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Microplastics in the school classrooms of Shiraz, Iran

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Abstract

Microplastics (MPs) are a pervasive and ubiquitous environmental contaminant. However, very little information exists on the quantities or characteristics of MPs in the indoor setting. In the present study, MPs have been isolated from settled classroom dust samples collected from 50 schools in the city of Shiraz, Iran. Concentrations of MPs on a number basis ranged from about 80 to over 56,000 MP per g of dry dust and there was an increase in concentration towards the centre and southeast of the city. The geographical distribution is attributed to a larger population and student density, higher traffic loading and greater industrialization in the centre and southeast and a prevailing wind from the northwest. MPs were dominated by fibres of > 250 μm in length, and Raman spectrometry and SEM-EDX analysis of selected samples revealed that MPs were mainly constructed of polyethylene terephthalate or polypropylene but were contaminated by various metals (e.g. lead, titanium, antimony) used as additives or acquired from the environment. Calculations using data for elementary schools indicate that children in the age range 6 to 14 years may be exposed to between about 5 and 440 MP day^{-1} through inadvertent ingestion. The health impacts of MPs on children are unknown but the results of the present study indicate a requirement for research in this area.

Keywords: Microplastics; Dust; Children; School; Classroom; Exposure

1. Introduction

Indoor dust comprises a complex and heterogeneous assortment of particles derived from a multitude of internal and external sources, and includes fragments of skin, animal dander, plant debris, crumbs of food, micro-organisms, textiles, soot, construction materials, paint flakes, paper fibres, pollen, soil particulates and aerosols (Butte and Heinzow, 2002; Turner and Symonds, 2006). Because the average person spends the majority (up to 90%) of his or her time in the indoor environment, including the home, vehicles, schools and public buildings, characterisation of and exposure to dusts have received considerable attention in the scientific literature (Kurt-Karakus, 2012; Kadi et al., 2018; Zhu and Kurunthachalam, 2018; Caban and Stepnowski, 2020; Liu and Mabury, 2020).

A particular concern in this respect is dust exposure to young children because of their low body mass, rapidly developing organs, activities close to the floor and tendencies for inadvertent ingestion of non-food objects (Hwang et al., 2008). Accordingly, the quality and potential health impacts of nursery and elementary school dusts have been the focus of many recent studies. Here, contaminants and characteristics examined include metals and metalloids (Ma et al., 2020), phosphorus flame retardants (Deng et al., 2018), brominated flame retardants (Harrad et al., 2010), semi-volatile organic compounds (Raffy et al., 2017), man-made vitreous fibres (Walker et al., 2012), bacterial composition (Nygaard and Charnock, 2018), fungal populations (Balolong et al., 2017) and inflammatory potential (Huttunen et al., 2016). Distinctly lacking, however, is an evaluation of the concentration and potential impacts of microplastics (MPs) in the school environment.

MPs are highly pervasive particulates, operationally defined as < 5 mm in length or diameter, that are ubiquitous in the aquatic environment, soils and external dusts and which display a range of effects on wildlife (Abbasi et al., 2017; Fackelmann and Sommer, 2019; Helmberger et al., 2019). Concerns have also been raised regarding the exposure of MPs to humans through the consumption of food (Santillo et al., 2017; Farady, 2019). However, recent studies suggest that exposure is greater from MP fallout on to food while being consumed (Catarino et al., 2018) or through contact with a wide range of apparel and indoor furnishings (Abbasi and Turner, 2021). Clearly, MPs, and in particular those of a fibrous nature, are a ubiquitous constituent of indoor dust (Dris et al., 2017) but one that has received very little attention.

The present study represents the first systematic investigation of MPs in the school setting. Here, and using established techniques, we quantify and characterize MPs in settled dusts retrieved from classrooms in a wide range of elementary and high schools in the city of Shiraz, Iran. The results provide an insight into the nature, sources and geographical-demographical controls on MPs in schools and allow us to estimate MP exposure to schoolchildren while in the classroom.

2. Material and methods

2.1 Study area

The current study was performed in the city of Shiraz, an important trade centre located in the Fars province of Iran (29°33′ to 29°41′ N and 52°29′ to 52°36 E; Figure 1). The population of the city of about 1.6 million is contained within an area of about 240 square kilometers at the foot of the Zagros Mountains around a seasonal river and at 1,500 m above sea level. The average annual rainfall and temperature are 337 mm and 16.8 °C, respectively.

2.2 Sampling and experimental setup

With permission from the Ministry of Education in Shiraz, a total of 50 indoor dust samples were collected during the dry season (May 2018) from various elementary (6 to 14 years) and high schools (15 to 18 years). The schools are located in Figure 1 and are defined in terms of gender, educational stage and overall size in Table 1.

Table 1: Details of the Shiraz schools considered in the present study.

School	Stage	Gender	No. students
S1	high	boys	488
S2	high	girls	20
S3	elementary	boys	85
S4	elementary	girls	410
S5	high	girls	595
S6	elementary	girls	280
S7	high	boys	450
S8	high	boys	100
S9	high	girls	300
S10	high	girls	800
S11	high	boys	295
S12	elementary	mixed	184
S13	high	boys	82
S14	elementary	boys	480
S15	elementary	girls	352
S16	high	girls	21
S17	high	girls	420
S18	high	girls	403
S19	high	girls	271
S20	high	girls	186
S21	elementary	girls	56
S22	elementary	boys	65
S23	high	boys	155
S24	high	girls	343
S25	elementary	girls	370
S26	elementary	mixed	540
S27	high	boys	459
S28	elementary	boys	50
S29	elementary	mixed	107
S30	high	girls	200
S31	elementary	mixed	406
S32	high	girls	233
S33	high	boys	100
S34	high	boys	344
S35	high	girls	282
S36	elementary	boys	76
S37	high	boys	203
S38	high	boys	251
S39	high	boys	36
S40	elementary	mixed	110
S41	elementary	mixed	99
S42	high	girls	21
S43	high	boys	87
S44	elementary	boys	71
S45	high	boys	288
S46	high	boys	331
S47	high	boys	100
S48	high	girls	197
S49	elementary	girls	100
S50	high	girls	100

Areas of (mainly tiled) flooring of about 1 m^2 near to the corners of between two and ten classrooms in each school (with a range of 10 to 35 pupils per classroom) were selected for sampling. Floors were firstly swept with a horse-hair brush and cleaned with filtered water (Buch Holm Blue Band, grade 589/3) using a damp, cotton cloth. After one month, the schools were re-visited and settled dust from the floors was swept onto a metal plate and transferred to glass containers (one per school), with equipment cleaned using filtered water between schools.

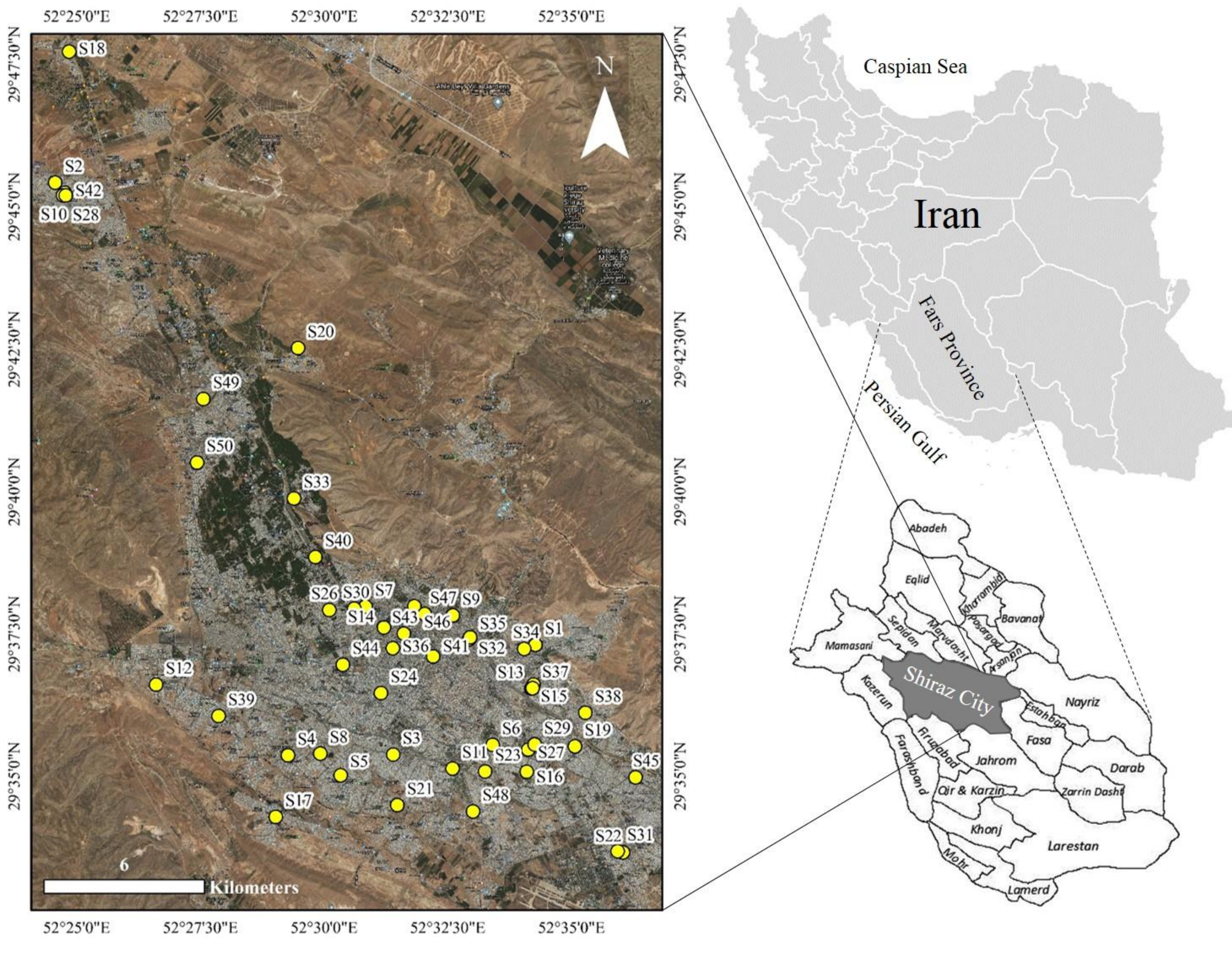

Figure 1. Location of the study area and the schools sampled in the city of Shiraz.

2.3. Sample treatment and microplastic extraction

Dust samples of 1 g were transferred to individual glass beakers using a steel spoon and dried for 24 h at 25^{o}C in a clean room. Dried samples were subsequently passed through a 5-mm pore size sieve (stainless steel) to remove macroplastics and other coarse debris like stones and plant remains before being stored in clean glass beakers covered with aluminium foil.

MPs were retrieved from the dust samples according to Abbasi et al. (2019). Thus, organic matter in the samples was removed by oxidation with 30% hydrogen peroxide (Arman Sina, Tehran) until bubble formation ceased. After a period of settlement, residual H_2O_2 was decanted and remaining particulate matter washed using deionized water and dried in a sand bath at 60°C for 2 h. MPs were separated out by flotation in a saturated solution of $ZnCl_2$ (Arman Sina, Tehran; density 1.6 – 1.8 g cm^{-3}), with the decanted contents subsequently centrifuged at 4000 rpm and filtered through 2 µm pore size S&S filter papers (blue band, grade 589/3). Filters containing MPs were air-dried for 48 h at 25^{o}C in a clean room and transferred to Petri dishes for physical and chemical characterization.

2.4. Microplastic identification

MP particles on each filter (and including microrubbers) down to about 30 to 50 µm in size (depending on shape) were visually identified, counted, and characterized under a binocular microscope (Carl-Zeiss) at up to 200 x magnification using a 250 µm probe and ImageJ software. Identification and characterisation were based on shape, color, size, thickness, non-shininess, hardness and non-organic surface structure (Abbasi et al., 2019; Abbasi and Turner, 2021). Specifically, size was scaled according to length, L ($L \leq 100$ µm, $100 < L \leq 250$ µm, $250 \leq L < 500$ µm, $500 \leq L < 1000$ µm, $1000 \leq L < 5000$ µm), colour was categorized as black-grey, yellow-orange, white-transparent, red-pink or blue-green, and shape or type was classified as fibre (with a length to diameter ratio in excess of three), primary (distinctive or regular shapes, including pellets, granules and spheres) or secondary (irregular particles, like fragments and films, derived from larger plastics).

Morphological characteristics and specific structure, chemical composition and polymeric construction were determined on selected MPs (n = 21) comprising a range of different shapes and colours and school types. This was achieved using a high vacuum scanning electron microscope (SEM, TESCAN Vega 3, Czech Republic) with a resolution of 2 nm at 20 kV and equipped with an energy-dispersive X-ray microanalyzer (EDX), and a micro-Raman spectrometer (µ-Raman-532-Ci, Avantes, Apeldoorn, Netherland) with a laser of 785 nm and Raman shift of 400-1800 cm^{-1}. For SEM-EDX, MPs were mounted on double-sided copper adhesive tape on microscope slides and gold-coated, while for Raman spectroscopy, particles were attached to microscope slides via double-sided adhesive tape.

2.5. Quality control

In order to prevent sample contamination, laboratory equipment was washed with phosphate-free soap, double rinsed with filtered water and soaked in 10% HNO_3 for 24 h before being rinsed twice with double-distilled water, dried at room temperature in a clean room and, where appropriate, protected by aluminium foil. Laboratory benches were thoroughly cleaned with ethanol, laboratory clothing was cotton-based and all reagents and solutions were filtered through S&S blue band filters. A control dish left open throughout the sample processing protocol revealed no airborne MP contamination. Optimum precision and consistency of visually determined parameters was attained with the same operator throughout the study.

2.6. Statistical analyses

The spatial distribution of data was mapped out using ArcGIS version 10.3 and an inverse distance weighted interpolation. Statistical analyses were performed using SPSS *v*19. Normality of the data was checked using the Shapiro-Wilk tests, and the Kruskal-Wallis H-test was used to determine differences ($p = 0.05$) in MP concentrations between independent sample groups (age, gender, and elementary and high schools).

3. Results

3.1. Microplastic characteristics

Examples of MPs identified by optical binocular microscopy are shown in Figure 2. Many of these samples are fibres of various sizes and colours, while others are regular shapes (blue and red hexagonal primary MPs), fragments of different colours (including paints) and fragments of (mainly black) rubbers with evidence of abrasion and disintegration. Raman spectrometry revealed that out of 15 fibres analysed, eight were polyethylene terethphalate (PET), five were polypropylene and two were polystyrene, and out of six primary and secondary MPs analysed, three were PET, two were polypropylene and one was nylon.

Figure 2. Optical microscope images of different types of microplastic retrieved from dust samples collected in various schools. Plastic fragments of varying colours and sizes are evident in all images, synthetic fibres are evident in (a), (b), (c), (e) and (f), black rubber fragments are evident in (e) and (h), and hexagonally-shaped primary plastics are evident in (f) and (h).

The surface characteristics of MPs examined by SEM along with indicative elemental concentrations revealed by EDX are exemplified in Figure 3. The surfaces of fibres and primary and secondary MPs appear to be relatively smooth whereas the edges of primary and secondary MPs are rougher and more irregular and are consistent with the impacts of abrasion and disintegration referred to above. Carbon, nitrogen and oxygen are the dominant elements, reflecting the composition of the polymeric matrix, while high concentrations of zinc and chlorine may, partly, result from sample contamination by residual $ZnCl_2$ during the flotation process. Additionally, these and other elements may be present either as functional additives or reaction residues in the plastic itself or as components of extraneous material that is adhered to or adsorbed onto the plastic surface. Although EDX cannot discriminate different types of association, it is likely that relatively high concentrations of certain metals in some samples (e.g. lead, titanium, antimony) reflect the presence of contemporary and historical additives and catalytic residues in plastics and paints (Murphy, 2001) while lower and more uniform concentrations of elements that are not often added to plastics and/or are more indicative of geogenic material (e.g., aluminium, manganese and sodium) are largely present in fugitive material captured from the environment.

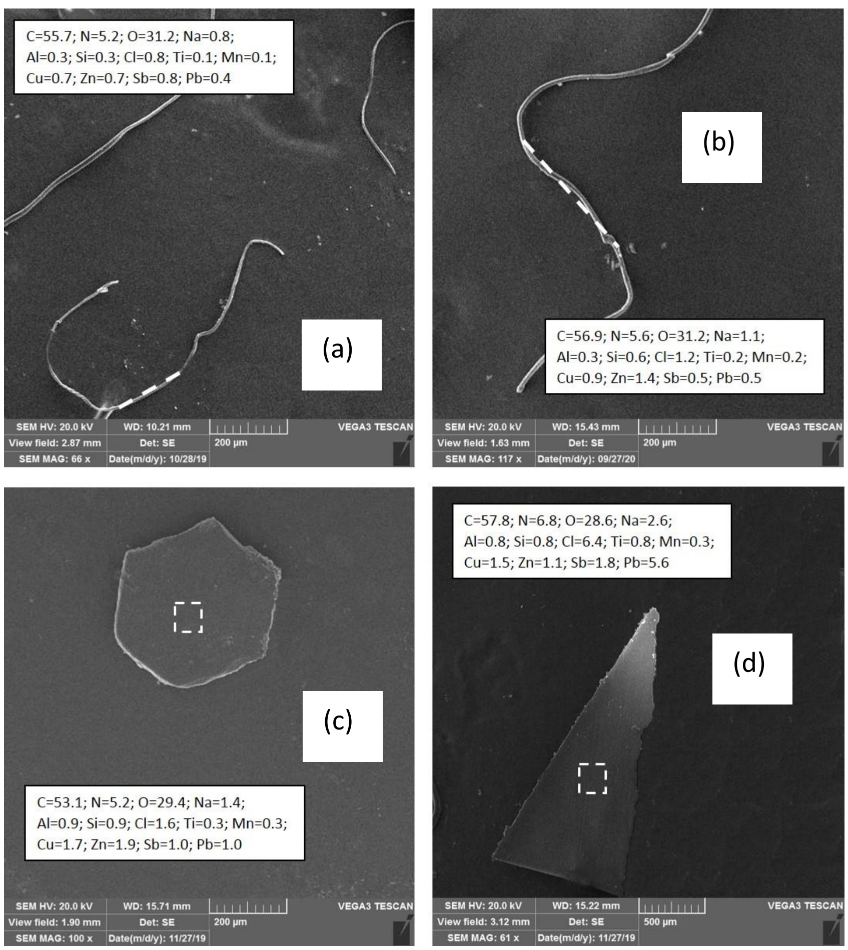

Figure 3. SEM-EDX images of two MP fibres (a and b), a hexagonally-shaped primary MP (c) and a secondary MP fragment (d). Indicative elemental concentrations (on a percentage w/w

basis) are shown inset and were determined in the regions defined by the broken lines or rectangles.

3.2. Microplastic concentrations and distributions

Table 2 shows the total number and percentage distribution of MPs identified in the 50 school dust samples from the Shiraz metropolis categorized according to color, size (*L*) and shape, along with statistical summaries of MP concentrations per g of dust for these categories. Overall, 188,566 MPs were identified, with the dominant colours neutral (white-transparent = 30.2% and black-grey = 46.6%) and the least abundant yellow-orange (3.3%). MP size was distributed relatively evenly between the length categories, and about 85% of MPs were fibrous in nature, 11% were primary particles (and mainly black spherules $\leq$ 250 μm in size) and 4% were secondary fragments.

The total concentrations of MPs identified in the dust samples from each school are shown in Figure 4. Concentrations of MPs were highly variable among the schools sampled, ranging from 81 MP g^{-1} in high school S13 to 55,830 MP g^{-1} in high school S43, with an overall average and median concentration of 3771 MP g^{-1} and 899 MP g^{-1}, respectively. There was no statistical difference in MP concentration according to student educational stage or gender, but there was a significantly greater concentration in girls' high schools than girls' elementary schools and in boys' high schools than in boys' elementary schools. Regarding shape, fibres comprised more than 90% of MPs in most cases, and in some schools (S4, S12, S22, S39) primary and/or secondary MPs were entirely absent. However, in six boys' high schools (S33, S34, S37, S39, S43, S46) the contribution of fibres was < 70% (and as low as 12%), with primary particles largely making up the remaining MP stock.

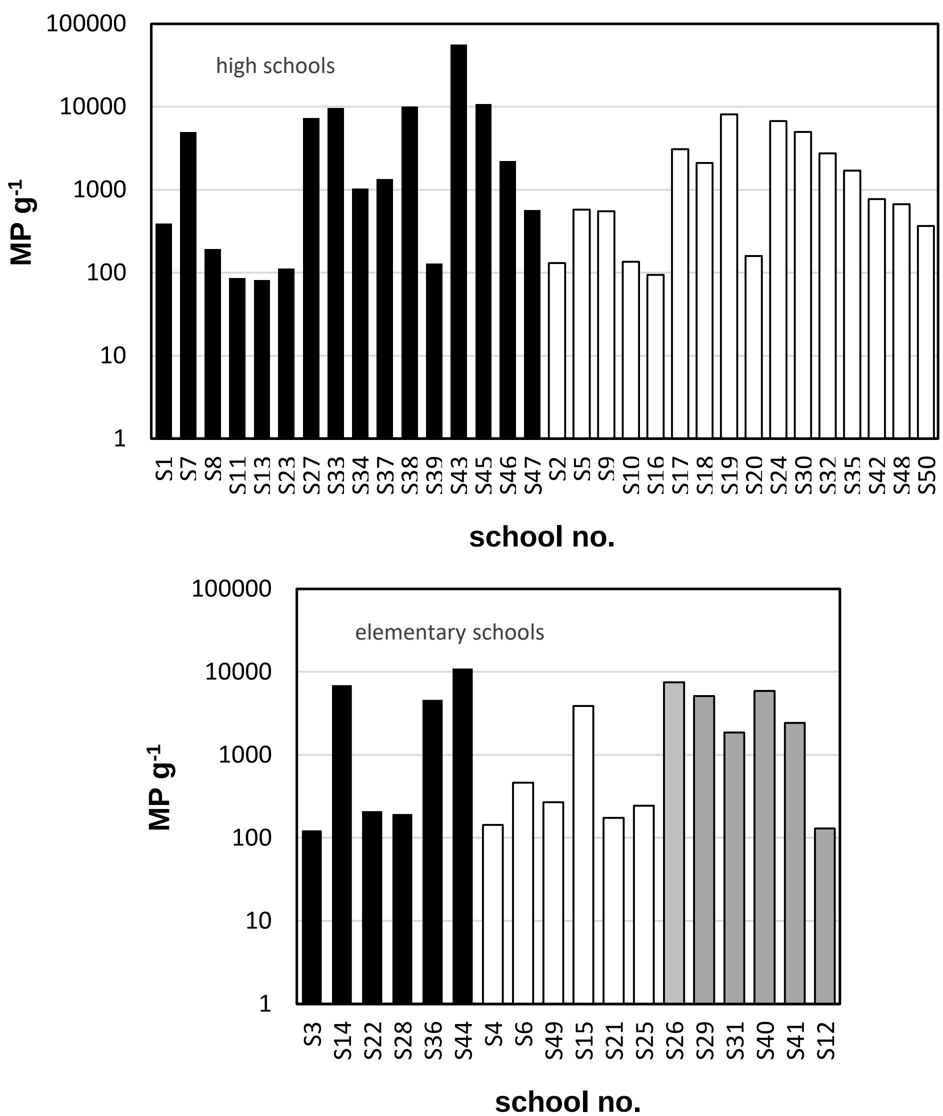

Figure 4. Concentration of MPs (number per g) in dusts from the different types of school (black = boys'; white = girls'; grey = mixed).

The spatial distribution of MP concentrations and student numbers in the schools of Shiraz is mapped out by interpolation in Figure 5. There is a clear increase in MP concentration from the northwest to the centre and southeast of the city that was also associated with a concomitant increase in the proportion of fibrous MPs amongst the samples.

Table 2: Number and percentage of MPs retrieved from the 50 school dust samples categorized according to colour, size and shape-type, and statistical parameters defining the distribution of MP concentrations within each category (MP g^{-1}).

colour	*n*	%	mean	sd	median	min	max
white-transparent	56937	30.2	1139	1568	200	0	7142
yellow-orange	6156	3.3	123	232	17.5	0	1110
red-pink	14797	7.8	296	588	54.5	4	3500
blue-green	22877	12.1	457	687	75.5	0	2495
black-grey	87799	46.6	1756	5861	440	8	41541
size, µm							
$L \leq 100$	26396	14.0	528	1935	29.0	0	13564
$100 \leq L \leq 250$	34968	18.5	699	1638	111	0	10947
$250 \leq L \leq 500$	43229	22.9	865	1723	147	11	11226
$500 \leq L \leq 1000$	46482	24.7	930	1650	216	6	10552
$L \geq 1000$	37491	19.9	750	1456	210	7	9541
shape-type							
fibre	159471	84.6	3189	5774	576	27.0	36780
primary	21629	11.5	433	1942	24.5	0	13453
secondary	7466	4.0	149	789	10.5	0	5597

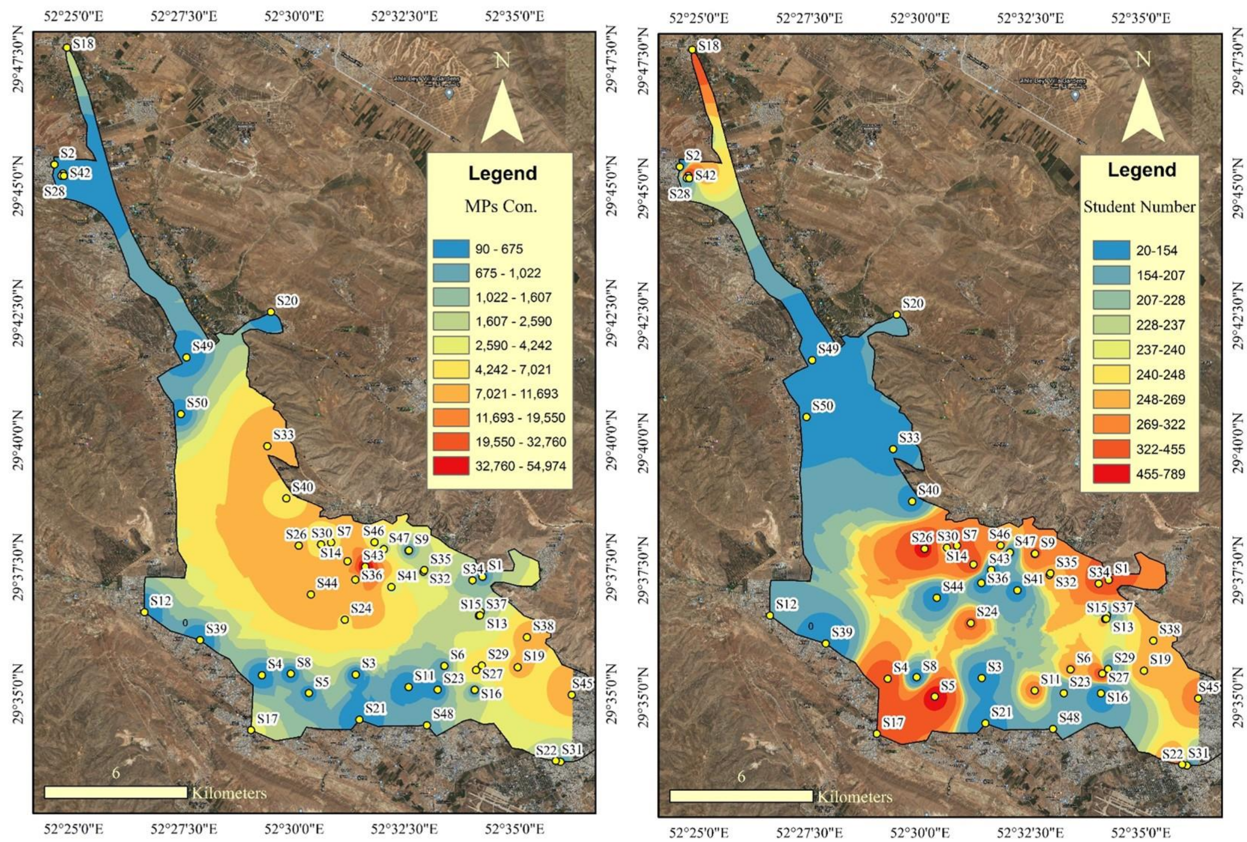

Figure 5. The spatial distribution of MP concentrations in the dust samples from schools of Shiraz (left) and their student numbers (right), mapped and interpolated using ArcGIS *v*10.3.

4. Discussion

There has been a great deal of scientific attention paid to air and dust particle quality in classrooms, and in particular those of elementary schools (Harrad et al., 2010; Canha et al., 2015; Gou et al., 2016; Salin et al., 2017; Deng et al., 2018; Becerra et al., 2020). However, the present study is significant in that it is the first to systematically document and quantify MPs in the school setting. Given the ubiquity of MPs in the indoor and outside environments (Catarino et al., 2018; Gasperi et al., 2018; Henry et al., 2018; Abbasi et al., 2019), including in household dust (Zhang et al., 2020a; Soltani et al., 2021), the broad observations are not surprising. Nevertheless, they provide an insight into the types and origins of MPs in schools and allow potential exposure to children to be assessed.

The sources of MPs, and in particular fibrous MPs, are more densely distributed indoors than outdoors and account for concentrations of airborne plastics (number per m^3) that are considerably higher in the former (Dris et al., 2017). General, interior sources of microfibres include polyester- and polyolefin-based clothing, carpets and other soft furnishings (Zhang et al., 2020a). In schools, additional fibrous, primary and secondary MPs may be generated by various items and activities that include school uniforms, soft, felt and rubber toys, packaging, painting and artwork, and the general wear and tear of shoes, plastic or laminated furniture, electrical housings and insulation and other plastic-based fittings. MPs may also be introduced (through windows or doors) or tracked in (on shoes and clothing) from the external environment (Kurt-Karakas, 2012; Leppanen et al., 2020), with the significance of this route likely related to local geology and land use, the proximity of road traffic and specific industries, and the degree of building ventilation.

Although there are no other published studies dealing with MPs in the school setting, our results may be compared with those from the household and office environments given by Dris et al. (2017). Here, concentrations of fibres in dust retrieved from vacuum cleaner bags ranged from about 190,000 g^{-1} to 670,000 g^{-1}. While these concentrations are an order of magnitude greater than the highest concentrations reported in the present study (Figure 4), two thirds of the fibres counted by Dris et al. (2017) were constructed of natural material, like cotton, wool and cellulose acetate, and much of the flooring cleaned was carpeted. Amongst the synthetic fibres observed, there was also a high incidence of polypropylene MPs, consistent with the capture of material commonly used in carpet pile.

Unlike MPs in the external environment, those originating from indoors are not subject to natural physical and (photo-) chemical weathering or dispersion by wind and rainwater-stormwater. Consistent with lack of exterior exposure, many MPs exhibited little weathering under the SEM (Figure 4) and many of the non-neutral MPs were brightly coloured and displayed little evidence of photo-bleaching (Figure 3). One consequence of the presence of unweathered MPs in the present study is that the particle size distribution is skewed towards the higher end of the classifications considered, with about 67% of MPs in excess of 250 μm in length (Table 2).

One would also expect the abundance of MPs in schools to be dependent on the interplay between the nature and significance of the internal and external sources referred to above and the frequency and efficacy of dry and wet surface cleaning. The concentration of MPs weighted for mass of dust, however, is not predicted to be related to the latter because cleaning practices do not selectively remove plastic or non-plastic dust. Specifically, therefore, the geographical variation in MP concentrations shown in Figure 5 may be related to a number of demographic and climatic factors. These include the central and southern regions of Shiraz having a higher population (and student) density, older school buildings (up to 60 years old), greater industrialization, higher traffic loading and lower income per capita than the northern regions, as well as a prevailing wind direction from the northwest to southeast. These observations not only provide an insight into some of the drivers of MP accumulation in schools but also suggest that wind is an important vector for regional transportation, and especially for microfibres in the external environment (Abbasi et al., 2019).

Exposure to MPs in the classroom arises from contact with and inadvertent ingestion of settled dusts and the inhalation of dusts that are airborne because of classroom activities (Becerra et al., 2020). In order to quantify MP exposure to the youngest, elementary school children by ingestion through hand-to-mouth activities, direct mouthing of objects, consumption of contaminated food and inhalation and subsequent swallowing, a U.S. Environmental Protection Agency best estimate of daily soil and dust ingestion of 100 mg may be employed (U.S. EPA, 2011). Specifically, if it is assumed that a child spends 40% of its active, waking day in the school classroom and, therefore, consumes 40 mg of dust, estimates of MP exposure on a number basis may be gained by multiplying this mass by the concentration of MPs measured in the elementary school dusts. Estimates, shown for the eighteen elementary schools sampled in Table 1 along with summary statistics for the dataset, reveal a mean value of about 113 MP per day and a range from about 5 to 438 MP per day. These estimates do not factor in size or mass and, because of the difficulty in identifying MPs smaller than 30 to 50 μm, are likely to represent underestimates on a number basis. Nevertheless, compared with other exposure pathways (Zhang et al., 2020b), an estimated average annual intake of about 40,000 MPs suggests that activities in the classroom represent a highly significant route of exposure for young children.

The impacts and modes of action of ingested and inhaled MPs on human health, and in particular on the health of children and vulnerable individuals, are unclear (Wright and Kelly, 2017). However, it is likely that the significance of any impacts is inversely related to particle size. Thus, in vitro and animal studies have shown that absorption of MPs > 150 μm is probably negligible, MPs < 150 μm may be translocated from the gut cavity to the lymph and circulatory system, MPs < 20 μm have the potential to penetrate organs, and MPs 0.1 to 10 μm are able to cross cell membranes and the blood-brain barrier (Bouwmeester et al., 2015; Schirinzi et al., 2017; Barboza et al., 2018). Moreover, theoretical considerations reveal that the rate of mobilization of additives and reaction residues from plastics, including those known to be harmful to human health (e.g. lead), increases with a reduction in particle size (Town et al., 2018).

Table 3: Estimated daily ingestion of MPs from the classroom for elementary school children.

School	MPs per day
S3	4.9
S4	5.7
S6	18.6
S12	5.2
S14	277.0
S15	155.9
S21	7.0
S22	8.4
S25	9.7
S26	298.6
S28	7.7
S29	204.1
S31	74.6
S36	183.6
S40	235.7
S41	96.8
S44	438.5
S49	10.7
mean	113.5
sd	132.3
median	46.6
minimum	4.9
maximum	438.5

5. Conclusions

In summary, this study is the first systematic investigation of MPs in the school setting. The concentration of MPs in settled classroom dusts from elementary and high schools in Shiraz, Iran, ranges from about 80 to over 55,000 MP g^{-1}, with the majority of MPs of a fibrous nature that appear to be constructed of PET or polypropylene. Calculations indicate that elementary school children may be exposed to between about 5 and 440 MP per day through ingestion, at least within the particle size range considered. Although the health impacts of MPs on children are unknown, their ubiquity in the indoor and outdoor environments underscores the importance of future research in this area.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Ethical Approval

We have read and accept the "Ethical Responsibilities of Authors" section.

Consent to Participate

Sajjad Abbasi: Initial idea, Sampling, Laboratory actions, Conceptualization, Methodology, Investigation, Interpretation, Writing-original draft.

Consent to Publish

The article will be published as subscription.

Authors Contributions

Sajjad Abbasi: Initial idea, Conceptualization, Methodology, Investigation, Writing-original draft

Andrew Turner: Conceptualization, Investigation, Interpretation, Writing-final draft

Reza Sharifi: Laboratory activity

Mohammad Javad Nematollahi: Laboratory activity

Mehrzad Keshavarzifard: Laboratory activity

Tahereh Moghtaderi: Sampling

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Competing Interests

The author declares that have no financial interests.

Availability of data and materials

The data will be available if requested.

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