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Seasonal Variations in Microplastic Abundance and Removal Efficiency in Wastewater Treatment Plants in Bangkok, Thailand

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ABSTRACT

Wastewater treatment plants (WWTP) are significant contributors to the release of microplastics into aquatic environments. Due to the limited information available in Thailand, examining microplastics from WWTPs could assist the Thai government in establishing guidelines for future microplastic control. This study identified microplastics in various WWTPs across Bangkok, Thailand, during two seasons: the dry period (February to May 2022) and the wet period (June to October 2022). The findings revealed a higher abundance of microplastics during the wet season compared to the dry season. In both influent and effluent, fibers were the predominant shape, making up approximately 86.65% during the dry period and 94.37% during the wet period. Fragments, films, granules, and foam were also detected in all samples. Polyethylene terephthalate (PET), polyethylene (PE), and polypropylene (PP) were the most common polymers present in the microplastic samples. The study also highlighted that the removal efficiency of microplastics from WWTPs ranged from 16.7% to 85.4% during the dry period and from 27.6% to 81.0% during the wet period. These results underscore the importance of long-term monitoring and quantification of microplastics in different WWTP systems in Bangkok. This data can be utilized to estimate microplastic loading in WWTPs and develop effective strategies for microplastic removal from wastewater.

INTRODUCTION

Plastics are materials invented and developed for use in daily life (Mao et al. 2020, Plastics Europe and European Association of Plastics Recycling 2017). The demand for plastic products has increased significantly over the past few decades, leading to enormous amounts of plastic waste contaminating the environment. Monomers that are not easily biodegradable, such as polypropylene (PP), are widely used to produce common plastic materials (Geyer & Jambeck 2017) because of their high stability and durability. Generally, microplastics are plastic particles smaller than 5 mm in diameter(Talvitie et al. 2017). Most originate from personal care products such as scrubs, cosmetics, and toothpaste (Suaria et al. 2020) and may occur from the breakdown of large plastic waste through mechanical, biological, chemical, and photo-oxidized degradation (Galafassi et al. 2019, Gatidou et al. 2019).

Microplastics are severe environmental pollutants. Improper disposal of plastic waste worldwide has led to the accumulation of microplastics in a variety of environmental compartments, including soil, air, rivers, lakes, oceans, biota, and food (Eo et al. 2019, Grbic et al. 2020, Karbalaei et al. 2018, Hamid et al. 2018, WHO 2019, Yu et al. 2020, Zhang et al. 2019). Microplastics threaten the environment, animals, and humans because of their toxic components, that is, chemical additives such as Bisphenol A or other toxic compounds such as polychlorinated biphenyls, all of which can be absorbed (Eerkes-Medrano et al. 2015, Gallo et al. 2018, Yong et al. 2020). Marine species are adversely affected by these substances owing to their mechanisms of action, including absorption, ingestion, or unintentional capture and uptake.

Wastewater treatment plants (WWTP) are generally referred to as point sources of microplastics discharged into aquatic environments. Globally, microplastics have been detected in WWTP effluents in Asia, Europe, the USA, Australia, China, and Russia (Prata 2018). Although the relationship between microplastics in aquatic environments and WWTP has not been reported (Carr et al. 2016), several studies have shown that WWTP can effectively remove approximately 50–99% of microplastics (Iyare et al. 2020,

Table 1: Details of selected wastewater treatment plants from Bangkok, Thailand.

Locations	Population	Area (km^2)	Treatment Capacity (m^3/day)	Treatment System	1st Treatment	2nd Treatment
WWTP-A	432,000	33.4	150,000	Cyclically activated sludge	Screening Grit chamber	Sequence-batch activated sludge
WWTP-B	1,080,000	37	350,000	Biologically activated sludge with nutrient sludge	Screening Grit chamber	Conventional activated sludge Sedimentation tank
WWTP-C	120,000	20	120,000	Four-step feed Activated sludge Biological nutrient removal	Screening Grit chamber	Step-feed Anoxic/Oxic Sedimentation tank
WWTP-D	120,000	2.7	30,000	Contact stabilization activated sludge	Screening Grit chamber	Contact stabilization activated sludge Sedimentation tank
WWTP-E	70,000	4.1	40,000	Two-Stage activated sludge	Screening Grit chamber	Two-stage activated sludge Sedimentation tank

Liu et al. 2019). However, owing to the limitations of the different units used in WWTP (Jiang et al. 2020, Lv et al. 2019, Tagg et al. 2020), different amounts of microplastics may be released into the aquatic environment. As a result, this study aimed to investigate the types and amounts of microplastics in the influent and effluent of different WWTP during the wet and dry seasons.

MATERIALS AND METHODS

Five existing domestic WWTPs located in Bangkok, Thailand, namely WWTP-A, WWTP-B, WWTP-C, WWTP-D, and WWTP-E, were selected to identify microplastics in the influents and effluents. Each treatment plant operated under different activated sludge processes, including the use of cyclically activated sludge, biologically activated sludge with nutrient sludge, four-step feed activated sludge biological nutrient removal, contact stabilization activated sludge, and two-stage activated sludge. The treatment capacities of each plant are listed in Table 1. Water samples were collected from February to May 2022 (dry period) and from June to October 2022 (wet period).

A flow diagram of the selected wastewater plants is shown in Fig. 1. All five WWTPs had different treatment systems, which may have affected the microplastic removal efficiency. Therefore, water sample collection in different seasons may help determine the removal efficiency of microplastics from different wastewater treatment processes.

A 50-L water sample from the influent and a 100-L water sample from the effluent were collected using a rotary pump (12V/DC 8A). The pump head was placed on the surface of the water at a depth of approximately 30 cm, and the water samples were passed through a sieve size of 0.3 mm (No. 50) made of stainless-steel mesh sieves. All the particles remaining on the mesh sieves were then rinsed using distilled water before being passed through a glass bottle. The water samples in the bottles were kept in a refrigerator at 4°C.

Microplastic Analysis

Microplastics were analyzed following modifications to the National Oceanic and Atmospheric Administration method (Masura et al. 2015). Each sample was poured through 0.3-mm (No. 50) stainless-steel mesh sieves and flushed using distilled water to transfer the particles to the beaker. The sample was dried at 90°C in a hot-air oven for 24 hours or more. To digest organic particles, the Fenton reagent was used by mixing 20 mL of 30% hydrogen peroxide with 20 mL of 0.05 M Ferrous sulfate (Gundogdu et al. 2018). Thereafter, the mixtures were heated to 75°C for 30 min. In addition, 5-M sodium chloride (NaCl) was prepared by mixing 6 g of NaCl per 20 mL of sample to increase the density of the aqueous solution. The digested samples were rinsed into a glass funnel and allowed to settle overnight. The floating microplastics were filtered through 0.3-mm (No. 50) stainless-steel mesh sieves. The remaining samples were transferred into a Petri dish and dried at 90°C by using a hot-air oven for 24 h before being taken to identify the amounts and types of microplastics.

Microplastic Identification

The physical characteristics of the MP particles from the remaining samples, including shape, size, and abundance, were determined using a stereomicroscope (Olympus, SZ61TR) at 40X magnification (Crawford 2017, Hidayaturrahman & Lee 2019). In addition, the chemical characteristics of the microplastics were identified using a Fourier-transform infrared spectrophotometry (FT-IR, Bruker Alpha II) attenuated total reflectance technique in the 4000–650 cm-1 wave range with 64 scans at a resolution of 8 cm-1 (Ribeiro-Claro et al. 2017). Different types of microplastic particles were identified by comparing the

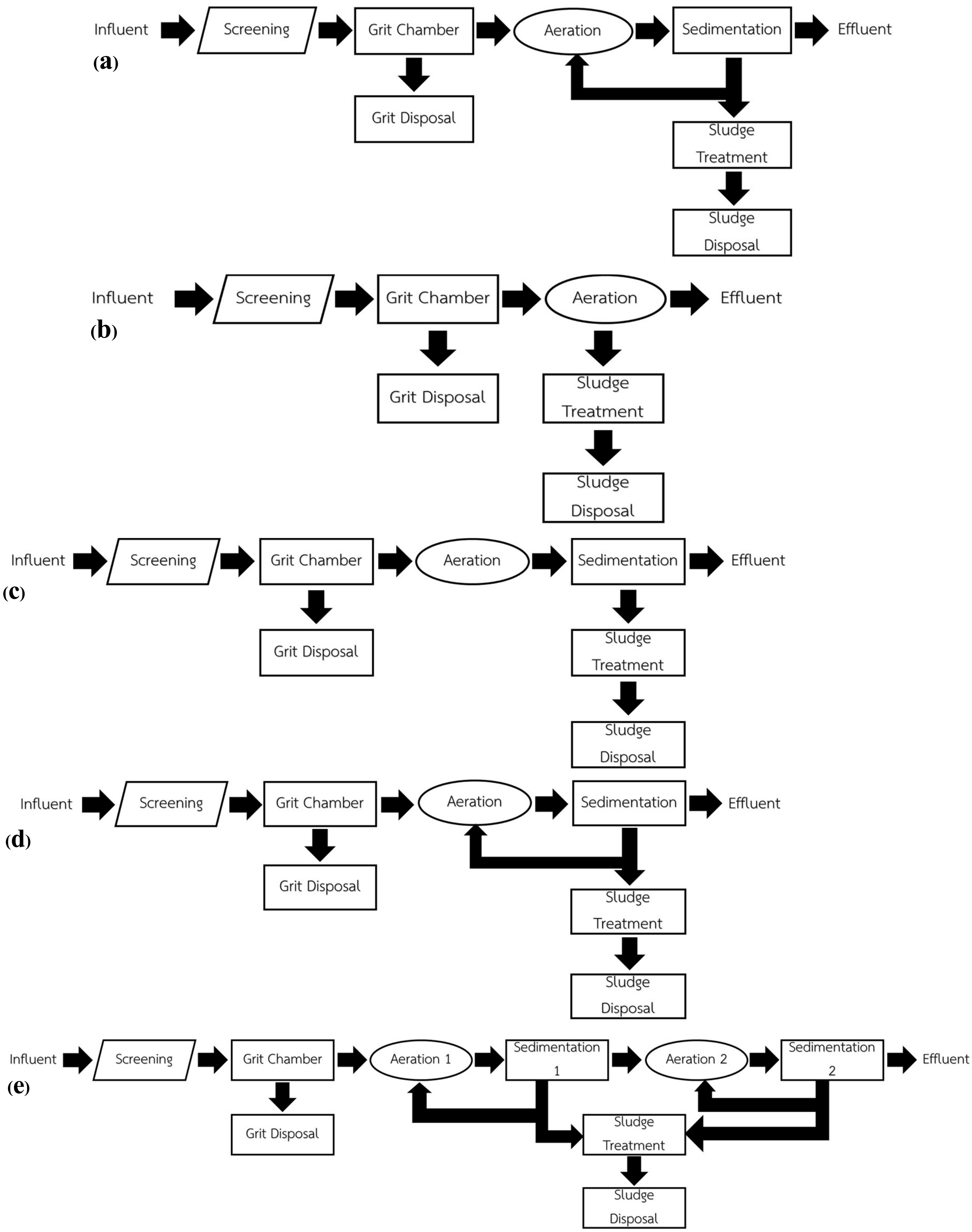

Fig. 1: Flow diagram of existing wastewater treatment systems in Bangkok; (a) WWTP-A, (b) WWTP-B, (c) WWTP-C, (d) WWTP-D and (e) WWTP-E.

standards of polymer spectra in a database (Qiu 2016, Jung et al. 2018).

RESULTS AND DISCUSSION

Variation of Microplastics from the Influent and Effluent of the Existing Wastewater Treatment Plants in Bangkok

In this study, seasonal variations in microplastic concentrations were evaluated to determine the removal efficiency of microplastics from the five existing WWTPs located in Bangkok. The abundances of microplastics from the five existing WWTP (WWTP-A, WWTP-B, WWTP-C, WWTP-D, and WWTP-E) are shown in Table 2. The amount of microplastics in the influent was higher than that in the effluent during both seasons (dry and wet seasons). The concentration of microplastics from the influents of WWTP-D was the highest (approximately 2.04 items/L) while that from the influents of WWTP-C, WWTP-E, WWTP-B, and WWTP-A were approximately 1.85, 1.22, 0.56, and 0.42 items/L, respectively, for the dry period. During the wet period, the highest amount of microplastics in the influent was from WWTP-C (2.69 items/L), followed by WWTP-A, WWTP-D, WWTP-B, and WWTP-E (2.45, 1.70, 1.24, and 0.76 items/L, respectively). Seasonal microplastic abundance was observed in the influent samples. The difference in microplastic concentration depends on a variety of factors, such as population, surrounding land use, combined sewer systems, and domestic water demand (Long et al. 2019, Mason et al. 2016, Tang et al. 2020).

During the COVID pandemic in Thailand since March 2020 (Rajatanavin et al. 2021), the majority of the population was locked down to prevent the spread of COVID-19, leading to a high-density population in a limited area. Consequently, wastewater from human activities, such as the use of personal care products, is the main source of microplastics released into the environment daily (Waller et al. 2017). Therefore, the number of microplastics in the influent of WWTP-D increased. In addition, microplastics from WWTP-A and WWTP-B were found at low concentrations due to an increase in the wastewater receiving area and its properties, such as the size, shape, density, and buoyancy of microplastics (Kowalski et al. 2016). In addition, most low-density microplastics float on the water surface (Kay et al. 2018). More than half of all microplastics produced can float and disperse on water surfaces (Kukulka et al. 2012).

In Bangkok, the air is easily dried during the dry period, which leads to microplastic accumulation along drainage lines and reduces the amount of microplastics entering WWTP. In contrast, during the wet period, microplastic concentrations increased at WWTP-A, WWTP-B, and WWTP-C.

The increase in the amount of microplastics entering the WWTP may have been due to the use of combined sewer systems in Bangkok (Kuster & Kuster 2017). During the rainy season, water flow velocity and other hydraulic parameters may also affect the amount of microplastics (Roscher et al. 2022). In addition, stormwater runoff causes a resuspension flux, which increases the amount of low-density microplastics (He et al. 2021, Jarlskog et al. 2020, Ziajahromi et al. 2020). As a result, more microplastics entered the WWTP. These results agree well with a previous study (Wilyalodia et al. 2023) reporting that the microplastics concentration of Ciliwung River, Jakarta Indonesia, was higher in the rainy season compared with the dry season and this behavior as consistent with this studies.

The receiving area between wastewater and runoff water is a major pathway for the release of microplastics into the environment (Wang et al. 2022). This leads to low concentrations of microplastics (Le et al. 2023).

This is due to the dilution of runoff water from the WWTP. The type of residential area might be another important factor affecting an increase in microplastic abundance. Therefore, it will be necessary to determine the relationship between residential areas and microplastics in future studies.

The concentrations of microplastics in the effluent of WWTP-D were found to be at the highest level, approximately 0.80 items/L. In addition, the concentrations

Table 2: Abundance of microplastics from WWTPs.

Locations	Microplastics found in wastewater treatment plants (items/L)			
	Dry period		Wet period	
	Influent	Effluent	Influent	Effluent
WWTP-A	0.42±0.21	0.35±0.25	2.45±1.18	0.77±0.38
WWTP-B	0.56±0.14	0.46±0.27	1.24±0.80	0.40±0.25
WWTP-C	1.85±0.45	0.27±0.07	2.69±1.16	0.51±0.10
WWTP-D	2.04±0.39	0.80±0.26	1.70±0.39	0.42±0.15
WWTP-E	1.22±0.47	0.37±0.16	0.76±0.35	0.55±0.27

of microplastics in WWTP-B, WWTP-E, WWTP-A, and WWTP-C were approximately 0.46, 0.37, 0.35, and 0.27 items/L, respectively, during the dry period. During the wet period, the highest concentration of microplastics was found in WWTP-A (0.77 items/L). The concentrations of microplastics in WWTP-E, WWTP-C, WWTP-D, and WWTP-B were approximately 0.55, 0.51, 0.42, and 0.40 items/L, respectively. Yang et al. (2020) reported that 0.59 items/L of microplastics were determined in the final effluent. This was similar to the results of the final effluent from a WWTP in Australia, which contained 0.28 items/L (Ziajahromi et al. 2017). However, the microplastic concentrations in the final effluent from different WWTP worldwide vary from 0.005 to 447 items/L (Lares et al. 2018, Sun et al. 2019). This variation may be due to several factors, including the composition of raw wastewater, units used in the treatment plants (Mahon et al. 2017), sampling, sample processing, and characterization methods (Lares et al. 2018).

Although microplastics in the effluent were detected at relatively low concentrations, the total discharge of microplastics released from the WWTP was of high concern because of the large amount of wastewater discharged into rivers daily. The results showed that the effluent from the WWTP was a potential major source of microplastic pollution in the aquatic environment. As a result, the discharge of the effluent from the WWTP may drastically increase the number of microplastics in the downstream of the river.

Determination of Removal Efficiency of Microplastics from Wastewater Treatment Plants

Fig. 1 shows a flow diagram of the wastewater treatment system of each study area. The same steps were used for the wastewater treatment processes when passing the influent through screening using a grit chamber. In addition, the important steps to eliminate microplastics were grit trapping, grease removal, and primary settlement (Murphy et al. 2016). Secondary treatment processes, such as the use of activated sludge, have been reported to be highly effective in removing microplastics (Lares et al. 2018, Talvitie et al. 2017). This may be because the sludge flocs in the aeration tank accumulated the remaining plastic debris (Jeong et al. 2016, Scherer et al. 2017). In addition, chemicals used (such as flocculating agents) may affect microplastic removal, leading to the formation of suspended particulates as flocs (Murphy et al. 2016). Some microplastics may become trapped in these unstable flocs and may not settle. This leads to their dispersion into aquatic environments (Carr et al. 2016). Generally, microplastics return from the sludge to aeration tanks. The rest is sent to a sludge filter press for further disposal or conversion into fertilizer (Hongprasith et al. 2020). Consequently, microplastics are released into soil and accumulate in the food chain, which may ultimately affect the environment (Murphy et al. 2016).

Wastewater treatment systems generally remove up to 99% of microplastics (Carr et al. 2016, Hidayaturrahman & Lee 2019, Talvitie et al. 2017).

The efficiency of microplastic removal at the WWTP was calculated by comparing the amount of microplastics in the influent with that in the effluent from the WWTP. Eq. 1 was used to calculate the number of microplastics per liter (items/L).

$$\text{Efficiency of microplastic removal (\%)} = \frac{\text{influent samples} - \text{effluent samples}}{\text{influent samples}} \times 100\% \quad \ldots(1)$$

The results showed that the highest removal efficiency for the dry period was approximately 85.41% at WWTP-C and approximately 69.67%, 60.78%, 17.86%, and 16.67% for WWTP-E, WWTP-D, WWTP-B, and WWTP-A, respectively. During the wet period, the highest removal efficiency at WWTP-C was approximately 81.04%. The removal efficiencies of WWTP-D, WWTP-A, WWTP-B, and WWTP-E were approximately 75.29%, 68.57%, 67.71%, and 27.63%, respectively. In this study, the removal efficiency of microplastics in the wastewater treatment systems was relatively low compared to that in other studies (Carr et al. 2016, Hidayaturrahman & Lee 2019, Talvitie et al. 2017).

Determination of Microplastic Shapes from Wastewater Treatment Plants

All the particles were examined under a stereomicroscope (Olympus SZ61TR). Microplastics are classified into six shapes: fibers, fragments, films, sheets, granules, and foams (Wu et al. 2018). Fig. 2 shows the shapes of the microplastics obtained from the WWTP. The proportions of microplastic particle types are shown in Fig. 3. Fibers were the major shape of microplastics found in both the influent and effluent. The fibers found in the influent and effluent of the five WWTP for the dry and wet periods ranged from 81.65 to 88.34%, 83.85 to 90.65%, and from 91.29 to 96.91% and 88.21 to 95.25%, respectively. These findings are similar to those of Ziajahromi et al. (2017) for the fiber-dominant shape of microplastics from a WWTP. In addition, fibers are the largest source of primary microplastics (Kooi & Koelmans 2019, Obbard 2018). Kittipongvises et al. (2022) found that microplastics were composed of approximately 39–82%. As the shapes of microplastics may originate from shredded products, their origins can be inferred (Cheung et al. 2016, Helm 2017). Physical or chemical processes can break down large plastic packing products into small plastic particles until they become fragmented microplastics (Liu et al. 2019). Fibers originate from synthetic fiber products used in daily life and are released from shredded clothes and textile washing, thus passing through domestic wastewater (Allen et al. 2019, Hernandez et al. 2017). Browne et al. (2011) reported that the washing of a polyester textile can release more than 100 microplastic fibers per liter. As a result, fibers are most likely to remain in effluents (Liu et al. 2019, Talvitie et al. 2017).

Fragment films, sheet granules, and foam were observed at all time points. Researchers have found that fibers and fragments are the dominant microplastic type (Fu & Wang 2019).

However, in this study, no plastic microbeads, personal cosmetic products, or other industrial products were found in the WWTP. This was probably due to the ban on microbeads in Thailand since January 1, 2020. This regulation was used for Thailand's roadmap of a plastic waste management plan for 2018 to 2030 issued by the Pollution Control Department (Ministry of Natural Resources and Environment 2018).

In summary, seasonal changes are a key factor that differentiates microplastic contamination such as fibers, which is consistent with previous studies to show that the microplastics in the rainy season are higher than in the dry season (Kim et al. 2022).

Polymer Types of Microplastics from Wastewater Treatment Plants

FT-IR was used to identify the polymer types of microplastics in the wastewater. The results of the microplastic polymer types will enhance the quality and performance of the plastic materials produced in WWTP. As a result, the polymer types of microplastics are very important for demonstrating the persistence of plastics in the environment (Sun et al. 2019). As shown in Fig. 4, the transmission spectra of the microplastic particles were mainly found in three types of plastic polymers: polyethylene terephthalate (PET), polyethylene (PE), and polypropylene (PP). There were also different types of microplastic polymers found in the WWTP, including Nylon, Polystyrene, Polyvinyl chloride (PC), and PP. However, the three main types of microplastic polymers found in the influent and effluent of the WWTP during all periods were PET, PE, and PP (Andrady 2011, Ben-David et al. 2021, Ziajahromi et al. 2017).

The types of microplastics were found to be similar in the five WWTPs during both periods (Table 3). For WWTP-A, the major polymer type of microplastic was PET in the influent and PP, PE, PET, and Ethylene-vinyl acetate (EVA) in the effluent. The major polymer types of microplastics in WWTP-B were EVA in the influent and PET in the effluent. The major polymer types of microplastics in WWTP-C were PE and PET in both the influent and effluent. In addition, the

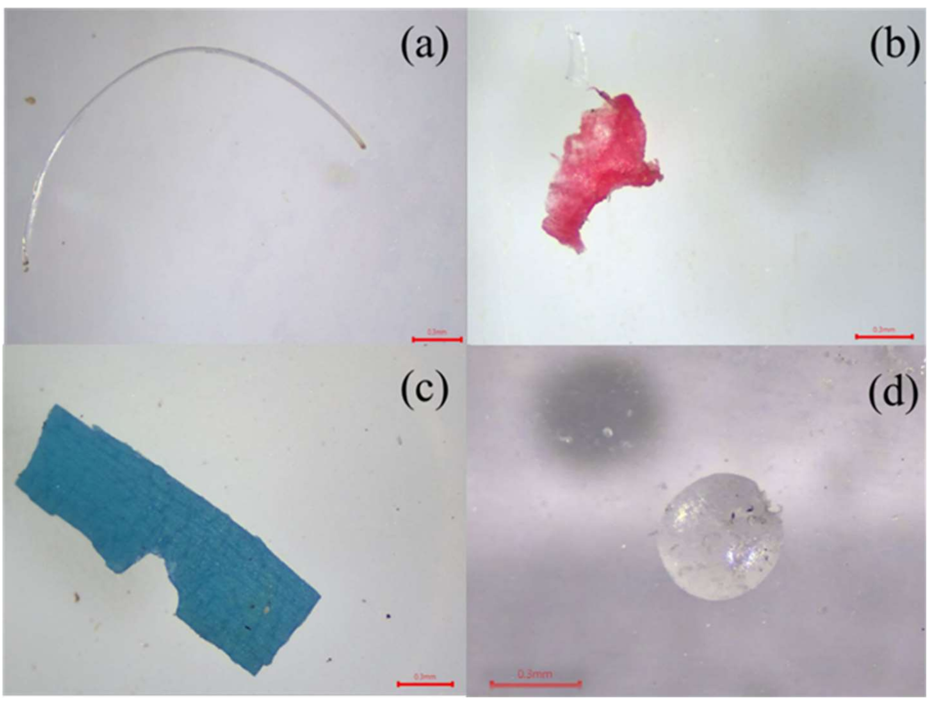

Fig. 2: Examples of microplastic shapes found in wastewater treatment plants: (a) fiber, (b) fragment, (c) sheet, and (d) granule.

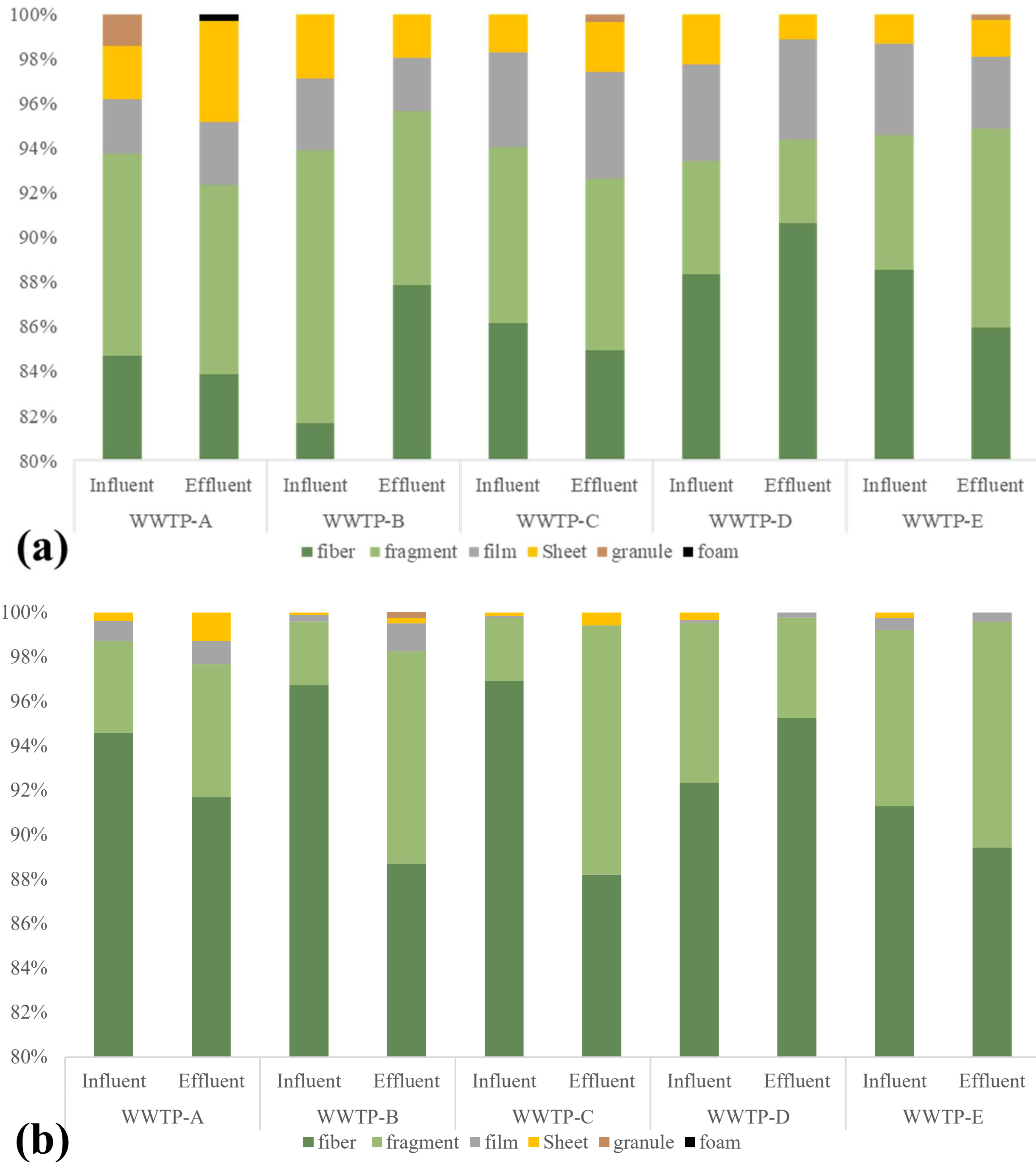

Fig. 3: Proportion of microplastic particle types. (a) dry period and (b) wet period.

major polymer types of microplastics in WWTP-D were PP and PET in the influent and PET in the effluent. The major polymer types of microplastics in WWTP-E were PET and EVA in the influent and PP and PET in the effluent. The types of polymers will enhance the prediction of the origin of microplastic development(Desforges et al. 2014). From this study, it was found that microplastic generation may originate from food packaging, water bottles, and plastic bags (PE and PP). They may also be generated from packaging fibers and fabrics (PET) (Edgar Hernandez 2017, Zhao et al. 2015). These findings may help in the control of the sources of microplastic production to prevent water pollution from

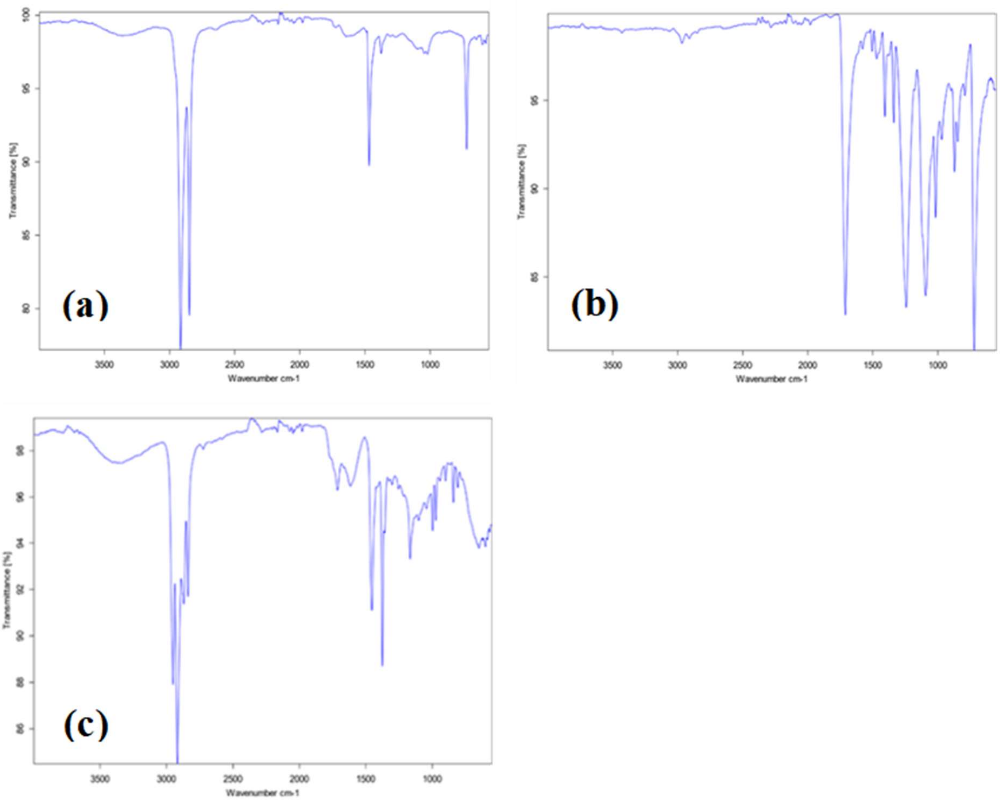

Fig. 4: IR spectrum (from FTIR spectroscope) of microplastic samples found in wastewater treatment plants. (a) Polyethylene, (b) polyethylene terephthalate, and (c) polypropylene.

Table 3: Microplastic polymer types from influent and effluent of wastewater treatment plants.

Period	System	Location	Polymer types								
			PP	PE	PET	Nylon	ABS	PTFE	PS	PVC	PC
Dry	WWTP-A	Influent	√		√		√	√			
		Effluent	√	√	√				√		
	WWTP-B	Influent	√		√	√				√	√
		Effluent	√	√	√	√			√	√	
	WWTP-C	Influent	√	√	√		√		√	√	
		Effluent	√	√	√						√
	WWTP-D	Influent	√	√	√	√			√	√	
		Effluent	√	√	√				√	√	√
	WWTP-E	Influent	√	√	√		√				
		Effluent	√	√	√			√		√	
Wet	WWTP-A	Influent		√	√			√		√	√
		Effluent	√	√	√			√		√	
	WWTP-B	Influent	√	√	√	√					√
		Effluent	√	√	√	√			√		
	WWTP-C	Influent		√	√		√			√	
		Effluent	√	√	√						√
	WWTP-D	Influent	√	√	√				√		
		Effluent	√	√	√	√			√	√	
	WWTP-E	Influent	√	√	√		√				
		Effluent	√	√	√	√				√	

WWTP. They can also be used for the improper management of plastic waste in landfills to reduce MP release into the environment.

CONCLUSIONS

Microplastics were quantified in the influent and effluent of existing wastewater treatment plants (WWTP) during both dry and wet periods. The results indicated that microplastic concentrations varied across different WWTPs. Predominantly, fibers were the most common shape of microplastics detected, followed by fragments, films, granules, and foam. Using FT-IR analysis, the primary types of polymers identified were PET, PE, and PP, suggesting that microplastics likely originate from packaging and textile materials. Consequently, microplastics contaminate domestic wastewater and enter WWTPs. The quantity of microplastics also fluctuated between dry and wet seasons. Specifically, the rainy season exhibited higher microplastic influx and discharge at WWTPs due to turbulent flows facilitating their transport. Additional factors, such as laundry activities, may influence the release of microplastics into domestic wastewater. Further research is needed to pinpoint specific sources of microplastics entering WWTPs and to explore additional technologies for their removal.

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