Environmental Toxicology and Pharmacology

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

--Manuscript Draft--

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Abstract:	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, inconsistence 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.
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Declaration of Interest Statement

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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

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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, inconsistence 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.

<u>Our response:</u>

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 ($PM_{2.5}$) 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."

Thuan Van Tran

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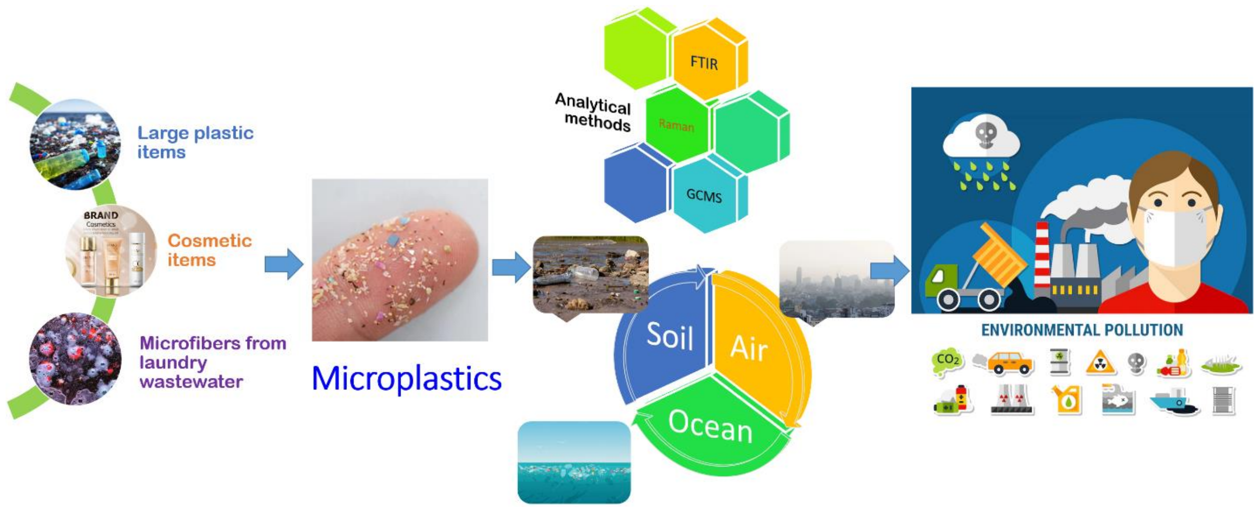
Graphical Abstract



- 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

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

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Table of contents

Abstract

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, inconsistence 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.

Keywords: Microplastics; occurrence; analytical methods; health impact; environmental 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 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 ($PM_{2.5}$) 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.

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

2. Classification, source and occurrence of microplastics

2.1. Classification of microplastics

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

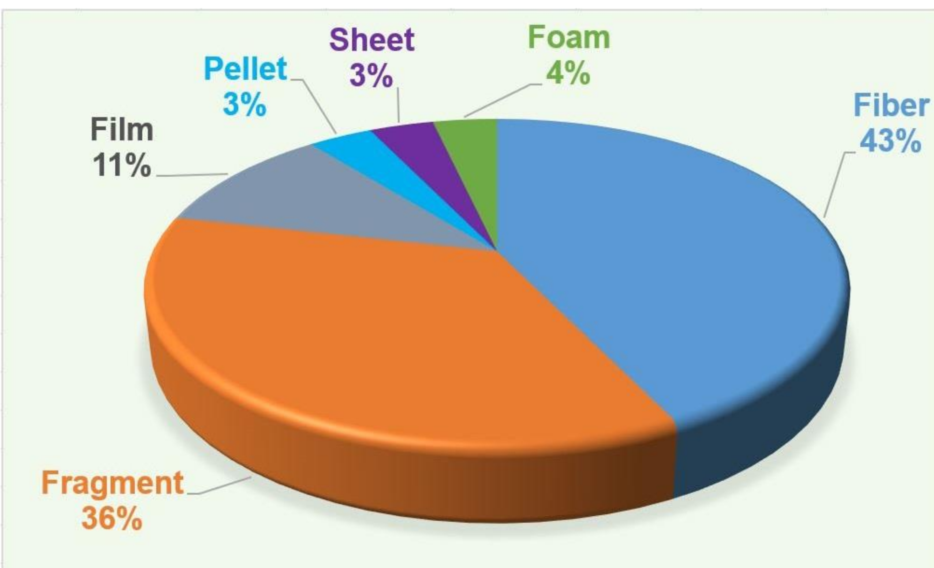

Fig. 1. Statistical data from previous works on the proportion of microplastics (fiber, fragment, film, foam, pellet, sheet) in the environment.

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

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

- Polyvinyl chloride (PVC): PVC was firstly synthesized in 1872 by German chemist Eugen Baumann. In his experiment, vinyl chloride gas a sealed tube was exposed under sunlight and polyvinyl chloride was produced as a white solid. From there, PVC has been become one of the widely used plastic in the world. Many technologies have also applied to optimize the production of polyvinyl chloride and reduce its by-products (Asadinezhad et al., 2012). This polymer is typically a synthetic resin having chemical formula $(C_2H_3Cl)_n$. It is estimated that about 40 million tons of polyvinyl chloride are produced annually. There are two major kinds of PVC, including rigid and flexible types. Polyvinyl chloride has valuable properties such as electric insulation, durability, flame retardancy, chemical and heat resistance. Therefore, PVC is a main component in the manufacturing of pipes, medical devices, electric wires, and cable insulation.
- Polymethyl methacrylate (PMMA): this plastic is a synthetic product of polymerization of methyl methacrylate ($CH_2=C[CH_3]CO_2H$). Polymethyl methacrylate was firstly developed in 1928 by many scientists. This polymer is transparent and rigid, often called “engineering plastics”, and used as a substitute for glass, involving optical devices, shatterproof windows, skylights, and aircraft canopies. Polymethyl methacrylate has many important properties such as good tensile and flexural strength, high transparency, UV tolerance.

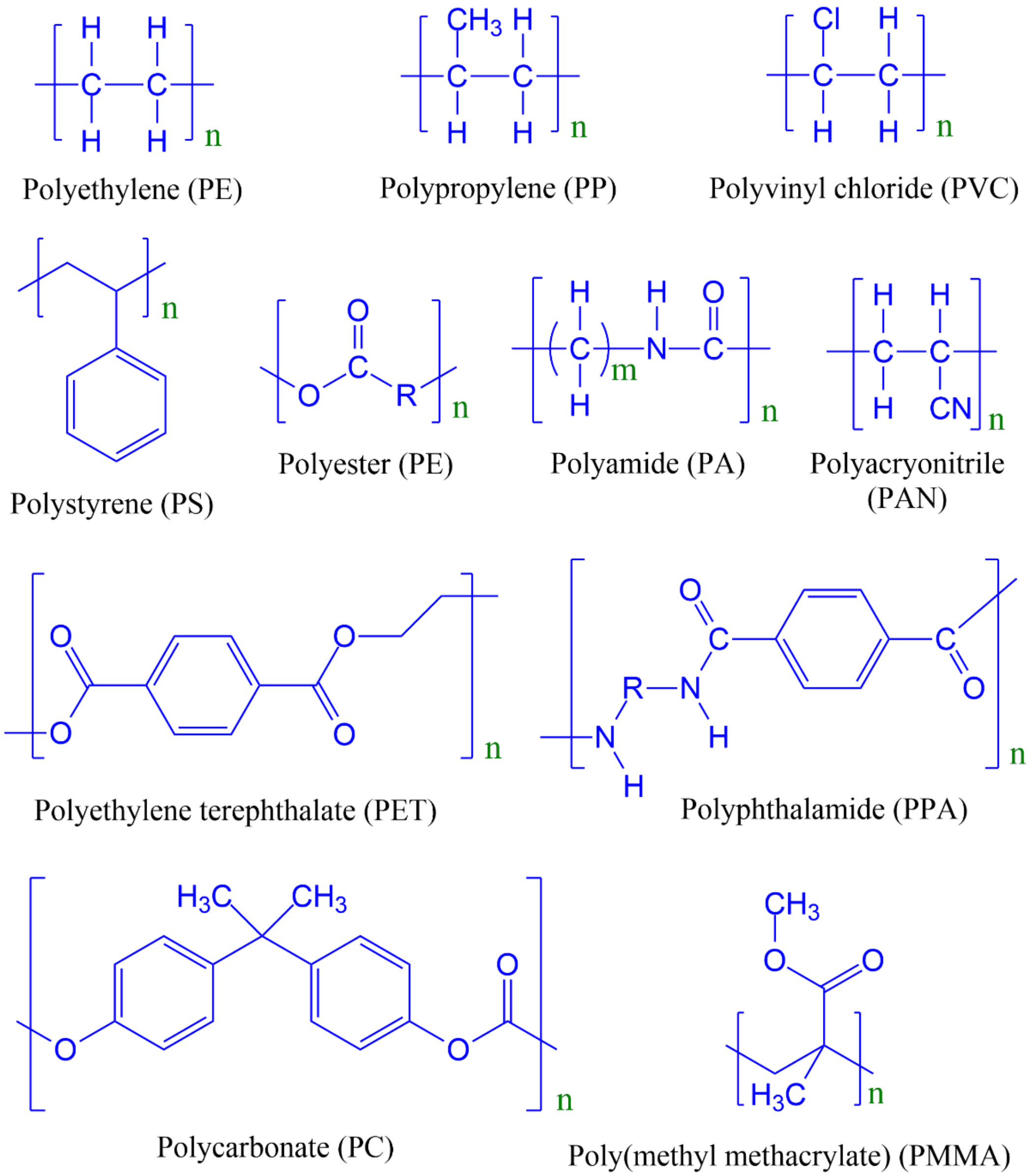

Fig. 2. Molecular structure of several common microplastics including polyethylene (PE), polypropylene (PP), polyvinyl chloride (PVC), polystyrene (PS), polyester (PE), polyamide (PA), polyaryonitrile (PAN), polyethylene terephthalate (PET), polyphthalamide (PPA), polycarbonate (PC) and poly(methyl methacrylate) (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 various channels such as discharging of personal care products from households, and laundering of clothing made from synthetic textiles (Khadir et al., 2022). There is still limited knowledge of degradation mechanism of primary microplastics into secondary microplastics. As emerging pollutant, however, both primary and secondary microplastics cause harmful effects on the environment and human health.

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

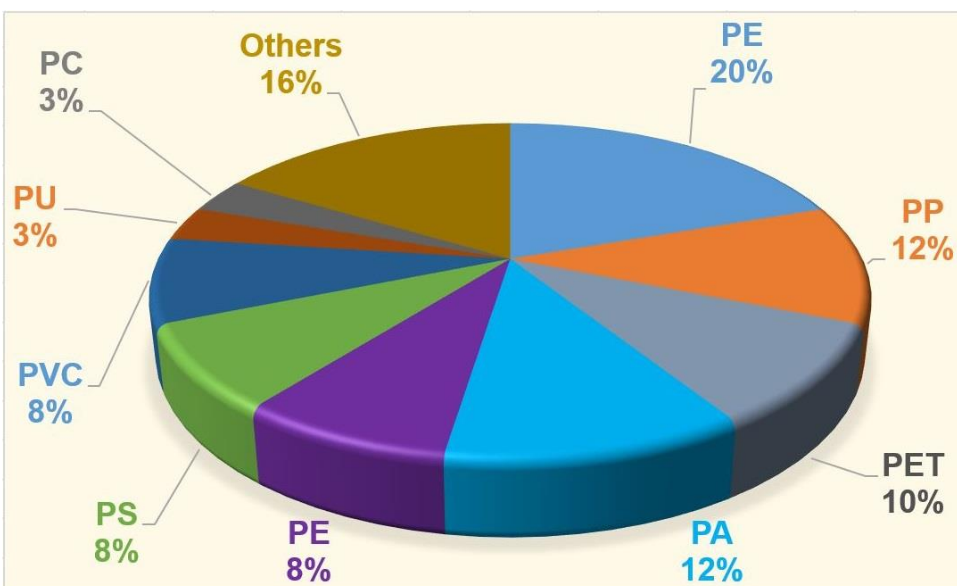

Fig. 3. Statistical data from previous works on the composition of microplastics detected in the environment.

2.2. Source of microplastics

Microplastics are small or very small pieces of plastics, with size of between 1 μm and 5000 μm. 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 fiberous 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 μm 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 as a result of human activities (Hartline et al., 2016; Kole et al., 2017). The source of these microplastics pollutions can come from recreation and tourism activities such as fishing.

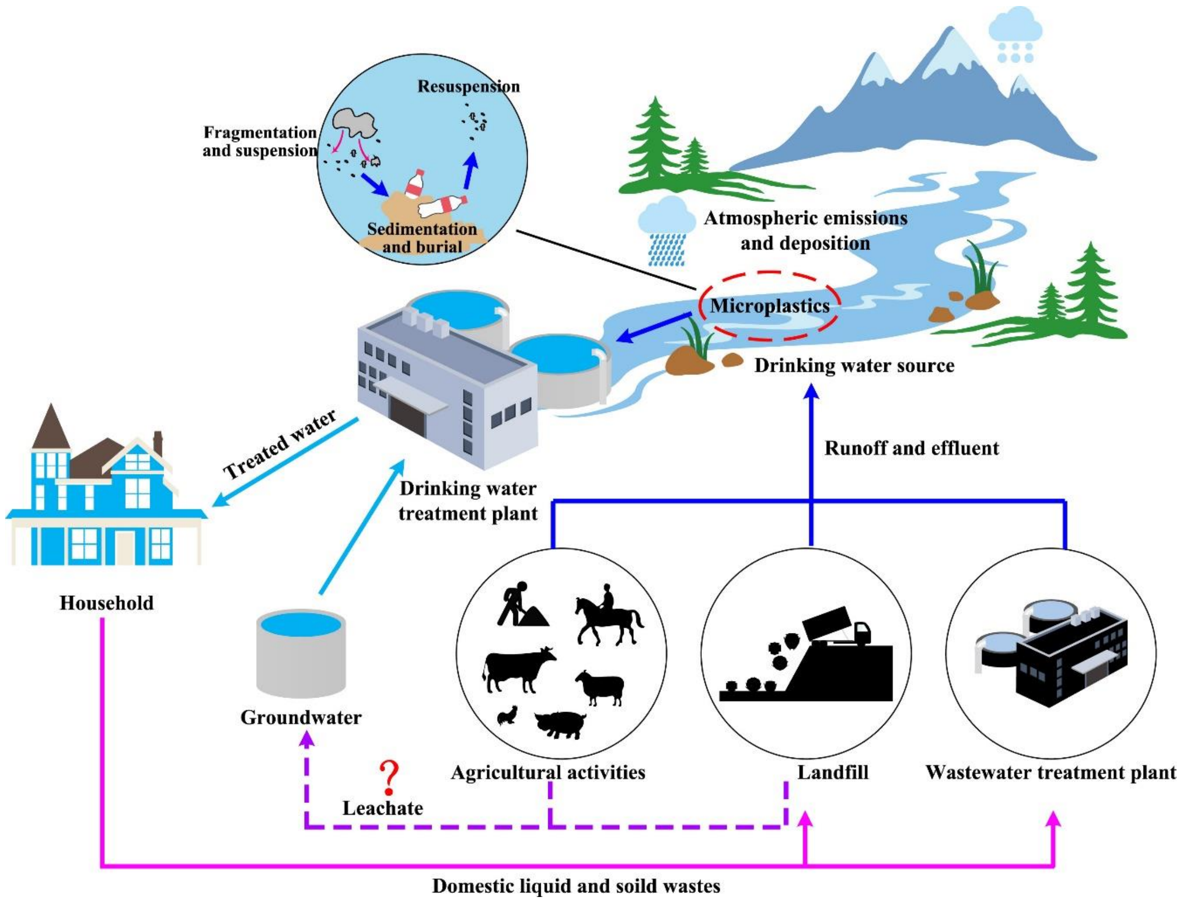

Fig. 4. Occurrence and transport of microplastics in the environment. Reproduced from the reference (Shen et al., 2020) with permission of Elsevier. Copyright © 2020, Elsevier.

2.3. Occurrence of microplastics in the environment

2.3.1. Microplastics in the atmosphere

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

Among atmospheric microplastics, fine particulate matter ($PM_{2.5}$) with size of 2.5 micrometers and smaller is emerging as a major air contaminant. $PM_{2.5}$ are very small particles in the air, and thus, it is very hard to prevent their impacts. The presence of $PM_{2.5}$ in air reduce the visibility, and makes human respiratory system more vulnerable (Xing et al., 2016). As a result, $PM_{2.5}$ is really a 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. Fiberous microplastics accounted for 92% and a density of 575–1,008 particles m^{-2} day^{-1}, which 20 times higher than that in remote area. The presence of plastic fibers(0.6–3.3 m^{-3}) and plastic fragment (5.6–12.6 m^{-3}) 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.

2.3.2. Microplastics in aquatic environment

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

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

2.3.3. Microplastics in soil

Microplastics present in soil are stored, translocated, and degraded into secondary microplastics, which can leach out groundwater sources. He et al. (2018) suggested that soil biota can influence the accumulation and fate of microplastics. It was reported that microplastics strongly affect the physicochemical and biological properties of soil. Indeed, they can change the soil microbial communities and soil functions (Guo et al., 2020). Many works also demonstrated negative impacts of microplastics on seed germination and plant growth (Huang et al., 2022; F. Wang et al., 2020; B. Xu et al., 2020). Depending on plastic type, size, and content, influence of microplastics on soil and soil organisms can be varied.

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

3. Analytical methods of microplastics

3.1. Visual observation

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

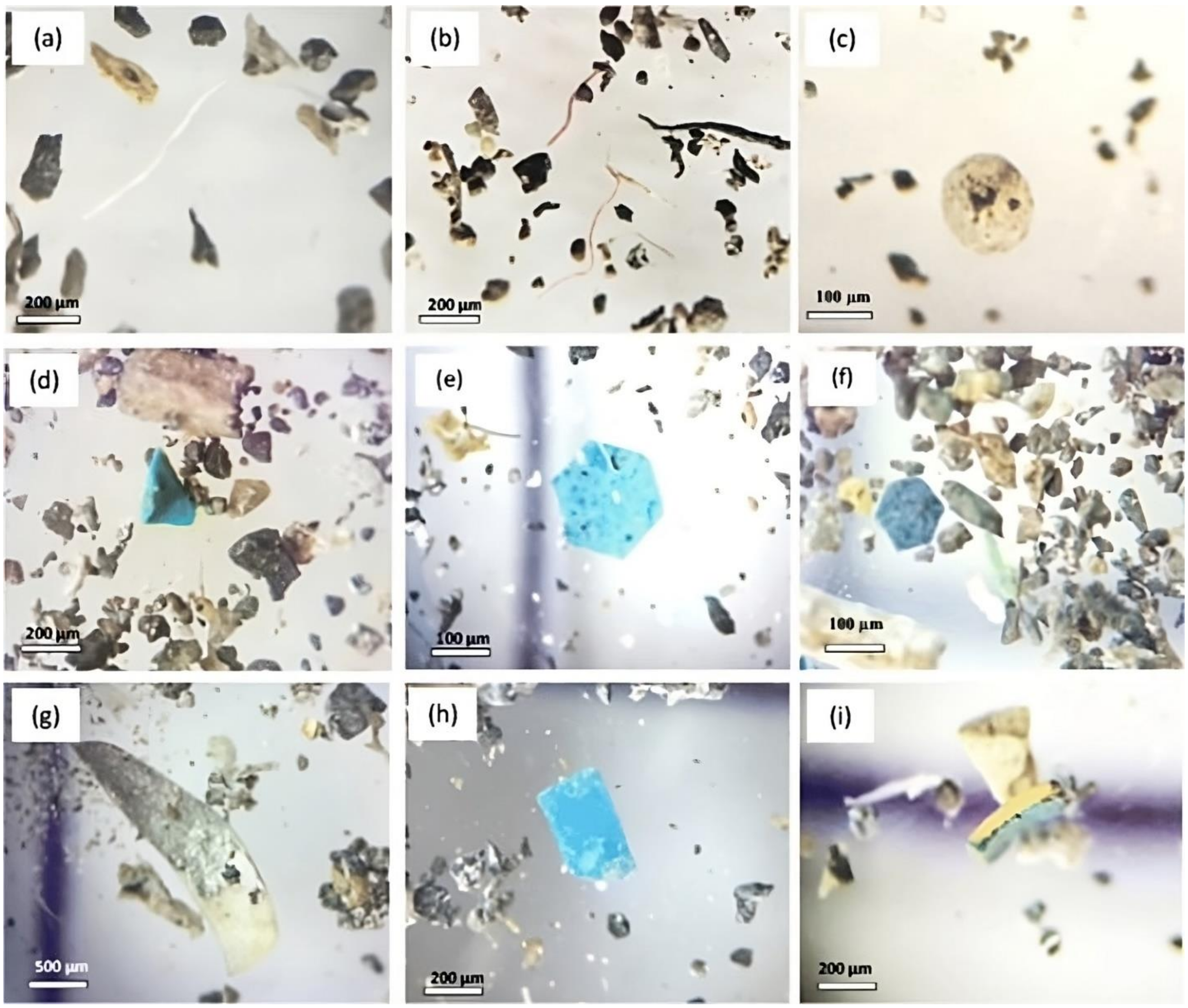

Fig. 5. Optical microscope images of microplastics such as (a) transparent fiber, (b) red fiber, (c) transparent sphere, (d) green granule, (e, f) blue hexagonal fragments, (g) white granule covered with silver shiny film, (h) blue granule, and (i) sample of microplastics fragments. Reproduced

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

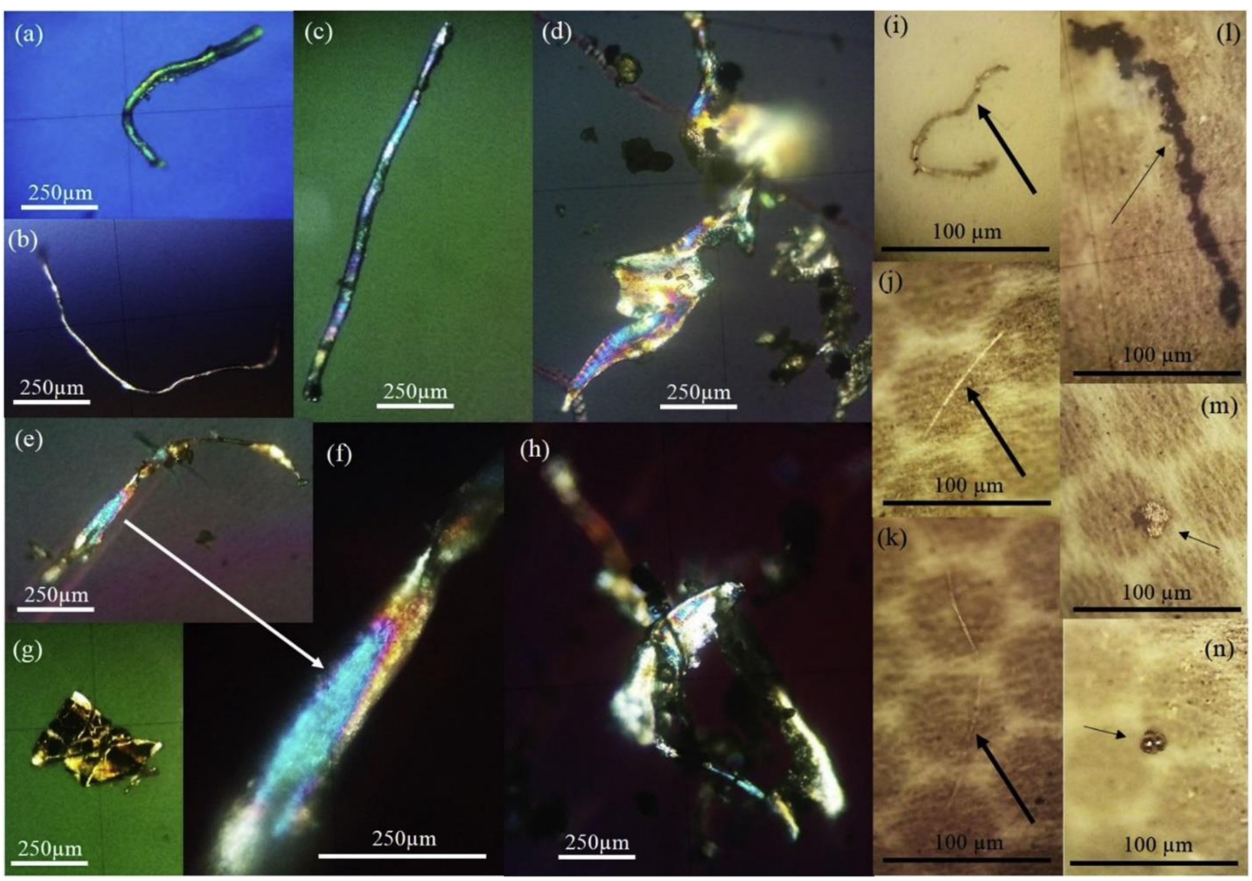

Fig. 6. Polarized-light microscopic images of (a-c) microplastic fibers (d-f, h) film-like microplastics, (g) a fragmented microplastic, (i-k) microplastic fibers, (l) fibrous microrubbers, (m-n) metallic particles in air filter. Reproduced from the reference (Abbasi et al., 2019) with permission of 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 μm) (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 mm), μ-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 μm) (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 should be conducted before a regular measurement. In summary, the biggest disadvantage of FTIR-based method for identification of microplastics is time-consuming, just appropriate with well-trained spectral technicians (Xu et al., 2019). Therefore, this technique is just applied with selected samples rather than screening samples.

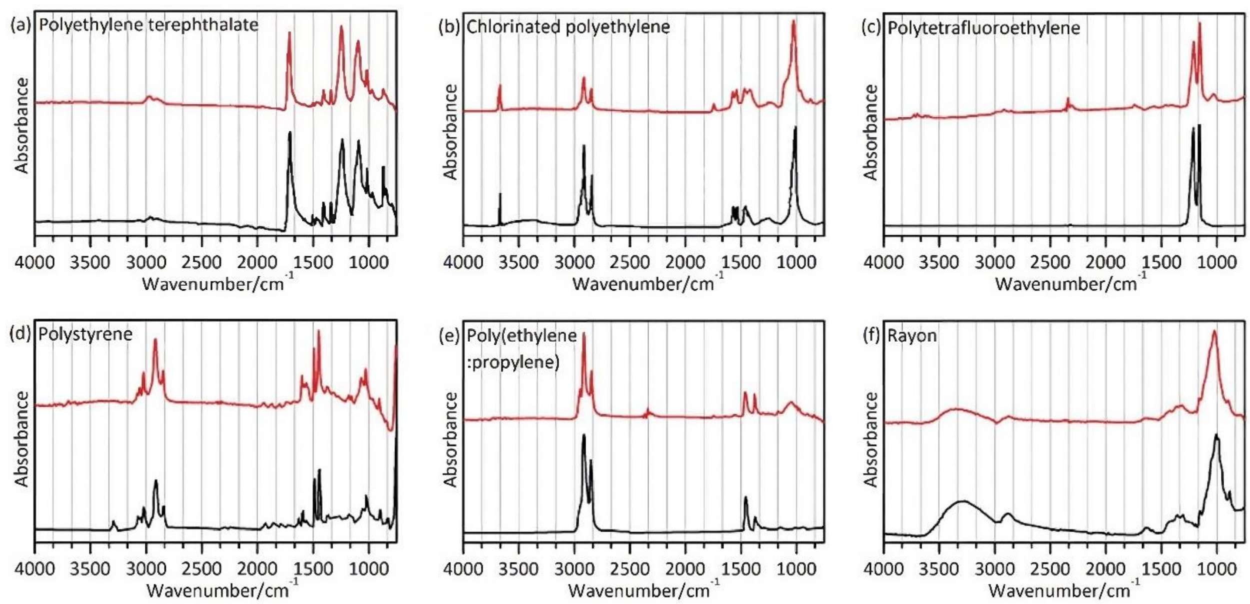

Fig. 7. An example of FTIR technique for identification of microplastics (top, red color) and spectra from the Sadtler Library (bottom, black color) as references. Microplastics includes (a) polyethylene terephthalate, (b) chlorinated polyethylene, (c) polytetrafluoroethylene, (d) polystyrene, (e) poly(ethylene 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).

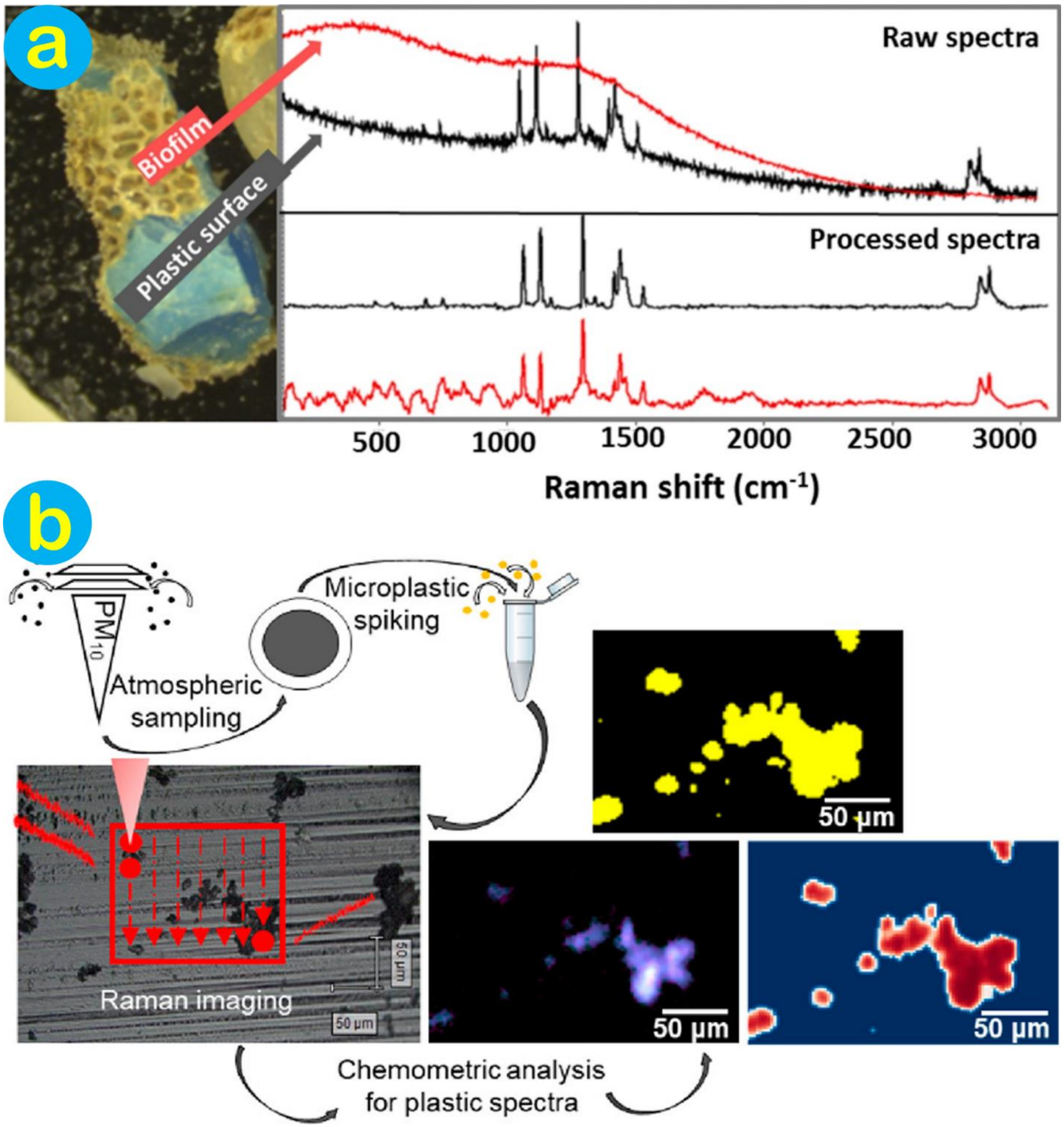

Fig. 8. (a) Raman spectra of a trawl (polyethylene) particle with biofilm covering. Reproduced from the reference (Ghosal et al., 2018). with permission of Elsevier. Copyright © 2018, Elsevier. (b) An illustration of Raman spectral imaging combined with chemometric analysis for detection of both virgin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

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

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

3.4. Scanning electron microscopy

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

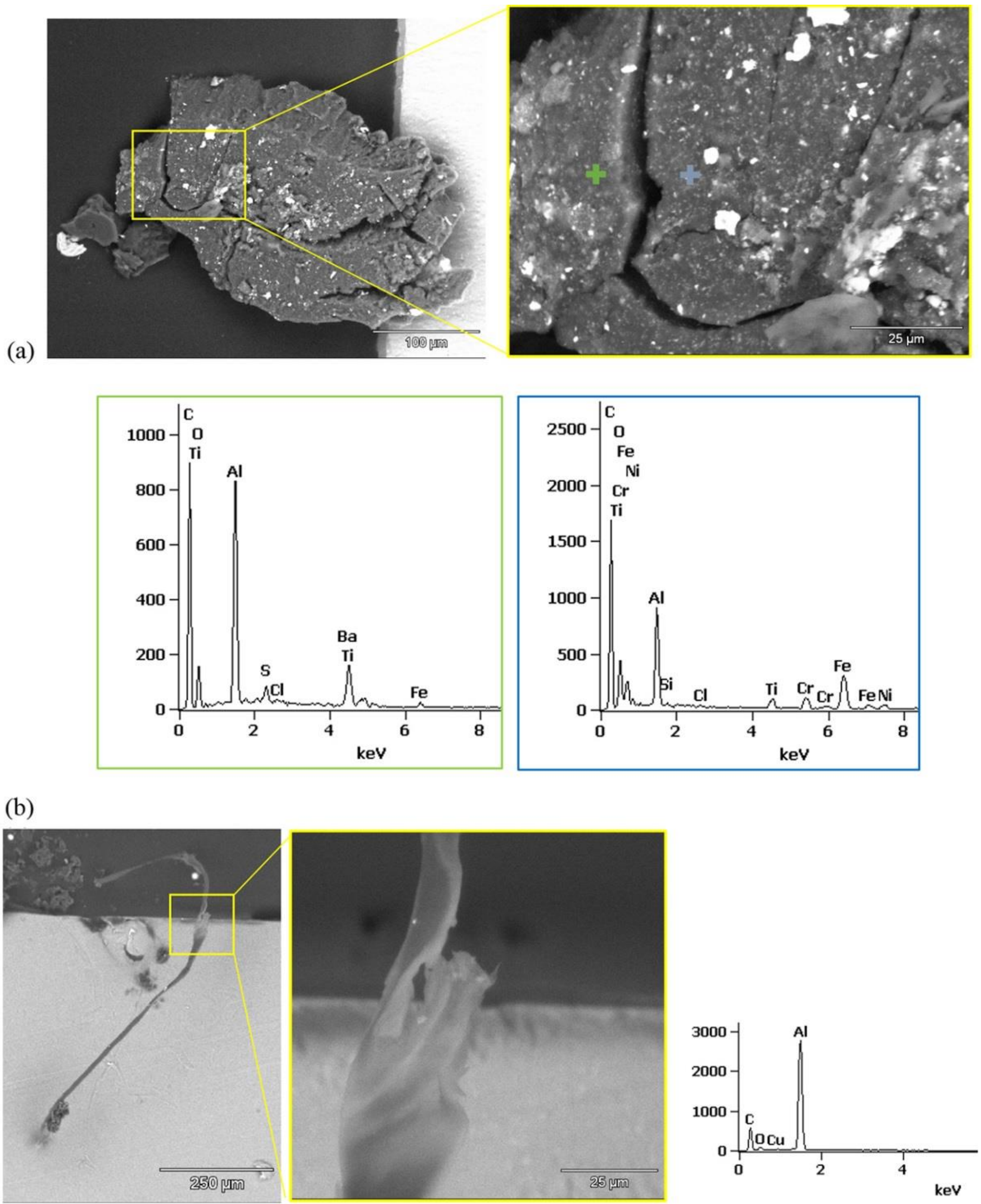

Fig. 9. (a) The SEM-EDS spectra of degraded microplastics with the surface and chemical composition. (b) Polyethylene terephthalate fiber from a fish sample with carbon and oxygen as main components. Reproduced from the reference (Wagner et al., 2019) with permission of ACS. Copyright © 2019, American 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 no 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

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

4. Environmental and health impacts

4.1. Environmental impacts

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

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

4.2. Health impacts

Major exposure of microplastics on human health can be through inhalation, ingestion and dermal contact pathways. Microplastics widely present in both indoor and outdoor urban atmospheres; and thus, their effect on human health though inhalation is worth considering (Y. Wang et al., 2021; Wu et al., 2022). For example, Yang et al. (2022b) assessed harmful impacts (e.g., pathogen and infections) of microplastics exposure on human lung and respiratory system. Prata (2018b) found that airborne microplastics caused dyspnea symptoms as well as airway and interstitial inflammatory responses in exposed workers. Some hazardous pollutants such as heavy metal dusts and pesticides or pharmaceutical drugs can be adsorbed onto microplastics (Gao et al., 2021). They act as vectors and subsequently enter the human body through inhalation, resulting in many potential threats such as lung malfunctions and cancers. However, there are very few solid evidences of what health problems and how the effects of microplastics on inhalation system are (Prata, 2018a). We recommend that more investigations of the effect of microplastics on respiratory system should be undertaken insightfully.

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

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

5. Challenges and research future

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

For the detection of microplastics in the environment, lacks of equivalence and analytic method standardization as well as inconsistence in sampling collection can be a main issue, making results of monitoring microplastics incomparable (Chen et al., 2020). It is evident that the collection of indoor and outdoor airborne microplastics samples in remote sites is still challenging due to difficulty of power, cost, and analytic instruments. The current sampling and preparation methods are still manual, causing many human errors while the analytic cost remains high (Prata et al., 2019). Moreover, the treatment or reduction of airborne microplastics in atmosphere is not a simple task once the weathering factors significantly dominate. It is urgently suggested to develop new sampling methods, as well as global analytic standardization for facilitating microplastics studies.

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

6. Conclusions

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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Conflicts of interest/Competing interests

The authors declare that there are no conflicts of interest.

Availability of data and material

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

Compliance with Ethical Standards

The authors declare that

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

Code availability

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

Authors contributions

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.

All authors read and approved the final manuscript.

Ethics approval

Not applicable

Consent to participate

Not applicable

Consent for publication

Not applicable

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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 µm	Visual detection, FTIR-ATR	0.35–2,522 items 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 µm	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 µm	Stereo-microscope	3,183–10,950 items m^{-3}	(S. Wang et al., 2020)
Dian Lake, China	Cropped and buffer soils	Not reported	Fiber, fragment, film; 500–1,000 µm	Visual detection	7,100–12,200 particles 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 µm (41.2%), 50–150 µm (30.67%), 150–300 µm (28.17%)	Stereo-microscope	71,750–42,960 particles 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 µm	Stereo-microscope	600–10,400 particles 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 µm (72.84%) and > 300 mm (27.16%)	FTIR	340 particles kg^{-1}	(Piehl et al., 2018)

Swiss Geoportal, Switzerland	Floodplain soils	Polypropylene, polyethylene, polyvinyl chloride, polyamide, polycarbonate, and styrene butadiene	Film and fragment; < 1000 μm	FTIR	<593 particles 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 kg^{-1}	(Fuller and Gautam, 2016)
Paris, France	Atmospheric fallout	Polyethylene terephthalate, polyamide, polyurethane	Fiber, 50–5000 μm	FTIR-ATR	110 particles m^{-2} day^{-1} (urban), 53 particles m^{-2} day^{-1} (sub-urban)	(Dris et al., 2016)
Paris, France	Indoor and outdoor airs	Polyester, polyamide, polypropylene	Fiber; 50–1650 μm (outdoor), 50–3250 μm (indoor)	FTIR-ATR	1–60 fibers m^{-3} (indoor), 0.3–1.5	(Dris et al., 2017)

					fibers m^{-3} (outdoor)	
Asaluyeh County, Iran	Airborne dusts	Not reported	Fiber; 2–100 μm	Fluorescence, polarized light, SEM	1 fiber m^{-3}	(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^{-2} day^{-1}	(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^{-3}, 5.6–12.6 fragment m^{-3}	(Gaston et al., 2020)
London, UK	Airborne indoor and outdoor	Polyamide, polyaryonitrile, polyethersulfone,	Fiber (92%), others (fragment,	FTIR	575–1,008 particles m^{-2} day^{-1}	(Wright et al., 2020)

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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Abstract

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, inconsistence 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.

Keywords: Microplastics; occurrence; analytical methods; health impact; environmental 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 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 ($PM_{2.5}$) 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.

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

2. Classification, source and occurrence of microplastics

2.1. Classification of microplastics

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

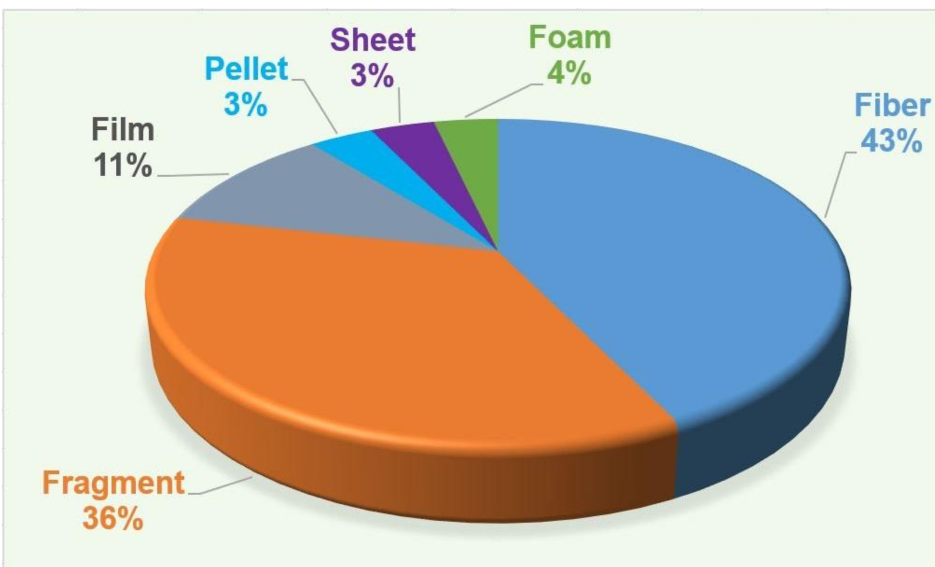

Fig. 1. Statistical data from previous works on the proportion of microplastics (fiber, fragment, film, foam, pellet, sheet) in the environment.

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

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

- Polyvinyl chloride (PVC): PVC was firstly synthesized in 1872 by German chemist Eugen Baumann. In his experiment, vinyl chloride gas a sealed tube was exposed under sunlight and polyvinyl chloride was produced as a white solid. From there, PVC has been become one of the widely used plastic in the world. Many technologies have also applied to optimize the production of polyvinyl chloride and reduce its by-products (Asadinezhad et al., 2012). This polymer is typically a synthetic resin having chemical formula $(C_2H_3Cl)_n$. It is estimated that about 40 million tons of polyvinyl chloride are produced annually. There are two major kinds of PVC, including rigid and flexible types. Polyvinyl chloride has valuable properties such as electric insulation, durability, flame retardancy, chemical and heat resistance. Therefore, PVC is a main component in the manufacturing of pipes, medical devices, electric wires, and cable insulation.
- Polymethyl methacrylate (PMMA): this plastic is a synthetic product of polymerization of methyl methacrylate (CH_2=C[CH_3]CO_2H). Polymethyl methacrylate was firstly developed in 1928 by many scientists. This polymer is transparent and rigid, often called “engineering plastics”, and used as a substitute for glass, involving optical devices, shatterproof windows, skylights, and aircraft canopies. Polymethyl methacrylate has many important properties such as good tensile and flexural strength, high transparency, UV tolerance.

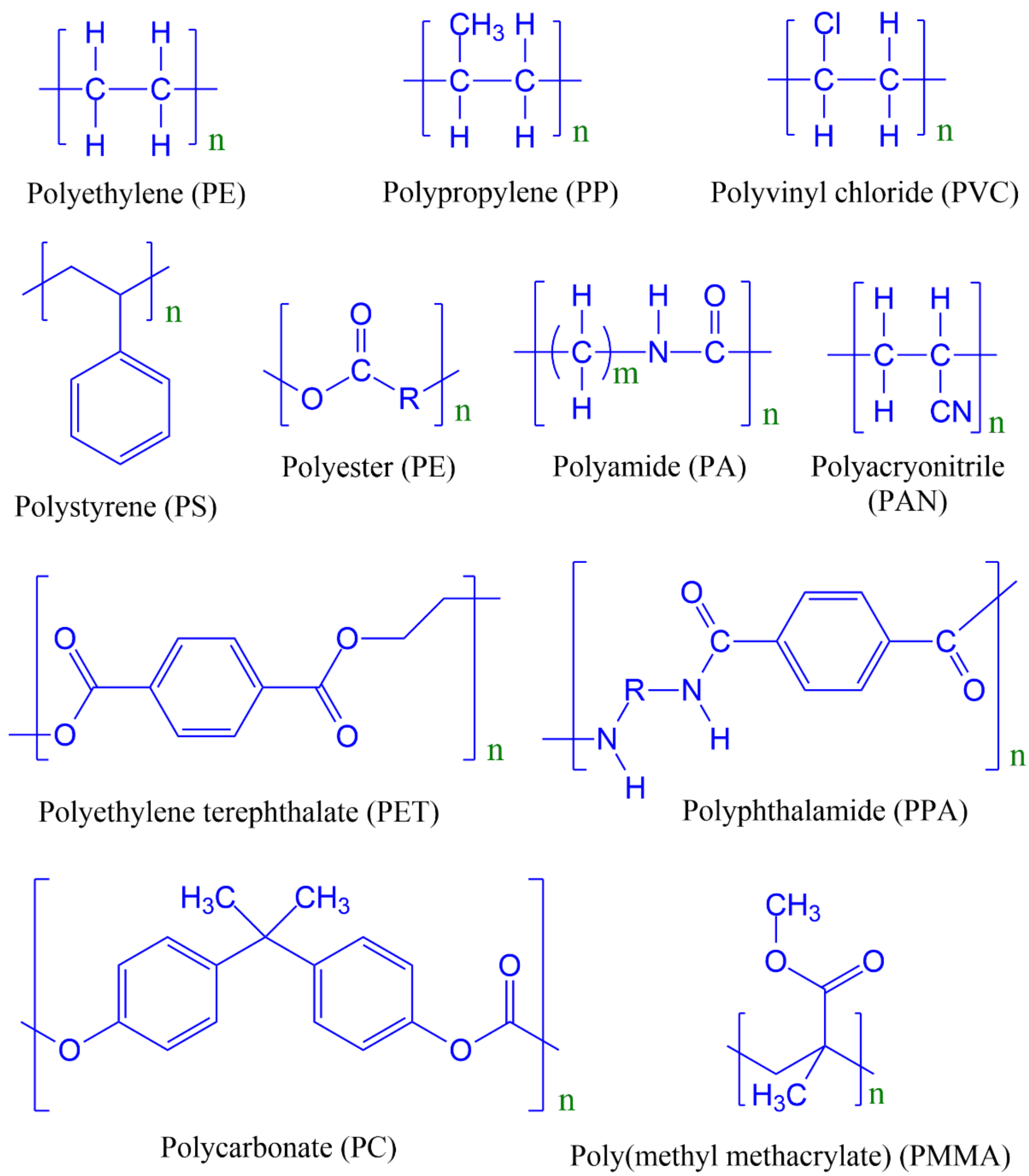

Fig. 2. Molecular structure of several common microplastics including polyethylene (PE), polypropylene (PP), polyvinyl chloride (PVC), polystyrene (PS), polyester (PE), polyamide (PA), polyaryonitrile (PAN), polyethylene terephthalate (PET), polyphthalamide (PPA), polycarbonate (PC) and poly(methyl methacrylate) (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 various channels such as discharging of personal care products from households, and laundering of clothing made from synthetic textiles (Khadir et al., 2022). There is still limited knowledge of degradation mechanism of primary microplastics into secondary microplastics. As emerging pollutant, however, both primary and secondary microplastics cause harmful effects on the environment and human health.

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

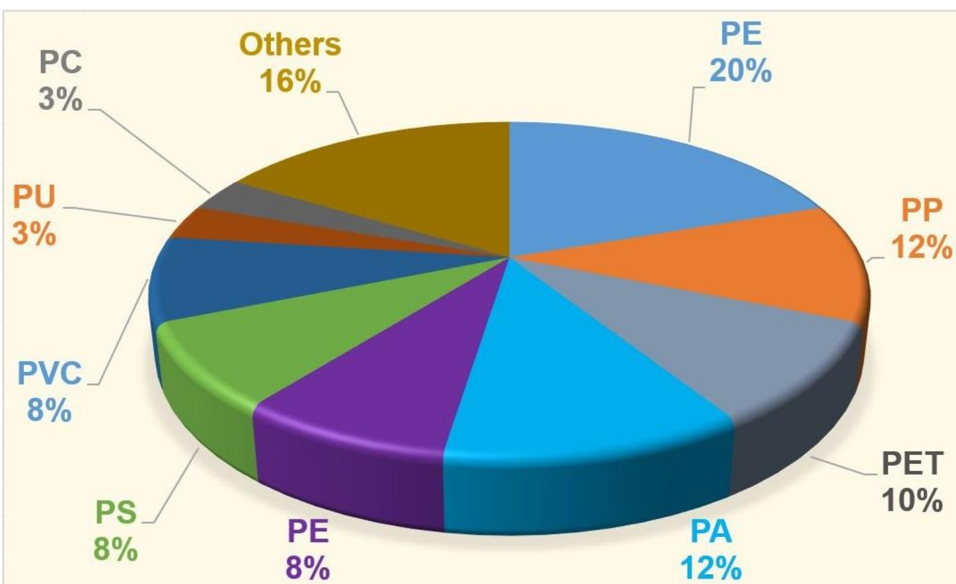

Fig. 3. Statistical data from previous works on the composition of microplastics detected in the environment.

2.2. Source of microplastics

Microplastics are small or very small pieces of plastics, with size of between 1 μm and 5000 μm. 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 fiberous 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 μm 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 as a result of human activities (Hartline et al., 2016; Kole et al., 2017). The source of these microplastics pollutions can come from recreation and tourism activities such as fishing.

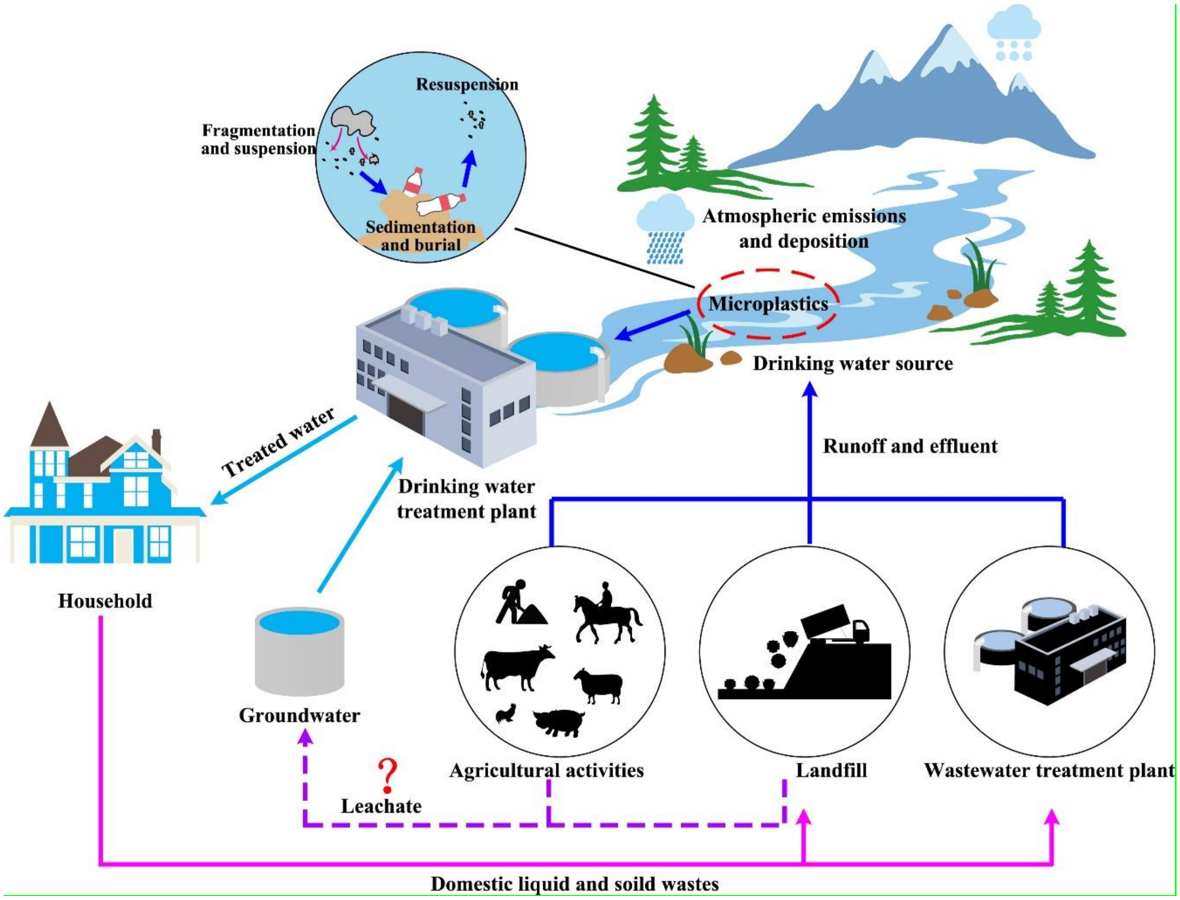

Fig. 4. Occurrence and transport of microplastics in the environment. Reproduced from the reference (Shen et al., 2020) with permission of Elsevier. Copyright © 2020, Elsevier.

2.3. Occurrence of microplastics in the environment

2.3.1. Microplastics in the atmosphere

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

Among atmospheric microplastics, fine particulate matter ($PM_{2.5}$) with size of 2.5 micrometers and smaller is emerging as a major air contaminant. $PM_{2.5}$ are very small particles in the air, and thus, it is very hard to prevent their impacts. The presence of $PM_{2.5}$ in air reduce the visibility, and makes human respiratory system more vulnerable (Xing et al., 2016). As a result, $PM_{2.5}$ is really a 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. Fiberous microplastics accounted for 92% and a density of 575–1,008 particles m^{-2} day^{-1}, which 20 times higher than that in remote area. The presence of plastic fibers(0.6–3.3 m^{-3}) and plastic fragment (5.6–12.6 m^{-3}) 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.

2.3.2. Microplastics in aquatic environment

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

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

2.3.3. Microplastics in soil

Microplastics present in soil are stored, translocated, and degraded into secondary microplastics, which can leach out groundwater sources. He et al. (2018) suggested that soil biota can influence the accumulation and fate of microplastics. It was reported that microplastics strongly affect the physicochemical and biological properties of soil. Indeed, they can change the soil microbial communities and soil functions (Guo et al., 2020). Many works also demonstrated negative impacts of microplastics on seed germination and plant growth (Huang et al., 2022; F. Wang et al., 2020; B. Xu et al., 2020). Depending on plastic type, size, and content, influence of microplastics on soil and soil organisms can be varied.

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

3. Analytical methods of microplastics

3.1. Visual observation

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

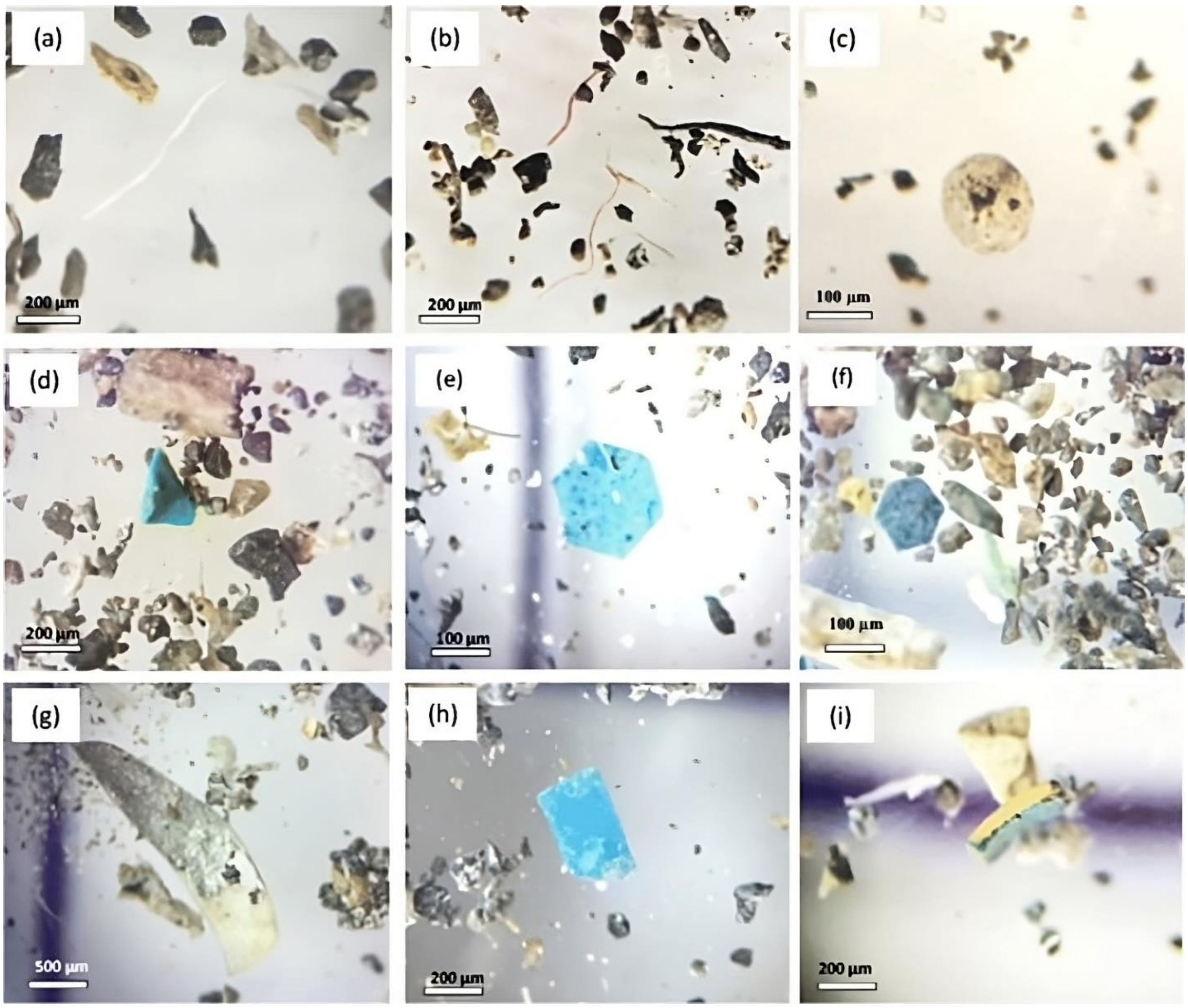

Fig. 5. Optical microscope images of microplastics such as (a) transparent fiber, (b) red fiber, (c) transparent sphere, (d) green granule, (e, f) blue hexagonal fragments, (g) white granule covered with silver shiny film, (h) blue granule, and (i) sample of microplastics fragments. Reproduced

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

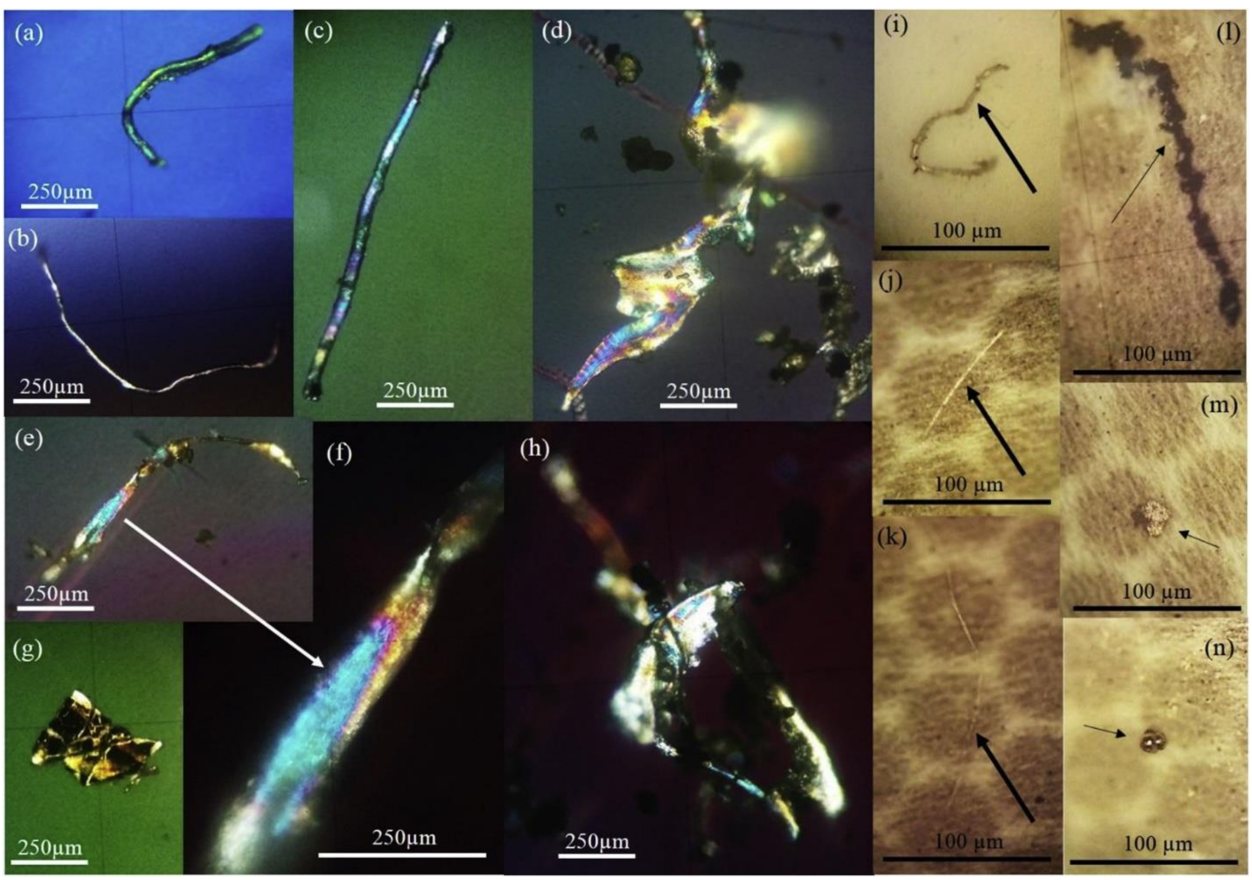

Fig. 6. Polarized-light microscopic images of (a-c) microplastic fibers (d-f, h) film-like microplastics, (g) a fragmented microplastic, (i-k) microplastic fibers, (l) fibrous microrubbers, (m-n) metallic particles in air filter. Reproduced from the reference (Abbasi et al., 2019) with permission of 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 μm) (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 mm), μ-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 μm) (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 should be conducted before a regular measurement. In summary, the biggest disadvantage of FTIR-based method for identification of microplastics is time-consuming, just appropriate with well-trained spectral technicians (Xu et al., 2019). Therefore, this technique is just applied with selected samples rather than screening samples.

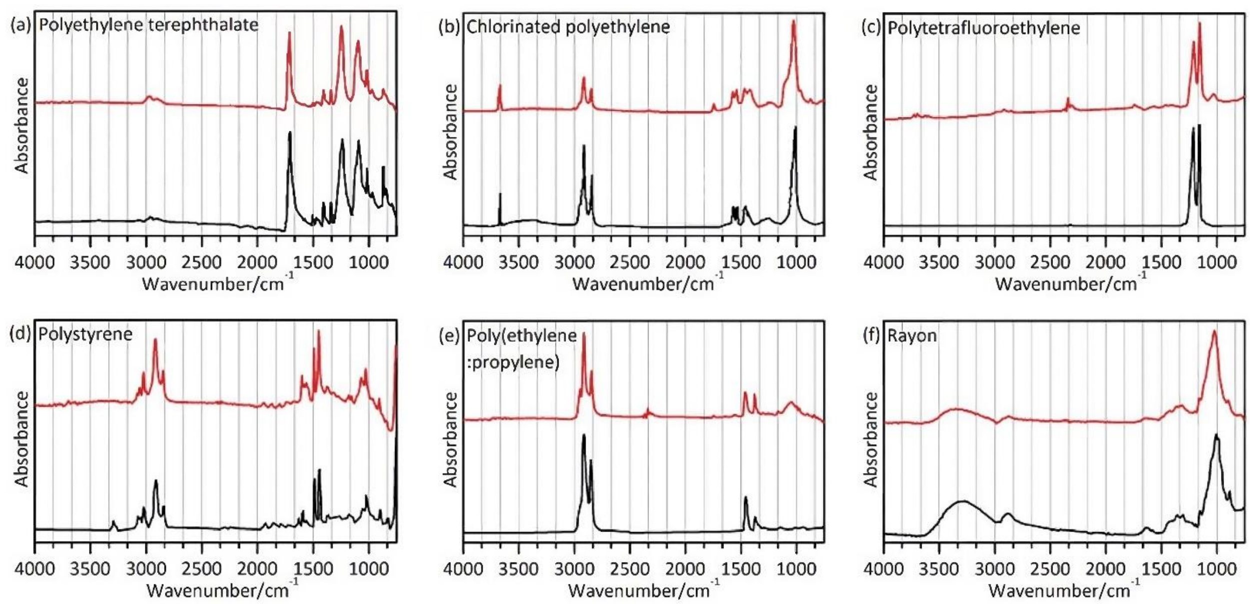

Fig. 7. An example of FTIR technique for identification of microplastics (top, red color) and spectra from the Sadtler Library (bottom, black color) as references. Microplastics includes (a) polyethylene terephthalate, (b) chlorinated polyethylene, (c) polytetrafluoroethylene, (d) polystyrene, (e) poly(ethylene 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).

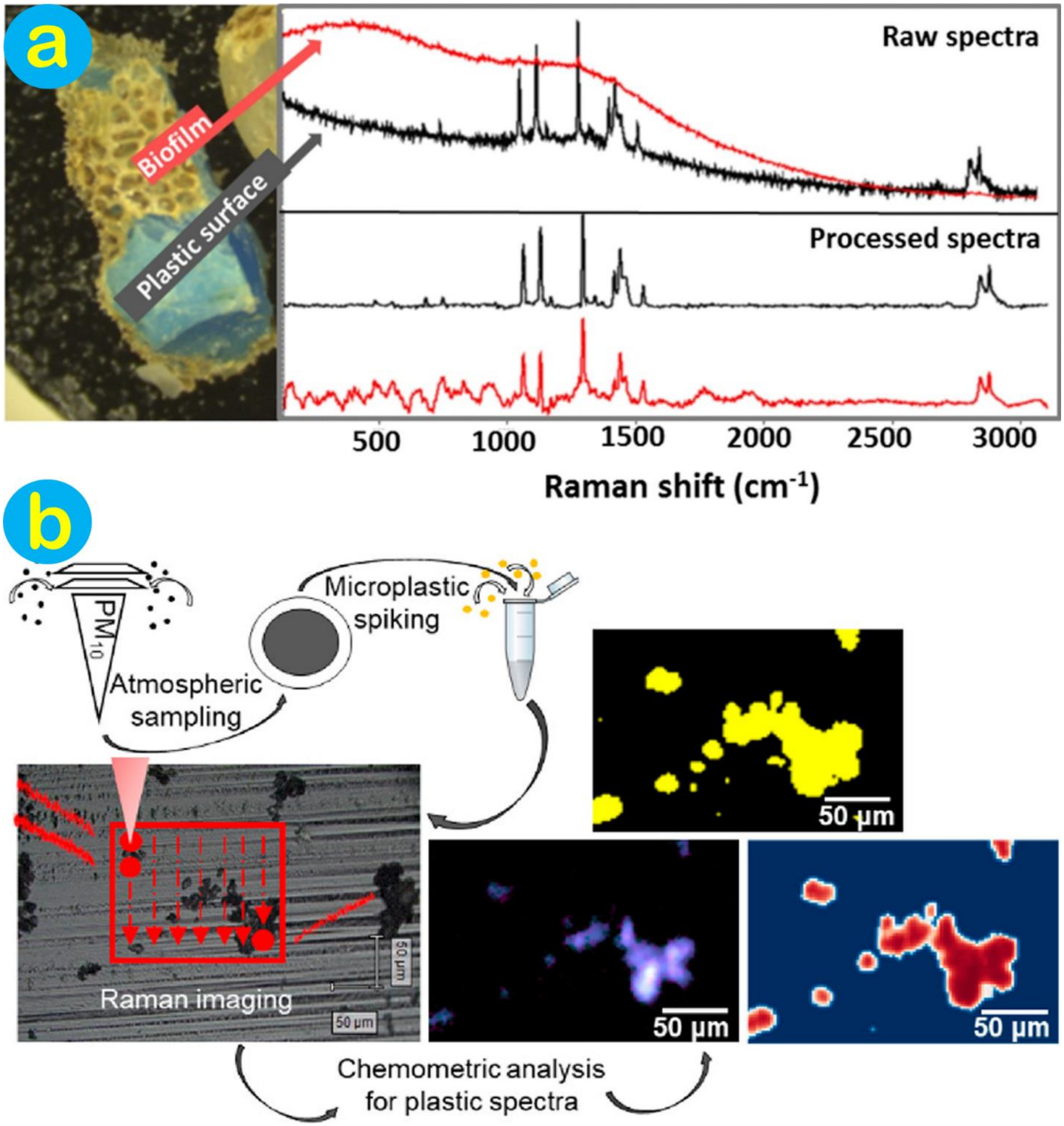

Fig. 8. (a) Raman spectra of a trawl (polyethylene) particle with biofilm covering. Reproduced from the reference (Ghosal et al., 2018). with permission of Elsevier. Copyright © 2018, Elsevier. (b) An illustration of Raman spectral imaging combined with chemometric analysis for detection of both virgin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

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

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

3.4. Scanning electron microscopy

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

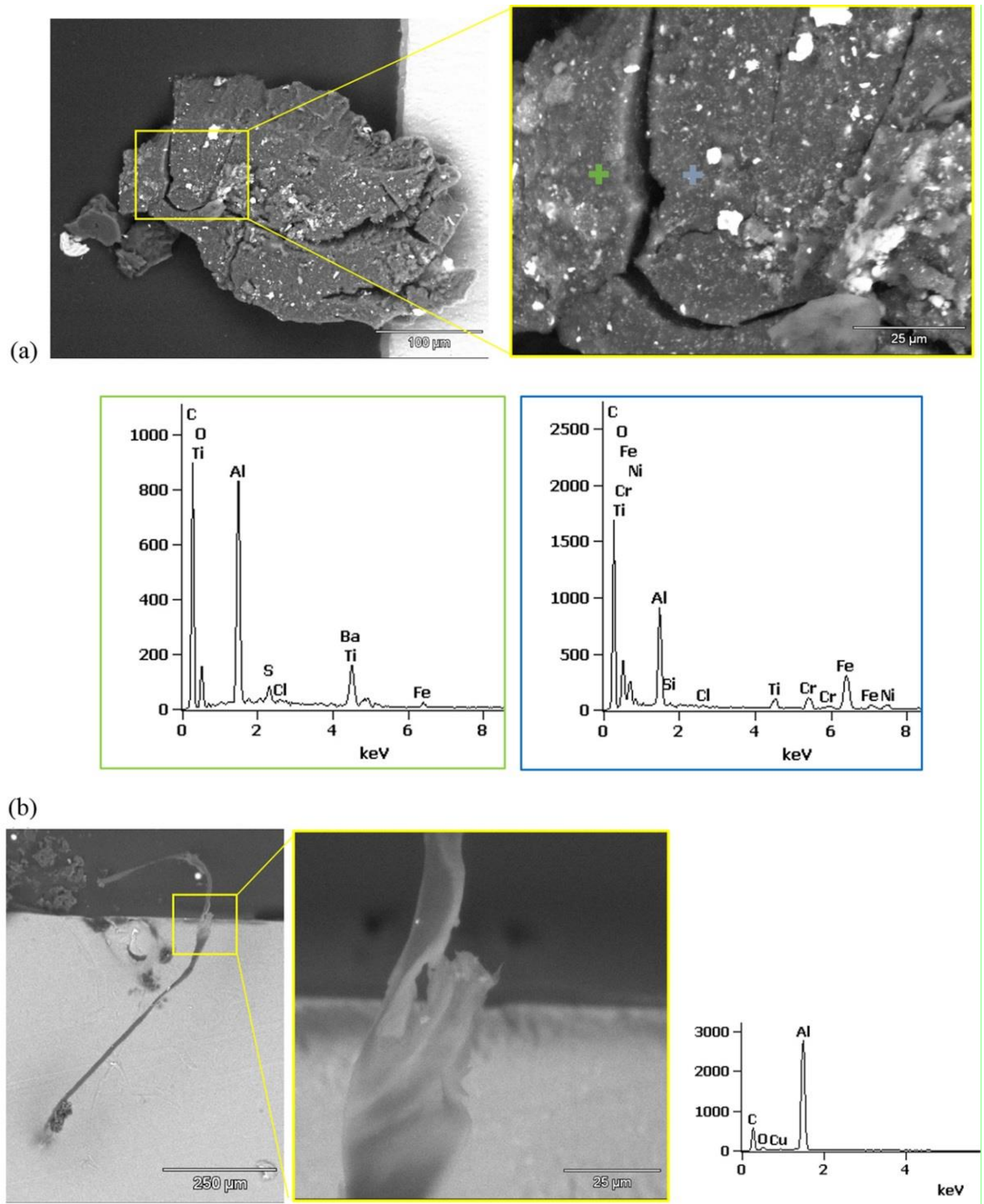

Fig. 9. (a) The SEM-EDS spectra of degraded microplastics with the surface and chemical composition. (b) Polyethylene terephthalate fiber from a fish sample with carbon and oxygen as main components. Reproduced from the reference (Wagner et al., 2019) with permission of ACS. Copyright © 2019, American 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 no 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

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

4. Environmental and health impacts

4.1. Environmental impacts

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

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

4.2. Health impacts

Major exposure of microplastics on human health can be through inhalation, ingestion and dermal contact pathways. Microplastics widely present in both indoor and outdoor urban atmospheres; and thus, their effect on human health though inhalation is worth considering (Y. Wang et al., 2021; Wu et al., 2022). For example, Yang et al. (2022b) assessed harmful impacts (e.g., pathogen and infections) of microplastics exposure on human lung and respiratory system. Prata (2018b) found that airborne microplastics caused dyspnea symptoms as well as airway and interstitial inflammatory responses in exposed workers. Some hazardous pollutants such as heavy metal dusts and pesticides or pharmaceutical drugs can be adsorbed onto microplastics (Gao et al., 2021). They act as vectors and subsequently enter the human body through inhalation, resulting in many potential threats such as lung malfunctions and cancers. However, there are very few solid evidences of what health problems and how the effects of microplastics on inhalation system are (Prata, 2018a). We recommend that more investigations of the effect of microplastics on respiratory system should be undertaken insightfully.

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

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

5. Challenges and research future

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

For the detection of microplastics in the environment, lacks of equivalence and analytic method standardization as well as inconsistence in sampling collection can be a main issue, making results of monitoring microplastics incomparable (Chen et al., 2020). It is evident that the collection of indoor and outdoor airborne microplastics samples in remote sites is still challenging due to difficulty of power, cost, and analytic instruments. The current sampling and preparation methods are still manual, causing many human errors while the analytic cost remains high (Prata et al., 2019). Moreover, the treatment or reduction of airborne microplastics in atmosphere is not a simple task once the weathering factors significantly dominate. It is urgently suggested to develop new sampling methods, as well as global analytic standardization for facilitating microplastics studies.

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

6. Conclusions

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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Conflicts of interest/Competing interests

The authors declare that there are no conflicts of interest.

Availability of data and material

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

Compliance with Ethical Standards

The authors declare that

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

Code availability

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

Authors contributions

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.

All authors read and approved the final manuscript.

Ethics approval

Not applicable

Consent to participate

Not applicable

Consent for publication

Not applicable

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873 **Table 1. S**ources, 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 µm	Visual detection, FTIR-ATR	0.35–2,522 items 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 µm	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 µm	Stereo-microscope	3,183–10,950 items m^{-3}	(S. Wang et al., 2020)
Dian Lake, China	Cropped and buffer soils	Not reported	Fiber, fragment, film; 500–1,000 µm	Visual detection	7,100–12,200 particles 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 µm (41.2%), 50–150 µm (30.67%), 150–300 µm (28.17%)	Stereo-microscope	71,750–42,960 particles 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 µm	Stereo-microscope	600–10,400 particles 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 µm (72.84%) and > 300 mm (27.16%)	FTIR	340 particles kg^{-1}	(Piehl et al., 2018)

Swiss Geoportal, Switzerland	Floodplain soils	Polypropylene, polyethylene, polyvinyl chloride, polyamide, polycarbonate, and styrene butadiene	Film and fragment; < 1000 µm	FTIR	<593 particles 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 kg^{-1}	(Fuller and Gautam, 2016)
Paris, France	Atmospheric fallout	Polyethylene terephthalate, polyamide, polyurethane	Fiber, 50–5000 µm	FTIR-ATR	110 particles m^{-2} day^{-1} (urban), 53 particles m^{-2} day^{-1} (sub-urban)	(Dris et al., 2016)
Paris, France	Indoor and outdoor airs	Polyester, polyamide, polypropylene	Fiber; 50–1650 µm (outdoor), 50–3250 µm (indoor)	FTIR-ATR	1–60 fibers m^{-3} (indoor), 0.3–1.5	(Dris et al., 2017)

					fibers m^{-3} (outdoor)	
Asaluyeh County, Iran	Airborne dusts	Not reported	Fiber; 2–100 µm	Fluorescence, polarized light, SEM	1 fiber m^{-3}	(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^{-2} day^{-1}	(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^{-3}, 5.6–12.6 fragment m^{-3}	(Gaston et al., 2020)
London, UK	Airborne indoor and outdoor	Polyamide, polyaryonitrile, polyethersulfone,	Fiber (92%), others (fragment,	FTIR	575–1,008 particles m^{-2} day^{-1}	(Wright et al., 2020)

polyamide,	film, foam)
polypropylene,	(8%)
polyvinyl chloride,	
polystyrene,	
polyurethane	