have shown their significant concentration in indoor air [32–34], generating substantial worry for human health owing to inhalation (air), ingestion (food, drinks, dust), and dermal contact (dust, fabrics, cosmetics). According to some researchers, people exposed to indoor MPs inhale an average of 26–130 airborne MPs daily [29]. Cox et al. (2019) identified an average concentration of 9.8 MPs per m^3; the results showed that males and females were exposed to 170 and 132 MPs per day, respectively, while male and female children were exposed to 110 and 97 MPs per day [35]. Based on an average global airborne MP concentration of 0.685 particles/m^3 and a breathing rate of 8.64 m^3 per day, Domenech and Marcos calculated a relatively low global human daily inhalation intake of 5.9 MPs per day [36]. Other researchers have suggested that the number might reach as high as 272 MPs per day [37]. Different sampling techniques and environments may be the leading causes of the variability. Other factors such as how a space is used and occupied, the type of ventilation used, where the sampling equipment was placed, how much outside air entered the indoor environment, and the accumulation of primary and secondary MPs may also have impacted the results' variability.

Chemical additives like BPA, phthalates, esters of phthalic acid, some heavy metals like zinc (Zn), mercury (Hg), or lead (Pb), or chemical compounds like flame retardants are frequently added to MPs to improve their quality, and these additives increase the toxicity of MPs [38]. When exposed to ultraviolet light, weathering, or aging, the MPs have the potential to become even more hazardous since these processes may alter their chemical makeup [14, 18, 39]. The escalating issue of indoor air pollution caused by MPs should be appropriately addressed. Potential dangers to human health and the environment have been linked to MPs in indoor spaces. To solve this problem, researchers must identify the origins and routes of MP pollution and then develop and apply countermeasures. The potential health consequences of indoor MPs must be better understood, and appropriate solutions must be identified. Thus, additional further research is required.

This study aims to examine the existence of MPs in different university classroom deposition samples, their distribution, and the sources that these MPs may have. The physical characterization uses an optical, chemical analysis with μ-Raman, a scanning electron microscope, and energy-dispersive X-ray spectroscopy (SEM–EDX) to characterize the deposition samples.

2 Materials and methods

Deposition samples were taken from the four classrooms in the civil engineering department of Eskişehir Technical University, Türkiye, in March 2022. Detailed information about these classrooms is mentioned in the supplementary file. Petri dishes were used to collect the deposition samples from classrooms. Previous MP studies have adopted samplers like Petri dishes to collect MP deposition samples like stainless steel basins [34], glass beakers [40], glass Petri dishes [41–43], and a Whatman quartz filter in a glass Petri dish [43]. One petri dish was collected from each classroom. During the analysis, plastic materials were avoided for quality control of MPs present in the samples; only glass material was used. All the solutions used in the study were pre-filtered through the same type of filters used in the actual analysis of samples to remove the contaminants if present [44]. Access to the laboratory was limited. Cotton laboratory attire and nitrile gloves were used to reduce the possibility of contamination. The laboratory was routinely cleaned to mitigate any contamination arising from laboratory activities. The laboratory's ventilation system comprises windows and a door. Nevertheless, the facilities were closed in order to minimize contamination, and all tests were conducted inside a controlled laminar flow environment. Before collecting the samples, Petri dishes were washed three times with filtered Milli-Q-DI (TKA Genpure UV) water, then once with filtered methanol (HPLC ≥ 99.9%), and thermally treated at 150 °C for 3 h. Petri dishes were kept open in all the classrooms for one week. The deposition samples collected on the Petri dishes were cleaned with the filtered Milli-Q-DI water and filtered through PTFE filters (0.45 μm, 47 mm). The filters were stored in the glass petri dishes and kept for drying in a desiccator at room temperature. Once the filters were dried properly, they were analyzed under a stereomicroscope, μRaman, and SEM–EDX.

A stereomicroscope made by Carl Zeiss microscopy GmBh called the Stemi 508 was utilized to identify (or confirm) MPs and morphological changes. MPs are physically characterized based on their size, shape, and color. This data may aid in identifying the potential origins of MPs and their pathways into indoor classrooms. Morphological changes were clear. Morphological changes in MPs during degradation and fragmentation refer to alterations in their physical characteristics. This includes size reduction, surface roughening, color changes, and shape alterations. Understanding these transformations is vital in assessing MP pollution's ecological and health risks. The Axiovision SE64 Rel.4.9.1 software included with the Axiocam 105 color camera served as the operating system for the stereomicroscope. A variety of magnification powers, including 0.6×, 0.8×, 1×, 1.25×, 1.6×, 2×, 2.5×, 3.2×, 4×, and 5×, are available on the microscope.

The eyepiece's magnification is standardized at 10x, and the total magnifications range from 6×to 50×. All the magnifications were used due to the MPs' size variations; however, 5×was used mostly. If undesired items (undesired items refer to any objects that are not MPs like glass beads, hair, insect fragments, or wood particles) were present during the stereomicroscope examination, they were removed with tweezers. Petri dishes were closed immediately after examination under a stereomicroscope to limit air contact.

The chemical constituents of MPs can facilitate the identification of plastic varieties present in the specimens and ascertain their possible association with hazardous chemicals or additives. µRaman measurements for the university classrooms were performed by an alpha 300R confocal Raman microscope (WITec), with a grating of G2:600 g/mm BLZ = 500 nm, and a thermoelectrically cooled charge-coupled device (CCD) detector. The 532 nm radiation of a PS laser and a 10×objective (NA = 0.25; WD = 9.3 mm) and 50×objective (NA = 0.8; WD = 0.57 mm) and 100×(NA = 0.9; WD = 0.31 mm) EC Epiplan-Neofluar Disc Zeiss) were used. Thorlabs GmbH laser intensity checker controlled the laser intensity. µRaman spectra were recorded in the wavenumber range of 152–4287 cm^{-1}, having a spectral center of 2500 with laser power of 6.20 mW and an integration time of 11 s per scan were used. The oscilloscope integration time was 0.5 s. For each spectrum, 15 scans were accumulated. For each sample, 15 particles were randomly selected for MP analysis, and a total of 60 particles were scanned from all four samples. The Raman system was operated by control five software (WITec). Under the µRaman, each filter was measured from left to right or right to left, then moved down slowly. Each filter should be read at least two to three times to reduce the error while taking the spectra. For better illustration, smoothing and baseline correction were done. The spectra obtained in the Raman microscope were compared with reference spectra from the Raman polymer database using open specy [45]. The spectra were also cross-checked with the previous literature [46–49].

Elemental analysis provides insights into the fundamental constitution of the MPs and the morphology of the samples collected. Representative MPs from indoor deposition classroom filters were selected and characterized for their morphology and elemental composition using a Backscatter Electron (BSE)—SEM (FEG-SEM; Zeiss Supra 50 VP) coupled with an EDX Microanalyzer (INCA Energy; Oxford Instruments). A Backscatter electron detector (BSD) was used during the analysis. The WD was 10 mm while the 20 kilovolts (kV) was used for electron high tension. The BSE-SEM imaging mode is based on the principle that dark regions represent elements with low atomic numbers, and bright regions represent elements with high atomic numbers. All the samples were sprinkled over double-sided carbon tape and mounted on the SEM, and the surface morphology and micro and nano region elemental composition were determined. The surface morphology and element composition results were printed as black-and-white images and tables. The SEM–EDX measurements were taken after the optical and µRaman microscope analysis. The advantage of doing this is that the carbon covering of filters for SEM–EDX measurements affects the filters and can not be used again if kept for a long time.

2.1 Physical characterization of microplastics in this study

MPs have different sources, types, shapes, and colors. To find the chemical composition of these MPs, it is essential first to identify if the samples contain MPs and characterize them morphologically. Different microscopes (light, optical, stereo, and fluorescent) can be used to identify MPs physically. Dry filters should be used to assess MPs under these microscopes, as wet filters reflect the microscope's light. Typically, covered filters will dry after 24 h at room temperature, but depending on the moisture of the filter and the temperature in the laboratory, it may take longer. The presence of MPs was defined using the following criteria [18, 54].

- No cellular or biological features are seen in the MPs (fibers, fragments, films, lines, foam, and pellets).
- Fibers exhibit consistent thickness over their whole length and should not be entirely straight- which indicates a biological origin and should not be tapered at the end; fragments possess rounded shapes; films demonstrate transparency; lines indicate straightness, fibrous and thin; foam has a sponge-like texture; and pellets assume a cylindrical form.
- MPs should be clear and uniformly colored (blue, red, black, yellow, etc.)
- If the MPs are not colored, i.e., transparent or white, they should be studied carefully under high magnification to rule out an organic origin.
- Biofilms and other organic or inorganic adherents must be removed from the MPs to avoid artifacts that impede clear and accurate identification.
- If a particle could not be identified as MPs or the image was not clear enough, it was not counted as MP.

The particles were cautiously scrutinized in the examinations, and only those that met the above criteria were classified as MPs. In addition to the criteria above, identifying these MPs in the indoor deposition samples was also characterized by referring to the relevant literature study [55–58]. These MPs were identified based on their source, type, shape, and color [18]. For the statistical analysis and graph generation of the acquired data, the computing tools used in this work were Microsoft Excel, SPSS, and Origin. The research used methodological techniques, namely using an ANOVA single-factor analysis. In order to ensure the utmost accuracy and reliability of the research results, we used a thorough and systematic approach, using all of the most rigorous analytical methods available.

3 Results and discussion

3.1 Physical characterization

The physical characterization of indoor deposition university classroom samples was analyzed under a stereomicroscope (Fig. 1). MPs were characterized based on type, color, and size. The dominant types were fibers with different colors (black, transparent, blue, and red). Based on the questionnaire, the reason can be the clothes worn by students and teachers. The different indoor deposition university classroom samples showed significant differences in type, color, and size. The MPs in classrooms 1, 2, 3, and 4 ranged from 197 to 2104, 131–2659, 67–2534, and 84–1590 μm. The average size range was 120–2222 μm. Small-sized MPs (< 150 μm) can be ingested by living organisms, migrate through the intestinal wall, and reach lymph nodes and other body organs [31]. In addition, MPs (< 2.5 μm) may cross the respiratory barrier and remain in the lungs, which means air pollution caused by MPs is closely related to respiratory and cardiovascular toxicities [30]. Polystyrene beads (6 μm) significantly affected the body length measurements of *D. magna* [59]. The morphological alterations in the MPs were readily apparent when observed under the stereomicroscope. These changes encompassed the presence of cracks, broken edges, ridges, grooves, and rough and uneven surfaces. These conspicuous signs indicate the degradation of the MPs, which, over time, will lead to the formation of smaller plastic particles, such as nanoplastics [10, 14, 60, 61]. These changes have environmental implications, impacting how MPs interact with ecosystems and organisms and may lead to the formation of smaller, potentially more harmful particles (nanoplastics) [14, 54]. Consequently,
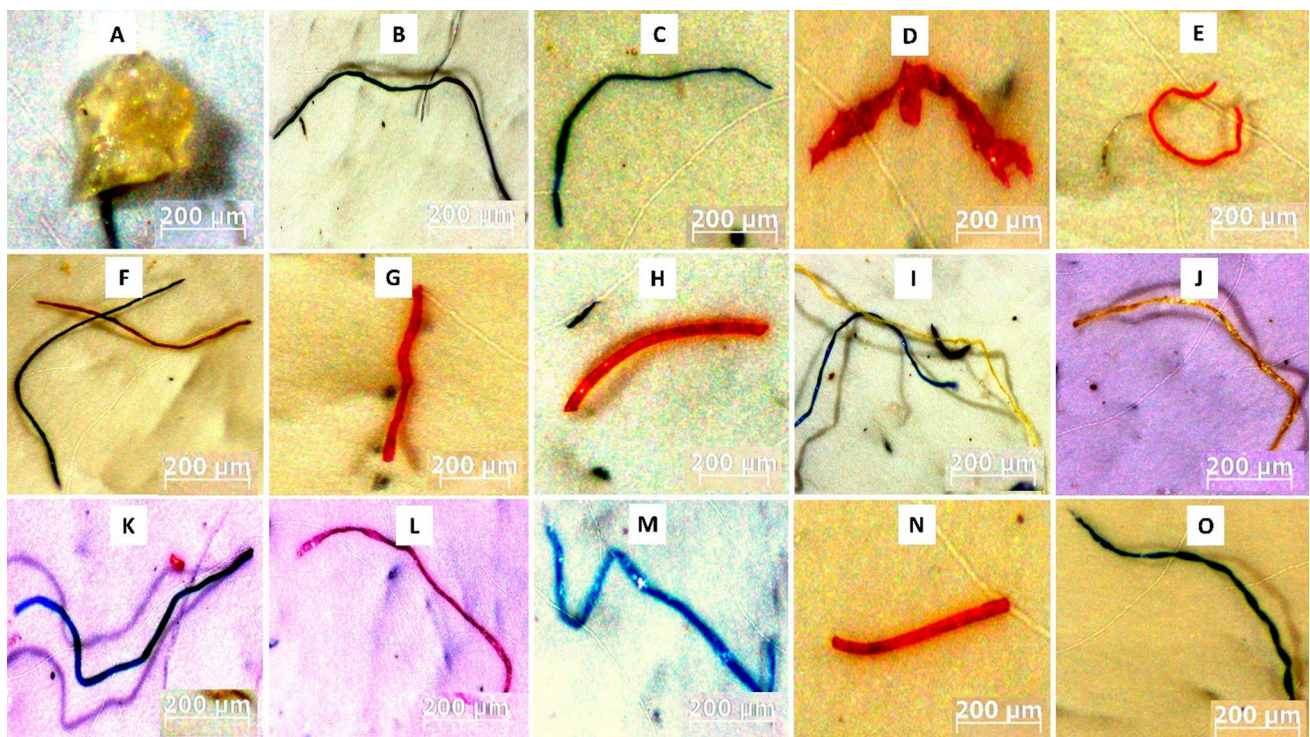
Fig. 1 Examples of some microplastics found in indoor deposition university classrooms and classified by shape and color (**A**): gold fragment, (**B–O**): black, red, transparent, and blue fiber

there will be an increase in the concentration of nanoplastics within the classrooms. To date, limited studies have been done on the indoor deposition of MPs in dormitories, apartments, offices, and corridors [34, 62], houses [40, 41], university (reception room), university (office, hallway, classroom), house, dining room in the apartment, the dining hall in campus, restaurant, office, and classroom [32, 43, 63]. The results were similar to those of Dris et al. [62]; they found that fibers as the dominant deposition type of MPs in apartment and office with a size range of 50–4850 μm and Zhang et al. [34] also found fibers as a dominant type of deposition MPs in dormitory, office, and corridor with size < 5 mm having colors like transparent, blue, red, yellow, black, purple, and green. Zhang et al. [34] are the only one who has characterized indoor deposition MPs until now based on color. The results also agreed with Amato-Lourenço et al. [32]; they found fiber, fragment, and film types of deposition MPs with a size range of 50.03–989.12 μm in the university (reception room). The results also followed the indoor deposition of MPs in houses [40, 41] and university (office, hallway, classroom), house, dining room in the apartment, the dining hall in campus, restaurant, office, and classroom [42, 43]. It is critical to determine the chemical makeup of the identified MPs in addition to their physical characteristics.

3.2 Chemical characterization

The μRaman analysis of indoor deposition classroom samples showed different MPs. Fifteen particles were scanned from each sample, and fifty-three were identified as MPs. A total of 11 different types of MPs were identified. Their spectrums were plotted with the match degrees (Fig. 2). These MPs include polyamide (PA resin), polymethyl methacrylate (PMMA), rubber (RB), polyvinylidene difluoride (PVDF), Polyamide 6 (PA 6), Polyamide 12 (PA 12), polypropylene (PP), polyhydroxybutyrate (PHB), (PTFE), polyethylene (PE), and poly(vinyl alcohol) (PVA). The sources for these MPs can be clothes, shoes, plastic bags, stationery materials etc. [13, 18]. Based on the published research, the matching score of identified MPs was higher. This study's matching scores of identified MPs varied between 55 and 95%. Few studies have addressed the matching score, and the findings have ranged from 27 to 97% [50–53]. Matching scores can be significantly boosted
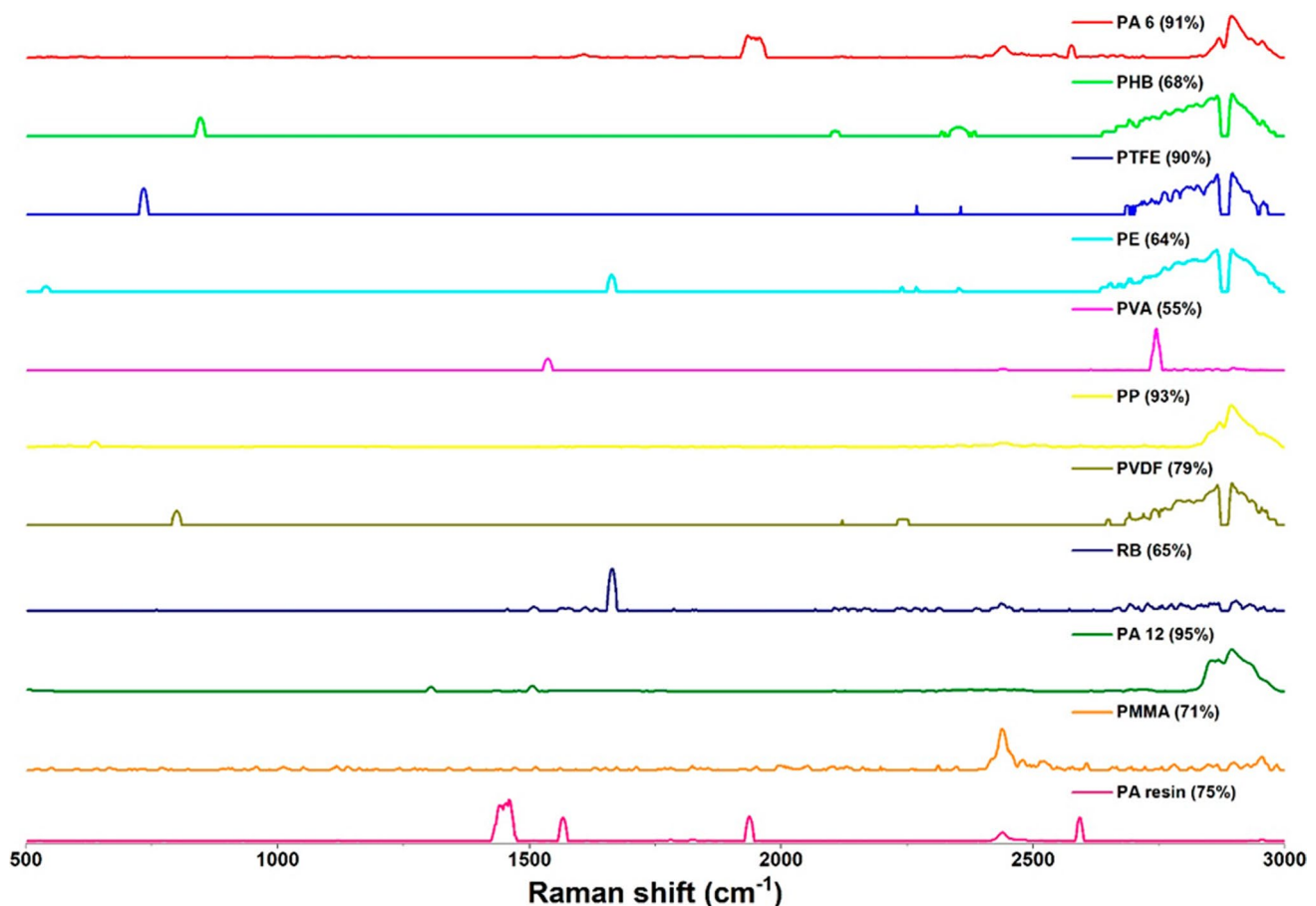

Fig. 2 Micro Raman spectra of microplastics found in indoor deposition classroom samples (75%)* percentage of relevance

using more complete commercial libraries if the algorithm leverages multicomponent correlations in the matching process. Perhaps part of the difficulty is that commercial and custom libraries only include spectra from polymers that the environment has not degraded. As per the author's knowledge, this is the first indoor deposition classroom study where 11 different MPs were found. In contrast, as in other deposition indoor studies, only a standard or a limited number of MPs were seen. However, the results were similar to indoor deposition studies like Dris et al. [62], identified PA, PP, and PE MPs in apartment and office deposition samples for the first time. The findings concurred with the deposition studies conducted in homes [40]; they found polyethylene terephthalate, PA, acrylic, PP, polyacrylonitrile, PE, and PMMA, and [41] found PE, polyester, polyethylene terephthalate, PA, and polyvinyl chloride. Additionally, the findings paralleled the deposition study of Zhang et al. [34] in dormitory, office, and corridor with MPs as polyester, rayon, acrylic, cellophane, PP, PS, and PA. The deposition investigations in different indoor environments like a university (reception room) by Amato-Lourenço [32] found PP, polyester, low-density polyethylene, and PS, university (office, hallway, classroom) and house by Yao et al. [43] found PS, polyethylene terephthalate, PE, polyvinyl chloride, and PP and dining room in an apartment, the dining hall in campus, restaurant, office, classroom by Fang et al. [42] found polyethylene terephthalate, PE, and PA supported the findings of this study. Most of these indoor studies found fiber as a dominant type of MP.

The distribution of MPs varied among the indoor deposition classroom samples (Fig. 3). The MPs found in most of the deposition classroom samples were PA 6, PP, and PA 12. These are used in producing PA fibers, which are widely used in textiles, carpets, and packaging materials. MPs identified under μRaman were further characterized based on their type and color (Fig. 4). The fiber was again the dominant type of MP seen under the μRaman. The reason can be the clothes worn by students. The number of identified MPs among the scanned particles varied in indoor deposition classrooms. The nine MPs were identified in classrooms 1 and 2, while 13 were from classroom 3 and 12 from classroom 4. The Anova single factor of the data for the distribution of the identified MPs among the indoor university deposition classroom samples showed a significant difference (P = 0.03). This statistical significance implies that there are discernible variations in the presence of MPs within different indoor university deposition classrooms. These results hold importance for understanding the potential sources and factors influencing MP contamination within university classrooms. Further investigation and exploration of specific variables contributing to the observed differences could provide valuable insights into the dynamics of microplastic distribution in indoor environments. This study found that the composition and concentration of MPs were slightly different from those found in other studies; this discrepancy could be attributable to differences in sampling locations, appropriate sources, sampling volume, number of particles scanned, size of MPs, and the type of instrument used (Table 1). It is crucial to characterize MPs chemically, but it is also important to determine their structural components, additives, and other contaminants.

Fig. 3 Distribution of microplastics found in each indoor deposition classroom
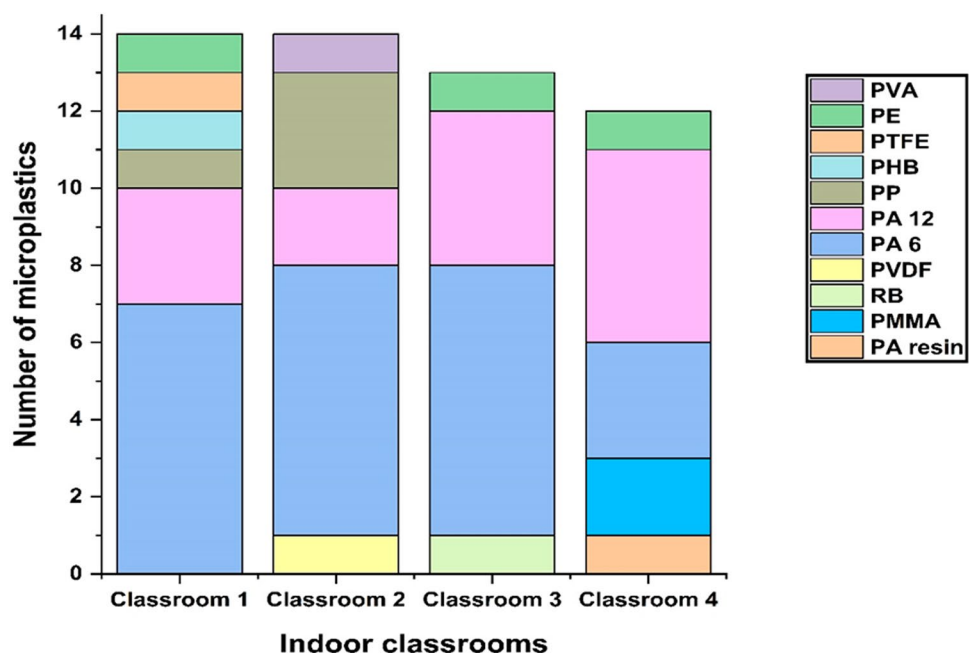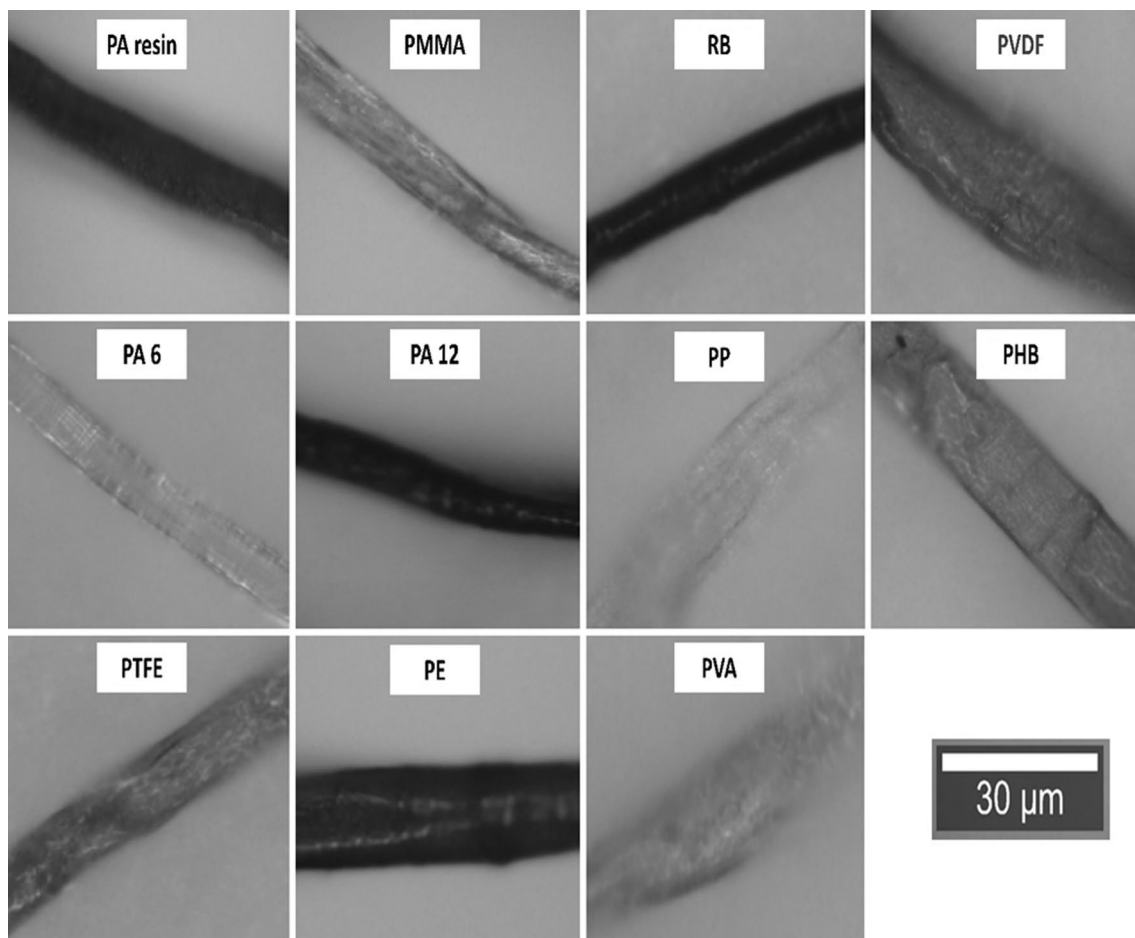
Fig. 4 Typical representation of indoor market microplastics seen under micro Raman and are categorized by type and color (PA resin, PMMA, RB, PVDF, PA 6, PA 12, PP, PHB, PTFE, PE, and PVA); black, blue, white, and transparent fibers

3.3 Elemental analysis

SEM characterized the surface characteristics of MPs found in the indoor deposition university classroom samples, while EDX revealed their percentage elemental concentrations. The SEM–EDX analysis of indoor deposition in university Classroom one showed the presence of different elements (Fig. 5) in two MPs. The common element was carbon (C), fluorine (F), silicon (Si), and oxygen (O). C, F, and O had higher concentrations in both the fiber type of MPs, while Si and gold (Au) in fiber-A and Si in fiber-B type of MP had lower concentrations.
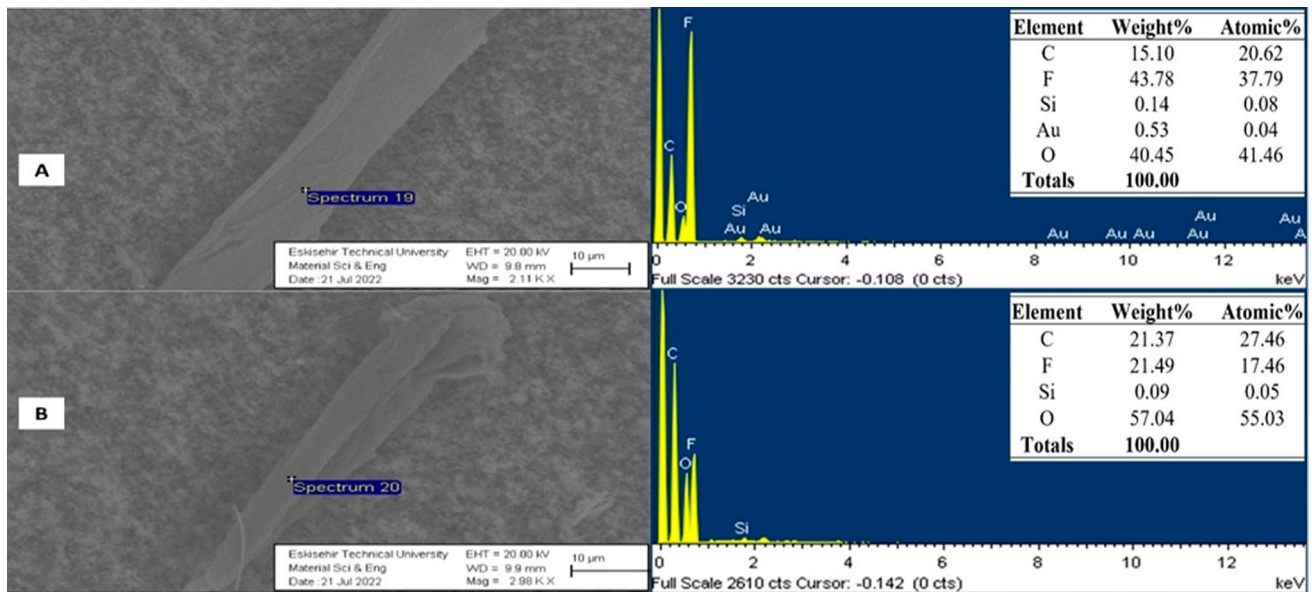
In Classroom two, the common element was C, F, and O in two fiber MPs (Fig. S1). All the elements had the highest concentration in both the MPs except calcium (Ca) in the fiber-A type of MP. The results of SEM–EDX in university Classroom three indicated the presence of various elements in two fiber MPs, as depicted in (Fig. S2). The common elements were C, O, F, and Au. All the elements had the highest concentration in both the MPs except Au in the fiber-A type of MP. The indoor deposition university Classroom four showed the presence of different elements (Fig. S3) in two fiber MPs. The common was elements C, O, and F. In the fiber-A type of MP, all the elements had the highest concentration in both the MPs except sulfur (S) and Au, while in fiber-B, all the elements had the highest concentration.

C, F, Si, Au, O, Ca, and S were the common elements in all deposition of university classroom samples. The differences were seen in their percentage concentrations; however, C, F, and O mostly had the higher weight percentage concentrations. The fibers were identified as the predominant kind of MPs based on SEM–EDX research. None of the indoor deposition studies has used SEM–EDX to analyze MPs (Table 1). The results followed the findings of Abbasi et al. [64]; they found C, nitrogen (N), O, and Si in the indoor dust samples of classrooms. Furthermore, the results also agreed with the results of Kashfi et al. [65], who found C and O as dominant elements in all MPs, while N, Ca,

Table 1 Comparing the findings of this study to the current literature on indoor deposition studies

Sample type	Location	Sampling site	Instruments used	Concentration	Plastics identified	MPs form	MPs size	MPs color	References
Indoor deposition	Turkey	University classrooms	Stereomicroscope, µRaman, and SEM–EDX	9–13 MPs identified per classroom	PA 6, PP, and PA 12	Fiber and fragment	120–2222 µm	Black, transparent, blue, and red	This study
	France	Apartment and office	ATR-FTIR	1586–11,130 fibers m^{-2} day^{-1}	PA, PP, and PE	Fiber	50–4850 µm	Unreported	[62]
	China	Dormitory, office, and corridor	Stereomicroscope and µFTIR	Dormitory (9.9×10^{3}), office (1.8×10^{3}) and corridor (1.5×10^{3}) MPs/m²/day	PL, CV, AR, PR, PP, PS, and PA	Fiber	< 5 mm	Transparent, blue, red, yellow, black, purple, and green	[34]
	UK	House	Stereomicroscope and µFTIR analysis	1414±1022 MPs m^{-2} day^{-1}	PET, PA, AR, PP, PAN, PE, and PMMA	Fiber, fragment, film, sphere, and foam	< 5 mm	Unreported	[40]
	Australia	House	Stereomicroscope, fluorescence stereomicroscope, and µFTIR	22–6169 fibers m^{-2} day^{-1}	PE, PL, PET PA, and PVC	Fiber, fragment, and film	50–5000 µm	Unreported	[41]
	Brazil	University (reception room)	Fluorescence microscope and ATR-FTIR	309±215 MPs m^{-2} day^{-1}	PP, PL, LDPE, and PS	Fiber, fragment, and film	50.03–989.12 µm	Unreported	[32]
	USA	University (office, hallway, classroom) and house	Stereomicroscope and Raman	$(6.20 \pm 0.57) \times 10^{3}$ — $(1.96 \pm 1.09) \times 10^{4}$ fibers m^{-2} day^{-1}	PS, PET, PE, PVC, and PP	Fiber, film, and irregular particle	Unreported	Unreported	[43]
	China	Dining room in apartment, dining hall in campus, restaurant, office, classroom	Fluorescence stereomicroscope and µFTIR	$(7.6 \pm 3.9) \times 10^{5}$ MPs m^{-2} day^{-1}	PET, PE, and PA	Fiber and fragment	5.9–5000 µm	Unreported	[42]

Element	Weight%	Atomic%
C	15.10	20.62
F	43.78	37.79
Si	0.14	0.08
Au	0.53	0.04
O	40.45	41.46
Totals	**100.00**	

Element	Weight%	Atomic%
C	21.37	27.46
F	21.49	17.46
Si	0.09	0.05
O	57.04	55.03
Totals	**100.00**	

Fig. 5 SEM–EDX images of two microplastics found in the indoor deposition of university classroom one are classified by shape (**A** and **B**) fiber. Chemical element concentrations are expressed as a percentage

and Si were the other elements in the indoor dust samples of hospital, mosque, kindergarten, university, and house. Besides these indoor dust studies, the results of this study were similar to the indoor dust samples of schools [66]. Nematollahi et al. [66] found that MPs were composed of a high percentage of C and O with SEM–EDS, while the MPs had a minor percentage of other elements, including N and Si, in the indoor dust samples of the school.

Due to environmental exposure, MPs exhibited nonuniform surface texture and degradation patterns, such as grooves, pits, cracks, etc. Mechanical and chemical deterioration, collisions, and friction caused by the moment of the people, or the effect of detergents and washing of clothes, may cause these surface texture imperfections [67–69]. Physical abrasion and chemical weathering against sunlight, air, and humidity increase the surface roughness of some MPs and enhance their contaminant adsorption [14, 70]. The patterns aid in the adhesion of additional particles to the surface of MPs, increasing the toxicity and health risk of MPs to humans like Si [10, 31]. High quantities of C, O, N, and plastic-specific chemical components demonstrate the correct identification of MPs (e.g., chlorine in polyvinyl chloride) [70]. Other elements may be present in the plastic as functional additives or reaction leftovers or as components of exogenous material attached to or adsorbed onto the plastic surface. Si are likely adsorbed onto the surface of MPs, and silicate minerals such as clays may cause their presence [66]. To achieve a wide range of colors, textures, and functionality, Si has been used in paints, which might be pigments, binders, or additives [71, 72]. The lower and more uniform concentrations of elements not commonly added to plastics and/or are more indicative of geogenic material, e.g., Si [73]. As these additives are not chemically bonded to the polymeric matrix, they can be released into the environment due to weathering [74]. Minerals like gypsum naturally contain S [75], which is used in buildings. F is used in the pharmaceutical industry, mouthwash and is found in soil [76–78]. Au might have come with a sample used to coat it before SEM–EDX analysis.

3.4 Comparison with literature

Due to the limited samples collected in this study, it may not provide an accurate comparison to the current literature. Indoor deposition study is minimal in comparison to indoor dust and air research. Furthermore, most research employed an optic microscope with µRaman or µFTIR, and none utilized SEM–EDX or a combination of optical microscopy, µRaman, and SEM–EDX. The type and number of MPs identified in deposition studies varied compared with this research, but so far, only one study [34] has characterized the MPs based on their color. The indoor environments investigated in deposition samples are lesser than those examined in ambient and dust studies [12, 18]. Previous research has employed varying units to quantify the concentration of MPs, potentially attributable to methodological discrepancies (Table 1). Variations have been observed in the quantity or concentration of MPs detected indoors. This variability may be attributed to differences in sampling locations, sampling methodologies, sample volumes, and other factors. Fiber and fragments have

been identified as the predominant types of MP observed in previous studies and the current study. Most prior research has identified MPs of larger size than those observed in the present study (Table 1). This finding suggests challenges in accurately detecting and characterizing smaller-sized MPs.

4 Limitations

In the subsequent part, the limitations of this study will be expounded upon the limits inherent in this study, offering a realistic evaluation of the obstacles and restrictions experienced throughout this research.

- Counting MPs with a microscope is challenging because of varying visibility based on magnification level. Accurate MP counting is difficult because MPs observed at lower magnifications are disregarded at higher magnifications and vice versa. Counting MPs by shooting and analyzing them in ImageJ takes time and effort. The variable size range of MPs in a sample makes it challenging to establish the best resolution for photographing them. Since MPs may twist or pass through the sieve or sampler vertically, their size may not be what we expect. Smaller MPs are more likely to cling to larger MPs, making it difficult to count both with the same magnification. Even if counting MPs is theoretically conceivable, it takes time and is prone to inaccuracy.
- Since the distribution of MPs on filters is often nonuniform, assessing the polymeric composition of randomly selected MPs or a filter section may make determining the real MP count more difficult.
- The study may have only focused on a limited number of samples and no triplicate sampling being conducted in university classrooms, meaning that the results may not indicate the community as a whole. This could prevent the findings from being broadly applied.
- No procedural or open-air blanks were collected to determine the contamination of MPs due to the unavailability of resources.

5 Conclusion and recommendations

The physical characterization of indoor deposition university classroom samples showed the presence of fibers as the dominant type of MPs with different colors (black, transparent, blue, and red). The reason can be the clothes worn by students and teachers. The indoor deposition samples exhibited notable variations in type, color, and size. The average size range was 120–2222 μm. The μRaman analysis of indoor deposition classroom samples identified different MPs, and the number of identified MPs among the scanned particles varied in indoor deposition classrooms. Sixty particles from all four indoor deposition classroom samples were scanned under the μRaman, and fifty-three particles were identified as MPs. A total of 11 different types of MPs were identified. The distribution of MPs varied among the indoor deposition classroom samples. The MPs found in most of the deposition classroom samples were PA 6, PP, and PA 12. This study found that the composition and concentration of MPs were slightly different from those found in other studies; this discrepancy could be attributable to differences in sampling locations, appropriate sources, sampling volume, number of particles scanned, size of MPs, and the type of instrument used. C, F, Si, Au, O, Ca, and S were the common elements in MPs analyzed from the collected samples. The differences were seen in their percentage concentrations; however, C, F, and O mostly had the higher weight percentage concentrations. The surfaces of fibers are relatively smooth; however, the edges are rougher and more irregular, which is consistent with the abrasion and disintegration. SEM–EDX has not been used in any indoor deposition study to examine MPs. This study's findings might help shape public policy and public health strategies to minimize indoor classroom MP pollution and safeguard human health and the environment. The further recommendations are mentioned as follows.

- Due to the small size of MPs, the complexity of indoor environments, and the variety of sources, collecting and evaluating indoor MP samples is a significant challenge. There should be universally accepted procedures for sampling and analysis.
- Showing the percentage prevalence of MPs is critical for facilitating result comparison and establishing a meaningful threshold for MP presence.
- MPs can be found indoors from various items, external sources, and even human activities, making it difficult to trace their origins. This makes it tough to attribute the origins of MP pollution inside buildings.

- To analyze all possible characteristics of MP presence in the indoor environment and determine the scope of the problem, it is essential to examine not only the forms but also the nature of the spaces in which they occur, methods of generation and dissemination, and physical and chemical properties.
- There is a lack of information on MPs found indoors, including their prevalence, abundance, and chemical makeup in indoor environments. This hinders efforts to find solutions to the problem of MP pollution indoors.

Data availability The author confirms that the data supporting the findings of this study are available in the article.

Declarations

Ethics approval and consent to participate Not applicable.

Consent for publication Not applicable.

Competing interests The author has no conflicts of interest to declare.

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