TYPE Original Research
PUBLISHED 03 June 2024
DOI 10.3389/fsufs.2024.1397348

OPEN ACCESS

EDITED BY
Reza Rastmanesh,
American Physical Society, United States

REVIEWED BY
Khalid Z. Elwakeel,
Jeddah University, Saudi Arabia
Sonia Gomes,
University of Porto, Portugal

*CORRESPONDENCE
M. Belal Hossain
✉ belal.hossain@nstu.edu.bd
Pallab Kumer Sarker
✉ psarker@ucsc.edu

RECEIVED 07 March 2024
ACCEPTED 06 May 2024
PUBLISHED 03 June 2024

CITATION
Hossain MB, Yu J, Sarker PK, Banik P, Sultana S, Nur A-AU, Haque MR, Rahman MM, Paray BA and Arai T (2024) Microplastic accumulation, morpho-polymer characterization, and dietary exposure in urban tap water of a developing nation. *Front. Sustain. Food Syst.* 8:1397348. doi: 10.3389/fsufs.2024.1397348

Microplastic accumulation, morpho-polymer characterization, and dietary exposure in urban tap water of a developing nation

M. Belal Hossain[1,2]*, Jimmy Yu[1], Pallab Kumer Sarker[3]*, Partho Banik[2], Salma Sultana[2], As-Ad Ujjaman Nur[2], Md. Rashedul Haque[4], Md. Mostafizur Rahman[4], Bilal Ahamad Paray[5] and Takaomi Arai[6]

[1]School of Engineering and Built Environment, Griffith University, Nathan, QLD, Australia, [2]Department of Fisheries and Marine Science, Noakhali Science and Technology University, Sonapur, Bangladesh, [3]Environmental Studies Department, University of California, Santa Cruz, Santa Cruz, CA, United States, [4]Laboratory of Environmental Health and Ecotoxicology, Department of Environmental Sciences, Jahangirnagar University, Dhaka, Bangladesh, [5]Department of Zoology, College of Science, King Saud University, Riyadh, Saudi Arabia, [6]Environmental and Life Sciences Programme, Faculty of Science, Universiti Brunei Darussalam, Gadong, Brunei Darussalam

The recent detection of microplastics (MPs) in a large number of commercially important food items and beverages, including tap water, has drawn significant attention because of direct exposure and negative health effects on humans. Nevertheless, there is insufficient information on microplastic contamination in the tap water of developing countries. In the present study, we primarily analyzed supplied tap water samples from four major cities in Bangladesh to determine and characterize MPs using a stereomicroscope and Fourier transform infrared spectroscopy (FTIR). Several indices were employed to calculate human health exposures to microplastics. MPs were found in all of the water samples tested, with an overall mean of 35.33 ± 19.55 particles/L. The results of this study diverge from those of comparable research conducted globally, revealing that tap water in Bangladesh exhibited higher levels of contamination compared to other nations. MPs were found in three different shapes (fibers, fragments, and films), with fibers dominating the samples (96.2%), and 98.1% of the microplastics were less than 0.5 mm in size. Six different colors of MPs were observed, and transparent particles were dominant (63.9% of all observed MPs). FTIR infrared spectrum analysis revealed two major types of polymers: low-density polyethylene (LDPE) and high-density polyethylene (HDPE). The projected daily consumption of microplastics was determined to be 2.65 particles per person per day, raising potential concerns for human health. The findings show that the treatment process of the water supply system is inadequate. Additionally, the sources of microplastics in tap water may come from where the water was collected for treatment and may be linked to a variety of anthropogenic activities, such as urbanization, sewage discharge, industrial waste disposal, and runoff from catchment areas.

KEYWORDS

microplastics, dietary intake, human health, polymers, tap water

1 Introduction

Microplastics (MPs) have recently sparked much interest as emerging contaminants in aquatic habitats (Tong et al., 2020; Hossain et al., 2023; Han et al., 2024). Throughout the world, MPs with various chemical compositions, including polyethylene, polypropylene, acrylic resin, polyamide, polyester, and styrofoam, have been identified (Hossain et al., 2024). Plastic manufacturing plants, waste from industry, discharges of sewage, and the biological destruction of plastic debris are all contributors to microplastics in the natural environment, particularly in water bodies (Andrady, 2011; da Costa et al., 2016; Mason et al., 2016; Mintenig et al., 2017). The environmental harm caused by microplastics stems from both their chemical and physical attributes. They can absorb and accumulate a range of detrimental substances, including persistent organic/inorganic pollutants and metals (Prunier et al., 2019; Rodrigues et al., 2019; Elgarahy et al., 2021; Barboza et al., 2023). Moreover, various hazardous infections and microbes can establish a stable habitat within microplastics over prolonged durations. Recent evidence suggests that microplastics may also induce irritation or obstruct the gastrointestinal tract of animals (Wright et al., 2013). Some periodic research has investigated whether microplastics interact with human cells. Microplastics are rapidly absorbed by animals and travel through the food web, where they have a wide variety of deleterious impacts on both living organisms and human beings (Browne et al., 2008; Phillips and Bonner, 2015; Lourenço et al., 2017; Matias et al., 2023; Nirmala et al., 2023).

Although the risk of microplastics in drinking water to human health is currently low, understanding potential exposure routes is crucial (Chowdhury et al., 2023; Huan et al., 2023). Bangladesh has improved water access but faces a high global contamination rate. It ranked eighth for mishandling plastic waste in 2010, discarding around 310,000 metric tons into marine waters (Jambeck et al., 2015). The Water Supply and Sewerage Authority (WASA) strives to optimize resources, primarily using deep tube wells for water, though water quality remains a concern, with analyses revealing hazardous substances. Bangladesh annually produces millions of tons of plastic for various sectors, contributing significantly to land-based microplastic pollution (Fahmida et al., 2013; Alom and Habib, 2016). Given these factors, it is vital to investigate the presence, distribution, and risks of microplastics in supplied waters to ensure environmental health and human well-being (BIDA, 2021).

In recent years, research on microplastics has surged, shedding light on their presence and adverse effects across diverse environments (Chowdhury et al., 2023; Huan et al., 2023; Nirmala et al., 2023). Numerous investigations have effectively explored the presence and adverse effects of these microplastics in various ecological settings, including deserts (Wang et al., 2021; Li et al., 2022; Chandrakanthan et al., 2023), mountain terrains and foothills (Padha et al., 2022; Zhang et al., 2022), and coastal, marine, and urban areas (Gola et al., 2021; Hengstmann et al., 2021; Squadrone et al., 2021; Yang et al., 2021; Yin et al., 2021; Zhang et al., 2021; Purwiyanto et al., 2022; Pushan et al., 2022), revealing the widespread contamination of microplastics. Notably, microplastics have been detected in human consumables such as bottled water, drinking water, table salts, honey, sugar, and seafood, raising concerns about their potential health impacts (Liebezeit and Liebezeit, 2013; Karami et al., 2017; Oßmann et al., 2018; Pivokonsky et al., 2018; Smith et al., 2018; Mintenig et al., 2019; Noman et al., 2022). Kosuth et al. (2018) found that over 20% of tap water samples from 14 nations contained tiny plastic particles, with a significant portion (98.3%) being fibrous microplastics. Additionally, their study, along with Mintenig et al. (2019), focused on microplastic concentrations in tap water, specifically within customer residences along distribution networks. Despite the global concern, there is a notable lack of data on microplastic concentrations in tap water from major cities of Bangladesh, posing risks to millions of residents. Only two investigations conducted by Hossain et al. (2023) and Muhib et al. (2023) delved into the detection of diverse microplastics within plastic containers utilized for drinking water, tap water, and food packaging in Bangladesh. These previous investigations did not specifically address the dietary intake of microplastics via drinking water in the cities. This underscores the urgent need to understand microplastic presence in water distribution networks to safeguard drinking water quality. Studying microplastics in tap water in major cities in Bangladesh presented a unique environmental context due to its densely populated urban areas, complex water systems, and challenges with poor waste management. Research conducted in this context provided insights that were not covered in studies conducted in other regions, offering a more comprehensive understanding of microplastic pollution in diverse environmental settings. Focusing on urban tap water allows for a direct assessment of human exposure to microplastics through drinking water consumption, which is a critical pathway for potential health effects. This approach provides a more accurate estimation of human health risks compared to studies that primarily focus on environmental contamination without considering the direct impact on human populations. In addition, to the best of our knowledge, there are no data on microplastic concentrations in tap water from major cities of Bangladesh, despite the fact that tap water is being supplied to at least 5 million people by major city corporations in Bangladesh. Therefore, it emphasizes the importance of understanding the presence of microplastics in the water supply distribution network in relation to human accessibility and, consequently, the protection of drinking water quality. City people of Dhaka, Chattogram, Khulna, and Rajshahi mainly drink tap water every day, and they might be exposed to severe long-term health problems. Therefore, this study aimed to address the research gaps related to microplastic contamination in consumer water distribution networks by (i) quantifying microplastic abundance, (ii) characterizing the morphological types and polymeric structures of microplastics, (iii) estimating the dietary intake of microplastics through drinking tap water, and (iv) identifying potential sources of microplastics in supplied tap water from Bangladesh. While the study focuses on Bangladesh cities, the findings may have broader implications for other urban areas facing similar challenges worldwide. This information will increase the awareness of local inhabitants, help policymakers take further steps, and serve as a reference for future studies on microplastic contamination.

Abbreviations: BIDA, Bangladesh Investment Development Authority; HDPE, High-Density Polyethylene; LDPE, Low-Density Polyethylene; MPs, Microplastics; PC, Polycarbonate; PET, Polyethylene terephthalate; PP, Polypropylene; PS, Polystyrene; PVC, Poly Vinyl Chloride; FTIR, Fourier transform infrared spectroscopy; gm./cm^3, Gram per centimeter cube; M, Meter; mm, Millimeter; µm, Micrometer; km, Kilometer; L, Liter; H, Hour.

2 Materials and methods

2.1 Study area

Tap water samples were obtained from four major cities of Bangladesh, namely, Dhaka, Chattogram, Khulna, and Rajshahi (two stations per city). Despite the disadvantages that an extensive population emphasizes, Bangladesh currently has approximately 3,000 small and large plastics companies (Hossain et al., 2024). Plastic has been ranked as the 12th most profitable export industry in Bangladesh. With explosive growth, individual plastic consumption in our country has risen dramatically from 2.07 kg in 2005 to 3.5 kg in 2014, with a daily production of 3,000 tons of plastic garbage, accounting for 8% of the total produced waste (Mahmudul, 2019). Dhaka, being the capital and largest city, represents the central region, while Chattogram, Khulna, and Rajshahi represent the southeastern, southwestern, and northwestern regions, respectively. This geographical diversity ensures a comprehensive understanding of microplastic contamination patterns across various socio-economic and environmental contexts within the nation. However, the sampling locations included both communal (such as library spaces, marketplaces, sports facilities, restrooms, and playgrounds) and privatized (such as public housing developments) real estate. Because the public and private sectors exhibit a shared freshwater transportation network similar to that of individual households, collecting samples from both governmental and non-governmental properties allows for the investigation of microplastics in Bangladesh's tap water, particularly water provided to residences and work environments that are meant for use by people. The selected study regions reflect a strategic approach aimed at investigating microplastic pollution comprehensively, considering factors such as population density, regional representation, water usage patterns, and potential human exposure pathways within the context of a developing nation. The locations of all the sampling coordinates are presented in Figure 1.

2.2 Sample collection and preparation

A combined 72 samples, each comprising 500 mL of water from the Water Supply and Sewerage Authority (WASA), were gathered between April and June 2022. Three samples were collected for each data point to ensure representativeness (Pivokonský et al., 2020; Hossain et al., 2023, 2024). Following collection, the water samples were preserved in an icebox at −20°C for storage. Then, the collected samples were delivered to the Laboratory of Ecology, Environment, and Biodiversity (LEEB) Noakhali for further microplastic analysis. In a broader sense, water treatment for human consumption relies on mechanical groundwater infiltration. As a result, unprocessed water slowly seeps through the sedimentary material of gravel and sand into underground reservoirs (Kirstein et al., 2021). In the laboratory, sampling bottles were thawed at room temperature and then directly filtered through a 5-micron cellulose nitrate membrane filter (Minipore, India) (Banik et al., 2022; Hossain et al., 2023) without digestion. Filters were transferred to dimmed glass Petri dishes, coated with 70% ethanol, and frozen at −20°C for subsequent processing (Kirstein et al., 2021; De Frond et al., 2022). Coating the filters with ethanol helps to fix the particles in place and prevents microbial growth that could degrade the samples (Joo et al., 2021).

2.3 Microscopic identification of microplastics and polymer analysis

For microscopic identification and quantification of microplastics, the whole filter paper was split into four quarts, and each quart was checked carefully. The filter paper was observed under a light stereomicroscope (Leica EZ4E, Germany) at 8x to 35x magnification, following Hossain et al. (2021) and Banik et al. (2022). A high-resolution camera was used to obtain images of the MPs, which were attached to a microscope, and the size ranges of the MPs were measured using ImageJ software (ver. 2.0.0) (Banik et al., 2024). The suspicious plastic particles were removed by a hot needle test (De Witte et al., 2014; Banik et al., 2022). During this process, some portion of the plastic may stick to the needle or be lost due to the melting process, resulting in a potential loss of sample. Therefore, we considered this potential loss when using the hot needle test method and accounted for it in the analysis. The physical characteristics of the microplastics, such as type/shape, color, and size, were examined following Banik et al. (2022). The polymer type (chemical composition of the MPs) was identified by using Fourier transform infrared spectroscopy (FTIR, Nicolet 6,700, Thermo Fisher Scientific, United States). The method identifies the polymer type of microplastics by exposing the sample to infrared radiation, which causes specific chemical bonds within the material to absorb energy. The resulting absorption spectrum, showing peaks at characteristic wavelengths, is unique to each polymer type. Then, FTIR spectra were compared with a database (Hummel Polymer and Additives, Polymer Laminate Films, Cross SectionsWizard, HR Spectra IR Demo, and Aldrich Vapour Phase Sample Library) to verify the individual plastic items (Veerasingam et al., 2021).

2.4 Contamination control

Laboratory glass beakers and Petri dishes, as well as other necessary equipment, were washed with filtered deionized distilled water (DDW) before and after use. Plastic equipment was strictly avoided as much as possible during the measurement of microplastics except at the time of sample collection. To minimize cross-contamination, a cotton lab coat, non-plastic gloves, and face masks were used by the laboratory operator. All the necessary instruments and the laboratory surfaces were wiped and washed with 30% ethanol before and after conducting the experiments. For the control, a total blank experiment was conducted following the same procedure, and no synthetic components were found in the blank sample.

2.5 Dietary intake of MPs

The following calculation was used to compute the dietary intake of microplastics in water (Almaiman et al., 2021):

$$\text{ExposureCM} / \text{BW}$$

where C is the recommended consumption of water/person/day, M is the average microplastic particles/L, and BW is the average body weight for an adult. The World Health Organization's (WHO)

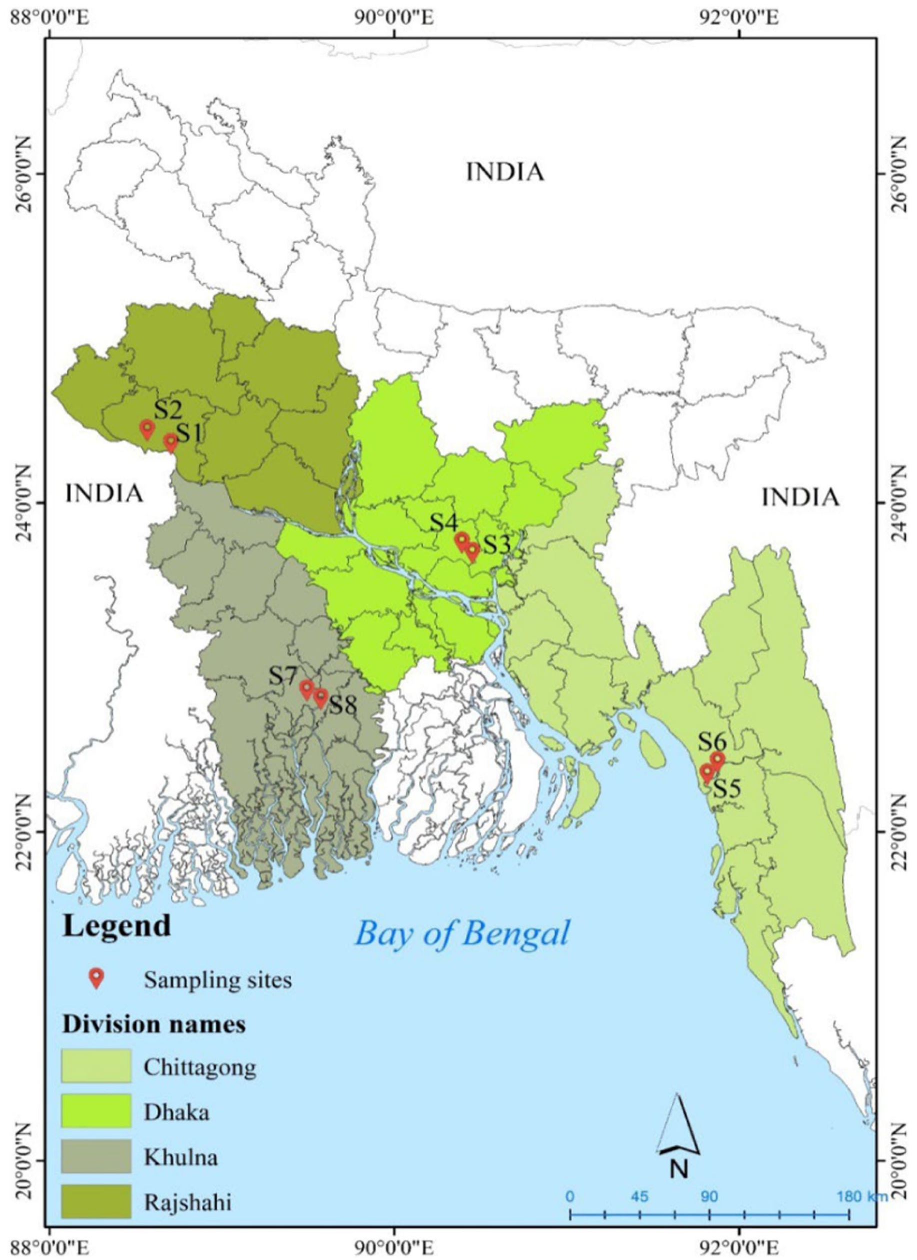

FIGURE 1
Figure showing sample collection points from four major cities of Bangladesh, i.e., Rajshahi (S1 and S2), Dhaka (S3 and S4), Chattogram (S5 and S6), and Khulna (S7 and S8).

recommended daily water intake (4.5 L/day) for an adult was used to calculate the *per capita* exposure estimate (Grandjean and Leparoux, 2004) because reliable data on drinking water consumption in Bangladesh are lacking. The average weight of adult men/women in Bangladesh is 60 kg (Ullah et al., 2017).

2.6 Statistical analysis

The quantity of microplastics in tap water was estimated by dividing the number of detected microplastics by the total quantity of tap water from each sampling point. MPs were quantified in terms of items/L for abundance and mean standard deviation (SD) for concentration. The mean abundance of microplastics at each site was contrasted using one-way ANOVA in RStudio, with a probability threshold less than 0.05 considered significant. Descriptive statistics were used to report the quantity of MPs in every dimension, morphotype, and color group.

3 Results and discussion

3.1 Abundance of MPs

MPs ranging from 10 to 74 items/L were detected in all three tap water samples from four major cities in Bangladesh, with an average

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of 35.33 ± 19.55 items/L. The abundance of MPs at the different sampling sites decreased in the order of S7 > S8 > S6 > S3 > S5 > S4 > S2 > S1 (Figures 2, 3), and some typical microscopy images are shown in Figure 4. The higher abundance of microplastics in tap water at location S7 in Khulna compared to location S1 in Rajshahi could be attributed to a number of factors, including the density of population, growing urbanization, proximity to pollution sources, waste management practices, hydrological circumstances, and land use patterns. One-way analysis of variance (ANOVA) revealed highly significant variation ($F = 8.54$, $p = 0.0002$) among the sampling sites. Tukey's pairwise comparison also demonstrated highly significant differences between S1 and S7 ($p = 0.0018$), S1 and S8 ($p = 0.002$), S2 and S7 ($p = 0.002$), and S2 and S8 ($p = 0.0023$) and significant differences between S4 and S7 ($p = 0.015$) and between S4 and S8 ($p = 0.017$). Further analysis was conducted among the major cities and revealed highly significant differences between almost all pair groups, except for Rajshahi and Khulna ($p = 0.16$) and Khulna and Chittagong ($p = 0.44$). However, a significant positive correlation ($r = 0.968$, $p = 0.032$) was detected between population density and abundance (Figure 5).

The findings of this study, in contrast with those of other comparable studies conducted worldwide (Table 1), show that the tap water of Bangladesh is more highly contaminated than the tap waters of Poland, Denmark, Mexico, Sweden, Germany, England and Wales, the UK, Norway, and Spain (Połeć et al., 2018; Strand et al., 2018; Uhl et al., 2018; Johnson et al., 2020; Shruti et al., 2020; Dalmau-Soler et al., 2021; Kirstein et al., 2021; Weber et al., 2021). In contrast, Tong et al. (2020) reported that the concentration of 440 MPs/L in tap water from China was much greater than that in our study. The variation in microplastics among the studies might be caused by the volume of samples, methodologies applied, type of water source, materials of pipes used for water distribution arrangements, and weather conditions (Tong et al., 2020). However, plastic pipes and thread seal tapes were used in Bangladesh to supply household water, which might increase microplastic contamination in the tap water. Although few investigations have been conducted on microplastic contamination in tap water, further studies are recommended to determine the sources and variations of MPs in Bangladesh.

3.2 Morphological characteristics of microplastics

3.2.1 Types and shapes of microplastics

Three different types of microplastics were detected in the tap water of Bangladesh, e.g., fibers, fragments, and films. Among the three types, fibers were predominant, accounting for 96.2% of the total observed MPs, followed by films (3.1%) and fragments (0.7%) (Figure 6A). All the fibers were filamentous in shape, whereas the fragments and films were irregular. The highest number of fibers was recorded in S8 (average of 59.33 items/L), and the lowest was recorded in S1 (average of 14 items/L). Fragments were found only in S6, whereas fibers and films were found at every sampling site. However, the maximum numbers of films were observed for S5 and S7 (Figure 6A). A similar trend was observed in the tap water from Denmark, Mexico, Sweden, and Spain (Strand et al., 2018; Shruti et al., 2020; Kirstein et al., 2021). In contrast, Weber et al. (2021) and Tong et al. (2020) found fragments to be the dominant type of microplastic in tap water. Fibers in the environment mainly originate from textile and domestic washing runoff (Pivokonsky et al., 2018; Banik et al., 2022). Nevertheless, the occurrence of different types and shapes of microplastics needs further study to properly manage microplastic contamination in tap waters.

3.2.2 Color of microplastics in tap water

In the tap water samples, transparent microplastics were predominant (63.9% of the total observed MPs). In addition, five different colors composed 36.1% of the total microplastics. The

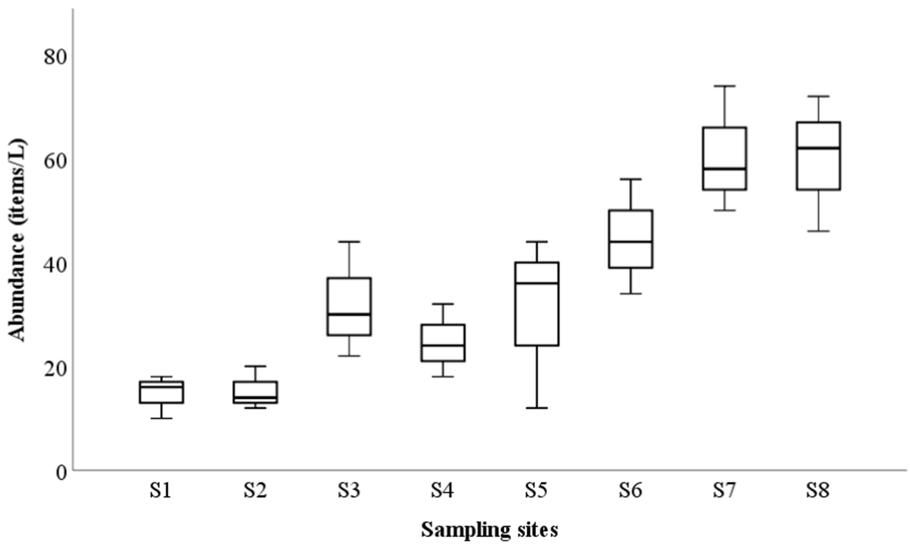

FIGURE 2
Microplastic abundance in tap water samples from four major cities of Bangladesh. X-axis represents the stations of studied cities, and Y-axis represents the concentration of microplastics in items/L.

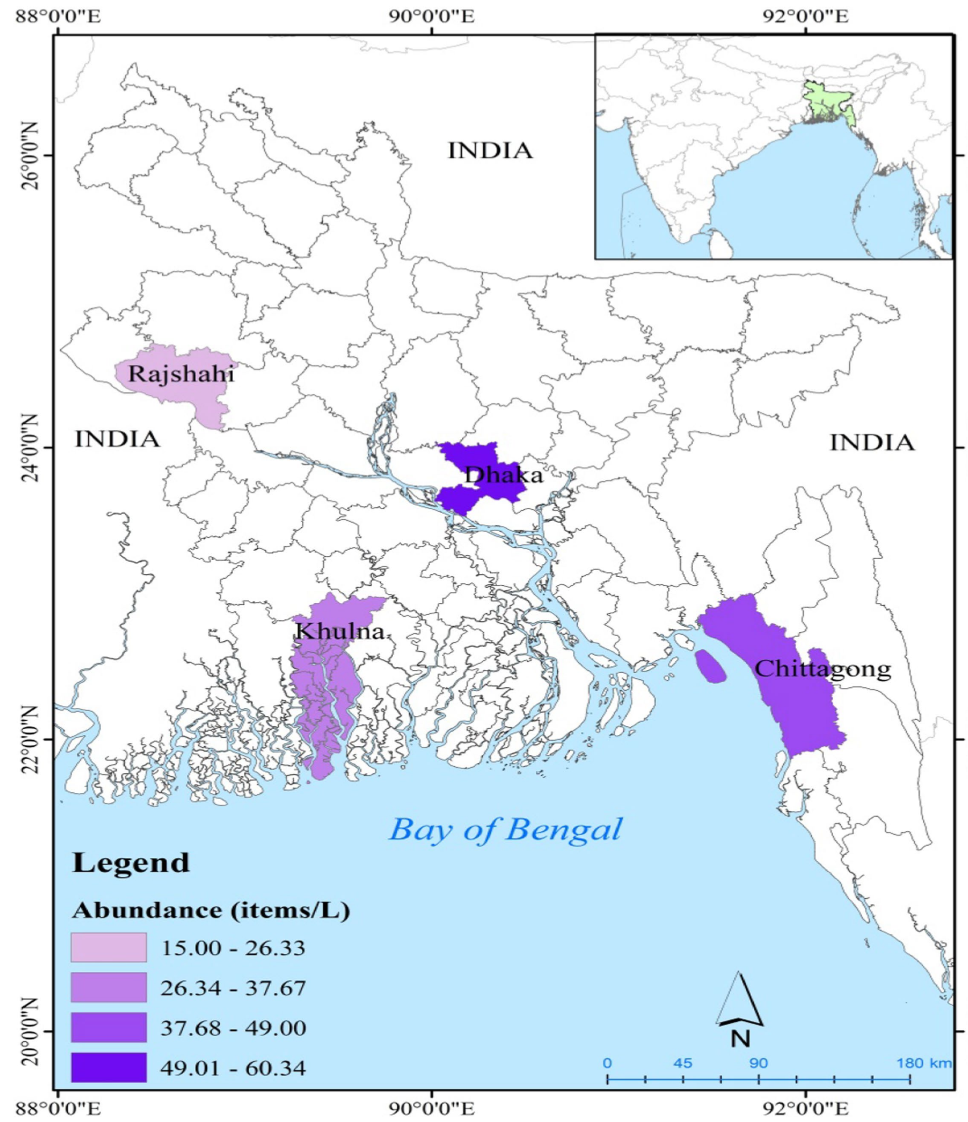

FIGURE 3
Spatial distribution of microplastic concentration in tap water samples from four major cities of Bangladesh. The higher color density of violet shows the higher concentration of microplastics in the figure.

observed colors decreased in the order of violet (11.6%), green (10.1%), blue (5.7%), pink (5.2%), and red (3.5%). Violet and pink-colored microplastics were observed at all the sampling sites, and the others differed among the stations (Figure 6B). The color of tap water microplastics has been less studied in previous studies. However, the main sources of colored microplastics are textile by-products. In addition, domestic cloth and carpet-washing effluents also play a vital role in increasing the number of colored MPs in the environment (Banik et al., 2022). On the other hand, the bleaching process and aging of MPs are responsible for producing transparent particles (Hossain et al., 2021). Therefore, future studies are essential to address this research gap.

3.2.3 Size of microplastics in tap water

In the present investigation, the sizes of the observed microplastics were grouped into three types, and the percentages of the size ranges are shown in Figure 6C. However, microplastics less than 0.5 mm in size were predominantly observed in this study, accounting for 98.1% of the total observed microplastics. Water treatment facilities may be more efficient at filtering out larger particles but less so for smaller microplastics, allowing those less than 0.5 mm to remain in tap water. In contrast, microplastics in the 0.5–1 mm size range comprised 1.7%, and those in the 1–5 mm size range comprised 0.2% of the MPs. Five of the eight sampling sites had only smaller microplastics (<0.5 mm), whereas larger microplastics (1–5 mm) were detected only in S6. A similar trend was observed in previous studies conducted worldwide where smaller MPs were predominantly observed (Połeć et al., 2018; Strand et al., 2018; Uhl et al., 2018; Johnson et al., 2020; Tong et al., 2020; Dalmau-Soler et al., 2021; Kirstein et al., 2021; Weber et al., 2021). The findings of the present study were consistent with those of earlier studies and indicated that researchers should pay more

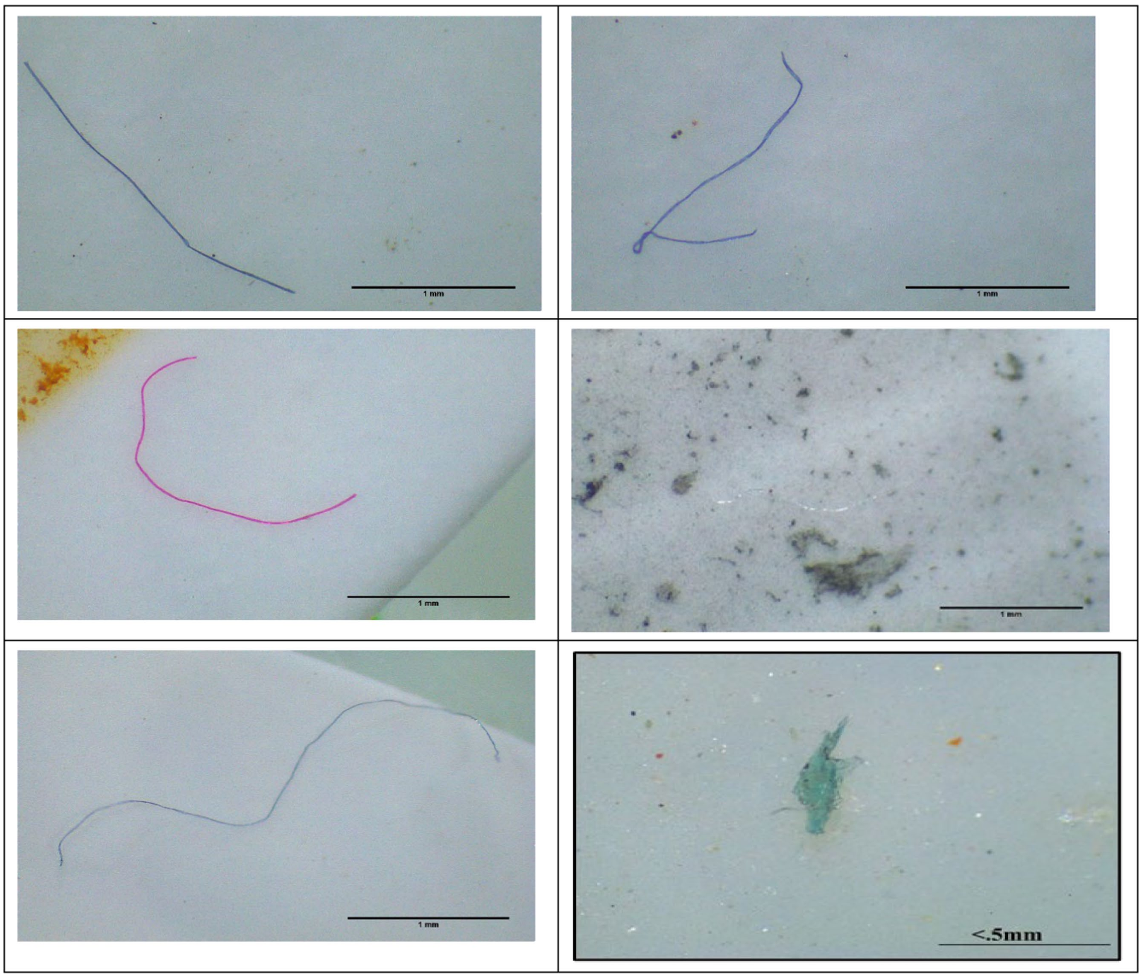

FIGURE 4
Microscopic images of different shapes of microplastics isolated from the tap water samples in the studied areas (scale bar = 1 mm).

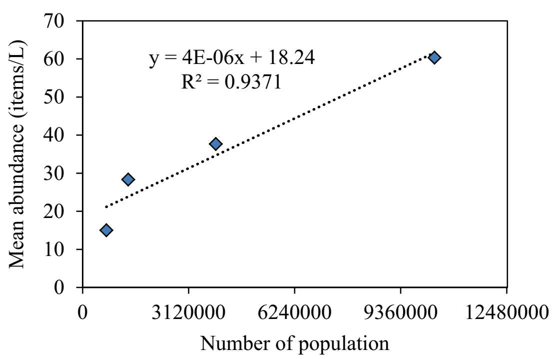

FIGURE 5
Figure showing Pearson's correlations between the mean abundance of microplastics and the population density of studied cities in Bangladesh.

attention to small microplastics. Smaller MPs in tap water cannot be sensed by consumers, and therefore, these might be taken up by consumers of tap water. Researchers have observed MPs in human and marine organism feces (Possatto et al., 2011; Schwabl et al., 2019), indicating the uptake of MPs through the mouth. The potential impact of microplastics on human health has not yet been confirmed (Barboza et al., 2018; Revel et al., 2018); hence, a detailed investigation of MP contamination in tap waters is essential.

3.3 Polymer characterization of microplastics

FTIR spectroscopy was performed on 35% of the total samples, which contained an ideal variation of identified plastic debris since they were the most common and representative of the analysis. In the present study, low-density polyethylene (LDPE), high-density polyethylene (HDPE), ethylene vinyl acetate (EVA), and polyethylene terephthalate (PETE) were identified through FTIR analysis (Supplementary Figure S1). The spectra of LDPE and HDPE showed identical peaks at 2916 cm^{-1} and 2,846 cm^{-1} and at 2914 cm^{-1} and 2,848 cm^{-1}, respectively, indicating C-H stretching. In contrast, the peaks at 1466 cm^{-1} and 1,462 cm^{-1} for LDPE and at 1470 cm^{-1} and 1,462 cm – 1 for HDPE indicated CH_2 bending. The CH_3 band is represented by the peak at 1382 cm^{-1} in

TABLE 1 Summary of microplastic contaminations (items/L) in tap water from different regions of the world compared with the present findings.

Country	Type of water	Abundance (items/L)	Size ranges	Types of MPs	Chemical composition	References
Bangladesh	Tap water	35.33 ± 19.55	>0.5 mm (98.1%)	Fibers (96.2%) > films (3.1%) > fragments (0.7%)	LDPE, HDPE, EVA, PETE	Present study
Poland	Tap (untreated potable water)	Detected but not quantified	0–0.045 mm	Irregularly shaped	Particles (fragments)	Połeć et al. (2018)
Denmark	Tap water	0.3	< 0.3 mm (mainly 0.02–0.1 mm)	Fibers (82%), fragments (14%) & films (4%)	PET, PP, PS, ABS, & PU	Strand et al. (2018)
Mexico	Public drinking water fountains	18 ± 7	0.5–5 mm (50%); <0.5 mm (50%)	Fibers (domain) and fragments	PTT & epoxy resin	Shruti et al. (2020)
Sweden	Tap (potable water)	0.174	< 0.15 mm (32% < 0.02 mm)	Fibers (19%) & Fragments (81%)	PA, PET & acrylates (majority)	Kirstein et al. (2021)
Germany	Tap (treated potable water)	<1	>0.01 mm	Fragments & fibers	PET, PP, PS & PE	Weber et al. (2021)
England & Wales, UK	Tap (Treated portable water)	0–0.011 n/L (>LOD), 0–0.003 n/L (>LOQ)	>0.025 mm	–	ABS and PS (domain, >LOQ)	Johnson et al. (2020)
Norway	Tap water	<1 n/L (below LOD)	>0.1 mm	–	–	Uhl et al. (2018)
Spain	Tap water	0.01	83 to 3,228 µm	Fibers (58%) > fragments (42%)	PP, PES, PA	Dalmau-Soler et al. (2021)
China	Tap water	440 ± 275	3 µm to 4,453 µm	Fragments > fibers > Spheres	PE, PP, PS, PET	Tong et al. (2020)

PVC, polyvinyl chloride; PA, polyamide; PE, polyethylene; PS, polystyrene; PP, polypropylene; PU, polyurethane; PET, polyethylene terephthalate; ABS, acrylonitrile butadiene styrene; PTT, polytrimethylene terephthalate; PMMA, polymethylmethacrylate; LOD, limit of detection; LOQ, limit of quantification; nd, not described.

the LDPE spectrum. Furthermore, wavelengths of 730 cm^{-1} and 719 cm^{-1} in the LPDE and 717 cm^{-1} in the HDPE indicate CH_2 rock. However, the spectra of EVA showed prominent peaks at 2920 cm^{-1} and 2,850 cm^{-1}, indicating C-H bond stretching, whereas the peaks at 1747 cm^{-1} and 1769 cm^{-1} represent C=O stretching and CH_2/CH_3 stretching, respectively. Moreover, PETE showed prominent peaks at 1726 cm^{-1}, indicating C=O stretching; at 1241 cm^{-1} and 1,035 cm^{-1}, indicating C-O stretching; and at 713 cm^{-1}, indicating aromatic C-H bond stretching. However, due to the aging of microplastics and degradation procedures, several identical peaks of HDPE and EVA polymers were not found in the FTIR spectrum (Sathish et al., 2019; Banik et al., 2022). PE and PETE were recorded as the major polymer types of microplastics in tap water in China, Germany, and Denmark (Strand et al., 2018; Tong et al., 2020; Weber et al., 2021). These polymers are generally used in food and beverage packaging, wrapping cosmetic items, houseware, food containers, and shopping bags (Novotna et al., 2019; Banik et al., 2022).

3.4 Dietary intake of microplastics from tap water

In the present investigation, we evaluated the daily food intake of microplastics per person to determine the effects of exposure to microplastic pollutants on human health and to assist in establishing dietary recommendations for public health policy. The *per capita* daily dietary intake of microplastics was reported to be 2.65 particles/person per day according to the mean value of microplastics (35.33 particles/L) in water and the average recommended consumption of water (4.5 L/day as proposed by the WHO) for an adult (60 kg). In Bangladesh, where freshwater sources are already stressed due to pollution and over-extraction, the intrusion of microplastics into drinking water raises health concerns. The consumption of microplastics through tap water raises significant issues regarding bioaccumulation in the human body of studied areas. These microscopic plastic particles can build in tissues over time, potentially causing adverse health impacts, such as inflammation, hormone disruption, abdominal pain, constipation or even bowel obstruction, and cancer development (Pirsaheb et al., 2020; Amran et al., 2022; Feng et al., 2023).

3.5 Source identification of microplastics

Principal component analysis (PCA) and cluster analysis (CA) can be employed to address the prevalence of microplastics in a more comprehensible way due to the varying quantities of plastics in different sample areas. PCA of three different microplastics (fibers, fragments, and films) revealed their distributions in the tap waters of eight stations (Figure 7A), covering four districts exhibiting significant variations across their distributions from each sampling location. In the present investigation, PCA revealed two major PC components accounting for 56.18 and 43.82% of the total variation in PC1 and PC2, respectively, representing the percentage of the total variability in the dataset (Figure 7A), which provided insight into the dominant patterns or trends in the microplastic contamination characteristics under analysis. By analyzing the loadings of variables within each

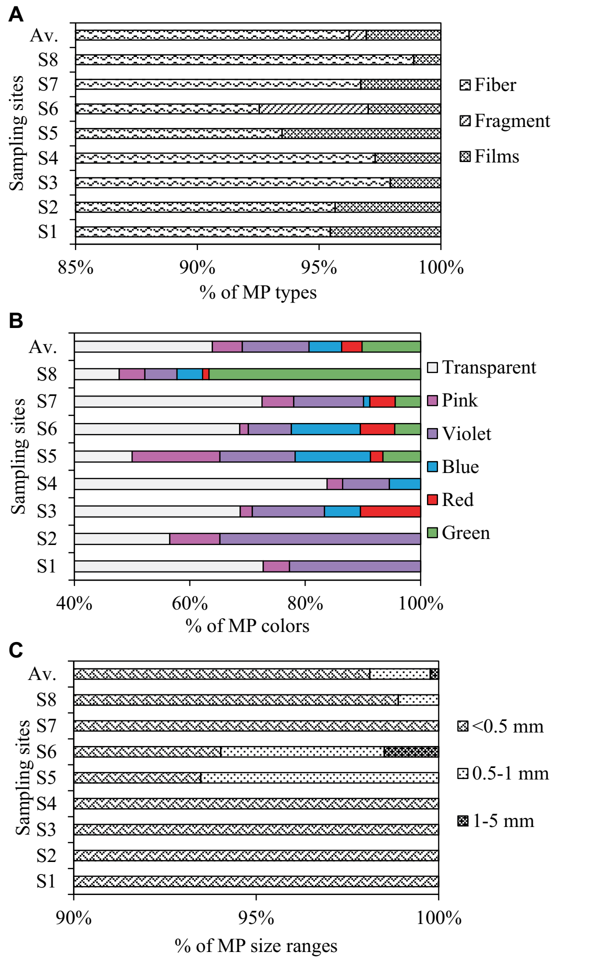

FIGURE 6
Morphological characteristics of microplastics were shown in this figure where **(A)** types, **(B)** color, and **(C)** size of microplastic fractions in tap water samples from studied cities.

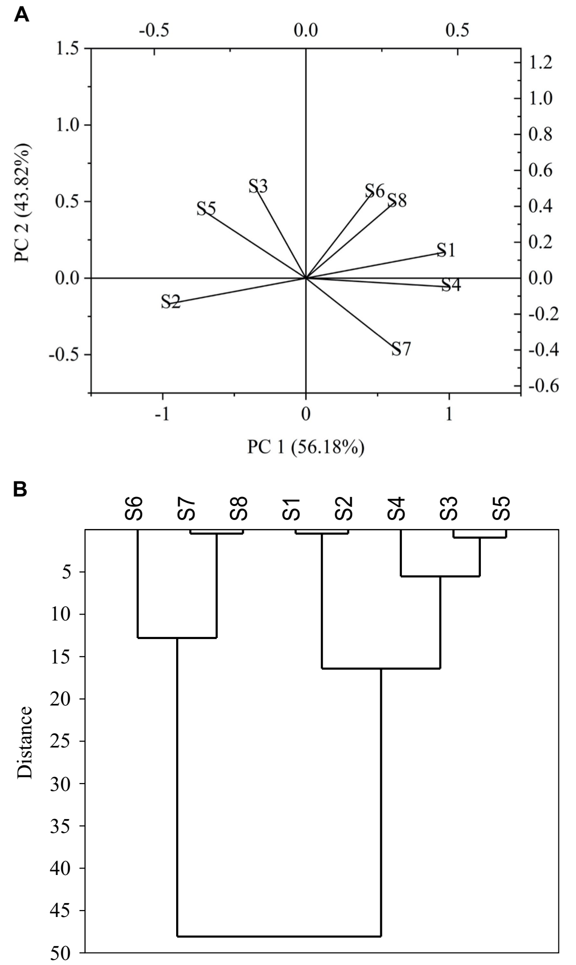

FIGURE 7
Figure illustrates **(A)** Principal component analysis (PCA) among three types of microplastics, i.e., fibers, fragments, and films and **(B)** cluster analysis (CA) among the eight sampling stations from studied areas.

principal component, it was determined which sources contribute most to the observed patterns of microplastic contamination. Accordingly, the findings specified that industrial discharge, building supplies, sewage waste, domestic goods, and other man-made activities were probable sources of microplastics (BIDA, 2021; Hossain et al., 2022; Islam et al., 2022).

Cluster analysis is commonly used to provide a similar set of sampling sites with special heterogeneity. An identical collection of sites is shown in one cluster, and dissimilar sites are plotted in another cluster to highlight specific locations of exposure. Group 1 consisted of two sites, S7 and S8, with high microplastic concentrations in the TW samples, and group 2 consisted of two sites, S1 and S2, while group 3 comprised of S3 and S5 (Figure 7B). Regardless of the challenge in detecting the contributory factors of microplastics in the current research, the presence of microplastics in the treated tap water of the studied regions (both public and private spaces) is likely to be linked to various anthropogenic activities, such as runoff from catchment areas and other anthropogenic activities, such as wastewater discharge, urbanization, dumping of industrial waste, and sewage water, near these sites (Lam et al., 2020; Hasan et al., 2022). At present, because of the ongoing proliferation of growing urbanization and industrialization in Bangladesh, both surface water and groundwater are being contaminated (Faroque and South, 2022), and plastic pollution and industrial waste threaten the portability of safe drinking water (Haseena et al., 2017).

3.6 Limitations of the study

There are various constraints to studying the contamination of microplastics in urban tap water in Bangladesh. Primarily, the absence of standardized sampling and analytic methodologies impedes the capacity to precisely compare findings between research and geographic regions. Furthermore, the insufficient resources and inadequate infrastructure also created obstacles in carrying out a thorough sampling process, which could result in the underestimating of the actual magnitude of contamination by microplastics (MPs). In addition, the complex characteristics of urban water systems, such as deteriorating infrastructure, discharge from industrial activities, and unregulated waste disposal methods, made it challenging to pinpoint and address the sources that contribute to the pollution of microplastics (MPs). In addition, the ever-changing movement of water and the process of mixing in urban networks can lead to variations in the concentrations of microplastics (MPs) over space and time. This requires extensive sampling to obtain accurate and representative data. The lack of studies, especially addressing microplastics (MPs) in drinking water in Bangladesh, highlights the necessity for additional investigation to comprehend the scope and consequences of this rising environmental concern.

4 Conclusion

Improved sanitation and water supply, coupled with enhanced governance of water resources, have the potential to stimulate economic growth in countries and play a crucial role in alleviating poverty. Hence, the present research investigated the availability, composition, and dietary intake of microplastics (MPs) in a sample of supplied tap water from Bangladesh for the first time. All analyzed water samples were found to contain microplastics, with an average concentration of 35.33 ± 19.55 particles/L. Notably, three morphotypes of microplastics were identified, with fibers constituting approximately 96.2% of the total abundance, suggesting contamination from both synthetic and natural fibers. Transparent microplastics were abundant, which could be attributed to the bleaching process in water. LDPE and HDPE were the most predominant polymers identified, demonstrating broad usage in dispensing and washing bottles, pipes, plastic parts for industrial components, laboratory supplies, and plastic containers around the studied locations. The estimated daily dietary intake per person (2.65 particles/person/day) was comparatively greater than that in other countries. More research into microplastic risk estimation might help us comprehend the effects of microplastics in drinking water on people's well-being. Administrators and policymakers should strictly monitor the tap water supply since it may pose major health concerns to individuals.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary material, further inquiries can be directed to the corresponding authors.

Author contributions

MHo: Conceptualization, Supervision, Writing – original draft, Writing – review & editing. JY: Project administration, Resources, Writing – review & editing. PS: Resources, Writing – review & editing. PB: Data curation, Investigation, Methodology, Writing – original draft. SS: Data curation, Investigation, Writing – original draft. A-AN: Investigation, Methodology, Writing – original draft. MHa: Data curation, Investigation, Writing – original draft. MR: Formal analysis, Methodology, Writing – original draft. BP: Investigation, Writing – review & editing. TA: Methodology, Writing – review & editing.

Funding

The author(s) declare financial support was received for the research, authorship, and/or publication of this article. This study was also supported by Researchers Supporting Project Number (RSP2024R144), King Saud University, Riyadh, Saudi Arabia.

Acknowledgments

Assistance from all volunteers is acknowledged. The authors would like to extend their sincere appreciation to the Researchers Supporting Project Number (RSP2024R144), King Saud University, Riyadh, Saudi Arabia.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

The author(s) declared that they were an editorial board member of Frontiers, at the time of submission. This had no impact on the peer review process and the final decision.

Publisher's note

Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fsufs.2024.1397348/full#supplementary-material

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