water

MDPI

Article

Microplastics in the Syr Darya River Tributaries, Uzbekistan

Yulia Frank [1,*], Alijon Khusanov [2], Mansur Yuldashov [3], Egor Vorobiev [1], Svetlana Rakhmatullina [1], Alexey Rednikin [1], Sherzodbek Tashbaev [2], Sarvinoz Mamatkarimova [2], Kristina Ruchkina [1], Sirojiddin Namozov [4], Laziz Turaev [4], Jobir Sobirov [4], Akramjon Yuldashev [2] and Danil Vorobiev [1]

1. Biological Institute, Tomsk State University, Tomsk 634050, Russia; ruchkinakristina99@mail.ru (K.R.)
2. Department of Zoology and Biochemistry, Andijan State University, Andijan 170100, Uzbekistan; a_xusanov75@adu.uz (A.K.); akramyuldashev@edu.uz (A.Y.)
3. Department of General Zootechny and Veterinary, Tashkent State Agrarian University, Tashkent 100140, Uzbekistan; mansuryuldashov@mail.ru
4. Institute of Zoology, Academy of Sciences of Republic of Uzbekistan, Tashkent 100047, Uzbekistan; sirojiddin.namozov.90@mail.ru (S.N.)

* Correspondence: yulia.a.frank@gmail.com

Abstract: The objective of the study was a pre-screening of the microplastic (MP) content in surface water and benthic sediments of Kara Darya and Chirchiq rivers, the first-order tributaries of the Syr Darya River (Uzbekistan). For the first time, surface water and benthic sediment samples were taken from this region, and quantitative screening of MPs 0.15–5.00 mm in size was performed. A combined visual and µRaman-based methodology was used to quantify and characterize artificial polymer microparticles from the surface water and bottom sediments of two rivers. The average abundance of MPs in the Kara Darya River and Chirchiq River waters was found to be 4.28 ± 0.09 and 0.95 ± 0.36 items per m^3, and that in benthic sediments attained 244 ± 28.9 and 333 ± 11.5 items per kg of dry soil, respectively. MP concentration in surface water and benthic sediments of the Kara Darya River significantly exceeded (*p*-value < 0.01) that in the Chirchiq River. Microfibers were most abundant; the proportion of MP fibers in the water of the Kara Darya and Chirchiq rivers amounted to 89 and 95%, respectively, and that in benthic sediments of the rivers was 86 and 84%, respectively. The dominance of microfibers may indicate the route of entry to the rivers through domestic wastewater treatment plant discharges. The polymer microparticles in the surface water and benthic sediments of the Kara Darya and Chirchiq rivers were mainly represented by polyethylenterephtalate (PET), which accounted for half of all MPs detected in the Kara Darya River. Microparticles of textile origin were particularly abundant in the Kara Darya River, where viscose and nylon fibers were also found, which suggests the leading role of synthetic textiles in the pollution. The reported data are the first experimental evidence of MP pollution of the Syr Darya tributaries, but the distribution and circulation of MPs in surface water in Central Asia requires further comprehensive studies.

Keywords: microplastics; Uzbekistan; Syr Darya River system; textile microfibers; surface water; benthic sediments

check for updates

Citation: Frank, Y.; Khusanov, A.; Yuldashov, M.; Vorobiev, E.; Rakhmatullina, S.; Rednikin, A.; Tashbaev, S.; Mamatkarimova, S.; Ruchkina, K.; Namozov, S.; et al. Microplastics in the Syr Darya River Tributaries, Uzbekistan. *Water* **2023**, *15*, 3698. https://doi.org/10.3390/w15203698

Academic Editors: Xueqiang Lu and Chengtao Li

Received: 27 September 2023
Revised: 16 October 2023
Accepted: 19 October 2023
Published: 23 October 2023

1. Introduction

Plastics have been mass-produced and extensively used since the mid-20th century [1–3]. The annual production of plastics worldwide attained 390.7 million tons in 2021 [4]; about 10% of all globally produced plastic ends up in the ocean [5]. Asian countries, in particular China, Indonesia, the Philippines, Thailand and Vietnam, produce approximately half of all plastic and an equal amount of global marine plastic waste [4,6]. Improper disposal and subsequent fragmentation of plastic waste contribute to the formation of microplastics (MPs) with sizes < 5 mm and thus to global environmental pollution. Due to their physicochemical properties and small sizes, MPs are prone to transport to different parts of the Earth and circulate in soils, the hydrosphere, the atmosphere and the biosphere [7]. MPs can persist in nature for a long time (20–500 years) due to their extremely low decomposition rate [8].

Rivers play a critical role in the transport of terrestrial MPs to the marine environment [9]. The MP content in continental water bodies is apparently closely correlated with the efficiency of plastic waste management on land; the expected and (in many cases) confirmed levels of river pollution in Asian countries are higher compared to other regions of the world [10]. Another significant source of MP water pollution is wastewater from wastewater treatment plants (WWTPs), which release huge amounts of synthetic textile microfibers [11,12] and microspheres from cosmetic products [13] into the water.

A quantitative analysis of MP pollution in rivers and flowing lakes in areas of external runoff is particularly important since these plastic polymers pose a great threat to the oceans. For areas with no access to the ocean, the problem of the quality of surface water as a valuable resource comes to the fore since water bodies in these areas are susceptible to MP pollution due to adverse physiological effects induced in invertebrates, fish and warm-blooded animals by MPs [14].

The distribution of MPs in freshwater ecosystems is addressed in an increasing number of studies, which indicates the high relevance of this issue, even though the studies mostly report data on rivers and lakes in China [10]. Moreover, the Yangtze River basin in China is currently the most intensively studied water basin in the world [15]. A regression analysis of the data array on the global MP content in freshwater ecosystems revealed the most polluted regions: Asia > North America > Africa > Oceania > South America > Europe [16]. The observed distribution is relative to an extent, since a lot of evidence has been obtained for MPs in water bodies in many regions of the world, yet for some areas quantitative data are not available. Central Asia, which includes Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan and Uzbekistan, is not represented on the global research map of MP pollution of surface water [17]. The MP content and circulation in watercourses in Central Asian countries have not been studied. Large-scale pollution from industrial wastewater and agricultural return water is reported for water resources in Kazakhstan, Uzbekistan and Tajikistan [18]. The studies also highlight pollution from urban wastewater due to the lack or imperfection of wastewater collection systems and an adverse impact of household waste disposal sites on surface water. A number of authors focus on the problem of MP pollution and the relevance of quantitative assessment of the content of MPs in watercourses of Uzbekistan [19], yet no attempts have been made to analyze their abundance in surface water of the Republic of Uzbekistan.

The aim of this study was to perform pre-screening of the MP content in the surface water and benthic sediments of the Kara Darya and Chirchiq rivers, the first-order tributaries of the Syr Darya River.

2. Materials and Methods

2.1. Study Area

The study objects were the Kara Darya and Chirchiq rivers, the Syr Darya River tributaries (Figure 1). The Kara Darya River is the left tributary of the Syr Darya River; it originates in Kyrgyzstan and flows through the Fergana Valley in Uzbekistan. The drainage basin area of the Kara Darya River exceeds 30 thousand km^2, the river extends for 180 km [18]. The Chirchiq River also originates in Kyrgyzstan and flows through the territories of Uzbekistan and Kazakhstan; its total drainage basin area is 14.2 thousand km^2.

Both rivers feature high flow regulation. Large reservoirs are located in the sub-basins of the Kara Darya and Chirchiq rivers. For instance, the volume of the Andijan reservoir on the Kara Darya River is 1.75 km^3. The Chirchiq River below the Charvak reservoir is regulated for both hydropower and irrigation [18].

Figure 1. Schematic map indicating the location of sampling points (★) on Kara Darya and Chirchiq rivers in the Syr Darya basin, Central Asia. Source of the background map: UNEP, 2011 [18].

2.2. Sampling

Sampling of surface water and benthic sediments was performed for the studied rivers in October 2022 in the Republic of Uzbekistan. Samples from the Kara Darya River were taken in the Andijan region below the Andijan hydroelectric power plant (40°53′30.5″ N 72°30′29.5″ E). Samples from the Chirchiq River were taken near the city of Gazalkent (41°34′24.9″ N 69°45′17.06″ E). Sampling points are presented in Figure 1. Both rivers feature high flow regulation. Large reservoirs are located in the sub-basins of the Kara Darya and Chirchiq rivers. For instance, the volume of the Andijan reservoir on the Kara Darya River is 1.75 km^3. The Chirchiq River below the Charvak reservoir is regulated for both hydropower and irrigation [18].

Surface water samples from the two rivers were taken using a PP-3 manta trawl (TSU, Tomsk, Russian Federation) with a neuston net (330 μm) to capture floating plastic debris from the upper 15 cm water layer. The sampler was equipped with a flow meter (Hydro-Bios, Altenholz, Germany) to measure the water volume. For sampling, the trawl was set at a depth of 50 cm for 15 min to capture floating plastic debris. Further, all solid particles were collected in individual screw cap jars, rinsing the mesh with river water, and the samples were then transported to the laboratory. Three individual water samples were taken from both the Darya and Chirchiq rivers.

Sediment samples were taken in the areas close to the shore (~1 m from the water's edge) between rocks in a random order as described in [20], using a metal Petersen bottom grab with a capture area of 1/80 m^2. The grab was lowered to the bottom, sediments were scooped from a specified area and the device slammed and lifted samples to the surface. The contents of one grab sampling were packed and analyzed separately. Three individual samples of bottom sediments were taken from each point to average and subsequently statistically process the results.

2.3. Laboratory Processing of Samples

MP particles were extracted from water samples using a modified protocol based on organic matter oxidation using peroxide and particle density separation [21]. All solid particles <5 mm in size were sequentially filtered and dried. Organic material was removed from the samples via double treatment with 30% H_2O_2 supplemented with a 0.05 M Fe^{2+} solution at 70 °C. Plastic particles were extracted from mineral impurities via density separation in a saturated NaCl solution (~1.20 g cm^{-3}) for 12 h. Polymer particles were collected on glass-fiber membrane filters with a pore diameter of 1 μm (Pall Corporation, Ann Arbor, MI, USA) via vacuum filtration.

The organic matter content in benthic sediments was evaluated using a loss on ignition test (LOI, %). For testing, air-dry soil samples were calcined to constant weight in a muffle furnace at 900 °C, and the proportion of organic matter was evaluated with the gravimetric method [22]. The granulometric composition of benthic sediments was assessed through separating particles by their deposition rate [23].

MP particles were extracted from benthic sediments as reported previously for Siberian rivers [20]. Sediment samples taken from a certain area were dried to an air-dry state at 80 °C and weighed. After that, 3 test samples of 50 g each taken from each of the samples were analyzed individually to obtain objective data. The test samples were thoroughly mixed and separated by density in a NaCl solution (~1.20 g cm^{-3}), then the upper phase (1/2 by volume) was further processed and analyzed. The density separation procedure was repeated twice more. H_2O_2 was then added to the final concentration of 0.73% and left for 24 h to oxidize organic matter. After that, the final density separation was performed, and the samples were filtered under vacuum to collect particles on glass-fiber membrane filters (1 μm).

2.4. Quantatitative Analysis and Particle Characterization

Preliminary visual analysis and counting of particles were performed using a Micromed MC2 stereomicroscope (Observational Instruments LLC, St. Petersburg, Russia) equipped with a ToupView USB 2.0 CMO S digital camera (Hangzhou ToupTek Photonics Co., Hangzhou, China) and ToupView 3.7.6273 software. Microparticles of artificial polymers were classified into groups according to their size (0.15–0.30 mm, 0.30–1.00 mm, 1.00–2.00 mm, 2.00–3.00 mm, 3.00–4.00 mm and 4.00–5.00 mm) and morphology (spheres, films, fibers and irregularly shaped fragments as described in [24]).

The plastic origin of the particles was tested and their polymer composition was determined using microscopy coupled with Raman spectroscopy (μRaman). Raman spectra were obtained using an InVia Basic (Renishaw, Wotton-under-Edge, UK) confocal Raman dispersion spectrometer equipped with a DM 2500 M microscope (Leica, Wetzlar, Germany) with 5×, 20× and 50× objectives at Tomsk Regional Centre for collective use of scientific equipment at Tomsk State University. Excitation was performed with a continuous semiconductor laser (wavelength of 785 nm and power of 100 mW). The maximum laser intensity did not exceed 5–10% to avoid sample heating and destruction. The signal spectrum was accumulated over 1 s, and the number of scans attained 200. The spectra were measured in the 100–1800 cm^{-1} range with a spectral resolution of 1 cm^{-1}. The obtained Raman spectra were then compared with those of the known plastic materials available in PublicSpectra.

Primary data were mathematically processed using Microsoft Excel 2010 software. The arithmetic mean, standard error of the mean (SE), minimum and maximum bounds, standard deviation (SD) and coefficient of variation (Cv) were determined. The comparative analysis of the quantitative data was performed using a nonparametric Mann–Whitney U test.

The average MP concentration in water samples was expressed in items per 1 m^3, and that in benthic sediments was evaluated in items per kilogram of dry soil and per 1 m^2 of bottom surface.

2.5. Quality Assurance and Quality Control

To prevent MP contamination of the samples, the materials and the implements used for field and laboratory processing were made of stainless steel, glass and aluminum when possible; cotton clothing was used for laboratory studies and for sampling. Laboratory processing of the samples was conducted in a laminar box to prevent airborne contamination along with reagent/solution pre-filtration using glass 1 μm membrane filters. The filters with the collected MPs were stored in closed clean glass Petri dishes until microscopy and spectroscopy studies were performed.

External laboratory contamination of the samples during their preparation and storage was controlled using replicated procedural blanks of negative controls ($n = 3$ for each set of samples), as recommended in [25]. When examining the filters, 0 to 1 fibers were found per one blank filter. For samples found to be laboratory-contaminated, the results were corrected by excluding fibers of similar morphology from further analysis.

3. Results

3.1. Quantitative Content and Morphology of MPs in Surface Water of Kara Darya and Chirchiq Rivers

The average MP concentration in the surface water of the Kara Darya and Chirchiq rivers amounted to 4.28 ± 0.09 and 0.95 ± 0.36 items per m^3, respectively (Table 1). The total MP concentration in the Kara Darya River was significantly ($p < 0.01$) higher compared to that in the Chirchiq River. The data obtained for three individual samples showed a greater variance for the Chirchiq River (Table 1).

Table 1. MP content in surface water of Kara Darya and Chirchiq rivers, items per m^{-3}.

River	Mean ± SE	Min–Max	SD	Cv, %
Kara Darya	4.28 ± 0.09	4.19–4.46	0.16	3.60
Chirchiq	0.95 ± 0.36	0.27–1.49	0.62	65.5

Note: min–max—minimum and maximum value; SD—standard deviation; Cv—coefficient of variation.

The morphology of the MPs extracted from the surface water of the Kara Darya and Chirchiq rivers is shown in Figure 2 (1 and 2, correspondingly). The figure demonstrates particle shape (a) and size range (b). Microphotographs (c) illustrate MP particles from the surface water of the rivers.

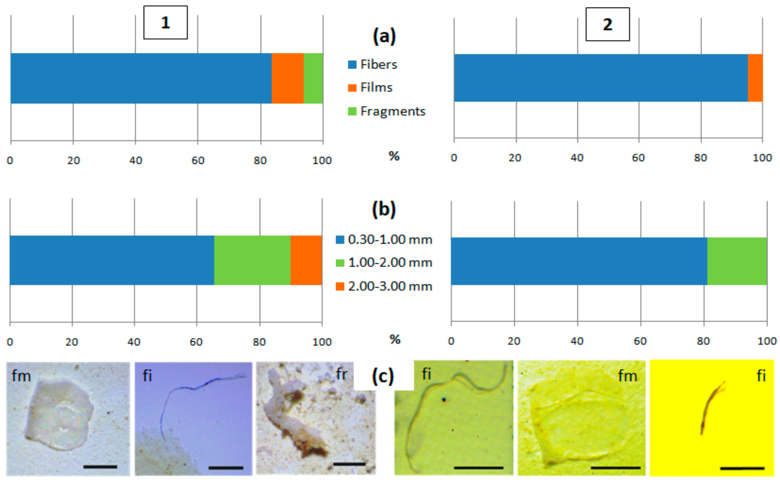

Figure 2. Morphology of MP particles extracted from surface water of Kara Darya (**1**) and Chirchiq (**2**) rivers, including shape (**a**) and size range (**b**). Microphotographs (**c**) illustrate MP particles: fm—film; fi—fiber; fr—fragment; 0.5 mm scale.

In terms of morphology, microfibers dominated in the water of both rivers Figure 2a; their proportion in the Chirchiq River attained > 95%. Part of the MP particles extracted from the surface water of the Chirchiq River represented polymer films. In addition to fibers and films, irregularly shaped microfragments accounting for 6.1% of the total MP amount were detected in the Kara Darya River (Figure 2(1a,c)). MP particles detected in the surface water of the Kara Darya River ranged from 0.30 to 3.00 mm, while those from the Chirchiq River varied from 0.30 to 2.00 mm. The vast majority of MP particles from both rivers fell into the 0.30–1.00 mm category (Figure 2b).

3.2. MP Content in Benthic Sediments of Kara Darya and Chirchiq Rivers and Sediment Characteristics

Microparticles of artificial polymers were extracted from benthic sediments of both rivers (Table 2). The average MP concentration in benthic sediments varied from 244 items per kg in the Chirchiq River to 333 items per kg in the Kara Darya River. In terms of the bottom surface area, the concentration was measured in thousands (Chirchiq) and tens of thousands (Kara Darya) MP particles (Table 2). The MP content in benthic sediments of the Kara Darya River was significantly higher ($p < 0.01$) than that in the Chirchiq River.

Table 2. MP content in benthic sediments of Kara Darya and Chirchiq rivers, items per m^3.

River (Items)	Mean ± SE	Min–Max	SD	Cv, %
Kara Darya (items per kg^{-1}/items per m^{-2})	333 ± 11.5/ 22,160 ± 768	313–353/ 20,830–23,490	20.0/1330	6.00
Chirchiq (items per kg^{-1}/items per m^{-2})	244 ± 28.9/ 4459 ± 527	187–273/ 3405–4986	50.0/913	20.5

Note: min–max—minimum and maximum value; SD—standard deviation; Cv—coefficient of variation.

Figure 3 represents the morphology of MP samples taken from benthic sediments of the Kara Darya (1) and Chirchiq (2) rivers, including shape (a) and size range (b). Microphotographs (c) illustrate MP particles collected from the rivers.

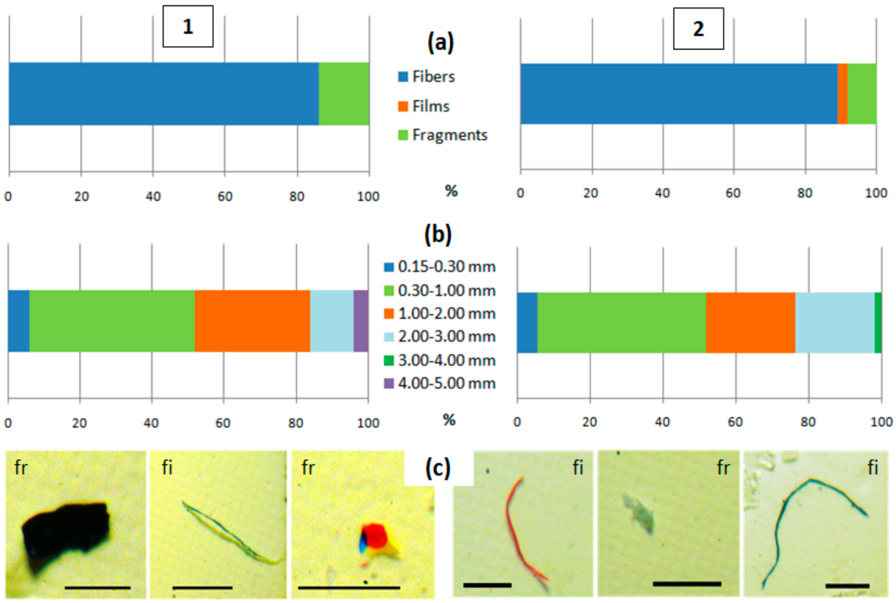

Figure 3. Morphology of MP samples taken from benthic sediments of Kara Darya (**1**) and Chirchiq (**2**) rivers, including shape (**a**) and size range (**b**). Microphotographs (**c**) illustrate MP particles: fr—fragment; fi—fiber; 0.5 mm scale.

In benthic sediments of the Kara Darya River, the MP size varied from 0.15 to 5.00 mm with a predominance of particles of 0.30–1.00 mm and 1.00–2.00 mm along the largest axis (Figure 3(1b)). Figure 3(1a,c) show MP fibers and irregularly shaped fragments. The morphology of the particles extracted from benthic sediments of the Chirchiq River was similar to that in the Kara Darya River. Almost half of the MP particles can be referred to the 0.30–1.00 mm category (Figure 3(2b)); more than 89% of the particles are fibers (Figure 3(2a,c)). In addition to fibers, microfragments and microfilms were extracted from benthic sediments of the Chirchiq River.

In terms of the organic matter content, defined as loss on ignition (%), benthic sediments in the Kara Darya River are classified as mineral (LOI < 10%), and those in the Chirchiq River are classified as mixed, close to mineral (Table 3).

Table 3. Granulometric composition of benthic sediments in the studied rivers by fractions (%) and losses on ignition.

River	LOI, %	Sand Fractions, µm			Clay Fractions, µm		
		1000–250	250–50	50–10	10.0–5.00	5.00–1.00	<1.00
Kara Darya	7.55	84.3	4.02	2.40	1.76	2.56	4.96
Chirchiq	10.4	94.9	1.24	1.12	2.08	0.32	0.32

Note: The proportion of each fraction is presented.

Benthic sediment samples from the Kara Darya River used for quantitative MP analysis were defined as clayey sand [26] with physical sand content (>0.01 mm or 10 µm) of 90.7%, and physical clay content (<0.01 mm or 10 µm) of 9.3% (Table 3). The proportion of physical sand in bottom sediments of the Chirchiq River amounted to 97.3%, and that of physical clay attained 2.70% (Table 3), which characterizes benthic sediments as loose sand. The increased content of fine particles in benthic sediments of the Kara Darya River compared to the Chirchiq River may contribute to MP accumulation in benthic sediments.

3.3. Polymer Composition of MPs Extracted from Water and Benthic Sediments of the Syr Darya Tributaries

Microscopy coupled with Raman spectroscopy (µRaman) showed that the MPs found in the Chirchiq River represented a variety of polymers. Figure 4 shows the polymer constituents of MPs extracted from the surface water (W) and benthic sediments (BS) of the Chirchiq (1) and Kara Darya (2) rivers obtained based on µRaman data. Spectra and microphotographs of individual MP particles from the Syr Darya tributaries are presented in Figure 4(3). The most common polymer was polyethylenterephtalate (PET), which amounted to 57.2 and 44.5% of the total MP content in water and benthic sediments, respectively. Next in prevalence were particles from PSU mixtures (22.2%). Spectra identical to polymethylpentene (PMP), poly(m-phenylene terephthalamide) (PPTA) and polyacrylonitrile (PAN) were identified; each of the polymers accounted for 11.1% of the total MP content detected in water. In benthic sediments of the Chirchiq River, polypropylene (PP) particles were next in prevalence (28.6%), followed by polybutadien (PBD) and polyvinyl fluoride (PVF) that accounted for 7.14% each (Figure 4(1)).

The main polymer constituents of the MPs found in the Kara Darya River were predominantly PET (Figure 4(2)). This type of plastic accounted for more than half of the particles (57.1%) found in water. In addition to PET, only viscose (VI) particles (42.9%) were found in water, which belong to cellulose-based artificial fibers and were taken into account in quantitative MP estimates. Benthic sediments primarily contained PET (58.3%) and viscose (25.0%) microparticles, but part of the MP spectra (16.7%) was equally distributed between polyamide (PA) or nylon and polyurethane elastomers (PTMG-MDI-BD) (Figure 4(2)).

Thus, up to 58.3% of the total MP content in the Kara Darya River and up to 57.2% of the total MP content in the Chirchiq River are represented by PET particles. Despite the dominance of PET, each of the Syr Darya tributaries is characterized by a specific profile of MP pollution due to the contribution of other plastics. Examples of PET, PAN and viscose fibers and a PP fragment from the studied rivers are shown in Figure 4(3).

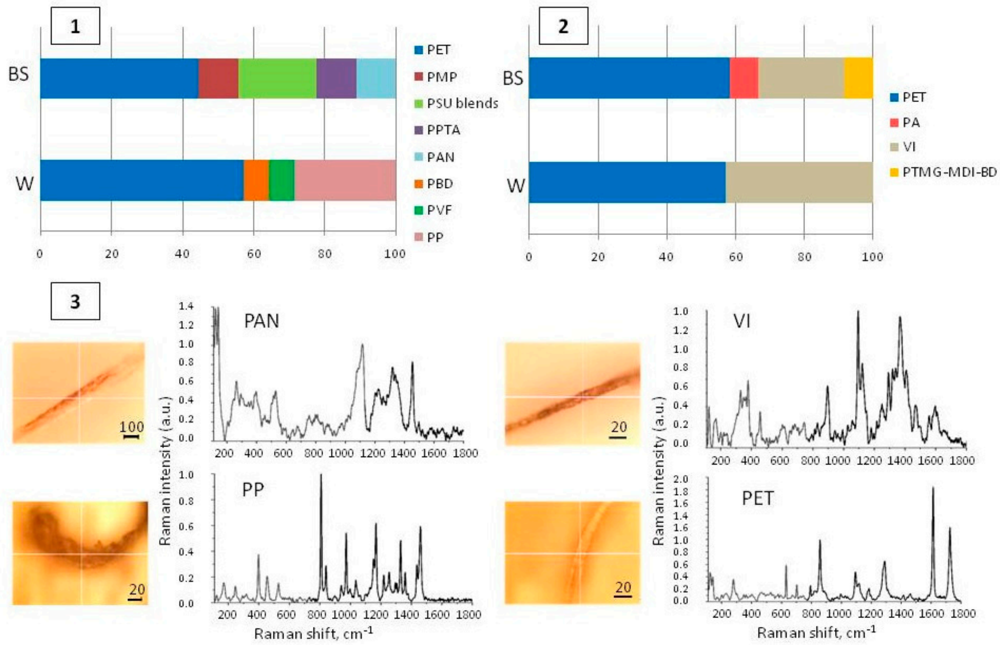

Figure 4. Polymer constituents of MPs extracted from surface water and benthic sediments of Chirchiq (**1**) and Kara Darya (**2**) rivers obtained based on µRaman data, µm scale.

4. Discussion

In this study, MPs were detected in water and benthic sediment samples taken from the Syr Darya tributaries located in the territory of the Republic of Uzbekistan. The concentration of MP particles detected in surface water was relatively low: 4.28 ± 0.09 items per m^3 in Kara Darya and 0.95 ± 0.36 items per m^3 in the Chirchiq River (Table 1). The size of the MPs detected in the water ranged from 0.15 to 3.00 mm. A similar methodology employed for sampling and laboratory preparation of samples taken from water of the sparsely populated Yenisei basin showed a comparable particle content of 2.58 to 2.95 items m^{-3} [20]. Up to 1300 items per m^3 of synthetic microfibers, including finer particles, were found in the Volga tributary, the Levinka River [27]. In the rivers of China, the MP content attains tens of thousands of particles per cubic meter, for example, 3.67 to 10.7 MP items (<0.50–5.00 mm) per liter were found in water of the Wei River (tributary of the Yellow River), which is equivalent to 3670–10,700 items m^{-3} [28]. Apart from the finest particles, which amounted to 68.1%, the MP content in the Wei River remains high and exceeds 1000 items per m^3. Most likely, regional discrepancy may be due to differences in population size and/or the amount of economic activity within river basins or watersheds.

A quantitative analysis of the MPs deposited in benthic sediments of the Syr Darya tributaries revealed that the average concentration of 0.15–5.00 mm MP particles extracted from bottom sediments varied in terms of kg of dry soil from 244 ± 28.9 items in Chirchiq to 333 ± 11.5 items in Kara Darya (Table 2). The obtained results are comparable with data on the MP content in benthic sediments of the large Eurasian river Yenisei and its tributary, Lower Tunguska, where 353 ± 153 and 422 ± 241 items per kg were detected, respectively [18]. The level of plastic pollution in benthic sediments of the Syr Darya tributaries is much lower than the content of MP particles of a similar size in some watercourses in Asia and Europe. A total of 320–1320 and 2052 ± 746 items per kg were detected in benthic sediment samples taken from the Wei River in China and the Ebro River in Spain, respectively [28,29]. Up to 10,500 MP items per kilogram of dry weight were detected in benthic sediments of Amsterdam canals [30].

Compared with the world data, the MP content found for both tributaries of the Syr Darya River was not the highest, yet the MP concentration in the water and benthic sediments of the Kara Darya River was significantly ($p < 0.01$) higher than that in the Chirchiq River. This may be due to regional features of plastic waste management, wastewater treatment efficiency and pollution sources located upstream from the sampling site of the Kara Darya River.

As was previously shown, the MP content in freshwater sediments might depend not only on the location of potential sources of pollution, but also on hydrological factors and the physicochemical and mechanical properties of sediments [31,32]. A direct correlation between the MP content and the organic matter content was revealed for benthic sediments of the Lower Tunguska and Yenisei rivers [20]. However, in this study, we assume that there is a relationship between MP accumulation and the granulometric composition of benthic sediments. Benthic sediments of the Kara Darya River were represented by cohesive sand with a larger proportion of fine fractions, although they contained less organic matter compared to benthic sediments of the Chirchiq River (Table 3). The proportion of physical clay (<0.01 mm) amounted to 9.3% in benthic sediments of the Kara Darya River, and to only 2.7% in those of the Chirchiq River. An increased concentration of MPs may enhance their accumulation in benthic sediments.

The morphology of particles extracted from water and sediments of the Syr Darya tributaries was analyzed to identify potential sources of watercourse pollution. The most common morphology of MPs was fibers that amounted to 89 and 95% in water, and to 86 and 84% in sediments of the Kara Darya and Chirchiq rivers, respectively (Figures 2 and 3). Microfibers are the most common type of plastic debris found in freshwater environments [33]. A review of published data on MP distribution in freshwater environments of the Russian Federation [34] showed that these particles occur in benthic sediments of all the studied water bodies and in the surface water of most rivers and lakes. Thus, microfibers of <1.50 mm accounted for up to 95% of the total amount of MP particles extracted from water and sediments of the Neva and Neva Bay tributaries [35]. In Asian freshwater environments, fibers are also dominant and are reported in 95% of 166 published original studies [10]. Among the main sources of artificial microfibers polluting rivers, the authors indicate the textile industry, untreated wastewater and discharge from municipal WWTPs, which do not fully retain MPs [36–40]. Numerous studies show that the amount of MP items discharged from WWTPs can attain 9×10^4 items per m^{-3} [38]. Textile fibers 1 μm–5 mm in size, which are released during wear, washing and drying of clothing and household textiles, are defined as a distinct type of environmental pollutant that can pose a risk to human health [12].

The μRaman analysis showed that about half of all particles detected were PET. PET is the polymer base of polyester products and is widely used in clothing and home textiles, either as a single material or mixed with cellulose fibers to enhance mechanical properties and durability [12]. Considering that fibers are the most common morphology of microplastics and PET is the main fiber constituent, discharges from WWTPs and wastewater from private households can be considered the most likely sources of local pollution. De Falco et al. [41] reported that microfiber release is most intensive when washing woven polyester compared to other synthetic fabrics. The authors showed that the number of fibers released during a single wash of polyester textiles with a standard load of 5 kg attains 6,000,000 items. It should be noted that PET-based fibers account for the majority (>70%) of global synthetic textile production [42]. An analysis of the published data showed that occurrence of the main textile polymers in the world's oceans can be expressed as follows: PET > PAN > PP > PA [12]. Of the above polymers, PAN and PP were detected in the Chirchiq River, and PA particles were found in benthic sediments of the Kara Darya River. Aramid fibers composed of poly(p-phenylene terephthalamide) (PPTA) were also found in water of the Chirchiq River. A significant proportion of fibers from the Kara Darya River consisted of viscose (almost 43% of all particles in water and 27% in benthic sediments). Semi-synthetic yarns based on cellulosic raw materials, such as lyocell and viscose, are also widely used in the textile industry and are usually cut into staple fibers, which increases their release during use and washing [43].

The polymer composition of MP samples found in the Kara Darya and Chirchiq Rivers confirm the leading role of synthetic textile fibers in the pollution of watercourses in Uzbekistan. Differences in the minor part of polymer morphologies in the two tributaries of the Syr Darya River form specific MP profiles that may reflect additional features of river pollution.

5. Conclusions

The screening of plastic particles 0.15 to 5.0 mm in size from the water and benthic sediments of the Syr Darya tributaries, the Kara Darya and Chirchiq rivers, provides a preliminary quantitative assessment of pollution. The average concentration of MP particles in the surface water of the Kara Darya and Chirchiq rivers was 4.28 ± 0.09 and 0.95 ± 0.36 items per m^3, and in benthic sediments these values amounted to 244 ± 28.9 and 333 ± 11.5 items per kg of dry soil, respectively. The MP concentration in water and benthic sediments of the Kara Darya River was significantly ($p < 0.01$) higher than that in the Chirchiq River, which may be due to regional features of wastewater management, wastewater treatment efficiency and the location of point sources of plastic pollution.

Among the MPs extracted from water, particles of 0.30–1.00 mm along the largest axis predominated significantly; particles of >3.00 mm were not detected. In benthic sediments, the size range of MPs was wider (0.15–5.00 mm). In the water of the Kara Darya and Chirchiq rivers, the proportion of fibers was 89 and 95%, and in benthic sediments these values attained 86 and 84%, respectively. The dominance of fibers, which had PET, a component of polyester, as their main constituent in the polymer composition of MPs may indicate domestic and municipal wastewater treatment plant discharges as a source of pollution with textile microfibers. The polymer profile characteristic of textiles (PET, PA, PAN, viscose) is particularly pronounced in the Kara Darya River. The regulation of watercourses in Uzbekistan can have a positive effect on the accumulation and circulation of microfibers in river and canal systems. To confirm the hypothesis about the leading role of synthetic textiles in the MP pollution of watercourses in different regions of Uzbekistan, we plan to conduct regular sampling and monitoring studies in the immediate vicinity of the discharge sites of WWTPs.

The obtained data are the first evidence of MP pollution of the Syr Darya tributaries in the territory of the Republic of Uzbekistan and watercourses of Central Asia in general. However, the distribution and circulation of MPs in surface water of Uzbekistan requires a comprehensive study to develop a large-scale observation network for pollution source identification.

Author Contributions: Conceptualization, Y.F., M.Y., A.K. and D.V.; methodology, Y.F., L.T. and A.Y.; formal analysis, A.R. and S.T.; investigation, Y.F., E.V., S.R., A.R., S.M., K.R. and S.N.; resources, A.Y. and D.V.; data curation, M.Y., J.S., L.T. and D.V.; writing—original draft preparation, Y.F., A.K., S.T. and D.V.; writing—review and editing, J.S. and A.Y.; visualization, E.V., S.R. and A.R.; supervision, D.V.; project administration, Y.F. and A.K.; funding acquisition, D.V. and A.Y. All authors have read and agreed to the published version of the manuscript.

Funding: The study was supported by the Development Program of Tomsk State University (Priority–2030), Project No. 2.2.3.22 ONG, and the Program "Microplastics in the Environment" of Andijan State University.

Data Availability Statement: Not applicable.

Acknowledgments: We are grateful to Andrey Trifonov for help with the construction of the PP-3 Manta trawl and to Valery Svetlichnyi for the excellent technical assistance in μRaman analysis.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Horton, A.A. Plastic Pollution: When Do We Know Enough? *J. Hazard. Mater.* **2022**, *422*, 126885. [CrossRef] [PubMed]
2. Versteeg, F.G.; Hegeman, N.C.; Sebakhy, K.O.; Picchioni, F. RAFT Polymerization of a Biorenewable/Sustainable Monomer via a Green Process. *Macromol. Rapid Commun.* **2022**, *43*, 2200045. [CrossRef] [PubMed]
3. Sebakhy, K.O.; Gavrilov, M.; Valade, D.; Jia, Z.; Monteiro, M.J. Nanoparticles of Well-Defined 4-Arm Stars Made Using Nanoreactors in Water. *Macromol. Rapid Commun.* **2014**, *35*, 193–197. [CrossRef] [PubMed]

4. Plastics Europe. Enabling a Sustainable Future. Plastics—The Facts. Available online: https://plasticseurope.org/knowledge-hub/plastics-the-facts-2022 (accessed on 20 September 2023).
5. Sun, J.; Zhu, Z.R.; Li, W.H.; Yan, X.; Wang, L.K.; Zhang, L.; Jin, J.; Dai, X.; Ni, B.J. Revisiting Microplastics in Landfill Leachate: Unnoticed Tiny Microplastics and Their Fate in Treatment Works. *Water Res.* **2021**, *190*, 116784. [CrossRef]
6. Geyer, R.; Jambeck, J.R.; Law, K.L. Production, use, and fate of all plastics ever made. *Sci. Adv.* **2017**, *3*, e1700782. [CrossRef]
7. Bank, M.S.; Hansson, S.V. The Plastic Cycle: A Novel and Holistic Paradigm for the Anthropocene. *Environ. Sci. Technol.* **2019**, *53*, 7177–7179. [CrossRef]
8. Wright, S.L.; Kelly, F.J. Plastic and Human Health: A Micro Issue? *Environ. Sci. Technol.* **2017**, *51*, 6634–6647. [CrossRef]
9. Lebreton, L.C.M.; Van Der Zwet, J.; Damsteeg, J.W.; Slat, B.; Andrady, A.; Reisser, J. River plastic emissions to the world's oceans. *Nat. Commun.* **2017**, *8*, 15611. [CrossRef]
10. Kumar, P.; Inamura, Y.; Bao, P.N.; Abeynayaka, A.; Dasgupta, R.; Abeynayaka, H.D.L. Microplastics in Freshwater Environment in Asia: A Systematic Scientific Review. *Water* **2022**, *14*, 1737. [CrossRef]
11. Ziajahromi, S.; Neale, P.A.; Leusch, F.D.L. Wastewater treatment plant effluent as a source of microplastics: Review of the fate, chemical interactions and potential risks to aquatic organisms. *Water Sci. Technol.* **2016**, *74*, 2253–2269. [CrossRef]
12. Periyasamy, A.P.; Tehrani-Bagha, A. A review on microplastic emission from textile materials and its reduction techniques. *Polym. Degrad. Stab.* **2022**, *199*, 109901. [CrossRef]
13. Rochman, C.M.; Kross, S.M.; Armstrong, J.B.; Bogan, M.T.; Darling, E.S.; Green, S.J.; Smyth, A.R.; Veríssimo, D. Scientific Evidence Supports a Ban on Microbeads. *Environ. Sci. Technol.* **2015**, *49*, 10759–10761. [CrossRef] [PubMed]
14. Huang, W.; Song, B.; Liang, J.; Niu, Q.; Zeng, G.; Shen, M.; Deng, J.; Luo, Y.; Wen, X.; Zhang, Y. Microplastics and associated contaminants in the aquatic environment: A review on their ecotoxicological effects, trophic transfer, and potential impacts to human health. *J. Hazard. Mater.* **2021**, *405*, 124187. [CrossRef]
15. D'Avignon, G.; Gregory-Eaves, I.; Ricciardi, A. Microplastics in lakes and rivers: An issue of emerging significance to limnology. *Environ. Rev.* **2022**, *30*, 228–244. [CrossRef]
16. Chen, H.; Qin, Y.; Huang, H.; Xu, W. A Regional difference analysis of microplastic pollution in global freshwater bodies based on a regression model. *Water* **2020**, *12*, 1889. [CrossRef]
17. AWI-LITTERBASE. Available online: https://litterbase.awi.de (accessed on 20 September 2023).
18. UNECE (United Nations Economic Commission for Europe). *Second Assessment of Transboundary Rivers, Lakes and Groundwaters*; United Nations Publications: Geneva, Switzerland; New York, NY, USA, 2011; p. 428. ISBN 9789210549950.
19. Shoergashova, S. Microplastic pollution of water bodies. *Univers. Tech. Sci. Electron. Sci. J.* **2020**, *7*, 15–17.
20. Frank, Y.A.; Vorobiev, D.S.; Kayler, O.A.; Vorobiev, E.D.; Kulinicheva, K.S.; Trifonov, A.A.; Soliman Hunter, T. Evidence for microplastics contamination of the remote tributary of the Yenisei River, Siberia—The pilot study results. *Water* **2021**, *13*, 3248. [CrossRef]
21. Masura, J.; Baker, J.; Foster, G.; Arthur, C. *Laboratory Methods for the Analysis of Microplastics in the Marine Environment: Recommendations for Quantifying Synthetic Particles in Waters and Sediments*; NOAA Technical Memorandum NOS-OR&R-48; NOAA Marine Debris Division: Silver Spring, MD, USA, 2015; p. 39. [CrossRef]
22. Sutherland, R.A. Loss-on-ignition estimates of organic matter and relationships to organic carbon in fluvial bed sediments. *Hydrobiologia* **1998**, *389*, 153–167. [CrossRef]
23. *ISO 11277:2020*; Soil Quality—Determination of Particle in Mineral Soil Material—Method by Sieving and Sedimentation. 3rd ed. Technical Committee ISO/TC 190/SC 3 Chemical and Physical Characterization: Geneva, Switzerland, 2020; p. 38.
24. Frias, J.P.G.L.; Nash, R. Microplastics: Finding a consensus on the definition. *Mar. Pollut. Bull.* **2019**, *138*, 145–147. [CrossRef]
25. Koelmans, A.A.; Mohamed Nor, N.H.; Hermsen, E.; Kooi, M.; Mintenig, S.M.; De France, J. Microplastics in freshwaters and drinking water: Critical review and assessment of data quality. *Water Res.* **2019**, *155*, 410–422. [CrossRef]
26. Kachinskyj, N.A. *Physics of Soil*; Vysshaya Shkola: Moscow, USSR, 1965; p. 323. ISBN 978-5-4458-5455-5.
27. Yasinskii, S.V.; Venitsianov, E.V.; Kashutina, E.A.; Sidorova, M.V.; Ershova, A.A.; Makeeva, I.N. Contribution of microparticles to the transport of pollution by rivers and groundwaters in a large city. *IOP Conf. Ser. Earth Environ. Sci.* **2021**, *834*, 012047. [CrossRef]
28. Ding, L.; Mao, R.F.; Guo, X.; Yang, X.; Zhang, Q.; Yang, C. Microplastics in surface waters and sediments of the Wei River, in the northwest of China. *Sci. Total Environ.* **2019**, *667*, 427–434. [CrossRef] [PubMed]
29. Simon-Sanchez, L.; Grelaud, M.; Garcia-Orellana, J.; Ziveri, P. River Deltas as hotspots of microplastic accumulation: The case study of the Ebro River (NW Mediterranean). *Sci. Total Environ.* **2019**, *687*, 1186–1196. [CrossRef] [PubMed]
30. Leslie, H.A.; Brandsma, S.H.; Van Velzen, M.J.M.; Vethaak, A.D. Microplastics en route: Field measurements in the Dutch river delta and Amsterdam canals, wastewater treatment plants, North Sea sediments and biota. *Environ. Int.* **2017**, *101*, 133–142. [CrossRef]
31. Zobkov, M.; Belkina, N.; Kovalevski, V.; Zobkova, M.; Efremova, T.; Galakhina, N. Microplastic abundance and accumulation behavior in Lake Onego sediments: A journey from the river mouth to pelagic waters of the large boreal lake. *J. Environ. Chem. Eng.* **2020**, *8*, 104367. [CrossRef]
32. Zobkov, M.B.; Chubarenko, I.P.; Esiukova, E.E.; Belkina, N.A.; Kovalevsky, V.V.; Zobkova, M.V.; Efremova, T.A.; Galakhina, N.E. Lakes as accumulators of microplastics on their way from land to the World Ocean: A review of research. *Izv. RGS* **2021**, *153*, 68–86. [CrossRef]

33. Szymanska, M.; Obolewski, K. Microplastics as contaminants in freshwater environments: A multidisciplinary review. *Ecohydrol. Hydrobiol.* **2020**, *20*, 333–345. [CrossRef]
34. Frank, Y.; Ershova, A.; Batasheva, S.; Vorobiev, E.; Rakhmatullina, S.; Vorobiev, D.; Fakhrullin, R. Microplastics in Freshwater: A Focus on the Russian Inland Waters. *Water* **2022**, *14*, 3909. [CrossRef]
35. Pozdnyakov, S.R.; Ivanova, E.V.; Guzeva, A.V.; Shalunova, E.P.; Martinson, K.D.; Tikhonova, D.A. Studying the Concentration of Microplastic Particles in Water, Bottom Sediments and Subsoils in the Coastal Area of the Neva Bay, the Gulf of Finland. *Water Resour* **2020**, *47*, 599–607. [CrossRef]
36. Cowger, W.; Gray, A.B.; Eriksen, M.; Moore, C.; Thiel, M. Evaluating wastewater effluent as a source of microplastics in environmental samples. In *Microplastics in Water and Wastewater*; Karapanagioti, H.K., Kalavrouziotis, I.K., Eds.; IWA Publishing: London, UK, 2019; pp. 109–131. [CrossRef]
37. Kabir, A.H.M.E.; Sekine, M.; Imai, T.; Yamamoto, K.; Kanno, A.; Higuchi, T. Assessing small-scale freshwater microplastics pollution, land-use, source-to-sink conduits, and pollution risks: Perspectives from Japanese rivers polluted with microplastics. *Sci. Total Environ.* **2021**, *768*, 144655. [CrossRef]
38. Liu, Y.; You, J.; Li, Y.; Zhang, J.; He, Y.; Breider, F.; Tao, S.; Liu, W. Insights into the horizontal and vertical profiles of microplastics in a river emptying into the sea affected by intensive anthropogenic activities in Northern China. *Sci. Total Environ.* **2021**, *779*, 146589. [CrossRef] [PubMed]
39. Strady, E.; Kieu-Le, T.-C.; Gasperi, J.; Tassin, B. Temporal dynamic of anthropogenic fibers in a tropical river-estuarine system. *Environ. Pollut.* **2020**, *259*, 113897. [CrossRef] [PubMed]
40. Wong, J.K.H.; Lee, K.K.; Tang, K.H.D.; Yap, P.S. Microplastics in the freshwater and terrestrial environments: Prevalence, fates, impacts and sustainable solutions. *Sci. Total Environ.* **2020**, *719*, 137512. [CrossRef] [PubMed]
41. De Falco, F.; Gullo, M.P.; Gentile, G.; Di Pace, E.; Cocca, M.; Gelabert, L.; Brouta-Agnésa, M.; Rovira, A.; Escudero, R.; Villalba, R.; et al. Evaluation of microplastic release caused by textile washing processes of synthetic fabrics. *Environ. Pollut.* **2018**, *236*, 916–925. [CrossRef]
42. Textile Exchange. Preferred Fiber & Materials Market Report. Available online: http://textileexchange.org/app/uploads/2022/10/Textile-Exchange_PFMR_2022.pdf (accessed on 20 September 2023).
43. Elhawary, I.A. Fibre to Yarn. In *Textiles and Fashion*; Elsevier: Amsterdam, The Netherlands, 2015; pp. 191–212.