



MICROPLASTIC POLLUTION IN MALAYSIA: STATUS AND CHALLENGES – A BRIEF OVERVIEW

(Pencemaran Mikroplastik di Malaysia: Status dan Cabaran – Suatu Tinjauan Ringkas)

Nurul Shahfiza Noor^{1,2}, Noorfatimah Yahaya^{1,2}, Nur Nadhirah Mohamad Zain^{1,2}, Nik Nur Syazni Nik Mohamed Kamal^{1,2}, Mohd Syahir Mansor^{2,3}, Mohd Yusmaidie Aziz^{1,2}, and Maisarah Nasution Waras^{1,2*}

¹*Department of Toxicology, Advanced Medical and Dental Institute (AMDI), Universiti Sains Malaysia, Bertam, 13200 Kepala Batas, Penang, Malaysia*

²*Advanced Management Liver Malignancies Research (Liver-ENRICH) Program, Advanced Medical and Dental Institute (AMDI), Universiti Sains Malaysia, Bertam, 13200 Kepala Batas, Penang, Malaysia*

³*Biomedical Imaging Department, Advanced Medical and Dental Institute (AMDI), Universiti Sains Malaysia, Bertam, 13200 Kepala Batas, Penang, Malaysia*

*Corresponding author: maisarah.waras@usm.my

Received: 3 April 2024; Accepted: 15 May 2024; Published: 29 June 2024

Abstract

Microplastics (MPs) are widespread and infiltrate the environment through unregulated use in diverse industrial processes such as the manufacturing of cleaning products, cosmetics, fertilizers, and pharmaceuticals, as well as from the degradation of larger plastic items. Due to this ubiquitous nature, combined with the fact that MPs possess the capacity for biomagnification within the food chain, MPs may constitute a major threat to human health. Hence, the scientific community and regulatory authorities are increasingly focusing their attention on this issue, leading to continuous developments in both legislation and the scientific literature concerning MPs. The review aims to provide an overview of the state-of-the-art occurrences of MPs, identification, detection, and quantification of MPs, degradation of MPs, and health effects of MPs from the perspective of Malaysia. A brief overview of the latest scientific research and recent developments on MPs (until the year 2024) will provide insights into the current understanding of MPs and their health implications. Furthermore, this review will serve as a valuable reference for further studies related to MPs in Malaysia and could help in informing future policy decisions.

Keywords: Microplastic, emerging contaminants, occurrence, analytical methods, degradation

Abstrak

Mikroplastik (MPs) adalah sebaran meluas dan meresap ke dalam alam sekitar melalui penggunaan yang tidak terkawal dalam pelbagai proses industri seperti pengilangan produk pembersihan, kosmetik, baja, dan farmaseutikal, serta daripada peluruhan bahan plastik yang lebih besar. Disebabkan sifatnya yang meluas ini, serta hakikat bahawa MPs mempunyai kapasiti untuk biomagnifikasi dalam rantai makanan, MPs boleh menjadi ancaman besar kepada kesihatan manusia. Oleh itu, komuniti saintifik dan pihak berkuasa bagi pengawalan semakin memberi tumpuan kepada isu ini, yang membawa kepada perkembangan berterusan dalam perundangan dan literatur saintifik mengenai MPs. Tinjauan ini bertujuan untuk memberikan gambaran keseluruhan tentang kejadian MPs, pengenpastian, pengesanan, dan pengukuran MPs, degradasi MPs, dan kesan kesihatan MPs dari perspektif Malaysia. Gambaran ringkas tentang penyelidikan saintifik terkini dan perkembangan terkini berkaitan dengan MPs (sehingga

tahun 2024) akan memberikan pemahaman semasa tentang MPs dan implikasinya kepada kesihatan. Selain itu, tinjauan ini boleh dijadikan sebagai rujukan yang berharga untuk kajian lanjutan berkaitan dengan MPs di Malaysia dan boleh membantu dalam membentuk keputusan dasar pada masa akan datang.

Kata kunci: mikroplastik, pencemar baharu, kemunculan, kaedah analisis, degradasi

Introduction

Microplastics (MPs) are scientifically defined as plastic fragments with sizes of less than 5 mm and are of different shapes, sizes, and polymer compositions [1]. MPs are further classified into two, which are primary and secondary MPs [2]. Primary MPs, including polyethylene (PE), polypropylene (PP), and polystyrene (PS) particles, are derived from many different sources [3], while secondary MPs originate through physical, chemical, and biological processes that lead to the breakdown of plastic debris [4, 5]. Researchers estimate that ten million metric tons of plastic waste and MPs enter the oceans every year and project that the total amount of plastic waste circulating the world's oceans will be 150 million tons by 2025 [6]. Malaysia has one of the largest plastic production industries globally comprising more than 1,300 plastic manufacturers. In 2016, Malaysia exported resin products with a total value of RM30 billion Malaysian Ringgits (RM) to plastic manufacturers worldwide [7]. The plastic industry in Malaysia is segmented into seven main sectors including agriculture, household products, packaging, construction, electronics, automotive, and others such as furniture and medical devices [7]. In Asia, the percentage of plastic in solid wastes generated in Malaysia ranks second after the Philippines [8]. In 2020, roughly 148,000 tons of plastic were used for food packaging in Malaysia [9]. Based on the Worldwide Fund (WWF) report, Malaysians are among the biggest per-capita plastic packaging users in South-East Asia and the region is responsible for more than half of the plastic litter in the world's oceans. It is reported too, that Malaysia produced 0.94 million tons of improperly disposed of plastic waste, of which 0.14 to 0.37 million tonnes may have potentially leaked into the ocean [10]. The country was thus, ranked the eighth-worst country responsible for mismanagement of plastic waste and third in the list of countries contributing most to marine plastic pollution [11].

MPs are ubiquitous, highly stable, have a long endurance, break up readily and have the potential to leach toxic plastic chemical additives. MPs can adsorb a variety of persistent organic environmental pollutants, thereby enhancing their bioavailability, toxicity, and dispersion [12, 13]. Then, it will eventually penetrate the food chain and might cause health problems such as

endocrine disruption and gut inflammation when ingested by humans and other organisms [10, 14, 15]. Given the significant threat posed by MPs pollution in Malaysia, this review aims to examine the updated status and challenges of MPs in Malaysia by discussing aspects such as MPs occurrence and distribution, uptake by aquatic organisms, degradation, effects on human health, and analytical methodologies for detection and analysis up to the year 2024. It is hoped that readers and researchers will benefit from this review by gaining a better understanding of MPs and by developing appropriate strategies for the management, mitigation, removal, and analysis of MPs.

Understanding MPs: Properties and Distribution

To effectively tackle this issue, a comprehensive understanding of MPs is crucial. This section will delve into the physical, chemical, and biological properties of MPs, exploring factors such as size, shape, polymer composition, and their potential for interaction with environmental pollutants. Following this, we will examine the abundance and distribution of MPs in Malaysia, focusing on data from various environmental compartments (e.g., rivers, coastal waters, and sediments).

Physical, chemical, and biological properties of MPs

Due to the degradation of MPs through processes such as oxidation, solar exposure, biofilm growth, and thermal aging [2], different physical properties of MPs have been reported [16, 17]. The degradation process breaks the particles into micro and nano-sized particles [17, 18], and facilitates their entry into living systems [19]. The shape of these polymeric particles plays a significant role in their interactions with biological systems in the aquatic environment. A study reported by Au et al. in 2015 [20] revealed that the toxic effect of polypropylene fibers on the amphipod *Hyaella azteca* was influenced by the particle shape. Additionally, the surface area of the MPs can be correlated to particle size. The alterations in the surface area of MPs particles are closely linked to their size, with surface ablation attributed to particle fragmentation [21]. Examples of shapes of MPs include microfibers, pellets, and fragments. The size can be whittled down by repeated filtration to provide the finest particles, the density can be from high to low density, colour can be varied, and

the fragmentation increases the surface area gradually.

In addition, MPs can exist in amorphous or semi-crystalline form [22]. The most common MPs polymer types found in the aquatic environment are polyethylene (25%), polyethylene terephthalate (16.5%), polyamide (12%), polypropylene (14%), polystyrene (8.5%), polyvinyl alcohol (6%), and polyvinyl chloride (2%) [15], [23], [24]. Polyethylene and polypropylene are semi-crystalline polymers, while polyvinyl chloride, polystyrene, and polyethylene terephthalate are amorphous polymers [21]. In general, plastic particles are resistant to microbial attack due to their high crystalline nature, thus posing challenges for the biodegradation process [25]. However, recent research has shown that various microorganisms, including bacteria and fungi, can contribute to the degradation of plastics [26, 27]. Other factors such as the soil conditions, the type of organisms involved, pre-treatment methods, polymer characteristics (e.g., mobility, toxicity, crystallinity, molecular weight, functional groups, substituents, and the presence of plasticizers or additives), as well as both biotic and abiotic conditions, are also vital factors in the biodegradation process [28].

Abundance and distribution of MPs in Malaysia

Examining the prevalence of microplastic pollution requires two-part approach where understanding both its abundance, which reflects the quantity of particles present, and its distribution, revealing the spatial extent and variability across various ecosystems. Learning the abundance and distribution of MPs is especially crucial for researchers to understand the sources and transportation pathways of these pollutants. Data of MPs abundance have yet to cover all waterway and terrestrial environments in Malaysia (Figure 1). However, the growing research is providing valuable insights. It is also important to note that the reported data are resulted from different methods and some studies reported the

data with different unit.

As presented in Table 1, MPs are detected in estuarine, beaches, marine and freshwaters, coastal and offshore, agricultural soil, and air in various states of Malaysia. Sediments act as a sink for MPs, leading to higher concentrations compared to water. Therefore, many studies reported MPs abundance is higher in sediment than in surface water for Seberang Prai, Pulau Pinang and Setia Wetland, Terengganu (4000 pcs/kg and 5.97 items/g respectively). While in surface water, Seberang Prai was reported to have the highest abundance of MPs (1407 pcs/L) in Malaysia. MPs are detected higher in abundance in Seberang Prai than in Kuala Muda and Balik Pulau because of industrialization and urbanization intensity of the area. MPs have also been detected in agricultural soil in the Klang Valley, with concentrations ranging from 1.5-6.0 particles/kg. This suggests agricultural activities as a potential source of MPs pollution in soil [29]. Compared to other Asian countries, Malaysia has a lower MPs abundance in soil than China but higher than Bangladesh. Finally, only a few studies have measured MPs in Malaysian air, covering locations like Kuala Lumpur, Bangi, and Terengganu. Perlis was reported to have higher airborne MPs concentrations than Kuala Lumpur, possibly due to fewer buildings [30].

The scarcity of data, particularly regarding geographic coverage, restricts our complete understanding of the national picture of MPs pollution in Malaysia. While existing studies provide valuable insights, further research employing standardized methodologies is crucial. This research should encompass diverse environmental compartments (e.g., rivers, coastlines, remote areas) to obtain a more comprehensive understanding of MPs abundance and distribution. This information is essential for assessing the potential ecological and human health risks associated with MPs pollution in Malaysia.

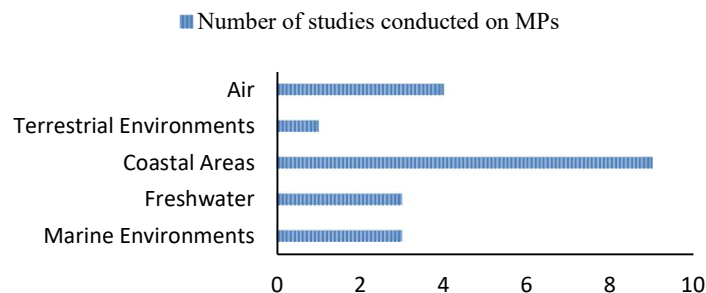


Figure 1. Number of studies conducted for abundance of MPs in Malaysia

Table 1. Abundance of MPs in Environmental Compartment in Malaysia

State	Location	Sample Type	Microplastics Concentration	Reference
Perlis	Timah Tasoh, Perlis	Air	983 ± 146 particles/m ² /d	[30]
Pulau Pinang	Seberang Perai	Surface water	1407 ± 124.265 pcs/L	[31]
		Coastal bottom sediment	350 ± 25.892 pcs/kg	
		Estuarine sediment	4000 ± 29.174 pcs/kg	
	Penaga	Surface water	358 ± 50.991 pcs/L	
		Coastal bottom sediment	18.070 pcs/kg	
		Estuarine sediment	940 ± 15.773 pcs/kg	
	Balik Pulau	Surface water	273 ± 24.943 pcs/L	
		Coastal bottom sediment	255 ± 22.368 pcs/kg	
	Kuala Muda	Surface water	201 ± 21.214 pcs/L	
		Coastal bottom sediment	290 ± 24.505 pcs/kg	
		Estuarine sediment	430 ± 7.234 pcs/kg	
Selangor/Kuala Lumpur	Klang River estuary	Surface water	2.47 particles/L	[32]
	Langat River Sementa Man grove	Surface water	1464.8 items/L	[33]
		Sediment	-	[34]
	Area, Kapar Bangi	Air	340 ± 30 MPs/m ² /day	[35]
	Klang Valley	Soil	$1.5\text{--}6.0$ particles/kg	[29]
	Univerisit Teknologi Malaysia (Kuala Lumpur)	Air	$97 - 775$ particles/m ² /day	[36]
	Negeri Sembilan	Port Dickson	4.65 particles/L	[37]
Johor	Skudai River	Surface water	360 ± 60 particles/ per kg	[38]
	Tebrau River	Surface water	640 ± 80 particles/ per kg	[38]
Pahang	Kuantan Port	Surface water	$0.14\text{--}0.15$ pcs/L	[39]
	Kelantan Bay	Sediment	-	[40]
Kelantan	Kelantan River	Surface water	179.6 items/L	[33]
	Kuala Nerus	Surface water	$0.13\text{--}0.69$ pcs/L	[39]
		Surface water	1687 particles/ m ⁻³ and 1900 particles/ m ⁻³ in estuary and offshore, respectively	[41]
	Terengganu	Sungai Dungun Pulau Perhentian	102.8 items/m ³	[42]
	Pulau Redang	Surface water	588.33 ± 111.77 items/L	[43]
	Pulau Kapas	Surface water	314.67 ± 58.08 items/L	[43]
		Surface water	359.8 ± 87.70 items/L	[43]

Sarawak	Pulau Tenggol Setiu Wetland	Surface water	294.33 ± 101.64 items/L	[43]
		Surface water	0.36 items/L	[44]
		Sediment	5.97 items/g	[44]
	Chagar Hutang	Air	274 ± 95 MPs/m ² /day	[35]
	Coastal area	Air	5476 ± 3796 MPs/m ² /day	[45]
	Miri River Estuary	Surface water	10.7 - 14.3 particles /L	[46]
		Sediment	283.7 - 456.2 particles/kg	[46]
	Miri Coast, NW Borneo	Sediment	83 - 327 particles/90g	[47]
	Pasir Pandak Beach	Sediment	60 - 328 items/m ²	
	Tanjung Aru Beach, Kota Kinabalu	Sediment	857 MPs/kg	[48]
Sabah	UMS ODEC Beach, Kota Kinabalu	Sediment	160 MPs/kg	[48]

Impacts of MPs Pollution

The presence of microplastics (MPs) in the environment poses significant threats to both aquatic ecosystems and human health. This section will explore the potential consequences of MPs pollution, focusing on two key areas, which are the uptake of aquatic organism and potential human health risks.

Uptake by aquatic organisms

Studies have shown that MPs have made their way into a range of organisms living in Malaysia's aquatic environments, including seafood. These minute plastic particles are ingested by organisms through both direct consumption and indirect trophic transfer mechanisms [1]. Planktonic creatures, larvae, invertebrates, and fish have all been found to have ingested MPs in Malaysian waters [1]. This alarming trend extends to commercial fish species in Malaysia, raising potential health risks for consumers [10].

The contamination of seafood with MPs poses significant threats to both food security and human health. Studies have revealed that commercially valuable fish and shellfish species are affected by MPs contamination [49]. For instance, an investigation discovered that 80% of sampled *Decapterus muroadsi*

fish had ingested MPs resembling their natural prey, indicating a pathway for these particles to enter the human food chain. The presence of MPs in seafood is therefore a cause for concern regarding its potential health implications for consumers.

Beyond seafood, MPs have also been identified in other organisms inhabiting Malaysia's aquatic environments. A study in the Terengganu estuary and offshore waters of Malaysia detected MPs in seawater and zooplankton [41]. This widespread presence underscores the extensive contamination of MPs within Malaysia's marine ecosystem. Another study reported that marine species such as *Scapharca cornea*, cage cultured and wild *Lates calcarifer*, *Namalycastis sp.*, and zooplankton have ingested MPs [50]. This suggests that MPs are found in Malaysia's aquatic environment and are being ingested by various wildlife species.

A study delved into the presence of MPs within commercially harvested marine fish off the northwestern coast of Malaysia's Peninsular region [51]. The study unveiled the presence of MPs in the digestive tracts of four distinct species of commercial marine fish: *Atule mate*, *Crenimugil seheli*, *Sardinella fimbriata*, and *Rastrelliger brachysoma*. This observation underscores

the potential risk of MPs infiltrating the human food chain through the consumption of contaminated fish. Another specific example of MPs ingestion by animals in Malaysia is the study conducted by Ratnam and Mohd Zanuri [52]. They found that blood cockles (*Tegillarca granosa*), a commonly consumed seafood in Malaysia, were contaminated with MPs in Kuala Juru, Pulau Pinang. This contamination poses a threat to seafood safety and potentially jeopardizes human health due to the potential toxicity of MPs.

Another study focused on the contamination of water bodies in Malaysia and its impact on marine organisms intended for human consumption [54]. The study found that commercial fish in seafood markets and abiotic sea products such as salts were contaminated with MPs. Marine organisms, including zooplankton, mussels, oysters, shrimp, and fish, were found to ingest MPs, further contributing to their presence in the human food chain. Efforts are underway to address the issue of MPs pollution in Malaysia. One study explored the possibility of polypropylene MPs degradation by bacteria isolated from Malaysian mangrove ecosystems [54]. Encouragingly, the study identified specific bacterial strains capable of breaking down polypropylene MPs, suggesting biodegradation as a potential remediation strategy.

The existence of MPs in seafood items presents challenges when assessing their health effects. The proportion of fiber-type MPs varies among different food items, and there are disparities between MPs levels in food and the adverse outcomes observed in animal studies [55]. Therefore, further research is imperative to gain a more comprehensive understanding of the potential health risks associated with consuming MPs in seafood [51, 59].

Effects of MPs exposure to human health

The potential health risks associated with MPs exposure in human is still under investigations. However, existing research suggested several possible pathways of exposure and potential health effects relevant to Malaysia. The primary route suggested is ingestion, often through the consumption of seafood as suggested earlier. Inadequate wastewater treatment facilities may

also contribute to MPs contamination in drinking water (ingestion route) [56]. Exposure through inhalation route can occur when airborne MPs are respired, and dermal exposure is possible through personal care products and clothing containing MPs. The findings from cellular and animal experiments have demonstrated that MPs can impact various systems within the human body, including the digestive, respiratory, endocrine, reproductive, immune, and nervous systems.

Initially, when MPs are ingested, they can affect the digestive system, which may result in inflammation and subsequent gastrointestinal symptoms. These symptoms include abdominal pain, bloating, and alterations in bowel habits. MPs can also disrupt the balance of beneficial and harmful bacteria in the intestinal microbiome, contributing to gastrointestinal symptoms [57, 58]. Furthermore, MPs can serve as carriers for environmental toxic substances, such as bisphenol A (BPA), which can be absorbed into the body and cause health issues related to the endocrine and reproductive systems. Recent research even detected MPs in the placentas of pregnant women, emphasizing the need for further study on potential adverse effects [59].

In addition to their physical effects on the digestive system, MPs can also cause chemical toxicity by absorbing and accumulating environmental toxins such as heavy metals and polycyclic aromatic hydrocarbons [60]. These toxins can enter the body when MPs are ingested, leading to various gastrointestinal symptoms like nausea, vomiting, and abdominal pain. Both *in vitro* experiments with human cells and *in vivo* data from mice suggest that MPs can elicit adverse health effects, primarily through mechanisms involving inflammation, oxidative stress (resulting in increased production of reactive oxygen species), disturbances in lipid metabolism, gut microbiota imbalances, and neurotoxicity. For instance, exposure to certain MPs has been shown to increase the expression of inflammatory genes like Interleukin 6 (IL-6) and interleukin 8 (IL-8) in human cells [61]. Animal experiments have shown that MPs can disturb lipid metabolism in the liver, increase oxidative stress, affect acetylcholine esterase activity, and finally lead to intestinal microbiota

imbalances. Furthermore, exposure to MPs can exacerbate lipid-metabolism disturbances and inflammatory responses, especially in diabetic mice [62].

Concerning the immune system, accumulated exposure to MPs has been observed to induce chronic inflammation and homeostasis changes in animal experiments [63]. In addition, studies involving human lung cells have shown that MPs can activate innate immunity by regulating the expression of genes and proteins involved in the immune response [61]. Further research is required to fully understand the negative effects of MPs on the human immune system. Regarding the respiratory system, inhalation of MPs can lead to oxidative stress in the airways and lungs, resulting in respiratory symptoms such as coughing, sneezing, shortness of breath, and fatigue. Recent research has even linked nano-sized plastics to mitochondrial damage in human respiratory cells [64]. Finally, there is neurotoxicity induced by MPs has been reported in animal experiments, with findings showing that exposure to MPs can accumulate in the central nervous system, causing microglia activation and neuron damage

[65]. This can lead to cognitive dysfunction, locomotor function changes and altered anticholinesterase activity in animals.

In conclusion, MPs have the potential to affect numerous systems in the human body. Even though many of the studies have been conducted on animals, further research is required to completely understand the degree of their effects and the mechanisms involved in humans. A complete understanding of these hazards and their long-term implications is still developing.

Analytical methodologies for determination of MPs

Effectively addressing MPs pollution requires reliable methods for their detection and analysis. This section will explore the various analytical methodologies currently employed to determine the presence and abundance of MPs in the environmental compartment, aquatic animal, and consumer products in Malaysia. Generally, the experimental design of MPs detection usually comprises of sample collection, sample preparation, sorting (physical characterization) and chemical characterization (Figure 2).



Figure 2. The general flow of MPs particles analysis

Sample collection

The technique to collect sample for MPs analysis in Malaysia depends on the type of sample itself and the purpose of the analysis (Table 2). For environment sample like marine water and sediment, the purpose was mostly to characterize and quantify the abundance of MPs particles in the environment or area selected. For instance, to quantify the extent of MPs in mangrove forest in Selangor, triplicate samples of sediment were collected from the surface of soil until 5 cm depth based on 50 cm x 50 cm quadrant [34]. Sampling quadrant was also adapted for sediment sample collection in Kota Kinabalu [48] and Pasir Pandak Beach [66]. For atmospheric MPs deposition, sample collection applied passive sampling technique[30, 45].

MPs are prevalent in marine environments and have been reported in commercial marine fish and other aquatic organism worldwide. For aquatic organism sample, like, bivalve or fishes, the purpose of the study is to investigate the digestion of those animals of the MPs particles polluted in the sampling area. Sample collection will either from the local area/market [67, 68, 69] or random collection by hand [70]. Processing of those animals will be dissection to obtain the guts, gills, and tissue. Sometimes, the whole organism was processed for the analysis of MPs particles itself. To analyse MPs particles in items like bottled water, fish meal products and personal products, these products were sourced from local market [71-74].

Table 2. Sample collection for different matrices in MPs particle analysis in Malaysia

Matrix	Sample Collection and Process
Surface water	Collection using stainless steel bucket and sampler [39, 46] Collection using water grab sampler [40]
Sediment	Collection using shovel [34] Collection using box corer [38] Collection using Ekman Grab sampler [40, 46] Collection using scoop [48]
Fishes	Caught at coordinated location [75] Purchases from local market [68]
Zooplankton	Collection by water pump [41]
Bivalve	Handpicked during low tide [70]
Sea cucumber	Random collection [76]
Products (dried fish, salt, canned sardine, bottled water, and fish meal product)	Purchased from Malaysian market [73, 74, 77, 78]
Human colectomy	Collection from patients who are scheduled to do colectomy. Specimen harvested after surgery [79]
Polychaete worm	Collection by hand [80]
Atmospheric deposition (air)	Collection through passive sampling in 24 h using a glass petri dish containing a glass microfibre filter paper [30, 45]

Sample preparation

After collection, the preparation of samples involves extraction of MPs from the sample matrices. Extraction of MPs includes manual sorting, density separation, filtration, and digestion method. Digestion process using acid or enzyme is needed for organic materials to dissolve. Digestion process is applied for matrices like fish, polychaete worm, and canned and dried fish. After digestion, some environment matrices apply density separation in sorting out the MPs particles. Density separation is applied through salt addition like sodium chloride (NaCl) or sodium iodide (NaI) or zinc chloride (ZnCl₂) [81]. Then, particles will be filtered by sieving through size exclusion or membrane filter. Filtered and separated MPs particles will be then characterized by physical and chemical characteristics.

Sorting (physical characterization)

After extraction, the isolated MPs are set for characterization to determine the particle size, shape, colour, surface texture and other characteristics to discriminate MPs from other particles (physical characterization). Then, this process is usually followed by identification of chemical composition such as the

functional groups, molecular weight and structure, and degree of polymerization of polymers in MPs [82].

The goal of physical characterization is to do preliminary analysis to determine shape, size, and morphology of MPs collected [83]. In other words, the filtered MPs particles will be screened and distinguished from non-plastic before chemical characterization. Some main physical characterization techniques are visual inspection, laser diffraction particle size analysis and dynamic light scattering. For MPs analysis in Malaysia in this paper, the methods employed for physical characterization are visual analysis (Table 3). Visual analysis technique in physical characterization is applied for most type of samples such as environment (sediment and water), animals, (fishes and bivalve) and products (canned food, packed food, and bottled water) and personal products. The process of visual analysis consists of observing the MPs particles with naked eyes or with microscopes. Then, the particles will be classified and counted based on the shape, colour, and size [83]. Analysis with naked eyes only applies for greater size range of MPs particles (1-5 mm). On the other hand, microscope images that can provide the shape and the quantity of MPs particles. This technique

was seen used on MPs analysis 1-5 μm in size for all samples in Table 2. On the other hand, those MPs particles that are lacking distinct colours and shapes are sorted using SEM. In studies analysing MPs in dried fish, canned sardines, marine fishes, and human colectomy specimens [79], SEM was combined with EDX. This common approach provides elemental analysis, enabling the differentiation of inorganic MPs particles.

Chemical characterization

Determination of the composition of the detected and extracted MPs is crucial to assist the establishment of the methods for treating MPs pollution [84]. For MPs analyses in Malaysia, Fourier transform infrared spectroscopy (FTIR), Raman spectroscopy, and thermal analysis (Table 3).

Fourier transform infrared spectroscopy

Fourier transform infrared spectroscopy (FTIR) provides information about the functional groups present for MPs that are more than 20 μm in size [81]. It obtains chemical information of chemical bonds and functional group of samples through vibrational spectroscopy technique. FTIR is a non-invasive analysis that requires simple sample pre-treatment process. Also, it is also less vulnerable to interference from autofluorescence originating from plastic additives components [82]. Currently, FTIR is widely used for chemical characteristics of MPs analysis in Malaysia.

There are three analysis techniques of FTIR which are specular reflection, transmission and attenuated total reflection (ATR). The selection of the right techniques depends on the properties of the sample. ATR mode, for example, will be selected for samples that are thick or strong infra-red (IR) absorbent. MPs have been identified and characterized by ATR- FTIR for marine water [39], sediment samples [34, 39, 46, 66, 85] and personal products collected in Selangor [71]. Micro-FTIR is also growing technique in Malaysia for analysing MPs as small as 10 μm . Researchers have used it to study MPs not only in deposited atmospheric dusts, but also in human tissue samples (from colon surgery) and in zooplankton samples.

Raman spectroscopy

Raman spectroscopy is one of the widely used methods for identifying chemical composition of MPs. It works by analysing the frequency shift of light scattered from a sample due to the Raman effect. The frequency shift can determine the sample's vibrational modes and identify the chemical substances present. Raman spectroscopy is widely accepted for its many advantages including minimal sample damage, requirement of small sample sizes, potential for high throughput screening, and environmental friendliness (as reported by Huang et al. [82]).

In contrast to FTIR, Raman spectroscopy faces limitations when it comes to detecting for samples with fluorescence [82]. Besides, the Raman spectra generated by plastic additive within MPs and contaminants adhering to the particle surfaces may overlap with the Raman spectra of the plastic polymers itself. This interferes the function of Raman spectroscopy in identification of the MPs. A. Karami et al. [67] developed a time effective and low-cost protocol for sample preparation of MPs analysis in fish while protecting the integrity of the plastic polymers. Raman spectroscopy has been shown to be a reliable technique to identify MPs in dried fish, salt, and tropical shark species [68, 77, 86]. Raman spectroscopy can detect MPs greater than 10 μm in size, whereas micro-Raman spectroscopy offers higher resolutions, enabling detection up to 1 μm [83]. A. Karami et al. has successfully used micro-Raman to detect MPs in canned sardine and sprat products with size ranging from 190 to 3800 μm . Karbalei et al. detected MPs in commercial fish meal with particle size from 149-7800 μm [73].

Thermal analysis

Thermal analysis is a technique to study the functional change of temperature and time of a material [82]. Pyrolysis-GCMS (Py-GC/MS) is one of the classical methods for thermal analysis that was used for analysis of MPs in Polychaete worms in Setiu Wetlands [80]. Analysis with Py-GC/MS using a selective ion monitoring mode detected pyrolytic products and fragment ions associated with various polymers, including polyvinyl chloride, polypropylene, polyethylene, polyethylene terephthalate, polyamide,

and polymethylmethacrylate. The study demonstrated the valuable application of Py-GC/MS techniques for monitoring MPs, especially when dealing with analytical sample in large quantities. Usage of Py-GCMS must be complemented with optical techniques due to its inability to determine the number and other physical characteristic of the MPs extracted.

While the current analytical methods offer valuable insights, advancements in MPs analysis are constantly evolving. These advancements hold great promise for improving our understanding of MPs pollution in Malaysia. Currently, visual counting is a common method for quantifying MPs. However, this technique can be time-consuming and prone to human error. Emerging techniques, such as flow cytometry and microfluidics, offer the potential for automated, high-throughput analysis, allowing for more accurate quantification of MPs abundance in environmental samples [87, 88]. At the same time, there is a crucial need to identify the source of the MPs pollution for understanding their pathways into the environment and to develop effective mitigation plan. Advanced spectroscopic techniques, such as Raman spectroscopy coupled with multivariate analysis, can potentially be used to fingerprint the specific types of plastic present in MPs [89]. This information can help to identify the sources of plastic pollution, such as specific industries or consumer products.

As MPs research in Malaysia continues to grow, it is essential to establish standardized protocols for sample collection, preparation, and analysis across different research groups, as previously emphasized. This standardization will ensure data consistency and facilitate comparisons between studies conducted in various locations and by different researchers.

In conclusion, the analytical methods employed in Malaysia provide valuable insights into the presence and abundance of MPs in the environment. However, continuous advancements in MPs analysis offer exciting possibilities for the future. Techniques like flow cytometry and microfluidics hold promise for more

accurate and automated MPs quantification, while advanced spectroscopy with chemometrics can help pinpoint the sources of plastic pollution. Moving forward, efforts to standardize sampling and analysis protocols across research groups in Malaysia are crucial for strengthening the nation's expertise in MPs analysis. By embracing these advancements and fostering a collaborative research environment, Malaysia can become a leader in tackling the challenge of MPs pollution.

Current challenges and data gaps

A report published by Minister of Science, Technology and Innovation (MOSTI) has revealed a roadmap plan to achieve towards zero single-use plastics in 2030 [7]. This plan highlighted the significant challenges hindering Malaysia's efforts to achieve zero single-plastic use by 2030. These challenges include:

- a) Limited public awareness: Many Malaysians lack sufficient knowledge about the environmental impact of single-use plastics and the benefits of alternatives.
- b) Low recycling rate: The current recycling infrastructure struggles to handle the volume of plastic waste generated, leading to improper disposal and environmental pollution.
- c) Cost factor: Biodegradable alternatives to single-use plastics are often more expensive, making it difficult for consumers and businesses to adopt them readily.
- d) Enforcement difficulties: Effectively enforcing regulations against single-use plastics can be challenging due to limited resources and monitoring capabilities.
- e) Waste management needs: Improvements are needed throughout the plastic waste management system, from collection and sorting to recycling and treatment facilities.

While these challenges are well-defined, several critical data gaps hinder the development of the targeted solutions. Table 4 described some of the data gaps that need to be addressed.

Table 3. Summary of common methods used in extraction, physical and chemical characterization of MPs

Matrix	Extraction Method	Physical Characterization Method	Analytical Instrument	References
Sediment	Density separation	SEM, spectroscopy, microscopy	FTIR, ATR-FTIR, μ -FTIR	[38, 46, 48]
Water	Filtration	SEM, microscopy	FTIR, ATR- FTIR, μ -FTIR	[33, 39, 42, 43]
Soil	Density separation followed by filtration	Microscope	FTIR	[29]
Air	Filtration	Stereomicroscope, selective fluorescent staining using Nile Red	μ -FTIR, ATR-FTIR	[35, 45]
Biota (tissues)	Digestion (chemical or enzymatic) followed by filtration	SEM, Stereomicroscope, FESEM-EDX	FTIR, μ -Raman spectroscopy, μ -FTIR, ATR-FTIR	[68, 69, 70]

Abbreviations: FTIR=Fourier Transform Infrared Spectroscopy; μ -FTIR=Micro-FTIR; ATR-FTIR= Attenuated total reflectance-FTIR; FESEM-EDX=Field Emission Scanning Electron Microscopy-Energy Dispersive X-ray Spectroscopy; SEM=Scanning Electron Microscope

Table 4. Data gap in MPs pollution in Malaysia

Area of Data Need	Specific Data Need	Importance for Addressing MPs Pollution
Sources of MPs pollution	Types and quantities of MPs from various industries	To identify major contributors of MPs to the environment
Distribution of MPs	Research on MPs abundance in rivers, coastal waters, and offshore environments throughout Malaysia should continue to cover the rest of the area which are not covered	To understand the spread and accumulation of MPs in different environments.
	Research on atmospheric MPs deposition should be further conducted	To understand the spread and accumulation of MPs in different environments
Impacts of MPs pollution	Potential pathways of microplastic ingestion (food, water)	To develop strategies to mitigate these risks
	Epidemiological studies on health effects of microplastic exposure.	To evaluate potential human health risks from microplastic contamination
	The presence of MPs in seafood and other products should be further examined covering all areas and types	To develop strategies to mitigate these risks

Conclusion

Microplastic pollution has emerged as a complex environmental challenge in Malaysia, with significant implications for both ecological health and human well-being. This review has examined the current understanding of MPs pollution in Malaysia, encompassing its abundance, potential impacts on biota and human health, and the analytical methods employed for its detection. The research conducted so far highlights the widespread presence of MPs in various environmental matrices in Malaysia, raising concerns about their potential ecological and human health risks. The potential for MPs to accumulate in the food chain and their ability to adsorb harmful pollutants necessitates further investigation to fully understand their long-term effects. Moving forward, addressing MPs pollution in Malaysia requires a comprehensive multi-pronged approach. This includes promoting the development and adoption of sustainable plastic production practices, coupled with effective waste management strategies to minimize plastic waste generation and improper disposal. Additionally, ongoing research efforts are crucial to develop efficient technologies for MPs detection, removal, and potential biodegradation. Public awareness campaigns are also essential to promote responsible plastic consumption and waste disposal practices among Malaysians. By implementing a combination of these strategies, Malaysia can play a leading role in combating MPs pollution and preserving its rich natural environment for future generations.

Acknowledgement

This study was supported by the Universiti Sains Malaysia, Short Term Grant with account code number: 304/CIPPT/6315592. This study also aligned with the mission and vision of the Advanced Management of Liver Malignancies Research Program 311.CIPPT.4119149 & 311.CIPPT.411988, Universiti Sains Malaysia.

References

1. Smith, M., Love, D. C., Rochman, C. M., and Neff, R. A. (2018). Microplastics in seafood and the implications for human health. *Current Environmental Health Reports*, 5(3): 375-386.
2. Andrady, A. L. (2017). The plastic in microplastics: A review. *Marine Pollution Bulletin*, 119(1): 12-22.
3. Horton, A. A., Walton, A., Spurgeon, D. J., Lahive, E., and Svendsen, C. (2017). Microplastics in freshwater and terrestrial environments: Evaluating the current understanding to identify the knowledge gaps and future research priorities. *Science of the Total Environment*, 586: 127-141.
4. Shim, W. J., Hong, S. H., and Eo, S. (2018). Marine microplastics: Abundance, distribution, and composition. In E. Zeng, (Ed.). *Microplastics contamination in aquatic environments: An emerging matter of environmental urgency* (pp. 1–26). Elsevier.
5. Ivar do Sul, J. A., Costa, M. F., and Fillmann, G. (2014). Microplastics in the Pelagic environment around oceanic islands of the Western Tropical Atlantic Ocean. *Water, Air, & Soil Pollution*, 225(7): 2004.
6. Landrigan, P. J., Stegeman, J. J., Fleming, L. E., Allemand, D., Anderson, D. M., Backer, L. C., Brucker-Davis, F., Chevalier, N., Corra, L., Czerucka, D., Bottein, M.-Y. D., Demeneix, B., Depledge, M., Deheyn, D. D., Dorman, C. J., Fénichel, P., Fisher, S., Gaill, F., Galgani, F., ... Rampal, P. (2020). Human health and ocean pollution. *Annals of Global Health*, 86(1): 151.
7. MESTECC (2018). *Malaysia's Roadmap Towards Zero Single-Use Plastics 2018-2030*.
8. Moh, Y. C., and Abd Manaf, L. (2014). Overview of household solid waste recycling policy status and challenges in Malaysia. *Resources, Conservation and Recycling*, 82: 50-61.
9. The Star (2021, March 16). *Tackling increasing plastics pollution in Malaysia*. The Star.
10. Ma, Z., Ibrahim, Y. S., and Lee, Y. (2020). Microplastic pollution and health and relevance to the Malaysia's roadmap to zero single-use plastics 2018-2030. *Malaysian Journal Medicine Sciences*, 27(3): 1-6.
11. Meijer, L. J. J., Van Emmerik, T., Van Der Ent, R., Schmidt, C., and Lebreton, L. (2021). More than 1000 rivers account for 80% of global riverine plastic emissions into the ocean. *Science Advances*, 7(18): eaaz5803.

12. Adegoke, K. A., Adu, F. A., Oyebamiji, A. K., Bamisaye, A., Adigun, R. A., Olasoji, S. O., and Ogunjinmi, O. E. (2023). Microplastics toxicity, detection, and removal from water/wastewater. *Marine Pollution Bulletin*, 187: 114546.
13. Okoye, C. O., Addey, C. I., Oderinde, O., Okoro, J. O., Uwamungu, J. Y., Ikechukwu, C. K., Okeke, E. S., Ejeromedoghene, O., and Odii, E. C. (2022). Toxic chemicals and persistent organic pollutants associated with micro-and nanoplastics pollution. *Chemical Engineering Journal Advances*, 11: 100310.
14. Jin, Y., Xia, J., Pan, Z., Yang, J., Wang, W., and Fu, Z. (2018). Polystyrene microplastics induce microbiota dysbiosis and inflammation in the gut of adult zebrafish. *Environmental Pollution*, 235: 322-329.
15. Yang, C. Z., Yaniger, S. I., Jordan, V. C., Klein, D. J., and Bittner, G. D. (2011). Most plastic products release estrogenic chemicals: A potential health problem that can be solved. *Environmental Health Perspectives*, 119(7): 989-996.
16. Rouillon, M., and Taylor, M. P. (2016). Can field portable x-ray fluorescence (pXRF) produce high quality data for application in environmental contamination research? *Environmental Pollution*, 214: 255-264.
17. Lambert, S., and Wagner, M. (2016). Characterisation of nanoplastics during the degradation of polystyrene. *Chemosphere*, 145: 265-268.
18. El Hadri, H., Gigault, J., Maxit, B., Grassl, B., and Reynaud, S. (2020). Nanoplastic from mechanically degraded primary and secondary microplastics for environmental assessments. *NanoImpact*, 17(10): 100206.
19. Avio, C. G., Gorbi, S., and Regoli, F. (2017). Plastics and microplastics in the oceans: From emerging pollutants to emerged threat. *Marine Environmental Research*, 128: 2-11.
20. Au, S. Y., Bruce, T. F., Bridges, W. C., and Klaine, S. J. (2015). Responses of *Hyaella azteca* to acute and chronic microplastic exposures. *Environmental Toxicology and Chemistry*, 34(11): 2564-2572.
21. Crawford, C. B., and Quinn, B. (2017). Plastic production, waste and legislation in C. B. Crawford & B. B. T.-M. P. Quinn (Eds.), microplastics pollutants (pp. 39–56). Elsevier.
22. Ashrafy, A., Liza, A. A., Islam, M. N., Billah, M. M., Arafat, S. T., Rahman, M. M., and Rahman, S. M. (2023). Microplastics pollution: A brief review of its source and abundance in different aquatic ecosystems. *Journal of Hazardous Materials Advances*, 9: 100215.
23. Burns, E. E., and Boxall, A. B. A. (2018). Microplastics in the aquatic environment: Evidence for or against adverse impacts and major knowledge gaps. *Environmental Toxicology and Chemistry*, 37(11): 2776-2796.
24. Bond, T., Ferrandiz-Mas, V., Felipe-Sotelo, M., and van Sebill, E. (2018). The occurrence and degradation of aquatic plastic litter based on polymer physicochemical properties: A review. *Critical Reviews in Environmental Science and Technology*, 48(7-9): 685-722.
25. Mueller, R.-J. (2006). Biological degradation of synthetic polyesters—enzymes as potential catalysts for polyester recycling. *Process Biochemistry*, 41(10): 2124-2128.
26. Ren, L., Men, L., Zhang, Z., Guan, F., Tian, J., Wang, B., Wang, J., Zhang, Y., and Zhang, W. (2019). Biodegradation of polyethylene by *Enterobacter* sp. D1 from the guts of wax moth *Galleria mellonella*. *International Journal of Environmental Research and Public Health*, 16(11): 1941.
27. Jumaah, O. S. (2017). Screening of plastic degrading bacteria from dumped soil area. *IOSR Journal of Environmental Science, Toxicology and Food Technology*, 11(05): 93-98.
28. Ahmed, T., Shahid, M., Azeem, F., Rasul, I., Shah, A. A., Noman, M., Hameed, A., Manzoor, N., Manzoor, I., and Muhammad, S. (2018). Biodegradation of plastics: Current scenario and future prospects for environmental safety. *Environmental Science and Pollution Research*, 25(8): 7287-7298.
29. Praveena, S. M., Hisham, M. A. F. I., and Nafisyah, A. L. (2023). Microplastics pollution in agricultural farms soils: Preliminary findings from tropical environment (Klang Valley, Malaysia).

- Environmental Monitoring and Assessment*, 195(6): 650.
30. Hashim, H. A., Jamian, A., Yusuf, N. R., Naidu, S. Y., Paad, D. M., and Ishak, K. M. (2023). Evaluation of deposited atmospheric microplastic characteristic within Malaysia cities airshed. *Chemical Engineering Transactions*, 106: 1105-1110.
 31. Tan, E., and Mohd Zanuri, N. B. (2023). Abundance and distribution of microplastics in tropical estuarine mangrove areas around Penang, Malaysia. *Frontiers in Marine Science*, 10: 1148804.
 32. Zaki, M. R. M., Ying, P. X., Zainuddin, A. H., Razak, M. R., and Aris, A. Z. (2021). Occurrence, abundance, and distribution of microplastics pollution: An evidence in surface tropical water of Klang River Estuary, Malaysia. *Environmental Geochemistry and Health*, 43(9): 3733-3748.
 33. Anuar, S. T., Abdullah, N. S., Yahya, N. K. E. M., Chin, T. T., Yusof, K. M. K. K., Mohamad, Y., Azmi, A. A., Jaafar, M., Mohamad, N., Khalik, W. M. A. W. M., and Ibrahim, Y. S. (2023). A multidimensional approach for microplastics monitoring in two major tropical river basins, Malaysia. *Environmental Research*, 227: 115717.
 34. Barasarathi, J., P., A., C.U., E., and S.H., F. (2014). Microplastic abundance in selected mangrove forest in malaysia. *Proceeding of The ASEAN Conference on Science and Technology 2014*: pp. 18-20.
 35. Hee, Y. Y., Hanif, N. M., Weston, K., Latif, M. T., Suratman, S., Rusli, M. U., and Mayes, A. G. (2023). Atmospheric microplastic transport and deposition to urban and pristine tropical locations in Southeast Asia. *Science of The Total Environment*, 902: 166153.
 36. Afiq Daniel Azmi, M., Yasin, N. L. N. M., Norruwaida, J., Hasnatul, A. H., Dewika, M., and Sara, Y. Y. (2023). Analysis of suspended atmospheric microplastics size at different elevation in Universiti Teknologi Malaysia, Kuala Lumpur. *IOP Conference Series: Earth and Environmental Science*, 1144(1): 012009.
 37. Zainuddin, A. H., Aris, A. Z., Zaki, M. R. M., Yusoff, F. M., and Wee, S. Y. (2022). Occurrence, potential sources and ecological risk estimation of microplastic towards coastal and estuarine zones in Malaysia. *Marine Pollution Bulletin*, 174: 113282.
 38. Sharijan, S., Azman, S., and Mohd Said, M. I. (2018). Microplastics pollution in Skudai and Tebrau River, Malaysia. *Proceedings of 7th International Graduate Conference, Conference of Engineering, Science and Humanities*, pp. 16-18
 39. Khalik, W. M. A. W. M., Ibrahim, Y. S., Tuan Anuar, S., Govindasamy, S., and Baharuddin, N. F. (2018). Microplastics analysis in Malaysian marine waters: A field study of Kuala Nerus and Kuantan. *Marine Pollution Bulletin*, 135: 451-457.
 40. Saipolbahri, N., Anak Bitlus, M. L., Ismail, N. A., Fauzi, N. M., and Subki, N. S. (2020). Determination of microplastics in surface water and sediment of Kelantan Bay. *IOP Conference Series: Earth and Environmental Science*, 549(1): 012059.
 41. Taha, Z. D., Md Amin, R., Anuar, S. T., Nasser, A. A. A., and Sohaimi, E. S. (2021). Microplastics in seawater and zooplankton: A case study from Terengganu estuary and offshore waters, Malaysia. *Science of the Total Environment*, 786: 147466
 42. Yang Hwi, T., Ibrahim, Y. S., and Khalik, W. M. A. W. M. (2020). Microplastic abundance, distribution, and composition in Sungai Dungun, Terengganu, Malaysia. *Sains Malaysiana*, 49(7): 1479-1490.
 43. Yusof, K. M. K. K., Anuar, S. T., Mohamad, Y., Jaafar, M., Mohamad, N., Bachok, Z., Mohamad, N., AND Ibrahim, Y. S. (2023). First evidence of microplastic pollution in the surface water of Malaysian Marine Park Islands, South China Sea during COVID-19. *Marine Pollution Bulletin*, 194: 115268.
 44. Ibrahim, Y. S., Hamzah, S. R., Khalik, W. M. A. W. M., Ku Yusof, K. M. K., and Anuar, S. T. (2021). Spatiotemporal microplastic occurrence study of Setiu Wetland, South China Sea. *Science of The Total Environment*, 788: 147809.
 45. Chenappan, N. K., Ibrahim, Y. S., Anuar, S. T., Yusof, K. M. K. K., Jaafar, M., Ahamad, F., Sulaiman, W. Z. W., and Mohamad, N. (2024). Quantification and characterization of airborne microplastics in the coastal area of Terengganu,

- Malaysia. *Environmental Monitoring and Assessment*, 196(3): 1-15.
46. Liong, R. M. Y., Hadibarata, T., Yuniarto, A., Tang, K. H. D., and Khamidun, M. H. (2021). Microplastic occurrence in the water and sediment of Miri River Estuary, Borneo Island. *Water, Air, and Soil Pollution*, 232(8).
47. Alexander Tampang, A. M., and Mohan Viswanathan, P. (2022). Occurrence, distribution and sources of microplastics in beach sediments of Miri Coast, NW Borneo. *Chemosphere*, 305: 135368.
48. Zahari, N. Z., Vincent, S. D., Cleophas, F. N., Budin, K., and Sabullah, M. K. (2023). Abundance, distribution, and characterization of microplastics on two recreational beaches in Kota Kinabalu, Sabah, Malaysia. *Water (Switzerland)*, 15(15): 2681.
49. De-la-Torre, G. E. (2020). Microplastics: an emerging threat to food security and human health. *Journal of Food Science and Technology*, 57(5):1601-1608.
50. Sulaiman, R. N. R., Bakar, A. A., Ngadi, N., Kahar, I. N. S., Nordin, A. H., Ikram, M., and Nabgan, W. (2023). Microplastics in Malaysia's aquatic environment: Current overview and future perspectives. *Global Challenges*, 7(8): 2300047.
51. Foo, Y. H., Ratnam, S., Lim, E. V., Abdullah, M., Molenaar, V. J., Shau Hwai, A. T., Zhang, S., Li, H., and Mohd Zanuri, N. B. (2022). Microplastic ingestion by commercial marine fish from the seawater of Northwest Peninsular Malaysia. *PeerJ*, 10: e13181.
52. Ratnam, S., and Mohd Zanuri, N. B. (2022). Microplastic ingestion of blood cockles (*Tegillarca granosa*) in Kuala Juru, Pulau Pinang. *Journal of Survey in Fisheries Sciences*, 9(1): 97-115.
53. Usman, S., Abdull Razis, A. F., Shaari, K., Amal, M. N. A., Saad, M. Z., Mat Isa, N., ... and Ibrahim, M. A. (2020). Microplastics pollution as an invisible potential threat to food safety and security, policy challenges and the way forward. *International Journal of Environmental Research and Public Health*, 17(24): 9591.
54. Habib, S., Iruthayam, A., Shukor, M. Y. A., Alias, S. A., Smykla, J., and Yasid, N. A. (2020). Biodeterioration of untreated polypropylene microplastic particles by Antarctic bacteria. *Polymers*, 12(11): 2616.
55. Kwon, J. H., Kim, J. W., Pham, T. D., Tarafdar, A., Hong, S., Chun, S. H., Lee, S. H., Kang, D. Y., Kim, J. Y., Kim, S. Bin, and Jung, J. (2020). Microplastics in food: A review on analytical methods and challenges. *International Journal of Environmental Research and Public Health*, 17 (18): 1-23.
56. Yu, Q., Hu, X., Yang, B., Zhang, G., Wang, J., and Ling, W. (2020). Distribution, abundance and risks of microplastics in the environment. *Chemosphere*, 249: 126059.
57. Bouwmeester, H., C. H. Hollman, P., and J. B. Peters, R. (2015). Potential health impact of environmentally released micro- and nanoplastics in the human food production chain: Experiences from nanotoxicology. *Environmental Science & Technology*, 49(15): 8932-8947.
58. Abbasi, S., Moore, F., and Keshavarzi, B. (2021). PET-microplastics as a vector for polycyclic aromatic hydrocarbons in a simulated plant rhizosphere zone. *Environmental Technology and Innovation*, 21: 101370.
59. Ragusa, A., Svelato, A., Santacroce, C., Catalano, P., Notarstefano, V., Carnevali, O., Papa, F., Rongioletti, M. C. A., Baiocco, F., Draghi, S., D'Amore, E., Rinaldo, D., Matta, M., and Giorgini, E. (2021). Plasticenta: First evidence of microplastics in human placenta. *Environment International*, 146: 106274.
60. Lee, Y., Cho, J., Sohn, J., and Kim, C. (2023). Health effects of microplastic exposures: Current issues and perspectives in South Korea. *Yonsei Medical Journal*, 64(5): 301-308.
61. Forte, M., Iachetta, G., Tussellino, M., Carotenuto, R., Prisco, M., De Falco, M., Laforgia, V., and Valiante, S. (2016). Polystyrene nanoparticles internalization in human gastric adenocarcinoma cells. *Toxicology in Vitro*, 31: 126-136.
62. Liu, S., Wang, Z., Xiang, Q., Wu, B., Lv, W., and Xu, S. (2022). A comparative study in healthy and diabetic mice followed the exposure of polystyrene microplastics: Differential lipid metabolism and

- inflammation reaction. *Ecotoxicology and Environmental Safety*, 244: 114031.
63. D  tre  , C., and Gallardo-Esc  rate, C. (2018). Single and repetitive microplastics exposures induce immune system modulation and homeostasis alteration in the edible mussel *Mytilus galloprovincialis*. *Fish and Shellfish Immunology*, 83: 52-60.
64. Lin, S., Zhang, H., Wang, C., Su, X. L., Song, Y., Wu, P., Yang, Z., Wong, M. H., Cai, Z., and Zheng, C. (2022). Metabolomics reveal nanoplastic-induced mitochondrial damage in human liver and lung cells. *Environmental Science and Technology*, 56(17): 12483-12493.
65. Shan, S., Zhang, Y., Zhao, H., Zeng, T., and Zhao, X. (2022). Polystyrene nanoplastics penetrate across the blood-brain barrier and induce activation of microglia in the brain of mice. *Chemosphere*, 298: 134261.
66. Idrus, F. A., Roslan, N. S., and Harith, M. N. (2022). Occurrence of macro- and microplastics on Pasir Pandak Beach, Sarawak, Malaysia. *Jurnal Ilmiah Perikanan Dan Kelautan*, 14(2): 214-230.
67. Karami, A., Golieskardi, A., Choo, C. K., Romano, N., Ho, Y. Bin, and Salamatinia, B. (2017). A high-performance protocol for extraction of microplastics in fish. *Science of the Total Environment*, 578: 485-494.
68. Matupang, D. M., Zulkifli, H. I., Arnold, J., Lazim, A. M., Ghaffar, M. A., and Musa, S. M. (2023). Tropical sharks feasting on and swimming through microplastics: First evidence from Malaysia. *Marine Pollution Bulletin*, 189: 114762.
69. Jaafar, N., Azfaralariff, A., Musa, S. M., Mohamed, M., Yusoff, A. H., and Lazim, A. M. (2021). Occurrence, distribution and characteristics of microplastics in gastrointestinal tract and gills of commercial marine fish from Malaysia. *Science of the Total Environment*, 799: 149457.
70. Ibrahim, Y. S., Azmi, A. A., Abdul Shukor, S., Anuar, S. T., and Abdullah, S. A. (2016). Microplastics Ingestion by *Scapharca cornea* at Setiu Wetland, Terengganu, Malaysia. *Middle-East Journal of Scientific Research*, 24(6): 2129-2136.
71. Suardy, N. H., Tahrir, N. A., and Ramli, S. (2020). Analysis and characterization of microplastic from personal care products and surface water in Bangi, Selangor. *Sains Malaysiana*, 49(9): 2237-2249.
72. Praveena, S. M., Shaifuddin, S. N. M., and Akizuki, S. (2018). Exploration of microplastics from personal care and cosmetic products and its estimated emissions to marine environment: An Evidence from Malaysia. *Marine Pollution Bulletin*, 136: 135-140.
73. Karbalaei, S., Golieskardi, A., Watt, D. U., Boiret, M., Hanachi, P., Walker, T. R., and Karami, A. (2020). Analysis and inorganic composition of microplastics in commercial Malaysian fish meals. *Marine Pollution Bulletin*, 150: 110687.
74. Praveena, S. M., Shamsul Ariffin, N. I., and Nafisyah, A. L. (2022). Microplastics in Malaysian bottled water brands: Occurrence and potential human exposure. *Environmental Pollution*, 315: 120494.
75. Ibrahim, Y. Y. S., Rathnam, R. R., and Anuar, S. (2017). Isolation and characterisation of microplastic abundance in *Lates calcarifer* from Setiu Wetlands, Malaysia. *Malaysia Journal of Analytical Science*, 21(5): 1054-1064.
76. Jannah, M., Husin, M., Mazlan, N., Shalom, J., Shirwan, M., and Sani, A. (2021). Evaluation of microplastics ingested by sea cucumber *Stichopus horrens* in Pulau Pangkor, Perak, Malaysia. *Environmental Science and Pollution Research*, 28: 61592-61600.
77. Karami, A., Golieskardi, A., Ho, Y. Bin, Larat, V., and Salamatinia, B. (2017). microplastics in eviscerated flesh and excised organs of dried fish. *Scientific Reports*, 7(1): 5473.
78. Karami, A., Golieskardi, A., Choo, C. K., Larat, V., Karbalaei, S., and Salamatinia, B. (2018). Microplastic and mesoplastic contamination in canned sardines and sprats. *Science of the Total Environment*, 612: 1380-1386.
79. Ibrahim, Y. S., Tuan Anuar, S., Azmi, A. A., Wan Mohd Khalik, W. M. A., Lehata, S., Hamzah, S. R., Ismail, D., Ma, Z. F., Dzulkarnaen, A., Zakaria, Z., Mustaffa, N., Tuan Sharif, S. E., and Lee, Y. Y. (2021). Detection of microplastics in human colectomy specimens. *JGH Open*, 5(1): 116-121.
80. Anuar, S. T., Altarawnah, R. S., Mohd Ali, A. A., Lee, B. Q., Khalik, W. M. A. W. M., Yusof, K. M.

- K. K., and Ibrahim, Y. S. (2022). Utilizing pyrolysis–gas chromatography/mass spectrometry for monitoring and analytical characterization of microplastics in polychaete worms. *Polymers*, 14(15): 3054.
81. Silva, A. B., Bastos, A. S., Justino, C. I. L., da Costa, J. P., Duarte, A. C., and Rocha-Santos, T. A. P. (2018). Microplastics in the environment: Challenges in analytical chemistry - a review. *Analytica Chimica Acta*, 1017: 1-19.
82. Huang, Z., Hu, B., and Wang, H. (2023). Analytical methods for microplastics in the environment: A review. *Environmental Chemistry Letters*, 21(1): 383-401.
83. Fu, W., Min, J., Jiang, W., Li, Y., and Zhang, W. (2020). Separation, characterization and identification of microplastics and nanoplastics in the environment. *Science of the Total Environment*, 721: 137561.
84. Song, Y. K., Hong, S. H., Jang, M., Han, G. M., Rani, M., Lee, J., and Shim, W. J. (2015). A comparison of microscopic and spectroscopic identification methods for analysis of microplastics in environmental samples. *Marine Pollution Bulletin*, 93(1-2): 202-209.
85. Matsuguma, Y., Takada, H., Kumata, H., Kanke, H., Sakurai, S., Suzuki, T., Itoh, M., Okazaki, Y., Boonyatumanond, R., Zakaria, M. P., Weerts, S., and Newman, B. (2017). Microplastics in sediment cores from Asia and Africa as indicators of temporal trends in plastic pollution. *Archives of Environmental Contamination and Toxicology*, 73(2): 230-239.
86. Karami, A., Golieskardi, A., Keong Choo, C., Larat, V., Galloway, T. S., and Salamatinia, B. (2017). The presence of microplastics in commercial salts from different countries. *Scientific Reports*, 7: 46173.
87. Zhang, Y., Zhang, M., & Fan, Y. (2023). Assessment of microplastics using microfluidic approach. *Environmental Geochemistry and Health*, 45(3): 1045-1052.
88. Tse, Y. T., Lo, H. S., Chan, S. M. N., and Sze, E. T. P. (2022). Flow cytometry as a rapid alternative to quantify small microplastics in environmental water samples. *Water*, 14(9): 1436.
89. Jin, N., Song, Y., Ma, R., Li, J., Li, G., and Zhang, D. (2022). Characterization and identification of microplastics using Raman spectroscopy coupled with multivariate analysis. *Analytica Chimica Acta*, 1197: 339519.