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Occurrence and characteristics of microplastics in surface water and sediment of Zayandeh-rud river, Iran

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Abstract

Background: Zayandeh-rud river is the most important river in the central regions of Iran and the present study aimed to provide new insights into microplastics (MPs) pollution in surface water and sediments of this river.

Methods: Water and sediment samples were collected in July 2021 from 19 sampling sites along the river. Organics matters were removed from the samples by wet peroxide oxidation (WPO), and MPs were extracted by floatation in $ZnCl_2$-saturated salt and filtration on a polytetrafluoroethylene (PTFE) membrane filter. Trapped MPs on the filter were counted and qualified by a stereomicroscope.

Results: MPs were found in 13 sites from 19 sampling sites along the river. The minimum and maximum levels of MPs in water samples were 0 and 51 ± 16.5 particles/m^3, respectively. MPs also were detected in the sediments of all sampling sites except the first two sampling sites (the maximum level was 58 ± 25.9 particles/kg as dry sediment). Fragments were the most common shape of MPs in both water and sediment samples. 72.3% of MPs detected in water samples were 1-5 mm in size, while this percentage for sediment was 49.2%. The five main polymer types found in water and sediment samples were polyethylene terephthalate (PET), polyethylene (PE), polypropylene (PP), polystyrene (PS), and polyvinyl chloride (PVC).

Conclusion: These levels of MPs in the water and sediments of Zayandeh-rud river and longtime persistence of plastics in the environment is a significant threat to environmental and human health and need serious attention to restrict MPs release into the river.

Keywords: Rivers, Polyvinyl chloride, Iran, Spectroscopy, Fourier transform infrared

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Introduction

Plastic has become a major commodity worldwide that penetrates every aspect of human life due to its unique properties such as cheapness, versatility, durability, and strength. Extensive use of plastics in packaging, medicine, construction, electronics, agriculture, and many other industries has led to intense growth in plastic production so its annual global production reached 368 million tons in 2019 (1). Plastics are made of a large variety of synthetic polymers, mainly polyethylene terephthalate (PET), polyethylene with various densities (LDPE, LLDPE, HDPE), polypropylene (PP), polystyrene (PS), polyvinyl chloride (PVC), polyamides (PA), and polyurethanes (PU) (2).

After the release of plastics into the environment, they are subjected to progressive breakdown by abiotic (physicochemical) and biotic factors in the environment, which leads to the fragmentation of large pieces of plastics into small pieces (less than 5 mm in diameter or length) called microplastics (MPs) (3). MPs are classified as primary and secondary MPs. Primary MPs are purposefully manufactured for the application in medicines, industries, and personal care products, while secondary MPs are formed through the fragmentation of larger plastic parts (4). Extensive use of plastics, as well as environmental persistence and improper disposal, has made MPs a significant threat to the environment and human health. It is estimated that each year, about 13 million tons of plastic waste enter the oceans, and the weight of plastics in aquatic environments will exceed that of fish (5).

MPs, due to their small size, are more easily ingested by living organisms and even transferred up the food chain (6). The ingestion of MPs can cause health effects such as false satiety, enzyme production inhibition, reproductive complications, growth retardation, and reduction and induction of oxidative stress (7). The adverse effects of MPs can be affected by the polymer types, size, shape, and color of MPs (8). Adsorption of toxic substances of water (e.g., heavy metals, pesticides, polyaromatic hydrocarbons, etc) on the large surface area of MPs enhances the accumulation, persistence, and transfer of these pollutants in the food chain (9). MPs surface is also a suitable substrate for the formation of microbial biofilms that may include dangerous pathogens for different organisms (10).

Research on aquatic MPs pollution from the small ponds and rivers to the great oceans has been a worldwide research topic since the 1970s (11), and large-scale investigations revealed huge MPs pollution accumulation in aquatic ecosystems (4). Rivers are important sinks for MP's pollution discharged from adjacent industrial and domestic pollution sources. Rivers are the main pathways for the transport of MPs from terrestrial origins to marine environments. Monitoring water quality and determination of MPs' content is a systematic way to track the fate and effects of MPs on the environment, but the degree of this pollution remains largely unknown due to inadequate monitoring (12). MPs after release to rivers might be temporarily suspended in the water column or settle in river sediments (temporarily or permanently), depending on the MPs' characteristics, river geomorphology, water flow velocity, water depth, currents, floods, etc (13). Therefore, the determination of MPs in both water and sediments of the river is necessary for a comprehensive evaluation of MPs occurrence. MPs pollution in water and sediments has been reported in several rivers around the world (14-17).

Zayandeh-rud is the most important river in the central regions of Iran. It starts in the central parts of the Zagros Mountains and flows 400 km eastward before ending in the Gavkhouni wetland, southeast of Isfahan province (Figure 1) (18).

Zayandeh-rud basin covers 41500 km^2 and supplies drinking water to about 5 million people. Many large industries in the province (e.g., steel mill companies, cement, power plants, and petrochemical industries) also supply their water from this river. Agriculture by the river is one of the most prosperous jobs in the province and provides the main portion of the required agricultural products for the people of the province. Gavkhouni wetland hosts a large number of birds that migrate to the area during winter (19). One of the largest cities located in the central Zayandeh-rud basin is Isfahan, which has a population of about 2 million people. Life in Isfahan is dependent on Zayandeh-rud.

There are multiple sources for MP release into Zayandeh-rud. The waste and effluent of many villages and small towns around the river, as well as the wastewater of many industries, are discharged into the river. There are several tourist places, natural promenades, and resorts all along the river. Due to, the drinking and agricultural use of Zayandeh-rud water, any contamination, including MPs is quite important and could directly affect community health.

To the best of our knowledge, there is no study evaluating the MPs occurrence in water and sediments of Zayandeh-rud. This study aimed to determine MPs abundance in water and sediment samples along Zayandeh-rud from its sources to the end of the urban section of the river

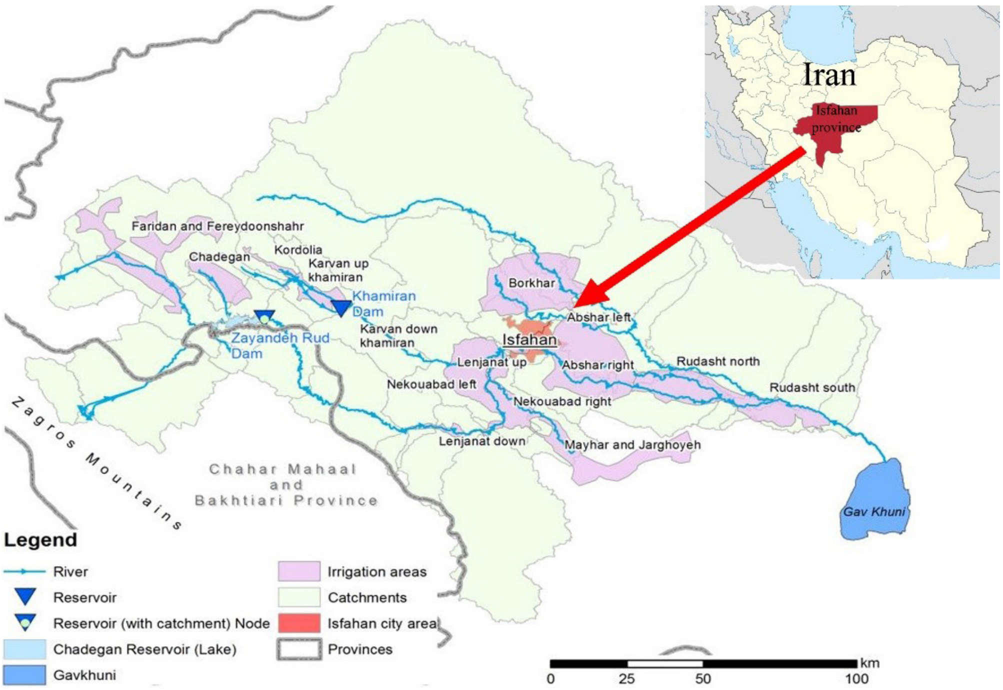

Figure 1. The map of Zayandeh-Rud in Isfahan province, Iran (18)

(Isfahan city). It was hypothesized that the MP pollution increased from the sources of the river to the urban areas.

Materials and Methods

Chemicals and equipment

NaCl, $ZnCl_2$, and Iron (II) sulfate were purchased from Merck chemicals company (Merck, Darmstadt, Germany). 30% H_2O_2 was purchased from Barad chemical company (Tehran, Iran). Polytetrafluoroethylene (PTFE) membrane filters were purchased from JET Biofil company (Guangzhou, China). Fourier transform infrared spectrometer (FTIR) (Bruker Optics, Milan, Italy) was used to determine polymer composition, and stereomicroscope (DSM3000, Sa-Iran, Iran) was used to count MPs.

Study area and sampling sites

Zayandeh-Rud, which has a length of 400 km and an average flow rate of 38 m^3/s, is the largest river in the central parts of Iran. Approximately, 350 km stretch of Zayandeh-rud (from the source of the river in the Zagros Mountains to the end of the urban part of the river after Isfahan city) was selected for this study. The sampling sites were selected according to the hydrology stations of the Isfahan water management organization and river direction. Finally, 19 sampling sites were selected according to the map presented in Figure 2. Water and sediment samples were taken once at the same sampling site in July 2021.

Water sample collection

A stainless-steel mesh sieve (mesh 250) was used for collecting all particles (>55 μm) in the river water. At each sampling site, 40 L of river water was taken by a stainless-steel water bucket and filtered through a plankton net. The trapped particles were removed from the net using 100 mL of deionized water in glass containers and taken to the laboratory for further analysis (13). The water sampling was repeated at each site in triplicate.

Sediment sample collection

Sediment samples were taken from the low-depth sides (shoreline) of the river. Three square plots (50 cm × 50 cm) of the riverbank were selected randomly at each sampling site. Sediment samples were taken to a depth of 2-5 cm roughly using a stainless-steel shovel, and then, transferred into a glass sampling container, mixed, and combined to make one sample (14,20).

Figure 2. Location of sampling sites along the main route of Zayandeh-Rud

Water sample preparation and extraction

The MPs abundance in the collected water samples was extracted according to the method suggested by the National Oceanic and Atmospheric Administration (NOAA) for the analysis of MPs in environmental samples with some little modifications (21). To remove > 5 mm particles, the collected water samples were run through 5 mm metal sieves, the residue was discarded, and the filtrate was processed for wet peroxide oxidation (WPO). Briefly, 20 mL of a 0.05 M Fe (II) solution and 20 mL of 30% H_2O_2 were added to each sample, mixed for 5 min at room temperature, and heated on a stirring hotplate (70°C) until gas bubbles were observed (starting the Fenton reaction). Then, the sample was removed from the hotplate and placed in the fume hood for 24 hours to complete the digestion of organic matter. The samples were covered with aluminum foil, avoiding atmospheric deposition of particles during the reaction. An additional 20 mL of 30% H_2O_2 was added to the sample whenever the organic particles were visible in the samples (22).

After the organic matter digestion, the sample was processed for density separation. 200 mL of saturated NaCl solution (1.2 g/mL) was added to the sample. This mixture was vigorously stirred for 5 minutes using a vortex mixer and left to settle for 4 hours. The second flotation procedure was applied to the sample by saturated $ZnCl_2$ solution (1.5 g/mL) to extract higher-density MPs such as PVC. The floatation procedure was repeated at least three times to extract the maximum amounts of MPs from the water samples. At the end of each floatation step, the supernatant containing floated particles was vacuum filtered through a PTFE membrane filter (Merck Millipore, diameter 25 mm, pore size 0.45 μm) using glass filtration apparatus and a vacuum pump. The filter was covered with aluminum foil and dried at 40°C for 24 hours. The filter was subjected to subsequent identification and quantification of the trapped MPs.

Sediment samples preparation and extraction

The MPs were extracted from the sediment samples based on the density separation technique according to the previously developed method by Masura et al (23) with some modifications. The sediments were dried in an incubator at 40°C for 72 hours and subjected to manual homogenization. 50 g of dry sediment sample was transferred into 500 mL glass flasks (in two replicates), and 200 mL of saturated NaCl solution (1.2 g/mL) was added to the flasks. This mixture was vigorously stirred for 5 min using a vortex mixer and left to settle for 4 hours. The second flotation procedure was applied to the sample by saturated $ZnCl_2$ solution (1.5 g/mL) to extract higher-density MPs such as PVC. The floatation procedure was repeated at least three times to extract the maximum amounts of MPs from the sediment samples. At the end of each floatation step, the supernatant, which contains floated particles, was sieved using a metal sieve (5 mm pore size) and transferred into a secondary glass flask, and processed for WPO as described previously. After WPO, the samples were vacuum filtered through a polytetrafluoroethylene (PTFE) membrane filter (Merck Millipore, diameter 25 mm, pore size 0.45 µm) using glass filtration apparatus and a vacuum pump. The filter was covered with aluminum foil and dried at 40°C for 24 h. The filter was subjected to the identification and quantification of the trapped MPs.

MPs quantification

The trapped MPs on the filter were observed and quantified under a stereomicroscope (DSM3000, Sa-Iran, Iran) with a magnification of up to × 100. MPs were distinguished from other particles according to the method described by Campbell et al (24). Briefly, suspected particles were tested using a heated needle tip to confirm that they would melt. This method significantly improves the quality of MPs identification. Detected MPs were counted and classified by shape (fiber, film, pellet, and fragment) (25). The size of MPs was also measured (at the longest dimension) and divided into different categories based on their size (1-5 mm and < 1 mm particles).

Identification of MPs

An attenuated total reflectance Fourier transform infrared spectrometer (FTIR) (Bruker Optics, Milan, Italy) was used to determine polymer composition by comparing the FTIR spectrums of samples and standard reference spectrum with similarity values mostly higher than 80%. Bruker Optics SH spectral libraries (Bruker Optics, Ettlingen, Germany) were used to compare samples and standard FTIR spectra (26).

Quality assurance/Quality control

MPs are present in environmental media, laboratory instruments, as well as protective equipment such as clothes and gloves. To avoid secondary pollution of samples by MPs during sampling and analysis procedures, preventive measures were taken according to the recommendations of previous studies (27). Briefly, only glass containers and metal sieves were used. The samples were covered with watch glass during preparation and stored in glass Petri dishes. The laboratory instruments were cleaned carefully with filtered deionized water. The time of exposure of samples to the air was reduced as much as possible. Nitrile gloves, cotton masks, and cotton lab coats were worn during all experiments. All experiments were carried out in a fume hood.

Statistical analyses

All statistical analyses were done using SPSS version 22.0 (SPSS Inc, Chicago, IL, USA), and all data were expressed as mean ± Standard Deviation (mean ± SD). The abundance of MPs in water samples was expressed in particles/m^3 and for sediment samples in particles/kg as dry weight of sediment. The homogeneity and normality of MPs abundance were determined by the Kolmogorov-Smirnov test. The differences among MPs abundance in sampling sites were determined using independent t test. Differences were considered statistically significant at $P < 0.05$. The Microsoft Excel 2016 software was used to draw charts and graphs.

Results

MPs abundance in water samples

MPs were found in water samples from 13 sites out of 19 sampling sites along the selected section of Zayandeh-rud river. The abundance of MPs in water samples from all sampling sites are presented in Table 1. As seen, in the first 5 sampling sites (near the sources of the river), no abundance of MPs was found, but from site #6 to the last site (#19), the abundance of MPs increased continuously in the water samples (Figure 3). The water sample from site #19 (at the end of the urban section of the river in Isfahan city) contained the highest level of MPs (51 ± 16.5 particles/m^3). The abundance of MPs in water samples from sampling site #6 to sampling site #19 was statistically different ($P < 0.05$).

Table 1. MPs abundance in water and sediment samples from 19 sampling sites along Zayandeh-rud river

Number	Sampling sites	Water sample (particles/m^3)		Sediment sample (particles/kg dry sediment)	
		Mean	SD	Mean	SD
#1	Chelgerd	0.0	0.0	0.0	0.0
#2	Ghaleh-Shahrokh	0.0	0.0	0.0	0.0
#3	Sad-e-Tanzimi	0.0	0.0	0.3	0.6
#4	Markadeh	0.0	0.0	1.3	1.5
#5	Pol-e-Zamankhan	0.0	0.0	4.7	2.5
#6	Cham Tagh	0.7	0.6	2.0	1.0
#7	Cham Noor	0.0	0.0	3.0	1.7
#8	Karchegan	1.3	1.2	6.7	4.5
#9	Bagh Bahadoran	2.7	1.5	12.7	9.1
#10	Cham Aseman	5.3	2.5	6.0	3.6
#11	Shahr-e-Zayandeh-rud	5.3	3.5	10.3	9.5
#12	Zarrin Shahr	8.0	4.6	26.0	14.5
#13	Vinicheh	8.3	2.1	20.0	11.4
#14	Nekoabad	13.0	4.0	23.3	16.3
#15	Falavarjan	18.3	6.5	56.7	6.7
#16	Dorcheh	26.3	7.6	41.3	19.1
#17	Pol-e-Vahid	35.0	14.5	62.3	36.3
#18	Pol-e-khajo	39.3	23.6	67.3	29.7
#19	Pol-e-Shahrestan	51.0	16.5	58.0	25.9

MPs abundance in sediment samples

Except for the first two sampling sites (#1 and #2, near the sources of the river), MPs were detected in all sediment samples (Table 1). The abundance of MPs in sediment samples increased significantly from the first sampling sites along the river to the last ones (Figure 3). The last 5 sampling sites (near and in Isfahan city) contained the highest levels of MPs in sediment samples as well. The abundance of MPs was not statistically different ($P > 0.05$) in these sites. The average abundance of MPs in the sediments of the urban section of Zayandeh-rud was 57.2 ± 11.2 particles/kg dry sediment.

The simple linear regression test (Pearson's parametric regression) was used to correlate the MPs abundance in water and sediment samples (Figure 4). The P value of this statistical analysis was < 0.001 and the correlation coefficient (r^2) was 0.891, indicating a strong relationship between MPs abundance in water and sediments of the river.

Shape and size of detected MPs

Detected MPs in water and sediment samples were classified by shape (fibers, pellets, and fragments) and size (1-5 mm and < 1 mm particles) according to their orthogonal longest axis. The distribution of MPs with different sizes in water and sediment samples is presented in Figure 5. The size of 49.2% of detected MPs in sediment samples was < 1 mm while this portion for water samples was 72.3%.

Typical shapes of detected MPs were taken by a digital camera attached to a stereoscopic microscope and are shown in Figure 6. The most common detected shape among the collected MPs in both the water and sediment samples were fragments (53.1% of collected MPs in water samples and 43.9% of plastic particles in sediment ones). The rest of the particles were either fibers or fragments (Figure 7). MPs in the form of pellets (according to the definition of pellet by Kershaw et al (25) were not detected in both water or sediment samples.

Identification of collected MPs

Types of collected plastic particles were identified using

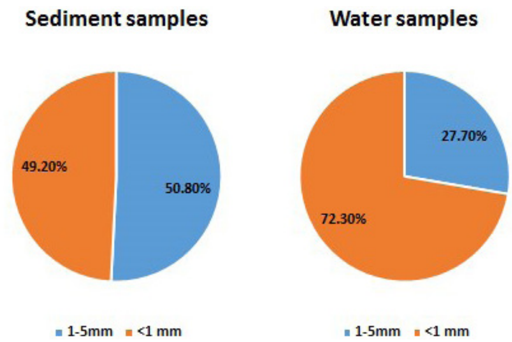

Figure 5. Size distribution of MPs detected in Zayandeh-rud

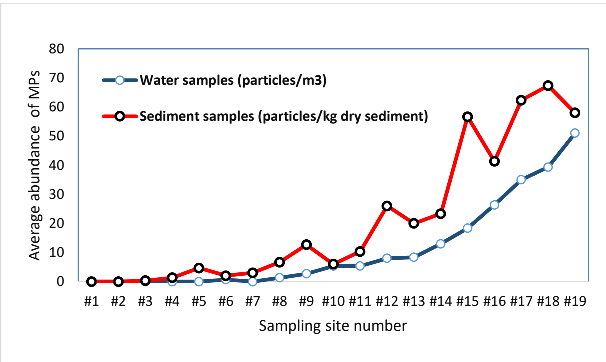

Figure 3. The trend of MPs pollution in water and sediment samples along Zayandeh-rud

Figure 6. Typical shapes of MPs detected in water and sediment samples of Zayandeh-rud

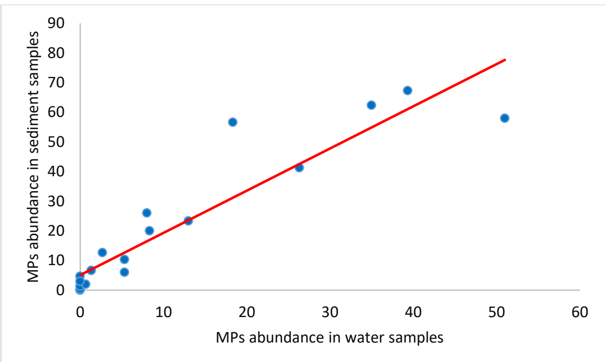

Figure 4. Correlation between MPs abundance in water and sediment samples in 19 sampling sites of Zayandeh-rud

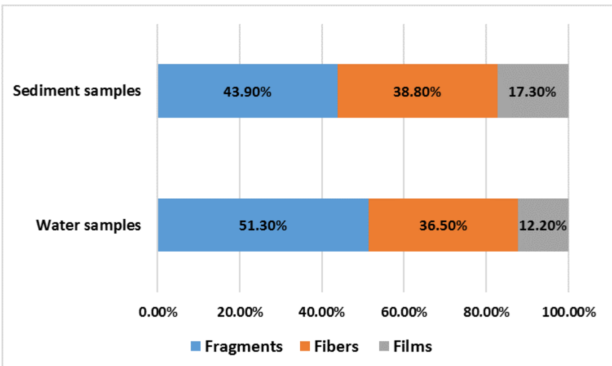

Figure 7. MPs with different shapes in water and sediment samples of Zayandeh-rud

FTIR spectroscopy. This method allows to identify plastic polymers based on their specific infrared absorption bands. Each polymer type was identified using the FTIR spectrum library and confirmed according to the proposed decision tree for polymer identification by Konechnaya et al (28).

The FTIR spectrum of the collected samples and the typical spectrum of the eight most commonly used polymers, including PE, PP, PVC, PS, PET, PMMA, PU, and polyamide (PA) (Nylon) (28), are provided in Figure 8. The presence of all eight polymers in detected MPs was confirmed, although the abundance of each type of polymer in the samples was significantly different. The five main polymer types found in water samples were PE, PET, PP, PS, and PVC, respectively, while PE, PP, PVC, PS, and PET were dominant in the sediments, respectively.

Discussion

The present study is the first work conducted on monitoring MPs levels in water and sediments of Zayandeh-rud river. So, there is no previous data on the MPs' pollution of Zayandeh-rud for comparison with the results of the present study. In this study, the obtained results were compared with the reported MPs levels in water and sediments of other rivers from different countries. But it should be noted that inter-study comparisons must be made with caution due to significant inconsistencies in the design of studies, sampling, and counting methods, as well as the units by which the abundance of MPs was reported.

MPs abundance in water samples

The results of 12 recent studies on the MPs determination in water and sediments of 12 rivers from 9 different countries are summarized and presented in Table 2. As can be seen, the abundance of MPs in some rivers like Pearl River in China (0.005 to 0.7 particles/m^3) (29) and the Tamsui River in Taiwan (2.5 to 83.7 particles/m^3) (30) were negligible, while the water of some other rivers like the Wei River in China contains significant amounts of MPs (3670 to 10700 particles/m^3) (31). Significant heterogeneity in the reported MPs levels by various studies can be attributed to sampling methods, geographical and natural conditions of the rivers, as well as industrial and anthropogenic activities in the river's basin.

In the present study, the average abundance of MPs in Zayandeh-rud river water was 51 ± 16.5 particles/m^3. These results are consistent with the reported range of MPs' abundance in similar studies (Table 2). No amounts of MPs were found in the 5 first sampling sites of Zayandeh-rud (near the headstream of the river). The source of Zayandeh-rud water is spring water and snow thawing. It seems that there is no notable source for the contamination of spring water and snow by the plastic particles, and so no amounts of MPs in the first sampling sites cannot be surprising. Determination of MPs abundance in snow and spring water in further studies could complete the findings of this study.

MPs levels in the last sampling sites (in Isfahan city) were about 50 times higher than the first sampling ones. Several small and large industries, agricultural activities in the river basin, the release of municipal and rural waste, and effluent to the river are the main sources of MPs in Zayandeh-rud River. As seen in Figure 3, no sudden sharp rise in MPs abundance was observed along the river, indicating that there are no hotspots for MPs release into the river and different sources enter MPs slowly and continuously to the river.

Plastic particles could release into the river in the form of MPs or larger plastic particles. These large particles undergo intense weathering and abrasion by the effects of sands in the river as well as surface runoff. The combined and additive effects of sands and runoff lead to the intensive fragmentation of larger plastic particles and production of MPs. It is not possible to determine what share of MPs entered directly into the rivers or was produced secondarily by mechanical degradation in the rivers.

MPs abundance in sediment samples

River sediment can act as a sink and temporary repository for the accumulation of sedimented MPs. MPs also accumulate in the sediments over the dry season (38). There is not any previous study on the MPs pollution of Zayandeh-rud river sediments in the literature. Therefore, here, the results of this study were compared with the results of similar studies on other rivers. MPs abundance in sediments of some important rivers from different countries is presented in Table 2. It must be considered that sediment samples collected from different layers, can result in inaccurate interpretation and comparison of the actual abundance of MPs in river sediments. As the majority of MPs are accumulated on the surface sediments (0-5 cm), this layer is regarded as the most polluted layer (39).

Detected amounts of MPs in Zayandeh-rud river sediments by the present study ranged from 0 to 58 ± 25.9 particles/kg. These levels are close to the lowest reported levels of MPs in sediments of similar rivers (Table 2). The findings of this study revealed that MPs are ubiquitous in sediments of Zayandeh-rud and all sampling sites (except for the first two sites) contained significant levels of MPs. MPs abundance in sediments increased significantly along the river from its sources to the urban section of the river in Isfahan city. This increase is not unexpected and is consistent with the increase in industrial and agricultural activities as well as human residential effects along the river. The strong correlation between MPs abundance in the water and sediment samples along the river indicated that MPs constantly exchange between these two phases (water and sediment), and the abundance of MPs in each

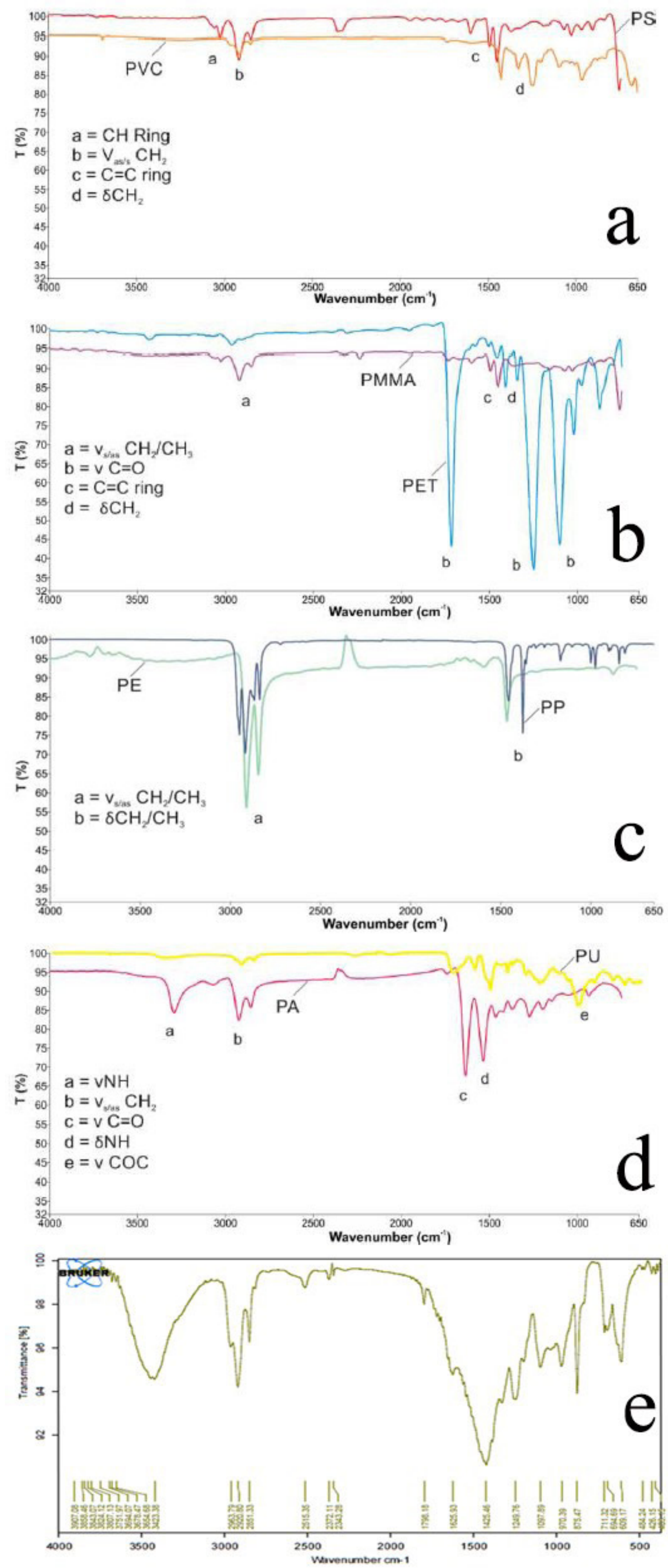

Figure 8. FTIR spectrum of collected MPs and typical spectra of eight most commonly used polymers (28). (a) Typical spectra of PVC and PS; (b) Typical spectra of PMMA and PET; (c) Typical spectra of PE and PP; (d) Typical spectra of PU and PA; e) FTIR spectrum of collected MPs

Table 2. MPs abundance in water and sediments of some important rivers worldwide

Study	River	Abundance of MPs	
		Water	Sediments
He et al (32)	Brisbane River, Australia	***	0.18 to 129.20 mg/kg or 10 to 520 items/kg
Castañeda et al (33)	St. Lawrence River, Canada	***	Average of 13759 ± 13685/m^2 of sediments
Jiang et al (34)	Tibet Plateau River, China	483 to 967 items/m^3	50 to 195 items/kg
Mani et al (35)	Rhine River, Germany	***	260 to 11070 MPs/Kg
Pan et al (36)	Zhangjiang River, China	Average of 246 items/m^3	***
Wong et al (30)	Tamsui River, Taiwan	2.5 ± 1.8 to 83.7 ± 70.8 particles/m^3	***
Mai et al (29)	Pearl River, China	0.005-0.7 particles/m^3	***
Sekudewicz et al (13)	Vistula River, Poland	1.6 to 2.55 items/L	190 to 580 items kg^{-1}
Chauhan et al (20)	Alaknanda, India	566 particles	389 particles
Ding et al (31)	Wei River, China	3.67 to 10.7 items/L	360 to 1320 items/kg.
Eo et al (37)	Nakdong River, South Korea	293 ± 83 to 4760 ± 5242 particles/m^3	1970 ± 62 particles/kg
Rodrigues et al (17)	Antuã River, Portugal	to 8.3 mg/m^3 or 58–193 items/m^3	13.5 to 52.7 mg/kg or 100 to 629 items/kg
Present study	Zayandeh-rud River, Iran	0 to 51 ± 16.5 particles/m^3	0 to 58 ± 25.9 particles/kg

*** Not measured

phase is affected by another phase.

Microplastic characteristics

Fragments were the most common shape of MPs found in Zayandeh-rud river (in both water and sediment samples), which is consistent with the results of previous similar studies (20,33,40), indicating that breaking of larger plastic pieces to smaller fragments is the main source of MPs in the river.

In terms of size, dominant portion of detected MPs in water samples were between 1 to 5 mm while in sediment samples, the share of MPs in two classes (1-5 mm and < 1 mm particles) was not significantly different (Figure 7). The tendency of larger plastic particles to precipitate and enter into river sediments is a possible cause of a higher share of 1-5 mm MPs in the sediment samples compared to the water samples. Comparison of MPs size ranges in the present study with those in similar works is challenging due to the use of various sieves (with different mesh sizes) for extracting MPs from rivers' water and sediments in different studies as well as the use of different classification methods for plastic particles based on their sizes.

The results of FTIR spectroscopy demonstrated that all the main common types of plastic polymers are ubiquitous in the water and sediment of Zayandeh-rud. Regarding the various sources for releasing plastic waste into rivers including industrial, agricultural, and municipal activities, the presence of all plastic types in the collected samples was not surprising. Dominant types of polymers in water and sediment were similar but the abundance of PP in water samples was higher than PET. The lower density of PP compared with PET and the tendency of PP MPs to float in water could be the main causes of this difference. PE and PP have been reported in previous studies as the two most common polymer types with widespread distribution in freshwater and marine environments (32). These findings are consistent with the results of the present study.

Conclusion

The present study aimed to investigate the MP pollution in Zayandeh-rud water and sediments. In this present study, MPs occurrence in 19 sampling sites along Zayandeh-rud river (from its sources in the Zagros mountains to the urban section of the river in Isfahan city) were determined and valuable information about MPs pollution pattern in Zayandeh-rud river was provided.

The findings of this study indicated that significant amounts of MPs release into the river from various sources, and the abundance of MPs in the water and sediment of the river increase continuously along the river course. The significant correlation between MPs abundance in the sediment and water samples confirmed the role of river sediments as an environmental sink for MPs. The results also demonstrated that not all plastic pollution is deposited in benthic or shoreline sediments and a significant amount of MPs is transferred by water flow to the end of the river in the Gavkhouni wetland. The presence of these levels of MPs pollution in the water and sediment of Zayandeh-rud and accumulation of this volume of MPs in the Gavkhouni wetland during the next years is quite serious. The water of Zayandeh-rud is used for supplying drinking water for about 3 million peoples in the river basin, and to irrigate thousands of hectares agricultural lands, risk assessment studies are strongly suggested. Determination of MPs pollution in the Gavkhouni wetland could complete the results of the present study and provide general insight about MPs pollution in the river basin.

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Authors' contribution

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Formal analysis: Bahareh Shoshtari-Yeganeh.
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Competing interests

The authors declare that they have no competing interests.

Ethical issues

The proposal for the present study was reviewed and approved by the Ethics Committee of Isfahan University of Medical Sciences (Ethical code: IR.MUI.RESEARCH.REC.1399.244).

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