



# A preliminary assessment of microplastics in indoor dust of a developing country in South Asia

Iqra Aslam · Abdul Qadir · Sajid Rashid Ahmad

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**Abstract** Microplastics (MPs) pollution is an emerging global environmental concern. Considering the high fraction of time people spend indoors, the human population can be directly exposed to this contamination through indoor dust. This preliminary study evaluates MPs' abundance and human health risk assessment in the deposited indoor dust. A total of forty dust samples ( $n=20$ ) were collected from homes in two different cities (Pakistan) in steel mesh pouches using the vacuum cleaner. The identification and quantification of MPs were conducted with a stereo microscope, whereas the qualitative assessment was performed with Fourier transform infrared spectroscopy (FTIR). The US EPA parameters to calculate the human health risk assessment were used to determine MPs' risk per-day/month/year. Overall, microfibers were the dominant category, followed by microfilms, micro-fragments, and nurdles. The chemical categorization of MPs was revealed as polyester, polyethylene, copolymers of polypropylene, and polyurethane. In Lahore, an average abundance of 241.45 (items/m<sup>2</sup>) MPs were observed compared to Sahiwal, with 162.1 (items/m<sup>2</sup>). More than 90%

of the identified MPs were microfibers, with higher detection frequency and abundance in Lahore than Sahiwal. The human health risk assessment revealed high exposure risk because of indoor MPs. Moreover, toddlers were more vulnerable as compared to adults at both low and high exposure risk scenarios. There is an imminent need to conduct in-depth risk assessment focusing on the respirable fraction of MPs.

**Keywords** Microplastics · Deposited indoor dust · Stereo microscope · FTIR · Color and shape · Geographical distribution

## Introduction

Microplastics are ubiquitous in the environment. In the recent past, the global production scale of plastics has surged from 1.5 to 335 million tonnes (Garside, 2019). More than 80% produced plastics belong to six categories: polyethylene, polypropylene, polyvinyl chloride, polyurethane, PE terephthalate, and polystyrene (PlasticsEurope, 2016). Although the environmental awareness has increased the recycling rate of plastic waste, still the remaining proportion are released into the environment either through direct degradation or as a by-product of various inefficient waste treatment procedures (Liu et al., 2018). Generally, the plastic fragments are categorized according to their size as macro, meso, micro, and nano-plastics ( $> 2$  cm, 5 mm,  $-2$  cm,  $<5$  mm, and  $<1$   $\mu$ m,

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respectively) (Horton et al., 2017). Among all the plastic fragments, microplastics (MPs) got serious attention because of their lethal impacts reported in various studies on marine, freshwater lakes, and rivers' organisms (Al-Thawadi, 2020; Bellasi et al., 2020; Thompson, 2015).

Since 1970, researchers have been sporadically reporting the presence of MPs; however, a pioneering study led by Richard Thompson effectively initiated the in-depth research related to MPs (Thompson, 2004). As the physical, chemical, and biological processes in terrestrial and freshwater environments are different from those in the oceans, it is important to separately investigate the profile distribution, spatio-temporal trends, and the effects of MPs in those media (Rochman, 2018). So far only a few studies have been carried out regarding the birds, soil, dust, and air (Zubris & Richards, 2005; Rillig, 2012; Abbasi et al., 2017; Huerta et al., 2017; Kole et al., 2017; Li et al., 2018a, b, c; Liu et al., 2019a, b; Zhang et al., 2020a, b), which demands further investigation in this area (Hurley & Nizzetto, 2018).

Indoor environment is a potential source of MPs. It poses high risk to humans (Prata, 2018), because in a modern world, 90% of people in the urban region are living a sedentary lifestyle and spend a large span of their time remained indoors (Lucattini et al., 2018). Since industrialization, the design of houses and buildings have advanced massively. Now, many synthetic polymers and chemicals are being used for interior attractiveness, efficiency, and cost-effectiveness (Pluschke & Schleibinger, 2018). Humans could be exposed to MPs via (1) ingestion, (2) inhalation, and (3) dermal exposure. Among them ingestion and inhalation are of major concern. MPs can adversely affect human health through direct exposure or indirectly by carrying other pollutants such as phthalates and bisphenol A (Liu et al., 2020).

There are two main sources of MPs: (1) primary sources and (2) secondary sources. Primary MPs are those that manufacturers produce intentionally for different purposes such as microbeads (cosmetics) and microfibers (textile). These MPs are released from the utilization of such products, whereas the secondary MPs are released from the degradation of large plastic particles because of photochemical, chemical, and mechanical processes (Galafassi et al., 2019). In the recent past, research studies by Prata et al. (2018), Catarino et al. (2018), Liu et al. (2019a, b), Cox

et al. (2019), Zhang et al. (2020a, b), and Soltani et al. (2021) studied the household dust as potential source of microplastics. These studies have reported indoor environment as a potential exposure pathway for humans. However, it is very important not to generalize the study results, and region-specific research investigations should be conducted to have better understanding of the microplastics hazard.

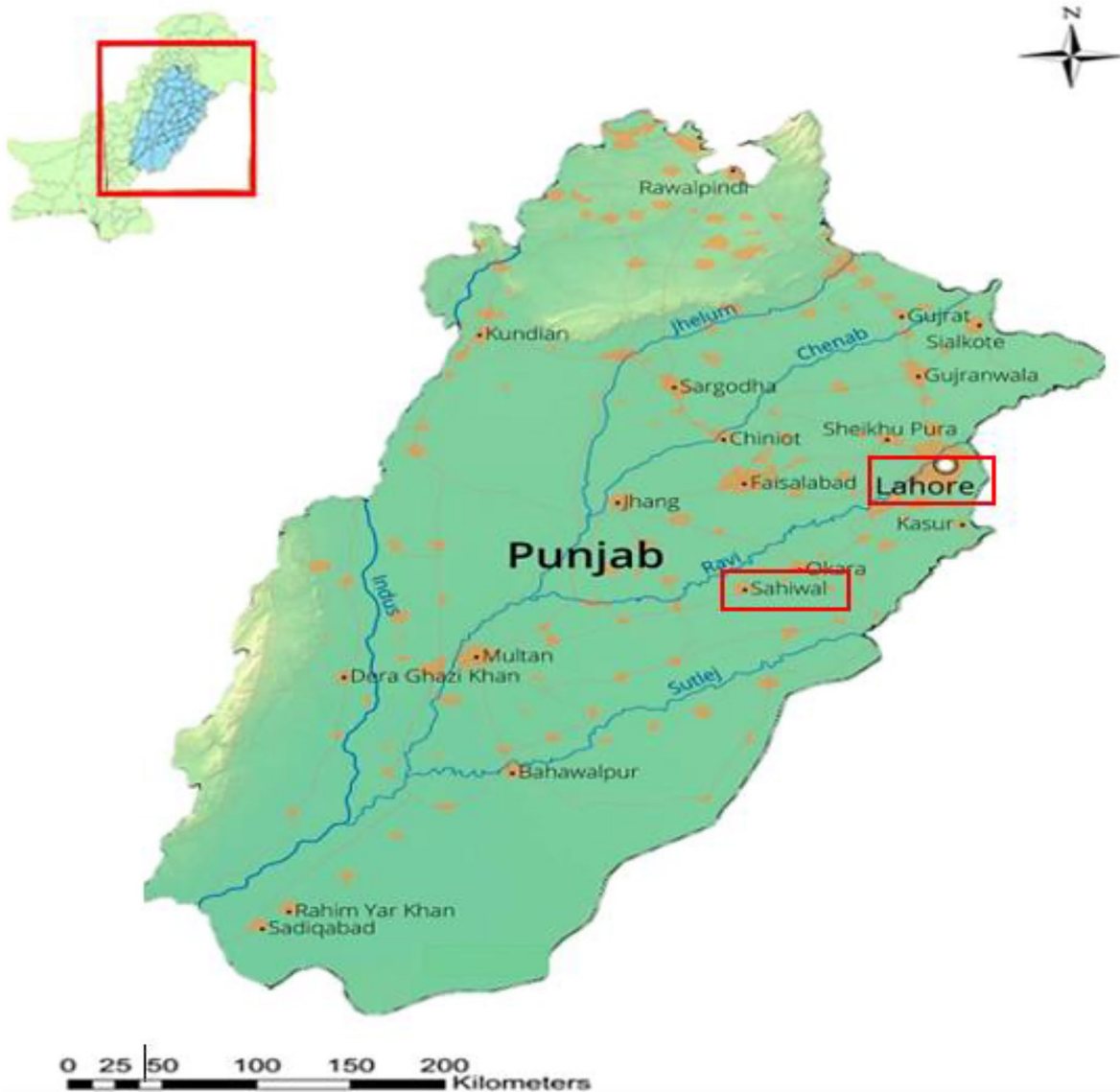
So far, in Pakistan, only few studies have been conducted in different environmental compartments such as in soil (Rafique et al., 2020), surface water (Irfan et al., 2020a, b), and sediments (Irfan et al., 2020a, b). Previously, to the best of our knowledge, no study was conducted regarding the presence of MPs in the indoor environment of the studied locations. Hence, this is the pioneer study to investigate the contamination of MPs in the urban indoor settings of Pakistan, using floor dust as an investigation matrix.

## Materials and methods

### Study area and sampling method

In March 2020, a sampling campaign was carried out in Punjab (Lahore and Sahiwal), Pakistan, as shown in Fig. 1. The sampling locations were categorized as urban (Lahore) and rural (Sahiwal). Lahore is a metropolitan city and the capital of Punjab province, which is situated between 31°32'59"N and 74°20'37"E. It is the second most populous city of Pakistan, with a total area of 1,772 km<sup>2</sup>, whereas Sahiwal lies between 30°39'40"N and 73°6'30"E, covering an average area of 60 km<sup>2</sup>. It is ranked as the 21st most populous region of Pakistan and is present 180 km away from Lahore (PCTPL, 2020).

A total of forty samples ( $n=40$ ) were collected, with twenty samples ( $n=20$ ) from each city. Several following factors were considered during the selection of residential sites and collection of the deposited dust. As1) for homogeneity, the single-story houses with an average of five occupants were selected, 2) dusty floors were sampled in the morning before cleaning, 3) dust sampling was carried out in the living rooms (Wang et al., 2013; Aslam et al., 2021). Figure S1 illustrates the sampling gears used for the collection of floor dust. The filter bag of portable vacuum cleaner (Electrolux) was replaced with a tailored steel mesh pouch (0.026  $\mu\text{m}$ ) used to avoid contamination,



**Fig. 1** Study area map showing the sampling cities (Punjab Maps, 2021)

as polyvinyl or cotton bags could be direct sources of microplastics. A representative composite dust sample was collected by vacuuming a 1 m<sup>2</sup> area from three different points in one house (Cao et al., 2015). The floor was vacuumed for 2 min per 1m<sup>2</sup> area (Cristale et al., 2018). After vacuuming, the steel mesh pouch was carefully removed and wrapped in an aluminum foil to avoid (1) the loss of dust and (2) contamination

and kept inside the pre-labeled zipped bags. All sampling gears were cleaned with methanol before each dust sample collection (Soltani et al., 2021). Moreover, while not using, all sampling gears were adequately covered with the aluminum foil. The collected samples were transported to the Environmental Toxicology Laboratory, University of the Punjab, Lahore, Pakistan, and stored at 4° C before further analysis.

## Extraction and cleanup

### *Dust sample preparation, extraction, and cleanup*

The dust samples were extracted by a previously mentioned oxidative extraction approach, with some modifications (Abbasi et al., 2019; Liu et al., 2019a, b). A schematic visual overview is provided in Fig. 2. Briefly, manual sorting of the indoor dust samples was carried out with a tweezer to remove hair and larger debris. Dust aliquot was added in a 250-mL beaker and

allow dust to detach from the filter paper and mix with the brine solution. Next, 10-min magnetic stirring was followed by pouring the mixture into a density separation flask. After settling for 120 min, the top fraction was homogenized through centrifugation for 6 min at 2000 rpm. Finally, the homogenized solution was vacuum filtered. Subsequently, the gridded filter paper was dried in a desiccator before the examination, using the stereo microscope and FTIR. To calculate the density, Eq. (1) was used (Quinn et al., 2017).

$$\text{Density} = \frac{\text{weight of the flask and brine solution} - \text{weight of the flask}}{\text{Volume of the flask}} \quad (1)$$

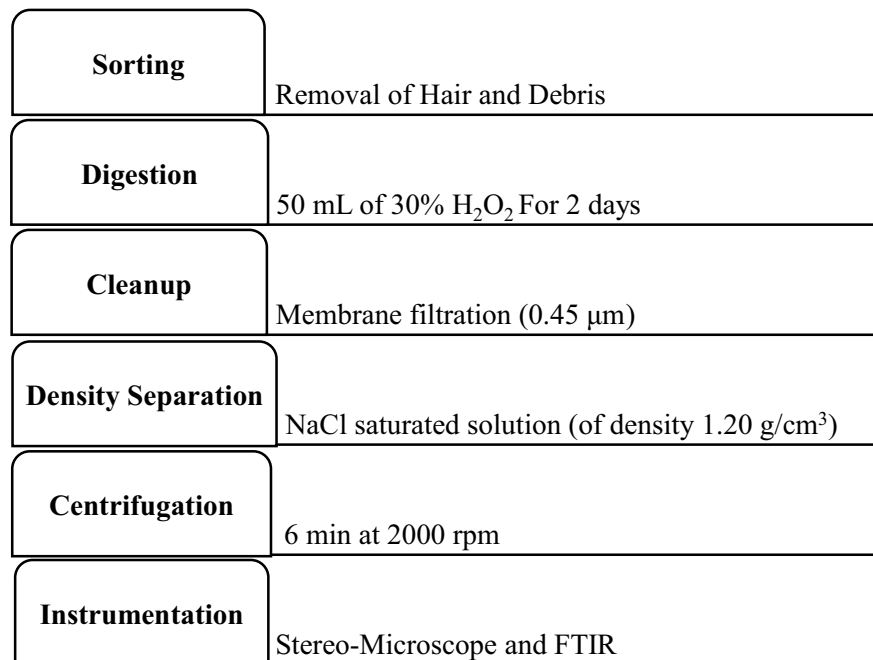
digested with 50 mL of 30% H<sub>2</sub>O<sub>2</sub> for 2 days (until the bubbling ends). For residual H<sub>2</sub>O<sub>2</sub> removal, membrane-filtration assembly coupled with MCE (mixed cellulose ester) filter paper (0.45 μm) was used, followed by washing with distilled water. Next, the filter paper was removed and placed in a pre-washed beaker for density separation, with NaCl saturated solution (density 1.20 g/cm<sup>3</sup>). The NaCl salt was used for cost-effectiveness and environmental friendliness.

First, 100 mL saturated solution was added to the beaker, followed by magnetic stirring. That would

### Quality control and quality assurance (QA/QC)

Strict quality control measures were followed throughout the analysis. The pre-cleaned glassware was sonicated and placed in an oven at 80 °C for 6 h before use. A laboratory blank was tested with each batch of sample extraction (10 samples) (Table S2). For the laboratory blank, a pre-cleaned Petri dish filled with distilled water was placed in the middle of the working area and later was subjected to all the steps of sample extraction with other dust samples.

**Fig. 2** Schematic flow diagram of dust sample preparation, extraction, and cleanup



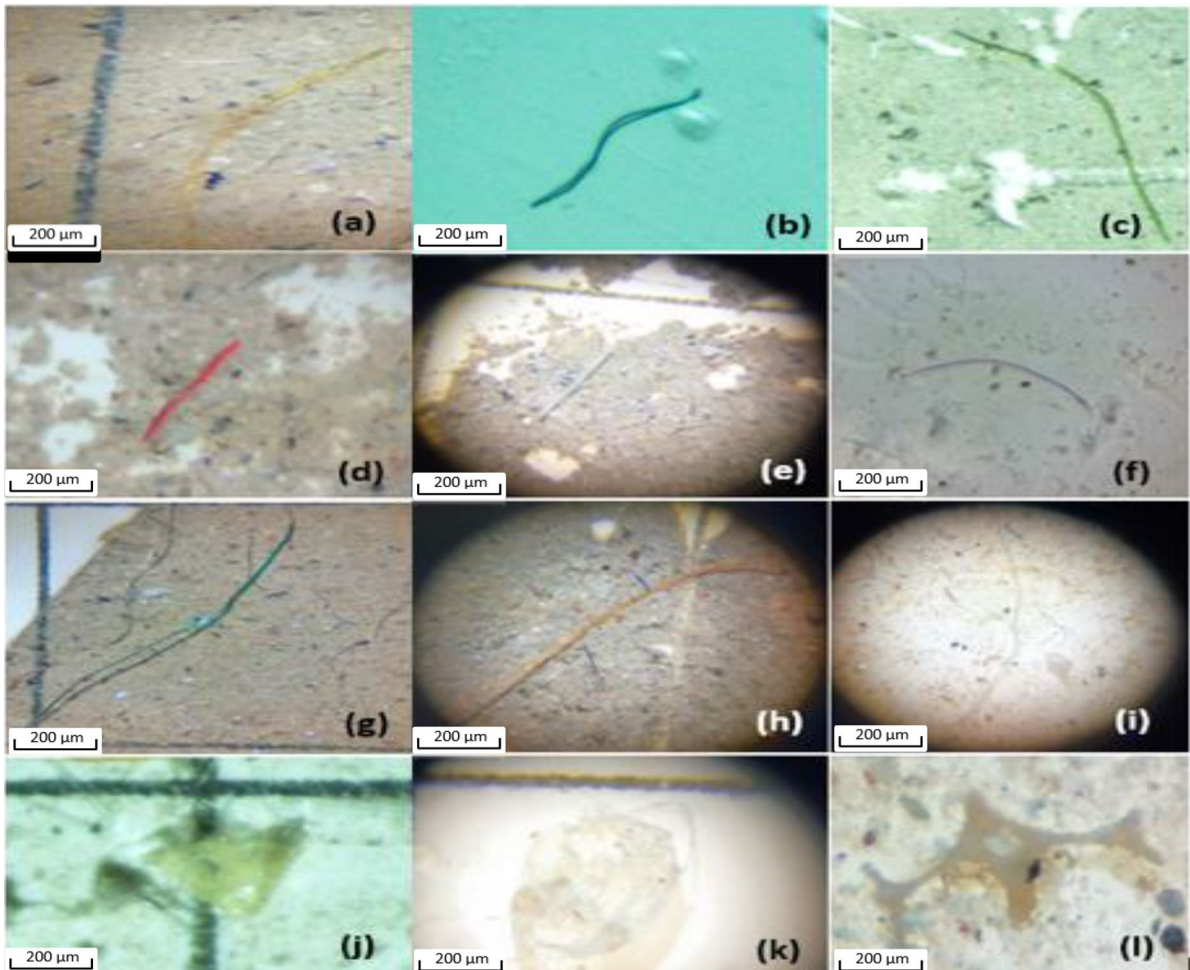


The final results were blank corrected. The graded filter papers were marked into four equal quarters for error-free counting. Moreover, it was made sure that the Petri dishes were covered with aluminum foil while not counting. The disk of the FTIR instrument was cleaned with methanol wipes before every sample analysis to avoid contamination and error in the reading.

Microscopic analysis of MPs

The residential dust samples were identified using a stereo microscope (Euromex – StereoBlue – SB.1402) with head (magnification  $\times 20/\times 40$ ) and zoom objective (magnification  $\times 7$  to  $\times 45$ ). The

criteria opted to identify the anthropogenic MPs is described elsewhere in detail (Dris et al., 2015). Briefly, while identifying it was assessed that the fibers should be equally thick in their entire length and straight. Additionally, careful consideration was made to distinguish the synthetic fibers from the cellular and organic structures. Figure 3 illustrates the collage of different types of MPs identified during the microscopic screening of the dust samples. The identified MPs were marked on the pre-prepared MPs’ datasheet against the different types and colors mentioned in the literature. The template of the datasheet is given in the SI. Overall, the microfibers were detected in a more significant proportion in all different colors. Comparatively, the other MPs



**Fig. 3** A collage showing range of different types and colors of MPs using stereo microscope as fibers: **a** yellow, **b** blue, **c** and **g** green, **d** red, **e** white, **f** purple, **h** orange, **i** transparent, **j** green fragment, **k** transparent sheet, and **l** transparent nurdle

such as films/sheets, fragments, foams, and nurdles were primarily detected in transparent categories in somewhat less proportion.

### FTIR examination of MPs

Different chemical compositions of MPs could have different toxic effects on the environment. Therefore, it is essential to categorize them according to their chemical nature (Mattsson et al., 2017; Alimi et al., 2021). Furthermore, the accuracy of visual assessment results could fluctuate depending on several different factors, such as human and instrumental errors (Catarino et al., 2018). Therefore, to further elucidate the visual assessment results, a Fourier transform infrared (FT-IR) coupled with an ATR (attenuated total reflectance) add-on was used for chemical classification (Model: Agilent Cary 630 FTIR) (Dris et al., 2017). Microplastics were analyzed on a wavelength range of ( $IR=650$  to  $4000\text{ cm}^{-1}$ ) (Zhang et al., 2020a, b). It is a widely used instrumental approach to determine the chemical categorization of microplastics with a  $50\text{-}\mu\text{m}$  size detection limit (Dris et al. 2016; Shim et al. 2017; Soltani et al., 2021).

For analysis, because of the large proportion of fibers, a sub-sample of fibers=15 was randomly selected from all identified colors (Soltani et al., 2021) to differentiate natural from synthetic fibers (Dris et al., 2016) (Fig. 4). Next, sheets, fragments, and nurdles were analyzed. The sample spectra were compared with the already in-built Agilent MicroLab FTIR Software Library of more than 9000 spectra.

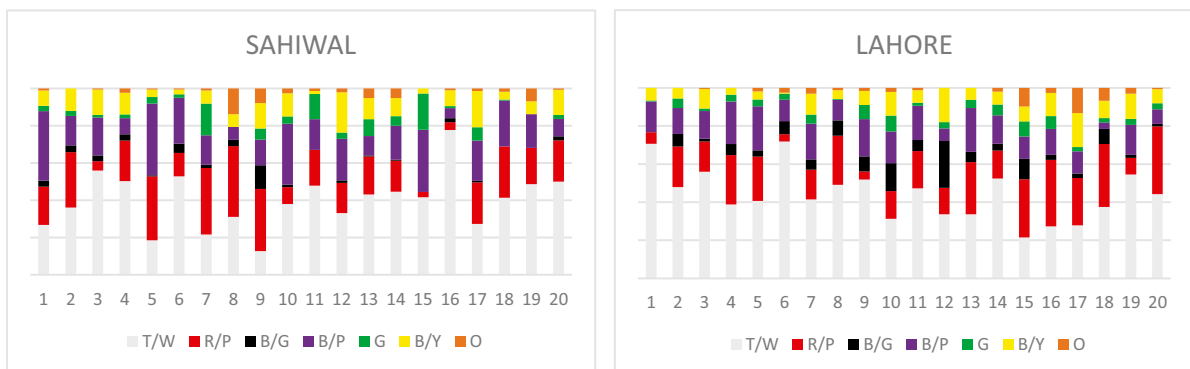
Moreover, as previously practiced by Soltani et al. (2021), to comply with the QA/QC standards, automatic outcome of the software was only considered when the spectrum match was  $>70\%$ ; otherwise, manual integration of the resultant spectrum was performed with the given library. The graphical outcome of Agilent MicroLab Spectra Software is shown in Fig. 5.

### Human health risk assessment

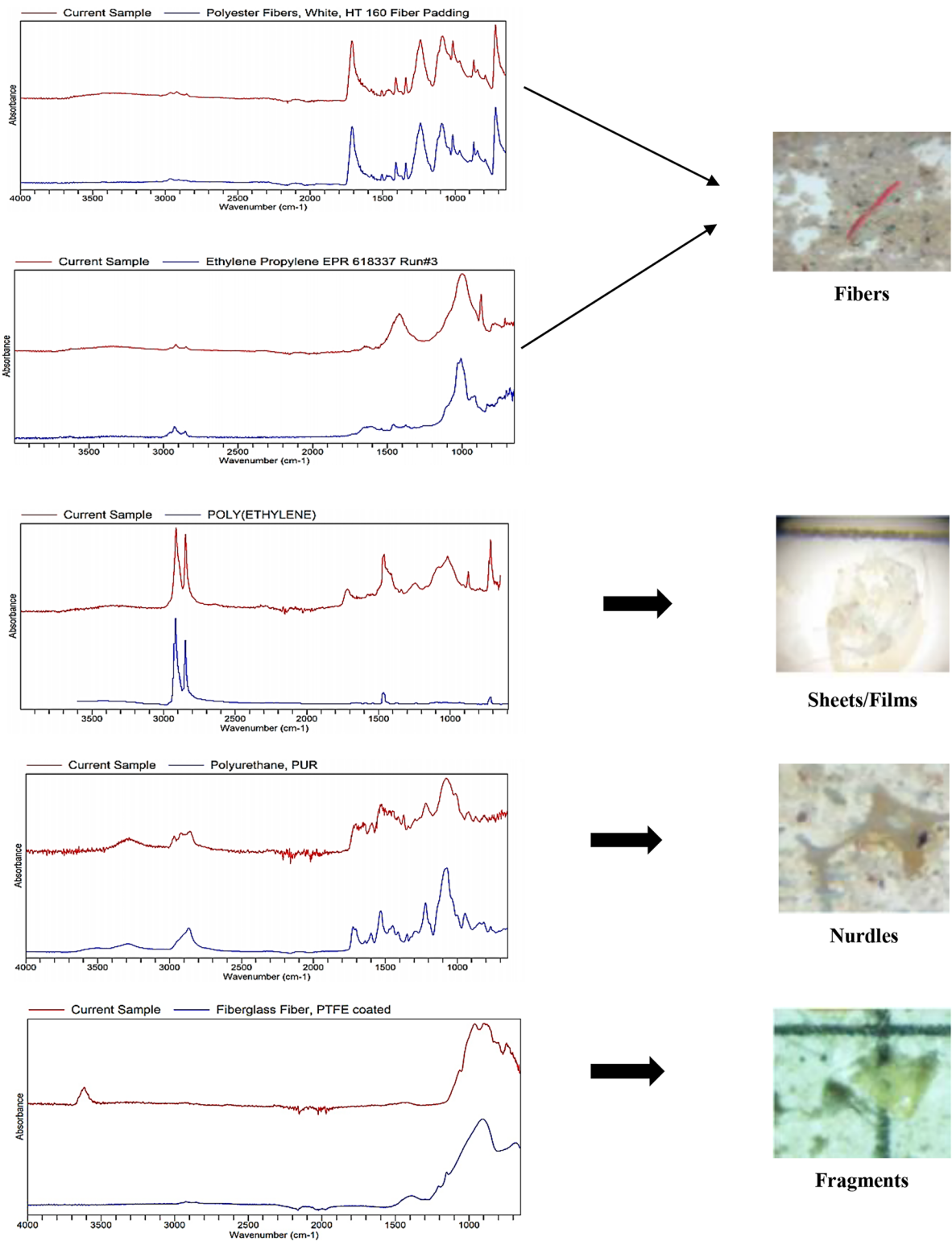
For MPs, dust inhalation and ingestion are considered two main exposure routes (Dris et al., 2015; Liu et al., 2019a, b). Indoor dust can provide a reasonable estimation for the contaminant's exposure, including MPs (Wright & Kelly, 2017). The human exposure of MPs (per-day and per-year) was calculated for the general public, including toddlers and adults, using Eq. (2) (Guo & Kannan, 2011).

$$EDI = \frac{MA_{(dust)} * F * IR}{M_{(kg)}} \quad (2)$$

where *EDI* is an estimated daily intake, *MA* is the microplastics abundance in the indoor dust (fibers/m<sup>2</sup>/day), *F* is the fraction of daily time spent indoors, *IR* is the inhalation and ingestion rates, and *M* represents the body weight. The detail of adopted assumed values for *F*, *IR*, and *M* is given elsewhere (EPA, 2011, 2014, 2017). Moreover, based on the daily fraction of time spent indoors, the per-month and per-years days are adjusted for both adults and toddlers. A brief description of parameters is given in S3.



**Fig. 4** Color distribution of microfibers at the individual sites



**Fig. 5** Chemical categorization of the identified MPs

## Data analysis

R studio and Microsoft Excel were used for the statistical data analysis. One-way ANOVA was performed to validate the variation between two data sets of Lahore and Sahiwal. Whisker boxplots were used to understand the distribution of microfibers in Lahore and Sahiwal. Furthermore, QGIS 3.2.0 was used to show the spatial distribution pattern of MPs.

## Results and discussion

Table 1 depicts the descriptive statistics for the sampling stations Lahore and Sahiwal. For each sampling site, detailed Tables 2 and 3 demonstrate the sample code, mesh pore size, color, shape, and abundance of MPs in Lahore and Sahiwal, respectively. Figure 6 illustrates the geographical distribution of MPs in the study areas, with a detailed table of coordinates given in Table S3. MPs were identified in all the studied samples, showing indoor dust as a significant MPs source. The result of the ANOVA test was significant ( $p$  value < 0.05) for the difference between the data sets of Lahore and Sahiwal.

### Lahore

Overall, in Lahore the mean abundance of different microplastics was as fibers ( $234.05 \pm 148.41$ ), films/sheets ( $3.20 \pm 6.45$ ), fragments ( $0.75 \pm 2.24$ ), and nurdles ( $3.45 \pm 6.67$ ). The range of fibers, sheets, fragments, and nurdles was 48–636, ND–27, ND–15, and ND–20, respectively. The highest MPs were detected at the sampling site 14 with 638 items/m<sup>2</sup> dust, whereas the least MPs were reported at the sampling site 10, with 48 items/m<sup>2</sup> dust.

### Sahiwal

Largely, in Sahiwal the average abundance of MPs was observed in the following order as fibers ( $159.02 \pm 79.65$ ) > films/sheets ( $0.95 \pm 1.39$ ) > fragments ( $0.10 \pm 0.31$ ) > nurdles ( $2.00 \pm 4.57$ ). The range of fibers, sheets, fragments, and nurdles was 29–341, ND–5, ND–1, and ND–17, respectively. The highest and lowest MPs were detected at the sampling site 5 and 8, with 344 items/m<sup>2</sup> and 32 items/m<sup>2</sup> of the dust, respectively.

### Abundance and profile distribution of MPs

Overall, the geographical distribution of detected MPs (fibers, films, fragments, and nurdles) showed higher abundance in the urban region of Lahore as compared to the rural area of Sahiwal (Fig. 6). In both Sahiwal and Lahore, the microfibers were accounted for the highest proportion and made up approximately 90% of all the different types of MPs detected (Fig. 7). The detection frequency of microfibers in Lahore was higher (180 to 350 items/m<sup>2</sup>) than Sahiwal (100–150 items/m<sup>2</sup>). The second most frequent category of MPs was the micro-films/sheets, with average percentage composition of 2.5%, followed by nurdles and fragments. There is clear evidence from the results of two different cities of Punjab, Pakistan, that MPs are prevalent in the indoor settings, with possible sources from clothes, furniture, curtains, sofas, and quilt (Dris et al., 2017; Zhang et al., 2020b). Previously, Rafique et al. (2020) studied the distribution of MPs in the outdoor soil of Lahore, Pakistan. Comparatively, the high proportion of microfibers in the present study is consistent with the previous findings. However, in the current studied areas, it has been observed that the indoor sources of MPs were imperative to determine the distribution of MPs in the

**Table 1** Descriptive statistics for the identified MPs in Lahore and Sahiwal

Lahore					Sahiwal				
MPs	Mean	Std	Range	% contribution	MPs	Mean	Std	Range	% contribution
Fibers	234.05	148.41	48–636	96.94	Fibers	159.05	79.65	29–341	98.12
Sheet	3.20	6.45	ND–27	1.33	Sheet	0.95	1.39	ND–5	0.59
Fragment	0.75	2.24	ND–15	0.31	Fragment	0.10	0.31	ND–1	0.06
Nurdles	3.45	6.67	ND–20	1.43	Nurdles	2.00	4.57	ND–17	1.23

ND not detected



**Table 2** Profile of MPs (color and type) identified in the residential dust samples of Lahore

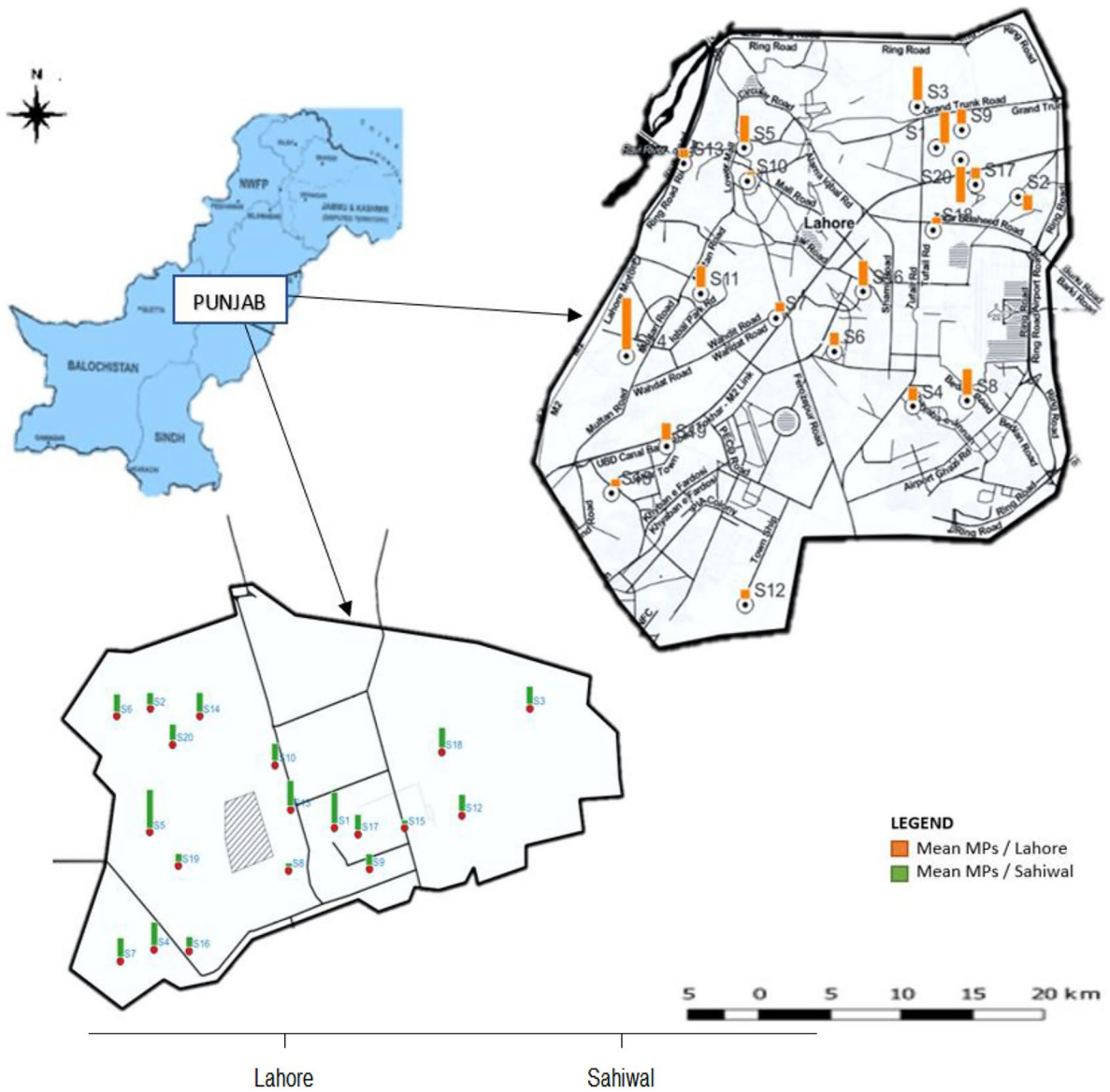
		<b>Lahore</b>																							
Sr	Mesh (µm)	Color	Transparent/white				Red/pink			Gray/black			Blue/purple			Green			Yellow/brown			Orange			Abundance (items/m <sup>2</sup> )
			Fb <sup>1</sup>	Fl <sup>2</sup>	Fr <sup>3</sup>	N <sup>4</sup>	Fb	Fl	Fr	Fb	Fl	Fr	N	Fb	Fl	Fr	Fb	Fl	Fr	Fb	Fl	Fr	Fb	Fl	
1	0.026		276	-	-	-	-	24	-	-	-	63	-	-	2	-	-	26	-	-	-	-	-	391	
2	0.026		95	-	-	-	-	42	-	-	13	-	-	27	-	-	10	-	-	11	-	-	-	198	
3	0.026		226	-	-	-	-	64	-	-	6	-	-	59	-	-	5	6	3	42	-	2	-	419	
4	0.026		54	17	1	-	-	36	-	2	8	-	-	31	-	-	5	-	1	5	10	-	1	171	
5	0.026		134	-	-	-	-	77	2	1	11	-	-	76	-	-	12	-	-	14	1	6	-	334	
6	0.026		115	3	-	-	-	6	-	-	11	-	-	18	-	-	5	3	-	1	-	4	-	166	
7	0.026		53	-	-	-	-	20	-	-	7	-	-	24	1	-	6	-	-	14	-	4	-	129	
8	0.026		158	2	-	1	-	83	-	-	26	-	-	35	-	-	1	-	-	15	-	4	-	325	
9	0.026		98	1	-	-	-	8	-	-	15	-	-	37	-	-	14	-	-	14	1	3	-	191	
10	0.026		15	-	-	-	-	7	-	-	7	-	-	8	-	-	4	-	-	6	-	1	-	48	
11	0.026		121	-	-	16	-	50	-	-	15	-	-	46	-	-	4	-	-	17	-	3	-	272	
12	0.026		41	-	-	-	-	17	-	-	30	-	-	8	-	-	4	-	-	22	-	-	-	124	
13	0.026		38	-	-	-	-	31	-	-	6	-	-	26	-	-	5	-	-	7	-	-	-	113	
14	0.026		333	2	-	-	-	94	-	-	22	-	-	95	-	-	36	-	-	43	-	13	-	638	
15	0.026		22	-	-	-	-	31	-	-	11	-	-	12	-	-	8	-	-	8	-	10	-	102	
16	0.026		81	-	-	15	-	103	-	-	8	-	-	40	-	-	20	-	-	36	-	8	-	311	
17	0.026		36	-	-	14	-	32	1	-	3	1	-	15	-	-	3	-	-	23	-	17	-	145	
18	0.026		33	-	-	1	-	29	-	-	7	-	-	3	-	-	2	-	-	8	-	6	-	89	
19	0.026		107	-	-	19	-	17	-	-	3	-	-	31	-	-	6	-	-	26	-	6	-	216	
20	0.026		192	10	-	-	-	154	3	-	6	-	-	33	-	-	14	-	-	32	-	3	-	447	

Fb fiber, Fl film/sheet, Fr fragment, N nurdle

**Table 3** Profile of MPs (color and type) identified in the residential dust samples of Sahiwal

Sr	Mesh (µm)	Color	Sahiwal																				Abundance (items/m <sup>2</sup> )		
			Transparent/white			Red/pink			Gray/black			Blue/purple			Green			Yellow/brown			Orange				
			Fb <sup>1</sup>	Fl <sup>2</sup>	Fr <sup>3</sup>	N	Fb	Fl	Fr	Fb	Fl	Fr	N	Fb	Fl	Fr	Fb	Fl	Fr	Fb	Fl	Fr		Fb	Fl
1	0.026		125	-	-	-	-	57	-	1	9	-	-	69	1	-	8	-	-	23	-	3	-	-	279
2	0.026		39	-	-	-	-	32	-	4	4	-	-	17	-	-	3	-	-	13	1	-	-	-	109
3	0.026		90	-	-	-	-	8	-	5	5	-	-	33	-	-	2	-	-	22	-	1	-	-	161
4	0.026		104	-	1	-	-	45	-	7	7	-	-	18	-	-	4	-	-	24	-	5	-	-	208
5	0.026		63	-	-	-	-	117	-	2	2	-	2	131	-	-	12	-	-	14	1	2	-	-	344
6	0.026		84	1	-	-	-	20	-	8	8	-	-	39	1	-	3	-	-	4	-	1	-	-	161
7	0.026		37	-	-	-	-	61	-	3	3	-	-	27	-	-	29	-	-	12	-	2	-	-	171
8	0.026		9	3	-	-	-	11	-	1	1	-	-	2	-	-	-	-	-	2	-	4	-	-	32
9	0.026		13	-	-	-	-	34	-	13	13	-	-	14	-	-	6	-	-	14	-	8	-	-	102
10	0.026		58	3	-	-	-	14	-	2	2	-	-	50	-	-	6	-	-	19	-	4	-	-	156
11	0.026		139	5	-	1	56	-	-	-	-	-	1	48	-	-	39	-	-	5	-	4	-	-	298
12	0.026		49	-	-	2	24	-	-	2	2	-	-	33	-	-	5	-	-	32	-	3	-	-	150
13	0.026		91	-	-	-	43	-	-	1	1	-	17	22	-	-	19	-	-	24	-	11	-	-	228
14	0.026		78	-	-	-	29	-	-	1	1	-	-	32	-	-	9	-	-	17	-	9	-	-	175
15	0.026		15	-	-	-	1	-	-	-	-	-	1	12	-	-	7	-	-	1	-	-	-	-	37
16	0.026		73	-	-	-	4	-	-	2	2	-	-	5	-	-	1	-	-	8	-	1	-	-	94
17	0.026		38	-	-	-	31	-	-	1	1	-	-	30	-	-	10	-	-	27	-	2	-	-	139
18	0.026		69	-	-	1	46	-	-	-	-	-	12	41	-	-	1	-	-	7	-	3	-	-	180
19	0.026		35	1	-	-	14	-	-	-	-	-	1	13	-	-	-	-	-	5	-	5	-	-	74
20	0.026		70	2	-	1	31	-	-	3	3	-	1	13	-	-	3	-	-	19	-	1	-	-	144

Fb fiber, Fl film/sheet, Fr fragment, N nurdle



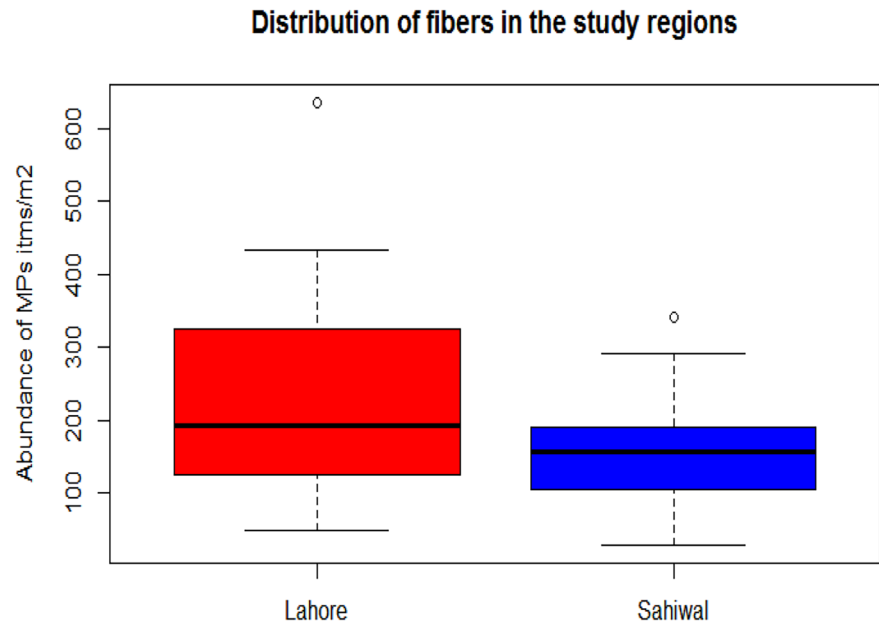
**Fig. 6** Spatial distribution of microplastics in the studied regions

residential settings, which resulted in a very high proportion of the microfibers.

Overall, the urban region of Punjab (Lahore) exhibited 67.14% more MPs than the rural area (Sahiwal). Previously, Abbasi et al. (2017) and Zhang et al. (2020a, b) reported similar results in Iran and 12 different countries of the world, respectively, where they found that the abundance of MPs was more significant in the urban region as compared to the rural states. This difference could be

attributed to the lifestyle of residents as it had been observed that the residents of Lahore were living a more lavish lifestyle and the modern interior was common in the houses as compared to the inhabitants of Sahiwal, which were living a relatively simple and modest lifestyle. Moreover, we observed a high density of shops, markets, traffic load, and industrial activity in the metropolitan area of Lahore as compared to Sahiwal, where there was more greenery and less traffic load.

**Fig. 7** Whisker plots showing the distribution of MPs in Lahore and Sahiwal



Comparatively, in the present study, for Lahore and Sahiwal, the per-day deposition of MPs was lower as compared to the deposition rate reported by Daris et al. (2017) in Paris' apartments, which was 1600–11,000 particles/day/m<sup>2</sup>. Similarly, the observed abundance of MPs in settled dust was many folds lower to the research study conducted by Zhang et al. (2020a, b) in China that reported 99,000 particles/day/m<sup>2</sup> in the university dormitory. This difference could be attributed to geographical difference, lifestyle, and methodology. Moreover, as emphasized by Ageel et al. (2022), in case of microplastics, there is a huge hindrance in comparison because of varying methodologies and units of MPs.

### Color distribution of MPs

Traditionally, microplastic fibers are classified according to their color distribution (Dris et al., 2017; Zhang et al., 2020a, b; Soltani et al., 2021). In the present study, the microfibers were classified into seven categories: white/transparent, red/pink, blue/purple, yellow/brown, green, black/gray, and orange. Overall, the color distribution of the identified MPs is given in Fig. 4. In Lahore, the average percentage composition of different colors of microfibers was white/

transparent (43.97%), red/pink (19.96%), blue/purple (14.65%), yellow/brown (8.59%), green (3.92%), black/gray (6.30%), and orange (2.62%), whereas in Sahiwal, the color distribution was found as white/transparent (39.94%), red/pink (20.54%), blue/purple (19.69%), yellow/brown (9.61%), green (5.12%), black/gray (2.28%), and orange (2.82%). White/transparent MPs were found in the highest proportion among the seven color classes. These results are consistent with previous findings, which reported white/transparent microfibers as the most abundant in the indoor environment (Abbasi et al., 2019; Narmadha et al., 2020; Yukioka et al., 2020; Zhang et al., 2020a, b). Additionally, in the present study, red/pink and blue/purple fibers were also found.

This color variation could be attributed to the washing/drying laundry (Dris et al., 2017) and sewing the cloths in indoor settings. Comparatively, black and gray MPs were abundant in Lahore as compared to Sahiwal. It could be because Lahore is a commercial hub, and the chances of drift in MPs from the wear and tear of vehicle tires are higher (Wang et al., 2019). In the past, research studies from the urban regions in Shanghai and Sydney also found black color fibers as the most abundant (Liu et al., 2019a, b; Soltani et al., 2021).

## Chemical categorization of MPs

According to the FTIR spectroscopy results, overall, the chemically most abundant microfibers were polyester followed by polyethylene-terephthalate (PET), a copolymer of polypropylene (ethylene-polypropylene), polyethylene, and polyurethane. These results are consistent with commonly distributed types of MPs. According to the literature, polypropylene (PP), polyethylene (PE), polyethylene terephthalate (PET), polystyrene (PS), polyurethane (PUR), polyvinyl chloride (PVC), and polycarbonate (PC) are the most widely manufactured MPs (Li et al., 2016). Among microfibers, approximately 70% had a natural origin, mainly from cotton in the form of cellulose. Around 20% of microfibers were anthropogenic with a petrochemical origin, whereas 10% were unidentified. The results of the present study indicate textile products as the dominant source of microfibers in the indoor environment; Dris et al. (2016) categorized microfibers as completely natural (cellulose), synthetic (polyester, polyethylene-terephthalate, and polyurethane), or a mixture of both. These findings are also supported by the fact that the textile industry is very active in Pakistan and uses both natural and synthetic fibers, especially polyester (Abbas & Halog, 2021). Polyethylene sheets, fiberglass (fiber-reinforced plastic) fragments (Rodrigues et al., 2019), and polyurethane nurdles were also observed in minor abundance. Some other sources of microplastics could be interior paints and by-products resulting from the weathering of plastic materials (Verschoor et al., 2017). According to an estimate, in Pakistan, 55 billion polyethylene shopping bags are being used every year (The News, 2018).

## Risk via inhalation and ingestion

The two imperative exposure routes to determine the human health risk assessment via indoor dust contaminants are (1) inhalation and (2) ingestion (Kim et al., 2018; Wright & Kelly, 2017). In the current study, the non-dietary exposure was estimated for adults and toddlers, considering the median concentration of microfibers. A detailed table of results is given in S3. Here, only particles/year values have been discussed. In Lahore, for adults and toddlers, the inhalation risk was 9402.27 and 58,184.38, whereas the ingestion risk was 17,629.25 and 290,921.88, respectively. In

Sahiwal, for adults, the inhalation and ingestion risks were observed as 7619.50 and 14,286.56, which was 47,152.01 and 235,760.07 for toddlers, respectively. Toddlers are severely exposed to MPs compared to adults because of their low body weight and frequent hand-to-mouth playing activities.

Concerning global comparison, per-annum exposure of MPs through inhalation was found lower for adults but higher for toddlers compared to what was reported by Cox et al. (2019) for American children and adults as 37,781–55,099 particles/year, respectively. Catarino et al. (2018) conducted a study in the UK, which reported risk as 13,731–68,415 particles/year for adults and toddlers, respectively. Comparatively, in the current research study, the risk was found lower for both adults and toddlers. Apart from the geographical variation, there could be other reasons for this difference, such as lifestyle and the sampling methodology. It is pertinent to mention here that this is not a true comparison because, in literature, there have been several different models to calculate the human health risk assessment of MPs, which are not identical to each other.

## Conclusion

The results revealed a high abundance and prevalence of microfibers in Pakistan's residential indoor dust samples. They were found in various colors, with transparent/white being the dominant one. Approximately 70% of microfibers showed natural origin (cellulose), whereas 20% were recognized as synthetic fibers. Comparatively, other categories of MPs (films, fragments, and nurdles) were observed in fewer proportions in both the studied sites. The results showed a greater abundance and detection frequency of MPs in the urban region (Lahore) than in the rural area (Sahiwal). It was observed that in the current study, the significant contributing sources of MPs were textile/clothing, house interior (curtains, sofas, paint), toys, shoes, lifestyle, and weathering of the plastic products. However, to a lesser extent, the abundance of MPs is also influenced by ambient activities such as industries, traffic load, and drift-in of MPs contaminants. There is no inclusive method to study the human health risk assessment, making comparison



very difficult. Therefore, in the future, it is imperative to work on a human health risk assessment model that has more in-depth parameters and could give a global perspective regarding the risk that humans could face because of MPs contamination.

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