RESEARCH ARTICLE

An unintended challenge of microplastic pollution in the urban surface water system of Lahore, Pakistan

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Abstract

Plastics are widely considered to be a major threat particularly in the urban areas owing to extensive use of plastic products. The current study is the first investigation to highlight the microplastics (MPs) pollution from the freshwater (Ravi River) located in the predominant urban center, i.e., Lahore, Pakistan. The concentration profile was quantified from surface water ($n = 19$) and sediments ($n = 19$) collected from different drains and canals of predominant freshwater resources in Lahore, Pakistan. The highest content of MPs was observed in the sullage carrier with mean concentration of $16{,}150 \pm 80$ MPs/m^3 and $40{,}536 \pm 202$ MPs/m^2 in the water and sediments respectively. The lowest level was detected in the link canals with mean concentration of 190 ± 141 MPs/m^3 in the water and 683 ± 479 MPs/m^2 in the sediments. The proportion of large size MPs (300 μm–5 mm) was maximum in the upstream section of Ravi river, whereas fine size MPs (50–150 μm) were dominant in the downstream section. In terms of shapes, the fragments were predominant with a relative abundance of 56.1% and 83.1% followed by fibers with a relative abundance of 38.6% and 11.8% in the water and sediments respectively. The chemical composition analysis showed that most of the fibers, fragments, and beads were polyethylene while the sheets were composed of polypropylene. Nevertheless, the foams isolated from the samples were composed of polystyrene. Within 24 h, about 2.4 ± 2.4 billion microplastic pieces were estimated to be transported from a single water channel into the river. The highest discharge of MPs was estimated from the sullage carrier with about 7 billion pieces/day.

Keywords Microplastic pollution · Freshwater microplastics · Surface water · Metropolitan city · Pakistan

Introduction

Plastics are polymerization-based monomers with special physicochemical properties and stable structure that can persist in

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the environment for hundreds of years (Jiang et al. 2018). During 2017, about 348 metric tons of plastics were produced and commercialized to manufacture packaging, construction material, textile, and consumer products (PlasticsEurope 2018). A smaller proportion is also used in transportation, electrical appliances, industrial machinery, and oil production (Parker 2018; PlasticsEurope 2018; We Forum 2018). Owing to widespread use and negligence, large quantities of plastic waste are generated (Barnes et al. 2009). This plastic waste is categorized into different classes (macro, meso, micro, and nano-plastics) of which the waste ranging 20 μm–5 mm is termed as microplastics (MPs). They can further be categorized into primary or secondary MPs on the basis of their sources (Cole et al. 2011; Strungaru et al. 2018). A large number of primary MPs are used in several cosmetic products as a scrubbing material (Napper et al. 2015), while secondary MPs are produced by the physical breakdown of large plastic fragments in the environment (Wagner et al. 2014).

Major sources of plastic waste include municipal solid waste, wastewater treatment plants (WWTPs), and industrial plants

using plastic pellets (Fendall and Sewell 2009; Lechner et al. 2014; Mason et al. 2016). About 80% of the plastics present in the oceans originates from the terrestrial areas and then makes its way into the aquatic environment (Li et al. 2016). Thus, MPs have been detected in almost every medium of the environment including the agricultural soils and even the far-off glaciers (Kornei 2019; Nizzetto et al. 2016; Treinish 2017; Zalasiewicz et al. 2016). Owing to their extremely small size, ubiquitous presences in the environment and physicochemical properties, variety of threats have been reported to the aquatic system (Avery-Gomm et al. 2018; Avio et al. 2017; Fossi et al. 2012; Provencher et al. 2010; Ribeiro et al. 2017; Thompson et al. 2009). Extremely small size plastics may cause entanglement of different terrestrial and aquatic organisms that might cause mortalities (Borunda 2019; Gregory 2009; Nunes et al. 2018; Ryan 2018; Votier et al. 2011; WWF 2019). MPs can serve as a carrier for a variety of persistent pollutants and facilitate their movement in the water bodies (Cole et al. 2011). Different types of persistent organic pollutants (POPs) were identified on the surface of MPs which enhances their importance as toxic waste (Frias et al. 2010). Some scientists have already suggested policies to include plastic waste in the hazardous waste category (Rochman et al. 2013).

On the other hand, 0.6 million tons of plastic is produced from around 6000 producers in Pakistan and contributes about 0.2 million tons of plastic waste into the Arabian Sea through the Mighty Indus (Dawn 2019). Polyethene bags are commonly used to carry different materials from the market and the number of plastic bags being used per annum reaches up to 55 billion (The News 2018). According to the International Trade Administration (ITA), it is estimated that nearly 6% of the total solid waste (48.5 million tons) produced in Pakistan consists of plastics (International Trade Administration 2019) and most of the waste is dumped at open places. Open dumping of municipal solid waste can be observed along with different water bodies e.g., canals, drains and rivers. Despite such a high plastic consumption and waste generation, Pakistan lags behind and the exact quantity of plastics in aquatic systems and MPs pollution from surface water is largely neglected. During the survey, the macroplastics present in Ravi River were enumerated. On average, 10–30 pieces/m^3 were observed in different parts of the river, whereas polystyrene pieces were also seen floating near flow regulating gates of barrages. Nevertheless, the river was found to be visibly clean and macroplastics were not a major problem.

Several studies have been reported previously, concerning the concentration, abundance, and distribution of MPs in the freshwater bodies. Chinese freshwater lakes (Su et al. 2016; Wang et al. 2017, 2018a; Xiong et al. 2018; Zhang et al. 2016), rivers (Hu et al. 2018; Lin et al. 2018; Peng et al. 2018; Tan et al. 2019; Wang et al. 2018b) and estuaries (Peng et al. 2017; Xu et al. 2018; Zhao et al. 2014, 2015) have been extensively studied in this regard. A number of studies have also been carried out in different Asian countries including India (Karthik et al. 2018; Kumar et al. 2018; Sruthy and Ramasamy 2017; Veerasingam et al. 2016; Vidyasakar et al. 2018), Sri Lanka (Koongolla et al. 2018; Viraj et al. 2019), Vietnam (Lahens et al. 2018), Oman (Aliabad et al. 2019), Iran (Akhbarizadeh et al. 2017) and Maldives (Imhof et al. 2017). So far, only one study concerning MPs quantification from Hawksbay beach is reported and the number of synthetic fibers was enumerated (Balasubramaniam and Phillott 2016). Therefore, it is immediately required to quantify the MPs level in the vicinity of urban centers. The current study is the first investigation to highlight the distribution of MPs from the surface water surrounded by significant sources of plastic waste. The objective of this study was to evaluate the prevalence and the spatial distribution of different MPs in the predominant drains and canals of Lahore district, Pakistan, thus highlighting the MPs contribution.

Material and methods

Sampling sites

The Ravi river is flowing through Lahore; the biggest residential, industrial, and business hub, receiving the different types of plastic waste. About 100-km-long section of Ravi River– from Ravi Siphon to Balloki Headworks was considered being in close proximity to Lahore (Fig. 1). This section is joined by different drains from Lahore city and link canals from the Chenab River and this part of the river was assumed to be the most polluted in terms of plastic pollution. The samples were collected from 19 sites. The selected locations include drains (n = 6; Shalimar Escape Channel, Upper Chota Ravi Drain, Shahdra Drain, Lower Chota Ravi Drain, Cantonment Drain, Hudiara Drain), link canals (n = 2; Upper Chenab, Qadirabad-Balloki) a nearby Sullage carrier (n = 1) and mainstream of Ravi river (n = 10; located in the upstream and downstream of the selected drains, sullage carrier and link canals). The sullage carrier is a major drain of Lahore City, receiving sewerage from two thickly populated towns of the city, i.e., Allama Iqbal Town and Gulshan-e-Ravi Town. Due to the massive littering of solid waste (especially polyethene bags), the channel is completely clogged at some points and large quantities of plastic debris can be observed floating throughout the channel. Moreover, concrete-lined banks of the channel (in order to prevent seepage) and fast water flow do not allow the deposition of plastics on its way from the city towards river. Hence, the MPs concentration in this channel was expected to be very high as compared to other drains selected in the study. Two different types of samples i.e., surface water and sediments, were collected from each location. Although water is the carrier for the plastics, their deposition into the sediments makes it very important to analyze sediments along with water
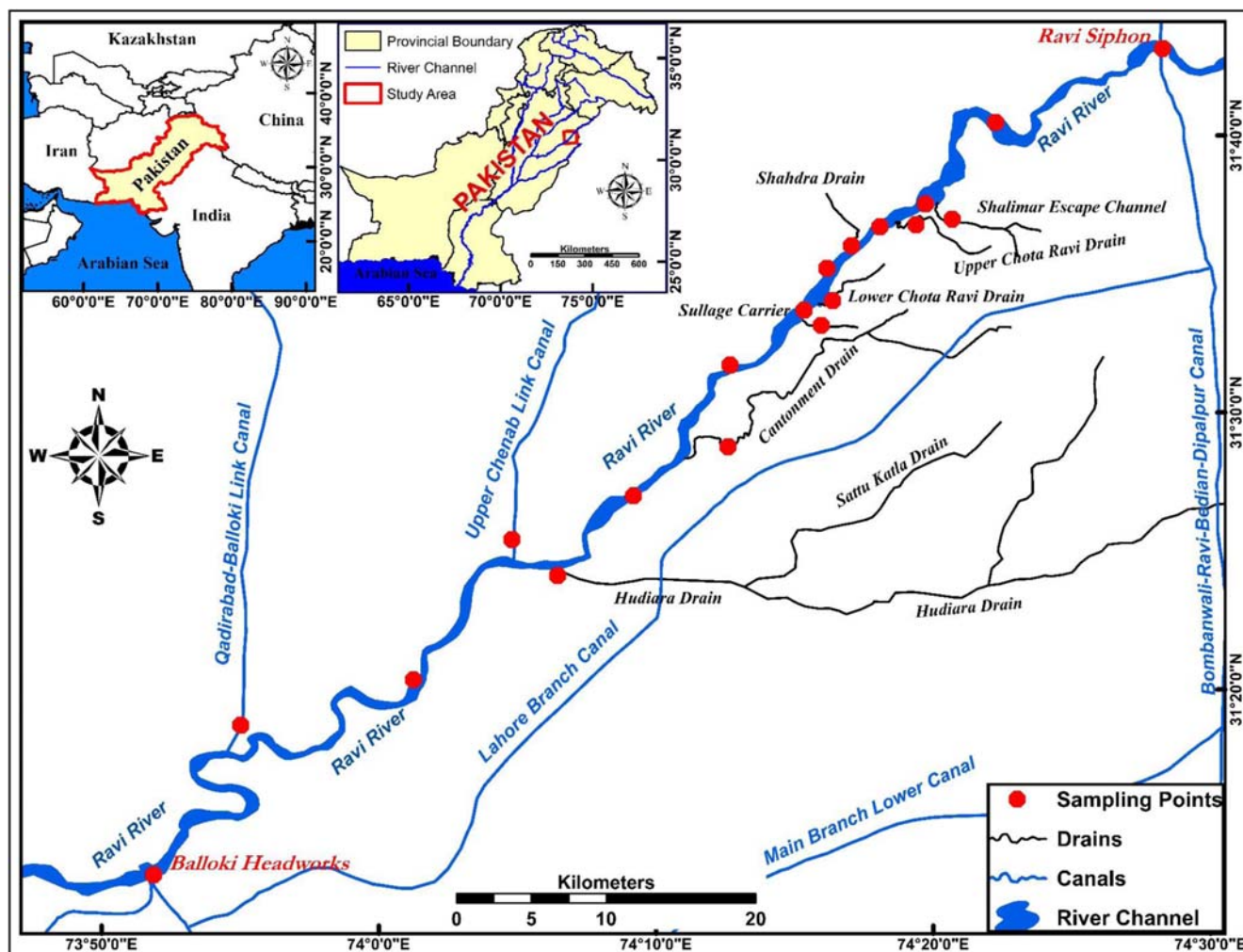
Fig. 1 Study area map showing Ravi river, drains, sullage carrier, link canals, and sampling sites

samples to determine the actual MPs load in a waterbody (Enders et al. 2019).

Sediments and surface water sampling

The surface sediments ($n = 19$) were collected from comparatively flat areas along the river and water channels (Klein et al. 2015). A stainless-steel quadrate (30×30 cm) was placed between the intertidal zone and the upper layer of sediments (1 cm, inside the quadrate) was removed and collected in the clean glass bottle using a stainless-steel spatula, whereas the surface water samples ($n = 19$) were collected in the vicinity of the sediment sampling points and pretreated on site. A 100 L of surface water was collected from each nearshore sampling point and filtered through a custom-made filtration assembly (Vermaire et al. 2017). The filtration assembly was prepared by joining three PVC funnels with the help of two PVC pipes of different diameters. The 5-mm and 150-μm nylon mesh was inserted in the upper and lower funnel respectively (Fig. S1). The upper mesh size (5 mm) excluded the

macroplastics (> 5 mm) and large debris from going into the samples while the lower mesh size (150 μm) was selected to avoid retention of material on the filter owing to high suspended loads in the drains and river. Concerning filtration, the assembly was kept in the vertical direction (5-mm filter facing upward) and the material retained on 5-mm mesh was carefully photographed and documented. For the collection of samples (< 5 mm), the assembly was inverted and the material on 150-μm mesh was carefully back washed into 500-ml glass sampling bottles using distilled water. The glass bottles were labeled, covered with aluminum foil, tightly closed with plastic lids, and transported to Environmental Toxicology Laboratory, College of Earth and Environmental Sciences, University of Punjab, Lahore-Pakistan for further analysis.

Samples preparation

At first, wet sieving was performed to clean and categorize the sediment samples. The purpose of wet sieving was to get rid of clay contents as water dissolved the clay and escaped from the

sieve (Blaud et al. 2017). Sieving was performed using 5-mm and 150-μm stainless steel sieves with the help of filtered tap water (through 50-μm mesh). Material on the 5-mm sieve was photographed and documented, while the material on the 150 μm sieve was washed until it was free from clay and the filtrate was almost transparent. The filtered material on the 150-μm sieve was carefully back washed and transferred into a glass beaker for digestion, whereas for water samples, no sieving was required.

The next step was the removal of organic matter; for the purpose, both the water and sediment samples were digested using wet peroxide digestion method (Munno et al. 2018). The Fenton's reagent (hydrogen peroxide —40 mL, 35%) and FeSO$_4$ (0.5 M—1:1) was mixed with 200 mL of sample. Fenton's reagent is recommended for the digestion of organic matter, as it produces no or negligible effects on MPs (Hurley et al. 2018; Tagg et al. 2017). The beaker was carefully covered with aluminum foil and stored for 24–72 h at room temperature. Few samples were followed by the secondary and tertiary digestion (depending on the organic matter content); the primary digested sample was filtered using a 50-μm steel sieve, washed thoroughly with filtered water and transferred back into the beaker for the subsequent digestion. After digestion, the homogenous solution containing different types of suspended particles was used for the density separation in which the separation of low-density materials from the high-density particles was achieved by using a Sediment Microplastic Isolation (SMI) unit (Coppock et al. 2017), detailed representation is provided in Fig. S2.

During the density separation, concentrated NaCl– as a floatation media was added in the SMI unit and placed at room temperature for 10 min. The contents of SMI units were filtered through 50-μm steel mesh in order to remove the impurities. Then, the digested sample (650 mL) was poured into the unit, the trapped air was removed, wrapped with aluminum foil, and placed for 12 h at room temperature. After 12 h, the contents of the SMI unit were transferred into a clean glass beaker. The unit was thoroughly rinsed and the recovered contents were filtered through a series of 300, 150, and 50-μm stainless steel sieves. Multiple sieves were also prepared for some samples to avoid thick layering on the sieve surface. Subsequently, the prepared sieves were covered with glass petri dishes before further analysis. Thus, the samples were classified into three classes, i.e., fine (50–150 μm), medium (150–300 μm), and large size MPs (300 μm–5 mm) based on their size.

MPs identification, quantification, and chemical analysis

MPs were also categorized into five types (fibers, sheets, fragments, foams, and beads) based on their shape. For the visual identification, the coarse sieves (300 μm) were observed under a stereomicroscope (IM-SZ-500, IRMECO GmbH,

Germany), while the fine sieves (50 μm and 150 μm) were observed under a high-resolution digital camera microscope (Koolertron UM012C, MUSTECH Electronics, China). Stereomicroscope was connected to a camera (BestScope BUC2B-1000C) and images were captured through TS View digital imaging software (Version 7.3, Tucsen Photonics). Similarly, images through the camera microscope were captured with the help of MicroCapture Plus 2.0 software. MPs were identified on the basis of visual characteristics, e.g. shape and color (Hidalgo-Ruz et al. 2012; Marine Environmental Research Institute 2015). A hot needle test was also applied using a sewing needle (fixed in the empty ink chamber of a ballpoint pen) for the confirmation of ambiguous materials (De Witte et al. 2014). The needle was heated on a spirit lamp until it became red hot and touched with ambiguous particles under the stereomicroscope. Clear melting behavior indicated that particle was synthetic otherwise categorized into natural substances, e.g., starch, cellulose, or chitin.

All the MPs observations were documented and the concentration was calculated in terms of MPs/m^3 and MPs/m^2 for the surface water and sediments, respectively. The composition of selected MPs *(n = 50)* was determined by Fourier transform infrared spectroscopy (Cary 630 FTIR Spectrometer, Agilent technologies with diamond ATR sensor and MicroLab FTIR software) (Zhao et al. 2019). The MPs particles were placed on the ATR sensor and their absorbance peaks were recorded. Furthermore, the comparison was made between recorded and standard peaks; thus, the composition of the particles was determined on the basis of peak similarity index.

Statistical analysis and calculations

ANOVA and Pearson correlation were applied using Microsoft Excel, 2016 (Ver. 1904) to evaluate the variance and correlation among the concentration of different types and size of the MPs. Spatial distribution of MPs was highlighted by ArcGIS (Version 10.3) and graphs were prepared using Origin Pro 2016, whereas the daily MPs contribution of each waterbodies was calculated by following derived formula (Gray and Simões 2008).

$$D_m = D_w C_m$$

whereas

D_m MPs discharge in particles/day
D_w Water Discharge in m^3/day
C_m MPs concentration in particles/m^3

Quality assurance and contamination control

The experiments were conducted in the controlled environment and preventive measures were taken to minimize the

material and atmospheric contamination (Kataoka et al. 2019). The water used during sampling and wet sieving was filtered through 50-μm sieve. All the reagents used during digestion and density separation were also filtered through 50-μm sieve. In order to prevent atmospheric contamination, sample beakers and density separators were covered with aluminum foil during the digestion and density separation, respectively. Moreover, the sieves used for microscopic observation were covered with clean glass petri dishes before and after filtration. Furthermore, to ensure the experimental accuracy, procedural blanks were prepared and analyzed. In order to check the atmospheric contamination, empty uncovered petri dishes were placed in the laboratory for a day, and no contamination was observed. On the other hand, Fenton's reagent was added in the filtered tap water and subjected to density separation (using filtered NaCl solution in each density separator) for 12 h. Then these blanks ($n = 3$) were filtered through sieves and analyzed under microscopes and no MPs were observed.

Results and discussion

Concentration profile of MPs in water and sediments

MPs were identified in all the water and sediment samples with an average concentration of 2074 ± 3651 MPs/m^3 and 3726 ± 9030 MPs/m^2 respectively (Table S1, Table S2). The quantified concentration from the surface water was comparable to the previously published reports from surface water of Dongting Lake (Average; 1464.29 MPs/m^3, Range; 900–2800 MPs/m^3) and Yuejin Lake (Average; 7050 MPs/m^3) in China (Jiang et al. 2018; Wang et al. 2018a; Yin et al. 2019). MPs concentration depends on population density and anthropogenic activities (Kataoka et al. 2019). Lahore is a metropolitan city of Pakistan and ranked 2nd among the most populated cities of the country. Effluents from a large number of industries and loads of municipal sewerage have turned Ravi River into a highly polluted river (Business Recorder 2016). Similar situation exists in China, where population density is high and the water bodies receive wastewater from major cities (Jiang et al. 2019). Pakistan is also importing the plastic from China and indiscriminate use of plastics makes the situation comparable in China and Pakistan. Furthermore, the findings of Castañeda et al. (2014), the benthic sediments from St. Lawrence River (Canada), were found to be highly contaminated ($13,832 \pm 13,677$ MPs/m^2) due to the direct addition of municipal and industrial effluents into the river. Similarly, the freshwater sediments were also reported with the varying concentrations of MPs; however, owing to different measurement units, the majority of those studies could not be compared with the current reported profile (Shahul Hamid et al. 2018). Hengstmann et al. (2018) reported a comparable average concentration of 2862 MPs/m^2 in the beach sediments of Rügen-

Germany. However, significantly lower concentrations (647 ± 720 MPs/m^2) were reported at a coral island in the Maldives. The possible reason was the site, as the Island is located at the remote distance in the Indian Ocean where no potential anthropogenic sources were present, irrespective of the present studies location (Imhof et al. 2017). Furthermore, the highest concentration of MPs was observed in the midsection of the river where most of the wastewater is disposed-off. These findings were consistent with the Castañeda et al. (2014) where an extraordinarily high concentration of MPs was found at the sites near to municipal and industrial sewers. The detailed comparisons of currently reported concentrations with the previously published reports are shown in Fig. 2.

Furthermore, the maximum concentration was recorded in the sullage carrier samples followed by drains, river, and link canals (Fig. 3). The reported high concentration in the sullage carrier may be related to its shorter length (~ 2.5 km) and concrete embankment lining. Lahore is a populated city with a population of 11.1 million and produces tons of waste every day from municipal, commercial and industrial sources. According to Town Municipal Authority (TMA), about 1400 tons of solid waste was produced per day of which 18.5% consisted of plastics (Sabiha-Javied et al. 2015). Most of the waste is dumped in the vicinity of the drains and canals which easily finds its way into these water bodies during the rainy season. An estimated amount of 8 million m^3 wastewater is produced from the city and no treatment is carried out before its disposal (Qureshi and Sayed 2014). The addition of municipal sewage into canals and rivers and anthropogenic activities might be the ultimate cause of the reported high concentrations in present study. A similar trend was observed in previously published studies and municipal sewage is reported as a potential MPs contributor mainly originating from clothes washing and degradation of large plastic products (Auta et al. 2017; Browne et al. 2011). Moreover, the high reported concentration in the sullage carrier may also correspond to the nearby industrial and commercial activities. The results of two-way ANOVA showed that there was a significant variation among the MPs concentration at different sampling sites ($p < 0.05$). This observed variation might be based on the variability of contributing sources and human activities in the vicinity of studied area.

Abundance and distribution of MPs in terms of defined categories and size

The surface water was dominated with the fragments having relative abundance, i.e., 56.1% followed by fibers (38.6%), sheets (2.5%), foams (2.2%) and beads (0.6%). The similar trends were observed from the previously reported studies regarding surface water representing the abundance of fibers and fragments (Horton et al. 2017; McCormick et al. 2014). A large proportion of fibers in the water can be related to

Fig. 2 Comparison of the current findings with the previous reported studies
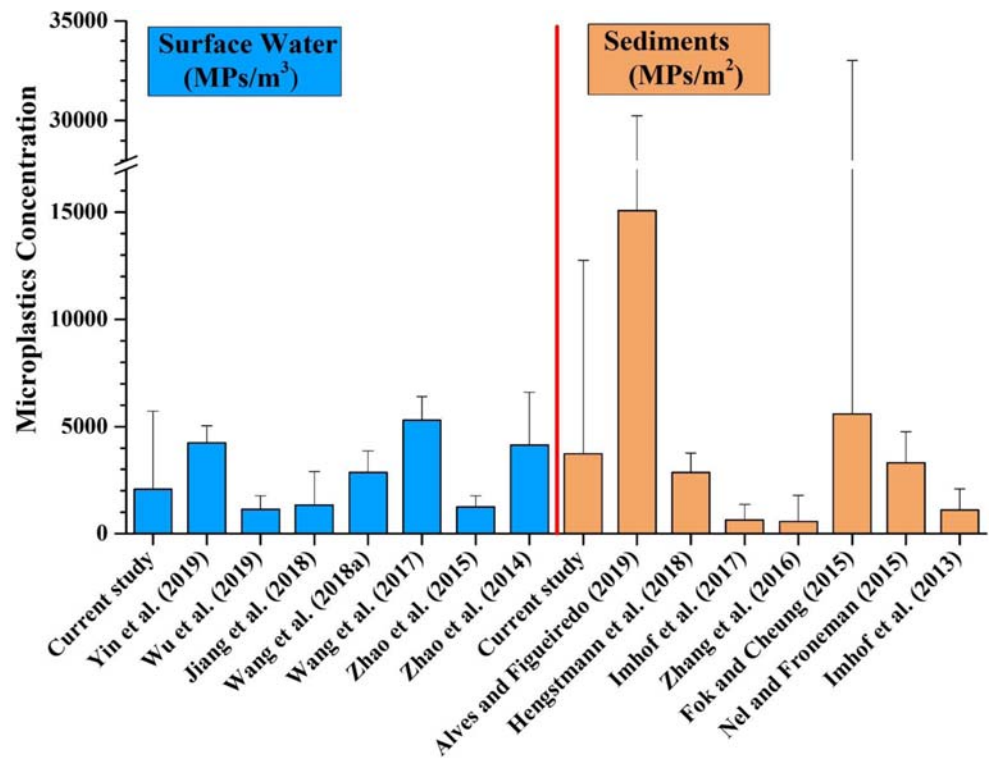
domestic activities such as washing of clothes, the ultimate cause of fibers into the sewers (Kang et al. 2018; Wang et al. 2017), whereas highest proportion of fragments in the water of sullage carrier can be related to degradation of nearby dumped municipal waste. Similarly, the relative proportion of fragments, fibers, foams, sheets and beads was 83.1%, 11.8%, 3.4%, 1.3% and 0.4% respectively in the sediment samples. Although, the sediment samples were dominated by the fragments, but the relative abundance of MPs types was comparable to previous studies (Fig. 4). The spatial distribution of MPs in terms of defined categories is shown in Fig. 5 while

some of the observed MPs are shown in Fig. S3 and S4. Despite being abundant in the freshwater environment, the fragments and fibers were also dominant in the estuarine sediments collected from the Gulf of Mexico with a relative abundance of 47.8% and 22.3%, respectively (Wessel et al. 2016). Moreover, fragments were also highly abundant (59.4%) in the coastal sediments (Bayo et al. 2019). The reported high content of fragments can also be related to large use of PE utensils and packaging materials (Claessens et al. 2011).

In terms of defined size, the large size MPs (300 μm– 5 mm) were found to be in the highest proportion in the water
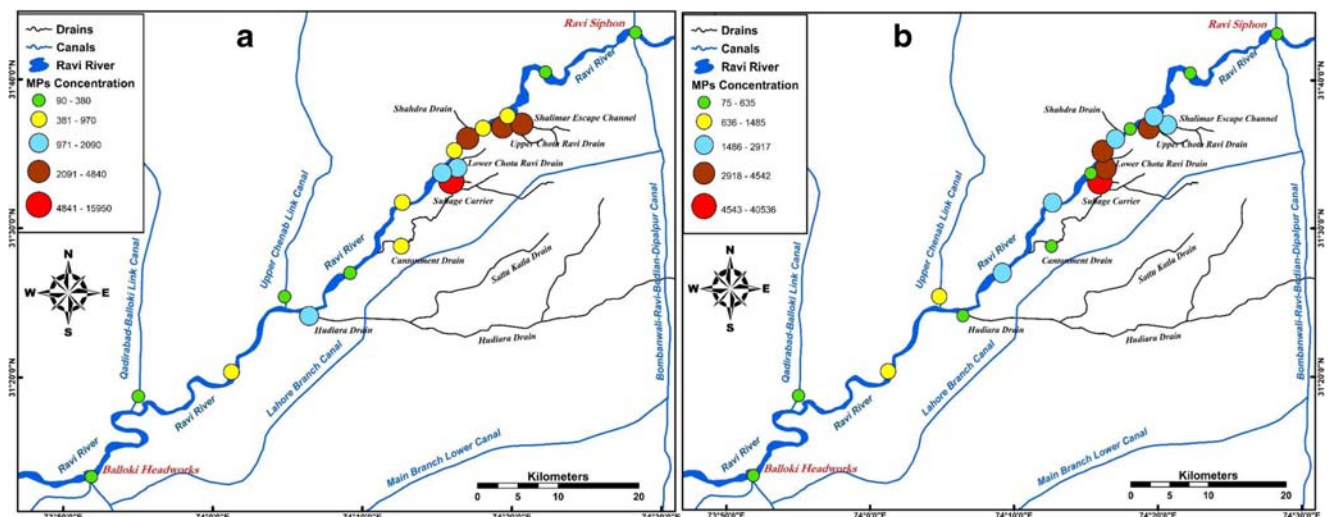

Fig. 3 Concentration profile of MPs in (**a**) surface water and (**b**) top sediments

Fig. 4 Comparison among the relative abundance of microplastic types reported by different studies
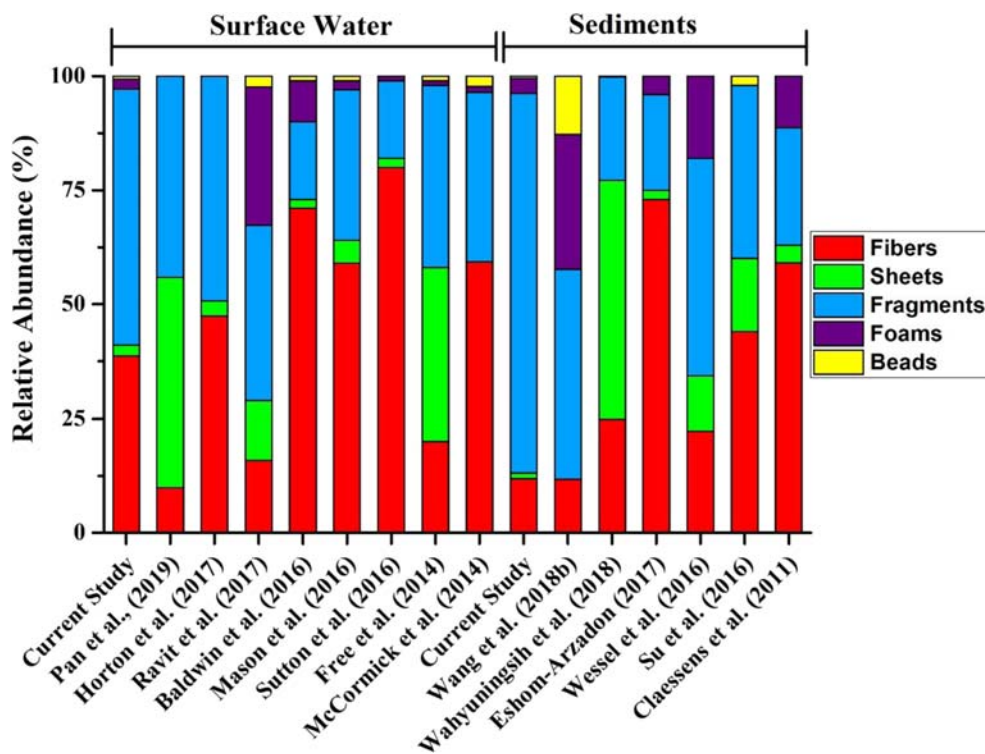
samples and the medium size MPs (150–300 μm) were dominant in the sediment samples (Fig. 6). A similar trend was observed from a study reported from China representing highest proportion of the medium size (50–300 μm) MPs in freshwater sediments (Wang et al. 2018b). The highest proportion of the large size MPs in the surface water could be due to the proximity of the source and maybe short time period of fragmentation (Isobe 2016; Pan et al. 2019). Fine size MPs were not detected in the upstream river section but their concentration increased in the downstream section. The increased concentration of MPs in the downstream section highlighted that the drains might be the potential sources of MPs to the

studied area (Castañeda et al. 2014; Estahbanati and Fahrenfeld 2016). Despite the presence of WWTPs around the world, varying concentrations of MPs were found in the downstream water bodies (Kang et al. 2018; Li et al. 2018; Mason et al. 2016; Raju et al. 2018; Sun et al. 2019). Nevertheless, the absence of wastewater treatment facilities in the selected study area depicted that municipal sewage is the ultimate cause of reported MPs pollution. Furthermore, a significant variation ($p < 0.05$) among the concentration of different size classes in the water samples at each location may be related to flow patterns of river, whereas the observed strong correlation ($r = 0.9$) in large and medium size MPs may
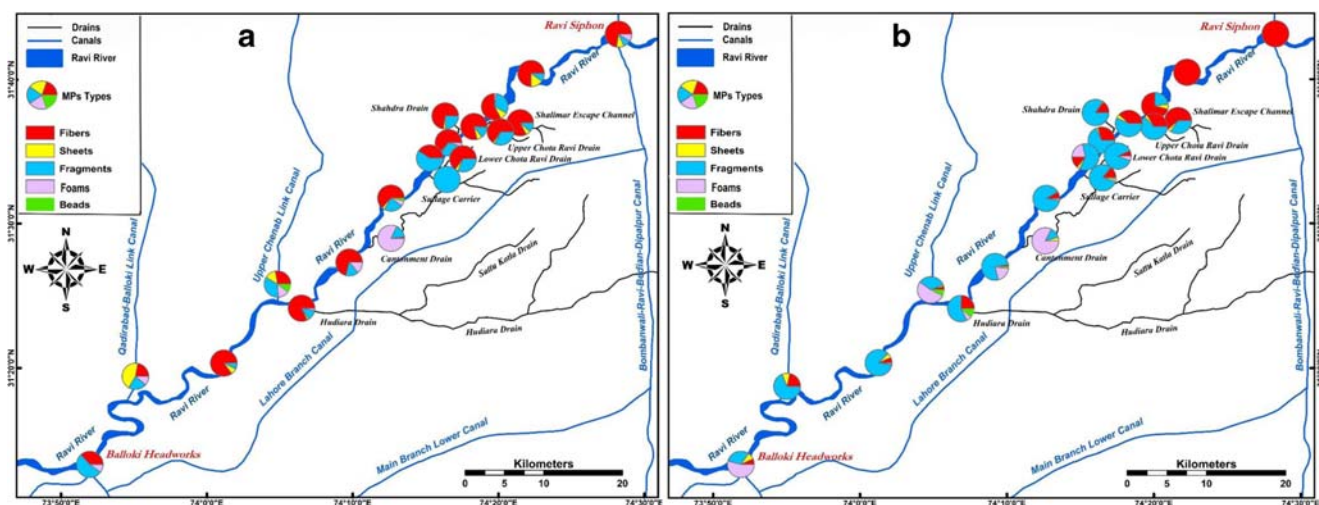
Fig. 5 Relative abundance of different MPs types in (**a**) surface water and (**b**) top sediments
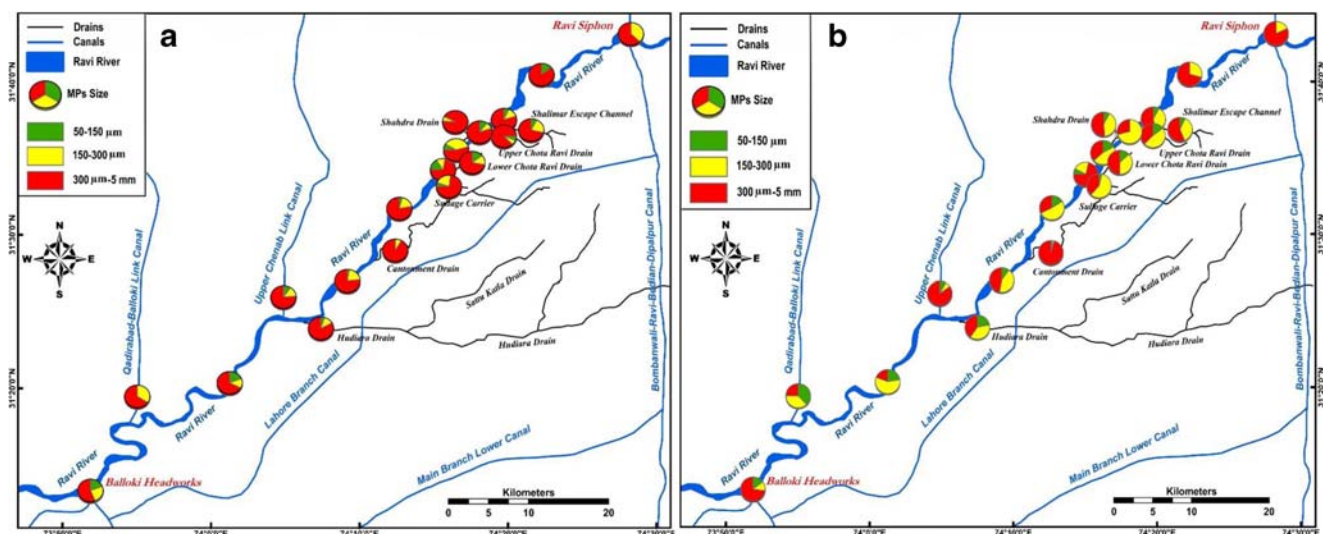
Fig. 6 Relative abundance of fine, medium and large size MPs in (a) surface water and (b) top sediments

be due to interlinked nearby anthropogenic sources. The information about the correlation is highlighted in the SI, Table S3.

Chemical composition

FTIR spectrometer was used for the identification of plastic polymers (Zhao et al. 2019). Representative MPs ($n = 50$) were collected from the 300-μm sieve and scanned through the ATR sensor. On the basis of the results obtained from the analysis of a representative fraction of particles, three different plastic polymers i.e. PE, PP, and PS, were detected in the present study. Concentrated NaCl solution ($d = 1.2$ g/cm^3) was a floatation media; thus, high-density polymers (e.g., PVC, PETE) were not detected (Coppock et al. 2017). However, the overall reported composition was consistent with many previous studies. It is evident from the literature that density of the floatation media used during density separation limits the number of polymers to be detected in the further analysis as only those polymers can be detected that have lower density than the floatation media itself (Hanvey et al. 2017; Löder and Gerdts 2015; Shahul Hamid et al. 2018). The composition analysis showed that the fragments, fibers and beads were composed of PE, the sheets consisted of PP, and the foams were composed of PS. Both forms of PE were detected in the current study, i.e., HDPE ($d = 0.93$–0.97 g/cm^3) and LDPE ($d = 0.91$–0.93 g/cm^3) but PS was mainly the expanded polystyrene (EPS, $d = 0.96$–1.04 g/cm^3), although the similarity index of different detected polymers was more than 80% for all the representative samples. Furthermore, the foam particles were purely made up of PS and their similarity index was the highest (Fig. S5).

Similar types of plastic polymers were detected in the littoral and beach sediments (Wang et al. 2017; Wessel et al. 2016) and both the PE and PP were also found to be the most abundant polymers in several reported studies (Pan et al. 2019; Shahul Hamid et al. 2018). Similarly, in the South Korean beach sediments, PS was the only plastic polymer detected (Heo et al. 2013; Lee et al. 2013; Shahul Hamid et al. 2018). In this region, PE is mostly used to make plastic utensils being used in the kitchen (e.g., jugs and bowls) and these utensils breakdown into small fragments when discarded in or near to the waterbodies. It was also reported that PE was used in more than 50% of facial scrubs sampled from the Spanish market (Godoy et al. 2019). PP is used to make wrappings used for packaging of different food items including candies and biscuits (Allahvaisi 2012). PE and PP are also considered to be widely used polymers in plastic products except the fibrous material mainly composed of PETE (Geyer et al. 2017; Hernandez et al. 2017; Zhao et al. 2019). PS beads are usually used to produce disposable food utensils, packing material, and sheets, and its contributing waste was widely observed alongside the water channels including drains and river itself. So, in this study, the detected polymers were found to be in a correlation with the potential usage of these polymers in the studied area.

Daily MPs discharge

On the basis of mean annual water flow, the average MPs load in the drains and canals was estimated to be 2.4 ± 2.4 billion MPs day^{-1} (Table 1). At minimum, 0.7 billion particles were discharged into the Ravi River from Shalimar Escape Channel within 24 h. The maximum contribution was made by the sullage carrier with 7 billion MPs particles per day. The reason might be the production units and open dumping sites along the channel. The floating plastic waste and runoff from the nearby dumping areas might be the reasons for the associated high discharge. Although the MPs pollution level in the link canals was lower than the drains, their daily MPs discharge values were greater than some drains that might be due to the

Water body	Category	Discharge (m^3 day^{-1})	Average load (MPs day^{-1})
Shalimar Escape Channel	Drain	2.1×10^{5a}	7.0×10^8
Upper Chota Ravi Drain	Drain	3.2×10^{5a}	1.1×10^9
Shahdra Drain	Drain	2.9×10^{5a}	1.4×10^9
Lower Chota Ravi Drain	Drain	1.5×10^{5a}	3.2×10^8
Sullage Carrier	Sullage Channel	4.3×10^{5b}	7.0×10^9
Cantonment Drain	Drain	5.1×10^{5a}	2.9×10^8
Hudiara Drain	Drain	1.0×10^{6b}	1.9×10^9
Upper Chenab canal	Link canal	1.9×10^{7c}	5.5×10^9
Qadirabad-Balloki canal	Link canal	3.5×10^{7c}	3.2×10^9
Mean (average)	–	6.4×10^6	2.4×10^9
Standard deviation	–	1.2×10^6	2.4×10^9
Total	–	5.7×10^7	2.1×10^{10}

[a] WASA, Lahore (unpublished data)

[b] Mahfooz et al. (2017)

[c] Irfan et al. (2019)

daily water discharge (Table 1). The corresponding MPs discharge was relatively higher than the studies conducted in Australia, Germany, Sweden, and the USA (Mintenig et al. 2017). The effluent was treated up to secondary level in Germany and reported an average discharge of 41,900 MPs day^{-1} from a single WWTP with a total expected discharge of 9–400 billion MPs $year^{-1}$. Because of the tertiary treatment of wastewater in the USA, the MPs discharge was calculated to be about 4.4 million MPs day^{-1} (Michielssen et al. 2016). These studies were conducted on the waterbodies installed with WWTPs, nevertheless in the present study area, no such treatment facility; therefore, the MPs load was higher than previously reported studies(Table 2). Only a few studies reported comparatively higher MPs concentrations in the treated effluents (Dris et al. 2015; Sun et al. 2019). Considering the individual estimated discharge of drains and canals, on average, 21.4 billion MPs might be released into Ravi river per day. The high reported discharge of the MPs may cause drastic effects on the aquatic fauna especially fish and other

freshwater invertebrates. The plastics may be predominated by different additives such as BPA and phthalates that may affect the aquatic environment and ultimately the consumers. In the future, a collaborative effort is required by local and federal authorities to limit the use of harmful polymers and plastics. The installation of WWTP and proper waste disposal is also recommended in the metropolitan city, Lahore (Carr et al. 2016; Murphy et al. 2016). Due to growing environmental concerns over the plastics pollution, policy-making and legislation are the key elements to protect the integrity of the urban aquatic ecosystems. Furthermore, the extended producer responsibility may also help to protect the water resources in Pakistan.

Conclusion

It is becoming evident that MPs pollution is predominant in freshwater bodies. Pakistan is clearly no exception in the

Country	Treatment level	Daily discharge (MPs day^{-1})	References
Pakistan	No treatment	2.4×10^9	Current Study
Finland	Up to secondary	1.0×10^7	Lares et al. (2018)
Germany	Up to secondary	4.2×10^4	Mintenig et al. (2017)
Australia	Up to secondary	4.6×10^8	Ziajahromi et al. (2017)
Netherlands	Up to secondary	7.5×10^8	Leslie et al. (2017)
Finland	Up to tertiary	1.3×10^6	Talvitie et al. (2017)
USA	Up to secondary	5.3×10^4	Mason et al. (2016)
USA	Up to tertiary	4.4×10^6	Michielssen et al. (2016)
France	Up to secondary	8.4×10^9	Dris et al. (2015)
Sweden	Up to secondary	4.3×10^4	Magnusson and Norén (2014)

paradigm; the reported investigation showed that the large size MPs (300 μm–5 mm) were dominant in the surface water system of metropolitan city, Lahore. Fragments were major contributors in the total MPs count; nevertheless, the fibers were dominant in the majority of the water samples. Sediments consisted of high proportion of the fragments with a very low proportion of beads and sheets. The proportion of foams was found to be higher in the water samples as compared to the sediment samples. Overall, the MPs concentrations quantified from the surface waters of the urban center, Lahore, were found to be comparable with the previously published work from different regions of the globe. Similarly, the daily MPs discharge from different drains and canals was also consistent with several international studies, whereas the lack of waste management facilities and proper recycling facilities is the ultimate cause of reported MPs pollution from the Lahore, Pakistan. Furthermore, with the growing use of plastic products in Pakistan, it is required to quantify and compare the MPs pollution level in different areas. This study was the first of its kind contributing significantly to bridge the knowledge gap concerning MPs pollution in surface water of the urban systems. In the future, detailed investigations are recommended to fully highlight the MP pollution from Pakistan. The efforts must also be made to aware the public with the impacts of these anthropogenic polymers on the human and ecosystem health to limit the use.

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