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Assessment of Indoor Microplastic Particles Pollution in Selected Sites of Mosul City

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ABSTRACT

Among the most significant sources of microplastics (MPs) for humans is indoor dust. However, very few researchers have studied the properties and abundance of MPs that existed in dust from different indoor environments. The current study investigated microplastic fallout in 90 locations (5 kindergartens, 6 mosques, 5 schools, 10 shops, 5 cafeterias, 6 hospitals, 25 dormitories, 7 barber salons, 6 offices, 5 scientific laboratories, 5 pharmacies, and 5 medical clinics) during six months. Among the ninety sampling sites, the most significant average of MPs was actually found in the kindergartens ($4.743\times10^3 \pm 427$ MP/m^2 /d), in contrast, the lowest abundance was in the medical clinics ($3.02\times10^2 \pm 62$ MP/m^2 /d). The majority of indoor dust samples contained MPs in the form of fibers. The dominant colour of dust samples was transparent, followed by black, red, blue, green, and yellow. A total of six types of polymers were identified, including polystyrene (PS, 39%), polyethylene terephthalate (PET, 20%), polypropylene (PP, 17%), polyethylene (PE, 13), polyamide (PA, 7%) and polyvinyl chloride (PVC, 3%). PS, PET, and PP represent most of the MPs polymer types discovered in indoor dust samples from various locations. These polymers are frequently used in fabrics, furniture, carpets, packaging, and synthetic fibers. Statistical analysis was performed on the results using Excel 2019. The results showed that there were statistically significant differences in each site with the other sites, except between (schools and mosques), (pharmacies, and medical clinics). The similarity between these sites in terms of people's activity or in terms of furniture, the lack of carpets and curtains could explain the insignificant difference.

Keywords: microplastic; dust deposition; shapes & colour; FTIR; indoor air pollution, Indoor dust.

INTRODUCTION

Microplastics (MPs) commonly refer to plastic particles less than 5 µm, while particles less than 0.1 µm are called Nanoplastics (NPs) (Alimi et al., 2018). Their presence has been found in a wide variety of environments (Chen et al., 2022; Rahman et al., 2021). All natural environments, including water, air, and soil, contain microplastics (Uddin et al., 2022). MPs are always being produced indoors because of furniture, cleaning habits, and activities, and the existence of air renovation even with low rates within the indoor environment may cause their formation (Liao et al., 2021a). Human health is greatly affected by the quality of the air in indoor spaces (Jenner et al., 2021a). The risk of exposure to microplastics for children is more significant, as they consume dust, and infants may also be exposed to MPs via ingestion, for example, fibrous MPs that settle on the floor. As children crawl and touch their mouths, they ingest settled dust every day (Gasperi et al., 2018). In most cases, people are unaware that airborne pollutants can negatively impact their health. (Liu et al., 2019). There is a wide variety of MPs that form in the air deposited, leading to the differentiation of sampling methods. Detecting deposited MPs was done by dry deposition (Zhang et al., 2020). It is important to monitor interior environments because 89% of activities take place indoors. According to certain research, indoor concentrations of suspended and deposited MPs are higher than outside concentrations (Fowler et al., 2022). The study (Prata, 2018) found that the microplastic concentrations in indoor environments more than those outdoors because MPs' levels are influenced by several factors (Zhang et al., 2020). Interestingly, microplastics that are created inside can end up polluting the environment outdoors. However, only 30% of particulates which are generated outdoors can cross over indoors (Prata, 2018). This emphasizes the significance of environment indoors as the primary source of exposure to airborne MPs (Prata et al., 2020a). There are several factors that determine the health risk associated with airborne MPs, such as their size, shape, and chemical composition (Liao et al., 2021a). The most commonly reported form was fibers, then followed by fragments (Wright and Kelly, 2017; Zhang et al., 2020). Recent studies have demonstrated that airborne MPs are composed of polyethylene (PE), polystyrene (PS), polypropylene (PP), polyvinyl chloride (PVC) and polyethylene terephthalate (PET) (Soltani, et al., 2021; Allen et al., 2019). In a previous study, three independent indoor sites were tested for man-made fibers in atmospheric fallout: one office and two private apartments. It found that the indoor fiber concentrations varied between 1,586 and 11,130 MP/m^2/d, resulting with fibers accumulation in settled dust (Liao et al., 2021a), and in another study, MPs were deposited between 22 and 6,169 MP/m^2/d (Soltani et al., 2021). There are limited numbers of studies about indoor microplastic pollution in the world and there are no studies on microplastic pollution in the city of Mosul/Iraq. Therefore, It would thus be important to quantify and characterize the MPs in indoor environments.

In this study, MPs deposition in the indoor environment was quantified and characterized at various locations, including (kindergartens, mosques, schools, shops, cafeterias, hospitals, dormitories, barber salons, offices, laboratories, pharmacies, and medical clinics). Microscope stereo-microscope analysis of air samples from these sites was performed to determine shape and colour, and Fourier transforms infrared (FTIR) analysis was used to determine polymer type. By conducting this study, indoor microplastics in urban environments can be characterized and their properties explored, providing information for future studies aimed at understanding airborne microplastic degradability, transport, and deposition, as well as their sources and health risks.

MATERIALS AND METHODS

Study area

This study was conducted in Mosul which is the second-largest city in Iraq in terms of population and area. Samples were taken from different environments under nearly conditions (without ventilation or any further house cleaning) for each environment. The sampling was performed in 90 locations as shown in (Figure 1).

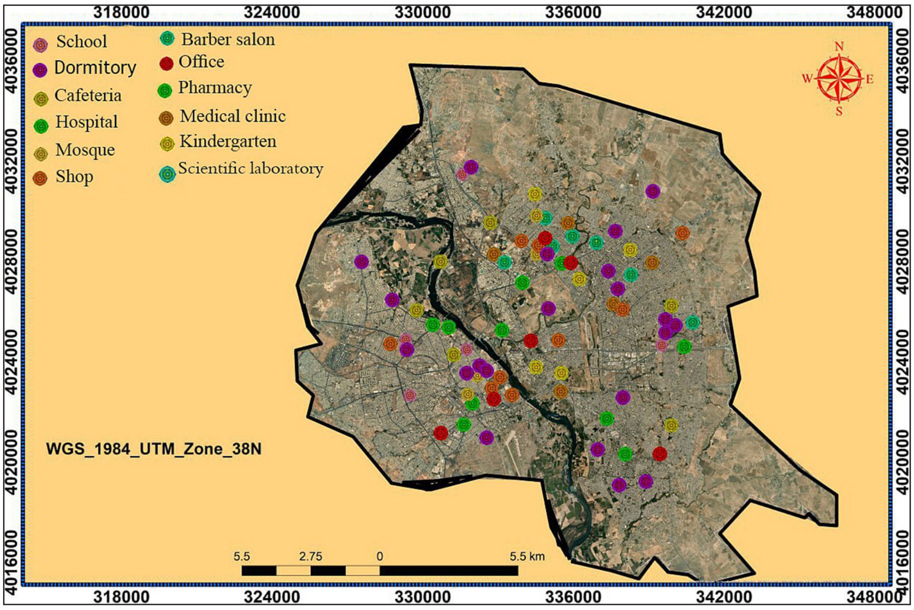

Figure 1. Sampling locations in Mosul City

Collection of indoor microplastics fallout samples

The deposition rate was calculated as the number of MPs counted for every square meter per day (Zhang and Diao, 2023). A total of 24 weeks were spent collecting indoor MPs fallout from August 2022 to February 2023. Table 1 depicted the number of microplastics for 90 locations with three replications (270 samples) in different buildings, as represented in Appendix. In order to increase the accuracy of the results, three replicates of each site were conducted on the same day and the collection of samples lasted 24 hours. Over the sampling period, the activities at the locations were ordinary. We tended to gain data closer to the facts. By closing all windows and doors leading to exterior areas and not using air conditioning, the maximum influence of air exchange can be minimized. Furthermore, no further house cleaning was conducted during the 270 samplings. To prepare the basins for sampling, ultrapure water was used to wash them then were placed 1.2 meters high on desks after sealing with aluminized paper (Zhang et al., 2020). After 24 hours of dry deposition, three replicates were done at each site. In the laboratory, wash water was filtered after basins being washed with 0.5 L of ultrapure water (Zhang et al., 2020). Figure 2 displayed the approach which is applied for microplastics analysis in the current study, a 5 m cellulose filter membrane is used to filter the water (pore size of 0.45 µm, size of 47 mm Ø). In order to accomplish this, a vacuum device was used. After samples had been filtered, they were placed in glass dishes and dried for follow-up analysis. To avoid particle loss or MPs pollution through various steps, the sample treatment process was excluded from flotation and digestion. To determine their shape, colour, and number, the MPs were examined with a stereomicroscope (Motic2300S-V37-45X Zoom, Italy). FTIR spectroscopy was used to further characterize the composition of the representative MPs (IRAffinity-1S, SHIMADUZ, Japan). The FTIR spectrum ranged from 4000 cm^{-1} to 600 cm^{-1}, with a sample capture time of 3 seconds. There were 15 scans in each measurement. In transmittance mode, the spectral resolution was 4 cm^{-1}. Furthermore, the FTIR offers the performance Lab Solutions IR software.

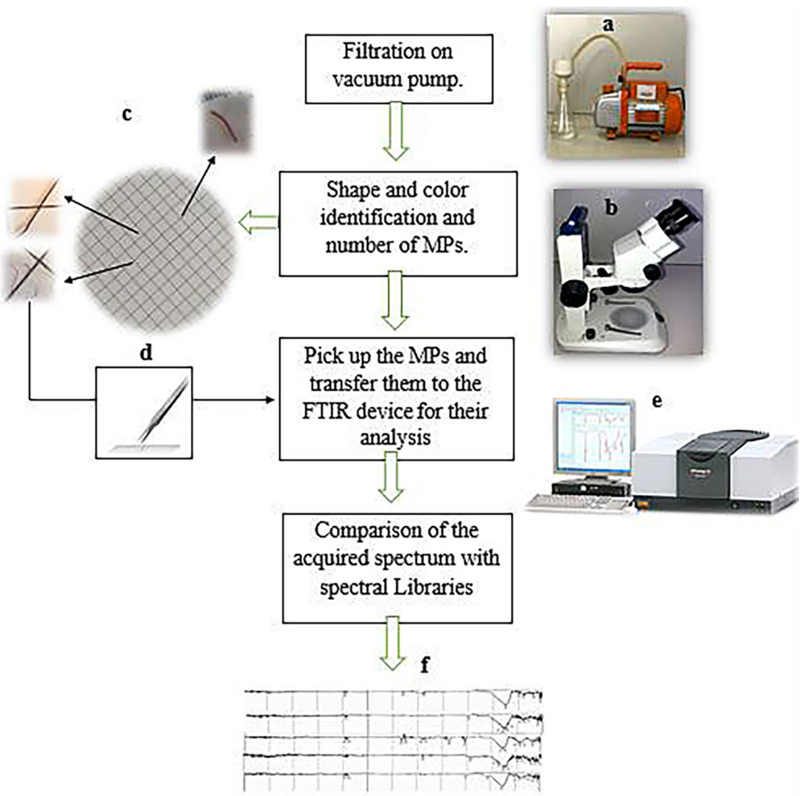

Figure 2. A schematic diagram showing the approach used for MPs analysis in this study (a) filtration device, (b) stereomicroscope to determine the color, number and shape of MPs, (c) article selection from filters for FTIR analysis, (d) forceps for capturing particles, (e) FTIR device for particle analysis to identify the type of polymer, (f) spectrums are compared with software library spectra

Table 1. Depicted the number of microplastics for 270 sample in different buildings

Building type	Sample location	R^x MPs /m² /d	R^{xx} MPs/m² /d	R^{xxx} MPs /m² /d	Average MPs /m² /d	Site description
Dormitory	House 1	933	1.133	1.083	1.050	Bedroom
	House 2	1.200	1.217	1.483	1.300	Bedroom
	House 3	1.200	1.433	717	1.117	Bedroom
	House 4	1.166	1.116	1.100	1.128	Bedroom
	House 5	1.700	1.083	1.183	1.322	Bedroom
	House 6	1.233	1.150	1.217	1.200	Bedroom
	House 7	650	1.217	1.183	1.017	Kitchen
	House 8	1.233	1.000	1.133	1.122	Kitchen
	House 9	1.117	1.133	1.300	1.156	Kitchen
	House 10	1.117	1.200	1.217	1.178	Kitchen
	House 11	1.117	1.183	1.267	1.189	Living room
	House 12	1.167	1.150	1.117	1.144	Living room
	House 13	1.267	1.233	1.283	1.261	Living room
	House 14	1.100	1.283	1.233	1.184	Living room
	House 15	1.083	1.117	1.233	1.167	Living room
	House 16	1.200	1.300	1.133	1.211	Living room
	House 17	1.250	1.200	1.117	1.189	Living room
	House 18	1.233	1.067	1.117	1.139	Living room
	House 19	1.133	1.200	1.167	1.167	Living room
	House 20	1.117	1.300	1.133	1.144	Living room
	House 21	1.100	1.233	1.067	1.133	Corridor
	House 22	1.250	1.150	1.133	1.178	Corridor
	House 23	1.233	1.150	1.217	1.200	Corridor
	House 24	1.200	1.033	1.200	1.145	Corridor
	House 25	1.233	1.250	1.283	1.255	Corridor
Offices	Office 1	833	767	950	850	Inside office
	Office 2	933	866	733	889	Inside office
	Office 3	733	783	850	789	Inside office
	Office 4	883	750	800	811	Inside office
	Office 5	767	733	1.467	989	Inside office
	Office 6	817	703	850	790	Inside office
Shops	Shop 1	2.033	1.900	1.717	1.883	Inside shop
	Shop 2	1.750	1.900	1.700	1.783	Inside shop
	Shop 3	2.150	1.767	1.483	1.800	Inside shop
	Shop 4	1.750	1.683	1.733	1.722	Inside shop
	Shop 5	1.750	1.617	1.867	1.717	Inside shop
	shop 6	1.700	1.750	1.767	1.739	Inside shop
	shop 7	1.617	1.900	1.583	1.761	Inside shop
	shop 8	1.717	1.917	1.533	1.733	Inside shop
	shop 9	1.717	1.650	1.833	1.722	Inside shop
	shop 10	1.717	1.833	1.650	1.733	Inside shop
Mosques	Mosques 1	1.900	2.550	2.317	2.256	Inside Mosque
	Mosques 2	2.283	2.067	2.400	2.250	Inside Mosque
	Mosques 3	2.267	2.200	2.333	2.267	Inside Mosque
	Mosques 4	2.367	2.100	2.417	2.261	Inside Mosque
	Mosques 5	2.350	1.600	2.317	2.089	Inside Mosque
	Mosques 6	2.333	2.450	2.066	2.283	Inside Mosque

Table 1. Cont.

Barbra salons	Salon 1	750	700	1.450	967	Inside salon
	Salon 2	900	767	1.000	889	Inside salon
	Salon 3	950	1.350	867	1.056	Inside salon
	Salon 4	733	917	883	844	Inside salon
	Salon 5	1.217	917	1.150	1.094	Inside salon
	Salon 6	933	817	833	861	Inside salon
	Salon 7	967	867	967	933	Inside salon
Medical clinics	Clinic 1	335	300	283	306	Inside medical
	Clinic 2	300	400	317	339	Inside medical
	Clinic 3	283	317	200	267	Inside medical
	Clinic 4	283	350	300	322	Inside medical
	Clinic 5	183	300	416	300	Inside medical
Hospitals	Hospital 1	1.183	1.300	1.383	1.289	Emergency room
	Hospital 2	1.200	1.217	1.083	1.167	Emergency room
	Hospital 3	1.150	1.067	1.267	1.161	Emergency room
	Hospital 4	1.700	1.266	1.283	1.417	Corridor
	Hospital 5	1.267	1.250	1.300	1.272	Corridor
	Hospital 6	1.133	1.067	1.233	1.144	Corridor
Schools	School 1	2283	2583	2.217	2.305	Classroom
	School 2	2083	2050	2150	2.094	Classroom
	School 3	2.167	2.133	1.933	2.077	Corridor
	School 4	3.100	2.250	1.717	2.356	Corridor
	School 5	2.267	2.383	2.250	2.300	Classroom
Kindergartens	Kindergarten1	4.220	5.767	4.550	4.840	Games hall
	Kindergarten 2	4.517	4.983	4.733	4.744	Games hall
	Kindergarten 3	5.283	4.870	4.517	4.890	Games hall
	Kindergarten 4	4.333	4.950	4.500	4.628	Corridor
	Kindergarten 5	4.667	4.617	4.500	4.594	Corridor
Pharmacies	Pharmacy 1	333	267	383	328	Inside pharmacy
	Pharmacy 2	386	350	300	345	Inside pharmacy
	Pharmacy 3	317	333	350	333	Inside pharmacy
	Pharmacy 4	383	367	433	344	Inside pharmacy
	Pharmacy 5	250	300	283	328	Inside pharmacy
Scientific laboratories	Laboratory 1	583	600	783	656	Inside Lab.
	Laboratory 2	550	583	433	522	Inside Lab.
	Laboratory 3	650	983	617	750	Inside Lab.
	Laboratory 4	567	728	650	648	Inside Lab.
	Laboratory 5	517	617	583	572	Inside Lab.
Cafeterias	Cafeteria 1	1.850	1.350	1.317	1.506	Inside cafeteria
	Cafeteria 2	1.817	1.350	1.600	1.589	Inside cafeteria
	Cafeteria 3	1.383	1.567	1.217	1.389	Inside cafeteria
	Cafeteria 4	1.367	1.350	1.317	1.350	Inside cafeteria
	Cafeteria 5	1.317	1.483	1.200	1.344	Inside cafeteria

Note: R^{x} – first repeat, it is taken from the front of the site, R^{xx} – Second repeat, it is taken in the middle of the site, R^{xxx} – third repeat, it is taken at the end of the site.

DATA ANALYSIS

In order to measure the abundance of microplastics, MPs/m^2/d was reported. The microplastic abundance was calculated using the mean and standard deviation for each sample analyzed in triplicate. The statistical analyses were conducted using Microsoft Excel 2019 software using ANOVA single factor analysis. If the difference in the number of MPs between sites (ΔMPs) is more than the least significant difference (LSD) defined as a significant difference, while the ΔMPs are less than the LSD defined as an insignificant difference (Qiang et al., 2021), the LSD value is calculated by the following equation.

$$\text{LSD} = t\alpha\sqrt{2MSE/\text{n}} \quad (1)$$

where: t – critical value gotten from t distribution table;
α – probability level at 0.05;
MSE – mean square within gotten from results of ANOVA table;
n – number of notes.

RESULTS AND DISCUSSION

Pollution amount of microplastics indoor

Over 24 weeks, we collected MPs from different indoor environments. Every sampling day, total MPs fallouts were gathered at ninety sites. Table 2 depicted the number of microplastics for 270 samples in different building as represented in Appendix. The deposition rates of average MP/m^2/d were as follow (Figure 3), 4.743×10^3 ± 427 MP/m^2/d in the kindergartens, 2.432×10^3±223 MP/m^2/d in the Mosques, 2.238×10^3 ±309 MP/m^2/d in Schools, 1.770×10^3±141 MP/m^2/d in shops, 1.432×10^3±196 MP/m^2/d in the cafeterias, 1.242×10^3±144 MP/m^2/d in Hospitals, 1.183×10^3±145 MP/m^2/d in the dormitories, 9.49×10^2±195 MP/m^2/d in the barber Salon, 8.53×10^2±168 MP/m^2/d in the offices, 6.25×10^2±134 MP/m^2/d in the scientific laboratories, 3.36×10^2±50 MP/m^2/d in the pharmacies and 3.02×10^2±62 MP/m^2/d in the medical clinics. Statistical analysis showed that the difference between each site with other sites was significant at (ΔMPs > LSD), expect the difference between (pharmacies and medical clinics) and (mosques and schools) was not significant when (ΔMPs < LSD). It is possible to explain these significant differences by several factors, including the differences between these sites in terms of carpet, curtains, furniture, and toys for children, as in kindergartens, and people's activity also plays a significant role in those differences. There is some similarity between pharmacies and medical clinics in terms of furniture and lack of carpets and curtains, which makes the difference not significant, while mosques and schools seem to have little difference as a result of the similarity in population density. Mosul's lifestyles have an

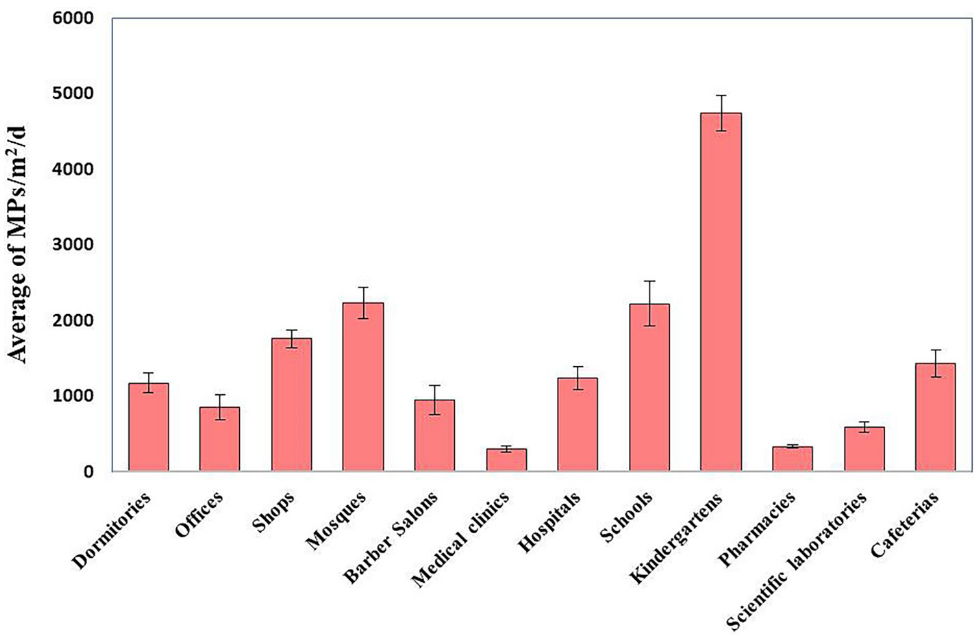

Figure 3. Average abundance of MPs in different sites

important role to play in creating ambient MPs, as residents dry their bedding, clothing, blankets, and pillows by exposing them to sunlight. When synthetic textiles are exposed to sunlight frequently, they are more likely to break down (Sørensen et al., 2021).

The kindergarten had the highest value because it frequently used plastic materials for toys, chairs, desks, boards, seats, etc. (Koutnik et al., 2023). A huge amount of textile products were available in mosque sites, which probably contributed to their high value. Medical clinics, scientific laboratories, and pharmacies had lower MP values than other indoor locations. The reason may be the weak of plastic products in these environments. The total average of MPs in all sites of this study was $1.425\times10^3\pm$ 986 MP/m^2/d in Mosul city, while in Paris was 6.358×10^3 MP/m^2/d (Dris et al., 2017).

Microplastic properties in indoor environments

Shape of microplastic

The shapes of microplastics in the environment are diverse. The most common types of microplastic shapes is fibers because fibers are likely to tear easily from clothes and furniture such as (curtains, polyamide, textiles, polyethylene-terephthalate or polypropylene carpets, etc.) (Dris et al., 2017) as present study in Figure 4. A primary microplastic's shape depends on the degradation and erosion processes (Zhu et al., 2022). In Figure 5, fiber is the most prevalent shape of MPs (about 93%), fragments (about 6%), and foam only makes up 1% of MPs (Figure 5). Clothes and textiles may release these fibers largely and easily during wearing and washing (Zhu et al., 2022). The results are similar to most

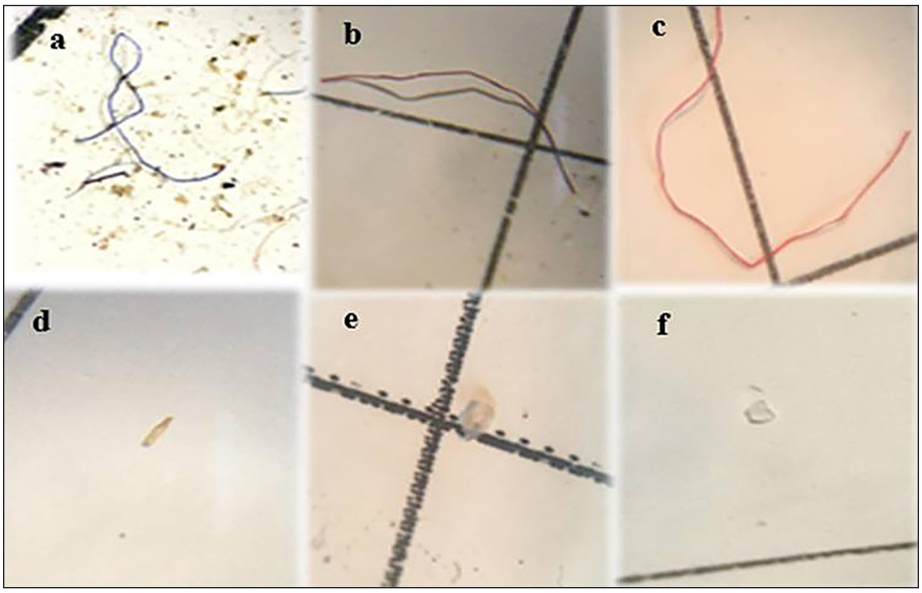

Figure 4. Images of microplastics, where (a), (b) and (c) are fibers, (d) and (e) are fragments while (f) is foam

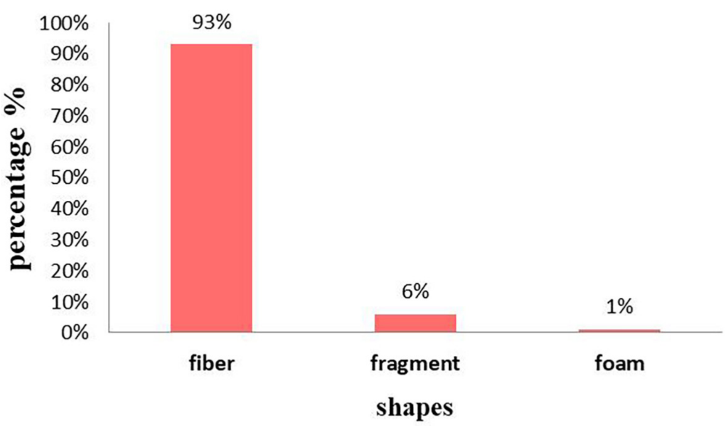

Figure 5. Percentage of MPs shapes of indoor

other atmospheric MPs studies, which reported about 90% fiber's shape (Klein and Fischer, 2019a; Jenner et al., 2021b).

Several indoor textiles and soft furnishings, such as clothes and curtains, contain artificial, fibers which are easily torn and released (Grande-Tovar et al., 2022). According to Liu et al. (2019) (Liu et al., 2019), fibers are the major kind of airborne and dust microplastics in the city of Shanghai, whereas, the second most dominant shape of microplastics was fragment existed within indoor dust samples. In German cities, fragments are the main type of airborne MPs (Klein and Fischer, 2019b). In general, polystyrene products are used for packing material, which is where foams can be generated (Chen et al., 2020).

Colour of microplastics within indoor samples

A wide range of colours have been reported for microplastics. (Figure 6), it was noted that the main dominant colours of examined microplastics were transparent, followed by black, blue, red, green, and yellow (Salthammer et al., 2022).

The use of transparent plastic bags for packaging is widespread. MPs with black colour in indoor dust may be mainly derived from building materials, textiles, and black clothes (Prata et al., 2020b).

Types of polymers

A good indicator of the origin of MPs is their composition. Different polymers formed some MPs with similar colours. As a result, MPs with similar appearances can come from many different backgrounds (Jenner et al., 2021a). This study demonstrated six types of polymers by using FTIR; they include PS, PET, PP, PE, PA, and PVC. The most dominant polymers of MPs particles were (PS, 39%), (PET, 20%), (PP, 17%), (PE, 13%), (PA, 7%), and (PVC, 3%), as shown in Table 2. Soltani et al, 2021 (Soltani et al., 2021), it was shown that PS is concentrated indoors due to the existence of people, furniture, moquette products, and carpeting in the indoor environment. Other studies have shown that PP, PS, PA, PES, rayon, acrylic and cellophane are common polymers in indoor air (Zhang et al., 2020). Also, in another report, it was Polyester (PES, 81%), (PE, 6%), (Nylon, 5%), (PP, 2%), and Other (6%) (Liao et al., 2021b).

A comparison of MPs abundance and characteristics in indoor dust from different sites

The shape, abundance, colour, and polymer composition of microplastics in indoor environments have been studied in a limited number of

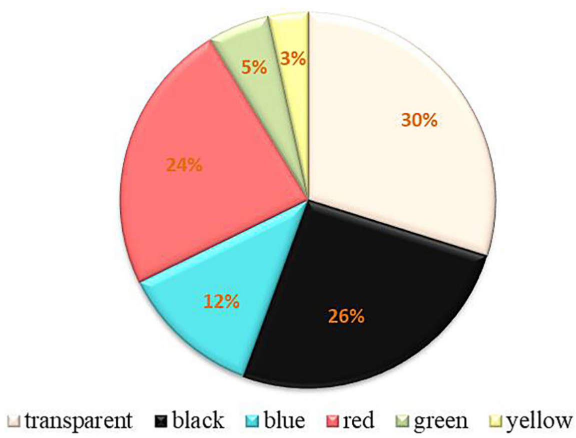

Figure 6. Percentage of MPs colors

Table 2. Polymer types percentage of microplastics in all sampling sites

Sites	Types						
	PE	PS	PET	PVC	PP	PA	other
Dormitories	10%	40%	23%	-	7%	17%	3%
Offices	-	49%	10%	-	40%	-	1%
Shops	9%	45%	27%	-	18%	-	-
Mosques	11%	44%	11%	-	33%	-	-
Barber Salons	13%	38%	25%	-	25%	-	-
Medical clinics	25%	63%	13%	-	-	-	-
Hospitals	10%	60%	30%	-	-	-	-
Schools	-	13%	50%	-	25%	13%	-
Kindergartens	24%	41%	12%	-	18%	6%	-
Pharmacies	-	31%	39%	18%	-	12%	-
Scientific laboratories	23%	38%	8%	-	29%	2%	-
Cafeterias	27%	45%	-	18%	9%	-	1%
Average	13%	39%	20%	3%	17%	7%	1%

Table 3. Comparison of MPs abundance and characteristics in indoor dust from different sites

Study area	Sample sites	Abundance (MP/m² /d)	Dominant shape	Dominant Colour	Dominant polymer composition	References
Paris, France	Different environments	1.586×10^3–1.1130×10^4	Fiber	NA	PA, PP, and PE.	(Gasperi et al., 2018)
Sydney, Australia	Houses	0.22×10^2–6.169×10^3	Fiber (90%), Fragment (7.7%) Films (2%)	black, green, blue, red, grey, brown, and transparent.	PE, polyester, PA, PS and polyacrylic.	(Soltani et al., 2021)
Shanghai, China	Different environments	1.2×10^3–1.4×10^4	Fiber (high ratio) Fragment (low ratio)	Transparent, blue, red, black, green, yellow, and paper	PP, PS, PA, PES, rayon, acrylic, and cellophane.	(Zhang et al., 2020)
Mosul, Iraq	Different environments	3.02×10^2–4.743×10^3	Fiber (94%) Fragment (6%) Foam (1%)	Transparent, black, red, blue, green, and yellow	PS , PET, PP, PE, PA and PVC	This study

studies, and they were compared with this study to understand how MPs pollution differs between different countries based on how much plastic material is used in their environment. As depicted in Table 3, previous studies assessed the microplastics in indoor environments and characterized them by colour, shape, and polymer type. The abundance of microplastics in indoor samples has highly valued variations: 1.2×10^3–1.4×10^4 MP/m²/d was recorded in Shanghai, China, followed by 1.586×10^3–1.113×10^4 MP/m²/d (Paris, France) and 0.22×10^2–6.169×10^3 MP/m² /d (Sydney, Australia). Comparatively, in this study, it was 3.02×10^2–4.743×10^3 MP/m²/d. Indoor microplastics come in a variety of shapes; including fiber, foam, fragments, and films. In France, Australia, Shanghai, China, and this study, fibers predominated indoor samples. Moreover, there were a variety of colours in the microplastics, transparent, black, blue, green, red, and yellow were the most prevalent. In some cases, plastic debris sources can be distinguished by their colour (Nematollahi et al., 2022; Zhang et al., 2020). However, this can be misleading. The colours of identified MPs in several studies are reviewed in Table 3. China reported black, blue, green, red, and yellow MPs (Zhang et al., 2020). While, in Australia, green, black, red, blue, brown, grey, and particles with transparent colour were controlled (Soltani et al., 2021).

CONCLUSIONS

This study confirms the presence of MPs in 90 Mosul's indoor areas. Kindergartens had the highest average amount of microplastics in indoor dust, followed by mosques, schools, shops, cafeterias, hospitals, dormitories, barber salons, offices, scientific laboratories, pharmacies, and medical clinics. Due to the ease of tearing fibers from clothing and furniture, most dust samples contained MPs in the form of fibers. A wide variety of colors were present in the MPs, including transparent, black, red, blue, green, and yellow. The most common polymer types discovered in indoor dust samples were PS, PET, and PP. The difference between each site and other sites was significant at (ΔMPs > LSD), except the difference between some location was insignificant. The relationship between pharmacies and medical clinics was little due to the similarity in terms of furniture and lack of carpets and curtains, as for mosques and schools were insignificant because of the density of the population.

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