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Microplastic occurrence and removal in unbranded refilled drinking water treatment systems: Implications for human exposure in Karawang, Indonesia

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ABSTRACT

It is undeniable that microplastics are found in many types of water, including drinking water. This study aims to investigate the presence of microplastics in one of the drinking water sources widely used by communities in Indonesia, namely unbranded refilled drinking water. The investigation was conducted at eight unbranded refilled drinking water depots in Karawang, West Java. A total of 2.00 L of raw and treated water samples were collected from each depot, prepared following the National Oceanic and Atmospheric Administration method, analyzed using an Olympus BX-41 microscope at tenfold magnification, and manually counted. The results showed that both raw and treated water from all unbranded refilled drinking water depots contained microplastics, with concentrations ranging from 15.50–42.00 particles/L and 6.50–17.50 particles/L, respectively. The dominant microplastics identified were fibers and fragments, with sizes ranging from 1.00–3.00 mm and less than 1.00 mm. Furthermore, the dominant color of the microplastics was black, indicating that the polymers were likely polyethylene, polypropylene, or polystyrene. This study provides novel evidence on microplastic contamination in unbranded refilled drinking water in Indonesia, offering baseline data for future environmental monitoring and risk assessment. These findings confirm that refilled drinking water consumed by communities in Indonesia may represent a potential pathway for the entry and accumulation of microplastics in the human body, posing significant health risks. Based on current findings, further research is required to improve water treatment performance and enhance public health protection.

Keywords: Karawang, microplastics, raw water, processed water, unbranded refilled drinking water.

INTRODUCTION

Plastic pollution in the aquatic environment has become a growing concern worldwide in recent years. Apart from causing pollution, plastic in the marine environment has also been proven to be one of the causes of microplastic abundance in waters through plastic destruction (Kooi et al., 2018; Lares et al., 2018; Liu et al., 202). Microplastics are plastic particles that measure less than 5.00 mm (Fauzi et al., 2024; Gambino et al., 2022; Fauzi et al., 2023a). Due to their small size, microplastics can be easily ingested by aquatic organisms and enter the food chain, potentially posing risks to ecosystem and human health (Sari et al., 2021; Tagg et al., 2020). In addition, their persistence and widespread distribution in water bodies highlight the urgent need for comprehensive monitoring and effective mitigation strategies.

Many studies have reported that microplastics are found in freshwater, commonly used as a water source for various community needs (Koelmans et al., 2019; Lambert and Wagner, 2018; Lenaker et al., 2019; Li et al., 2018; Wagner et al., 2014; Wang et al., 2017). This condition potentially contaminated treated water, such as tap water, as occurred in China, where 0.30 to 440.00 microplastic particles/L were found (Tong et al., 2020; Zhang et al., 2020). Tap water, which is used as raw water for drinking purposes, poses a significantly increased threat to human health, considering the similarity of microplastic properties with those of plastic, which are hard to decompose and toxic (Gambino et al., 2022; Kirstein et al., 2021). According to Carding et al., (2015); Gambino et al., (2022); and Lu et al., (2019), the effects were similar to oxidative stress, inflammatory and immunological responses, mitochondrial membrane disruption, gut microbiota, intestinal dysbiosis, etc.

Recently, microplastics have been found in bottled waters that are widely used by the public. Kirstein et al., (2021) reported that microplastics in bottled water in various countries were found to be 1.40–5.42 × 10^7 particles/L. Gambino et al., (2022) found that bottled water in Germany, Thailand, the USA, Italy, and Saudi Arabia was contaminated by 0.99–5864.00 microplastic particles/L. Furthermore, Aleksander-Kwaterczak et al., (2023) also reported that microplastics contaminated Polish bottled water as much as 87.00–188.00 particles/L. These findings indicate that bottled drinking water may represent a significant source of human exposure to microplastics. However, studies investigating microplastic contamination in alternative drinking water sources, particularly unbranded refilled drinking water, remain limited and require further investigation.

This condition shows the most concerning problem, considering the potential of long-term microplastic exposure to the entire community due to drinking water needs, which reach 2.50–3.00 L/person/day (Aleksander-Kwaterczak et al., 2023; Reed and Reed, 2013). In Indonesia, drinking water consumption is lower by 1.50–2.50 L/person/day (Harfika and Hanifah, 2021), where as much as 52.98% of the need is supplied with refillable drinking water from community storehouses, known as depots because of the affordable price. This high dependence on refilled drinking water may increase the potential risk of continuous microplastic exposure among the population.

To date, specific research on the MP abundance in refillable drinking water, especially in Indonesia, is current very limited. This research aims to investigate the presence of microplastics in raw and processed water used for refilled drinking water depot in Karawang, Indonesia. This research is expected to describe the conditions for microplastics in drinking water, one of the exposure pathways into the human body. The findings of this study are expected to provide baseline data for future monitoring and risk assessment of microplastic contamination in drinking water. In addition, this research may support the development of more effective water treatment and management strategies to protect public health.

MATERIALS AND METHODS

Raw and processed water used for drinking water sampling was carried out at eight unbranded refilled drinking water depots in Karawang, Indonesia (Figure 1). A 2.00 L raw water sample was collected through a water tap before flowing into the refilled drinking water treatment unit (Christanto, 2023). Meanwhile, 19.00 L or 1.00 gallons of processed water for refilled drinking water are taken for each depot. The type of gallon used for sampling was polyethylene terephthalate (PET) as mentioned by Christanto (2023) and Putra (2022).

The National Oceanic and Atmospheric Administration prepared water samples to remove organic matter and separate microplastics before analysis (Aliabad et al., 2019; Masura et al., 2015). The separated microplastics were analyzed using a microscope Olympus BX – 41 with ten times magnification to group them into 3.00–5.00 mm, 1.00–3.00 mm, and less than 1.00 mm. These particles were manually counted to determine their abundance in each sample using the formula:

$$A_{MP} = \frac{N_{MP}}{V_s} \quad (1)$$

where: A_{MP} – microplastics abundance (particles/L), N_{MP} – number of identified microplastics in sample (particles), V_s – volume of analyzed sample (L).

Furthermore, the physical properties of these microplastics, in shape and color, were also determined. The particles are categorized into fibers, films, foams, and fragments based on shape (Fauzi et al., 2023b). Meanwhile, the colors are black, yellow, transparent, white, red, blue, and green (Aliabad et al., 2019; Lin et al., 2018; Masura et al., 2015; Peng et al., 2017). All analyses in the current research were conducted in duplicate.

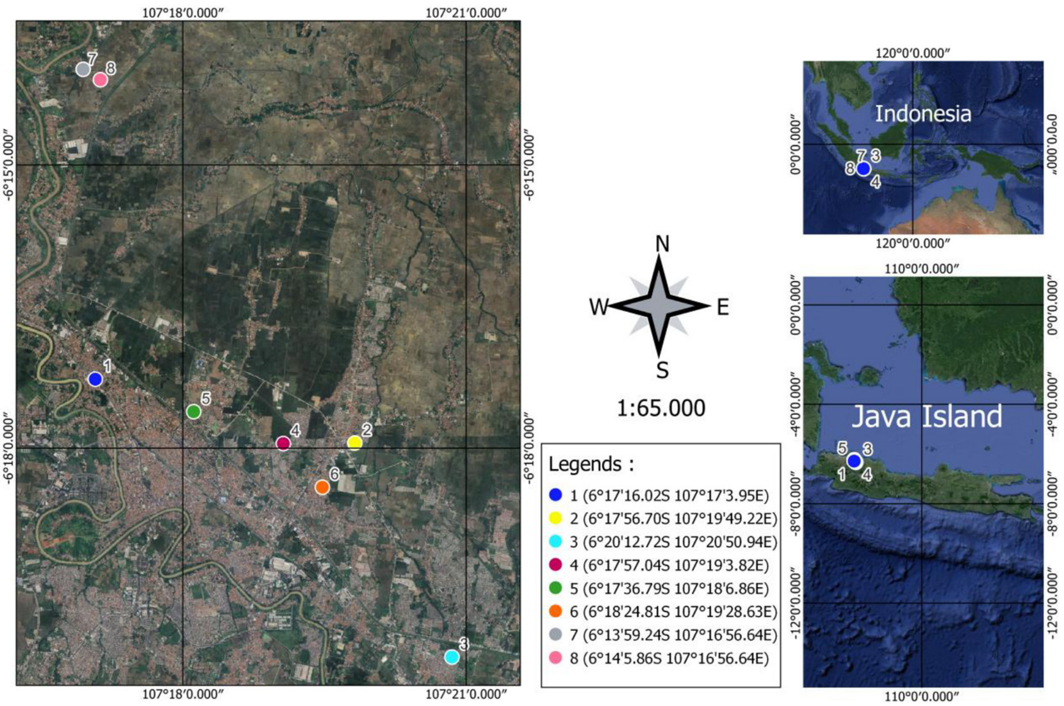

Figure 1. Map of raw and processed water sampling location in Karawang

The type of microplastic polymer found was also determined to identify its source. The analysis was performed using ATR-FTIR (Basri et al., 2021), Thermo Scientific Nicolet iS10 ATR-FTIR at a wavelength of 4000–650 cm^{-1}.

RESULTS AND DISCUSSION

The abundance of microplastics on raw water for unbranded refilled drinking water

Microplastics were detected in raw water samples, with a total abundance ranging from 15.50 to 42.00 particles/L (Table 1). The raw water used in the unbranded refilled drinking water process in current research comes from several springs (Wanayasa and Mount Salak) and groundwater in West Java. It is piped and stored in a water tower before being processed by the depots.

The presence of microplastics in raw water from springs for Depot-1 to Depot-5 is significantly influenced by anthropogenic activities. Still referring to Table 1, the abundance of MP from Depot-1 was significantly higher as compared to other depot sourced its water from spring water, while Depot-6 showed significantly higher among other depot sourced its water from groundwater. According to Yanuar et al., (2024) and Nesterovschi et al., (2023), the discharge of wastewater from domestic activities such as showers and

Table 1. The total abundance of microplastics in raw water

Depot	Source of raw water	The abundance of microplastic (particles/L)
1	Springs	42.00*
2		36.00
3		25.00
4		24.50
5		18.50
6	Groundwater	19.00*
7		16.50
8		15.50

Note: an asterisk symbol (*) indicates the highest significant abundance of MP in the same source of raw water.

washing near the springs is one of the significant contributors to microplastic pollution. It is further supported by his research, which found an abundance of microplastics ranging from 0.20–0.30 particles/L at six springs in Batu City, East Java (Yanuar et al., 2024). This finding is particularly relevant to the microplastic contamination pathways, where wastewater discharge is one of the primary routes for microplastic transfer into water (Van Emmerik et al., 2019).

Moreover, Nesterovschi et al., (2023) also found that microplastics with an average of 0.034-0.06 particles/L at three karst springs in Romania. This may be due to the fragmentation of plastic waste around the karst spring location, such as used bottles and plastic packaging. This assumption is also quite relevant, considering that secondary sources of microplastics come from fragmentation and mechanical destruction of plastic waste in the environment (Galafassi et al., 2019; Gambino et al., 2022; Nesterovschi et al., 2023). As Gambino et al., (2022) explained, due to their petite size and lightweight, fragmented plastics such as microplastics may be transported by wind or surface runoff from contaminated soil to spring

The abundance of microplastics for raw water derived from groundwater in Depot-6 to Depot-8 was 15.50–19.00 particles/L. Similar microplastic contamination was also found in groundwater in India, Germany, and Australia as much as 10.10 particles/L (Selvam et al., 2021); 0.01 particles/L (Mintenig et al., 2019); and 38.00±8.00 particles/L (Samandra et al., 2022), respectively. Similar to the sources of microplastic contamination in springs, the discharge of domestic wastewater and fragmented plastics also causes microplastics in groundwater.

Microplastics could enter the soil through porosity, permeability, and the activity of living organisms (Guo et al., 2020; Monkul and Özhan, 2021). Soil pores and permeability can facilitate the vertical and horizontal movement of fragmented microplastics along with water infiltration (Van Emmerik et al., 2019). Meanwhile, the tiny size of microplastics is also potentially moved by the excretion and movement of soil-living organisms because they are attached to their bodies.

Referring to the distribution of domestic wastewater in Indonesia, which combines grey water and black water in septic tanks, it is might be one of the factors in the presence of microplastics in groundwater through water infiltration (Samandra et al., 2022). It is reinforced by research by (Panno et al., 2019) which found a correlation between the abundance of microplastics in septic tank wastewater and groundwater in the United States. (Huang et al., 2021; Selvam et al., 2021; Waryati et al., 2023) also supported that wells close to residential areas, especially domestic wastewater discharge, have a higher potential for microplastic contamination up to the hyporheic zone and groundwater through rock fissures and aquifer fractures. These factors encourage the movement of microplastics in the soil, which potentially enter the groundwater system (Ren et al., 2021).

The findings of dominance shapes supported the alleged source of microplastic contamination in all samples were fibers and fragments were significantly higher than other shapes, with an average of 14.06 particles/L and 8.13 particles/L, respectively (Figure 2). According to (Yanuar et al., 2024), fibers come from wash wastewater containing ropes or threads from fabrics/textiles and plastics. The fibers found in eight raw water samples were dominated by 1.00–3.00 mm and less than 1.00 mm of microplastics, with an average of 6.88 particles/L and 3.88 particles/L, respectively. Meanwhile, the fragments in all samples most likely emerged from fragmented plastic waste. The dominant fragments found were less than 1.00 mm of 7.00 particles/L.

The dominance of fibers and fragments in the current study indicates the presence of other sources of microplastic contamination as plastic particles released from pipes and reservoir utilization (Angelina, 2023; Dalmau-Soler et al., 2021; Koelmans et al., 2019; Samandra et al., 2022). Figure 2 shows that 1–3 mm MP significantly dominated the films and fibers, while a size <1 mm significantly dominated the fragments. Plastic pipes in the water distribution might cause abrasion due to mechanical pressure that drives the release of microplastic particles into the water (Angelina, 2023; Dalmau-Soler et al., 2021). It is supported by Vega-Herrera et al., (2022), who reported that polymer microplastics in the form of polyethylene (PE), polypropylene (PP), polyisoprene (PI), polybutadiene (PMMA), polystyrene (PS), polyamide (PA), polyvinyl chloride (PVC), and PET were found in household tap water that uses plastic pipes in the distribution process. In addition, the microplastics released also increased with the age of the pipes and reservoirs (Mukotaka et al., 2021; Samandra et al., 2022; Shruti et al., 2020; Tong

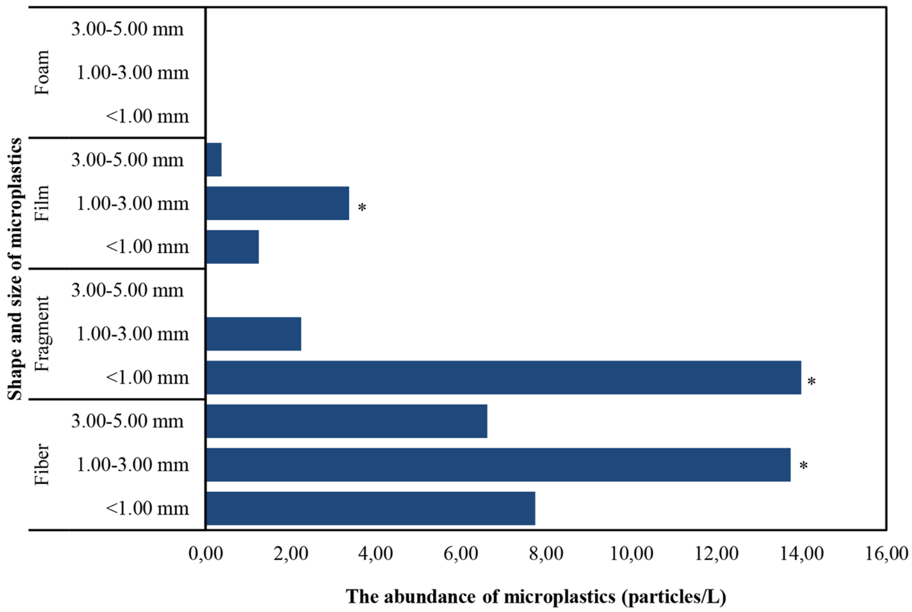

Figure 2. Shape and size of microplastics in raw water samples. An asterisk symbol (*) indicates the highest significant abundance of MP size from the same shape

et al., 2020; Venecia, 2023; Waryati et al., 2023). This information is related to the current conditions in the current study, where the pipe and reservoir materials used for the water distribution and storage before being processed by the depot are PVC and PE, respectively.

The abundance of microplastics in processed water for unbranded refilled drinking water

Microplastics in processed water for unbranded refilled drinking water originating from raw water (as investigated in the previous sub-section) showed a lower abundance, ranging from 6.50 to 17.50 particles/L (Table 2). These results show similarities with several previous microplastic studies in Indonesia, which found microplastics in refilled drinking water as many as 13.00–135.30 particles/L (Saraswati, 2023); 548.00±110.03-1134.33±144.14 particles/L (Angelina, 2023); 268.11±28.90 particles/L (Christanto, 2023); 139.17–190.30 particles/L (Putra, 2022); 0.10-1.10 particles/L (Syarif et al., 2021). It indicates the potential risks to public health and should be a significant concern.

Table 2 shows that the water treatment used for unbranded refilled drinking water, consisting of filtration and sterilization, can remove microplastics as much as 6.00–32.50 particles/L. Filtration in the water treatment process using GAC, SF, and RO, reported by (Gao et al., 2022), can remove the abundance of microplastics in refilled

Table 2. The abundance of microplastics on processed water

Depot	The abundance of microplastic (particles/L)	Type of water treatment		Removal (particles/L)
		Filtration	Sterilization	
1	9.50	Granular activated carbon (GAC) and sand filter (SF)	Ultraviolet	32.50
2	17.50	GAC and SF	Ultraviolet	18.50
3	17.50	GAC and SF	Ozonation and ultraviolet	7.50
4	9.00	GAC and SF	Ozonation and ultraviolet	15.50
5	8.50	GAC and SF	Ultraviolet	10.00
6	6.50	GAC, SF, and reverse osmosis (RO)	-	12.50
7	9.00	GAC, SF, and RO	-	7.50
8	9.50	GAC, SF, and RO	-	6.00

drinking water. However, the differences in the microplastic effectiveness removal found in this study may be influenced by the pore size of the filter used, where GAC, SF, and RO measuring 0.20–0.50 mm and 1 × 10^{-6} mm, respectively (Dalmau-Soler et al., 2021).

Following filter pore size, using a filter combination may increase the effectiveness of microplastic removal (Mintenig et al., 2019; Pivokonsky et al., 2018). As found in current research, where the highest effectiveness of microplastic removal was found in Depot-1 (32.50 particles/L), Depot-2 (18.50 particles/L), and Depot-4 (15.50 particles/L), which used a combination of GAC and SF. Furthermore, Depot-6, Depot-7, and Depot-8 combined GAC, SF, and RO showed a lower microplastic removal of 6.00–12.50 particles/L. The condition is due to the low abundance of microplastics in raw water before processing, dominated by sizes less than 1.00 mm, which the treatment can only partially remove.

Another factor that also affects the effectiveness of removal by the filter is the shape and size of the microplastic in the water. Figures 2 and 3 show that the microplastics (1.00–5.00 mm) removed in current research were dominated by fibers and films as much as 15.13 particles/L and 3.75 particles/L, respectively. Meanwhile, fragments are the most removed for microplastics with a size of less than 1.00 mm. Fragments and films that the filter can remove are illustrated in Figures 4b and 4c. Furthermore, Figures 2 and 3 show no difference in the microplastics with a size of less than 1.00 mm from the fiber. Due to their shape resembling a rope, tiny size, and diameter, fiber can pass the pores of the filter and escape the water treatment process (De Falco et al., 2019). The illustration of fiber can be seen in Figure 4a.

The colour of microplastics in raw and processed water for unbranded refilled drinking water

Figure 4 shows a similar dominance of microplastic colors between raw and processed water (Figure 5). The highly significant abundant microplastic colors in raw water are black, red, and transparent, with an abundance of 10.88 particles/L (44.16%), 4.00 particles/L (16.24%), 3.44 particles/L (13.96%). Meanwhile, the dominant colors of microplastics found in processed water were black, blue, transparent, and yellow, with an abundance of 3.56 particles/L (36.08%), 2.19 particles/L (22.15%), 1.50 particles/L (15.19%); and 1.50 particles/L (15.19%). This finding was similar to An et al., (2022) and Yanuar et al., (2024), who reported that black was the dominant color of microplastics in their study area, reaching 39.01% and 28.40%, respectively.

Zhang et al., (2020) and Murphy et al., (2016) stated that the color of microplastics can indicate the source of the contaminating microplastics. Supriyo and Noviana (2023) also informed that

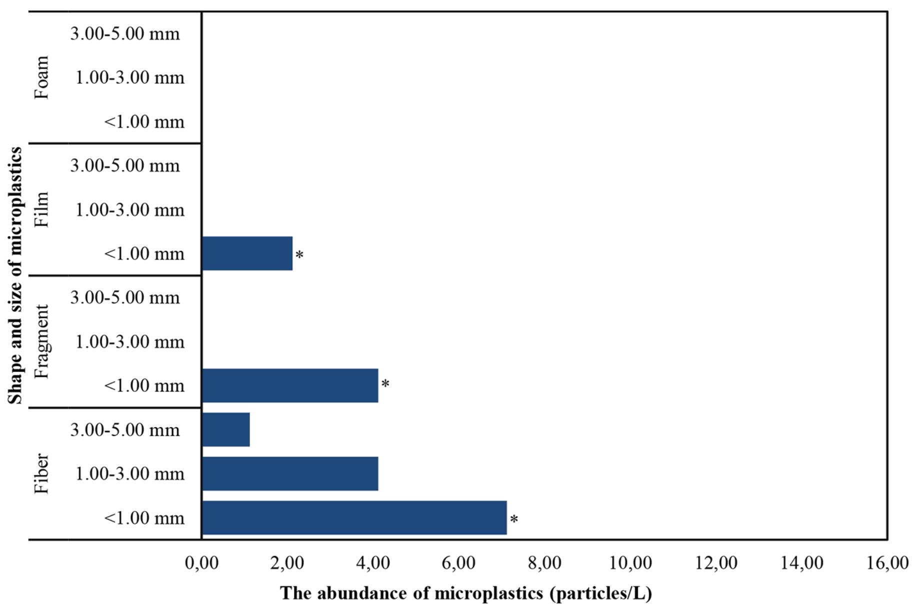

Figure 3. Shape and size of microplastics in processed water samples. An asterisk symbol (*) indicates the highest significant abundance of MP size from the same shape

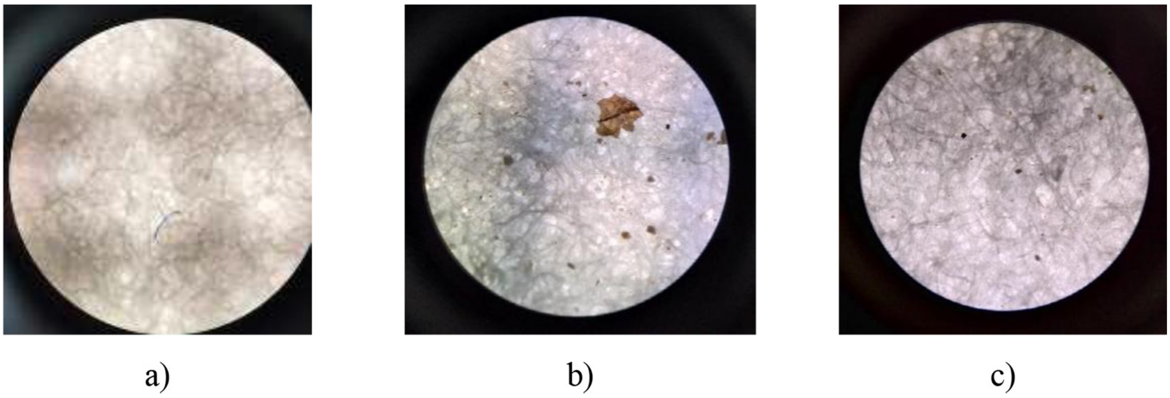

Figure 4. The shape of microplastic: a) fiber; b) fragment; c) film

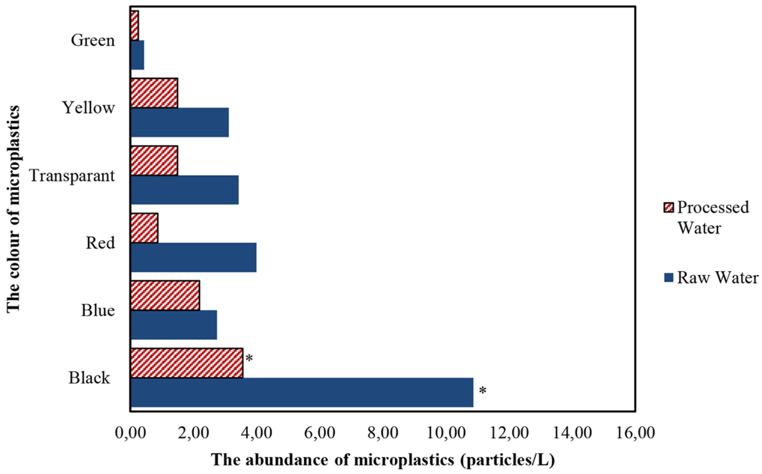

Figure 5. The colour of microplastics. An asterisk symbol (*) indicates the highest significant abundance of MP color from the water source

the various colors may be related to the chemical composition of the microplastics in the water. The black color of microplastics indicates that it is made of PP or PS polymers (Laksono et al., 2021). Dark colors can detect low-density PE polymers early (Kapo et al., 2020). In addition, microplastics with dense and bright colors indicate that microplastics have no discoloration and become transparent (Febriani et al., 2020; Kapo et al., 2020). Transparent colors are usually found in film-shaped microplastics, which are assumed from the original color of plastic packaging made by PP and PE polymers (Makhdoumi et al., 2021). Furthermore, green, blue, yellow, and red microplastics are likely from the original color of the plastic (Romaskila et al., 2023).

PP, PS, and PE are frequently plastic polymers in water that use plastic pipes for their supply system or storage tank. As found by Feld et al., (2021); Mintenig et al., (2019); Mukotaka et al., (2021); and Pittroff et al., (2021) that PP, PS, and PE are dominant polymers in tap water, which are processed from groundwater; this is reasonably related to the alleged polymers contained in microplastics found in the current study.

Potential risk to public health and further research

These results are a stark reminder of the potentially severe health risks microplastics pose in drinking water. Given that the average human consumes 1.50–2.50 L of water daily, ingesting a significant number of microplastic particles is a concerning reality. This continuous exposure could lead to profound health implications if not promptly addressed.

Despite microplastics' effects and toxic consequences in vivo on the human body, they are still unclear. To date, the toxicity of microplastics is frequently associated with their constituent polymer compounds, additives added during the manufacturing process, and their impact on humans. Additives used in plastic manufacturing, such as plasticizers, stabilizers, lubricants, dyes, and pigments, etc., may cause oxidative stress, lipid metabolism disorders, gut microbiota, mitochondrial membrane disruption, and even cancer in many organisms, including humans (Carding et al., 2015; Gambino et al., 2022; Hermabessiere et al., 2017). In addition, the ability of microplastics to adsorb and concentrate bacteria and viruses can potentially increase systemic inflammation, which might cause anemia in humans (Carding et al., 2015; Naik et al., 2019; Prendergast et al., 2015; Sari et al., 2021). However, the possible effects of microplastics still depend on the time and intensity of exposure and the immunological responses of human antibodies.

The translocation of microplastics in the human body occurs through the lymphatic system and blood circulation, which is influenced by their size and shape. The tiny fibers make their movement more straightforward across epithelial and endothelial cells into the circulatory system (Gray and Weinstein, 2017; Oberdörster et al., 2005). As reported by Leslie et al., (2022) that, as many as 1.60 μg/ml microplastics in human blood are identified as PET, PE, and PS. Meanwhile, larger microplastics can be excreted through the human excretory system, as found by N. Zhang et al., (2021), there are 1.00–36.00 particles of microplastics/g human feces in the size of 20.00 to 800.00 μm. Moreover, Schwabl et al., (2019) also found 20.00 particles of microplastics in every ten grams of human feces with a size of 50.00–500 μm.

Referring to this, the current study's processed water findings were dominated by fibers measuring less than 1.00 mm, which have great potential for translocation and accumulation in the human circulatory system. The current study has underscored the pressing need for further research to understand these factors and improve water treatment processes fully, highlighting the urgency and importance of this topic to the sustainability of human health.

CONCLUSIONS

The results showed that raw and processed water used in eight unbranded refilled drinking water depots in Karawang, West Java, contained microplastics with a total abundance ranging from 15.50–42.00 particles/L and 6.50–17.50 particles/L, respectively. Microplastic in raw water was dominated by fiber and fragments of 1.00–3.00 mm and less than 1.00 mm, as much as 13.75 particles/L and 14.00 particles/L, respectively. Meanwhile, the abundance of microplastics in processed water was dominated by fiber and fragments of less than 1.00 mm, as much as 7.13 particles/L and 4.2 particles/L. The abundance of microplastics in processed water showed that the treatment used in each depot removed microplastics with a size of 1.00–5.00 mm. Nevertheless, the presence of microplastics in processed water should increase the government's and the public's awareness of water utilization. More importantly, further studies are crucial to enhance water treatment technologies and remove microplastics in unbranded refilled drinking water.

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