

# Environmental Toxicology and Pharmacology

## A review on the occurrence, analytical methods, and impact of microplastics in the environment

--Manuscript Draft--

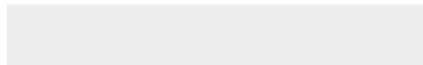
<b>Manuscript Number:</b>	ETAP-D-23-00415R2
<b>Article Type:</b>	VSI: Microplastic effects
<b>Keywords:</b>	microplastics; Occurrence; analytical methods; Health impact; Environmental Pollution
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<b>Abstract:</b>	<p>Nowadays, microplastic pollution is one of the globally urgent concerns as a result of discharging plastic products into the atmosphere, aquatic and soil environments. Microplastics have average size of less than 5 mm, are non-biodegradable, accumulative, and highly persistent substances. Thousands of tons of microplastics are still accumulated in various environments, posing an enormous threat to human health and living creatures. Here, we review the occurrence and analytical methods, and impact of microplastics in the environments including soil, aquatic media, and atmosphere. Analytical methods including visual observation, Fourier-transform infrared spectroscopy, Raman spectroscopy, scanning electron microscopy, and pyrolysis-gas chromatography-mass spectrometry were evaluated. We elucidated the environmental and human health impacts of microplastics with emphasis on life malfunction, immune disruption, neurotoxicity, diseases and other tangible health risks. This review also found some shortages of analytical equivalence and/or standardization, inconsistency in sampling collection and limited knowledge of microplastic toxicity. It is hopeful that the present work not only affords a more insight into the potential dangers of microplastics on human health but also urges future researches to establish new standardizations in analytical methods.</p>
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**July 8, 2023**

**Professor Michael D. Coleman**

**Editor in Chief**

***Environmental Toxicology and Pharmacology***

**Dear Editor,**

We are sending you the revised manuscript entitled

***“A review on the occurrence, analytical methods, and impact of microplastics in the environment”***

by Thuan Van Tran, A.A. Jalil, Tung M. Nguyen, Thuy Thi Thanh Nguyen, Walid Nabgan, Duyen Thi Cam Nguyen.

We addressed the remarks suggested by the reviewers in the revised manuscript. We are sending the requested files: “Response to Referees” file and the version of the revised manuscript.

Thank you very much for your approval!

We hope that the revised manuscript may be suitable for the publication on *Environmental Toxicology and Pharmacology*. We look forward to hearing from you at your earliest convenience.

Sincerely,

Thuan Van Tran

Corresponding author

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**Date:** July 8, 2023

**Professor Michael D. Coleman**

**Editor in Chief**

**Environmental Toxicology and Pharmacology**

**Re:** *Revision requested for ETAP-D-23-00415*

**Manuscript ID:** *ETAP-D-23-00415R2*

**Title of Paper:** ***A review on the occurrence, analytical methods, and impact of microplastics in the environment***

**Author(s):** Thuan Van Tran, A.A. Jalil, Tung M. Nguyen, Thuy Thi Thanh Nguyen, Walid Nabgan, Duyen Thi Cam Nguyen

**Journal:** *Environmental Toxicology and Pharmacology*

**Dear Professor Michael D. Coleman,**

We would like to express our gratitude for the Editor and Reviewer's efforts to improve the quality of our manuscript. We believe that our manuscript as a qualified paper in *Environmental Toxicology and Pharmacology*. We have tried our best to respond to all issues indicated in the review report fully. In the revised version, we have highlighted the changes to our manuscript using a bright green color. Here, we would like to address the reviewer's concerns as follows:

**Reviewer #2: The review entitled "A review on the occurrence, analytical methods, and impact of microplastics in the environment" reviewed the source, pollution status and analysis methods of MPs. The topic of this study is well and minor comments as below:**

**Our response:**

The authors sincerely thank your instructive comments!

The authors are very thankful for giving us the opportunity to revise this manuscript and answer your insightful questions.

We absolutely agree with you that the previous version of this manuscript is not enough good for publication and we are really sorry about some shortcomings raised by your critical comments.

Now, based on your constructive suggestions, we seriously worked to prepare a significantly modified revision with our highest effort with many additions and changes. We also hope that this revision can satisfy your reasonable requirements as well as high standards of the journal.

To help you easy to follow the possible changes in this revision, all corrections and/or modifications have been highlighted with **bright green color**.

Thank you so much!

**1) The novelty and importance of this study should be highlighted in the abstract section.**

**Our response:**

The authors sincerely thank your instructive comments!

We believe that your question is very reasonable! It is true that the importance of this study should be highlighted.

*Based on your kind suggestion, we revised the abstract as follows.*

“Nowadays, microplastic pollution is one of the globally urgent concerns as a result of discharging plastic products into the atmosphere, aquatic and soil environments. Microplastics have average size of less than 5 mm, are non-biodegradable, accumulative, and highly persistent substances. Thousands of tons of microplastics are still accumulated in various environments, posing an enormous threat to human health and living creatures. Here, we review the occurrence and analytical methods, and impact of microplastics in the environments including soil, aquatic media, and atmosphere. Analytical methods including visual observation, Fourier-transform infrared spectroscopy, Raman spectroscopy, scanning electron microscopy, and pyrolysis-gas chromatography-mass spectrometry were evaluated. We elucidated the environmental and human health impacts of microplastics with emphasis on life malfunction, immune disruption, neurotoxicity, diseases and other tangible health risks. This review also found some shortages of analytical equivalence and/or standardization, inconsistency in sampling collection and limited knowledge of microplastic toxicity. It is hopeful that the present work not only affords a more insight into the potential dangers of microplastics on human health but also urges future researches to establish new standardizations in analytical methods.”

Thank you so much!

**2. Introduction section should be improved and added some sentence about the environmental risks of MPs.**

**Our response:**

The authors sincerely thank your instructive comments!

We believe that your question is very reasonable! As your suggestion, we added a paragraph to show the environmental risks of microplastics.

*In detail, in page xx, lines xx-xx, we added the following paragraph:*

“Microplastics not only have negative impacts on terrestrial and aquatic animals but also combine with other toxins to cause synergistic effects in the environment (Koelmans et al., 2016). Considering microplastics as a transport vector, they can adsorb toxic chemicals such as persistent organic pollutants (Rodrigues et al., 2019), heavy metals (Sarkar et al., 2021), personal care products (Atugoda et al., 2021), pharmaceuticals (Wagstaff et al., 2022), antibiotics (Stapleton et al., 2023), printing dyes (Tubić et al., 2023), perfluoroalkyl substances (Mejías et al., 2023), pesticides (Sahai et al., 2023), insecticide (Zhou et al., 2023), etc. in wastewater and then transfer to aquatic species. Many studies evidenced that chemicals-loaded microplastics afford a higher toxicity than origin chemicals in various environments. For example, Verdú et al. (2023) reported that triclosan-adsorbed polyethylene microplastics caused a higher mortality against *Daphnia magna* adults than origin triclosan. The authors explained that microplastics biofouling in wastewater effluents exerted a stronger adsorption force on co-occurring triclosan. Sobhani et al. (2021) supplied a valuable proof of decreasing reproductive behavior in earthworms in the presence of perfluoroalkyl-loaded polyvinyl chloride microplastics. Researchers also found that this type of microplastic served as enhanced transport vector to transfer perfluoroalkyl substance to earthworms. Akhbarizadeh et al. (2021) investigated the role of fine particulate matter (PM<sub>2.5</sub>) as airborne carriers against polycyclic aromatic hydrocarbons (PAHs). This work found that adults inhaled 32.5–161.24 items of M2.5-bound PAHs per day, causing

potentially chronic health risks. It is important that the environmental and health risks of microplastics as a transport vector should be, therefore, evaluated.”

Thank you so much!

**3. The source of figure 1 and statistic data mentioned in this review should be added.**

**Our response:**

The authors sincerely thank your instructive comments!

We are really sorry that this important concern is not explained well in the main text. We are pleased to answer you as follows.

The data is collected herein based on results reported by all article articles that we found in previous works. Then, we use the statistical data for drawing figures (Figs. 1, 3).

Thank you so much!

**4. Quality of figures 4,5,7,9 should be improved.**

**Our response:**

The authors sincerely thank your instructive comments!

As your kind suggestion, we improved the quality of Fig. 4, 5, 7, 9.

Thank you so much!

**5. Conclusion should be further summarized and give the knowledge gap of current studies.**

**Our response:**

The authors sincerely thank your instructive comments!

As your kind suggestion, we improved the conclusion with addition of the knowledge gap of current studies as follows:

“Here, we systematically addressed the occurrence of microplastics in various environments including soil, aquatic media, and atmosphere. Airborne and aquatic microplastics were detected at very high concentrations. For the detection of microplastics, visual observation is widely applied for identification of large-size microplastics, while FTIR spectroscopy and SEM are reliable, but time-consuming and expensive techniques. The environmental impact of microplastics on aquatic species includes disruption of functions, productive toxicity, and neurotoxicity. Humans expose to microplastics through inhalation, ingestion and dermal contact pathways. Moreover, there is a limited understanding of microplastics toxicity to microorganisms, humans and animals in the past reports. There may be still a debate on whether microplastics can act as transport vectors to transfer toxic chemicals into living species. The current studies still have shortages of sample equivalence, standardization for analytical methods, inconsistent sampling of microplastics. To mitigate the release of microplastics into the environment, more regulations should be established. Our study also suggests that future research should have more insights into interaction mechanisms between microplastic particles and human tissues to minimize their effect in the environment.”

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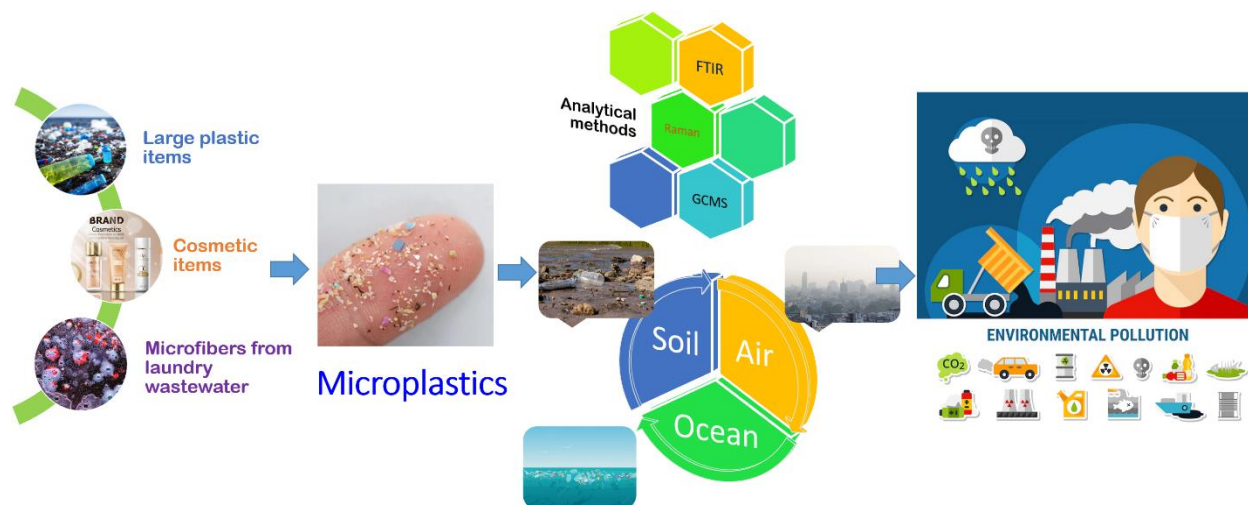
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- Occurrence, quantification and impacts of microplastics in the environment were reviewed
- Microplastics were found to be present widely in atmosphere and aquatic media at very high concentration
- Visual observation is the most widely used method to detect microplastics among techniques
- Microplastics potentially affect marine life malfunction, immune disruption, neurotoxicity, and tangible health risks

### **Author Contribution Statement**

*Thuan Van Tran*: Conceptualization, Writing – original draft; Writing – review & editing, Methodology, Investigation, Project management.

*A.A. Jalil*: English Editing, Writing – review & editing, Supervision.

*Tung M. Nguyen*: English Editing, Data curation.

*Thuy Thi Thanh Nguyen*: English Editing, Data curation.

*Walid Nabgan*: English Editing, Data curation; Writing – review & editing.

*Duyen Thi Cam Nguyen*: English Editing, Writing – original draft; Writing – review & editing, Methodology, Investigation

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4 **A review on the occurrence, analytical methods, and impact of microplastics**  
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24 **Abstract**

25           Nowadays, microplastic pollution is one of the globally urgent concerns as a result of  
26 discharging plastic products into the atmosphere, aquatic and soil environments. Microplastics  
27 have average size of less than 5 mm, are non-biodegradable, accumulative, and highly persistent  
28 substances. Thousands of tons of microplastics are still accumulated in various environments,  
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36 analytical equivalence and/or standardization, inconsistency in sampling collection and limited  
37 knowledge of microplastic toxicity. It is hopeful that the present work not only affords a more  
38 insight into the potential dangers of microplastics on human health but also urges future researches  
39 to establish new standardizations in analytical methods.

40 **Keywords:** Microplastics; occurrence; analytical methods; health impact; environmental  
41 pollution.

# 1. Introduction

Since human demands on food, clothing, personal care, and recreation are increasingly high, a huge amount of plastics are produced to meet these demands. According to statistic data, about 3 million tons of plastic is yearly produced, and a majority of this number has been become plastic waste (Chen et al., 2020). Nowadays, plastic pollution is one of the globally urgent concerns. Under exposure to many factors such as ultraviolet radiation, weathering and mechanical abrasion, plastic wastes entering the environment can be gradually degraded into smaller plastic particles, or microplastics (Shim et al., 2017). Microplastics have a size of less than 5 mm, are a major contributor to globally environmental pollution. Scientists have projected that the percentage of microplastics over the total pollutants will account for 13.2% by 2060 (Sharma et al., 2021). More seriously, microplastics have already been detected in various environments such as soil, atmosphere, ocean, drinking water, and creatures such as natural fish, and even human organs and tissues (Jiang, 2018; Ragusa et al., 2021). As a result, the occurrence, qualification, and impact of microplastics in the environment are of significant interest.

Microplastics not only have negative impacts on terrestrial and aquatic animals but also combine with other toxins to cause synergistic effects in the environment (Koelmans et al., 2016). Considering microplastics as a transport vector, they can adsorb toxic chemicals such as persistent organic pollutants (Rodrigues et al., 2019), heavy metals (Sarkar et al., 2021), personal care products (Atugoda et al., 2021), pharmaceuticals (Wagstaff et al., 2022), antibiotics (Stapleton et al., 2023), printing dyes (Tubić et al., 2023), perfluoroalkyl substances (Mejías et al., 2023), pesticides (Sahai et al., 2023), insecticide (Zhou et al., 2023), etc. in wastewater and then transfer to aquatic species. Many studies evidenced that chemicals-loaded microplastics afford a higher toxicity than origin chemicals in various environments. For example, Verdú et al. (2023) reported

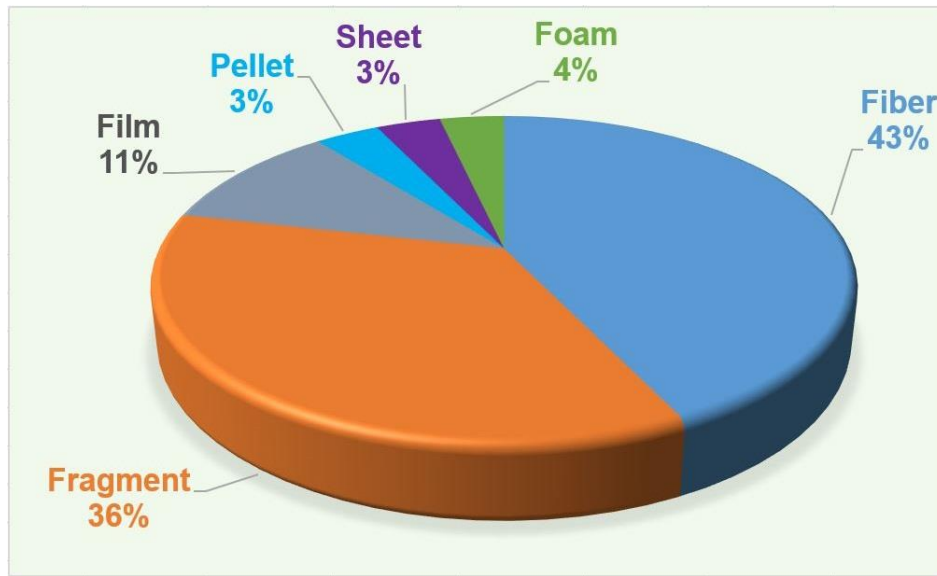
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4 65 that triclosan-adsorbed polyethylene microplastics caused a higher mortality against *Daphnia*  
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11 68 [\(2021\)](#) supplied a valuable proof of decreasing reproductive behavior in earthworms in the  
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24 73 inhaled 32.5–161.24 items of M2.5-bound PAHs per day, causing potentially chronic health risks.  
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26 74 It is important that the environmental and health risks of microplastics as a transport vector should  
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29 75 be, therefore, evaluated.

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32 76 Several qualification methods such as visual detection, Fourier transform infrared  
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34 77 spectroscopy (FTIR), Raman spectroscopy, scanning electron microscopy (SEM), and pyrolysis-  
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36 78 gas chromatography-mass spectrometry have been developed to detect microplastics in the  
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39 79 environment ([Prata et al., 2019](#)). However, there are many concerns about pros and cons that needs  
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41 80 to mentioned. Therefore, this review supplies state of the art findings of recently published studies.  
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44 81 The structure of the review to *(i)* focus on the classification and property of several common  
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46 82 plastics; *(ii)* examine the occurrence of microplastics in the environments such as atmosphere,  
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49 83 aquatic environment, and soil; *(iii)* discuss several qualification methods for detection of  
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51 84 microplastics; *(iv)* evaluate two aspects of environmental and health impacts. We also suggest  
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54 85 some challenges and future direction for the next studies.

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5 86 **2. Classification, source and occurrence of microplastics**  
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8 87 **2.1. Classification of microplastics**  
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12 88 Microplastics can be divided into two major types including primary and secondary  
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14 89 microplastics. Primary microplastics are very small particles using for commercial purposes.  
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16 90 Meanwhile, secondary microplastics are degraded products derived from the breakdown of larger  
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18 91 plastics due to exposure under some harsh conditions such as ultraviolet radiation from sunlight  
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20 92 wave action, and wind abrasion (Shen et al., 2020). To be more specific, Fig. 1 illustrates the  
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22 93 statistical data analysis from previous works showing the proportion of microplastics in the  
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24 94 environment. Accordingly, the percentage of fiber and fragment accounts for nearly 80%.  
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58 96 **Fig. 1.** Statistical data from previous works on the proportion of microplastics (fiber, fragment,  
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60 97 film, foam, pellet, sheet) in the environment.  
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65 98 Microbeads are derived from personal care products and plastic pellets. They are used for  
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67 99 industrial manufacturing. Plastic fibers are used for synthetic textiles and fishing nets. There are

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several common examples of primary microplastics such as polyethylene (PE), polypropylene (PP), polyvinyl chloride (PVC), polystyrene (PS), polyester (PE), polyamide (PA), polyaryonitrile (PAN), polyethylene terephthalate (PET), polyphthalamide (PPA), polycarbonate (PC) and poly(methyl methacrylate) (PMMA) (Fig. 2).

- Polyethylene (PE): Among widely used plastics, PE is the most common plastic in the world. This polymer is thermoplastic with a chemical formula  $(C_2H_4)_n$ . In fact, it can be modified by cross-linked with other polymers to create a thermoset plastic having many applications. PE has a range of mechanical properties which depend majorly on the extent and type of branching, crystallinity and molecular mass. Geyer et al. estimated that over 100 million tons of polyethylene resins are produced annually, accounting for 34% of the total plastics market as of 2017 (Geyer et al., 2017a). According to statistic data, the PE derived microplastics are the most common composition (20%) of microplastics detected in the environment. The widespread presence of PE plastics may be because they are inexpensively produced and have been using in packaging film, trash and grocery bags, and many housewares for a long time.

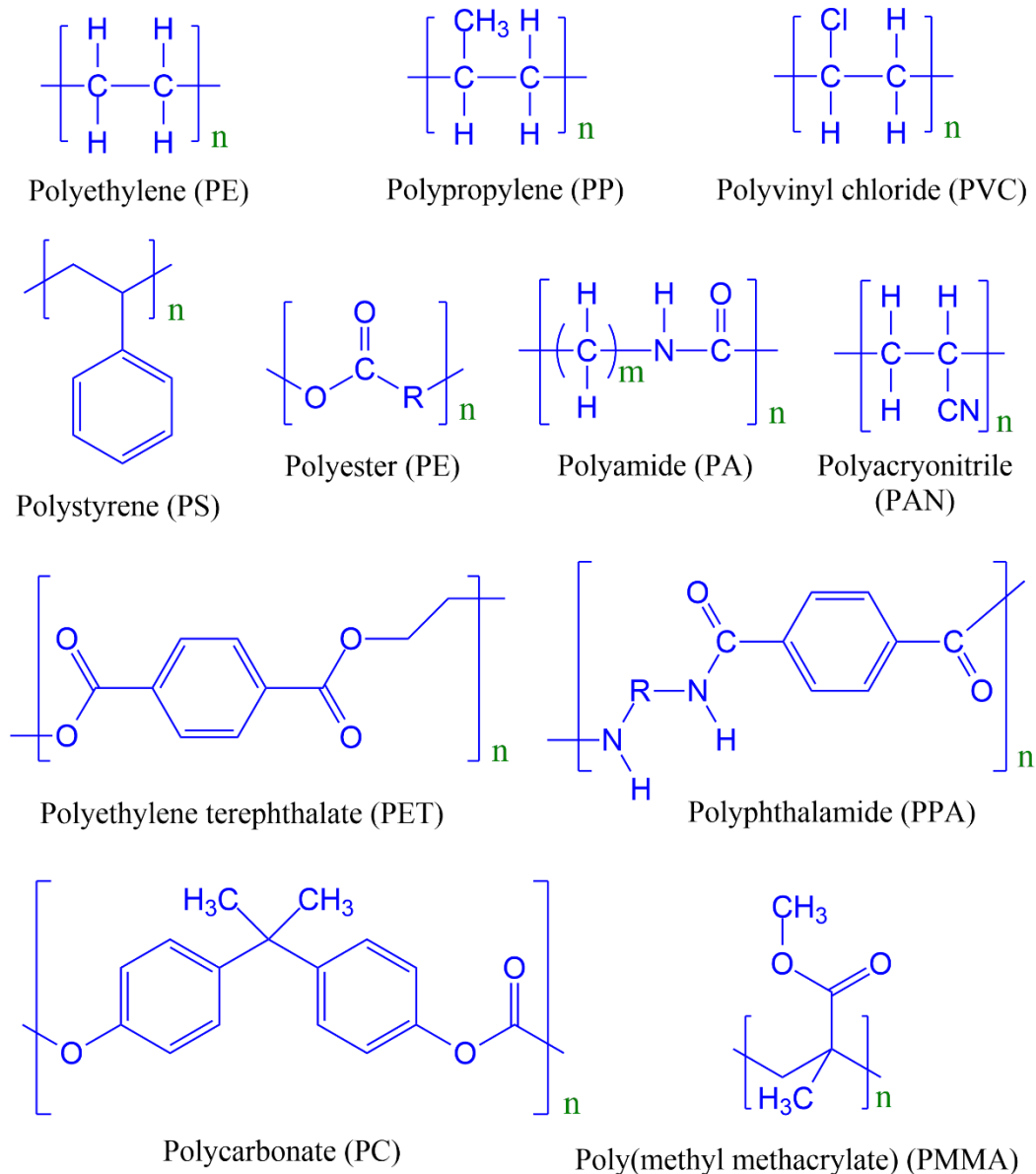
- Polypropylene (PP): this plastic is a synthetic resin produced through the polymerization of propylene monomer. Similar to PE, this polymer is also a thermoplastic with a chemical formula  $[-CH_2-CH(CH_3)-]_n$ . As a polyolefin resin, PP can be molded or extruded into many plastic products depending on flexibility, toughness, weight, heat resistance, etc. PP plastics have been widely using in many products such as ropes, tapes, carpets, and clothing. It is estimated that the global demand for polypropylene exceeds many thousand tons, where Asia accounts for half of polypropylene amount. As a result, the presence of polypropylene microplastic particles has commonly found in soils, rivers, cannels, etc.

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123 According to Fig. 3, the composition of microplastics based on statistical data analysis  
124 from previous works showing that PP have been commonly detected in the environment.

125 ■ Polyvinyl chloride (PVC): PVC was firstly synthesized in 1872 by German chemist Eugen  
126 Baumann. In his experiment, vinyl chloride gas a sealed tube was exposed under sunlight  
127 and polyvinyl chloride was produced as a white solid. From there, PVC has been become  
128 one of the widely used plastic in the world. Many technologies have also applied to  
129 optimize the production of polyvinyl chloride and reduce its by-products (Asadinezhad et  
130 al., 2012). This polymer is typically a synthetic resin having chemical formula  $(C_2H_3Cl)_n$ .  
131 It is estimated that about 40 million tons of polyvinyl chloride are produced annually. There  
132 are two major kinds of PVC, including rigid and flexible types. Polyvinyl chloride has  
133 valuable properties such as electric insulation, durability, flame retardancy, chemical and  
134 heat resistance. Therefore, PVC is a main component in the manufacturing of pipes,  
135 medical devices, electric wires, and cable insulation.

136 ■ Polymethyl methacrylate (PMMA): this plastic is a synthetic product of polymerization of  
137 methyl methacrylate ( $CH_2=C[CH_3]CO_2H$ ). Polymethyl methacrylate was firstly developed  
138 in 1928 by many scientists. This polymer is transparent and rigid, often called “engineering  
139 plastics”, and used as a substitute for glass, involving optical devices, shatterproof  
140 windows, skylights, and aircraft canopies. Polymethyl methacrylate has many important  
141 properties such as good tensile and flexural strength, high transparency, UV tolerance.



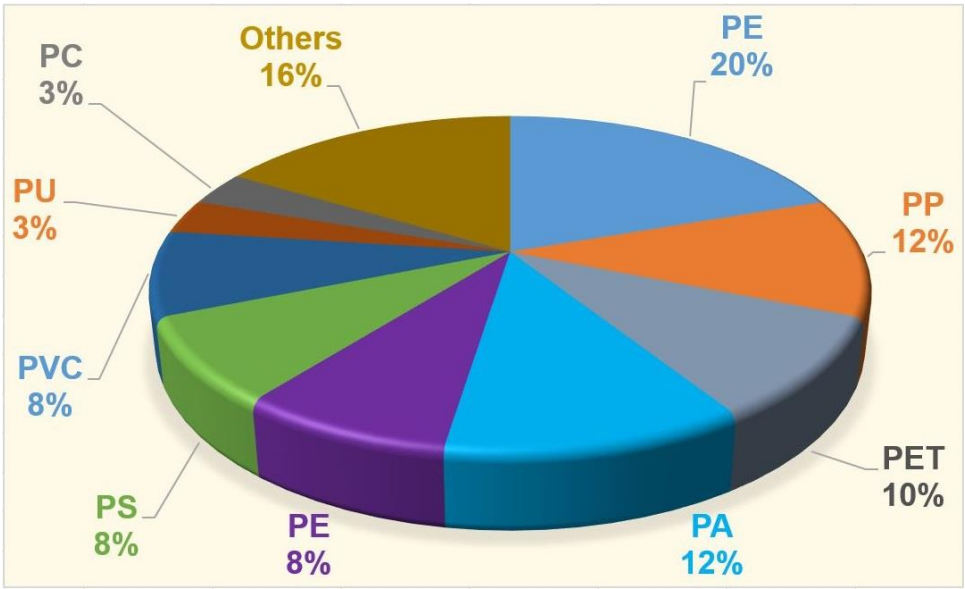
**Fig. 2.** Molecular structure of several common microplastics including polyethylene (PE), polypropylene (PP), polyvinyl chloride (PVC), polystyrene (PS), polyester (PE), polyamide (PA), polyaryonitrile (PAN), polyethylene terephthalate (PET), polyphthalamide (PPA), polycarbonate (PC) and poly(methyl methacrylate) (PMMA).

Secondary microplastics can come from the breakdown of water bottles or nylons, etc. Release of primary microplastics from mentioned sources to the environment can undergo through

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149 various channels such as discharging of personal care products from households, and laundering  
150 of clothing made from synthetic textiles (Khadir et al., 2022). There is still limited knowledge of  
151 degradation mechanism of primary microplastics into secondary microplastics. As emerging  
152 pollutant, however, both primary and secondary microplastics cause harmful effects on the  
153 environment and human health.

154 Chemically, almost microplastics consist of two main elements including carbon and  
155 hydrogen in their polymeric structure. Other known chemicals, such as phthalates, polybrominated  
156 diphenyl ethers, polyvinyl chloride, and tetrabromobisphenol A can contain bromide, chlorine, and  
157 oxygen. Moreover, chemical additives in microplastics with the purpose of mechanical  
158 enforcement or thermal resistance are typically present in microplastics. They can leach out of the  
159 microplastics after discharge into the environment, causing many negative effects. The properties  
160 of microplastics can be optically characterized by color, shape, size, transparency, etc. (Table 1).  
161 For their size, there is a range of MPs size between 1  $\mu\text{m}$  and 5000  $\mu\text{m}$ .



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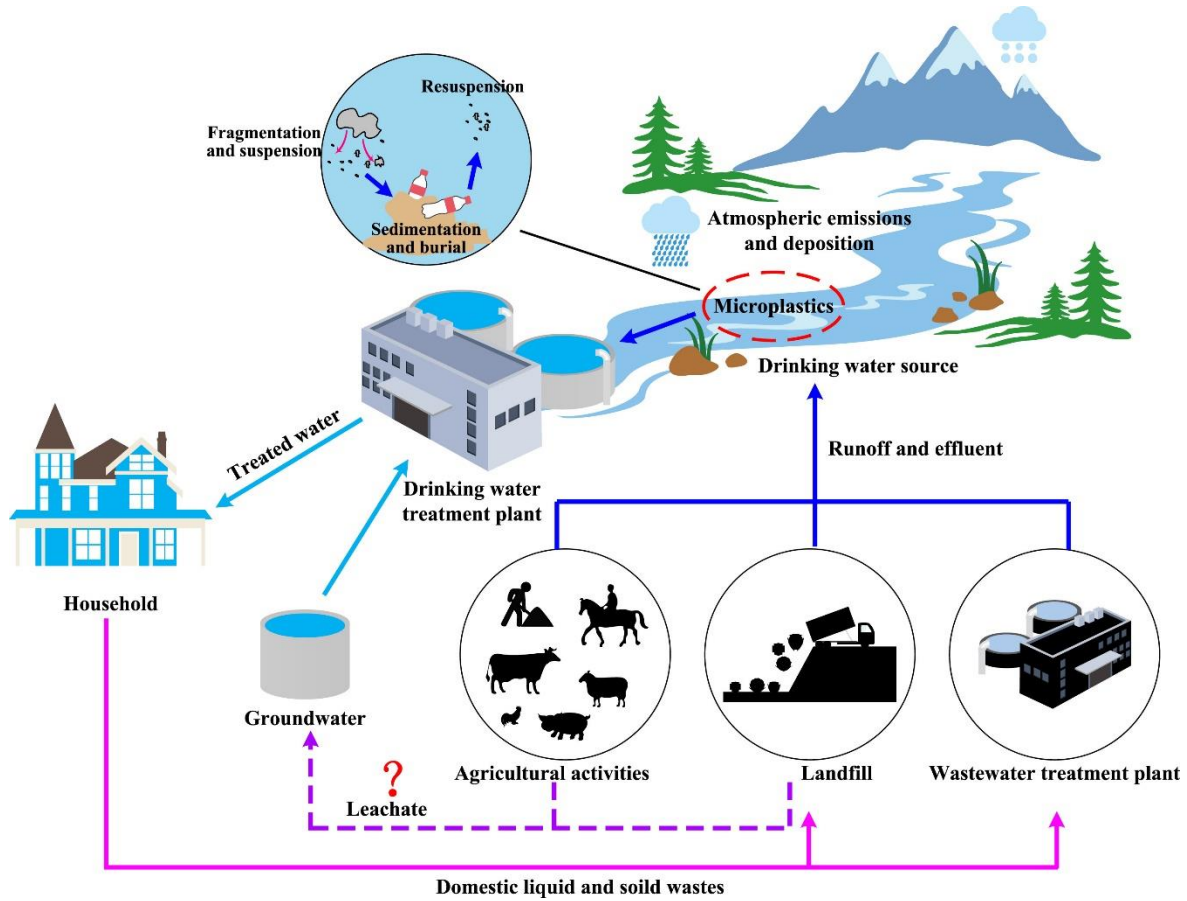
**Fig. 3.** Statistical data from previous works on the composition of microplastics detected in the environment.

**2.2. Source of microplastics**

Microplastics are small or very small pieces of plastics, with size of between 1  $\mu\text{m}$  and 5000  $\mu\text{m}$ . In general, they appear in the environment as a result of plastic pollution. Nowadays, the pollution of microplastics is globally occurred with a wide variety of primary products, from personal care products and cosmetics to synthetic textiles, clothing, plastic bags or bottles. Such products enter the environment through various channels such as municipal households, hospital wastewaters, human activities, and agricultural activities. Although wastewater treatment plants can be partially treated microplastics, the effluents are still present in almost sites such as rivers, seas, atmosphere, chemosphere all over the world (Fig. 4).

Primary products are a main contributor to microplastics pollution. However, after the time eluting in the environment, primary microplastics are gradually degraded as a consequence of photodegradation, thermo-degradation, biodegradation into smaller particles in the form of fragments, pellets, microbeads and fibers. For example, Strady et al. observed the abundant presence of fibrous microplastics in 21 aquatic environments such as rivers, lakes, bays, and beaches in Vietnam (Strady et al., 2021). Meanwhile, Wang et al. reported that microplastics with size of 52–5,392  $\mu\text{m}$  has a range of shapes such as fiber, fragment, and pellet, which were originated from polyethylene, polypropylene, polyethylene terephthalate (F. Wang et al., 2021). At the same trend, Piehl at al. found the presence of film and fragment shaped microplastics from degraded products of polyethylene, polystyrene, polyvinyl chloride, polyethylene terephthalate (Piehl et al., 2018). Moreover, many works reported the unintentional pollution from microplastics

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4 185 as a result of human activities (Hartline et al., 2016; Kole et al., 2017). The source of these  
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6 186 microplastics pollutions can come from recreation and tourism activities such as fishing.  
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41 188 **Fig. 4.** Occurrence and transport of microplastics in the environment. Reproduced from the  
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43 reference (Shen et al., 2020) with permission of Elsevier. Copyright © 2020, Elsevier.  
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47 190 **2.3. Occurrence of microplastics in the environment**

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50 191 **2.3.1. Microplastics in the atmosphere**

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54 192 With the rapid development of transportation vehicles and industries, the pollution of  
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56 193 microplastics in the atmospheric environment has become serious. The source of atmospheric  
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58 194 microplastics can come from release of plastic dusts of traffic activities and plastic industries.  
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195 Among atmospheric microplastics, fine particulate matter (PM<sub>2.5</sub>) with size of 2.5 micrometers  
196 and smaller is emerging as a major air contaminant. PM<sub>2.5</sub> are very small particles in the air, and  
197 thus, it is very hard to prevent their impacts. The presence of PM<sub>2.5</sub> in air reduce the visibility, and  
198 makes human respiratory system more vulnerable (Xing et al., 2016). As a result, PM<sub>2.5</sub> is really a  
199 concern for human health.

Airborne microplastics easily transport in indoor and outdoor air due to their low density  
and small size (Prata, 2018a). Wind, pressure change and other weather factors can affect the  
movement of microplastics in air. Dris et al. (2016) estimated that 29% of the fibers in atmospheric  
fallout derived from petrochemicals in Paris, France. Atmospheric fallout of fibers was found  
higher at more urban sites. At the same trend, Wright et al. (2020) detected fifteen different  
petrochemical-based polymers in airborne indoor and outdoor in London, UK. Fibrous  
microplastics accounted for 92% and a density of 575–1,008 particles m<sup>-2</sup> day<sup>-1</sup>, which 20 times  
higher than that in remote area. The presence of plastic fibers( 0.6–3.3 m<sup>-3</sup>) and plastic fragment  
(5.6–12.6 m<sup>-3</sup>) in coastal California, USA was recorded in a recent study (Gaston et al., 2020).

A number of publications demonstrated that several hazardous pollutants, e.g., heavy metal  
dusts, coal dust, etc. can be adsorbed onto the microplastics, and subsequently enter the human  
body through inhalation (Huang et al., 2021; Kalčíková et al., 2020; Waring et al., 2018; Yang et  
al., 2022). In that case, microplastics act as carrier of these hazardous contaminants. Upon the  
effect of weather factors such as wind, hazardous contaminants-loaded microplastics are likely to  
distribute around various geographical regions. In the suitable condition, they can release toxic  
substances or aggregate in biota (Fu et al., 2021). Therefore, the presence of microplastics in the  
atmosphere needs to be diagnosed, detected and controlled properly.

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### 217 2.3.2. *Microplastics in aquatic environment*

218 The presence of microplastics in the aquatic environment has been known for a long time.  
219 The major source of water contaminant by microplastics is discharging of polymeric household  
220 products such as food packaging and preservation plastics (e.g., nylons), personal care products  
221 (e.g., hair spray), etc. [Jiang \(2018\)](#) estimated that household plastics have been increasingly  
222 discharged from the aquatic media between 5,000 and 80,000 tons. [Strady et al. \(2021\)](#) found the  
223 abundance of fibrous microplastics (0.35–2,522 items m<sup>-3</sup>) in sediments, and surface waters.  
224 Meanwhile, [Wang et al. \(2020\)](#) screened the presence of microplastic fibers and fragments by  
225 stereo-microscope in Beijiang River, China. They found a large density of aquatic microplastics  
226 (3,183–10,950 items m<sup>-3</sup>).

227 As a pollutant, microplastics can be detected in creature body because they digest  
228 microplastics as food. Even, [Li et al. \(2021\)](#) suggested that aquatic species (e.g., natural fishes)  
229 ingest microplastics unintentionally through their breathing, and capture microfibers was rejective  
230 behavior. As a result, microplastics enter the fish body, and indirectly transport through the food  
231 chains. At the same trend, [Vivekanand et al. \(2021\)](#) concluded that aquatic lives feed microplastics  
232 in aquatic media and ecological risks is very serious. It is proposed that establishing global  
233 collaboration, effective policies as well as control strategies to mitigate the discharge of  
234 microplastics into aquatic media are very urgent.

### 235 2.3.3. *Microplastics in soil*

236 Microplastics present in soil are stored, translocated, and degraded into secondary  
237 microplastics, which can leach out groundwater sources. [He et al. \(2018\)](#) suggested that soil biota  
238 can influence the accumulation and fate of microplastics. It was reported that microplastics

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4 239 strongly affect the physicochemical and biological properties of soil. Indeed, they can change the  
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7 240 soil microbial communities and soil functions (Guo et al., 2020). Many works also demonstrated  
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9 241 negative impacts of microplastics on seed germination and plant growth (Huang et al., 2022; F.  
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12 242 Wang et al., 2020; B. Xu et al., 2020). Depending on plastic type, size, and content, influence of  
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14 243 microplastics on soil and soil organisms can be varied.

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17 244 Moreover, Zhang and Liu (2018) compared the concentration of microplastics between  
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20 245 cropped and buffer soils by visual detection, finding that plastic fibers, fragments, and films were  
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22 246 mostly present in soil with concentration of 7,100 and 12,200 particles  $\text{kg}^{-1}$ , respectively.  
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24 247 Furthermore, Rafique et al. (2020) investigated soils from agricultural areas, drains, and dumping  
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27 248 sites in Lahore, Pakistan. The results showed that microplastics were present in soil at very  
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29 249 concentration (42,960–71,750 particles  $\text{kg}^{-1}$ ). They explained that rapid urbanization and  
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32 250 extensive use of plastic products could be potential contributors to microplastics pollution in soil.  
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34 251 At the same trend, many microplastics originated from acrylic, polyester, nylon, and polyvinyl  
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37 252 chloride were found in agricultural soil in Mellipilla, Chile (Corradini et al., 2019). It is suggested  
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39 253 that strict regulations should be implemented to prevent plastic pollution and protect soil resources.  
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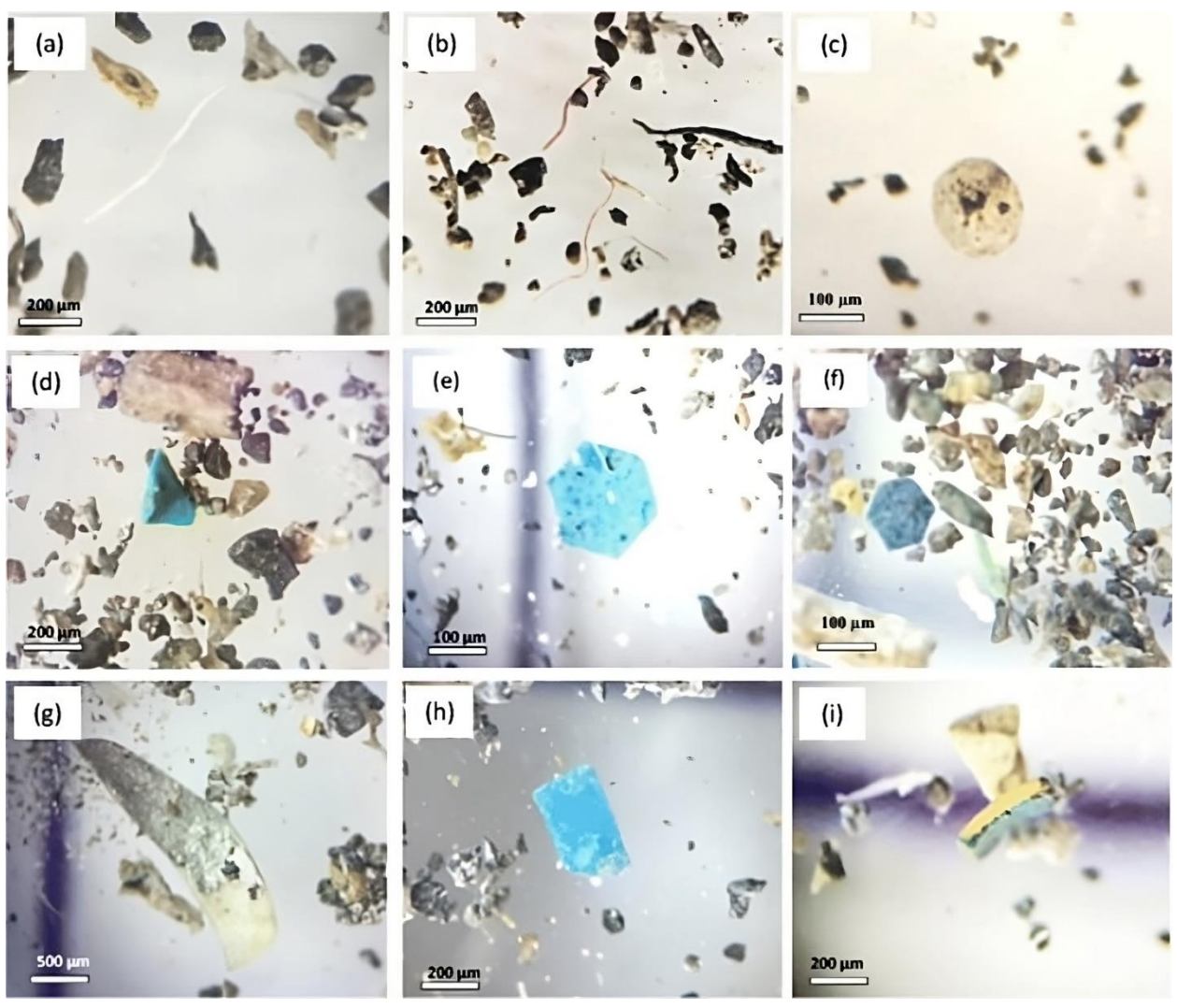
### 42 254 **3. Analytical methods of microplastics**

#### 43 255 **3.1. Visual observation**

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50 256 Visual observation is widely applied for microplastics identification because it does not  
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52 257 require complex technique and high cost inspection. This observation is based on the properties of  
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55 258 particle size, shape, color, surface and transparency (Shim et al., 2017). To be more specific, Fig.  
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57 259 5 illustrates the particle size, shape, color, surface and transparency of the microplastics under  
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60 260 visual observation. In general, the observer will record the color covering the surface of  
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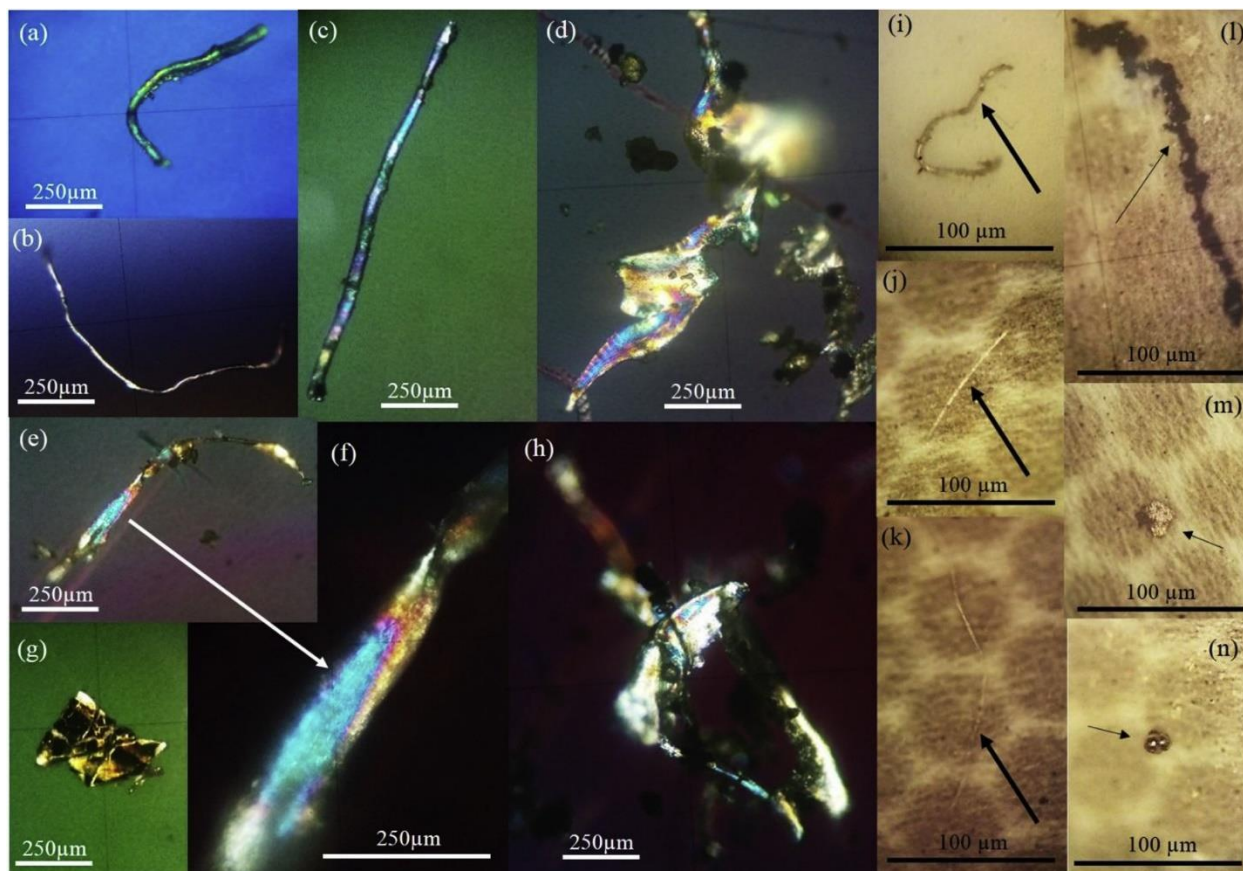
261 microplastics. Nowadays, with the advent of stereomicroscope technique, the visualization  
262 methods become reliable and simple (Song et al., 2015). In this case, microplastics from the  
263 prepared samples can be directly seen under an optical microscope, resulting in a low cost of  
264 measurement.



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266 **Fig. 5.** Optical microscope images of microplastics such as (a) transparent fiber, (b) red fiber, (c)  
267 transparent sphere, (d) green granule, (e, f) blue hexagonal fragments, (g) white granule covered  
268 with silver shiny film, (h) blue granule, and (i) sample of microplastics fragments. Reproduced

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4 269 from the reference (Dehghani et al., 2017) with permission of Springer Nature. Copyright © 2017,  
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10 271 However, the biggest disadvantage of optical microscope is that the samples can be only  
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12 272 detected at a large size of higher 500  $\mu\text{m}$  (Chen et al., 2020). Otherwise, large errors can be  
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14 273 received due to the subjectivity of the examiner. It is suggested that visual observation should be  
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16 274 combined with fluorescence techniques for better detection of microplastics. Indeed, other  
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18 275 microscopic techniques such as fluorescence, and polarized light can give high resolution images  
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20 276 of microplastics with small sizes. For example, microplastics and microrubbers in air and street  
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22 277 dusts from urban sampling site can be clearly detected by polarized-light microscopic images as  
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27 278 shown in Fig. 6.



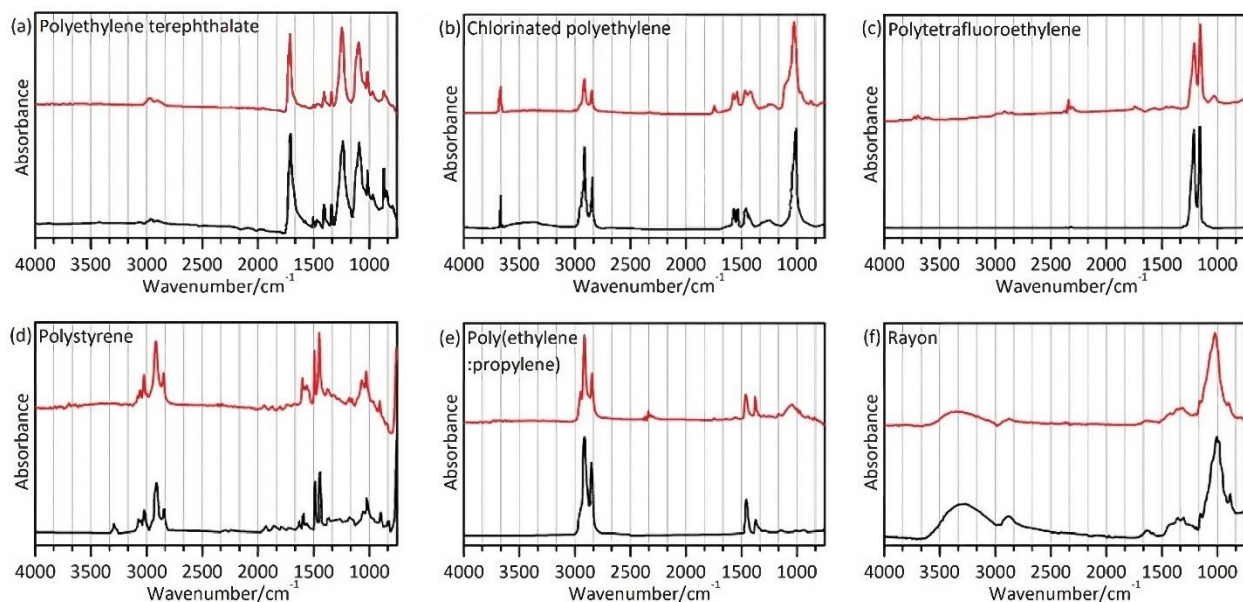
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**Fig. 6.** Polarized-light microscopic images of (a-c) microplastic fibers (d-f, h) film-like microplastics, (g) a fragmented microplastic, (i-k) microplastic fibers, (l) fibrous microrubbers, (m-n) metallic particles in air filter. Reproduced from the reference (Abbasi et al., 2019) with permission of Elsevier. Copyright © 2019, Elsevier.

### 3.2. Fourier transform infrared spectroscopy

Apart from visual inspection, Fourier transform infrared (FTIR) spectroscopy is one of the most widely used technique to detect the presence of polymeric structure of microplastics (Veerasingam et al., 2021). This technique supplies information about the chemical bonds as well as footprints which aid to diagnose a type of microplastics. With a spectrum obtained from FTIR, a chemical formula can be automatically suggested based on spectral library of known substances. This technique is considered as highly reliable, but it can lack of accuracy and require many trial with microplastics with very small size ( $< 50 \mu\text{m}$ ) (Shim et al., 2017). In that case, FTIR can be replaced with a micro FTIR spectroscopy to ensure levels of acceptable accuracy. With microplastics having larger particle size ( $> 500 \text{nm}$ ),  $\mu$ -ATR-FTIR is more preferable and rapid (Käppler et al., 2018). As an example, Fig. 7 shows an example of FTIR technique for identification of microplastics and spectra from the Sadtler Library (bottom, black color) as references.

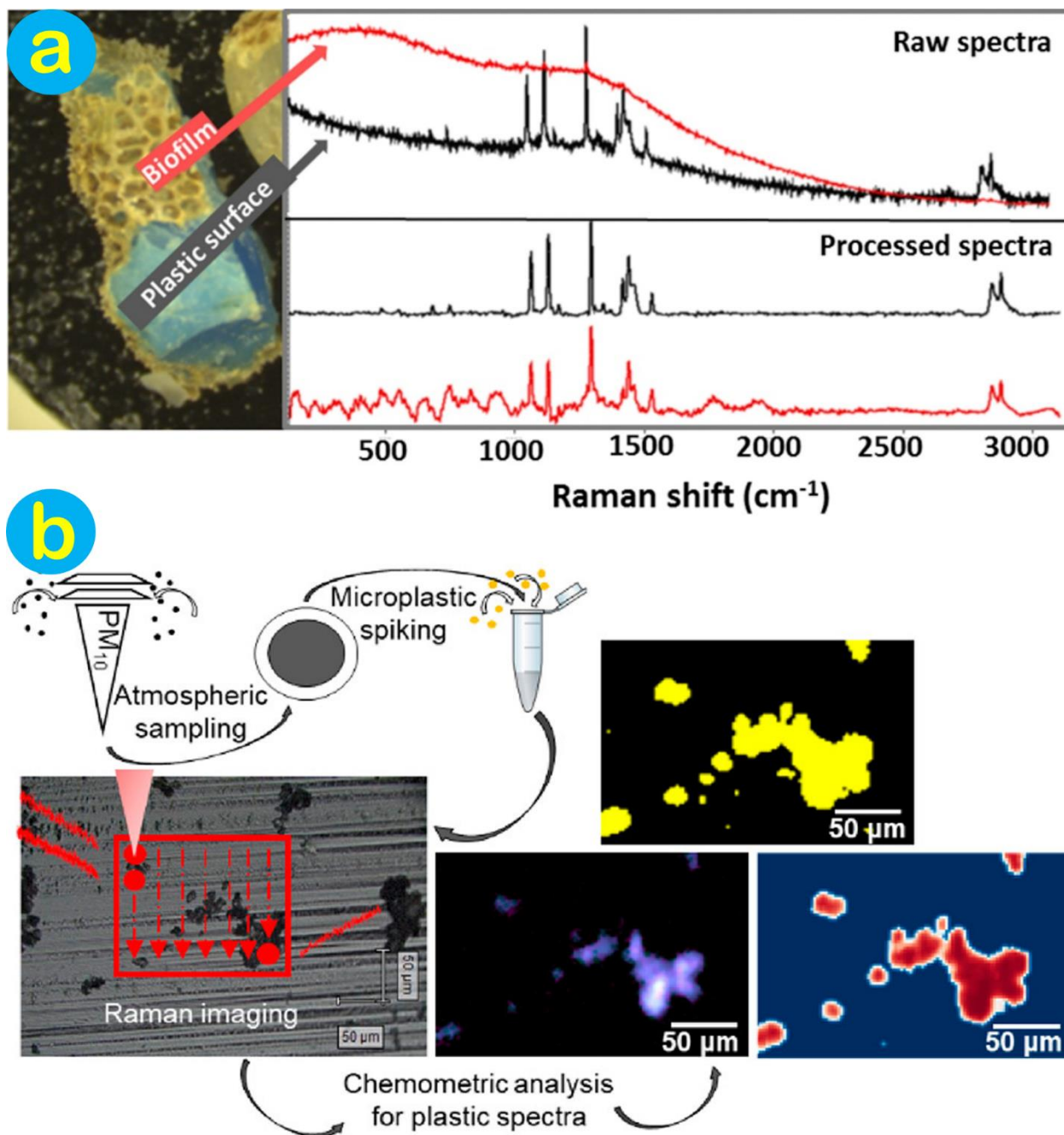
Other state of the art techniques such as FPA-FTIR are used to screen almost type of current microplastics on a filter paper. However, airborne microplastics may not be a suitable subject to be detected by both ATR-FTIR and FPA-FTIR due to their tiny size ( $< 5 \mu\text{m}$ ) (Primpke et al., 2017). Moreover, the spectra of FTIR technique can be strongly noised because of impurities covering on the surface of microplastic particles. As a result, a careful pretreatment of the sample



**Fig. 7.** An example of FTIR technique for identification of microplastics (top, red color) and spectra from the Sadtler Library (bottom, black color) as references. Microplastics includes (a) polyethylene terephthalate, (b) chlorinated polyethylene, (c) polytetrafluoroethylene, (d) polystyrene, (e) poly(ethylene propylene), (f) rayon. Reproduced from the reference (Ding et al., 2019) with permission of RSC Publishing. Copyright © 2019 RSC Publishing.

### 3.3. Raman spectroscopy

This method is widely used to detect the presence of microplastics in different media. Laser beams are excited to irradiate into the target sample. The reflection signals are recorded to determine the frequency shift. Each of different chemical gives different frequency shifts (Fig. 8a).



316  
 317 **Fig. 8.** (a) Raman spectra of a trawl (polyethylene) particle with biofilm covering. Reproduced  
 318 from the reference (Ghosal et al., 2018). with permission of Elsevier. Copyright © 2018, Elsevier.  
 319 (b) An illustration of Raman spectral imaging combined with chemometric analysis for detection  
 320 of both virgin and environmental microplastics. Reproduced from the reference (Levermore et al.,  
 321 2020) with permission of ACS. Copyright © 2020, American Chemical Society.

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4 322 Raman techniques only requires a small amount of sample, but supplies reliable  
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7 323 information about the molecular structure. With microplastics having particle size of less than  
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9 324 1000  $\mu\text{m}$ , Raman spectroscopy is a suitable choice (Lenz et al., 2015). Even, Araujo et al. (2018)  
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11 325 suggested that Raman spectroscopy could give an automated mapping and library matching of tiny  
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14 326 size microplastics ( $< 20 \mu\text{m}$ ) with fast detection. Levermore et al. (2020) reported the use of Raman  
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16 327 spectroscopy coupling with chemometric analysis for detection of both virgin and environmental  
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19 328 microplastics ( $\geq 2 \mu\text{m}$ ), as shown in Fig. 8b. This proposed method could also detect outdoor  
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21 329 airborne microplastics ( $> 5 \mu\text{m}$ ) from an urban sampling site in London, UK. To detect  
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24 330 microplastics with sizes less than 1  $\mu\text{m}$ , surface-enhanced Raman spectroscopy by Klarite  
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26 331 substrates has been reported in a recent study (G. Xu et al., 2020).  
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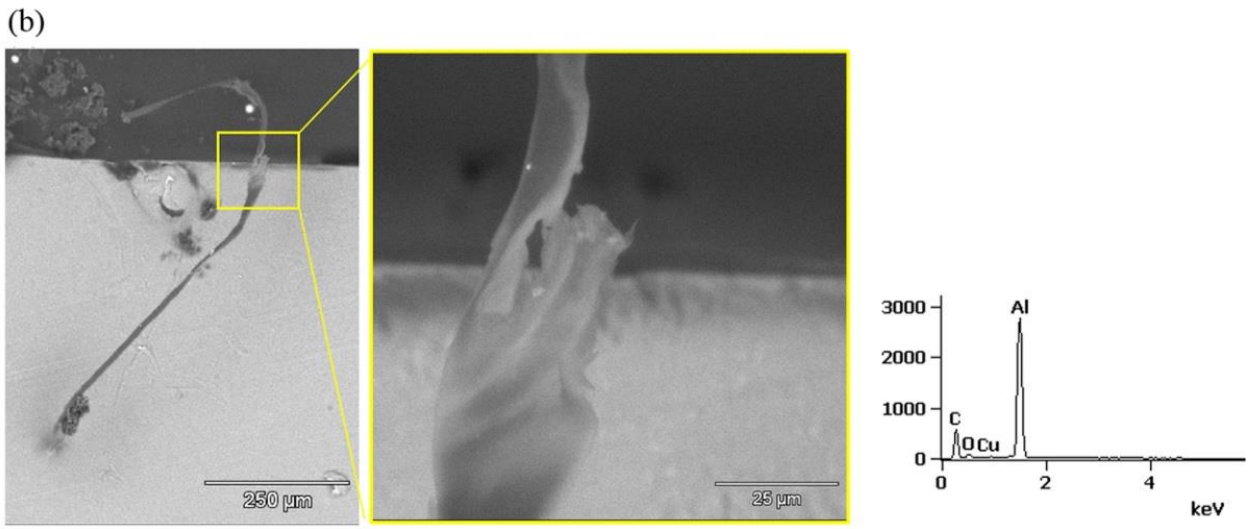
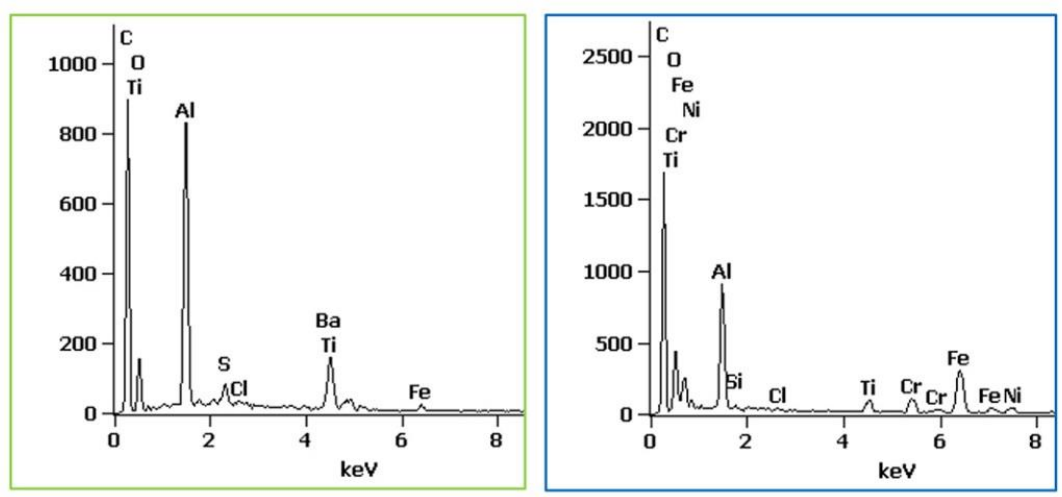
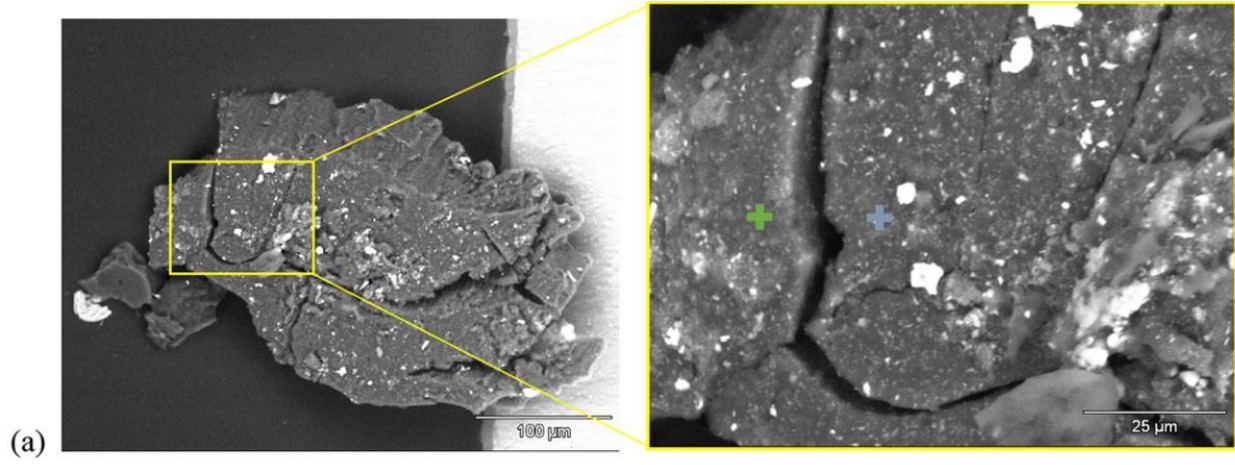
29 332 As same as FTIR technique, Raman spectra signals can be noised because of impurities  
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32 333 covering on the surface of microplastics or any additives or attached components, suggesting  
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34 334 careful pretreatment of the sample. Moreover, the Raman-based method for identification of  
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37 335 microplastics is a time-consuming processing and the sample can be destructed by Raman  
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39 336 irradiations.  
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#### 42 337 ***3.4. Scanning electron microscopy*** 43 44

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46 338 To obtain a high resolution image with a large magnification, scanning electron microscopy  
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48 339 (SEM) is used in the analysis of the morphological structure of microplastics. High-intensity  
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51 340 electron beams are generated to scan the surface of microplastics, and high resolution images are  
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53 341 detailed by interaction between electron beams and the sample surface (Rocha-Santos and Duarte,  
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56 342 2015). As a result, surface textures of microplastics including groove, pit, fracture and flake can  
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343 be shown in SEM images. In many cases, the chemical composition of microplastics needs to be  
344 identified to found out their molecular structure.



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**Fig. 9.** (a) The SEM-EDS spectra of degraded microplastics with the surface and chemical composition. (b) Polyethylene terephthalate fiber from a fish sample with carbon and oxygen as main components. Reproduced from the reference (Wagner et al., 2019) with permission of ACS. Copyright © 2019, American Chemical Society.

A combination of scanning electron microscopy and energy-dispersive X-ray spectroscopy is required, namely SEM-EDS. This technique not only provides information on the surface but also elemental composition of microplastics. Indeed, Wagner et al. (2019) used the SEM-EDS spectra to analyze the surface and chemical composition of degraded microplastics as illustrated in Fig. 9. Wang et al. (2017) reported great potential of SEM-EDS combined with optical microscopy for detection of polyvinyl chloride in ocean trawl and fish guts. However, SEM and SEM-EDS are time-consuming and expensive for identification of microplastics. As a result, they are not preferable for wide investigation with numerous samples.

### 3.5. Pyrolysis-gas chromatography-mass spectrometry

The chemical composition of microplastics can be identified using pyrolysis-gas chromatography-mass spectrometry (GC-MS) through the analysis of thermal degradation products of the sample. A temperature program can be set up to record the degradation periods of the sample. Mass spectrometry coupled with gas chromatography can provide information about the mass-to-charge (m/z) ratio of fragments of degraded microplastics. This technique is not depended on some characteristic textures such as color, shape and size of microplastics samples. It can suggest some types of common microplastics by referring to a spectral library. Analyzing microplastics by GC-MS obtains reliable results, but the samples are completely destructed by the thermal process. Many works applied this method to identify many kinds of microplastics

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368 (Duemichen et al., 2019; Picó and Barceló, 2020; Primpke et al., 2020). For example, Fischer and  
369 Scholz-Böttcher (2017) reported that GC-MS could analyze simultaneous trace of eight common  
370 plastics such as polystyrene, polyvinyl chloride, polyester, polypropylene, etc. Moreover, this  
371 technique requires well-trained technicians and a very high cost operation. It is also not suitable  
372 for identifying a large number of samples.

## 373 **4. Environmental and health impacts**

### 374 *4.1. Environmental impacts*

375 Among emerging pollutants (EPs), microplastics are almost non-biodegradable,  
376 accumulative, and highly persistent substances. As a result, both primary and secondary  
377 microplastics have been detected in various kinds of environments, such as atmosphere, oceans,  
378 drinking water, ground water, and even creature body. For example, airborne microplastics are  
379 likely to transport regionally or globally due to their tiny size, low density, and versatility (Horton  
380 and Dixon, 2018; Zhang, 2017). Thereby, airborne microplastics account for increasing  
381 bioaccumulation in both marine and terrestrial environments (Batoool et al., 2022). It was estimated  
382 that a huge amount of microplastics between 4.8 million and 12.7 million tons already entered the  
383 oceans each year, and seriously, the number are projected to increase tenfold by 2025 (Jambeck et  
384 al., 2015). Although many global measures are taken to mitigate this impact, the release of  
385 microplastics are being continued. Consequently, the environmental impacts of microplastics have  
386 been presented and recorded in recent literatures (Wright et al., 2013). Indeed, microplastics were  
387 detected in the digestive tracts or tissues of different invertebrate sea creatures, like crustacean,  
388 crab (Piarulli et al., 2019; Ribeiro et al., 2019). Many species such as fishes, birds, shrimps ingest  
389 microplastics that float on the water surface as food (Jiang et al., 2022). Microplastics do not

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390 supply energy, resulting in the fact that aquatic species consume less food and energy than their  
391 actual demand (Wang et al., 2019). As a result, their life functions such as growth and reproduction  
392 can be seriously influenced.

393 Zooplankton is an aquatic microorganism in the marine and fresh water, and acts as a vital  
394 food source for many secondary consumers. Many researches demonstrated that microplastics are  
395 readily ingested by zooplankton, causing many influences on marine life (Botterell et al., 2020;  
396 Cole et al., 2016; Vroom et al., 2017). For example, Botterell et al. (2019) summarized several  
397 factors influencing the bioavailability of microplastics to zooplankton. They collected and  
398 analyzed data from the past studies, and indicated that a majority of publications (45%) confirmed  
399 the negative effects of microplastics on feeding behavior, growth, development, reproduction and  
400 lifespan of zooplankton. By contrast, a minority of works (14%) reported an insignificant impacts  
401 of plastic ingestion. Specifically, Beiras et al. (2019) claimed that polyethylene microplastics are  
402 not responsible for bioaccumulation or toxicity of 4-nonylphenol and 4-methylbenzylidene-  
403 camphor as plastic additive to sea-urchin larvae, a marine zooplankton. These authors concluded  
404 that assumptions of microplastics as vectors of hydrophobic chemicals to planktonic marine  
405 organisms should be reconsidered. Despite some controversial arguments, we recommend that  
406 microplastics could have potential risks to aquatic organisms and creatures.

407 **4.2. Health impacts**

408 Major exposure of microplastics on human health can be through inhalation, ingestion and  
409 dermal contact pathways. Microplastics widely present in both indoor and outdoor urban  
410 atmospheres; and thus, their effect on human health though inhalation is worth considering (Y.  
411 Wang et al., 2021; Wu et al., 2022). For example, Yang et al. (2022b) assessed harmful impacts

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412 (e.g., pathogen and infections) of microplastics exposure on human lung and respiratory system.  
413 [Prata \(2018b\)](#) found that airborne microplastics caused dyspnea symptoms as well as airway and  
414 interstitial inflammatory responses in exposed workers. Some hazardous pollutants such as heavy  
415 metal dusts and pesticides or pharmaceutical drugs can be adsorbed onto microplastics ([Gao et al.,](#)  
416 [2021](#)). They act as vectors and subsequently enter the human body through inhalation, resulting in  
417 many potential threats such as lung malfunctions and cancers. However, there are very few solid  
418 evidences of what health problems and how the effects of microplastics on inhalation system are  
419 ([Prata, 2018a](#)). We recommend that more investigations of the effect of microplastics on  
420 respiratory system should be undertaken insightfully.

421 In addition to inhalation, microplastic exposure can go through ingestion and dermal  
422 contact routes as a result of consumption of foodstuff packaged by plastic products. Cox et al.  
423 estimated the amount of microplastics intaken by male and female adults is between 94,000 and  
424 11,000 particles per year through ingestion of foodstuff ([Cox et al., 2020](#)). Nearly one third  
425 Australian population consumed bottled water has annually exposed to 400 microplastic particles  
426 ([Samandra et al., 2022](#)). Many publications reported the presence of microplastics in drinking  
427 water, beer, and food products ([Eerkes-Medrano et al., 2019](#); [Jin et al., 2021](#)). No wonder  
428 microplastics have been detected in liver tissues and organs ([Horvatits et al., 2022](#)). Similarly,  
429 Ragusa et al. used Raman spectroscopy to detect microplastics in human placenta as first evidence  
430 ([Ragusa et al., 2021](#)). Very recently, a study reported the presence of polymers including  
431 polyethylene terephthalate, polyethylene and acetonitrile butadiene from plastics in human blood  
432 at a concentration of 1.6 µg/mL ([Leslie et al., 2022](#)). The authors pyrolysis quantified the samples  
433 using an analytical method by pyrolysis-gas chromatography/mass spectrometry. This publication  
434 was the first evidence of bioavailability of microplastic uptaken in human bloodstream.

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435           Although the past literature indicated that microplastics might take responsibility for the  
436 disruption of immune function and neurotoxicity in marine species such as bivalve *Mytilus* (Canesi  
437 et al., 2015), *Tegillarca granosa* (Tang et al., 2020), and *Hediste diversicolor* (Urban-Malinga et  
438 al., 2022), the same effect in humans are not reported yet. It is still unclear that how intermediates  
439 and degradation products from microplastics contributed to neurotoxicity, oxidative stress and  
440 inflammation in humans. Understanding of interaction mechanisms between microplastic particles  
441 and human tissues as well as knowledge on microplastic toxicity should be insightfully explored  
442 in future research.

## 5. Challenges and research future

444           Nowadays, the global population growth and climate change strongly exert the effort of  
445 microplastic mitigation. Human demands on food, clothing, personal care, and recreation are  
446 increasingly high, discharging a huge amount of plastic wastes, and posing a potential threat to the  
447 environment. Scientists recently estimated that the amount of plastic waste in landfills or in the  
448 natural environment could reach 12,000 million metric tons by 2050 (Geyer et al., 2017b).  
449 Seriously, while the minority of these wastes (only 21%) have been recycled and incinerated as  
450 means of treatment, 79% is still accumulated in the environment. Upon the scenario of escalating  
451 such plastics pollution, the act of global governments and policy makers in the control or  
452 replacement of plastics remains mostly spineless. This barrier will be an inevitable challenge for  
453 the eradication of microplastics from the environment in the next many years.

454           For the detection of microplastics in the environment, lacks of equivalence and analytic  
455 method standardization as well as inconsistency in sampling collection can be a main issue, making  
456 results of monitoring microplastics incomparable (Chen et al., 2020). It is evident that the

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457 collection of indoor and outdoor airborne microplastics samples in remote sites is still challenging  
458 due to difficulty of power, cost, and analytic instruments. The current sampling and preparation  
459 methods are still manual, causing many human errors while the analytic cost remains high (Prata  
460 et al., 2019). Moreover, the treatment or reduction of airborne microplastics in atmosphere is not  
461 a simple task once the weathering factors significantly dominate. It is urgently suggested to  
462 develop new sampling methods, as well as global analytic standardization for facilitating  
463 microplastics studies.

464           Moreover, mechanisms of degradation of primary microplastics are controversial or no  
465 insightful due to the complexity of multi-interaction among many factors in the environment  
466 (Bacha et al., 2021; Liu et al., 2022). Effect and toxicity of airborne microplastics on human  
467 inhalation system are still unclear. Moreover, adsorption of some hazardous pollutants such as  
468 heavy metals and pesticides onto microplastics should be a worth considering phenomenon.  
469 Finally, the extensive efforts should be devoted to mitigating the microplastics from the  
470 environments. Design and development of novel treatment methods such as photocatalysis,  
471 nanofiltration, and reverse osmosis and green bio-based methods such as enzymes-based  
472 bioreactors will be tremendously enhanced (Othman et al., 2021). The contribution of microbial  
473 communities and enzymatic process to biodegradation of microplastics in soils, sediments, and  
474 aquatic media may be a promising and sustainable trend for future researches.

## 475 **6. Conclusions**

476           Here, we systematically addressed the occurrence of microplastics in various environments  
477 including soil, aquatic media, and atmosphere. Airborne and aquatic microplastics were detected  
478 at very high concentrations. For the detection of microplastics, visual observation is widely applied

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479 for identification of large-size microplastics, while FTIR spectroscopy and SEM are reliable, but  
480 time-consuming and expensive techniques. The environmental impact of microplastics on aquatic  
481 species includes disruption of functions, productive toxicity, and neurotoxicity. Humans expose to  
482 microplastics through inhalation, ingestion and dermal contact pathways. Moreover, there is a  
483 limited understanding of microplastics toxicity to microorganisms, humans and animals in the past  
484 reports. There may be still a debate on whether microplastics can act as transport vectors to transfer  
485 toxic chemicals into living species. The current studies still have shortages of sample equivalence,  
486 standardization for analytical methods, inconsistent sampling of microplastics. To mitigate the  
487 release of microplastics into the environment, more regulations should be established. Our study  
488 also suggests that future research should have more insights into interaction mechanisms between  
489 microplastic particles and human tissues to minimize their effect in the environment.

**Acknowledgment**

491 This research is funded by Foundation for Science and Technology Development Nguyen Tat  
492 Thanh University, Vietnam.

**Disclosure declarations**

**Funding information**

495 There was no external funding for this study.

**Conflicts of interest/Competing interests**

497 The authors declare that there are no conflicts of interest.

**Availability of data and material**

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499 The authors declare that all data and materials support their published claims and comply with  
500 field standards.

501 **Compliance with Ethical Standards**

502 The authors declare that

- 503 ● The manuscript has not been published anywhere nor submitted to another journal.
- 504 ● The manuscript is not currently being considered for publication in any another journal.
- 505 ● All authors have been personally and actively involved in substantive work leading to the  
506 manuscript, and will hold themselves jointly and individually responsible for its content.
- 507 ● Research does not involve any Human Participants and/or Animals.

508 **Code availability**

509 The authors declare that software application or custom code supports their published claims and  
510 comply with field standards.

511 **Authors contributions**

512 *Thuan Van Tran*: Conceptualization, Writing – original draft; Writing – review & editing,  
513 Methodology, Investigation, Project management.

514 *A.A. Jalil*: English Editing, Writing – review & editing, Supervision.

515 *Tung M. Nguyen*: English Editing, Data curation.

516 *Thuy Thi Thanh Nguyen*: English Editing, Data curation.

517 *Walid Nabgan*: English Editing, Data curation; Writing – review & editing.

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518 *Duyen Thi Cam Nguyen*: English Editing, Writing – original draft; Writing – review & editing,  
519 Methodology, Investigation.

520 *All authors read and approved the final manuscript.*

521 **Ethics approval**

522 Not applicable

523 **Consent to participate**

524 Not applicable

525 **Consent for publication**

526 Not applicable

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873 **Table 1.** Sources, properties, and identification of microplastics in various environments

Location	Media	Polymer	Shape, size	Detection method	Abundance	Ref.
aquatic environments (rivers, lakes, bays, beaches), Vietnam	Sediments, surface waters	Polyethylene, polypropylene, alkyd resin polyester, polyolefins, polyester, polystyrene, polyamide	Fiber; 300–5,000 $\mu\text{m}$	Visual detection, FTIR-ATR	0.35–2,522 items $\text{m}^{-3}$	(Strady et al., 2021)
Liaohe Estuary, China	Sandworm, mollusks, crustacean, and fish	polyethylene, polypropylene, polyethylene terephthalate	Fiber, fragment, and pellet; 52–5,392 $\mu\text{m}$	FTIR	0.83–3.87 items/individual	(F. Wang et al., 2021)
Beijiang River, Pearl River Delta, China	Wild freshwater fishes and surface waters	Not reported	Fiber, fragment; <500 $\mu\text{m}$	Stereo-microscope	3,183–10,950 items $\text{m}^{-3}$	(S. Wang et al., 2020)
Dian Lake, China	Cropped and buffer soils	Not reported	Fiber, fragment, film; 500–1,000 $\mu\text{m}$	Visual detection	7,100–12,200 particles $\text{kg}^{-1}$	(Zhang and Liu, 2018)

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4	Lahore,	Soils from	Not reported	Fiber, sheet,	Stereo-	71,750–
5						
6	Pakistan	agricultural		and fragment;	microscope	42,960
7						
8		areas,		300–5000 $\mu\text{m}$		particles
9						
10		drains,		(41.2%), 50–		$\text{kg}^{-1}$
11						
12		dumping		150 $\mu\text{m}$		
13						
14		sites,		(30.67%),		
15						
16		industrial		150–300 $\mu\text{m}$		
17						
18		areas,		(28.17%)		
19						
20		lawns,				
21						
22		parks,				
23						
24		roadsides				
25						
26	Melipilla,	Agricultural	Acrylic, polyester,	Fiber and	Stereo-	600–10,400
27						
28	Chile	soils from	nylon, polyvinyl	fragment; 40–	microscope	particles
29						
30		sewage	chloride, low-density	2,700 $\mu\text{m}$		$\text{kg}^{-1}$
31						
32		sludge	polyethylene			
33						
34		disposals				
35						
36	Middle	Farmland	Polyethylene (67.9%),	Film (65.43%)	FTIR	340
37						
38	Franconia,	soils	polystyrene (13.58%),	and fragment		particles
39						
40	Germany		polyvinyl chloride	(25.93%);		$\text{kg}^{-1}$
41						
42			(4.94%), polyethylene	5000–50,000		
43						
44			terephthalate (2.47%),	$\mu\text{m}$ (72.84%)		
45						
46			poly(methyl	and > 300 $\mu\text{m}$		
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48			methacrylate) (1.24%)	(27.16%)		
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4	Swiss	Floodplain	Polypropylene,	Film and	FTIR	<593	(Scheurer
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6	Geportal,	soils	polyethylene,	fragment; <		particles	and
7							
8	Switzerland		polyvinyl chloride,	1000 µm		kg <sup>-1</sup>	Bigalke,
9							
10							
11			polyamide,				2018)
12							
13			polycarbonate, and				
14							
15			styrene butadiene				
16							
17							
18	Sydney,	Industrial	Polyethylene,	Not reported	FTIR	300–	(Fuller
19							
20	Australia	soils	polystyrene,		via a simple	67,500 mg	and
21							
22			poly(vinyl chloride),		pressurized	kg <sup>-1</sup>	Gautam,
23							
24			polyethylene		fluid extraction		2016)
25							
26			terephthalate,		method		
27							
28			polypropylene				
29							
30							
31							
32							
33	Paris, France	Atmospheri	Polyethylene	Fiber, 50–5000	FTIR-ATR	110	(Dris et
34							
35		c fallout	terephthalate,	µm		particles	al., 2016)
36							
37			polyamide,			m <sup>-2</sup> day <sup>-1</sup>	
38							
39			polyurethane			(urban), 53	
40							
41							
42							
43						particles	
44							
45						m <sup>-2</sup> day <sup>-1</sup>	
46							
47							
48						(sub-urban)	
49							
50	Paris, France	Indoor and	Polyester, polyamide,	Fiber; 50–1650	FTIR-ATR	1–60 fibers	(Dris et
51							
52		outdoor airs	polypropylene	µm (outdoor),		m <sup>-3</sup>	al., 2017)
53							
54				50–3250 µm		(indoor),	
55							
56				(indoor)		0.3–1.5	
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4					fibers m <sup>-3</sup>	
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6					(outdoor)	
7						
8						
9	Asaluyeh	Airborne	Not reported	Fiber;	Fluorescence,	1 fiber m <sup>-3</sup> (Abbasi
10	County, Iran	dusts		2–100 μm	polarized light,	et al.,
11					SEM	2019)
12						
13	Hamburg,	Urban and	Polyester, ethylene-	Fragment	Fluorescence	275 particles (Klein
14	Germany	rural air	vinyl acetate,	(>63–300 μm),	microscopy,	m <sup>-2</sup> day <sup>-1</sup> and
15			polytetrafluoroethylen	fiber (>63–300	μRaman	Fischer,
16			e, polyvinyl alcohol,	μm)	spectrum	2019)
17			polyethylene			
18			terephthalate			
19						
20	Coastal	Indoor and	Polystyrene,	Fiber (614–641	Micro-Raman	0.6– (Gaston
21	California, USA	outdoor airs	polyethylene	μm), fragment	and FTIR	3.3 fibers et al.,
22			terephthalate,	(58.6–104.8		m <sup>-3</sup> , 5.6– 2020)
23			polypropylene,	μm)		12.6 fragme
24			polyvinyl chloride,			nt m <sup>-3</sup>
25			polycarbonate,			
26			polyamide,			
27			acrylonitrile butadiene			
28			styrene			
29						
30	London, UK	Airborne	Polyamide,	Fiber (92%),	FTIR	575– (Wright
31		indoor and	polyaryonitrile,	others		1,008 particl et al.,
32		outdoor	polyethersulfone,	(fragment,		es m <sup>-2</sup> day <sup>-1</sup> 2020)
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polyamide, film, foam)  
polypropylene, (8%)  
polyvinyl chloride,  
polystyrene,  
polyurethane

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## **A review on the occurrence, analytical methods, and impact of microplastics in the environment**

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## 24 **Abstract**

25           Nowadays, microplastic pollution is one of the globally urgent concerns as a result of  
26 discharging plastic products into the atmosphere, aquatic and soil environments. Microplastics  
27 have average size of less than 5 mm, are non-biodegradable, accumulative, and highly persistent  
28 substances. Thousands of tons of microplastics are still accumulated in various environments,  
29 posing an enormous threat to human health and living creatures. Here, we review the occurrence  
30 and analytical methods, and impact of microplastics in the environments including soil, aquatic  
31 media, and atmosphere. Analytical methods including visual observation, Fourier-transform  
32 infrared spectroscopy, Raman spectroscopy, scanning electron microscopy, and pyrolysis-gas  
33 chromatography-mass spectrometry were evaluated. We elucidated the environmental and human  
34 health impacts of microplastics with emphasis on life malfunction, immune disruption,  
35 neurotoxicity, diseases and other tangible health risks. **This review also found some shortages of**  
36 **analytical equivalence and/or standardization, inconsistency in sampling collection and limited**  
37 **knowledge of microplastic toxicity. It is hopeful that the present work not only affords a more**  
38 **insight into the potential dangers of microplastics on human health but also urges future researches**  
39 **to establish new standardizations in analytical methods.**

40 **Keywords:** Microplastics; occurrence; analytical methods; health impact; environmental  
41 pollution.

## 42 1. Introduction

43 Since human demands on food, clothing, personal care, and recreation are increasingly  
44 high, a huge amount of plastics are produced to meet these demands. According to statistic data,  
45 about 3 million tons of plastic is yearly produced, and a majority of this number has been become  
46 plastic waste (Chen et al., 2020). Nowadays, plastic pollution is one of the globally urgent  
47 concerns. Under exposure to many factors such as ultraviolet radiation, weathering and mechanical  
48 abrasion, plastic wastes entering the environment can be gradually degraded into smaller plastic  
49 particles, or microplastics (Shim et al., 2017). Microplastics have a size of less than 5 mm, are a  
50 major contributor to globally environmental pollution. Scientists have projected that the  
51 percentage of microplastics over the total pollutants will account for 13.2% by 2060 (Sharma et  
52 al., 2021). More seriously, microplastics have already been detected in various environments such  
53 as soil, atmosphere, ocean, drinking water, and creatures such as natural fish, and even human  
54 organs and tissues (Jiang, 2018; Ragusa et al., 2021). As a result, the occurrence, qualification,  
55 and impact of microplastics in the environment are of significant interest.

56 Microplastics not only have negative impacts on terrestrial and aquatic animals but also  
57 combine with other toxins to cause synergistic effects in the environment (Koelmans et al., 2016).  
58 Considering microplastics as a transport vector, they can adsorb toxic chemicals such as persistent  
59 organic pollutants (Rodrigues et al., 2019), heavy metals (Sarkar et al., 2021), personal care  
60 products (Atugoda et al., 2021), pharmaceuticals (Wagstaff et al., 2022), antibiotics (Stapleton et  
61 al., 2023), printing dyes (Tubić et al., 2023), perfluoroalkyl substances (Mejías et al., 2023),  
62 pesticides (Sahai et al., 2023), insecticide (Zhou et al., 2023), etc. in wastewater and then transfer  
63 to aquatic species. Many studies evidenced that chemicals-loaded microplastics afford a higher  
64 toxicity than origin chemicals in various environments. For example, Verdú et al. (2023) reported

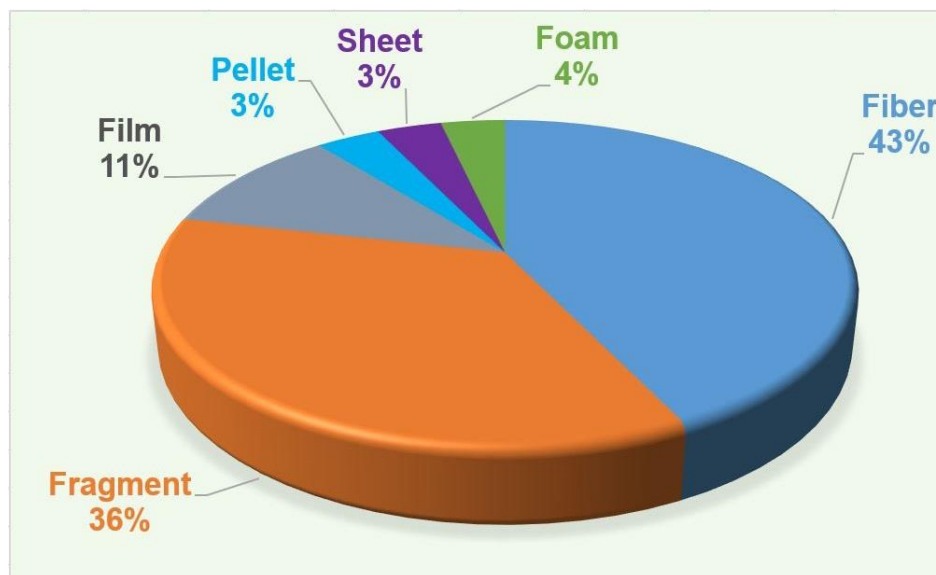
65 that triclosan-adsorbed polyethylene microplastics caused a higher mortality against *Daphnia*  
66 *magna* adults than origin triclosan. The authors explained that microplastics biofouling in  
67 wastewater effluents exerted a stronger adsorption force on co-occurring triclosan. Sobhani et al.  
68 (2021) supplied a valuable proof of decreasing reproductive behavior in earthworms in the  
69 presence of perfluoroalkyl-loaded polyvinyl chloride microplastics. Researchers also found that  
70 this type of microplastic served as enhanced transport vector to transfer perfluoroalkyl substance  
71 to earthworms. Akhbarizadeh et al. (2021) investigated the role of fine particulate matter (PM<sub>2.5</sub>)  
72 as airborne carriers against polycyclic aromatic hydrocarbons (PAHs). This work found that adults  
73 inhaled 32.5–161.24 items of M2.5-bound PAHs per day, causing potentially chronic health risks.  
74 It is important that the environmental and health risks of microplastics as a transport vector should  
75 be, therefore, evaluated.

76 Several qualification methods such as visual detection, Fourier transform infrared  
77 spectroscopy (FTIR), Raman spectroscopy, scanning electron microscopy (SEM), and pyrolysis-  
78 gas chromatography-mass spectrometry have been developed to detect microplastics in the  
79 environment (Prata et al., 2019). However, there are many concerns about pros and cons that needs  
80 to mentioned. Therefore, this review supplies state of the art findings of recently published studies.  
81 The structure of the review to (i) focus on the classification and property of several common  
82 plastics; (ii) examine the occurrence of microplastics in the environments such as atmosphere,  
83 aquatic environment, and soil; (iii) discuss several qualification methods for detection of  
84 microplastics; (iv) evaluate two aspects of environmental and health impacts. We also suggest  
85 some challenges and future direction for the next studies.

## 86 2. Classification, source and occurrence of microplastics

### 87 2.1. Classification of microplastics

88 Microplastics can be divided into two major types including primary and secondary  
89 microplastics. Primary microplastics are very small particles using for commercial purposes.  
90 Meanwhile, secondary microplastics are degraded products derived from the breakdown of larger  
91 plastics due to exposure under some harsh conditions such as ultraviolet radiation from sunlight  
92 wave action, and wind abrasion (Shen et al., 2020). To be more specific, Fig. 1 illustrates the  
93 statistical data analysis from previous works showing the proportion of microplastics in the  
94 environment. Accordingly, the percentage of fiber and fragment accounts for nearly 80%.



95

96 **Fig. 1. Statistical data from previous works on the proportion of microplastics (fiber, fragment,**  
97 **film, foam, pellet, sheet) in the environment.**

98 Microbeads are derived from personal care products and plastic pellets. They are used for  
99 industrial manufacturing. Plastic fibers are used for synthetic textiles and fishing nets. There are

100 several common examples of primary microplastics such as polyethylene (PE), polypropylene  
101 (PP), polyvinyl chloride (PVC), polystyrene (PS), polyester (PE), polyamide (PA), polyaryonitrile  
102 (PAN), polyethylene terephthalate (PET), polyphthalamide (PPA), polycarbonate (PC) and  
103 poly(methyl methacrylate) (PMMA) (Fig. 2).

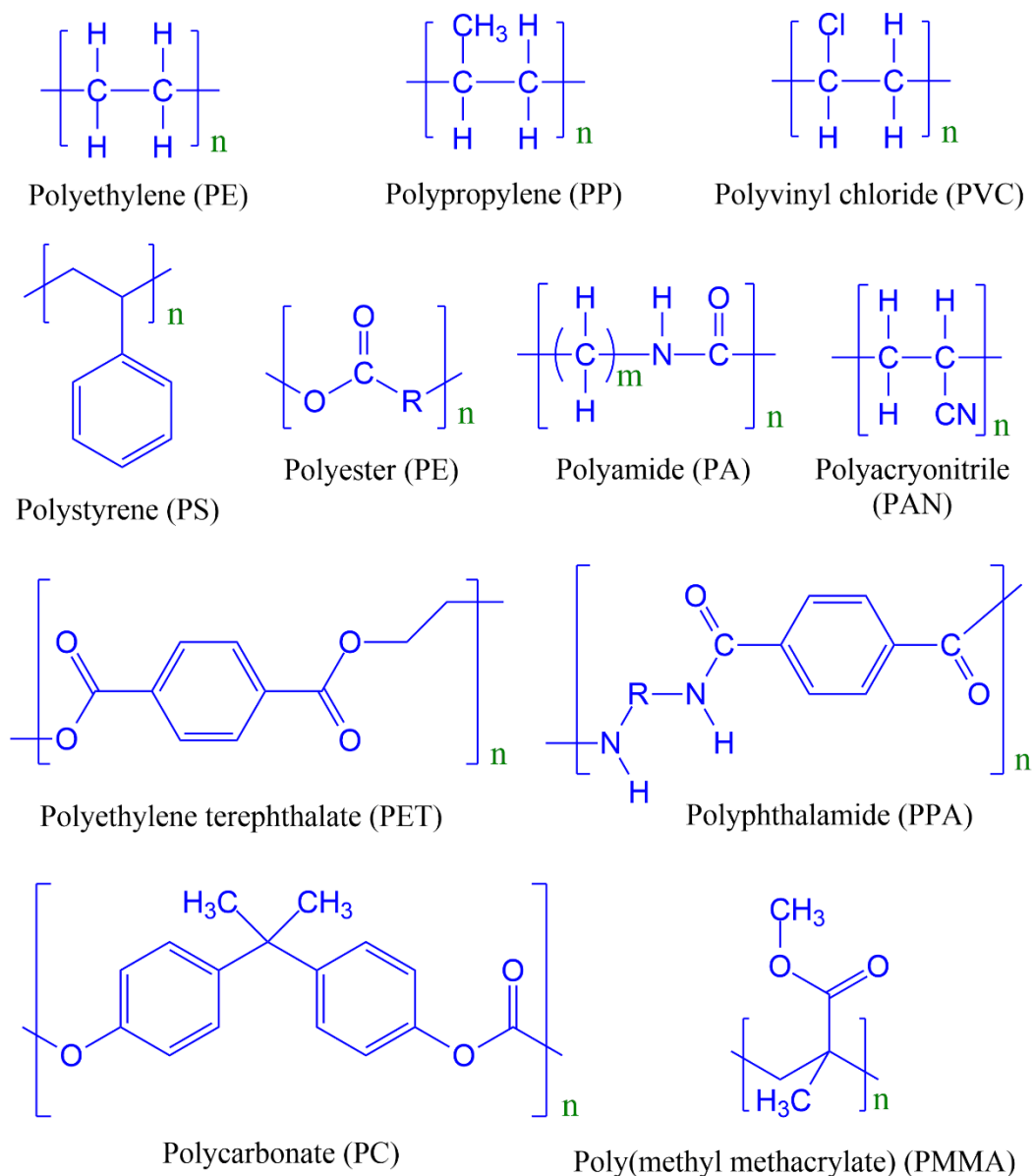
104 ■ Polyethylene (PE): Among widely used plastics, PE is the most common plastic in the  
105 world. This polymer is thermoplastic with a chemical formula  $(C_2H_4)_n$ . In fact, it can be  
106 modified by cross-linked with other polymers to create a thermoset plastic having many  
107 applications. PE has a range of mechanical properties which depend majorly on the extent  
108 and type of branching, crystallinity and molecular mass. Geyer et al. estimated that over  
109 100 million tons of polyethylene resins are produced annually, accounting for 34% of the  
110 total plastics market as of 2017 (Geyer et al., 2017a). According to statistic data, the PE  
111 derived microplastics are the most common composition (20%) of microplastics detected  
112 in the environment. The widespread presence of PE plastics may be because they are  
113 inexpensively produced and have been using in packaging film, trash and grocery bags,  
114 and many housewares for a long time.

115 ■ Polypropylene (PP): this plastic is a synthetic resin produced through the polymerization  
116 of propylene monomer. Similar to PE, this polymer is also a thermoplastic with a chemical  
117 formula  $[-CH_2-CH(CH_3)-]_n$ . As a polyolefin resin, PP can be molded or extruded into  
118 many plastic products depending on flexibility, toughness, weight, heat resistance, etc. PP  
119 plastics have been widely using in many products such as ropes, tapes, carpets, and  
120 clothing. It is estimated that the global demand for polypropylene exceeds many thousand  
121 tons, where Asia accounts for half of polypropylene amount. As a result, the presence of  
122 polypropylene microplastic particles has commonly found in soils, rivers, cannels, etc.

123 According to [Fig. 3](#), the composition of microplastics based on statistical data analysis  
124 from previous works showing that PP have been commonly detected in the environment.

125 ■ Polyvinyl chloride (PVC): PVC was firstly synthesized in 1872 by German chemist Eugen  
126 Baumann. In his experiment, vinyl chloride gas a sealed tube was exposed under sunlight  
127 and polyvinyl chloride was produced as a white solid. From there, PVC has been become  
128 one of the widely used plastic in the world. Many technologies have also applied to  
129 optimize the production of polyvinyl chloride and reduce its by-products ([Asadinezhad et](#)  
130 [al., 2012](#)). This polymer is typically a synthetic resin having chemical formula  $(C_2H_3Cl)_n$ .  
131 It is estimated that about 40 million tons of polyvinyl chloride are produced annually. There  
132 are two major kinds of PVC, including rigid and flexible types. Polyvinyl chloride has  
133 valuable properties such as electric insulation, durability, flame retardancy, chemical and  
134 heat resistance. Therefore, PVC is a main component in the manufacturing of pipes,  
135 medical devices, electric wires, and cable insulation.

136 ■ Polymethyl methacrylate (PMMA): this plastic is a synthetic product of polymerization of  
137 methyl methacrylate ( $CH_2=C[CH_3]CO_2H$ ). Polymethyl methacrylate was firstly developed  
138 in 1928 by many scientists. This polymer is transparent and rigid, often called “engineering  
139 plastics”, and used as a substitute for glass, involving optical devices, shatterproof  
140 windows, skylights, and aircraft canopies. Polymethyl methacrylate has many important  
141 properties such as good tensile and flexural strength, high transparency, UV tolerance.

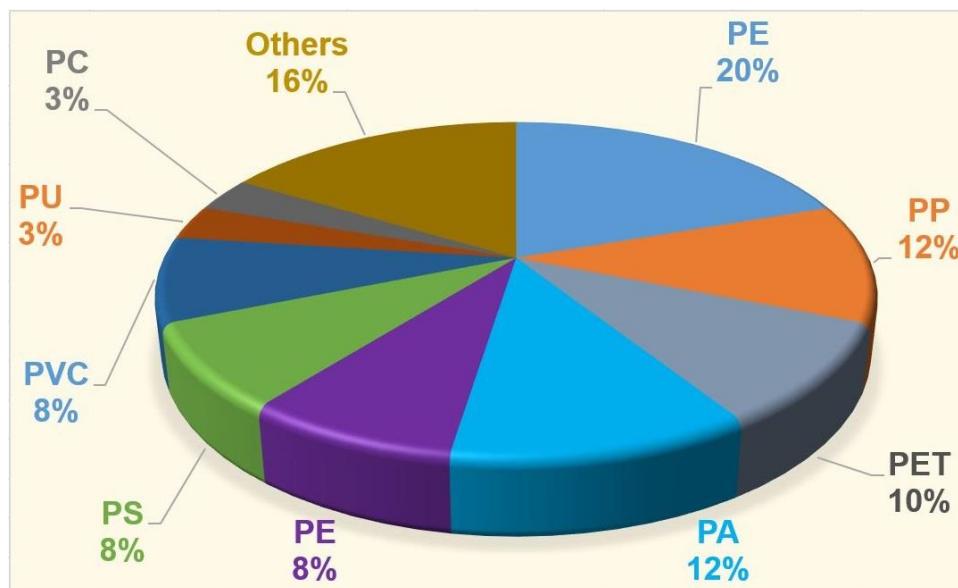


142  
 143 **Fig. 2.** Molecular structure of several common microplastics including polyethylene (PE),  
 144 polypropylene (PP), polyvinyl chloride (PVC), polystyrene (PS), polyester (PE), polyamide (PA),  
 145 polyaryonitrile (PAN), polyethylene terephthalate (PET), polyphthalamide (PPA), polycarbonate  
 146 (PC) and poly(methyl methacrylate) (PMMA).

147 Secondary microplastics can come from the breakdown of water bottles or nylons, etc.  
 148 Release of primary microplastics from mentioned sources to the environment can undergo through

149 various channels such as discharging of personal care products from households, and laundering  
150 of clothing made from synthetic textiles (Khadir et al., 2022). There is still limited knowledge of  
151 degradation mechanism of primary microplastics into secondary microplastics. As emerging  
152 pollutant, however, both primary and secondary microplastics cause harmful effects on the  
153 environment and human health.

154 Chemically, almost microplastics consist of two main elements including carbon and  
155 hydrogen in their polymeric structure. Other known chemicals, such as phthalates, polybrominated  
156 diphenyl ethers, polyvinyl chloride, and tetrabromobisphenol A can contain bromide, chlorine, and  
157 oxygen. Moreover, chemical additives in microplastics with the purpose of mechanical  
158 enforcement or thermal resistance are typically present in microplastics. They can leach out of the  
159 microplastics after discharge into the environment, causing many negative effects. The properties  
160 of microplastics can be optically characterized by color, shape, size, transparency, etc. (Table 1).  
161 For their size, there is a range of MPs size between 1  $\mu\text{m}$  and 5000  $\mu\text{m}$ .



162

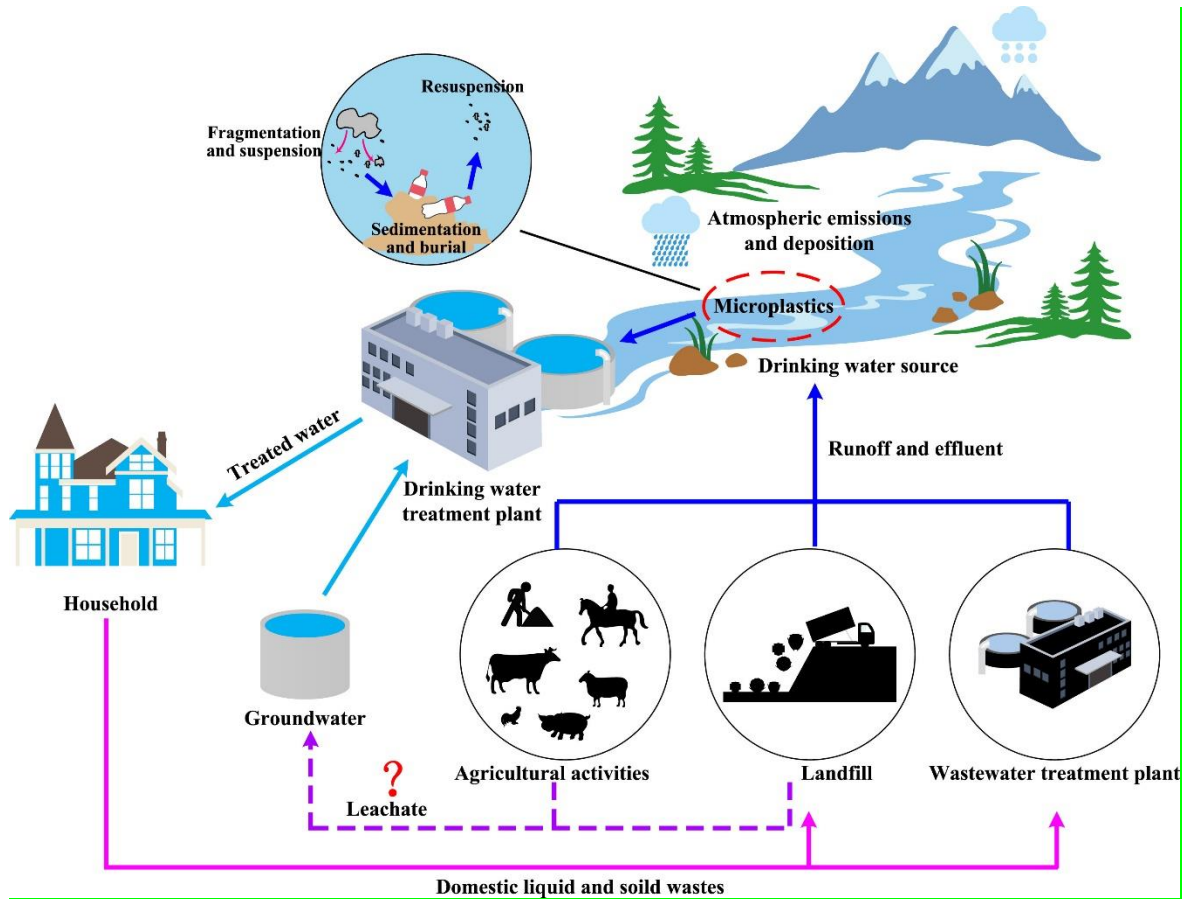
163 **Fig. 3. Statistical data from previous works on the composition of microplastics detected in the**  
164 **environment.**

## 165 *2.2. Source of microplastics*

166 Microplastics are small or very small pieces of plastics, with size of between 1  $\mu\text{m}$  and  
167 5000  $\mu\text{m}$ . In general, they appear in the environment as a result of plastic pollution. Nowadays,  
168 the pollution of microplastics is globally occurred with a wide variety of primary products, from  
169 personal care products and cosmetics to synthetic textiles, clothing, plastic bags or bottles. Such  
170 products enter the environment through various channels such as municipal households, hospital  
171 wastewaters, human activities, and agricultural activities. Although wastewater treatment plants  
172 can be partially treated microplastics, the effluents are still present in almost sites such as rivers,  
173 seas, atmosphere, chemosphere all over the world (Fig. 4).

174 Primary products are a main contributor to microplastics pollution. However, after the time  
175 eluting in the environment, primary microplastics are gradually degraded as a consequence of  
176 photodegradation, thermo-degradation, biodegradation into smaller particles in the form of  
177 fragments, pellets, microbeads and fibers. For example, Strady et al. observed the abundant  
178 presence of fibrous microplastics in 21 aquatic environments such as rivers, lakes, bays, and  
179 beaches in Vietnam (Strady et al., 2021). Meanwhile, Wang et al. reported that microplastics with  
180 size of 52–5,392  $\mu\text{m}$  has a range of shapes such as fiber, fragment, and pellet, which were  
181 originated from polyethylene, polypropylene, polyethylene terephthalate (F. Wang et al., 2021).  
182 At the same trend, Piehl at al. found the presence of film and fragment shaped microplastics from  
183 degraded products of polyethylene, polystyrene, polyvinyl chloride, polyethylene terephthalate  
184 (Piehl et al., 2018). Moreover, many works reported the unintentional pollution from microplastics

185 as a result of human activities (Hartline et al., 2016; Kole et al., 2017). The source of these  
 186 microplastics pollutions can come from recreation and tourism activities such as fishing.



187  
 188 **Fig. 4. Occurrence and transport of microplastics in the environment. Reproduced from the**  
 189 **reference (Shen et al., 2020) with permission of Elsevier. Copyright © 2020, Elsevier.**

190 **2.3. Occurrence of microplastics in the environment**

191 **2.3.1. Microplastics in the atmosphere**

192 With the rapid development of transportation vehicles and industries, the pollution of  
 193 microplastics in the atmospheric environment has become serious. The source of atmospheric  
 194 microplastics can come from release of plastic dusts of traffic activities and plastic industries.

195 Among atmospheric microplastics, fine particulate matter (PM<sub>2.5</sub>) with size of 2.5 micrometers  
196 and smaller is emerging as a major air contaminant. PM<sub>2.5</sub> are very small particles in the air, and  
197 thus, it is very hard to prevent their impacts. The presence of PM<sub>2.5</sub> in air reduce the visibility, and  
198 makes human respiratory system more vulnerable (Xing et al., 2016). As a result, PM<sub>2.5</sub> is really a  
199 concern for human health.

200 Airborne microplastics easily transport in indoor and outdoor air due to their low density  
201 and small size (Prata, 2018a). Wind, pressure change and other weather factors can affect the  
202 movement of microplastics in air. Dris et al. (2016) estimated that 29% of the fibers in atmospheric  
203 fallout derived from petrochemicals in Paris, France. Atmospheric fallout of fibers was found  
204 higher at more urban sites. At the same trend, Wright et al. (2020) detected fifteen different  
205 petrochemical-based polymers in airborne indoor and outdoor in London, UK. Fibrous  
206 microplastics accounted for 92% and a density of 575–1,008 particles m<sup>-2</sup> day<sup>-1</sup>, which 20 times  
207 higher than that in remote area. The presence of plastic fibers( 0.6–3.3 m<sup>-3</sup>) and plastic fragment  
208 (5.6–12.6 m<sup>-3</sup>) in coastal California, USA was recorded in a recent study (Gaston et al., 2020).

209 A number of publications demonstrated that several hazardous pollutants, e.g., heavy metal  
210 dusts, coal dust, etc. can be adsorbed onto the microplastics, and subsequently enter the human  
211 body through inhalation (Huang et al., 2021; Kalčíková et al., 2020; Waring et al., 2018; Yang et  
212 al., 2022). In that case, microplastics act as carrier of these hazardous contaminants. Upon the  
213 effect of weather factors such as wind, hazardous contaminants-loaded microplastics are likely to  
214 distribute around various geographical regions. In the suitable condition, they can release toxic  
215 substances or aggregate in biota (Fu et al., 2021). Therefore, the presence of microplastics in the  
216 atmosphere needs to be diagnosed, detected and controlled properly.

### 217 2.3.2. *Microplastics in aquatic environment*

218 The presence of microplastics in the aquatic environment has been known for a long time.  
219 The major source of water contaminant by microplastics is discharging of polymeric household  
220 products such as food packaging and preservation plastics (e.g., nylons), personal care products  
221 (e.g., hair spray), etc. [Jiang \(2018\)](#) estimated that household plastics have been increasingly  
222 discharged from the aquatic media between 5,000 and 80,000 tons. [Strady et al. \(2021\)](#) found the  
223 abundance of fibrous microplastics (0.35–2,522 items m<sup>-3</sup>) in sediments, and surface waters.  
224 Meanwhile, [Wang et al. \(2020\)](#) screened the presence of microplastic fibers and fragments by  
225 stereo-microscope in Beijiang River, China. They found a large density of aquatic microplastics  
226 (3,183–10,950 items m<sup>-3</sup>).

227 As a pollutant, microplastics can be detected in creature body because they digest  
228 microplastics as food. Even, [Li et al. \(2021\)](#) suggested that aquatic species (e.g., natural fishes)  
229 ingest microplastics unintentionally through their breathing, and capture microfibers was rejective  
230 behavior. As a result, microplastics enter the fish body, and indirectly transport through the food  
231 chains. At the same trend, [Vivekanand et al. \(2021\)](#) concluded that aquatic lives feed microplastics  
232 in aquatic media and ecological risks is very serious. It is proposed that establishing global  
233 collaboration, effective policies as well as control strategies to mitigate the discharge of  
234 microplastics into aquatic media are very urgent.

### 235 2.3.3. *Microplastics in soil*

236 Microplastics present in soil are stored, translocated, and degraded into secondary  
237 microplastics, which can leach out groundwater sources. [He et al. \(2018\)](#) suggested that soil biota  
238 can influence the accumulation and fate of microplastics. It was reported that microplastics

239 strongly affect the physicochemical and biological properties of soil. Indeed, they can change the  
240 soil microbial communities and soil functions (Guo et al., 2020). Many works also demonstrated  
241 negative impacts of microplastics on seed germination and plant growth (Huang et al., 2022; F.  
242 Wang et al., 2020; B. Xu et al., 2020). Depending on plastic type, size, and content, influence of  
243 microplastics on soil and soil organisms can be varied.

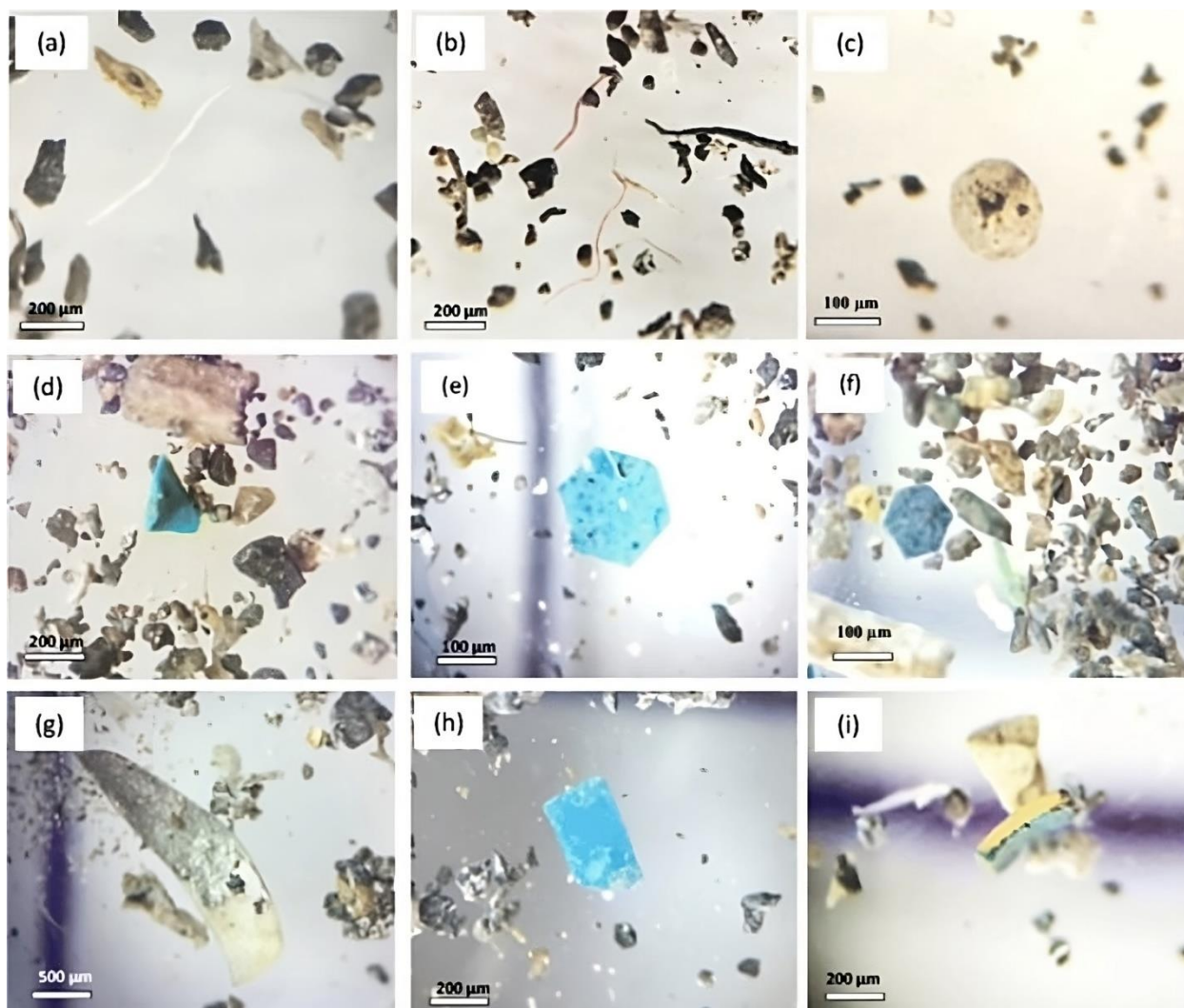
244 Moreover, Zhang and Liu (2018) compared the concentration of microplastics between  
245 cropped and buffer soils by visual detection, finding that plastic fibers, fragments, and films were  
246 mostly present in soil with concentration of 7,100 and 12,200 particles  $\text{kg}^{-1}$ , respectively.  
247 Furthermore, Rafique et al. (2020) investigated soils from agricultural areas, drains, and dumping  
248 sites in Lahore, Pakistan. The results showed that microplastics were present in soil at very  
249 concentration (42,960–71,750 particles  $\text{kg}^{-1}$ ). They explained that rapid urbanization and  
250 extensive use of plastic products could be potential contributors to microplastics pollution in soil.  
251 At the same trend, many microplastics originated from acrylic, polyester, nylon, and polyvinyl  
252 chloride were found in agricultural soil in Mellipilla, Chile (Corradini et al., 2019). It is suggested  
253 that strict regulations should be implemented to prevent plastic pollution and protect soil resources.

### 254 **3. Analytical methods of microplastics**

#### 255 **3.1. Visual observation**

256 Visual observation is widely applied for microplastics identification because it does not  
257 require complex technique and high cost inspection. This observation is based on the properties of  
258 particle size, shape, color, surface and transparency (Shim et al., 2017). To be more specific, Fig.  
259 5 illustrates the particle size, shape, color, surface and transparency of the microplastics under  
260 visual observation. In general, the observer will record the color covering the surface of

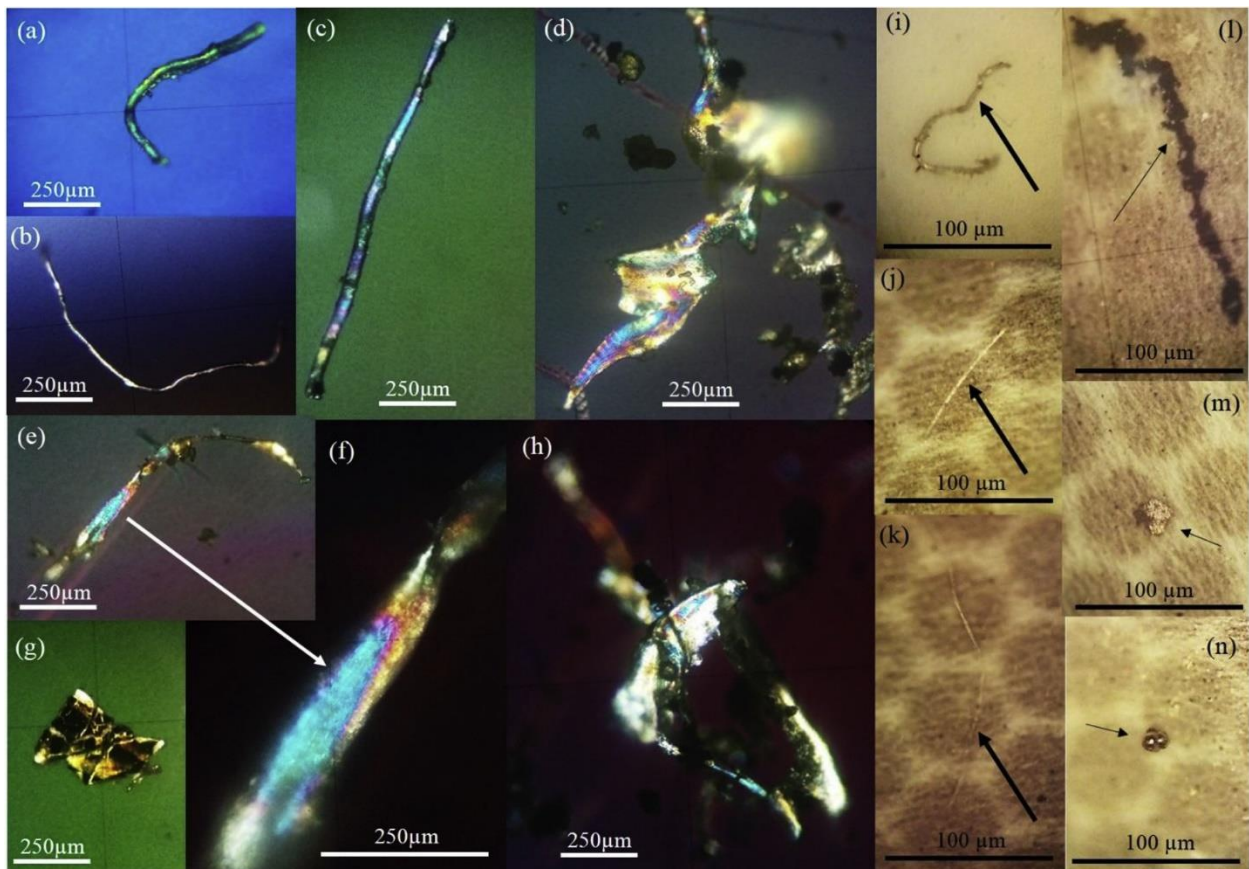
261 microplastics. Nowadays, with the advent of stereomicroscope technique, the visualization  
262 methods become reliable and simple (Song et al., 2015). In this case, microplastics from the  
263 prepared samples can be directly seen under an optical microscope, resulting in a low cost of  
264 measurement.



265  
266 **Fig. 5.** Optical microscope images of microplastics such as (a) transparent fiber, (b) red fiber, (c)  
267 transparent sphere, (d) green granule, (e, f) blue hexagonal fragments, (g) white granule covered  
268 with silver shiny film, (h) blue granule, and (i) sample of microplastics fragments. Reproduced

269 from the reference (Dehghani et al., 2017) with permission of Springer Nature. Copyright © 2017,  
270 Springer Nature.

271 However, the biggest disadvantage of optical microscope is that the samples can be only  
272 detected at a large size of higher 500  $\mu\text{m}$  (Chen et al., 2020). Otherwise, large errors can be  
273 received due to the subjectivity of the examiner. It is suggested that visual observation should be  
274 combined with fluorescence techniques for better detection of microplastics. Indeed, other  
275 microscopic techniques such as fluorescence, and polarized light can give high resolution images  
276 of microplastics with small sizes. For example, microplastics and microrubbers in air and street  
277 dusts from urban sampling site can be clearly detected by polarized-light microscopic images as  
278 shown in Fig. 6.



279

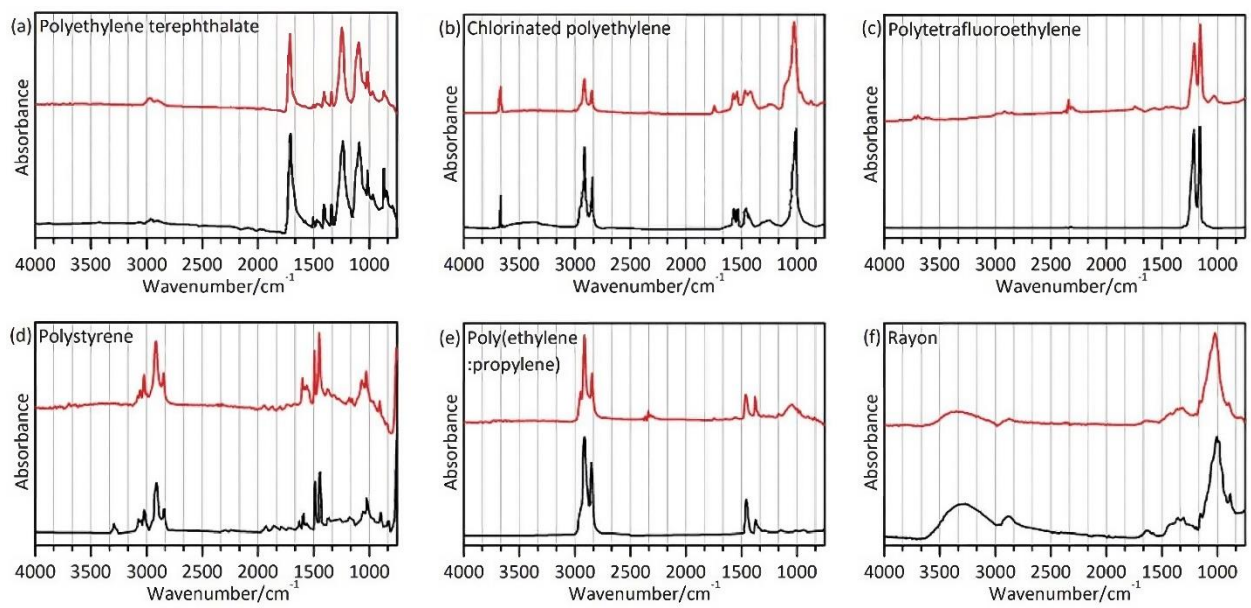
280 **Fig. 6.** Polarized-light microscopic images of (a-c) microplastic fibers (d-f, h) film-like  
281 microplastics, (g) a fragmented microplastic, (i-k) microplastic fibers, (l) fibrous microrubbers,  
282 (m-n) metallic particles in air filter. Reproduced from the reference (Abbasi et al., 2019) with  
283 permission of Elsevier. Copyright © 2019, Elsevier.

### 284 **3.2. Fourier transform infrared spectroscopy**

285         Apart from visual inspection, Fourier transform infrared (FTIR) spectroscopy is one of the  
286 most widely used technique to detect the presence of polymeric structure of microplastics  
287 (Veerasingam et al., 2021). This technique supplies information about the chemical bonds as well  
288 as footprints which aid to diagnose a type of microplastics. With a spectrum obtained from FTIR,  
289 a chemical formula can be automatically suggested based on spectral library of known substances.  
290 This technique is considered as highly reliable, but it can lack of accuracy and require many trial  
291 with microplastics with very small size ( $< 50 \mu\text{m}$ ) (Shim et al., 2017). In that case, FTIR can be  
292 replaced with a micro FTIR spectroscopy to ensure levels of acceptable accuracy. With  
293 microplastics having larger particle size ( $> 500 \text{ nm}$ ),  $\mu$ -ATR-FTIR is more preferable and rapid  
294 (Käppler et al., 2018). As an example, Fig. 7 shows an example of FTIR technique for  
295 identification of microplastics and spectra from the Sadtler Library (bottom, black color) as  
296 references.

297         Other state of the art techniques such as FPA-FTIR are used to screen almost type of current  
298 microplastics on a filter paper. However, airborne microplastics may not be a suitable subject to  
299 be detected by both ATR-FTIR and FPA-FTIR due to their tiny size ( $< 5 \mu\text{m}$ ) (Primpke et al.,  
300 2017). Moreover, the spectra of FTIR technique can be strongly noised because of impurities  
301 covering on the surface of microplastic particles. As a result, a careful pretreatment of the sample

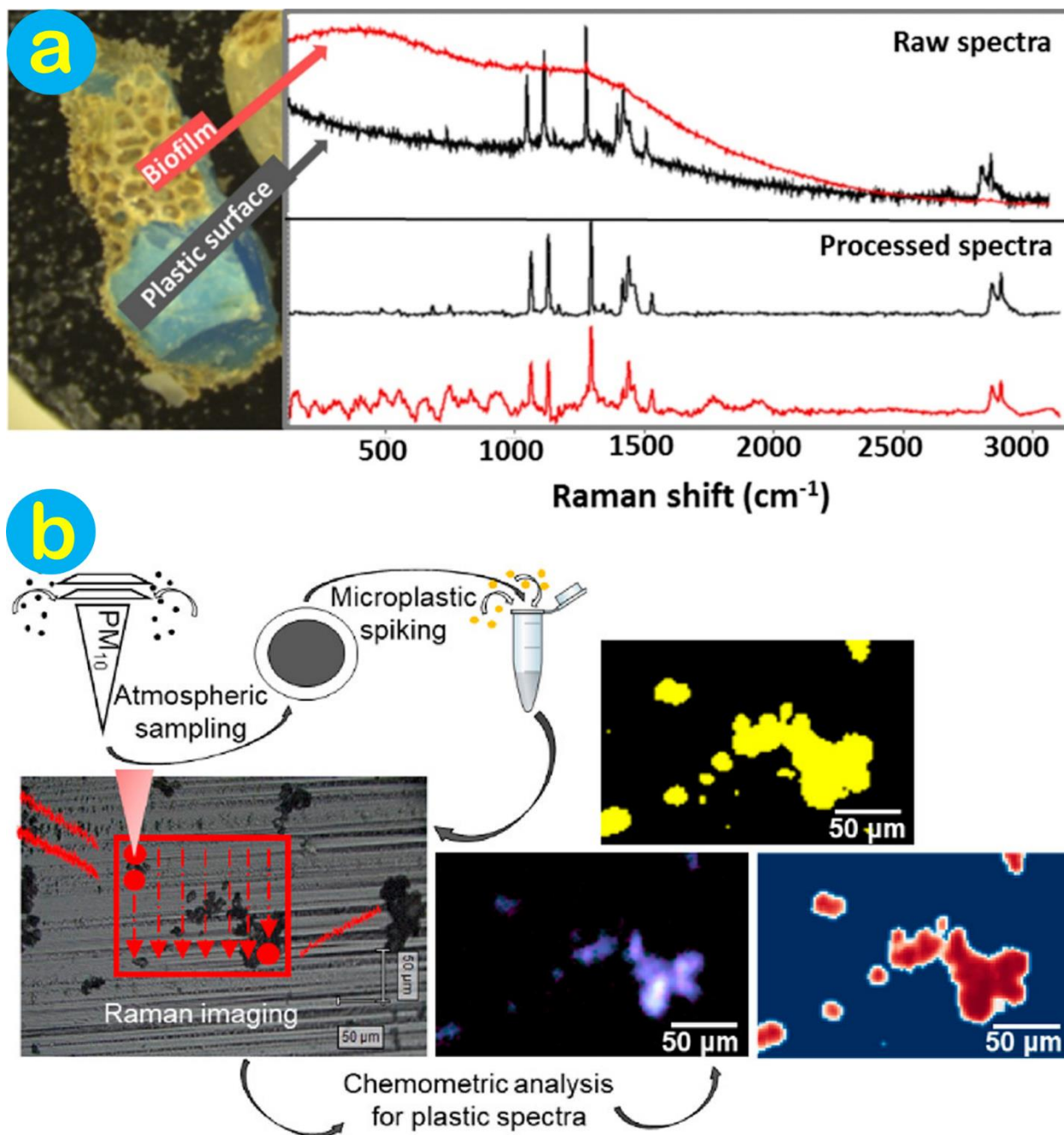
302 should be conducted before a regular measurement. In summary, the biggest disadvantage of  
303 FTIR-based method for identification of microplastics is time-consuming, just appropriate with  
304 well-trained spectral technicians (Xu et al., 2019). Therefore, this technique is just applied with  
305 selected samples rather than screening samples.



306  
307 **Fig. 7.** An example of FTIR technique for identification of microplastics (top, red color) and  
308 spectra from the Sadtler Library (bottom, black color) as references. Microplastics includes (a)  
309 polyethylene terephthalate, (b) chlorinated polyethylene, (c) polytetrafluoroethylene, (d)  
310 polystyrene, (e) poly(ethylene propylene), (f) rayon. Reproduced from the reference (Ding et al.,  
311 2019) with permission of RSC Publishing. Copyright © 2019 RSC Publishing.

### 312 3.3. Raman spectroscopy

313 This method is widely used to detect the presence of microplastics in different media. Laser  
314 beams are excited to irradiate into the target sample. The reflection signals are recorded to  
315 determine the frequency shift. Each of different chemical gives different frequency shifts (Fig. 8a).



316

317 **Fig. 8.** (a) Raman spectra of a trawl (polyethylene) particle with biofilm covering. Reproduced  
 318 from the reference (Ghosal et al., 2018). with permission of Elsevier. Copyright © 2018, Elsevier.  
 319 (b) An illustration of Raman spectral imaging combined with chemometric analysis for detection  
 320 of both virgin and environmental microplastics. Reproduced from the reference (Levermore et al.,  
 321 2020) with permission of ACS. Copyright © 2020, American Chemical Society.

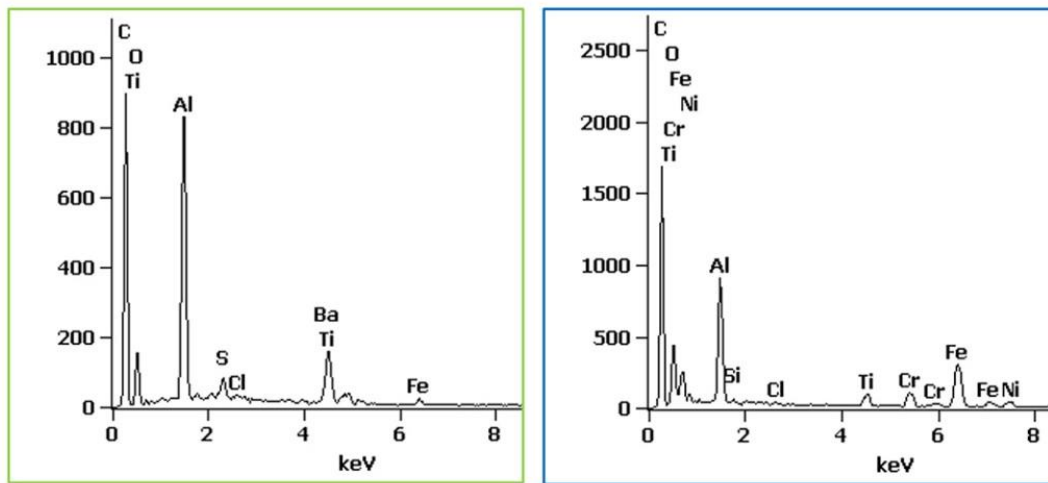
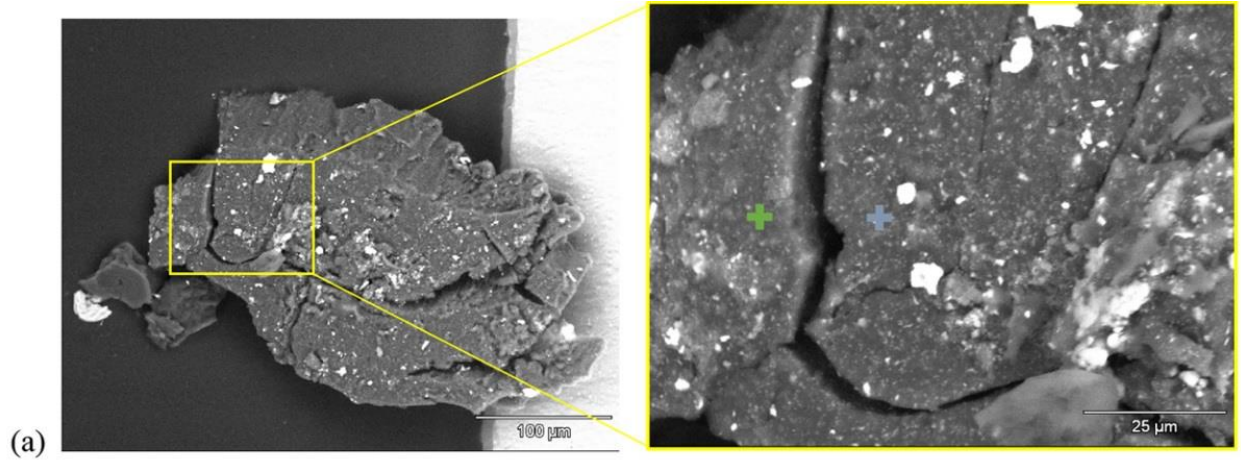
322 Raman techniques only requires a small amount of sample, but supplies reliable  
323 information about the molecular structure. With microplastics having particle size of less than  
324 1000  $\mu\text{m}$ , Raman spectroscopy is a suitable choice (Lenz et al., 2015). Even, Araujo et al. (2018)  
325 suggested that Raman spectroscopy could give an automated mapping and library matching of tiny  
326 size microplastics ( $< 20 \mu\text{m}$ ) with fast detection. Levermore et al. (2020) reported the use of Raman  
327 spectroscopy coupling with chemometric analysis for detection of both virgin and environmental  
328 microplastics ( $\geq 2 \mu\text{m}$ ), as shown in Fig. 8b. This proposed method could also detect outdoor  
329 airborne microplastics ( $> 5 \mu\text{m}$ ) from an urban sampling site in London, UK. To detect  
330 microplastics with sizes less than 1  $\mu\text{m}$ , surface-enhanced Raman spectroscopy by Klarite  
331 substrates has been reported in a recent study (G. Xu et al., 2020).

332 As same as FTIR technique, Raman spectra signals can be noised because of impurities  
333 covering on the surface of microplastics or any additives or attached components, suggesting  
334 careful pretreatment of the sample. Moreover, the Raman-based method for identification of  
335 microplastics is a time-consuming processing and the sample can be destructed by Raman  
336 irradiations.

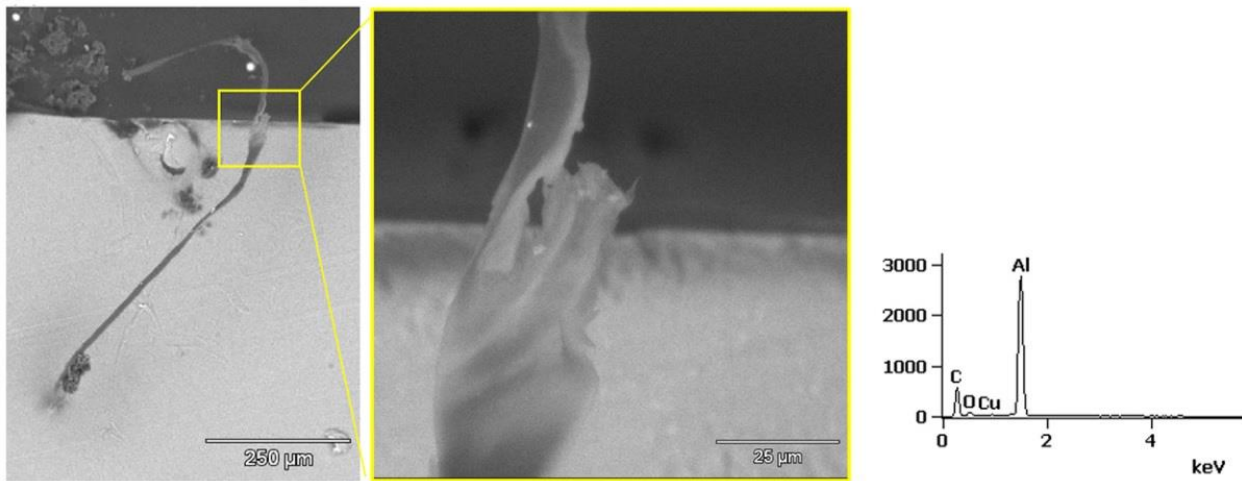
### 337 **3.4. Scanning electron microscopy**

338 To obtain a high resolution image with a large magnification, scanning electron microscopy  
339 (SEM) is used in the analysis of the morphological structure of microplastics. High-intensity  
340 electron beams are generated to scan the surface of microplastics, and high resolution images are  
341 detailed by interaction between electron beams and the sample surface (Rocha-Santos and Duarte,  
342 2015). As a result, surface textures of microplastics including groove, pit, fracture and flake can

343 be shown in SEM images. In many cases, the chemical composition of microplastics needs to be  
344 identified to found out their molecular structure.



(b)



345

346 Fig. 9. (a) The SEM-EDS spectra of degraded microplastics with the surface and chemical  
347 composition. (b) Polyethylene terephthalate fiber from a fish sample with carbon and oxygen as  
348 main components. Reproduced from the reference (Wagner et al., 2019) with permission of ACS.  
349 Copyright © 2019, American Chemical Society.

350 A combination of scanning electron microscopy and energy-dispersive X-ray spectroscopy  
351 is required, namely SEM-EDS. This technique not only provides information on the surface but  
352 also elemental composition of microplastics. Indeed, Wagner et al. (2019) used the SEM-EDS  
353 spectra to analyze the surface and chemical composition of degraded microplastics as illustrated  
354 in Fig. 9. Wang et al. (2017) reported great potential of SEM-EDS combined with optical  
355 microscopy for detection of polyvinyl chloride in ocean trawl and fish guts. However, SEM and  
356 SEM-EDS are time-consuming and expensive for identification of microplastics. As a result, they  
357 are not preferable for wide investigation with numerous samples.

### 358 *3.5. Pyrolysis-gas chromatography-mass spectrometry*

359 The chemical composition of microplastics can be identified using pyrolysis-gas  
360 chromatography-mass spectrometry (GC-MS) through the analysis of thermal degradation  
361 products of the sample. A temperature program can be set up to record the degradation periods of  
362 the sample. Mass spectrometry coupled with gas chromatography can provide information about  
363 the mass-to-charge ( $m/z$ ) ratio of fragments of degraded microplastics. This technique is no  
364 depended on some characteristic textures such as color, shape and size of microplastics samples.  
365 It can suggest some types of common microplastics by referring to a spectral library. Analyzing  
366 microplastics by GC-MS obtains reliable results, but the samples are completely destructed by the  
367 thermal process. Many works applied this method to identify many kinds of microplastics

368 (Duemichen et al., 2019; Picó and Barceló, 2020; Primpke et al., 2020). For example, Fischer and  
369 Scholz-Böttcher (2017) reported that GC-MS could analyze simultaneous trace of eight common  
370 plastics such as polystyrene, polyvinyl chloride, polyester, polypropylene, etc. Moreover, this  
371 technique requires well-trained technicians and a very high cost operation. It is also not suitable  
372 for identifying a large number of samples.

## 373 **4. Environmental and health impacts**

### 374 *4.1. Environmental impacts*

375 Among emerging pollutants (EPs), microplastics are almost non-biodegradable,  
376 accumulative, and highly persistent substances. As a result, both primary and secondary  
377 microplastics have been detected in various kinds of environments, such as atmosphere, oceans,  
378 drinking water, ground water, and even creature body. For example, airborne microplastics are  
379 likely to transport regionally or globally due to their tiny size, low density, and versatility (Horton  
380 and Dixon, 2018; Zhang, 2017). Thereby, airborne microplastics account for increasing  
381 bioaccumulation in both marine and terrestrial environments (Batoool et al., 2022). It was estimated  
382 that a huge amount of microplastics between 4.8 million and 12.7 million tons already entered the  
383 oceans each year, and seriously, the number are projected to increase tenfold by 2025 (Jambeck et  
384 al., 2015). Although many global measures are taken to mitigate this impact, the release of  
385 microplastics are being continued. Consequently, the environmental impacts of microplastics have  
386 been presented and recorded in recent literatures (Wright et al., 2013). Indeed, microplastics were  
387 detected in the digestive tracts or tissues of different invertebrate sea creatures, like crustacean,  
388 crab (Piarulli et al., 2019; Ribeiro et al., 2019). Many species such as fishes, birds, shrimps ingest  
389 microplastics that float on the water surface as food (Jiang et al., 2022). Microplastics do not

390 supply energy, resulting in the fact that aquatic species consume less food and energy than their  
391 actual demand (Wang et al., 2019). As a result, their life functions such as growth and reproduction  
392 can be seriously influenced.

393 Zooplankton is an aquatic microorganism in the marine and fresh water, and acts as a vital  
394 food source for many secondary consumers. Many researches demonstrated that microplastics are  
395 readily ingested by zooplankton, causing many influences on marine life (Botterell et al., 2020;  
396 Cole et al., 2016; Vroom et al., 2017). For example, Botterell et al. (2019) summarized several  
397 factors influencing the bioavailability of microplastics to zooplankton. They collected and  
398 analyzed data from the past studies, and indicated that a majority of publications (45%) confirmed  
399 the negative effects of microplastics on feeding behavior, growth, development, reproduction and  
400 lifespan of zooplankton. By contrast, a minority of works (14%) reported an insignificant impacts  
401 of plastic ingestion. Specifically, Beiras et al. (2019) claimed that polyethylene microplastics are  
402 not responsible for bioaccumulation or toxicity of 4-nonylphenol and 4-methylbenzylidene-  
403 camphor as plastic additive to sea-urchin larvae, a marine zooplankton. These authors concluded  
404 that assumptions of microplastics as vectors of hydrophobic chemicals to planktonic marine  
405 organisms should be reconsidered. Despite some controversial arguments, we recommend that  
406 microplastics could have potential risks to aquatic organisms and creatures.

#### 407 ***4.2. Health impacts***

408 Major exposure of microplastics on human health can be through inhalation, ingestion and  
409 dermal contact pathways. Microplastics widely present in both indoor and outdoor urban  
410 atmospheres; and thus, their effect on human health though inhalation is worth considering (Y.  
411 Wang et al., 2021; Wu et al., 2022). For example, Yang et al. (2022b) assessed harmful impacts

412 (e.g., pathogen and infections) of microplastics exposure on human lung and respiratory system.  
413 [Prata \(2018b\)](#) found that airborne microplastics caused dyspnea symptoms as well as airway and  
414 interstitial inflammatory responses in exposed workers. Some hazardous pollutants such as heavy  
415 metal dusts and pesticides or pharmaceutical drugs can be adsorbed onto microplastics ([Gao et al.,](#)  
416 [2021](#)). They act as vectors and subsequently enter the human body through inhalation, resulting in  
417 many potential threats such as lung malfunctions and cancers. However, there are very few solid  
418 evidences of what health problems and how the effects of microplastics on inhalation system are  
419 ([Prata, 2018a](#)). We recommend that more investigations of the effect of microplastics on  
420 respiratory system should be undertaken insightfully.

421 In addition to inhalation, microplastic exposure can go through ingestion and dermal  
422 contact routes as a result of consumption of foodstuff packaged by plastic products. Cox et al.  
423 estimated the amount of microplastics intaken by male and female adults is between 94,000 and  
424 11,000 particles per year through ingestion of foodstuff ([Cox et al., 2020](#)). Nearly one third  
425 Australian population consumed bottled water has annually exposed to 400 microplastic particles  
426 ([Samandra et al., 2022](#)). Many publications reported the presence of microplastics in drinking  
427 water, beer, and food products ([Eerkes-Medrano et al., 2019](#); [Jin et al., 2021](#)). No wonder  
428 microplastics have been detected in liver tissues and organs ([Horvatits et al., 2022](#)). Similarly,  
429 Ragusa et al. used Raman spectroscopy to detect microplastics in human placenta as first evidence  
430 ([Ragusa et al., 2021](#)). Very recently, a study reported the presence of polymers including  
431 polyethylene terephthalate, polyethylene and acetonitrile butadiene from plastics in human blood  
432 at a concentration of 1.6 µg/mL ([Leslie et al., 2022](#)). The authors pyrolysis quantified the samples  
433 using an analytical method by pyrolysis-gas chromatography/mass spectrometry. This publication  
434 was the first evidence of bioavailability of microplastic uptaken in human bloodstream.

435           Although the past literature indicated that microplastics might take responsibility for the  
436 disruption of immune function and neurotoxicity in marine species such as bivalve *Mytilus* (Canesi  
437 et al., 2015), *Tegillarca granosa* (Tang et al., 2020), and *Hediste diversicolor* (Urban-Malinga et  
438 al., 2022), the same effect in humans are not reported yet. It is still unclear that how intermediates  
439 and degradation products from microplastics contributed to neurotoxicity, oxidative stress and  
440 inflammation in humans. Understanding of interaction mechanisms between microplastic particles  
441 and human tissues as well as knowledge on microplastic toxicity should be insightfully explored  
442 in future research.

## 443 **5. Challenges and research future**

444           Nowadays, the global population growth and climate change strongly exert the effort of  
445 microplastic mitigation. Human demands on food, clothing, personal care, and recreation are  
446 increasingly high, discharging a huge amount of plastic wastes, and posing a potential threat to the  
447 environment. Scientists recently estimated that the amount of plastic waste in landfills or in the  
448 natural environment could reach 12,000 million metric tons by 2050 (Geyer et al., 2017b).  
449 Seriously, while the minority of these wastes (only 21%) have been recycled and incinerated as  
450 means of treatment, 79% is still accumulated in the environment. Upon the scenario of escalating  
451 such plastics pollution, the act of global governments and policy makers in the control or  
452 replacement of plastics remains mostly spineless. This barrier will be an inevitable challenge for  
453 the eradication of microplastics from the environment in the next many years.

454           For the detection of microplastics in the environment, lacks of equivalence and analytic  
455 method standardization as well as inconsistency in sampling collection can be a main issue, making  
456 results of monitoring microplastics incomparable (Chen et al., 2020). It is evident that the

457 collection of indoor and outdoor airborne microplastics samples in remote sites is still challenging  
458 due to difficulty of power, cost, and analytic instruments. The current sampling and preparation  
459 methods are still manual, causing many human errors while the analytic cost remains high (Prata  
460 et al., 2019). Moreover, the treatment or reduction of airborne microplastics in atmosphere is not  
461 a simple task once the weathering factors significantly dominate. It is urgently suggested to  
462 develop new sampling methods, as well as global analytic standardization for facilitating  
463 microplastics studies.

464 Moreover, mechanisms of degradation of primary microplastics are controversial or no  
465 insightful due to the complexity of multi-interaction among many factors in the environment  
466 (Bacha et al., 2021; Liu et al., 2022). Effect and toxicity of airborne microplastics on human  
467 inhalation system are still unclear. Moreover, adsorption of some hazardous pollutants such as  
468 heavy metals and pesticides onto microplastics should be a worth considering phenomenon.  
469 Finally, the extensive efforts should be devoted to mitigating the microplastics from the  
470 environments. Design and development of novel treatment methods such as photocatalysis,  
471 nanofiltration, and reverse osmosis and green bio-based methods such as enzymes-based  
472 bioreactors will be tremendously enhanced (Othman et al., 2021). The contribution of microbial  
473 communities and enzymatic process to biodegradation of microplastics in soils, sediments, and  
474 aquatic media may be a promising and sustainable trend for future researches.

## 475 **6. Conclusions**

476 Here, we systematically addressed the occurrence of microplastics in various environments  
477 including soil, aquatic media, and atmosphere. Airborne and aquatic microplastics were detected  
478 at very high concentrations. For the detection of microplastics, visual observation is widely applied

479 for identification of large-size microplastics, while FTIR spectroscopy and SEM are reliable, but  
480 time-consuming and expensive techniques. The environmental impact of microplastics on aquatic  
481 species includes disruption of functions, productive toxicity, and neurotoxicity. Humans expose to  
482 microplastics through inhalation, ingestion and dermal contact pathways. Moreover, there is a  
483 limited understanding of microplastics toxicity to microorganisms, humans and animals in the past  
484 reports. There may be still a debate on whether microplastics can act as transport vectors to transfer  
485 toxic chemicals into living species. The current studies still have shortages of sample equivalence,  
486 standardization for analytical methods, inconsistent sampling of microplastics. To mitigate the  
487 release of microplastics into the environment, more regulations should be established. Our study  
488 also suggests that future research should have more insights into interaction mechanisms between  
489 microplastic particles and human tissues to minimize their effect in the environment.

#### 490 **Acknowledgment**

491 This research is funded by Foundation for Science and Technology Development Nguyen Tat  
492 Thanh University, Vietnam.

#### 493 **Disclosure declarations**

#### 494 **Funding information**

495 There was no external funding for this study.

#### 496 **Conflicts of interest/Competing interests**

497 The authors declare that there are no conflicts of interest.

#### 498 **Availability of data and material**

499 The authors declare that all data and materials support their published claims and comply with  
500 field standards.

### 501 **Compliance with Ethical Standards**

502 The authors declare that

- 503 ● The manuscript has not been published anywhere nor submitted to another journal.
- 504 ● The manuscript is not currently being considered for publication in any another journal.
- 505 ● All authors have been personally and actively involved in substantive work leading to the  
506 manuscript, and will hold themselves jointly and individually responsible for its content.
- 507 ● Research does not involve any Human Participants and/or Animals.

### 508 **Code availability**

509 The authors declare that software application or custom code supports their published claims and  
510 comply with field standards.

### 511 **Authors contributions**

512 *Thuan Van Tran*: Conceptualization, Writing – original draft; Writing – review & editing,  
513 Methodology, Investigation, Project management.

514 *A.A. Jalil*: English Editing, Writing – review & editing, Supervision.

515 *Tung M. Nguyen*: English Editing, Data curation.

516 *Thuy Thi Thanh Nguyen*: English Editing, Data curation.

517 *Walid Nabgan*: English Editing, Data curation; Writing – review & editing.

518 *Duyen Thi Cam Nguyen*: English Editing, Writing – original draft; Writing – review & editing,  
519 Methodology, Investigation.

520 *All authors read and approved the final manuscript.*

521 **Ethics approval**

522 Not applicable

523 **Consent to participate**

524 Not applicable

525 **Consent for publication**

526 Not applicable

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872

873 **Table 1.** Sources, properties, and identification of microplastics in various environments

Location	Media	Polymer	Shape, size	Detection method	Abundance	Ref.
21 aquatic environments (rivers, lakes, bays, beaches), Vietnam	Sediments, surface waters	Polyethylene, polypropylene, alkyd resin polyester, polyolefins, polyester, polystyrene, polyamide	Fiber; 300–5,000 $\mu\text{m}$	Visual detection, FTIR-ATR	0.35–2,522 items $\text{m}^{-3}$	(Strady et al., 2021)
Liaohe Estuary, China	Sandworm, mollusks, crustacean, and fish	polyethylene, polypropylene, polyethylene terephthalate	Fiber, fragment, and pellet; 52–5,392 $\mu\text{m}$	FTIR	0.83–3.87 items/individual	(F. Wang et al., 2021)
Beijiang River, Pearl River Delta, China	Wild freshwater fishes and surface waters	Not reported	Fiber, fragment; <500 $\mu\text{m}$	Stereo-microscope	3,183–10,950 items $\text{m}^{-3}$	(S. Wang et al., 2020)
Dian Lake, China	Cropped and buffer soils	Not reported	Fiber, fragment, film; 500–1,000 $\mu\text{m}$	Visual detection	7,100–12,200 particles $\text{kg}^{-1}$	(Zhang and Liu, 2018)

Lahore, Pakistan	Soils from agricultural areas, drains, dumping sites, industrial areas, lawns, parks, roadsides	Not reported	Fiber, sheet, and fragment; 300–5000 $\mu\text{m}$ (41.2%), 50–150 $\mu\text{m}$ (30.67%), 150–300 $\mu\text{m}$ (28.17%)	Stereo-microscope	71,750–42,960 particles $\text{kg}^{-1}$	(Rafique et al., 2020)
Mellipilla, Chile	Agricultural soils from sewage sludge disposals	Acrylic, polyester, nylon, polyvinyl chloride, low-density polyethylene	Fiber and fragment; 40–2,700 $\mu\text{m}$	Stereo-microscope	600–10,400 particles $\text{kg}^{-1}$	(Corradini et al., 2019)
Middle Franconia, Germany	Farmland soils	Polyethylene (67.9%), polystyrene (13.58%), polyvinyl chloride (4.94%), polyethylene terephthalate (2.47%), poly(methyl methacrylate) (1.24%)	Film (65.43%) and fragment (25.93%); 5000–50,000 $\mu\text{m}$ (72.84%) and > 300 $\mu\text{m}$ (27.16%)	FTIR	340 particles $\text{kg}^{-1}$	(Piehl et al., 2018)

Swiss Geoportal, Switzerland	Floodplain soils	Polypropylene, polyethylene, polyvinyl chloride, polyamide, polycarbonate, and styrene butadiene	Film and fragment; < 1000 $\mu\text{m}$	FTIR	<593 particles $\text{kg}^{-1}$	(Scheurer and Bigalke, 2018)
Sydney, Australia	Industrial soils	Polyethylene, polystyrene, poly(vinyl chloride), polyethylene terephthalate, polypropylene	Not reported	FTIR via a simple pressurized fluid extraction method	300– 67,500 mg $\text{kg}^{-1}$	(Fuller and Gautam, 2016)
Paris, France	Atmospheri c fallout	Polyethylene terephthalate, polyamide, polyurethane	Fiber, 50–5000 $\mu\text{m}$	FTIR-ATR	110 particles $\text{m}^{-2} \text{day}^{-1}$ (urban), 53 particles $\text{m}^{-2} \text{day}^{-1}$ (sub-urban)	(Dris et al., 2016)
Paris, France	Indoor and outdoor airs	Polyester, polyamide, polypropylene	Fiber; 50–1650 $\mu\text{m}$ (outdoor), 50–3250 $\mu\text{m}$ (indoor)	FTIR-ATR	1–60 fibers $\text{m}^{-3}$ (indoor), 0.3–1.5	(Dris et al., 2017)

					fibers m <sup>-3</sup> (outdoor)	
Asaluyeh County, Iran	Airborne dusts	Not reported	Fiber; 2–100 μm	Fluorescence, polarized light, SEM	1 fiber m <sup>-3</sup>	(Abbasi et al., 2019)
Hamburg, Germany	Urban and rural air	Polyester, ethylene-vinyl acetate, polytetrafluoroethylene, polyvinyl alcohol, polyethylene terephthalate	Fragment (>63–300 μm), fiber (>63–300 μm)	Fluorescence microscopy, μRaman spectrum	275 particles m <sup>-2</sup> day <sup>-1</sup>	(Klein and Fischer, 2019)
Coastal California, USA	Indoor and outdoor airs	Polystyrene, polyethylene terephthalate, polypropylene, polyvinyl chloride, polycarbonate, polyamide, acrylonitrile butadiene styrene	Fiber (614–641 μm), fragment (58.6–104.8 μm)	Micro-Raman and FTIR	0.6–3.3 fibers m <sup>-3</sup> , 5.6–12.6 fragment m <sup>-3</sup>	(Gaston et al., 2020)
London, UK	Airborne indoor and outdoor	Polyamide, polyaryonitrile, polyethersulfone,	Fiber (92%), others (fragment,	FTIR	575–1,008 particles m <sup>-2</sup> day <sup>-1</sup>	(Wright et al., 2020)

polyamide, film, foam)

polypropylene, (8%)

polyvinyl chloride,

polystyrene,

polyurethane