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Airborne microplastic pollution in healthcare waste disposal systems: A cross-sectional study in Tehran

Rezvan Amiri[1], Abbas Shahsavani[1,2,], Anoshirvan Mohseni Bandpey[1,2], Shahriyar Bezzazpour[1], Seyed Nadali Alavi[1], Mehrnoush Abtahi[1], Majid Kermani[3]*

[1] Department of Environmental Health Engineering, School of Public Health and Safety, Shahid Beheshti University of Medical Sciences, Tehran, Iran

[2] Air Quality and Climate Change Research Center, Research Institute for Health Sciences and Environment, Shahid Beheshti University of Medical Sciences, Tehran, Iran

[3] Department of Environmental Health Engineering, School of Public Health, Iran University of Medical Sciences, Tehran, Iran

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CORRESPONDING AUTHOR:
ashahsavani@gmail.com

Tel: (+98 21) 22432040
Fax: (+98 21) 22432037

ABSTRACT

Introduction: Microplastics (MPs) pollution has become a significant global environmental concern, with various sources contributing to its spread. However, the release of MPs from healthcare waste disposal systems, which often involve shredding plastic waste, has not been widely studied. This research investigates the presence and concentration of MPs in the air surrounding autoclave and hydroclave devices at hospital waste disposal sites in Tehran.
Materials and methods: A cross-sectional study was conducted from May to August 2024 in eight hospitals in Tehran, encompassing both autoclave and hydroclave systems. Air samples were collected from distances of 0, 5, and 10 m from the waste management units during their operation and when they were off. A total of 48 samples were analyzed for microplastic particles using light microscopy and Raman spectroscopy to determine particle characteristics such as size, shape, and color.
Results: The average concentration of MPs in the air surrounding autoclave and hydrocalve devices was 45±43 (N/m^3) and higher concentrations were observed when the devices were active. No significant differences were observed between the autoclave and hydroclave systems. Microplastic particles in the air of the disinfected areas were mainly fibrous (95%) and black (70%), and the average particle length was 34.93 µm. Smaller particles, which pose more health risks, were the most common particles.
Conclusion: Hospital waste disposal units, especially their shredder systems, are a significant source of airborne MPs. These emissions, especially through inhalation are a potential health risk. This study highlights the need for further research and mitigation strategies to reduce microplastic emissions in healthcare settings.

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Introduction

Microplastics (MPs), defined as plastic particles smaller than 5 mm, have emerged as a pervasive environmental contaminant with global implications [1, 2].The accumulation of MPs in diverse ecosystems has escalated into a pressing global challenge, evidenced by their detection in even the most remote and pristine environments, such as the Arctic and Greenland. These particles, derived from various synthetic polymers, contribute significantly to environmental pollution and ecological imbalance [3, 4].

Although the long-term effects of MPs on human health remain uncertain, existing studies suggest their potential to induce oxidative stress, cytotoxicity, metabolic disturbances, immune system dysfunction, neurotoxicity, impaired fat digestion, and even carcinogenesis. Furthermore, MPs can serve as carriers for hazardous substances, including heavy metals, plasticizers, and other adsorbed chemicals, amplifying their environmental and health risks [5]. Despite their widespread presence, no regulatory standards currently govern the concentrations of MPs and nanoplastics in the air. Nonetheless, significant levels of these particles have been identified across various environmental matrices [6].

Humans are exposed to MPs via multiple pathways, including ingestion, inhalation, and dermal contact. Among these, airborne exposure is particularly concerning due to the propensity of MPs, especially fibers, to remain suspended in the atmosphere owing to their high surface area-to-volume ratio and low sedimentation rates. Inhalation of MPs is now recognized as a potential route of exposure that may contribute to adverse health outcomes [7].

Recent studies have identified waste management and recycling processes as significant sources of microplastic release into the environment [7, 8]. Golwala et al. highlighted municipal waste, sewage sludge, and food waste as overlooked contributors to microplastic pollution [8]. Similarly, He et al. reported that leachate from municipal landfills is a major source of microplastic contamination [9]. Suzuki et al. demonstrated that mechanical recycling processes for plastic waste generate considerable microplastic emissions [9].

Healthcare waste is notable for its substantial plastic content, a proportion that has surged during infectious disease outbreaks such as COVID-19 [9, 10]. These wastes, classified as hazardous due to their high microbial contamination and infectious nature, necessitate rigorous decontamination processes. In Iran, medical waste is predominantly treated using thermal disinfection methods such as autoclaving or hydroclaving, which operate under high pressure and temperature [11]. Mechanical shredders integrated into these systems are used to reduce waste volume, however, the mechanical abrasion and pressure inherent in the shredding process may unintentionally generate MPs.

The objective of this study is to investigate the presence and concentration of MPs in the air surrounding hospital waste disposal in Tehran. Specifically, the research aims to assess the release of microplastics during the operation of autoclave and hydroclave systems, identifying these units as potential sources of airborne microplastic pollution.

Materials and methods

Study area and sampling

Air samples were collected from the medical waste management departments of eight hospitals in Tehran between May and August 2024. Air sampling was conducted at four hospitals equipped with autoclave systems and four hospitals equipped with hydroclave systems. The geographical location of the hospitals is presented (Fig. 1). To determine airborne MP number concentration, we collected a total of 48 air samples, including 3 samples at distances of 0, 5, and 10 m from the management devices in operation, and one sample when the device was off. Total Suspended Particulate (TSP) was collected on Whatman fiberglass filter (47 mm; 1.2 µm pore size) using an air sampling pump at a flow rate of 50 L/min. Filters were then carefully removed using stainless steel tweezers and placed in round glass Petri dishes that had been cleaned beforehand. These dishes were kept closed and covered with aluminum foil until the analysis.

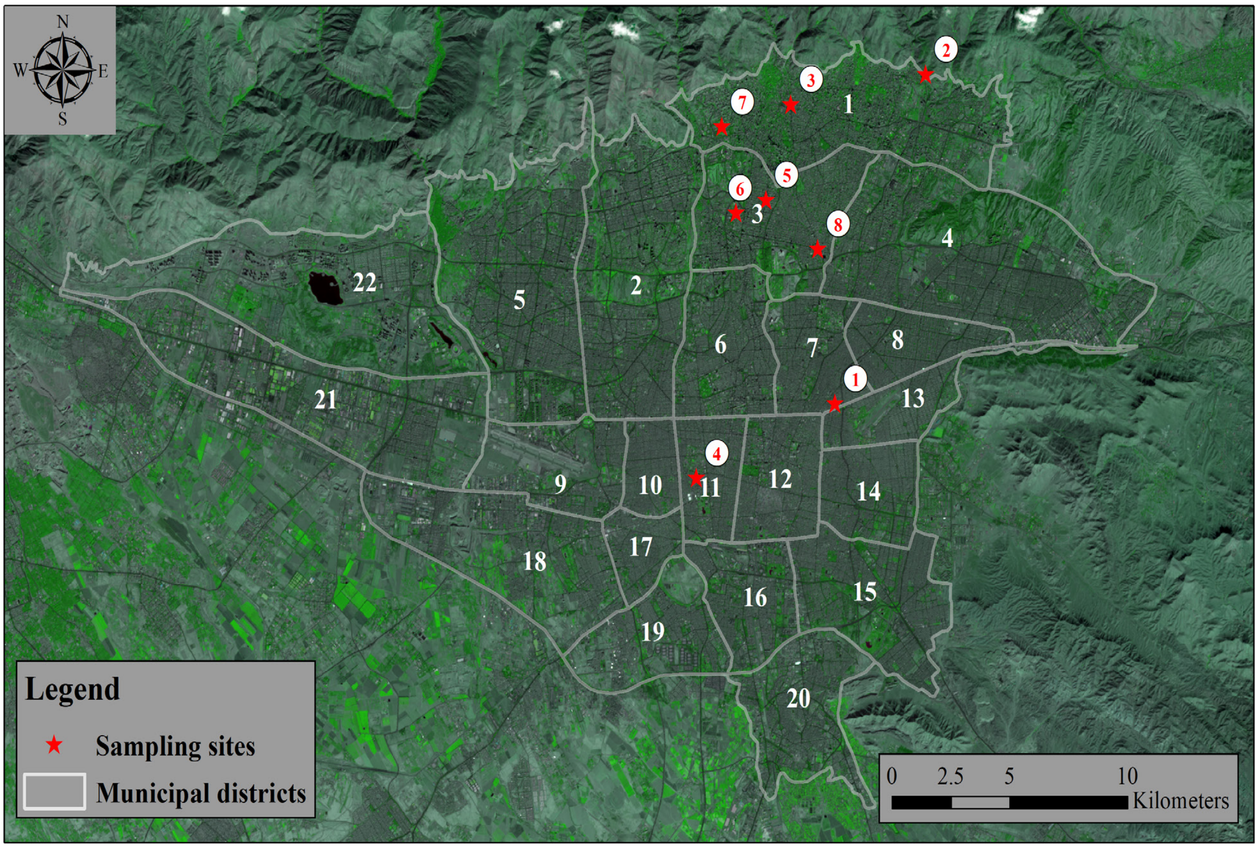

Fig. 1. Geographical location of studied hospitals in Tehran

Counting and characterization of microplastic particles

A stereo microscope with a camera and magnification capabilities ranging from 100x to 400x was utilized to investigate the size distribution, abundance, and classification of MPs. Particles were manually counted after photos were taken. Each particle's color, length, and shape were measured as part of the filter examination. A zigzag motion was employed during visual inspection of the filter surface. A μ-Raman spectroscopy (Horiba, Japan) was employed to confirm the chemical composition of suspected microplastic particles. The filters were directly irradiated using a 785 nm laser with an exposure time of 2 s and a laser power of 1 mW. The spectrometer was configured with a grating resolution of 600 lines/mm, and for each particle, five spectra were acquired to ensure accuracy and reliability of the results. The resulting spectra underwent baseline correction using Origin Pro software (Peak and Baseline module). Subsequently, these corrected spectra were compared against reference spectra from the Public Spectra Database to confirm material identity.

Quality control

Strict quality control procedures were implemented during sampling, preparation, and analysis to prevent potential contamination of the samples with MPs. A calibrated flowmeter was used to monitor and record the airflow rate through the filters while they were in operation. Fiberglass filters were combusted at 450 °C for 3 h. Afterward, the filters were stored in glass Petri dishes and wrapped with aluminum foil. Operational control filters (fiberglass) were also examined as negative controls during microscopic evaluations. Three control field blank samples were gathered throughout the sampling procedure.

Statistical analysis

Statistical analysis was conducted utilizing GraphPad Prism software Inc., version 9. Normality of data was performed using Shapiro Wilk test, and nonparametric testing method (Mann-Whitney U) was adopted when the data sets did not fit the normal distribution. If the data fitted normal distribution, t-test was performed to determine the differences in the quantities of MPs among different samples at the 95% confidence level. In this study, data were expressed in terms of number of particles/m^3. All data are outlined as mean ±SD unless otherwise stated, and all "differences" mentioned to indicate a statistically significant $P<0.05$.

Results and discussion

Airborne MPs abundance

The abundance of MPs is detected in the air surrounding autoclave and hydroclave devices. The MPs concentration was different among the hospitals, so that the highest concentration was observed in the medical waste disposal sections of Hospital 7 (179 N/m^3) and the lowest concentration was observed in Hospital 8 (6 N/m^3). The concentrations in the medical waste disposal sections for different hospitals were 86 N/m^3 (Hospital 1), 22 N/m^3 (Hospital 2), 31 N/m^3 (Hospital 3), 49 n/m^3 (Hospital 4), 146 N/m^3 (Hospital 5), and 53 N/m^3 (Hospital 6). Also, the t-test showed a statistically significant increase ($P_{value}<0.05$) in the concentration of MPs when the waste disinfection device was operating (71±22 N/m^3) compared to when it was off (13±3 N/m^3). In addition, the t-test analysis showed significant differences ($P_{value}<0.05$) in the concentration of MPs at 0 and 5 m distances from the disinfection device. The average concentrations at distances of 0, 5 and 10 m from the device were 71±22, 38±9 and 26±6 N/ m^3, respectively.

Disinfection units in Iranian hospitals usually operate under negative pressure ventilation systems with air exchange inside and outside the building. Most of these devices are equipped with shredding mechanisms to reduce the volume of waste, and the physical interaction between the shredding blades and plastic waste, as well as the laundry used in washing textiles and the way textiles are stored in the hospital, seems to be the main source of microplastic production. Consequently, hospital waste disinfection systems and textile washing and storage systems are known as important factors of microplastic pollution in indoor and outdoor air.

In the present study, the average concentration of atmospheric MPs in hospitals was 45±43N/ m^3, which is consistent with the result of a study conducted in Iran that measured an average concentration of MPs in indoor air of hospitals (29 N/m^3) [12]. There is a number of studies which reported the abundance of MPs in ranging from 0 to 282 n/m^3 [13-16]. This wide range of reported values is due to geographical differences in different regions, population structure (urban, rural, etc.), differences in meteorological variables (season, rainfall, etc.), sampling methods (including sampling height, sampling filter pore diameter, and particle size), and different preparation and analysis methods [17]. Also, The Mann-Whitney test showed no statistically significant difference in microplastic concentration between the two systems, indicating that the type of sterilization process (autoclaved or hydroclaved) did not have a significant impact on the release of MPs. Instead, the shredding system appears to be the main source of particle generation.

Physical properties of microplastic particles

Fig. 2 illustrates examples of MPs particles identified in this study. The average particle length was 34.93 µm, ranging from 4.77 to 274.68 µm. The length distribution followed a logarithmic pattern, with about 21.29% of the particles measuring between 10 and 20 µm, and 70.88% being smaller than 40 µm. These results are consistent with findings from previous studies [18-20]. Particles smaller than 100 µm have aerodynamic properties that allow them to remain suspended in the air and allow for long-range atmospheric transport. The presence of MPs in remote areas with minimal human activity, such as polar regions [21, 22] and remote mountainous areas [15, 23, 24], supports this conclusion. Particle size is an important consideration from a toxicological standpoint. While particles smaller than 10 µm are more likely to be inhaled, particles smaller than 5 µm can enter the lungs [25, 26]. Compared to bigger particles, smaller particles have a higher potential for health hazards and exhibit increased penetration and deposition in the human respiratory system [27, 28]. Smaller MPs may also have more detrimental consequences on health, according to toxicological research. In terms of particle morphology, the study discovered that 2% were granular, 3% were fragmented, and 95% were fibrous. Among MPs, the most prevalent color was black (70%), followed by red (21%), brown (4%), green (3%), and blue (2%). The distribution of hues is in line with earlier studies' findings, which showed that translucent, blue, red, green, and black were frequently seen [21] . However, it is crucial to not that environmental weathering processes, like UV light and chemical agents, have the ability to gradually alter MPs' color [20].

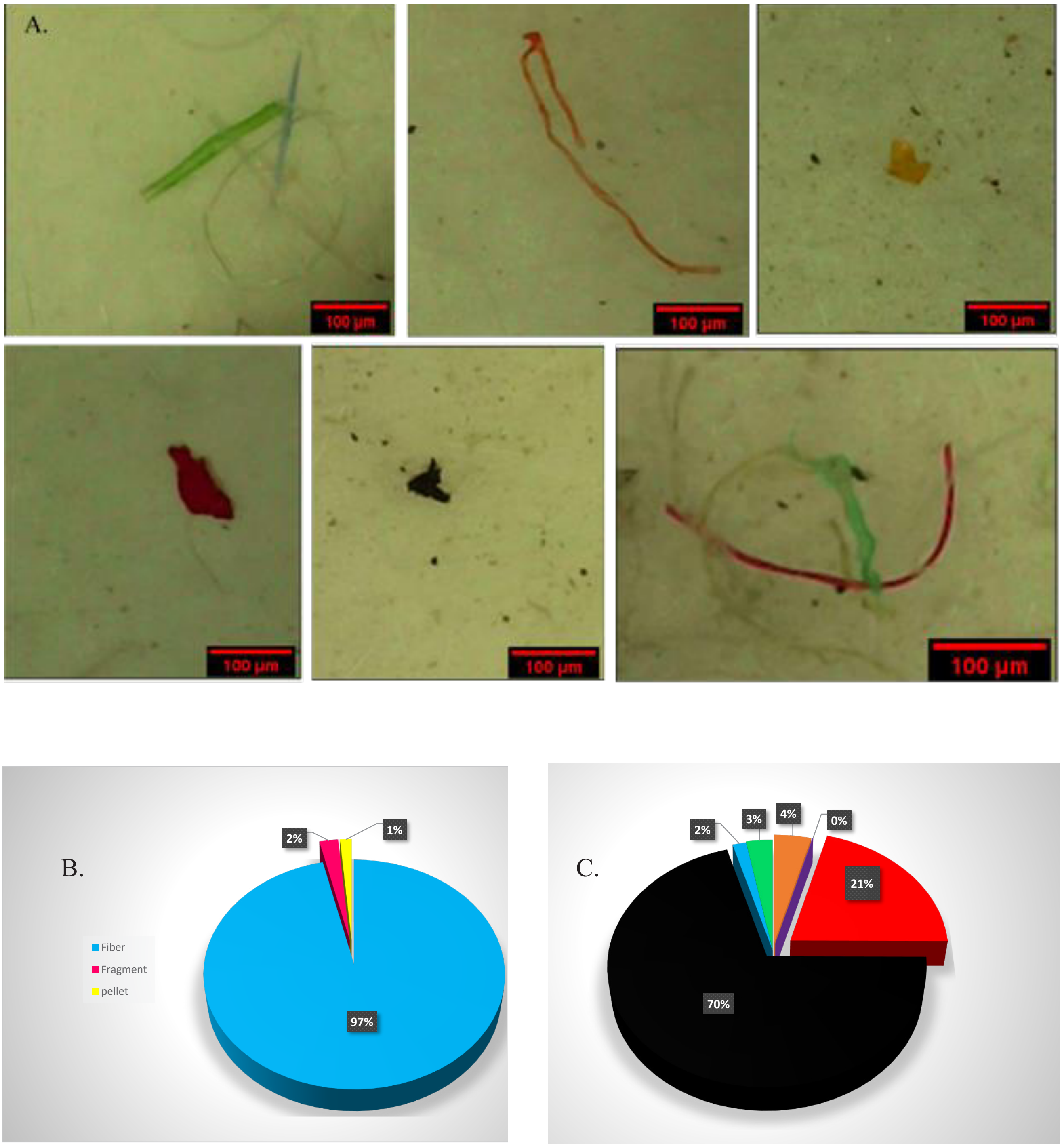

Fig. 2. Physical characteristics of microplastic particles within the hospital waste decontamination facility. A. Shape of selected microplastics identified in the study. B. Frequency distribution of the shapes of identified microplastic particles. C. Frequency distribution of the color of identified microplastic particles

A.

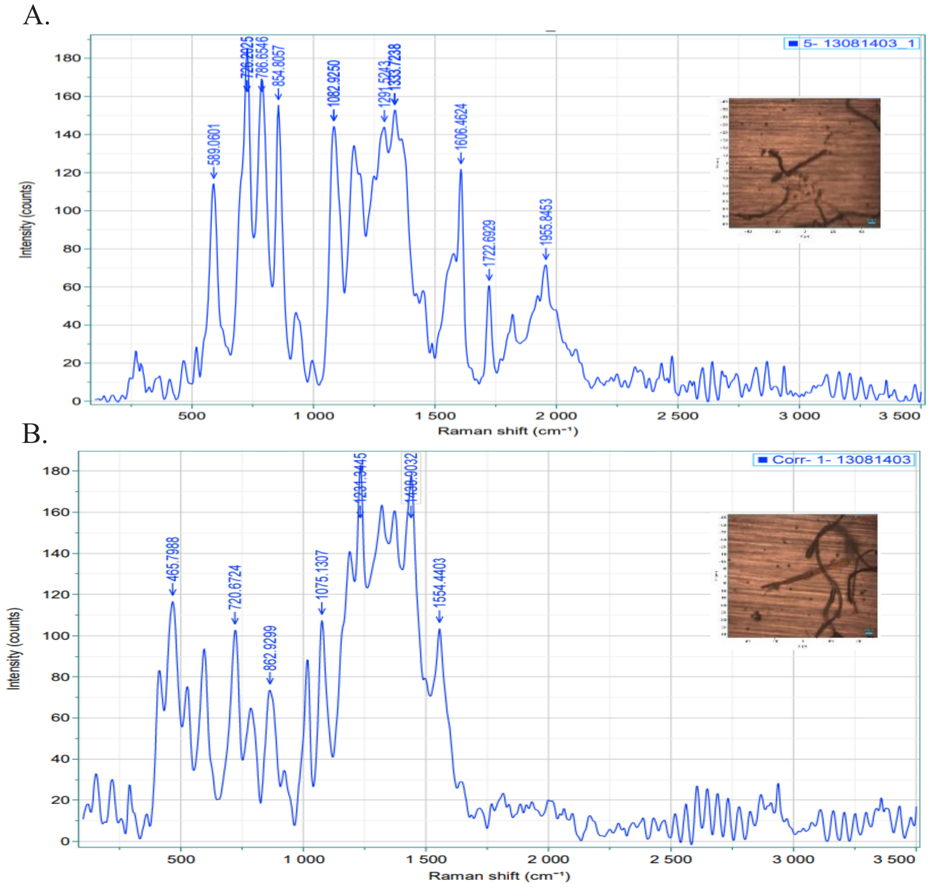

Fig. 3. Chemical characterization of microplastic particles using Raman microscopy spectroscopy. A. Spectrum from a black fibrous particle. B. Spectrum from a purple fibrous particle

Chemical characteristics of microplastic particles

The results obtained from the Raman microscopic spectroscopy analysis revealed the presence of polypropylene, polystyrene and polyvinyl chloride polymers in the air of medical waste disposal areas (Fig. 3). The spectroscopic results show that the MPs particles have undergone chemical weathering. Intense and moderate peaks in the 1000 cm^{-1} to 1500 cm^{-1} wavelength shift region are visible, corresponding to C-O, C=C, and C=O vibrations, which help identify the molecular structure of the polymer. Also, the C=O functional group indicates that the atmospheric microplastic particles have undergone chemical oxidation processes. Raman spectroscopy is a widely used technique for identifying and characterizing the polymeric composition of microplastic particles, offering significant insights into their chemical nature. From the standpoints of the environment and public health, it is essential to understand the polymeric composition of MPs. Polymeric composition can determine the origins of these particles and evaluate environmental fates of pollutants. MPs' mobility and environmental persistence are directly impacted by polymer characteristics like density and degradability. Furthermore, assessing the possible health hazards caused by MPs requires careful consideration of the nature of the polymers and the chemicals they include [22].

MPs are made up of different types of polymers. Common polymers include Polyethylene (PE), Polypropylene (PP), Polystyrene (PS), Polyvinyl Chloride (PVC), and Polyethylene Terephthalate (PET). Each of these polymers has different applications. For example, PE and PP are widely used in the production of packaging, while PET is used in the production of beverage bottles and textile fibers. Identifying the dominant polymer type in atmospheric MPs can provide clues about possible sources of contamination. In the present study, disposable medical equipment includes syringes, gloves, test tubes, blood and serum bags, catheters, surgical masks and gowns, as well as sterile packaging. Many medical devices and medications are used in sterile plastic packaging and plastic containers to store laboratory specimens, medications, and even patients' food, transportation equipment (trolleys, trays), Personal Protective Equipment (PPE): masks, face shields, gowns, and plastic gloves are used to protect medical staff and patients, which ultimately do not end up in the waste disposal department, and clothes and linens used by patients and staff that are sent to the laundry for washing are sources of microplastic emissions from hospitals.

The results of the current investigation are consistent with previous research on atmospheric MPs that verified the existence of a range of polymer compounds, such as nylon, polyethylene, polypropylene, polystyrene, polyvinyl chloride, and polyethylene terephthalate [15, 25, 26]. The literature has identified 19 different types of polymers, the most prevalent of which are Polyethylene (PE), Polyethylene Terephthalate (PET), Polypropylene (PP), Polystyrene (PS), and pPolyamide (PA) [27]. Inhaling MPs, especially those derived from polyethylene, has been linked to possible respiratory problems, such as respiratory tract irritation and discomfort. Additionally, the ability of polyethylene MPs to translocate and accumulate within internal organs remains an area of ongoing investigation, highlighting the need for further research into the long-term health effects of these particles [22, 28].

Conclusion

This study highlights hospital waste disinfection systems as previously overlooked sources of microplastic pollution in indoor and ambient air. The findings showed that the performance of waste disinfection devices, especially their shredding mechanisms, significantly contributes to the release of microplastic particles. The average concentration of MPs was higher when the devices were operating, and a significant decrease in concentration was observed with increasing distance from the source. The lack of significant differences between autoclaved and hydroclaved systems indicates that the type of disinfection process plays a minor role in the emission of MPs.

The physical properties of microplastic particles, including their predominantly fibrous shape and small size, indicate their potential for long-term suspension in the air and long-range atmospheric transport. This raises significant concerns about human exposure, particularly via inhalation, as smaller particles are more likely to penetrate deeper into the respiratory system and may pose higher toxicological risks. Disinfection units manage hazardous medical waste, but microplastic emissions pose environmental and health risks. Future research should explore alternative technologies and regulatory frameworks to control pollution and reduce risks to human health and the environment.

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Competing interests

The authors declare that they have no conflicts of interest.

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Ethics considerations

Ethical issues (Including plagiarism, Informed Consent, misconduct, data fabrication and/or falsification, double publication and/or submission, redundancy, etc) have been completely observed by the authors.

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