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Study the Effectiveness of Household Water Filtration Systems in Eliminating Plastic Particles in Mosul City, Iraq

Raghad N. Altaee[1], Kossay K. Al-Ahmady[2], Rasha Khalid Sabri Mhemid[1*]

[1] Department of Environmental Technologies, College of Environmental Science, University of Mosul, Mosul, 41002, Iraq

[2] President of the University of Mosul, Mosul, 41002, Iraq

* Corresponding author's e-mail: rashamhemid@uomosul.edu.iq

ABSTRACT

Plastic particles are considered a concerning issue on a global scale. This research aimed to examine the existence and features of microplastics (MPs) as well as evaluate the removal efficiency (RE%) of household water filter systems (HWFS). The research was conducted in 12 areas distributed across Mosul City. Various techniques, including Fourier transform spectroscopy (FTIR), stereomicroscopy, and scanning electron microscopy (SEM), were employed to accurately detect the presence of microplastics, analyze morphological properties, such as color, shape, and size, and determine the polymer types. The research findings showed that the efficiency of HWFS ranged from 93% to 30%, affected by several factors, including filter age and the number of its stages. Fibers and fragments were the most commonly encountered shapes of MPs accounting for about 94% of the examined instances. Around 52% of the total was characterized by a transparent color. An estimated 35% of MPs sizes were smaller than 10 µm. Out of all considered polymer types, polyvinyl chloride (PVC) represented the highest percentage, around 58%. Moreover, PVC was found to have a higher risk index compared to other types of polymers.

Keywords: microplastics, removal efficiency, household water filter system, Fourier transform infrared spectroscopy, stereomicroscope, scanning electron microscopy.

INTRODUCTION

The presence of MPs in tap water is becoming a global issue because of the risks associated with human consumption and health impacts on humans (Dalmau-Soler *et al*., 2022). Lately, people have become more conscious of the contaminants that impact the quality of water (Pizzichetti *et al*., 2021). Microplastic particles that are less than 5 millimeters in size can come from different sources and enter water systems (Albazoni *et al*., 2024). Microplastics are also classified according to size into large microplastics (5–1 mm), small microplastics (1 mm – 1 µm), and nanoplastics (< 1 µm), formed from oxidation processes induced by solar radiation (Hadeed and Al-Ahmady, 2022). There are two types of MPs: primary MPs, which are intentionally produced and utilized in industrial or trade products (such as paints, adhesives coatings, microbeads in cleansers and cosmetics), and secondary MPs, which result from the breakdown of larger aged-plastic debris (Gambino *et al*., 2022). Furthermore, microplastic contamination in drinking water can be caused by the drinking water supply network itself (Cherian et al., 2023). While plastic has profited our lives in terms of usage and cost, the careless disposal of used plastic creates serious environmental issues, where plastic breaks down into smaller pieces. As soon as it arrives in water bodies, it does not biodegrade easily, leading to accumulation over time (Al-Sarraj and Al-Ahmady, 2022). The most common MPs are manufactured from polyethylene terephthalate (PET), polyethylene (PE) (low-density PE, high-density PE), PP, PS, PVC, polyamide (PA), and polycarbonate (PC), according to (Sultan *et al*., 2023). Providing clean, safe drinking water may be challenging when MPs are present in drinking water, considered emerging pollutants. Several studies by (Li *et al*., 2023, Maurizi *et al*., 2023, Mohd Nor *et al*., 2023) have highlighted the presence of microplastics, in drinking water underscoring this concerning issue. Humans inevitably encounter long-term exposure to microplastics due to drinking water consumption, leading to health effects attributed to the physical and chemical characteristics of these particles (Brancaleone *et al*., 2024). Drinking water treatment can reduce particle concentrations by 90 percent, but high levels of microplastics may remain after treatment; treated water can contribute to MPs contamination (Cherian, 2021). Thus, MPs can be acquired from processed water. Even though municipal water treatment plants remove MPs from drinking water, they cannot remove them completely. As a result, home water purifiers are required to eliminate residual MPs in drinking water. There are several home water purifiers popular used to purify tap water inside houses, as follows: water cooler filter (WCF), HWFS, and point-of-use water filter (POU). Among these options, purifying tap water with HWFS is considered more effective than using WCF or POU filters. Therefore, this filter started attracting attention from individuals and began to gain popularity over time. The household water filter system consists of several stages of purification, as follows; the first stage (sediment pre-filter), removes sediments and dirt down to 5 microns from water. The second stage (granular activated carbon pre-filter), and the third stage (carbon block pre-filter): effectively remove over 99% of chlorine and chloramines. The fourth stage (reverse osmosis filter): removes toxic inorganic contaminants including lead, chromium, radium, arsenic, nitrates and many others. The fifth stage (activated coconut shell post-filter): improves the taste and odor of water. The sixth stage (mineral stone post-filter): adds mineral frames in the water. The seventh stage (pH equalization, post-filter): equalizes the pH value of water. The final stage (UV sterilized lamp filter): efficiently removes all types of bacteria, viruses, and other microorganisms (Rahim, and Othman, 2019). According to the authors' knowledge, there is no paper evaluating the existence of MPs in HWFS. Thus, it has been stressed that it is important to study MPs in HWFS to assess how their removal efficiency. Moreover, the morphological features of MPs in water samples can be evaluated utilizing optical microscopy. Afterwards, infrared spectroscopy can be employed to verify the identities of the detected particles.

This study investigates the effectiveness of HWFS in removing microplastics from the water system, in Mosul, Iraq. It also delves into the characteristics and qualities of microplastics. These findings will offer researchers insights, about the HWFS removal efficiency of microplastics.

MATERIAL AND METHODS

Data collection

A total of 24 water samples in triplicate were collected from 12 selected districts distributed in Mosul City from August 2023 to December 2023, as shown in Figure 1. Table 1 provides information on the stages and ages of filters available in these districts.

The process of collecting water involved taking samples before entering the water filtration system (tap water), and after treatment by the purification system (HWFS). Before taking samples from households the water was flushed for five minutes at the tap and glass bottles (one-liter) were rinsed with water (Almaiman *et al*., 2021). Then, the water samples were taken for laboratory measurements.

Physical properties and polymeric composition of microplastic in drinking water

In the lab, plastic particles were separated from the water sample using a 0.45 µm cellulose

Table 1. Household filter systems properties on each side of Mosul City

Left side from Mosul City		
Districts	Filter's age (days)	Filter's stage
Yarmija	547.5	6
Almasarif	15	6
Alakhaa	365	7
Alandils	150	7
Al-Qadisiyah	10	7
Alzuhur	584	8
Alkafaat	180	8
Alatibaa	7	8
Right side from Mosul City		
Districts	Filter's age (days)	
Nablus	730	5
Josak	195	5
Altayaran	30	5
Mushairfa	120	6

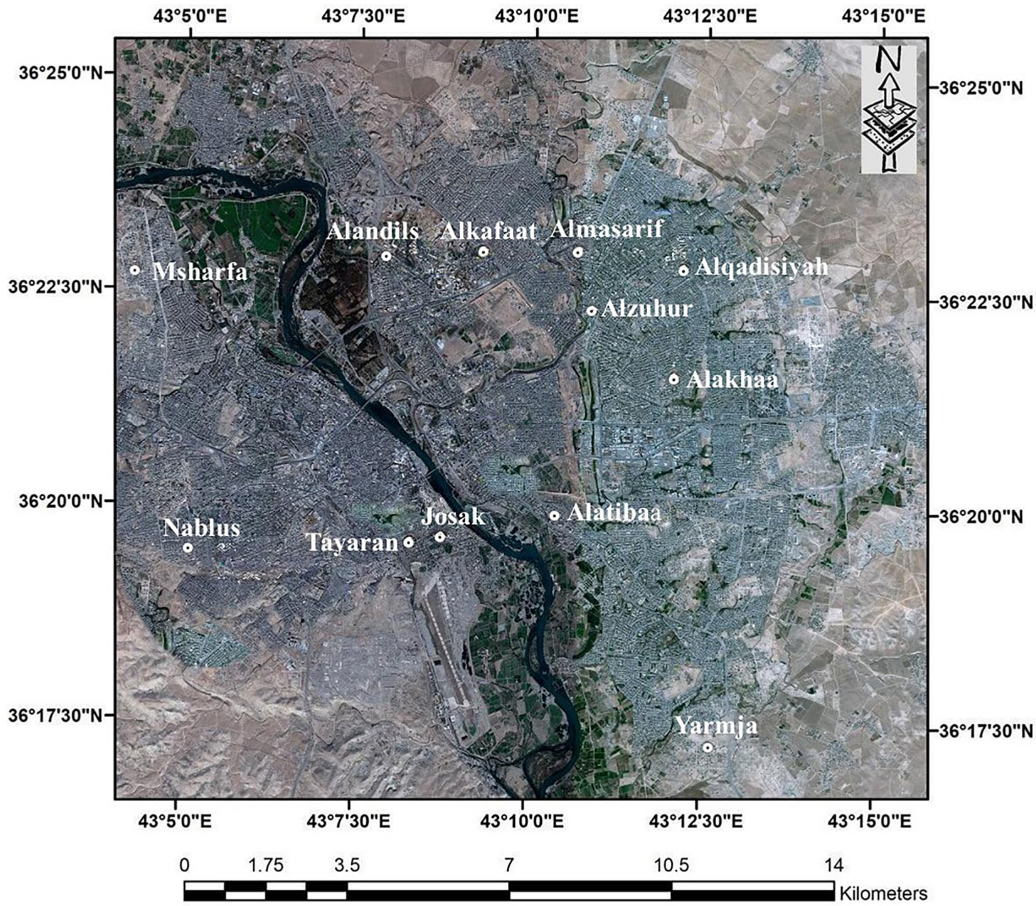

Figure 1. Sampling sites in the Mosul City

nitrate filter paper (CHMLAB Group, Spain) (Al-Sarraj and Al-Ahmady, 2022). Following that, MP numbers and their visual properties (color and shapes) were observed using a stereomicroscope (Motic2300S-V37-45X Zoom, Italy). The different shapes of microplastics were classified into fibers, fragments, foams, and others as detailed by (Hameed Sultan *et al*., 2023). Moreover, they were sorted based on colors like white, orange, red, black, blue, and yellow based on the research by (Cherian *et al*., 2023).

To determine the size of microplastics, a scanning electron microscope (SEM) from ZEISS Evo-10, Germany was employed. The plastic particles that remained on the filter paper after separating it from the water samples were taken to SEM analysis. As plastics are non-conductive, the particles were coated with a thin conductive layer of gold before analysis and viewed with an accelerating voltage of up to 13 kV surfaces to allow the SEM to observe the particles without interference, from compound peaks (Ramaremisa *et al*., 2024). Fourier transform infrared spectroscopy (IRAffinity-1S, SHIMADUZ, Japan) within the range of (4000 cm^{-1} and 600 cm^{-1}) for a sampling duration of 3 seconds was used to identify the polymer composition of the microplastics. Using a resolution of 4 cm^{-1}, fifteen scans were performed per measurement (Al-Hussayni *et al*., 2023). After that, microplastic samples were placed beneath a sample presser that had a built-in pressure sensor for analysis. It is possible to control the operation of the auto sample presser either through an APC program or a panel on the accessory. The spectral data obtained was then cross-referenced with databases to determine the polymer type from preceding references (Dalmau-Soler *et al*., 2022). Figure 2 depicts the procedure of this study.

RESULTS AND DISCUSSION

Removal efficiency of microplastics in HWFS

According to Figure 3, it was observed that the 8- and 7-stage filters exhibited the maximum removal efficiency achieving 93% at 7 days of age and 90% at 10 days of age, respectively. Further, the elimination reached 82%

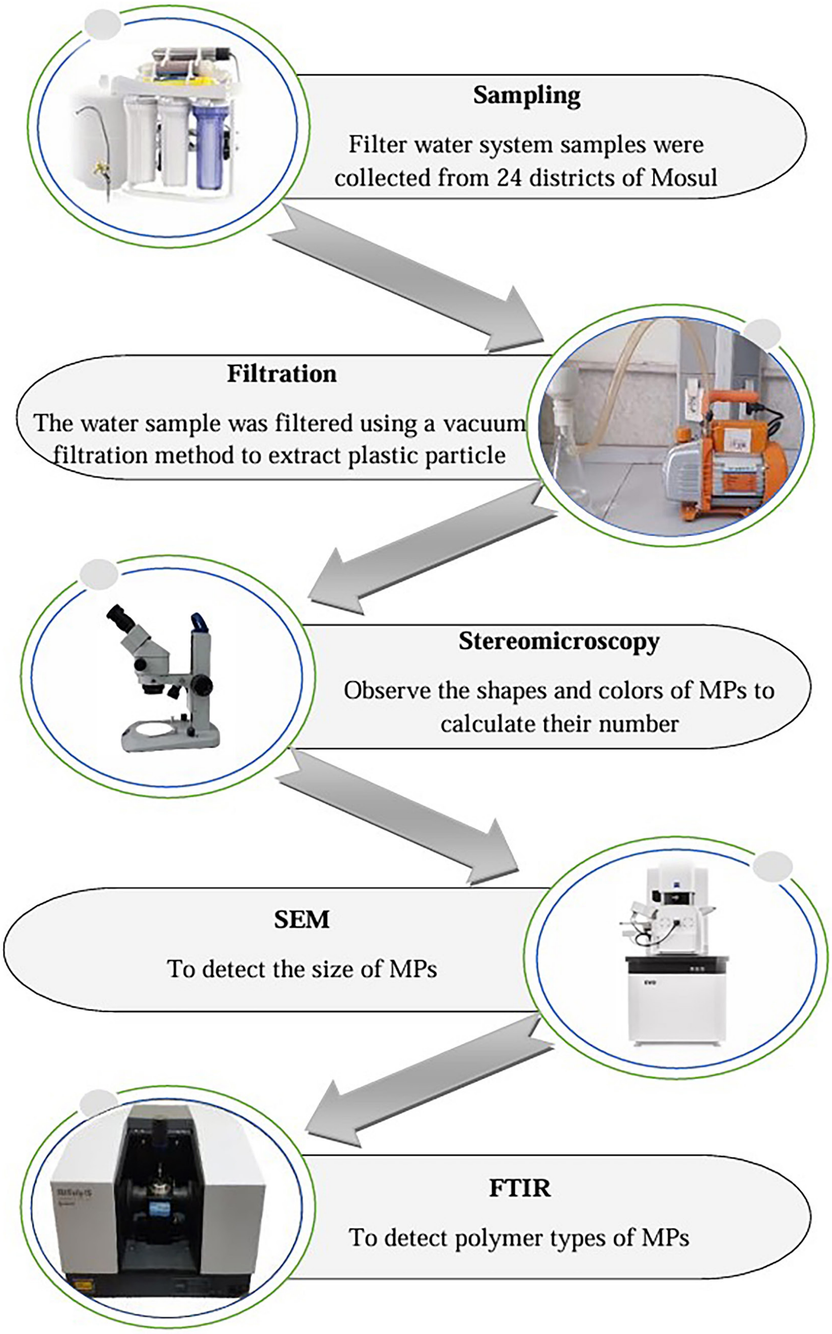

Figure 2. Diagram illustrating the method utilized in this research to analyze MPs

in the 5 stages within 30 days and 61% at 195 days. During the 6 stages filter, the rate stood at 87% after 15 days dropped to 74% at 120 days, and decreased to 46% after 548 days. As for the 7-stage filter, the RE% was about 77% at 150 days of age and 55% at 365 days. In turn, the 8-stage filter showed a removal efficiency (RE%) of 51% after 584 days. Additionally, the lowest removal efficiency recorded was 30% for a 5-stage filter with an age of 730 days. The findings suggest that both the age of the filter and the number of stages play a role, in influencing removal efficiency. It can be observed that there is no complete removal of plastic particles in the household filter system, despite the membrane pore size (0.0001–0.001) μm in the reverse osmosis unit being smaller than the size of plastic particles. The reason for this is probably that the filter membranes were originally manufactured using plastic and the fouling accumulated on the membranes (as a result of neglecting maintenance) obstructs those pores (Research Design and Standards Organization 2015).

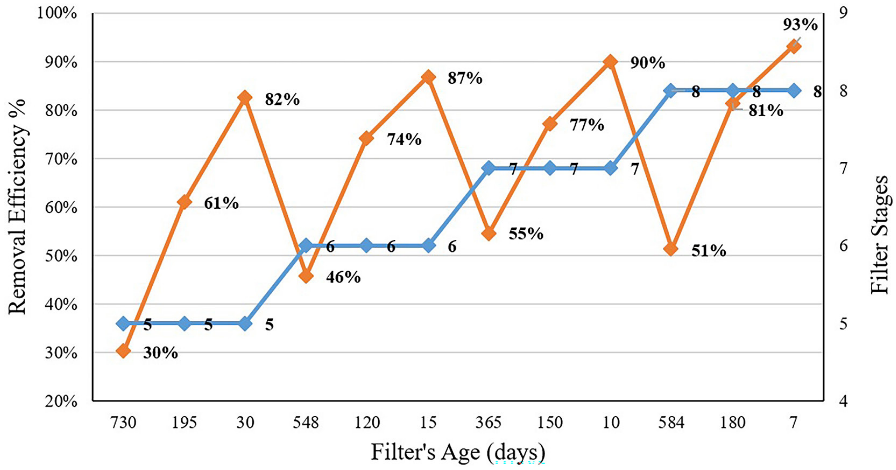

Figure 3. Removal efficiency of microplastics in the different water sampling of Mosul City

Microplastics characteristics

Microplastic shapes

Different kinds of microplastics shapes have been found in water filtered by household water filter systems in the sampling areas. The common forms detected were fibers and fragments as depicted in Figure 4. 94% of the microplastics identified were in the form of fibers and fragments while foam made up 3% and others comprised 3%. Researchers classified microplastics, in tap water into five categories. Fibers, fragments, films, foams and others (non identified) (Taghipour *et al*., 2023). Samples of these microplastics are displayed in the photographs shown in Figure 5.

Microplastic colors

Microplastics are found in different colors, like blue, black, red, orange, yellow and white (Ismanto *et al*., 2023). Recognizing the colors of microplastics is important for pinpointing their origins as depicted in Figure 6. Transparent microplastics accounted for the majority at 52%. That may be due to the repeated disintegration of plastic pieces, which causes them to lose their original color (Gao *et al*., 2022). Then comes blue (17%), white (9%), orange (7%,), yellow (5%), black (4%), red (4%), and other (not identified) (3%) were identified in the filtered water by the household filter system.

A previous study found the common colors of MPs as follows: transparent, blue, black, white, red, and green (Al-Sarraj and Al-Ahmady, 2022). Moreover, in another study, Zhao *et al*. (2022) discovered that plastic particles in tap water were of different colors, most notably transparent, black, white, red, blue, and others (not identified).

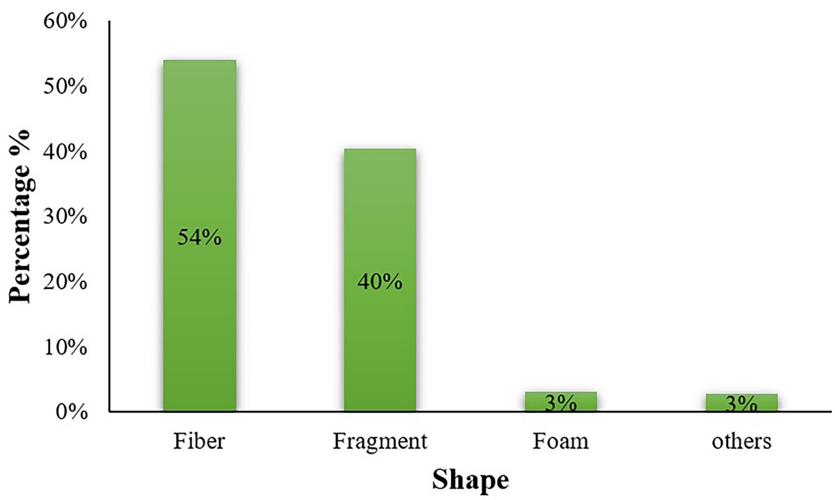

Figure 4. Percentage of microplastic shapes in water treated by household filter system

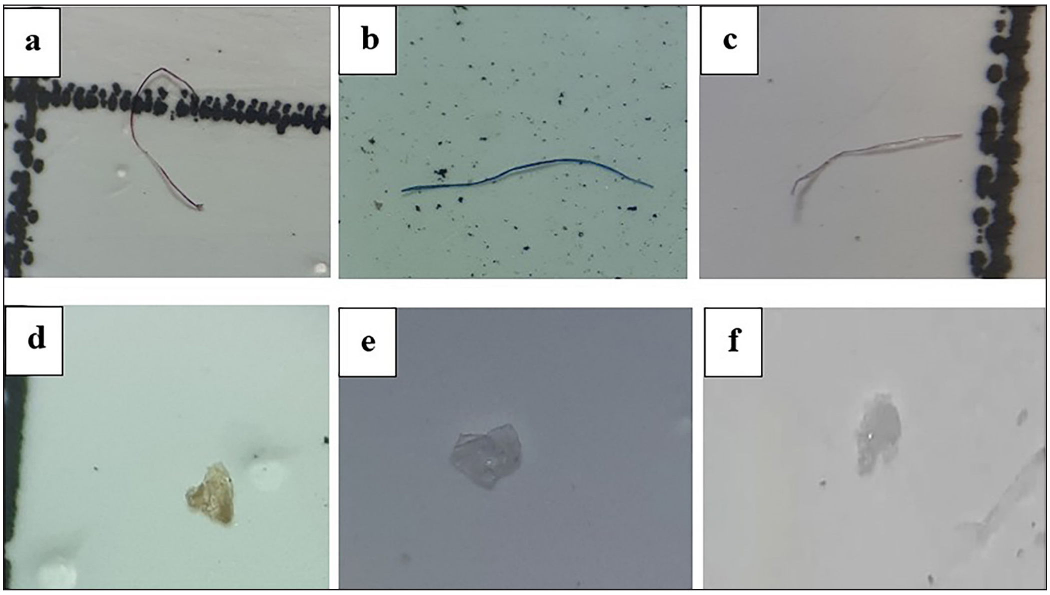

Figure 5. Stereomicroscope photographs of microplastic (45×), where (a), (b) and (c) fibers, (d) fragments, (e) and (f) foams

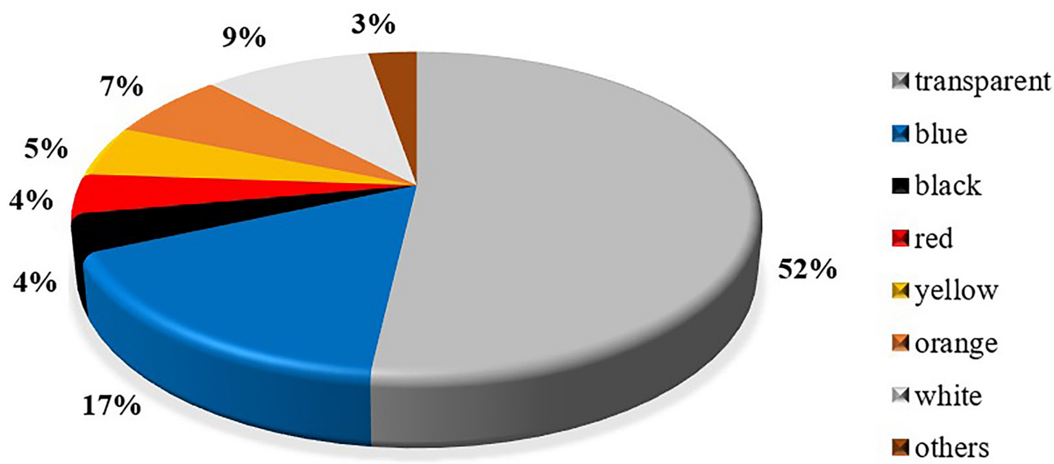

Figure 6. The colors of MPs in HWFS in the different water sampling of Mosul City

Microplastic sizes

This study appraises the range of sizes, from less than 10 µm to 200 µm categorizing them into four size groups; <10 µm, 10–50 µm, 50–100 µm and 100–200 µm as depicted in Figure 7. Figure 8 demonstrates the percentage of microplastic sizes. The detected sizes were ≤ 10 µm at a rate of 35% followed by the range of sizes from 10–50 µm at a proportion of 24%. The category of sizes from 50–100 µm at a percentage of 22%. The smallest percentage was observed between 100 and 200 µm standing at 19%. Negrete et al., (2023) have categorized microplastics found in drinking water into five sizes: 1–5 µm, 5–10 µm, 10–50 µm, 50–100 µm and < 100 µm. Furthermore, the majority of microparticles are 10 µm or smaller which is similar to the results obtained by (Tong *et al*., 2020) and (Feld *et al*., 2021). Hence, most of the particles present in filtered water have the potential to become absorbed and accumulate in the human body according to (Malak, 2021).

Types of polymers composition

In the water samples collected from HWFS researchers discovered types of polymers, as illustrated in Figure 9 and Figure A-1. In Mosul city the types of polymers found were PVC (58%), PA (9%), PET (15%), PE (5%), PP (7%), PS (3%) and some polymers that could not be identified

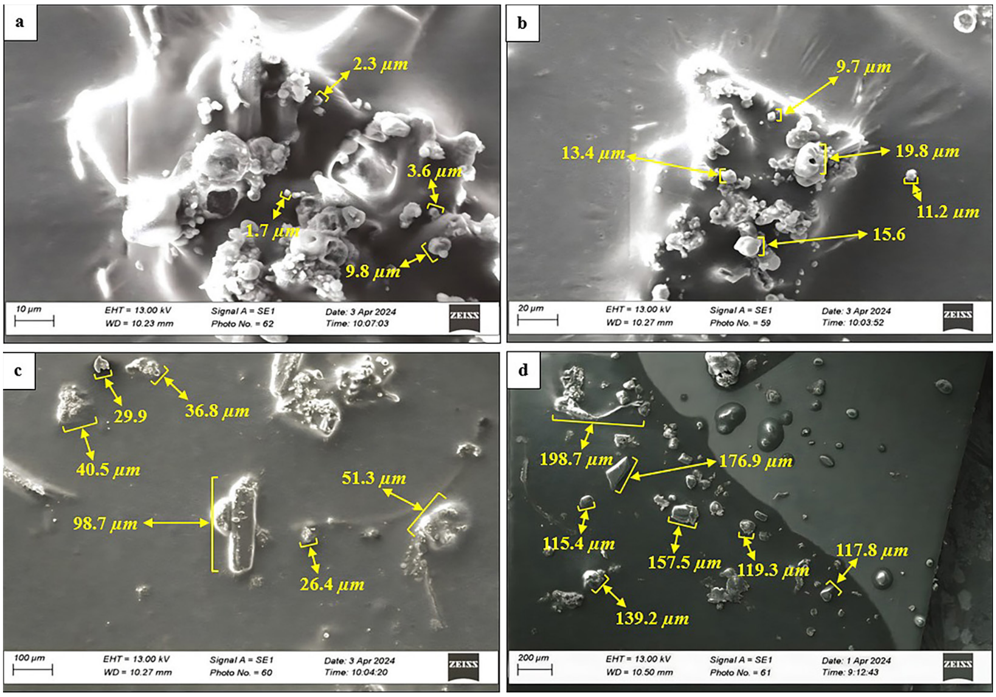

Figure 7. Scanning electron microscopy images of MPs, where (a) are ≤ 10 μm, (b) are between 10-20 μm, (c) are from 50 to ≤100 μm, and (d) are at 100 < MPs size ≤ 200 μm

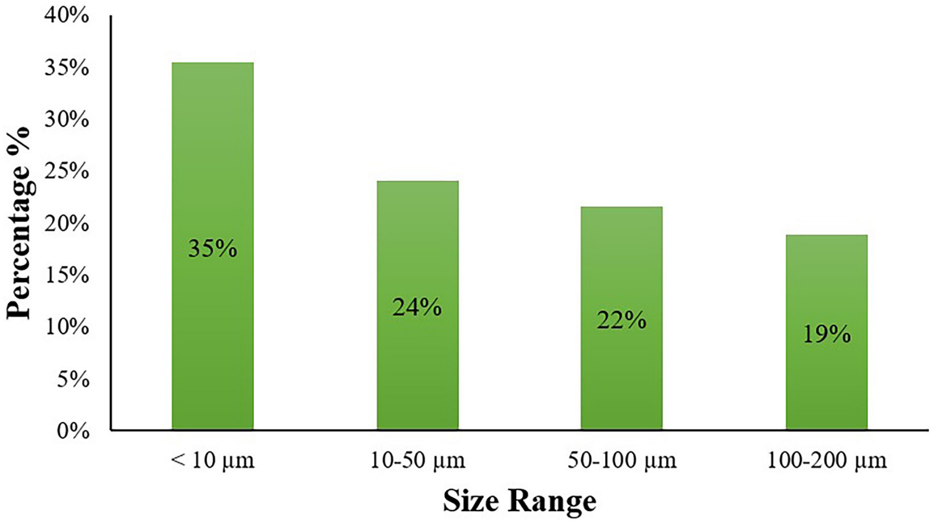

Figure 8. Percentage of microplastic size in treated water by HWFS

(3%). PVC accounted for the highest share at 58% when contrasted with polymer varieties. A recent study conducted by (Hameed Sultan *et al*., 2023) found that PVC is the most common type of polymer in drinking water due to that, the most of networks of drinking water in Mosul city, Iraq are made from PVC.

Polymer identification: PVC – polyvinyl chloride, PET – polyethylene terephthalate, PE – polyethylene, PA – polyamide, PP– polypropylene, PS –polystyrene, NI – non identified polymer

Evaluating the risk possible of microplastics

To assess the risks associated with microplastics, the methods outlined in a research paper by (Sultan *et al*., 2023) were applied. The Equations 1 and 2 were used to calculate risk index (*RI*):

$$RI = \sum_{i=1}^{n} Ei \quad (1)$$

$$Ei = Ti \times \left(\frac{c_i}{c_0}\right) \quad (2)$$

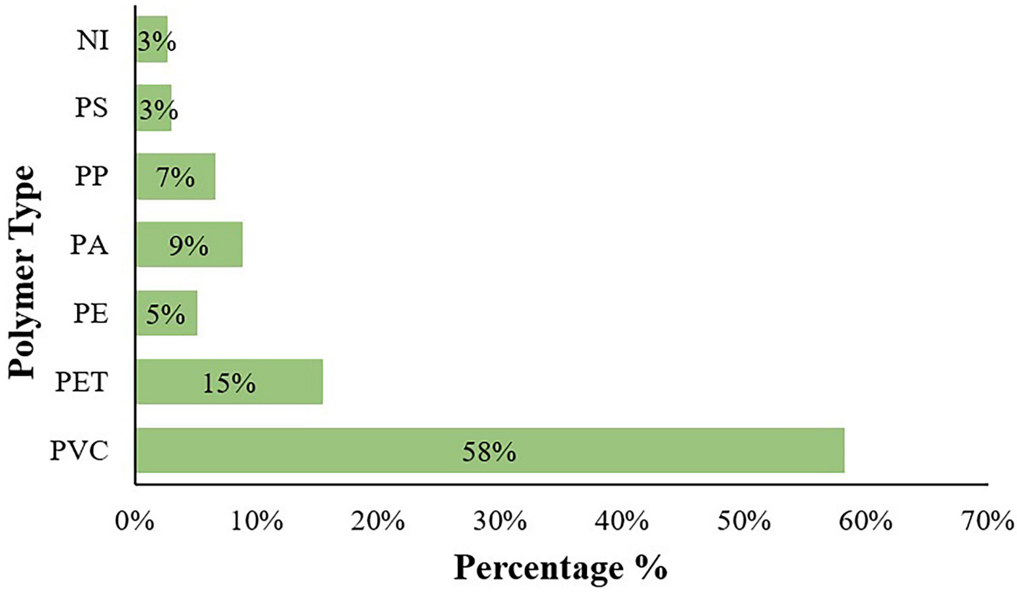

Figure 9. The proportion of polymer types of microplastics in treated water by HWFS

Table 2. Risk categories associated with microplastics (Sultan *et al.*, 2023)

Potential single risk index Ei	Risk category	Potential risk index RI	Risk category
40 >	Minor	150 >	Minor
80–40	Medium	300–150	Medium
160–80	High	600–300	High
320–160	Danger	1200–600	Danger
> 320	Extreme danger	1200 <	Extreme danger

Table 3. The potential risk of various microplastics in the water treated by HWFS (Zhang *et al.*, 2019)

Polymer	MPs/L	C_i/C_0	T_i^*	E_i	RI
PVC	30.50	0.95	10551	10056.42	10067.13
PET	8.08	0.25	4.00	1.01	
PE	2.67	0.08	11.00	0.92	
PA	4.67	0.15	50.00	7.29	
PP	3.50	0.11	0.00	0.00	
PS	1.58	0.05	30.00	1.48	
NI	1.42	0.04	0.00	0.00	

The study was focused on pinpointing environmental risk elements indicated by the risk index (*RI*) and ecological risk index (*Ei*), *Ti* denotes the chemical toxicity coefficient of the polymer component, whereas *Ci/Co* signifies the ratio of measured microplastic concentration to background levels. As a default, the lowest concentration of microplastic is assumed to be the background value in the absence of background information. Table 2 outlines risk levels based on *Ei* and *RI*. Preliminary evaluation indicates that specific areas in Mosul city could be at risk from microplastics. An assessment was conducted on the risks linked to five different polymers found in HWFS across 12 districts. The results presented in Table 3 reveal that the RI value stands at 10067.13. It is important to mention that microplastics (MPs) are extremely dangerous to the residents of Mosul City. according to Table 2.

In Table 3, the ecological risk index (Ei) illustrates the highest values for PVC, which can be associated with its high Ti values. When a polymer possesses a high Ti value it typically impacts the RI ranges mainly because of the notable variations in Ti values between these different polymer types. It is worth mentioning that this study highlighted a limited number of polymer types and provides an evaluation of their probable risks, where this risk index is assessed based on the monomer as detailed in (Gao *et al*., 2022).

CONCLUSIONS

Research was conducted to explore the existence of microplastics, their physical and polymeric composition characteristics and the effectiveness of HWFS in removing them. The findings showed that the filtration efficiency of HWFS ranged from 93% to 30% depending on factors, like the age of filter and the number of its stages. At 730 days old the lowest removal efficiency percentage for a 5-stage filter was observed. In contrast, the maximum removal efficiency percentage was recorded at 7 days old for an 8-stage filter. Most of these particles were transparent and with shapes of fibers and fragments. The majority of the discovered sizes were at < 10 µm. Among the types of microplastics detected, polyvinyl chloride (PVC) was found to be the most commonly identified material. PVC is considered a high-risk substance due, to its Ti value.

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