EnvironmentAsia
The international journal by the Thai Society of Higher Education Institutes on Environment

EnvironmentAsia 17(3) 2024 88-104
DOI 10.14456/ea.2024.38
ISSN 1906-1714; ONLINE ISSN: 2586-8861

Microplastics Pollution in Tap and Drinking Water Sources in Thailand and Health Impacts

Kesirine Jinda[1*], Thammarat Koottatep[2], Warunsak Liamlaem[1], Chawalit Chaiwong[2], Tatchai Pussayanavin[3], and Chongrak Polprasert[1]

[1] Department of Civil Engineering, Faculty of Engineering, Thammasat University, Pathum Thani, Thailand
[2] Environmental Engineering and Management, Asian Institute of Technology, Pathum Thani, Thailand
[3] Faculty of Science, Ramkhamhaeng University, Bangkok, Thailand

*Corresponding author: kesirine.jind@dome.tu.ac.th
Received: February 13, 2024; Revised: April 19, 2024; Accepted: June 14, 2024

Abstract

The increasing population and evolving consumption habits in developing countries present difficulties in managing solid waste. Plastic waste, especially single-use plastics, are a significant issue as they are entering the environment, notably the river ecosystems, at an alarming pace. In the environment, plastic wastes can be degraded into small sizes (less than 5 mm), called microplastics (MPs), which could contaminate the ecosystems and the food chain, including foodstuffs and water supply. This study aims to investigate MP contamination of tap and drinking water in public areas (some academic institutions) in central Thailand and analyzed potential health risks, including recommendations for health impact minimization. Tap water samples collected from a water supply treatment plant and Academic Institutions 1 and 2 in central Thailand were found to contain 304 ± 90, 270 ± 109 and 386 ± 102 MPs/L, respectively. In addition, MP concentrations of 211 ± 70 and 122 ± 60 particles/L were also found in drinking water samples collected from commercial bottled water and membrane filtration water, respectively. The MP sizes of 1 - 50 µm were most abundant in both the tap and drinking water samples whose shapes were mainly fragments and fiber. The questionnaire results revealed that the respondents mainly utilize the tap water (after some pre-treatment processes such as filtration and boiling) for drinking and food preparation, indicating potential health risks to the people who consume these water sources, and recommendations for health impacts minimization were proposed.

Keywords: Microplastics; Tap and drinking water; Consumption behaviors; Potential health risks; Microplastic removal

1. Introduction

Plastic wastes are particularly problematic, with single-use plastics leaking into the environment, including the marine environment, at an unprecedented rate (World Bank, 2022; Mihai *et al.,* 2021). A high rate of plastic consumption with a significant portion of single-use plastics brings many challenges related to land-based plastic pollution to Thailand. Improper waste management system and infrastructure mainly contribute to this plastic pollution. About 428 kt/year of mismanaged plastic wastes enter the environment as a result of inadequate collection of plastic waste and operation of unsanitary disposal facilities (Isangedighi *et al.,* 2020). Due to low collection rate and improper waste disposal, most mismanaged plastic wastes from land-based sources could be transported to become river-based plastic pollution (Isangedighi *et al.,* 2020). These plastic wastes are litters in aquatic environment zones (e.g., water body and sediment) (Isangedighi *et al.,* 2020). The large plastic wastes can be degraded and fragmented into small sizes called "microplastics (MPs)" with sizes smaller than 5 mm (Ahmed *et al.,* 2021). The MPs can be distributed and travel along rivers, thus contaminating raw water resources used for producing water supply (Global Water Research Coalition, 2015; Radityaningrum *et al.,* 2021).

During the recent years, MP contamination in tap and drinking water has been reported worldwide. Tong *et al.* (2020) reported 440 particles /L of MPs was contaminated in household conventional tap water in China. The MP concentration of 260.5 particles/L was found to retain in drinking water in Iran (Sharifi & Movahedian Attar, 2022). Moreover, MP contaminations in drinking water supply networks in Switzerland and France were reported to be 0.002 and 0.260 particles/L, respectively (Barbier *et al.,* 2022; Negrete Velasco *et al.,* 2023). In addition, the study of Tse *et al.* (2022) reported that 1L commercial bottled water was found to contain 19 - 334 particles of MPs. In Thailand, several studies have reported MP contamination in river water resources and tap water (Ta and Babel, 2020; Chanpiwat and Damrongsiri, 2021; Kankanige and Babel, 2020 - 2021; Ounjai *et al.,* 2022). The study of Chanpiwat and Damrongsiri (2021) reported that about 0.40 - 2.40 and 0.62 - 0.68 MPs/L were detected in freshwater and tap water samples, respectively, in two water supply systems in Bangkok in which raw water sources are from the Chao Phraya River and Maeklong River. In another study, about 609 MPs/L were observed in tap water samples from a conventional water treatment plant (Kankanige and Babel, 2021). The possible sources of MP contamination in the tap water were anticipated to be from the raw water source and contamination within the water treatment processes (Kankanige and Babel, 2021). The abundance of MPs found in tap water sources can lead to the occurrence of MPs in consumable water or drinking water produced from the tap water sources. An average MP concentration of 56 particles/L was determined in consumable tap water samples in a university, central Thailand (Tang and Hadibarata, 2021). Typically, Thai people mostly drink water from both public drinking fountains at public areas (e.g. academic institutions) and commercial bottled water. In addition, because sources of production of both public drinking and bottled water are from tap water, the MP contamination in drinking water has become an emerging concern in Thailand (Kankanige and Babel, 2020). Kankanige and Babel (2020) reported that the MP concentration of 140 ± 19 particles/L was found in single-use PET-bottled water. These MP contaminations can pose adverse impacts on human health through consumption of MP contaminated water (Bou Bouwmeester *et al.,* 2015)

Due to less efficiency of MP removal by conventional water treatment systems, the abundance of MPs still presents in the treated water at consumption points (Ta and Babel, 2020; Chanpiwat and Damrongsiri, 2021; Kankanige and Babel, 2020-2021; Ounjai *et al.,* 2022). In Thailand, with the conventional water treatment processes such as screening, coagulation, flocculation and sand filtration, the low MP removal efficiencies of 27 - 62.4% were achieved (Ta and Babel, 2020; Ounjai *et al.,* 2022). However, the MP removal efficiencies would be varied according to various operational factors and maintenance (Tang and Hadibarata, 2021). Due to low MP removal efficiencies and operational factors, smaller-sized MPs (6.5 - 53 μm) still dominates in treated water of a conventional water treatment plant in Thailand (Kankanige and Babel, 2021). However, not much evidences of health risk issues related to consuming MP contaminated water have been reported in Thailand. Apart from raw water source monitoring and control including enhancement of removal efficiency of pretreatment or at water treatment plant, post-treatment (e.g. filtration systems) might be applied to minimize human exposure risks at consumption points.

With respect to the above issues, this paper investigated MP contamination of tap and drinking water in public areas (some academic institutions) in central

Thailand and analyzed potential health risks, including recommendations for health impact minimization.

2. Methodology

2.1 Sample collection

Tap water samples were collected from distribution tank of the water supply treatment plant where raw water was from the Chao Phraya River, and two adjacent academic institutions located in the Pathumthani province, near Bangkok, Thailand (Figure 1). The distance between the water supply treatment plant and the Academic Institutions 1 and 2 is about 10 kilometers. The tap water samples were collected twice from four public taps of each Academic Institution. In addition, in Academic Institutions 1, drinking water samples were collected from three public drinking water fountains using commercial bottled waters (each with a volume of 20 L) produced from a nearby water purification facility. In Academic Institution 2, drinking water samples were collected from two commercial membrane filtration systems for MP analysis. Composite sampling was conducted using a cleaned wide-mouth glass bottle (250 mL) covered with aluminium foil and a stainless-steel cap prior to analysis in the laboratory (Kankanige and Babel, 2020-2021). All sampling points are located in Pathumthani province, central Thailand and the water samplings were conducted during January - March 2022.

2.2 Sample pretreatment, analysis and contamination prevention

The collected water samples were filtered with a 0.45 µm cellulose nitrate (CN) membrane by using a vacuum pump, then minimally rinsed with ultrapure water to ensure all residues were transferred. The filtered CN membranes were placed in clean petri dishes and pretreated by using Nile red staining (NR-S) techniques. The Nile red stock solution of 1 mg/mL was prepared in methanol and applied to cover overall area of each CN membrane to a working concentration of 10 µg/mL (Kankanige and Babel, 2020 - 2021; Meyers *et al.,* 2022; Shruti *et al.,* 2022). Each membrane was incubated in oven at 30 °C for 30 minutes and dried at room temperature for 24 hours prior to detection of MP abundance (number and shape).

Each dried membrane was visually captured under a fluorescence microscope (DeltaVisionTM Elite cell Imaging System, 4X magnification, DV Elite, GE HEALTHCARE, USA) for determination of MP abundance, shape and size. The strained MPs were performed as blue-fluorescence particles images. All of the observed MPs were visually counted for their abundance (particles per L of sample, part/L) and determined for their size and shape. The overall dimension of MPs was measured based on length according to five categories: < 50 µm, 51 - 100 µm, 101 - 200 µm, 201-300 µm, > 301 µm. In addition, MP shapes were sorted to fragments

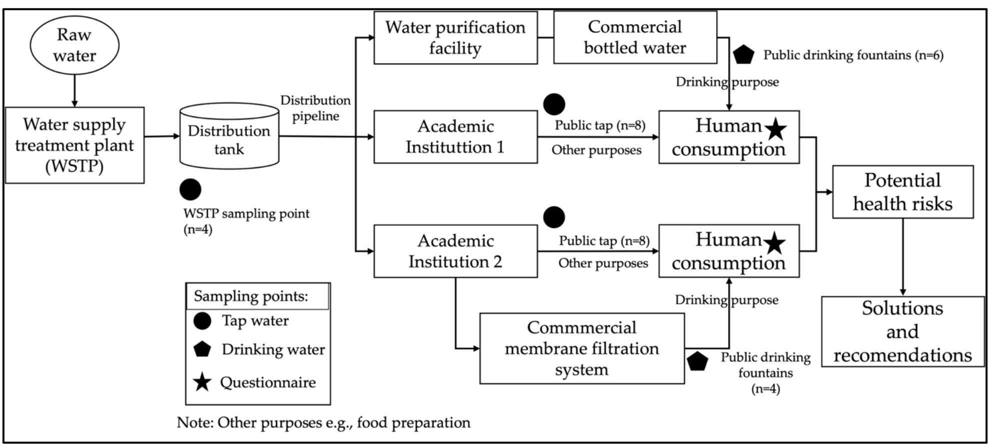

Figure 1. Sample collection locations

(similar width and length) and fibers (length longer than width) (Kankanige and Babel, 2020). The duplicate tests of the prepared samples were undertaken.

To minimize cross contamination, all sample preparation and analysis steps were conducted in a clean and separated analytical room. The blank samples of the ultrapure water were proceeded in a similar step to correct contamination during sample preparation steps. In addition, clean and dried personal protective equipment such cotton lab coats and latex gloves were applied during the sample analysis. All equipment and glassware were rinsed in triplicates with ultrapure water before use.

2.3 Questionnaire survey

A sample group was calculated according to Yamane's equation. The sample group calculation was made under the known population number of 225 people who commonly use taps and public dringking fountains in the Academic Institutions, and a 5% margin of error (Kharuddin *et al.,* 2020). Sample size was given by Equation (1).

$$n = \frac{N}{1+N(e)^2} \quad \text{Equation (1)}$$

Where; N = population is known
e = margin of error

Consequently, an online questionnaire survey was conducted in sample group of 143 users to observe consumption behaviors of personnel who consumed tap and drinking water in the two Academic Institutions, which covered 2 main aspects: 1) demographic data such as gender, age, and occupation or educational qualification and 2) consumption behaviors which involved five main questions: 1) Do you usually drink from public drinking fountains provided by the Academic Institutions?, 2) How many cups (size of 100mL each) of drinking water do you consume per day?, 3) Do you usually drink tap water from public taps in the Academic Institutions?, 4) Do you usually consume tap water via other routes (e.g. food cooked using tap water in the Academic Institutions)?, and 5) How many bowls (size of 500mL each) of tap water do you use in cooking at dormitories per day?. The results of the questionnaire survey were used to calculate MPs intakes and exposure loadings, as well as evaluating the potential health impacts of MPs.

2.4 MP removal efficiency

The MP removal efficiency (%) of the commercial membrane filtration systems of the Academic Institution 2 was calculated by Equation (2). The MP concentrations (CMP) in the tap water (influent) and the drinking water (effluent) after the filtration processes were used in the calculation (Kankanige and Babel, 2020).

$$\text{MP removal efficiency (\%)} = \frac{\text{Influent } C_{MP} - \text{Effluent } C_{MP}}{\text{Influent } C_{MP}} * 100 \quad \text{Equation (2)}$$

2.5 Estimated daily intake of MP

The MP daily intake was determined to evaluate the MP ingestion loading for humans through drinking water and food prepared from drinking water. The estimated daily intake of MPs (EDI_{MP}) was calculated using Equation (3) (Makhdoumi *et al.,* 2021; Huan *et al.,* 2023) according to the data of MP abundance and daily drinking water and food consumption. MP concentrations in drinking water (C_{MP}, particles/L) detected in the Academic Institutions and the ingestion rate (IR, L/person/d) which was the daily consumption volume of drinking water or volume of water used in food preparation, summarized from the results of the questionnaire survey were used in calculating EDI_{MP}.

$$EDI_{MP}\text{/person/d} = (C_{MP} * IR) \quad \text{Equation (3)}$$

2.6 Statistical analysis

Quantified data were tested by using analysis of variance (one-way ANOVA) in SPSS (Version 23.0) to determine their statistical significance ($p < 0.05$).

3. Results and Discussion

3.1 MP abundance, shapes and size distribution

The MP concentration of 7 ± 2 particles/L (MP sizes ranged from 1 - 100 µm) was found in samples of blank control. Despite the strict contamination prevention measures with a clean and separated analytical room, the samples were still contaminated with environmental MPs which is ubiquity and high sensitivity to the analyzed samples (Kankanige and Babel, 2021). The results suggested the significance of blank control to obtain more accurate data analysis.

Table 1 illustrates the MP abundance observed in the tap water samples collected from the water supply treatment plant and the Academic Institutions 1 and 2. The average MP concentrations of 304 ± 90, 270 ± 109 and 386 ± 102 particles/L were found in the tap water samples collected from distribution tank of the water supply treatment plant, the Academic Institution 1 and 2, respectively. The presence of high MP concentrations in the treated water (tap water) at the water supply treatment plant (304 ± 90 particles/L) was due mainly to the MP contamination in the river raw water source (Chanpiwat and Damrongsiri, 2021; Kankanige and Babel, 2020-2021; Tang and Hadibarata, 2021) and the inefficiency of the water supply treatment plant to remove MPs. Conventional water supply treatment plants in central Thailand were found to be less efficient in MP removal (27 - 62.4%) from freshwater source (Chanpiwat and Damrongsiri, 2021; Kankanige and Babel, 2021).

In Table 2, it is interesting to note that a study by Chanpiwat and Damrongsiri (2021) found MP concentration in the Bangkok tap water samples to be 0.62 - 0.68 particles/L, which were less than that in this study. The sample preparation methods used in Chanpiwat and Damrongsiri (2021), Barbier *et al.* (2022) and Negrete Velasco *et al.* (2023) were based on density separation and Wet Peroxide Oxidation (WPO) (without NR-S technique) which might be able to detect the MPs in limited size range (> 300 µm), resulting the MP concentrations in their water samples to be lower than those found in this study (Barbier *et al.,* 2022; Negrete Velasco *et al.,* 2023). The NR-S technique employed in this study gave better efficiency in tagging of smaller-sized MPs (< 300 µm) under fluorescence microscope (Kankanige and Babel, 2020 - 2021; Meyers *et al.,* 2022; Shruti *et al.,* 2022). Chatterjee *et al.* (2023) suggested that the applying the well-prepared NR-S without other pre-treatment methods (e.g. digestion, oxidation, filtration, and concentration), provided better determination for nanoplastic (single-particle counting) in water samples. Therefore, the sample preparation methods employed in this study were similar to those employed by Kankanige and Babel (2020; 2021) and Tong *et al.* (2020) which found the similar MP concentrations in tap water of 95 - 449 particles/L (Table 2). In consequence, the study of Kankanige and Babel (2021), which collected tap water samples from the similar location of this study, found the MP concentration to be 449 particles/L, higher than the result of this study, being 304 ± 90 particles/L. These observed high MP concentrations of 449 and 304 particles/L from tap water in this area suggest that improvement in operation and maintenance of the water treatment plant and distribution system should be undertaken to reduce the MP concentration in the tap water, and accordingly minimize potential health risks to the people who use this tap water for consumption or other purposes. During water supply distribution, these MPs could be partially trapped along the distribution pipes (Shen *et al.,* 2021), resulting in the average MP concentration of 270 ± 109 particles/L remaining in the tap water samples collected from the Academic Institution 1. Due to the long operation period (more than 51 years) of the Academic Institution 2, there could be deterioration of the pipelines which contributed to the higher MP concentration of 386 ± 102 particles/L in the tap water samples.

In addition, the MP concentrations in drinking water samples of this study were similar to those found in the study by Kankanige and Babel (2020) and Tse *et al.* (2022). The commercial membrane filtration systems in the Academic Institution 2 were able to further reduce the MPs in the drinking water to be 122 ± 60 particles/L (or, according to

Equation (2), about 70% removal efficiency), more effective than the filtered tap water or drinking water of the Academic Institution 1 whose MP concentrations were 211 ± 70 particles/L (or, according to Equation (2), about 22% removal efficiency). Accordingly, the MP concentration in the drinking water of the Academic Institution 1(commercial bottled water) was observed to be higher than that of the Academic Institution 2 (filtered water from commercial membrane filtration systems), possibly indicating that the packaging of the commercial bottled water might be one of sources for the MPs contaminated in the drinking water. Some previous studies highlighted that mechanical stress and environmental factors were significant factors in releasing the MPs from the packaging into the bottled drinking water (Oßmann *et al.,* 2018; Taheri *et al.,* 2023). With respect to the mechanical stress, the MP contaminations in the bottled drinking water were mainly contributed by cup-neck pressures (the opening and closing of the bottle cap) and the pressures during squeezing, cleaning and filling of bottles (Winkler *et al.,* 2019; Taheri *et al.,* 2023). The environmental factors such as UV exposures as well as the bottle age and storage time have also significant effects on MP release from in the water bottles. The older bottle which was stored and daily exposed to sunligh for long time could be mechnically fragmented, resulting in more peeling off of inner surface layer into water content than the new bottle (Oßmann *et al.,* 2018). The PET bottle used as reusable containers in the markects could be mostly damaged by photo-oxidative degradation at specific UV wavelenght of 300 nm, normally the near UV radiations (290 - 400 nm) of the sunlight (Singh & Sharma, 2008; Conradie *et al.,* 2022). The study of Conradie *et al.* (2022) reported that PET packaging was found to have about 1.4% mass loss due to degradation after 6 weeks of UV exposure at a maximum irradiance and peak intensity of 130 W/m² and 365 nm, respectively. Consequently, the degraded PET was found to have more mass loss (0.7%) when contact with water, this was likely due to hydrolytic degradation (Conradie *et al.,* 2022). Similarly, the promotion of PET degradation by both UV radiation and hydrolysis was found by Pinlova & Nowack (2024) who reported that the PET pellet started cracking after 30 days of UV exposure and submerged in water. After 75 days of experiment, the average crack coverage was found to increase from 6% to 37%. After 90 days, the cracked surface of the PET was prone to surface delamination and releasing some pieces of plastic (sized less than 50 µm) with a mild mechanical force. In addition, the studies by Oßmann *et al.* (2018) and Taheri *et al.* (2023) demonstrated that after 90 days of exposure to the sunlight, the MP concentrations in new bottled water raised to be more than 2,600 particles/L, while the MP concentrations were observed to be more than 8,300 particles/L in water with the old bottles (older than 3 months). These results indicated that the old reuseable bottles (more than 3 months) could potentially be one of the major factors causing the MP contaminations in bottled drinking water. Nevertheless, further experiments should be carried out in order to determine the MP fragmentation and removal mechanism from tap and drinking water.

Table 1. Average MP concentrations in tap and drinking water

Water sample	Source	Average MP concentration (particles/L)
Tap water	Water supply treatment plant (n = 4)	304 ± 90
	Academic Institution 1 (n = 8)	270 ± 109
	Academic Institution 2 (n = 8)	386 ± 102
Drinking water	Academic Institution 1 * (n = 6)	211 ± 70
	Academic Institution 2 **(n = 4)	122 ± 60

Notes: * Commercial bottled water
** Filtered water from commercial membrane filtration systems

Table 2. Sample preparation and identification methods of MPs in water samples

Location	Sampling point (volume of sample)	Type of sample	Pre-treatment methods (Filtration)		Sample preparation (working concentration)	Identification Methods (detected area)	MP concentration (particles/L)	MP sizes (µm)	Ref.
			In line (mesh sizes, µm)	In Lab (filter sizes)					
Bangkok	Treated water distribution (100 L)	Consumable tap water	50	Whatman® Grade GF/C filter paper	Density separation (sat-NaCl solution) and WPO [e]	µ-Raman spectroscopy (Over an area of 25% of the filter paper)	0.62 – 0.68	> 100	Chanpiwat and Damrongsiri (2021)
France	Drinking water network distribution points (500L)	Drinking water	10	0.2 µm Al_2O_3 [a] filters	Density separation (NaCl solution) and WPO [e]	µ-FTIR[h]	0.002 - 0.260	> 25	Barbier *et al.* (2022)
Switzerland	A conventional drinking water supply network (2,000 L)	Drinking water	500, 250, 125 and 63	0.45 µm CN [b] filter and 0.2 µm Al_2O_3 [a] filters	WPO [e]	OM [i] and FTIR [h]	0.002	> 63	Negrete Velasco *et al.* (2023)
Pathumthani province	Public taps in the campus (1 L)	Tap water	500, 300, and 53	0.45 µm membrane filter	WPO [e] and NR-S [f] (10 µg/mL)	FM [j] and OM [i]	95	6.5 - 500	Kankanige and Babel (2020)
Pathumthani province, Central Thailand	Treated water distribution after chlorination process (9 L)	Treated tap water	500, 300, and 53	0.45 µm membrane filter	WPO [a] and NR-S [f] (10 µg/mL)	Confocal Raman spectroscopy	449	1 - 500	Kankanige and Babel (2021)
Bangkok	Single-use plastic-bottled water	Drinking water	-	0.45 µm CN [b] filter	NR-S [f] (1 µg/L) and DAPI [g]	FM [j] and Confocal Raman spectroscopy	140 ± 19	6.5- > 50	Kankanige and Babel (2020)

Table 2. Sample preparation and identification methods of MPs in water samples (Cont.)

Location	Sampling point (volume of sample)	Type of sample	Pre-treatment methods (Filtration)		Sample preparation (working concentration)	Identification Methods (detected area)	MP concentration (particles/L)	MP sizes (µm)	Ref.
			In line (mesh sizes, µm)	In Lab (filter sizes)					
China	Household conventional water tap (1 L)	Tap water	-	PC [c] membranes 0.2 µm	NR-S [f] with green–fluorescence (5 mg/L)	FM [j] (sample area of 0.66%) and µ-Raman spectroscopy	440	3 - 4,453	Tong *et al*. (2020)
Hong Kong	Bottled water (1 L)	Drinking water	50	0.45 µm MCE [d] membrane filter	NR-S [f] with blue-fluorescence (10 µg/mL-, 1mg/mL)	Stereomicroscope and flow cytometry	19 - 334	10 - ≥ 50	Tse *et al*. (2022)
Pathumthani province, Central Thailand	Distribution tank	Tap water	-	0.45 µm CN [b] filter	NR-S [f] with blue-fluorescence (10 µg/mL)	FM [j] (all sample area is counted)	304 ± 90	1 - 300	This study
	Public taps in the AC [*] 1 (1 L)	Tap water					270 ± 109		
	Public taps in the AC [*] 2 (1 L)	Tap water					386 ± 102		
	Commercial bottled water in the AC [*] 1(1 L)	Drinking water					211 ± 70		
	Effluent of CMF [**] in the AC [*] 2 (1 L)	Drinking water					122 ± 60		

Notes: [*] AC (Academic Institution). [**] CMF (commercial membrane filtration systems)
[a] Al_2O_3 (aluminium oxide). [b] CN (cellulose nitrate membrane filter). [c] PC (black polycarbonate). [d] MCE (mixed cellulose esters).
[e] WPO (wet oxidation method). [f] NR-S (nile red staining method). [g] DAPI (4′,6- diamidino-2- phenylindole). [h] FTIR (fourier transform infrared spectrometer). [i] OM (Optical microscope). [j] FM (fluorescence microscope).

Figure 2 shows the shapes of MPs found in the tap and drinking water sources in which 86 - 99% were fragments (with sizes less than 200 µm, Figure 2(a) and the remaining were fibers (sizes larger than 200 µm). The fragments MPs in the water supply treatment system could originated from the raw water sources (Chanpiwat and Damrongsiri, 2021). Based on microplastic morphology (shape), the MPs found in the Chao Phraya River were predominated (> 90%) with fragments and fibers (Ta and Babel, 2020). The observed MP fragments in the river were mainly identified as secondary MPs which were originated from the degradation of large plastic wastes such as such as plastic bottles, bags, cups, straw, and wrappers (Ta and Babel, 2020; Ounjai *et al.,* 2022). Besides, the primary sources of these MPs might be from discharged municipal wastewater containing large amounts of MPs (Sadia *et al.,* 2022). Additionally, the fragment MPs in the tap sources of Academic Institution 1 and Academic Institution 2 could result from fragmentation of larger MPs during water treatment processes and their inefficiency in removing MPs from the raw water (Chanpiwat and Damrongsiri, 2021; Kankanige and Babel, 2021; Wu *et al.,* 2022). Meanwhile, the observed fragment MPs in the drinking water were anticipated to be from mechanical stress and environmental factors as previously discussed.

Figure 3(a) shows the MP size distribution in the tap water samples collected at the water supply treatment system and the Academic Institutions 1 and 2. The MP abundance was mainly in the sizes of 1 - 50 µm in all tap water samples, while larger sizes were present in less abundance. Similarly, the studies by Kankanige and Babel (Kankanige and Babel, 2020-2021) reported that the MP sizes ranged from 6.5 - 53 µm were found to be predominant in raw water, effluent of a water supply treatment plant and treated drinking water samples. These data indicated that conventional water treatment plant processes employing coagulation, flocculation and sand filtration being used at the water supply treatment plant were not effective in removing MPs containing in the raw water sources (Chanpiwat and Damrongsiri, 2021; Wu *et al.,* 2022).

Figure 3(b) shows the drinking water of the Academic Institution 2 had MP sizes of 1-50 µm of 38% MP abundance, less than those of the drinking water of the Academic Institution 1 of 69% MP abundance, suggesting the high efficiency of the two commercial membrane filtration systems installed at the Academic Institution 2 in removing MPs from the tap water samples. However, the remaining MPs in drinking water of Academic Institution 1 could be due to improper maintenance of the commercial membrane filtration system in which urgent actions to address this issue should be undertaken. The MP abundance (1 - 50 µm) found in drinking water of the Academic Institution 1 could possibly emanate during filling of the commercial bottled water and releases of MPs from the plastic bottles (Kankanige and Babel, 2020; Makhdoumi *et al.,* 2021).

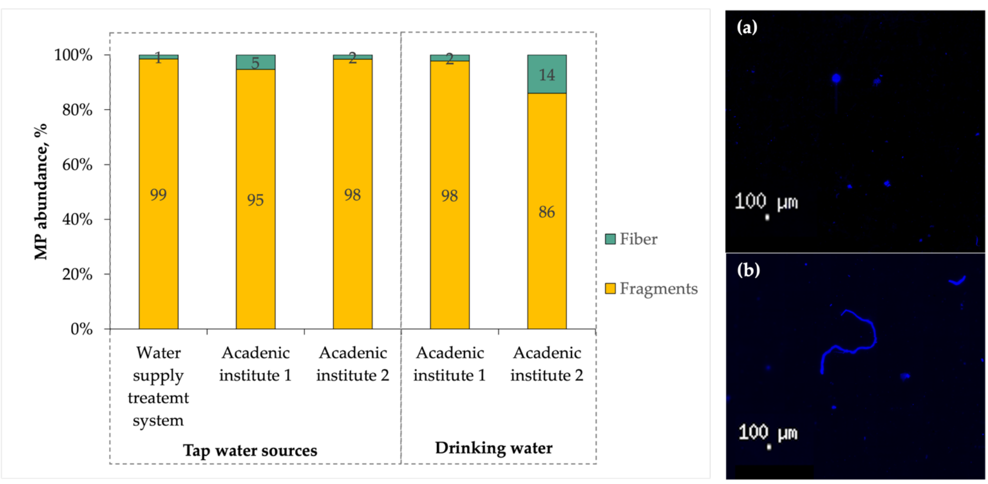

Figure 2. MP shapes in tap and drinking water samples and their morphology (a) fragments and (b) fibers

3.2 Consumption behaviors of tap and drinking water

The questionnaire survey was conducted with 143 respondents for observing personnel consumption of tap and drinking water. The demographic data showed that male was major respondents in this survey (57%), and 43% was female. Most of the respondents were 20 - 30 years old (86%) and about 14% of the respondents were 31 - 40 years old. Figure 4(a) shows personnel consumption of tap water via drinking and food preparation. Probably due to concerns about water quality and safety as well as aesthetic aspects e.g., odor, color, turbidity and taste of the tap water (Karujit *et al.,* 2022), all respondents (100%) did not directly drink the tap water. However, most of respondents (98%) preferred to consume tap water after some pre-treatment processes such as filtration and boiling and food preparation (Figure 4(a), similar to the previous study by Karujit *et al.* (2022). About 25% and 54% of households use 2 and 3 containers of tap water for food preparation and other purposes, equivalent to the volume of tap water uses in the range of 1,000 - 1,500 mL per household per day (averaged 4 members in a household). Accordingly, the maximum tap water used in household food preparation was estimated to be 0.4 L/person/d. Figure 4(b) shows that about 91% of the respondents usually drank from public drinking water fountains provided by the Academic Institutions, while the majority of respondents (86%) consumed about 200 - 500 mL of fountain water per day or the consumed drinking water of about 0.5 L/person/d was estimated.

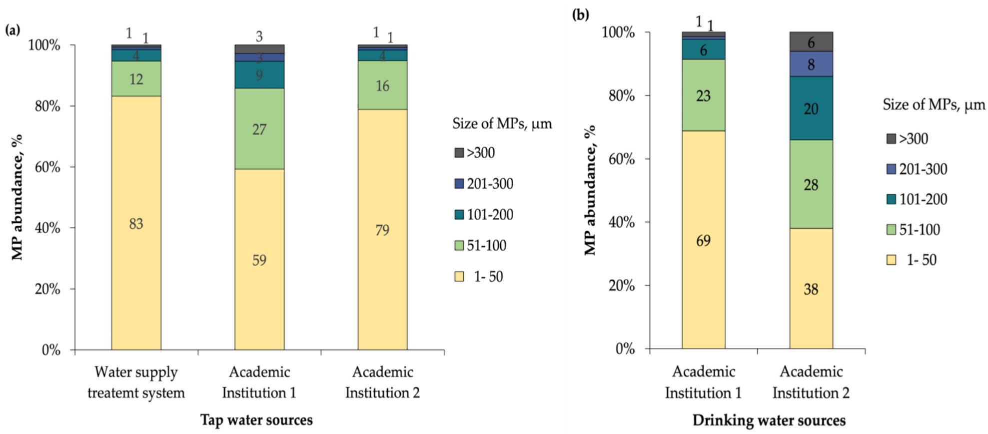

Figure 3. MP size distribution in water samples (a) tap water; (b) drinking water

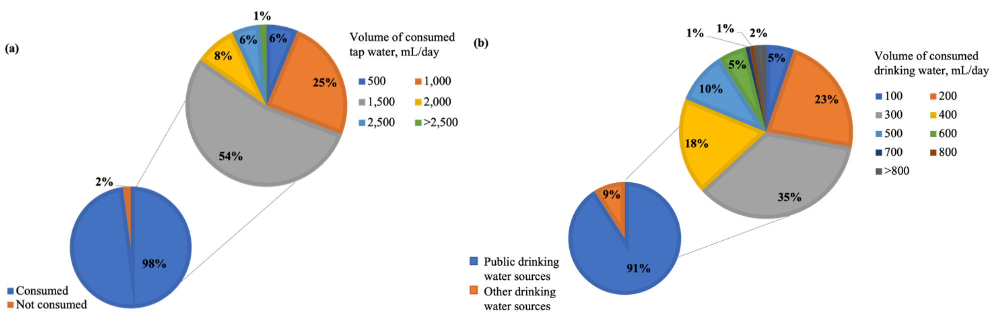

Figure 4. Daily personnel consumption of (a) tap water via drinking after pretreatment and food preparation and (b) public drinking water fountains

3.3 EDI_{MP} and potential health risks

The data of Table 1 and the personnel consumed tap and drinking water in section 3.2 were used to calculate the EDI_{MP} of the personnel at the Academic Institutions 1 and 2, according to Equation (2). From the questionnaire survey results, each personnel consumed drinking water about 0.5 L/person/d and the volume of tap water used in food preparation was about 0.4 L/person/d. Therefore, the EDI_{MP} of personnel of the Academic Institutions 1 and 2 were calculated to be 228 and 183 particles/person/d, respectively. When the MPs are ingested into the human digestive systems, they may cause some physical irritation to the gastrointestinal tract (Bouwmeester *et al.,* 2015). Moreover, the MPs with the size of less than 2 μm were observed in human blood and organs (Lithner *et al.,* 2011) as well as some of the MPs (50 μm) were reported to be transported from the gastrointestinal tract layer to lymph nodes in the liver and spleen (Revel *et al.,* 2018). These MP particles could then cause inflammations in surrounding tissues of the organs, resulting in many subsequent symptoms such as abdominal pain, bloating, and changes in bowel habits (Yuan *et al.,* 2022). There is a potential health risk of consuming microfibers sized < 0.5 μm wide and > 10 μm which can lead to more carcinogenic effect than other sizes (Wright & Kelly, 2017; Kankanige and Babel, 2021). Accordingly, the observed MPs sizes (1 - 50 μm) in this study indicated the potential health risks to the people consuming the tap and drinking water. There are some studies confirming the potential toxicity of the MPs in animals and human body. For instance, an animal toxicity study by Aghaei *et al.* (2022) reported that ingesting MPs (5 μm) and nanoplastics (50 nm) via drinking water in a concentration of 10^6 μg/L resulted in a 12% decrease in fetal weight of mice, Thus posing potential risks to human pragnancies in late gestation. Futhermore, a maximum concentration of 10 μg/mL of micro-polyester could generate high reactive oxygen species (ROS), resulting in oxidative stress in cerebral and epithelial human cells within 48 h of testing (Magrì *et al.,* 2018; Râpă *et al.,* 2023). Additionally, the study of da Silva Brito *et al.* (2024) illustrated that comsuming 100 μg/mL of nano and micro sized PET resulted in increased ROS and reducing antioxidant capacity of the keratinocytes cell (human skin cells) within 24 h. Accordingly, the responses of the cells could induce inflammatory effects to the cell line (da Silva Brito *et al.,* 2024). Hence, these evidences could give a caution to short term effects of MPs exposure on human. Besides, with high daily exposure of MPs, especially via tap and drinking water consumption, the long-term effects could be a critical issue on human heath.

3.4 Possible solutions and recommendations

The data reported in sections 3.1 and 3.2 suggest potential health risks from MP contamination to the people who consume either tap water or drinking water in Thailand or probably elsewhere. However, the toxic characterization of the MP particles should be further studied in order to verify the possible health risks of MP consumption. The sources of MP contamination obviously originate from improper disposal of plastic wastes and well as insufficient treatment efficiency of conventional wastewater treatment systems for treating wastewater contaminated by the MPs. These plastic wastes are degraded into small particles (less than 5 mm) and could be transported to nearby water sources and becoming contaminants of raw water sources used for producing water supply. The findings of this study also emphasize concerns about the effectiveness of employed commercial membrane filtration system and bottled water production processes in preventing the drinking water from the MPs. Evaluation of the presence of MPs in various locations, including raw sources, treatment plants, and the distribution systems for drinking water in Thailand, and a more comprehensive understanding of the points where the MPs enter the drinking water systems would provide a foundation for effective monitoring of contamination and the development of mitigation strategies. Besides, in light of the current research on MPs in drinking water, this study could serve as evidence that the presence of MPs is not only confined to tap water and bottled water, but also becoming more prevalent in various water resources. However, to understand the origins of the MPs, chemical analysis (e.g. FTIR) of the MP subsamples should be further undertaken. Given the increasing evidence of MPs in tap and drinking water, it is crucial for the relevant people in Thailand with drinking water fountains and those planning to install them to consider conducting assessments of MP contamination in the near future. Additionally, many conventional methods currently employed for producing drinking water could not be effective in removing MPs from drinking water. Therefore, it is imperative to devise novel approaches aimed at investigating the elimination mechanisms of MPs of water treatment processes through the application of appropriate theoretical models and some numerical simulation techniques, which can help improve MPs removal during water treatment. This could provide a valuable guidance for both academic research and practical production efforts. Some advanced water treatment processes for MP removal are also recommended for conventional water supply treatment plants (Table 3).

Overall, the actions to minimize MPs pollution by reducing both plastic uses and improper disposal of plastics wastes should involve all stakeholders to avoid environmental pollution. Enhancing waste management infrastructure and efficiency needs to be undertaken by the concerned authorities to achieve effective waste management and avoiding MPs formation from mismanaged plastic waste. Improved MP removal of wastewater treatment plant should be implemented. Employing advanced treatment processes and post-treatment before consumption could be more beneficail in reducing MPs contamination in tap and drinking water prior to human consumption. Some of possible approaches and mitigations are described below.

Reducing consumption of plastics

To minize MP pollution, reducing consumption of plastics is necessary. Reducing use of sigle-use plastics would reduce the amont of non-recyclable plastics in solid waste management systems, as well as the reduction of plastic littering to be degraded to MPs (Jain *et al.,* 2023; Nikpay and Toorchi Roodsari, 2024). Increasing awareness of consumers on environmental impact should be undertaken at both formal (e.g. in school) and informal (e.g. news, clean-up campaign) levels in which education and awarenese would provide long term solutions to reducing consumption of plastics (Prata *et al.,* 2019). Promoting use of reusable and biogradable materials should involve both plastic product manufacturers and consumer behaviour in using environmeantal friendly products (Wu *et al.,* 2017; Prata *et al.,* 2019). In addition, microbeads-free personal care products should be promoted in the market by reliable labelling, resulting in reduction of MP contamination in municipal wastewater (Prata *et al.,* 2019).

Effective waste management

Enhancing waste management infrastructure and efficiency is a significant key to properly manage plastic wastes and minimizing plastic waste leakages from solid waste management systems. Decreasing plastics debris entering environments can reduce formation of MPs. Integrated waste management apporach should be implemented by improving efficiencies of plastic waste separation and collection at source (Prata *et al.,* 2019). Plastic waste separation by polymer and color is benificial for recycling in manufacturing companies and obtaining better quality of recycled plastics. Although, recycling plastics is a part of plastic manufacture, due to high degree of contamination, the recycling of consumer waste is still limited and complex recycling methods are needed (Prata *et al.,* 2019). Additionally, some plastics which are difficult to be recycled could be utilized as feedstock of incineration and energy production plant (Prata *et al.,* 2019). Consequently, landfilling is considered as a final part of the integrated waste management apporach where residues produced from recycling processes and incineration should be properly disposed of.

Table 3. MP removal efficiencies by different water treatment technologies

Treatment technology	Treatment Stage	Location	Removal efficiency (%)	MP sizes (μm)	Ref.
Coagulation and sedimentation	Initial	China	40.5 – 54.5	1 – > 100	Wang *et al*. (2020)
Coagulation, flocculation, and sedimentation	Initial	United States	≤ 13.6	1 – 125	Zhang *et al*. (2020)
Sand filtration	Intermediate	China	29.0 – 44.4	1 – > 100	Wang *et al*. (2020)
Screen, clarification, filtration, chlorination	Full	Thailand	57.2 – 67.6	1 – 500	Kankanige and Babel (2021)
Coagulation, sedimentation, sand filtration, and chlorination.	Full	China	72.7	1 – > 100	Han *et al*. (2024)
Sedimentation, filtration, ozonation and GAC* filtration	Advanced	Czech Republic	88.0	1 – > 100	Pivokonský et al. (2020)
sedimentation, sand filtration, ozonation and GAC* filtration	Advanced	China	82.1 – 88.6	1 – > 100	Wang *et al*. (2020)
Aeration, sedimentation, sand filtration, GAC* filtration, disinfection.	Advanced	China	85 – 90	1 – > 100	Shen *et al*. (2021)
Coagulation, sand filtration, ozonation and GAC* Filtration and disinfection.	Advanced	Switzerland	98.0	63 – 250	Velasco *et al*. (2023)
Sedimentation, sand filtration, ozonation and GAC filtration, chlorination.	Advanced	China	83.0	1 – > 100	Han *et al*. (2024)
Filtration (filter media, anthracite, and cheesecloth)	Advanced	United States	86.9 – 99.9	1 - 125	Zhang *et al*. (2020)
Ultrafiltration	Post-treatment [a]	Thailand	96.9	50 – 500	Tadsuwan and Babel (2022)
Microfiltration	Point of use	Canada	78 – 86	30 – 1,000	Cherian *et al*. (2023)
Commercial membrane filtration (Ultrafiltration)	Post-treatment [a]	Thailand	70.0	1 – > 500	This study

Notes: *GAC (granular activated carbon), ** NO (None observed under microscope and SEM of the membrane filter, [a] Post-treatment at use point

Improvement of MP removal process in wastewater treatment plant

Currently, due to low MP removal efficiency of conventional wastewater treatment plants (WWTPs), discharging effluent of both municipal and industrial WWTPs can be a potential source of MPs in receiving water such as canal, rivers and oceans. The conventional treatmemnt processes in WWTPs should be upgraded to acheive higher MP removal efficiency and to prevent MPs discharging into surronding aquatic environments. Even though the conventional WWTPs could partially remove MPs through some treatment stages (e.g. screening, sedimentation), tertiary or advanced treatement should be undertaken to remove MPs before final effluent discharging (Katyal *et al.,* 2020). The advanced treatement such as dissolved air flotation, rapid sand filtration, disc filtration and membrane bioreactor filtration with MP removal efficienies of 95%, 97%, 99% and 99%, respectively, are recommened (Katyal *et al.,* 2020). Futhurmore, an additional filter plate is recommended to be installed within laundry machines to reduce MPs (fibers) contamination in the wastewater (Wu *et al.,* 2017; Ramasamy and Subramanian, 2021). Thus, these filtration techniques can significantly reduce MPs release from wastewater sources to the surrounding environment.

Employment of advanced treatment processes and post-treatment before consumption

Water treatment plants play an important role to prevent the MPs transfering into tap and drinking water. The conventional water treatement processes including coagulation, sedimentation, sand filtration, and chlorination have low MP removal efficiencies of 13.6 – 72.2 % (Table 3). To enhance the MP removal efficiencies, advanced treatment processes should be implemented. For instance, employing ozonation and GAC filtration could enhance MP removal efficiencies to be 83.0 – 90.0% (Table 3). The MP removal efficiencies of 86.9 – 99.9 % were achieved by advanced filtration processes (filter media, anthracite, and cheesecloth) in the drinking water production processes in the United States (Zhang *et al.,* 2020). Furthermore, a point of use device (e.g. microfiltration, ultrafiltration) can enhance better MP removal efficiencies about 70.0 – 96.9% (Table 3). Employing advanced treatment processes is the significant approach to reduce contamination level of MPs in tap and drinking water, as well as reducing potential health risks to consumers.

4. Conclusion

The average MPs concentrations of tap water of the water supply treatment plant and the Academic Institutions 1 and 2 were found to be 304 ± 90, 270 ± 109 and 386 ± 102 particles/L, respectively. The drinking water samples from commercial bottled water and filtered water from commercial membrane filtration systems were found to be 211 ± 70 and 122 ± 60 particles/L, respectively.The MP sizes of 1 - 50 µm were most abundant in both the tap and drinking water samples, whose shapes were mainly fragments and fibers. The questionnaire survey revealed the each person consumed about 0.5 L/person/d of drinking water and about 0.4 L/person/d of tap water used for food preparation. The EDIMP of the personnel of the Academic Institutions 1 and 2 were calculated to be 228 and 183 particles/person/d, respectively, indicating potential health risks from MP ingestion through consuming both tap and drinking water.To avoid these kinds of health impact from ingesting the MPs contained in tap and drinking water, actions to minimize health risks including: reduction in plastics uses, proper management of plastic wastes, regular maintenance of water supply treatment plants and water distribution pipelines, and additional post-treatment processes for removing MPs in tap water from conventional water supply treatment plants, are recommended.

Acknowledgment

Special thanks are due to Pichamon Hongthong, Panjama Sukeiam and Krurkkiet Konkomba for their help in water sample collection and staff at the water supply treatment plant for their collaboration in water sampling and questionnaire survey.

References

Aghaei Z, Sled JG, Kingdom JC, Baschat AA, Helm PA, Jobst KJ, et al. Maternal exposure to polystyrene micro-and nanoplastics causes fetal growth restriction in mice. Environmental Science & Technology Let-ters. 2022; 9(5): 426–30.

Ahmed MB, Rahman MS, Alom J, Hasan MDS, Johir MAH, Mondal MIH, et al. Microplastic particles in the aquatic environment: A systematic review. Sci Total Environ. 2021; 775(145793): 145793.

Barbier J-S, Dris R, Lecarpentier C, Raymond V, Delabre K, Thibert S, et al. Microplastic occurrence after conventional and nanofiltration processes at drinking water treatment plants: Preliminary results. Front Water. 2022; 4.

Bouwmeester H, Hollman PC, Peters RJ. Potential health impact of environmentally released micro-and nanoplastics in the human food production chain: experiences from nanotoxicology. Environmental science & technolo-gy. 2015; 49: 8932–47.

Chanpiwat P, Damrongsiri S. Abundance and characteristics of microplastics in freshwater and treated tap water in Bangkok, Thailand. Environ Monit Assess. 2021; 193(5): 258.

Chatterjee S, Krolis E, Molenaar R, Claessens MMAE, Blum C. Nile Red staining for nanoplastic quantification: Overcoming the challenge of false positive counts due to fluorescent aggregates. Environmental Challenges. 2023;13(100744):100744.

Cherian AG, Liu Z, McKie MJ, Almuhtaram H, Andrews RC. Microplastic removal from drinking water using point-of-use devices. Polymers (Basel). 2023; 15(6): 1331.

Conradie W, Dorfling C, Chimphango A, Booth AM, Sørensen L, Akdogan G. Investigating the physicochemical property changes of plastic packaging exposed to UV irradiation and different aqueous environments. Microplastics. 2022; 1(3): 456–76.

Da Silva Brito WA, Ravandeh M, Saadati F, Singer D, Dorsch AD, Schmidt A, et al. Sonicated polyethylene terephthalate nano- and micro-plastic-induced inflammation, oxidative stress, and autophagy in vitro. Chemosphere. 2024; 141813.

Global Water Research Coalition. Microplastics in freshwater resources science brief. Stirling, South Australia, Australia.

Han Z, Jiang J, Xia J, Yan C, Cui C. Occurrence and fate of microplastics from a water source to two different drinking water treatment plants in a megacity in eastern China. Environmental Pollution. 2024.

Huan LI, Long ZHU, Mindong MA, Haiwen WU, Lihui AN, Zhanhong YANG. Occurrence of microplastics in commercially sold bottled water. Science of The Total Environment. 2023; 867.

Jain R, Gaur A, Suravajhala R, Chauhan U, Pant M, Tripathi V, et al. Microplastic pollution: Un-derstanding microbial degradation and strategies for pollutant reduction. Science of The Total Environment. 2023.

Kankanige D, Babel S. Contamination by≥ 6.5 μm-sized microplastics and their removability in a conventional water treatment plant (WTP) in Thailand. Journal of Water Process Engineering. 2021; 40.

Kankanige D, Babel S. Identification of micro-plastics (MPs) in conventional tap water sourced from Thailand. J Eng Technol Sci. 2020; 52(1): 95–107.

Kankanige D, Babel S. Smaller-sized micro-plastics (MPs) contamination in single-use PET-bottled water in Thailand. Sci Total Environ. 2020; 717(137232): 137232.

Karujit W, Kuldilok P, Sakulna C. The Study of Perception, Attitude and Behavior of Water Users in the Service Areas of the Metropolitan Waterworks Authority to Design an Innovative Communication Cam-paign to Promote Perception Regarding the Quality of Tap Water. Journal of Communication Arts and Management. 2022; 26(2): 8–20.

Katyal D, Kong E, Villanueva J. Microplastics in the environment: impact on human health and future mitigation strategies. Environ Health Rev. 2020; 63(1): 27–31.

Kharuddin AF, Azid N, Mustafa Z, Kamari MN, Ku Ibrahim KF, Kharuddin D. Determination of sample size in early childcare centre (TASKA) service project in Malaysia: Classification and analytical approach. Vol 1, Issue 2, Dec 2020. 2020; 1(2): 104–12.

Lithner D, Larsson A, Dave G. Environmental and health hazard ranking, and assessment of plastic polymers based on chemical composition. Sci Total Environ. 2011; 409(18): 3309–24.

Magrì D, Sánchez-Moreno P, Caputo G, Gatto F, Veronesi M, Bardi G, et al. Laser ablation as a versatile tool to mimic polyethylene terephthalate nanoplastic pollutants: Characterization and toxicology assessment. ACS Nano. 2018; 12(8): 7690–700.

Makhdoumi P, Amin AA, Karimi H, Pirsaheb M, Kim H, Hossini H. Occurrence of microplastic particles in the most popular Iranian bottled mineral water brands and an assessment of human exposure. J Water Proc. engineering. 2021; 39(101708): 101708.

Meyers N, Catarino AI, Declercq AM, Brenan A, Devriese L, Vandegehuchte M, et al. Microplastic detection and identification by Nile red staining: Towards a semi-automated, cost-and time-effective technique. Science of the Total Environment. 2022; 823.

Mihai F-C, Gündoğdu S, Markley LA, Olivelli A, Khan FR, Gwinnett C, et al. Plastic pollution, waste management issues, and circular economy opportunities in rural communities. Sustainability. 2021; 14(1): 20.

Negrete Velasco A, Ramseier Gentile S, Zimmermann S, Stoll S. Contamination and removal efficiency of microplastics and synthetic fibres in a conventional drinking water treatment plant. Front Water. 2022; 4.

Nikpay M, Toorchi Roodsari S. Crafting a Scientific Framework to Mitigate Microplastic Impact on Ecosys-tems. Microplastics. 2024; 3: 165–83.

Nollet LML, Siddiqi KS, editors. Analysis of nanoplastics and microplastics in food. First edition. | Boca Raton: CRC Press, 2020. | Series: Food analysis and properties: CRC Press; 2020.

Oßmann BE, Sarau G, Holtmannspötter H, Pischetsrieder M, Christiansen SH, Dicke W. Small-sized microplastics and pigmented particles in bottled mineral water. Water Res. 2018; 141: 307–16.

Ounjai K, Boontanon SK, Piyaviriyakul P, Tanaka S, Fujii S. Assessment of microplastic contamination in the urban lower Chao Phraya River of Bangkok city, Thailand. J Water Health. 2022; 20(8): 1243–54.

Pinlova B, Nowack B. From cracks to secondary microplastics - surface characterization of polyethylene terephthalate (PET) during weathering. Chemosphere. 2024; 352(141305): 141305.

Pivokonský M, Pivokonská L, Novotná K, Čermáková L, Klimtová M. Occurrence and fate of microplastics at two different drinking water treatment plants within a river catchment. Sci Total Environ. 2020; 741(140236): 140236.

Prata JC, Silva ALP, da Costa JP, Mouneyrac C, Walker TR, Duarte AC, et al. Solutions and integrated strategies for the control and mitigation of plastic and microplastic pollution. Int J Environ Res Public Health. 2019; 16(13): 2411.

Radityaningrum AD, Trihadiningrum Y, Mar'atusholihah, Soedjono ES, Herumurti W. Microplastic contamination in water supply and the removal efficiencies of the treatment plants: A case of Surabaya City, Indonesia. J Water Proc.engineering. 2021; 43(102195): 102195.

Ramasamy R, Subramanian RB. Synthetic textile and microfiber pollution: a review on mitigation strate-gies. Environmental Science and Pollution Research. 2021; 28(31): 41596–611.

Râpă M, Darie-Niță RN, Matei E, Predescu AM, Berbecaru AC, Predescu C. Insights into Anthropogenic Micro-and Nanoplastic Accumulation in Drinking Water Sources and Their Potential Effects on Human Health. Polymers. 2023; 15(11).

Revel M, Châtel A, Mouneyrac C. Micro (nano) plastics: a threat to human health? Science & Health. 2018; 1: 17–23.

Sadia M, Mahmood A, Ibrahim M, Irshad MK, Quddusi AHA, Bokhari A, et al. Microplastics pollution from wastewater treatment plants: A critical review on challenges, detection, sustainable removal techniques and circular economy. Environ Technol Innov. 2022; 28(102946): 102946.

Sharifi H, Movahedian Attar H. Identification, quantification, and evaluation of microplastics removal efficiency in a water treatment plant (A case study in Iran). Air Soil Water Res. 2022; 15: 117862212211349.

Shen M, Zeng Z, Wen X, Ren X, Zeng G, Zhang Y, et al. Presence of microplastics in drinking water from freshwater sources: the investigation in Changsha, China. Environ Sci Pollut Res Int. 2021; 28(31): 42313–24.

Shruti VC, Pérez-Guevara F, Roy PD, Kutralam-Muniasamy G. Analyzing microplastics with Nile Red: Emerging trends, challenges, and prospects. J Hazard Mater. 2022; 423(Pt B): 127171.

Singh B, Sharma N. Mechanistic implications of plastic degradation. Polym Degrad Stab. 2008; 93(3): 561–84.

Ta AT, Babel S. Microplastic contamination on the lower Chao Phraya: Abundance, characteristic and interaction with heavy metals. Chemosphere. 2020; 257(127234): 127234.

Tadsuwan K, Babel S. Microplastic abundance and removal via an ultrafiltration system coupled to a conventional municipal wastewater treatment plant in Thailand. J Environ Chem Eng. 2022; 10(2): 107142.

Taheri S, Shoshtari-Yeganeh B, Pourzamani H, Ebrahimpour K. Investigating the pollution of bottled water by the microplastics (MPs): the effects of mechanical stress, sunlight exposure, and freezing on MPs release. Environ Monit Assess. 2022; 195(1): 62.

Tang KHD, Hadibarata T. Microplastics removal through water treatment plants: Its feasibility, efficiency, future prospects and enhancement by proper waste management. Environmental Challenges. 2021; 5(100264): 100264.

Tong H, Jiang Q, Hu X, Zhong X. Occurrence and identification of microplastics in tap water from China. Chemosphere. 2020; 252(126493): 126493.

Tse Y-T, Chan SM-N, Sze ET-P. Quantitative assessment of full size microplastics in bottled and tap water samples in Hong Kong. Int J Environ Res Public Health. 2022; 19(20): 13432.

Velasco AN, Gentile SR, Zimmermann S, Le Coustumer P, Stoll S. Contamination and removal efficiency of microplastics and synthetic fibres in a conventional drinking water treatment plant in Geneva, Switzerland. Science of The Total Environment. 2023; 880.

Wang Z, Lin T, Chen W. Occurrence and removal of microplastics in an advanced drinking water treatment plant (ADWTP). Sci Total Environ. 2020; 700(134520): 134520.

Winkler A, Santo N, Ortenzi MA, Bolzoni E, Bacchetta R, Tremolada P. Does mechanical stress cause microplastic release from plastic water bottles? Water Res. 2019; 166(115082): 115082.

World Bank. Plastic waste material flow analysis for Thailand: Summary report. World Bank; 2022.

Wright SL, Kelly FJ. Plastic and human health: A micro issue? Environ Sci Technol. 2017; 51(12): 6634–47.

Wu J, Zhang Y, Tang Y. Fragmentation of microplastics in the drinking water treatment process-A case study in Yangtze River region, China. China Science of The Total Environment. 2022; 806.

Wu W-M, Yang J, Criddle CS. Microplastics pollution and reduction strategies. Front Environ Sci Eng. 2017; 11(1).

Yuan Z, Nag R, Cummins E. Human health concerns regarding microplastics in the aquatic environment-From marine to food systems. Science of the Total Environment. 2022; 823.

Zhang Y, Diehl A, Lewandowski A, Gopalakrishnan K, Baker T. Removal efficiency of micro-and nano-plastics (180 nm-125 μm) during drinking water treatment. Science of The Total Environment. 2020;720.