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1	Atmospheric transport of microplastics during a dust storm
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32 Graphical Abstract



37 Abstract

Dust storms are common events in arid and semi-arid regions that have a wide range of impacts 38 on the environment and human health. This study addresses the presence, characteristics and 39 40 potential sources of microplastics (MPs) in such events by analysing MPs deposited with dust particles in the metropolis of Shiraz, southwest Iran, following an intense storm in May 2018. At 41 42 22 locations throughout the city, MP concentrations on a number basis ranged from 0.04 to 1.06per g of dust (median = 0.31 MP g^{-1}). Particles were mainly fibrous, with a mean diameter of about 43 20 μ m and > 50% under 100 μ m in length, and polymer makeup was dominated by nylon, 44 45 polypropylene and polyethylene terephthalate. Examination of selected MPs by scanning electron 46 microscopy revealed varying degrees of weathering and contamination by extraneous geogenic 47 particles amongst the samples. Using published MP concentrations in urban dusts and remote, arid 48 soils, we estimate that between about 0.1 and 5% of MPs deposited by the dust storm are derived from local sources within the metropolis, with the remainder arising from more distant sources. 49 HYSPLIT modelling, satellite imagery and published geochemical signatures of regional dust 50 particles suggest that the deserts of Saudi Arabia constitute the principal distal and transboundary 51 source. Dust storms may represent a significant means by which MPs are transported and 52 53 redistributed in arid and semi-arid environments and an important source of MPs to the oceans.

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55 Keywords: Microfibres; Weathering; Deposition; Source; Flux; Iran

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60 **1. Introduction**

Dust storms are intense suspensions of geogenic silt- and clay-sized particulates that may last for 61 62 several hours to several days. These events result from strong and turbulent winds acting on loose, 63 sparsely vegetated soils and lithological units in arid and semi-arid regions, and in particular in inland drainage basins, and have the propensity to transport airborne particles over long distances 64 (Tan et al., 2012; Srivastava et al., 2018; van der Does et al., 2018; Rashki et al., 2021). Dust 65 storms have many and varied impacts on weather, climate and the environment. For example, high 66 dust loadings may affect air temperature, cloud formation and convectional activity (including 67 68 hurricane intensity) and are believed to play a major role in the delivery of iron and other nutrients to the oceans (Goudie, 2009). Dust storms also have significant adverse impacts on agriculture, 69 70 urban infrastructure, solar power production, the economy, and human health and safety (Rashki 71 et al., 2021). Regarding the latter, high loadings of suspended geogenic particles are directly 72 responsible for transport accidents and respiratory complaints, cardiovascular diseases and other 73 illnesses (Pauley et al., 1996; Tam et al., 2012), while the presence of associated materials or chemicals, like bioaerosols, heavy metals and radionuclides, may pose additional allergenic or 74 75 chronic health risks (Ogorodnikov, 2011; Behrooz et al., 2020; Soleimani et al., 2020).

In the recent literature, the role of the atmosphere in the long-range transportation of microplastics (MPs) has been highlighted (Allen et al., 2019; Liu et al., 2020; Roblin et al., 2020). Thus, MPs, and in particular fibrous MPs that have relatively high aspect ratios (and surface area-to-volume ratios) and low settling velocities (Brahney et al., 2020; Wright et al., 2020), can be transported 100s or 1000s of km from their point of origin before undergoing dry or wet deposition (Liu et al., 2019; Abbasi and Turner, 2021; González-Pleiter et al., 2021). Because of their small size and persistence, MPs in the atmosphere are a concern from a human health perspective (Prata, 2018),

83 while their deposition in soils, lakes and the ocean represents a means by which MP may be moved between ecosystems and exert impacts on a wide range of organisms (Arias-Andres et al., 2019; 84 Sobhani et al., 2021). With dust storms capable of shifting significant quantities of loose soils, and 85 MPs known to be dispersed amongst soils remote from any urban, industrial and agricultural 86 sources (Feng et al., 2020; Abbasi et al., 2021a), it is hypothesized that storm events may act as a 87 vehicle for transporting considerable quantities of fine, resuspendable MP. Accordingly, the 88 present study involves the opportunistic sampling of dust deposited throughout the metropolis of 89 Shiraz, Iran, immediately after a particularly intense dust storm in May 2018. MPs were isolated 90 91 from the deposited dust particles, and quantified and characterized by established techniques in order to gain an insight into the significance of dust storms in Iran, and more generally, to the 92 global atmospheric dispersion and redistribution of plastics. 93

94

95 **2. Methods**

96 2.1. Study area and sample collection

97 Shiraz is the largest city of Fars province and southwestern Iran, with a population of about 1.6 million contained within an area of 240 km² and lying about 1500 m above sea level. The region 98 99 is arid in summer and rainy and mild in winter, with an annual average temperature and rainfall of 100 18°C and 337 mm, respectively, and predominantly southeasterly and easterly winds. The air 101 quality of Shiraz has declined over recent years because of the rapid growth in population, traffic 102 volume and industrialization (Gharehchahi et al., 2013), coupled with an increased incidence of dust storms (Alizadeh-Choobari et al., 2015). The frequency of dust "events" in Shiraz appears to 103 be between 1 and 3% (Alizadeh-Choobari et al., 2015) but on May 13th 2018, a particularly intense 104

dust storm occurred in the region that involved the transboundary transportation of geogenic
material originating in Saudi Arabia across the Persian Gulf (Abbasi et al., 2021b).

107 Settled dust particles from the storm were collected opportunistically from parked cars, an approach adopted by Bergmann et al. (2019) for the sampling of MPs in fresh European snow. 108 Twenty-two locations (encompassing urban, residential and commercial areas) within different 109 110 municipal sectors of Shiraz (Figure 1 and Table 1) were visited within six hours after the dust 111 storm by three operators, and five to ten cars at each location were selected from bays with restricted (i.e., not long-term) parking. Sampling involved the careful but rapid retrieval of material 112 113 from the central regions (about 40 x 40 cm) of windscreens or back windows using a pre-cleaned wooden brush with horsehair bristles and a stainless steel dustpan by an operator wearing cotton 114 115 clothing. Composite samples from each location were stored in 300 mL glass jars and the brush and pan were washed several times with filtered water between sampling locations. The general 116 117 atmospheric conditions in Shiraz at this time of year require car windows to be regularly cleaned 118 while driving and we assume, therefore, that the majority of material collected from the windows 119 arose largely from the storm and not from more general, ambient urban deposition.



125 2.2. Sample treatment and microplastic extraction

Dust samples were transferred to individual, 600-mL glass beakers using a stainless steel spoon 126 before being dried for 24 h at 25°C. Dried samples were then sieved through a 5-mm stainless steel 127 mesh, with 50 g of each weighed into individual clean beakers on a Libror AEL-40SM balance 128 (Shimadzu, Kyoto). The contents of each beaker were oxidized with 200-300 mL of 35% H₂O₂ 129 (Arman Sina, Tehran) at room temperature until bubble formation ceased. Remaining particulate 130 131 matter was washed with filtered, deionized water through a 150 mm diameter S&S filter paper (blue band, grade 589/3, 2 µm pore size) housed in a glass-ceramic vacuum filtration kit before 132 being dried in a sand bath at 60°C for 2 h. 133

To isolate MPs, each dried, digested sample was transferred to a saturated 300 mL solution of ZnCl₂ (Arman Sina, Tehran; density $1.6 - 1.8 \text{ g cm}^{-3}$) in a series of clean glass beakers, and the decanted contents were subsequently centrifuged at 4000 rpm before supernatants were vacuumfiltered through S&S filter papers. This process was repeated twice, with resulting filters air-dried for 48 h at 25 °C under laminar flow and transferred to glass Petri dishes for physical and chemical characterization.

140 2.3. Quality assurance and control

141 Appropriate measures were taken to minimize MP contamination in the laboratory. Thus, benches were cleaned with ethanol using cotton cloths, laboratory clothing was cotton-based and all 142 reagents and solutions were vacuum-filtered through S&S blue band filters ($< 2 \mu m$) before being 143 used. All glassware was washed with phosphate-free soap, double rinsed with filtered (< $2 \mu m$) 144 water and soaked in 10% Merck Suprapur HNO₃ for 24 h before being rinsed twice with double-145 distilled water and air-dried at room temperature in a clean room. Where possible, containers were 146 protected by covering or wrapping in aluminium foil. Controls, consisting of empty beakers that 147 were processed as above, revealed no detectable airborne MP contamination throughout sample 148 149 processing and storage.

150

151 **2.4.** *Microplastic identification*

MPs on filters were identified and quantified according to thickness and cross sectional properties, shininess, hardness, surface structure and reaction to a hot, 250 µm stainless steel needle under a binocular microscope (Carl-Zeiss) at up to 200 x magnification and with the aid of ImageJ software. Particle size, with a lower limit of about 20 to 50 µm depending on shape and colour, was estimated along the length of the longest axis, $L (L \le 100 \ \mu\text{m}, 100 < L \le 250 \ \mu\text{m}, 250 \le L < 500 \ \mu\text{m}, 500 \le L < 1000 \ \mu\text{m}, L \ge 1000 \ \mu\text{m})$, and colour was grouped as black-grey, yellow-orange, white-transparent, red-pink or blue-green. Shape was classified as film, fragment, spherule-granule or fibre, with the latter defined as having a length to diameter ratio of at least three and diameter estimated to the nearest 5 μ m with the aid of TCapture software.

The polymeric composition of a selection of MPs from different locations and of different colours, sizes and shapes (*n* = 39) was determined using a micro-Raman spectrometer (LabRAM HR, Horiba, Japan) with a laser of 785 nm, a Raman shift of 400-1800 cm⁻¹ and acquisition times between 20 and 30 s. Surface morphology was determined on 21 of these samples, after they had been mounted on microscope slides and gold-coated, using a high vacuum scanning electron microscope (SEM; TESCAN Vega 3, Czech Republic) operated with a resolution of 2 nm at 20 kV and equipped with an energy-dispersive X-ray microanalyzer (EDX).

168

169 2.5. Trajectory calculations

The origins of air masses and potential source range of material from the dust storm was evaluated from 48-h back trajectories for 13th May 2018, calculated using the National Oceanic and Atmospheric Administration online software, Hybrid Single Particle Lagrangian Integrated Trajectory (HYSPLIT) *v*4, and Global Forecast System (0.25 degree global) meteorological data. Trajectories were calculated at six-hour intervals at a height of 500 m above ground level and a resolution of 1 degree, and were integrated as frequency distributions.

176

177 **3. Results and Discussion**

178 3.1. Distribution and characteristics of microplastics

179 The number and distribution (by size and shape) of the MP identified in the present study are shown for each location sampled in Table 1. Overall, 485 MP were recorded that were dominated 180 by fibres $(n = 448 \text{ or} \sim 92\%)$. Small contributions arose from films (n = 35) and fragments (n = 2)181 but more regular spherules-granules were never detected. Regarding MP colour, > 50% were 182 white-transparent, 23% were red-pink, 10% were black-grey or yellow-orange, and < 5% were 183 184 blue-green; non-fibrous MP were dominated (~ 90%) by white-transparent films. The total number of MP at each location ranged from 2 to 53, with concentrations on a number basis ranging from 185 0.04 to 1.06 MP per g of dust. Overall, mean and median concentrations were 0.44 and 0.31 MP 186 g⁻¹, respectively, and 25th and 75th percentiles were 0.21 and 0.65 MP g⁻¹, respectively. 187

Fibres were single straight, curled or coiled strands or, occasionally, multiple, intertwined strands, 188 189 and diameters ranged from about 10 to 40 µm and averaged 18.7 µm. Over 60% of fibres were encountered in the smallest length category considered ($< 100 \mu m$), with a similar distribution 190 191 among size categories up to 1000 μ m (10 to 15%) but < 0.5% of fibres present above 1000 μ m. The percentage in the finest fraction is subject to some uncertainty because of the existence of MPs 192 below our size detection limit and the possibility that some larger fibres may fragment into smaller 193 194 particles during centrifugation. Nevertheless, the percentage of fibres in this fraction is larger than that reported for deposited dust particles sampled in Shiraz throughout the year (average $\sim 30\%$) 195 that had been processed and identified using the same methodology (Abbasi and Turner, 2021). 196 Based on a range of aspect ratios (β) from 3 to 100, diameters (d) as above and densities (ρ) for 197 the polymers shown in Figure 2 (from 1.0 to 1.4 g cm⁻³), we estimate aerodynamic equivalent 198 diameters (d_a) from the following equation (Wright et al., 2020): 199

200 $d_{\rm a} = (\rho \ln 2 \beta)^{1/2} d$ (1)

to range from about 13 to 130 μ m for the fibres detected in the present study.

Table 1: Location of each sampling station in Shiraz (see Figure 1), along with a summary of the
MP distribution by size and shape. Fibres are categorised according to length, *L*, but other
(remaining) MPs are not classified by shape or size. Concentration represents the number of MP
per g of dust.

Sample	UTM coordinates			MP fibres (<i>L</i> , μm)						
location	х	Y	< 100	100 <u><</u> L <250	250 <u><</u> L<500	500 <u><</u> L<1000	<u>></u> 1000	All sizes	Total	Concentration, MP g ⁻¹
1	653872	3274271	28	0	0	0	2	0	30	0.60
2	650842	3278127	22	8	1	5	0	1	37	0.74
3	651261	3279474	10	3	10	4	0	0	27	0.54
4	647803	3279769	10	0	0	0	0	0	10	0.20
5	644147	3282014	0	0	0	35	0	3	38	0.76
6	642555	3284973	11	2	0	0	0	2	15	0.30
7	640747	3284072	13	0	0	0	0	0	13	0.26
8	641853	3279579	28	17	0	0	0	2	47	0.94
9	646509	3274962	9	3	0	0	0	0	12	0.24
10	652295	3272590	2	0	0	0	0	0	2	0.04
11	653768	3276225	9	0	0	0	0	0	9	0.18
12	648930	3277346	8	0	0	0	0	0	8	0.16
13	647860	3272117	3	2	4	0	0	3	12	0.24
14	642604	3275416	5	0	11	0	0	0	16	0.32
15	642800	3283128	12	0	28	1	0	6	47	0.94
16	641370	3289215	11	0	0	0	0	0	11	0.22
17	646854	3278154	7	0	0	0	0	0	7	0.14
18	647076	3276095	0	2	13	0	0	8	23	0.46
19	644418	3275928	23	0	0	0	0	10	33	0.66
20	643999	3272283	50	3	0	0	0	0	53	1.06
21	654777	3270363	5	0	0	0	0	0	5	0.10
22	656267	3273264	15	13	0	0	0	2	30	0.60
total			281	53	67	45	2	37	485	
mean			12.8	2.4	3.0	2.0	0.1	1.7	22.0	0.44
min			0	0	0	0	0	0	2	0.04
max			50	17	28	35	2	10	53	1.06

The distribution of selected MPs (n = 39) from various locations by polymer type is shown in Figure 2, along with examples of Raman spectra for two fibres. About one half of the samples were constructed of nylon, with decreasing contributions from polypropylene, polyethylene terephthalate and polystyrene. Fibres (n = 31) were represented by all polymer types detected and reflect the nature of plastics used in textiles and fabrics (Henry et al., 2019), but films (n = 6) were constructed of only nylon and polypropylene and fragments (n = 2) were constructed of nylon.

213



Figure 2: (a) Relative abundance of 39 MPs by polymer type (PET = polyethylene

terephthalate), and Raman spectra for (b) a nylon fibre and (c) a polypropylene fibre.

SEM images of selected fibres and films are illustrated in Figure 3. Fibres are uniform in diameter, 219 220 with the scale bars confirming that sample diameters ranged from about 10 to 40 µm. The images suggest varying degrees of weathering and contamination by adherent mineral particles, with EDX 221 222 spectra of the latter (and in particular Al, Ca, Mg, Fe, Si and Ti) consistent with the geochemical 223 signature of soils and lithological units in Saudi Arabia and southwest Iran (Abbasi et al., 2021b). Specifically, the fibres shown in Figures 3a and 3b exhibit smooth surfaces with very little 224 225 evidence of weathering but contamination by extraneous material apparent in the latter case, while 226 the fibres shown in Figures 3c and 3d exhibit contamination and considerable but heterogeneous

weathering. In Figure 3c, indentations and pits are indicators of mechanical weathering while
flaking and granulation are more typical of photo-oxidation (Zbyszewski and Corcoran, 2011). In
Figure 3d, we suspect that the almost parallel but irregular, circular fractures normal to the length
of fibre result from shrinkage-expansion while exposed to extreme environmental temperatures.
The plastic films illustrated in Figures 3e and 3f contrast the effects of intense photo-oxidation
(granulation and flaking) and mechanical weathering (grooves and indentations) on the surface
morphologies of thin, angular plastic films.



Figure 3: SEM images of six MP retrieved from material deposited in Shiraz after the dust storm.

- 237 (a) Green polypropylene fibre, (b) red polypropylene fibre, (c) white polyethylene terephthalate
- fibre, (d) green polypropylene fibre, (e) colourless polypropylene film, (f) purple nylon film.

239 3.2. Origin of dust and microplastics

The air mass trajectory frequencies for the period directly preceding the dust storm and calculated using HYSPLIT are shown in Figure 4a. These frequencies indicate dominant westerly and southwesterly components associated with the event, with satellite imagery (Figure 4b) and geochemical signatures reported in Abbasi et al. (2021b) confirming that the most important source of dust is the Arabian Peninsula, and in particular the Saudi Arabian deserts. Here, resuspension of material is favoured by extensive accumulations of fine sand and silt, scattered vegetation and variable terrain (Engelbrecht et al., 2017).

The MPs deposited in Shiraz following the dust storm may, therefore, have both distant (or remote) 247 and more local origins. Distant MPs are carried by strong winds with geogenic material (e.g., 248 silicates, aluminosilicates, carbonates) from the Arabian Peninsula, and may be augmented by 249 entrainment of additional plastics in southwest Iran and, potentially, through breaking waves at 250 251 sea (Allen et al., 2020) as air moves across the Persian Gulf. Local MPs are resuspended with natural soils (mainly silt and clay) and anthropogenic particulates within the urbanized region of 252 253 Shiraz as the dust storm passes through the metropolis. Nematollahi et al. (2021) found a clear linear correlation between δ^{18} O and δ^{13} C isotopes measured in deposited dust particles in Shiraz 254 arising from the dust storm reported here that was attributed to the mixing of two particle end-255 members: namely, an "anthropogenic" population and a less contaminated but more "geogenic" 256 257 population. Likewise, it is proposed that MPs in deposited dust particles in Shiraz following the 258 dust storm are derived from and can be modelled by two end-member mixing.

259

261 3.3. End-member microplastic mixing model

262 In the present context, the end-members of MPs observed at a location impacted by a dust storm can be defined as those associated with geogenic material that are imported by the atmosphere 263 264 with strong winds, and those already resident at the location but suspended by the event itself (and including any material sampled from car windows that was present before the dust storm). The 265 two populations of MP may be different because of distinctly different sources, histories and ages, 266 but are more likely to exhibit some similarities because of the global reach of plastic products and 267 268 common means of generating MP, coupled with the mixing effects of previous dust events at the location of interest. Without characterizing the end-members themselves, it is not possible to 269 270 establish any clear differences in these populations. However, SEM observations suggest that MPs 271 imported form the Arabian deserts could exhibit distinctive weathering patterns (such as the shrinkage observed in Figure 3d), while a greater proportion of smaller, fibrous MPs observed in 272 the present study compared with MPs in settled dust particles of Shiraz suggests that imported 273 particles are relatively fine. Conversely, more general aerodynamic considerations and 274 275 observations in the literature suggest that more rapidly settling, larger fibres and non-fibrous particles are likely to have a local origin (Brahney et al., 2020; Loppi et al., 2021). Nevertheless, 276 and regardless of these characteristics, binary mixing can be considered numerically from MP 277 concentrations representative of the end-member populations. 278

Thus, typical concentrations of MPs on a number basis in background settled urban dust particles from Shiraz are about 25 MP g^{-1} (Abbasi and Turner, 2021), which is similar to the median concentration of MP measured in street dusts from the industrialized city of Asaluyeh, western Iran (about 15 MP g^{-1} ; Abbasi et al., 2019), while concentrations in desert soils remote from any urbanization and derived from the dispersion of distal sources average about 0.02 MP g^{-1} (Abbasi et al., 2021a). Assuming that dust and MPs exhibit similar entrainments into the atmosphere, the fractional contribution, f, of each end-member to the net concentration of MP observed in the dust storm, [MP]_{dust}, can be modelled as follows:

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$$[MP]_{dust} = f_{rem}[MP]_{rem} + f_{loc}[MP]_{loc}$$
(2)

where subscripts rem and loc refer to remote and local sources, respectively. Substituting $1-f_{loc}$ for f_{rem} :

$$290 \quad [MP]_{dust} = [MP]_{rem} - f_{loc}[MP]_{rem} + f_{loc}[MP]_{loc}$$
(3)

and rearranging yields:

292
$$f_{loc} = ([MP]_{dust}-[MP]_{rem})/([MP]_{loc}-[MP]_{rem})$$
 (4)

293 Using the typical or average end-member MP concentrations above for [MP]_{loc} and [MP]_{rem} of 20 and 0.02 MP g⁻¹, respectively, and the median MP concentration in Table 1 as [MP]_{dust} (0.31 MP 294 g^{-1}) results in a value of f_{loc} of 0.015; using the lowest and highest MP concentrations in Table 1 295 for [MP]_{dust} (0.04 and 1.06 MP g⁻¹, respectively) results in values of about 0.001 and 0.05, 296 respectively. Thus, the estimated range in contributions of MP that are local to Shiraz to the 297 sampled dust particles is about 0.1 to 5%, with variations amongst the locations presumably 298 reflecting differences in the proximity to or mobility of urban sources but displaying no clear 299 relationship with particle characteristics (e.g., size, colour or shape). The majority of MP are, 300 301 however, clearly imported from outside the region (and via Saudi Arabia and southwest Iran), with geochemical analyses of dust samples suggesting that the Arabian Peninsula provides the more 302 significant, transboundary contribution (Abbasi et al., 2021b). 303

306 3.4. Wider implications

The numerical estimates of MP origin are subject to various assumptions, including processes involved in the suspension-transport-deposition that are similar for both geogenic material and MPs. Nevertheless, they highlight the importance of dust events to the redistribution of MP in arid and semi-arid regions and add to the growing body of evidence in the literature supporting the more general long-range and transboundary atmospheric transport of fibrous MP (Allen et al., 2019; Brahney et al., 2020; Evangeliou et al., 2020).

Although the mass of mobile dust involved in the storm under study does not appear to have been 313 estimated, an earlier event occurring in the Arabian Peninsula and simulated by Jish Prakash et al. 314 (2015) suggested that nearly 100 Mt of dust was emitted, with 73 Mt deposited over the broader 315 region of study and including about 7 Mt deposited in the ocean. Assuming that the concentration 316 of MP in the soils acting as a source of dust is about 0.02 MP g⁻¹ (Abbasi et al., 2021b), we estimate 317 that such a storm could suspend about $2 \ge 10^{12}$ MP and deposit $1.5 \ge 10^{12}$ MP regionally, including 318 1.5×10^{11} MP in the ocean. Globally, it is estimated that about 2 billion tonnes of loose and poorly 319 320 vegetated arid soil are transported in the atmosphere each year (Perkins, 2001; Tanaka and Chiba, 321 2006), with the main source regions associated with the Sahara desert and the deserts of Asia, the Middle East, North and South America and Australia (Wang, 2015). Assuming that the soil 322 323 concentration of MPs employed in the present study is more generally applicable, dust storms could be responsible for the annual, atmospheric mobilization and transportation of about 4×10^{13} 324 325 MP. For representative fibrous MPs of unit density and 250 µm in length and 10 µm in diameter, this is equivalent to about a tonne of MPs. Dust storms, therefore, represents a significant means 326

by which MPs are redistributed in the environment and, given the proximity of many dust sources to the coastal zone, a potentially important, indirect source of MPs to the ocean. Moreover, with the intensity and frequency of droughts predicted to increase (Srivasta et al., 2018), along with increasing demands for water (Hoff, 2009) and plastic (Geyer et al., 2017), dust storms are likely to be of increasing importance to the global flux and cycling of environmental MPs.

The current study is also significant in highlighting the presence of a type of contaminant suspended in dust storms that has thus far been overlooked. The precise health impacts of airborne MPs, and in particular those that are inhalable, are unclear (Wright et al., 2019; Rahman et al., 2021), but any effects associated with dust storms should be considered along with those arising from the presence of other materials and chemicals, including dust itself, allergenic particles, like pollen and fungi, microbiological organisms, and heavy metals (Kellogg and Griffin, 2006).



- Figure 4: (a) Frequencies of air trajectories crossing a given area and arriving at Shiraz (starred)
 for 8th to 12th May 2018 calculated at 500 m and from 48 h air mass back-trajectories using
 HYSPLIT, and (b) NOAA satellite image of the region during the dust storm.

345 **4. Conclusions**

346 This study is the first to document MPs associated with and transported by a dust storm. With 347 respect to an intense event in the metropolis of Shiraz in May 2018, the majority of plastics isolated 348 from deposited dust particles were fibrous, with concentrations on a number basis ranging from < 0.05 to about 1.1 MP g⁻¹. MPs exhibited varying degrees of mechanical weathering, photo-349 350 oxidation and contamination by geogenic particulates, and the provenance of the latter, coupled with satellite imagery and HYSPLIT modelling, suggests that the majority of material brought into 351 352 Shiraz originates from the Saudi Arabian Peninsula. Within the uncertainties and assumption of a 353 two end-member MP mixing model, we estimate that > 90% of plastics in deposited dusts are derived from outside the city. Globally, dust storms could represent a significant means of MP 354

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transportation in the atmosphere and an important source of MPs to the ocean.

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