MICROPLASTICS AND HEAVY METALS ASSESSMENTS AND ITS ASSOCIATED HEALTH RISK IN FISHES FROM KERIAN, PINANG AND TEMBUS RIVER

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by

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LIST OF SYMBOLS

As	Arsenic
Cu	Copper
Pb	Lead
Fe	Iron
Zn	Zinc
Hg	Mercury
Cr	Chromium
Ni	Nickel
HNO_3	Nitric acid
H_2O_2	Hydrogen peroxide
KOH	Potassium hydroxide
Mg/kg	Milligram per kilogram
cm	Centimeter
g	Gram
µm	Micrometer
ml	Milliliter
Mg/L	Milligram per Liter
TSS	Total suspended solid
BOD	Biochemical oxygen demand
˚C	Degree Celsius
%	Percentage

LIST OF ABBREVIATIONS

MPs	Microplastics
HMs	Heavy metals
ATR-FTIR	Attenuated total reflectance Fourier-transform infrared
ICP-OES	Inductively coupled plasma optical emission spectrometry
LDPE	Low-density polyethylene
PS	Polystyrene
PP	Polypropylene
PC	Polycarbonate
PU	Polyurethane
ABS	Acrylonitrile butadiene styrene
PET	Polyethylene terephthalate
PE	Polyethylene
PVC	Polyvinyl chloride
PA	Polyamide
PMA	Poly (methyl acrylate)
PEVA	Poly (ethylene-vinyl acetate)
HDPE	High-density polyethylene
BPA	Bisphenol A
PCBs	Polychlorinated biphenyls
LOD	Detection limits
RfD	Reference dose
EDI	Estimated daily intake
THQ	Target hazard quotient
HI	Hazard index

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PENILAIAN MIKROPLASTIK DAN LOGAM BERAT SERTA RISIKO KESIHATAN DALAM IKAN DARI SUNGAI KERIAN, SUNGAI PINANG DAN SUNGAI TEMBUS

ABSTRAK

Sungai memainkan peranan penting dari segi ekologi dan ekonomi kepada komuniti setempat. Walau bagaimanapun, pertumbuhan pesat aktiviti antropogenik telah membawa kepada kemerosotan ekosistem melalui pelepasan mikroplastik (MPs) dan logam berat (HMs). MPs ialah zarah plastik kecil yang diklasifikasikan sebagai bahan pencemar dan telah banyak dilaporkan terdapat dalam organisma akuatik. MPs juga bertindak sebagai vektor kepada bahan pencemar toksik, yang membawa kepada bioakumulasi dalam ikan serta menimbulkan kebimbangan terhadap keselamatan makanan dan ketoksikan. Begitu juga, bioakumulasi HMs dalam ikan merupakan ancaman serius kepada kesihatan manusia. Kajian ini dijalankan untuk menyiasat kehadiran MPs dan HMs dalam spesies ikan dari Sungai Kerian, Pinang, dan Tembus di Pulau Pinang, Malaysia, serta menilai risiko kesihatan yang berkaitan. MPs diekstrak daripada saluran gastrousus ikan dan dikenal pasti melalui mikroskopi serta spektroskopi inframerah transformasi Fourier (FTIR), manakala HMs dalam tisu otot dianalisis menggunakan Spektrofotometer Pancaran Plasma Gandingan Aruhan (ICP-OES). Analisis statistik, ujian Kruskal–Wallis dan korelasi, telah dijalankan untuk menilai data. Sebanyak 409 MPs dikesan dalam 10 spesies ikan, dengan semua spesies menunjukkan kehadiran MPs. Spesies omnivor *Barbonymus schwanenfeldii* merekodkan jumlah tertinggi (36.50 ± 35.18 item/individu), didominasi oleh gentian dan fragmen, berkemungkinan dipengaruhi oleh aktiviti manusia berdekatan. Enam jenis polimer dikenal pasti iaitu polietilena (LDPE), polistirena (PS), polipropilena

(PP), polikarbonat (PC), poliuretana (PU), dan akrilonitril butadiena stirena (ABS). Logam berat dikesan dalam semua spesies ikan, dengan Fe mencatatkan kepekatan tertinggi (0.25 ± 0.09 mg/kg dalam *Scatophagus argus*), diikuti oleh Zn dan Cu, manakala Pb dan As dikesan pada tahap yang lebih rendah. Semua kepekatan berada dalam had yang dibenarkan oleh Akta Makanan Malaysia dan garis panduan FAO. Penilaian risiko menggunakan Pengambilan Harian Dianggar (EDI), Darjah Bahaya Sasaran (THQ), dan Indeks Bahaya (HI) menunjukkan tiada risiko bukan karsinogenik secara langsung (THQ dan HI < 1). Walau bagaimanapun, As menunjukkan nilai THQ yang tinggi (sehingga 1.04×10^{-2}), menandakan potensi kebimbangan jika pendedahan berpanjangan berlaku. Selain itu, korelasi negatif yang diperhatikan antara MPs dan HMs menunjukkan bahawa kehadiran MP mungkin berbeza bergantung kepada faktor seperti umur ikan, tabiat pemakanan, habitat, perubahan musim, jantina serta saiz, bentuk, warna, jenis dan bentuk pencemar. Secara keseluruhannya, dapatan ini menunjukkan bahawa ikan dari sungai-sungai tersebut pada masa ini tidak menimbulkan risiko kesihatan langsung kepada pengguna. Namun, pemantauan berterusan adalah penting memandangkan kadar pengambilan ikan yang tinggi di Malaysia serta implikasi ekologi jangka panjang akibat pencemaran MPs dan HMs. Kajian ini menyediakan data asas penting untuk penyelidikan lanjutan dan menyokong usaha dalam melindungi ekosistem akuatik serta keselamatan makanan.

MICROPLASTICS AND HEAVY METALS ASSESSMENTS AND ITS ASSOCIATED HEALTH RISK IN FISHES FROM KERIAN, PINANG AND TEMBUS RIVER

ABSTRACT

Rivers play an important role ecologically and commercially for local communities. However, the rapid growth of anthropogenic activities has led to ecosystem degradation through the discharge of microplastics (MPs) and heavy metals (HMs). MPs, small plastic particles classified as contaminants, are widely reported in aquatic organisms and act as vectors for toxic pollutants, leading to bioaccumulation in fish and raising concerns about food safety and toxicity. Similarly, HMs bioaccumulation in fish represents a serious threat to human health. This study aimed to assess the occurrence of MPs and HMs in fish from the Kerian, Pinang, and Tembus rivers in Penang, Malaysia, and their potential risks to human health. MPs were extracted from fish gastrointestinal tracts and identified by microscopy and Fourier transform infrared spectroscopy (FTIR), while HMs in muscle tissues were quantified using Inductively Coupled Plasma Optical Emission spectroscopy (ICP-OES). Statistical analyses, Kruskal–Wallis tests, and correlation were conducted to evaluate the data. A total of 409 MPs were detected across 10 fish species, with all species showing ingestion. The omnivorous *Barbonymus schwanenfeldii* recorded the highest abundance (36.50 ± 35.18 items/individual), dominated by fibres and fragments, likely influenced by proximity to human activities. Six polymer types were identified namely low-density polyethylene (LDPE), polystyrene (PS), polypropylene (PP), polycarbonate (PC), polyurethane (PU), and acrylonitrile butadiene styrene (ABS). Heavy metals were detected in all fish species, with Fe showing the highest concentration (0.25 ± 0.09 mg/kg in *Scatophagus argus*), followed by Zn and Cu, while Pb and As were found at lower levels. All concentrations were within the permissible limits set by the Malaysian Food Act and FAO guidelines. Risk assessment using Estimated Daily Intake (EDI), Target Hazard Quotient (THQ), and Hazard Index (HI) revealed no immediate non-carcinogenic risks (THQ and HI < 1). However, As displayed elevated THQ values (up to 1.04×10^{-2}), indicating potential concern under prolonged exposure. Furthermore, a negative correlation between MPs and HMs suggested that MPs may have varied depending on factors such as age, food preferences, habitat, seasonal changes, gender as well as pollutant size, shape, color, types, and forms. Overall, the findings highlight that fish from these rivers currently pose no direct health risks to consumers, but continuous monitoring is necessary due to high fish consumption rates in Malaysia and the long-term ecological implications of MPs and HMs. This study provides essential baseline data for future research and supports efforts to safeguard aquatic ecosystems and food safety.

CHAPTER 1

INTRODUCTION

1.1 General Introduction

The use of plastic in everyday life has been increasing steadily and is now being used in a wide range of applications. Plastic is popular because it is easily accessible, durable, lightweight, and cost-effective (Kamaruddin et al., 2022; Bucknall, 2020). However, proper disposal management has not matched the rapid growth in plastic production and the widespread use of plastic products. Many countries, including Malaysia, are struggling with the issue of a significant amount of plastic waste being improperly managed or not managed at all (Kamaruddin et al., 2022).

Plastic enters the environment through various pathways, such as discarded plastic goods, plastic degradation, industrial activities, and wastewater treatment plants (Sulaiman et al., 2023). The presence of plastic in both freshwater (Blettler et al., 2018; Hurley et al., 2020) and marine (Li et al., 2016; Williams-Wynn & Naidoo, 2020) environments underscores the increasing consumption of plastic and the inadequate management of plastic waste (Chapman, 2019; Oceng et al., 2023). Unlike materials that can biodegrade, plastic is photodegradable and breaks down into smaller particles when exposed to UV radiation. These smaller fragments are commonly referred to as microplastics (MPs) (Castro et al., 2018). In the environment, MPs constitute particles with a diverse range of chemical components, including hazardous substances. It has been shown that exposure to MPs and chemical pollutants can cause severe toxicity in various kinds of organisms (Ha & Yeo, 2018). Moreover, when disposed of in the environment, they absorb a variety of toxins from the surrounding atmosphere (Khalid et al., 2021).

Heavy metals (HMs) contamination is a global environmental issue in aquatic ecosystems. This problem arises from the toxic, persistent, and abundant nature of HMs in the environment, leading to their accumulation in aquatic habitats (Al-Badaii et al., 2016). HMs enter rivers from various activities including industrialization, population growth, and advancements in technology (Alsaffar et al., 2016). Additionally, various additives are used in plastic production to improve their properties. HMs such as lead (Pb), nickel (Ni), copper (Cu), and cobalt (Co) are also incorporated into new polymer plastics during the manufacturing process (Mohsen et al., 2022).

Research on MPs in freshwater ecosystems is still limited compared to that of marine environments (Khan et al., 2023). According to recent research, scientific documentation on MPs abundance in Malaysian waters is still limited and not fully understood (Chen et al., 2021). Many studies have shown that there is a problem of microplastic accumulation in many aquacultures' environments (Cholewińska et al., 2022; Ergün et al., 2023).

1.1.1 Microplastics in Fish

Plastic waste is known to accumulate in aquatic environments, where it can persist for decades or even centuries. This accumulation has led to the formation of MPs, which are small plastic particles with a diameter of less than 5 millimeters (Laskar & Kumar, 2019). MPs were produced by anthropogenic activities, including the breakdown of larger plastic, synthetic textiles, and personal care products. Once in the aquatic environment, these particles can persist for a long period of time and accumulate in sediments and water columns (Tursi et al., 2022; Xu et al., 2020). MPs may remain in the aquatic environment for decades due to natural degradation, but it will continue degrade due to physical, chemical, and biological processes (Chan et al., 2019; Jung et al., 2021). This debris can be consumed by various aquatic animals, including fish, plankton, and shellfish, causing physical and chemical toxicity, and impairing reproductive success and behaviour (Xu et al., 2020). In addition, MPs have been detected in many species of marine (Foo et al., 2022; Jaafar et al., 2021) and freshwater (Hamzah et al., 2021; Ibrahim et al., 2017) organisms. Besides, MPs are made with chemical additives, which can slowly migrate to the surface of the MPs and become hazardous to microorganisms and other species (Cao et al., 2021). Furthermore, these small particles can act as carriers and absorb a wide range of harmful pollutants, including organic compounds, HMs from the surrounding environment, posing potential risks to both organisms and humans (Anastopoulos et al., 2022; Kinigopoulou et al., 2022).

In Malaysian context, this issue is of particular concern given the country's exceptionally high fish consumption. Fish are a major source of dietary protein in Malaysia, with per capita consumption levels among the highest in Southeast Asia. According to Ahmad et al. (2016), the average Malaysian adult consumes about 168 g of fish per day, equivalent to 58-61 kg annually. This amount is nearly three times higher than the global average of 20.2 kg per year reported by FOA (2020). This high consumption rate underscores the significance of fish as a potential vector of MP exposure to the Malaysian population.

Several studies have estimated human dietary intake of MPs via fish consumption in Malaysia. Karami et al. (2017) reported that consumers of dried fish could ingested approximately 246 MPs annually, while more recent assessments involving fresh fish species from the Straits of Malacca and the South China Sea estimated higher intakes ranging between 413 and 578 MPs per person per year

(Ibrahim et al., 2025). Similarly, Foo et al. (2022) identified MPs in 93% of Indian mackerel (*Rastrelliger kanagurta*), projecting that regular consumers may ingest between 670 and 2017 MPs annually. Although the estimated levels vary depending on species, habitat, and calculation method, they consistently demonstrate that Malaysians are exposed to hundreds to thousands of MPs each year through fish consumption. This exposure is substantially higher compared to many neighbouring countries, reflecting Malaysia's strong reliance on fish as a staple food source.

1.1.2 Heavy metals in Fish

HMs are natural elements with high atomic weight and density at least 5 g/cm^3. They are major inorganic toxic pollutants identified among the absorbed toxic substances in MPs (Khalid et al., 2018). Although some heavy metals such as Cu, Mg, and Zn serve as essential trace elements with vital biological functions, many others, including Hg, Cd, As, and Cr, are toxic even at low concentrations (Koller et al., 2018). This substance is a common anthropogenic chemical substance found in mangroves, rising from a variety of sources, including agriculture runoff in Asia (Samsudin et al., 2019). Moreover, HMs are well studied pollutants in aquatic systems due to their persistence, poor biodegradability, and possible risks of bioaccumulation and biomagnification along the food chain (Yi et al., 2017). HMs enter the environment through natural or manmade activities, where they are transferred and accumulated by physical, chemical, and biological migrations (Li et al., 2020).

Therefore, overexposure to HMs may negatively impact aquatic ecosystems, disrupt the growth and activity of organisms, and harm human and animal health via the food chain (Cao et al., 2021). HMs accumulation in fish tissues may be passive or selective, and the differences in accumulation will reflect their bioavailability, physiological needs, feeding behaviour, exposure time, and environmental characteristics (Akhbarizadeh et al., 2018). HMs can enter fish tissues either in the dissolved fraction largely through direct uptake across the gills as well as across the gastrointestinal tract, or particulate fraction by taking contaminated sediments and by predation of organisms incorporating HMs. Once into the body, solubilized metals may complex with proteins and particulate bound metals can desorb in the gut, thus increasing the bioavailability of metal (Pane et al., 2004; Jomova et al., 2025). Fish are among the aquatic species that have had the heaviest metal content research done on them because they are strong indicators of heavy metal contamination in aquatic systems due to their size, age, and trophic level diversity (Rosli et al., 2018).

The toxicological effects of HMs on humans are of critical concern and are generally classified into cancer and non-cancer health risks, depending on the specific element, its chemical form, and the level and duration of exposure. For instance, chronic As exposure, particularly in the form of inorganic As, is one of the most well documented examples of heavy metal toxicity. Inorganic As is recognized as a Group 1 human carcinogen by the International Agency for Research on Cancer (IARC) and is strongly linked to cancers of the skin, bladder, and lungs, with evidence suggesting associations with liver and kidney cancers as well (Carlin et al., 2015; Naujokas et al., 2013). Non-cancer health effects of arsenic include cardiovascular disease, diabetes, neurological impairment, respiratory illness, and immune and endocrine disruption (Naujokas et al., 2013). Although As in fish is often present as arsenobetaine, which is considered non-toxic, trace amounts of inorganic arsenic have been reported in some seafood species, raising potential dietary concerns (Taylor et al., 2017; Luvonga et al., 2020). Pb represent another major global health concern, as no safe level of exposure has been identified. Even at very low blood concentrations, Pb exposure in children is associated with reduced intelligence quotient, impaired learning, and behavioral problems (Lanphear et al., 2005). In adults, chronic Pb exposure contributes to hypertension, renal dysfunction, and increased risk of cardiovascular diseases, which collectively result in a significant burden of morbidity and mortality at the population level (Chen et al., 2025).

1.2 Problem Statement

The pervasive use of plastics in anthropogenic activities, coupled with domestic, agricultural, and industrial processes, has significantly contributed to the pollution of Penang Rivers (Rosli & Yahya, 2017; Rosli & Yahya, 2013). Additionally, aquaculture exacerbates the pollution burden. The widespread use of synthetic materials such as nets, cages, and polystyrene floats introduces MPs into aquatic systems, while contaminated feed and antifouling agents contribute additional MPs and HMs (Makhdoumi et al., 2023). Studies have shown that commercial fish feed itself contains MPs and HM residues, which are transferred into farmed fish upon ingestion.

Previous research has reported the frequent occurrence of Cu, Fe, Pb, Zn, and As in Malaysian rivers, particularly in areas influenced by industrial, agricultural, and aquaculture activities. While Cu, Zn, and Fe are essential trace elements, they become harmful when present in excess, disrupting normal metabolic processes in aquatic organisms. Pb and As, on the other hand, are nonessential and highly toxic even at very low concentrations, with established links to neurological, developmental, and carcinogenic effects in humans. The repeated detection of these elements in riverine systems highlights their role as persistent contaminants of concern that may accumulate in aquatic biota and enter the human food chain. Previous monitoring has shown that these metals commonly exceed safe limits in Malaysian rivers due to industrial discharges, agricultural runoff, and aquaculture practices (Rosli & Yahya, 2017; River et al., 2014).

The danger lies in the combined effects of MPs and HMs. MPs act as vectors that adsorb heavy metals onto their surfaces due to their hydrophobic properties and large surface area (Zhu et al., 2020). Once ingested by fish, these particles release concentrated amounts of toxic metals into the gastrointestinal tract, which subsequently contribute to bioaccumulation in tissues and biomagnification along the food web (Makhdoumi et al., 2023). This dual contamination results in compounded toxicity: MPs can cause physical damage, inflammation, and oxidative stress, while HMs impair neurological, renal, hepatic, and reproductive functions in aquatic organisms and humans (Bashir et al., 2013; WHO, 2017).

Importantly, rivers serve as a primary pathway through which pollutants enter aquatic organisms. Fish inhabiting these rivers are directly exposed to MPs and HMs, making them reliable bioindicators of contamination and a critical link to human exposure through diet. Thus, the issue extends beyond river water quality alone to the safety of fish species that are widely consumed by local communities. Despite clear evidence that MPs and HMs individually pose significant risks, their combined occurrence in riverine fish from Penang's River systems has not been systematically investigated. The absence of baseline data on the levels and interactions of these contaminants in the Pinang, Kerian, and Tembus Rivers represents a critical knowledge gap. Therefore, this study seeks to establish baseline data on MP and HM contamination in fish species from these rivers, with particular attention to their potential ecological and human health impacts.

1.3 Objective of the Study

The study specifically aims to achieve the following objectives:

1. To assess the abundances and morphological characteristics of microplastics in fish species.
2. To determine the concentration of heavy metals contamination in fish species from Penang Rivers.
3. To evaluate the risks assessment and correlation between microplastics and heavy metals in fish.

1.4 Hypotheses of the Study

1. Microplastics are not present in fish species from Penang Rivers, or their abundances and morphological characteristics show no significant variation.
2. Microplastics are present in fish species from Penang Rivers, with varying abundances and distinct morphological characteristics.
3. Fish species from Penang Rivers do not contain detectable concentrations of heavy metals, or the levels do not exceed permissible limits.
4. Fish species from Penang Rivers contain detectable concentrations of heavy metals, which may exceed permissible limits.
5. There is no significant correlation between the presence of microplastics and heavy metals in fish, indicating no combined risks to food security and ecosystem health.
6. There is a significant correlation between the presence of microplastics and heavy metals in fish, indicating potential combined risks to food security and ecosystem health.

1.5 The Significance of the Study

This study is expected to clarify several key factors, such as:

i. Provide a data on the levels of microplastics and heavy metals in freshwater fish.

ii. Provide the preliminary risk assessment from consumption of fish from the Penang rivers.

1.6 Outline of Thesis Structure

This thesis consists of seven chapters:

Chapter 1 gives a brief information on the MPs and HMs in aquatic environment, impact to the aquatic life. The problem statement is presented, objective of the study research questions, significant of the study are outlined.

Chapter 2 provides a review of the literature on MPs within aquatic ecosystems, focusing on aquatic organisms, the various sources of pollution, and the impact on aquatic life. This chapter also discusses earlier studies that were involved in the investigation into the sources of MPs and HMs, toxicity, and their impact on aquatic life.

Chapter 3 explains steps that was taken throughout the earlier investigation. The study region is introduced in this chapter, followed by a description of the sample analysis. This chapter were also covering the study area, sampling techniques, and data analysis methods.

Chapter 4 shows the results and discussion. It will depict all the charts and tables to represent the results. The result and discussion of each objective were divided into three part which is part I, part II and part III.

Chapter 5 reports the conclusion on the research works, limitation and recommendation for or future research.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

In this chapter, the literature review is structured into four sections, exploring the occurrence and impact of both microplastics (MPs) and heavy metals (HMs) in aquatic environments. Section 2.2 provides an overview of MPs in aquatic environments, focusing on their sources and fate, which explains how MPs are generated and their pathways within ecosystems. This section also discusses the MPs accumulation and concentration in aquatic organism. The effects of MPs on aquatic organisms are addresses in this section, including both the physical impacts and chemical effects.

Section 2.3 shifts to HMs in aquatic environments, covering their sources and how these metals are introduced into aquatic ecosystems. The review continues, which discusses the bioaccumulation of HMs in aquatic organisms, followed by its negative effects on aquatic organisms

In Section 2.4, the relationship between MPs and HMs is analysed, focusing on how MPs can act as carriers of HMs, thus amplifying their potential toxicity. Finally, Section 2.5 presents a risk assessment of both pollutants, evaluating the ecological and human health risks associated with their presence in aquatic environments.

2.2 Microplastics in Aquatic Environment

Plastics, characterized by their extended durability, are artificial organic polymers originating from petroleum-derived sources, featuring substantial organic molecules. These polymers form the fundamental framework of plastics, composed of recurring carbon-based monomers or diverse carbon chains. Owing to their robustness and lasting nature, plastics exhibit resilience against degradation (Padervand et al., 2020). Around 300 million tons of plastic materials are produced globally each year; during the last 60 years, this amount has increased by more than 20 times. (Bajt, 2021). Municipal solid waste (MSW) generation in Malaysia is high, with daily averages of 0.5 to 1.9 kg per person. With an estimated 25% of the waste produced overall, plastics make up the majority of this waste (Choong et al., 2021). Eight million pieces of plastic are released into the ocean every day from land-based sources, mostly rivers, accounting for 10% of the plastic produced annually that ends up in the ocean (Bajt, 2021). Plastic can be transported to the open sea by ocean currents once it enters the water. Plastic is extremely resistant to environmental degradation and can take decades to degrade.

Due to their attributes, synthetic polymers have supplanted many naturally derived materials in modern society. The properties and suitability of plastics for specific applications are determined by their design, as they consist of long-chain organic polymers that may be homogeneous or composed of blended or cross-reacted types to achieve desired characteristic. Polymer chains are produced by combining chemical monomers, often derived from fossil fuels, into strands of repeating units. Polymers also occur naturally in molecules such as biodegradable deoxyribonucleic acid or starch, as well as more environmentally persistent cellulose and chitin. Table 2.1 shows the type of polymer and the uses identified in MPs. MPs can be classified into several shapes, including fibre, film, filament, fragment, and irregular forms. In addition, it is essential to identify the specific microplastic polymer type since it directly influences its chemical composition (Sulaiman et al., 2023).

Table 2.1 Characteristics and uses of polymers identified as MPs

Polymer type	Product uses
Polyethylene terephthalate (PET)	Bottles for water, soft drinks, juices, cleaners, etc., food jars/pots, clothes, plastic films, microwavable packaging, etc.
Polyethylene (PE)	Reusable bags, trays and containers, agricultural film, food packaging film, toys, milk bottles, shampoo bottles, pipes, houseware, floor tiles, shower curtains, bubble wrap, wire insulation and electric cables, rubbish bags, chemical and detergent bottles, buckets, plants pots, outdoor furniture
Polyvinyl chloride (PVC)	Window frames, profiles, floor and wallcovering, pipes, cable insulation, garden hoses, inflatable pools, plumbing and guttering, doors, shower curtains, credit cards, synthetic leather, cosmetic containers, commercial cling wrap, packaging.
Polypropylene (PP)	Food packaging, sweet and snack, wrappers, hinged caps, microwave containers, pipes, automotive parts, bank notes, etc.
Polystyrene (PS)	Food packaging (dairy, fishery), building insulation, electrical and electronic equipment, inner liner for fridges, eyeglasses frames, foam packaging, food containers, take-out clamshells, plastic tableware, disposable cups, plates and cutlery, boxes for compact discs and cassettes, etc
Polyurethane (PU)	Building insulation, pillows and mattresses, insulating foams, surface coatings, rollers for printing, used in cars, carpet, flexible foam in furniture, etc.
Polyamide (PA)	Fibres, bristles for toothbrushes, tubing, clothing, fishing line,
Poly (methyl acrylate) (PMA)	Perspex, plexiglass, eyeglass lenses, touch screens, etc. Poly (methyl acrylate) (PMA)
Poly (ethylene-vinyl acetate) (PEVA)	Adhesive, foam padding, foam floats, ski boots, bicycle saddles, hockey pads, boxing gloves and helmets, wakeboards, fishing rods handles, etc.
Others	Hub caps (ABS); optical fibres (PBT); roofing sheets (PC); cable coating in telecommunications (PTFE); many others in clothing, aerospace, medical implants, surgical devices, membranes, valves and seals, protective coatings, etc.

(Source: Jones et al., 2020)

2.2.1 Source and Fate of Microplastic in Aquatic Environment

There are basically two types of MPs available in the environment, primary and secondary MPs. Primary MPs are the by-products of particulate emissions released from industrial production, the release of plastics dust from plastics products (Laskar & Kumar, 2019). Plastic powders, granulates, and pellets are examples of primary MPs. These MPs are often used as exfoliants in various day-to-day products such as hand cleaners, toothpaste, and face washes. Primary MPs are also found in dental polishes (Vaid et al., 2021). When not properly discarded, these particles end up polluting the environment. In addition to their use in consumer products, primary MPs have diverse industrial applications. They are used as drilling fluids in gas and oil analysis, for cleaning metal surfaces and removing paint, and for rinsing engines (Ahmed et al., 2021).

Secondary MPs are larger plastic particulate material. Due to weathering effect, large size plastic material breaks down into smaller fragments (Laskar & Kumar, 2019). Abrasion of plastics is caused by UV light at the soil surface and by ocean waves. Secondary MPs are also generated by washing machines, which release fragments of textile fibers from synthetic materials during the laundering process (Fendall & Sewell, 2009). The primary sources of secondary MPs are discarded plastic debris from household items and industrial products. Secondary MPs are considered the most dominant type of MPs in the environment (Cole et al., 2011).

The release pathways of environmental MPs are diverse, primarily originating from human activities, transportation, and industrial sources. Most MPs accumulate in the ocean via river transport or direct discharge. Once released into the environment, MPs undergo various processes, including accumulation, degradation, and migration, under different environmental conditions. Eventually, these MPs can make their way into the human body (Wang et al., 2021). Figure 2.1 illustrates the different processes influencing MPs in aquatic ecosystems.

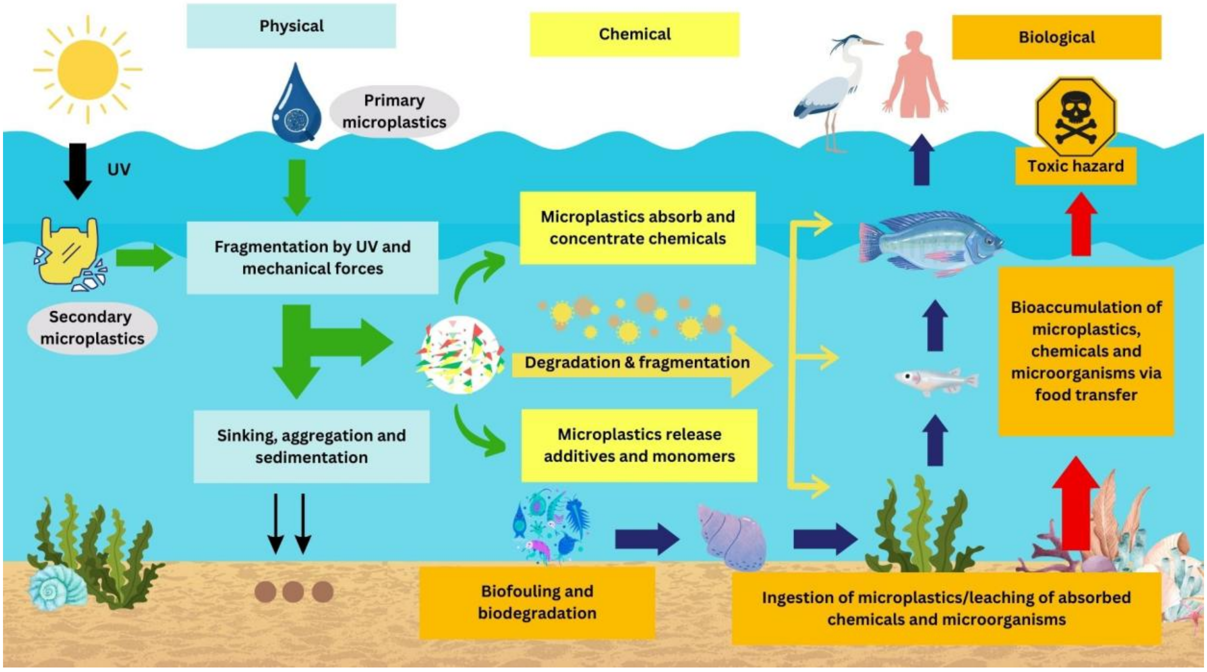

Figure 2.1 Physical, chemical and biological processes influencing MPs in aquatic ecosystems.

Depending on their chemical composition, density, and physical characteristics such as size and shape, MPs may remain in aquatic ecosystems close to where they are disposed of or travel via a variety of pathways to far-off places, such as glacial regions. About 15% of the MPs present in aquatic environments are suspended in the water, with the remaining 70% settling in the sediments. Due to differences in plastic degradation processes and water dynamics, which are influenced by wind, currents, ocean currents, and climate factors, the fate and distribution mechanisms of MPs in water are still unknown. Nonetheless, the spread of MPs appears to follow two possible paths: vertical and horizontal.

The horizontal distribution of MPs is influenced by the flow of water velocity, rainfall, and wind currents, all of which influence plastic trash transmit from land to aquatic environments (Talbot & Chang, 2022). Plastics that come into contact with water undergo abrasion, breakdown or degradation that gives rise to MPs that vary in size, shape, density, and chemical composition. Denser MPs will sink whereas lighter ones remain suspended because they are heavier than the surrounding water (Kowalski et al., 2016). The horizontal distribution of MPs is determined by their size as well as water dynamics, including flow velocity and riverbed slope. Furthermore, reservoirs and dams can alter water velocity and impact the destiny of MPs. Depending on the direction of the wind and water currents, suspended MPs can either float back to coastal areas or be carried to distant locations (Andrady, 2011; Isobe et al., 2014).

Vertical distribution of MPs involves their sinking to the seabed, riverbed, or ocean floor. This distribution is influenced by several factors (Haque & Fan, 2023):

i. The movement and direction of water velocity drive vertical turbulent mixing.
ii. Biota transfer: the transfer of biota depends on the movement of aquatic organisms.
iii. Biological fouling and aggregate formation: microorganisms, bacteria, plankton, and algae have an influence on biological fouling and the formation of aggregates.

The characteristics of MPs, such as their type, chemical composition, and surface morphology, as well as water conditions like temperature, pH, and the presence of microbes, all have an influence on biological fouling and aggregate formation. Biological fouling can be divided into three main stages, as identified by Haque and Fan (2023):

i. Microbes and nutrients in the water adhere to the surface of MPs.
ii. As microorganisms release extracellular polymeric substances, a biofilm is formed. This biofilm attracts more marine invertebrates and aquatic life.

iii. The biofilm, enriched with extracellular polymeric substances, continues to accumulate microbes and nutrients. This accumulation causes the MPs to form a dense cluster, eventually leading to their sinking to the bottom.

2.2.2 Microplastics in Aquatic Organisms

Plastic may be transferred across longer distances more easily when its size gradually decreases (Faure et al., 2015). Therefore, this implies that plastic can be recognized as a substantial emerging global pollutant, and Malaysia is not exempt from this trend. Particles that enter rivers have similar transportation mechanisms to other sediments, such as sand and silt, inside the river pathways (Horton & Dixon, 2017). Nevertheless, when it comes to MPs, it is possible that most rivers are restricted by the amount of supply in terms of transportation. This implies that rivers have the capacity to carry all the plastics that are deposited into them. Although plastics are generally buoyant, they are likely to settle along with sinking sediment particles in areas of slow-moving portions of water, resulting in the deposition of MPs (Horton & Dixon, 2017). Thus, due to their similarity to food, aquatic organisms that are near the sediment could mistake the particle for food (Su et al., 2019). In addition, aquatic organisms also ingest MPs through different feeding strategies (Garcia et al., 2020).

Moreover, once ingested, MPs are predominantly retained in the gastrointestinal tract of fish. Numerous studies have demonstrated that the majority of MPs remain confined within the gut, which is often excluded from human consumption. However, there is growing evidence that a proportion of MPs can translocate across the intestinal epithelium into the circulatory system, subsequently reaching metabolically active organs such as the liver, kidney, gills, and even muscle tissue (McIlwraith et al., 2021; Ghosh, 2025). Ghosh (2025) emphasized that MPs initially accumulate in the gut and gills, but circulation can facilitate their redistribution throughout the body, resulting in detectable concentrations in muscle and liver. This translocation process is influenced by particle size, shape, and surface properties, with fibers and nanoplastics demonstrating higher potential for barrier penetration (Ibrahim et al., 2025).

The physiological effects of MPs on fish are increasingly documented. Accumulation in the GIT can cause abrasion, blockage, and reduced feeding efficiency, while systemic distribution may lead to oxidative stress, inflammation, immune suppression, and metabolic disturbances (Bhuyan, 2022). Histopathological examinations also indicated liver, kidney damages, appearances of abnormal enzymatic activities of antioxidant bio-enzymes, and reproductive imbalance in fish species exposed to MPs (Ghosh, 2025). These biological effects are not only cause for concern for fish health and population structure, but also to human consumers, as MPs with their associated chemicals are transferred through bioaccumulation in tissues and by consumption of contaminated tissues.

2.2.3 Microplastics Concentration in Aquatic Organisms

The concentration of MPs in aquatic organisms varies depending on various factors, such as the type of organism, the size and shape of the MPs, and the concentration of MPs in the water. Generally, smaller organisms such as plankton have been found to accumulate higher concentrations of MPs than larger organisms like fish (Garcia et al., 2020). Studies have shown that MPs can accumulate in different parts of aquatic organisms, including the gills, intestines, liver, and muscles (Alfaro-Núñez et al., 2021; Issac and Kandasubramanian, 2021). Table 2.2 shows the summary of study findings reporting the MPs concentration in fish and Table 2.3 shows the summary of study findings reporting the MPs in bivalves.

Table 2.2 Summary of studies reporting the MPs in fish.

Species	MPs Concentration	Shape	Polymer type	Accumulation Organ	Sources
Fish	0.50-6.25 items/ind	Fiber, Fragment, Filament	PE, PP, ABS, PS & PET	Gastrointestinal tract	(Jaafar et al., 2021)
Fish	1260 - 1961 items/ind	Filament, Fragment, Foam	PA & PVA	Gastrointestinal tract	(Ibrahim et al., 2017)
Fish	0.91 ± 0.13 items/g	Fragment, Fiber	PP, PET & Cellulosic fiber	digestive tract	(Pradit et al., 2023)
Fish	688 ± 1.15 items/ind (eastern harbour) 645 ± 7.02 items/ind (western harbour)	Fiber, Foam, Film, Fragment	HDPE, PET, PS, PP, LDPE, CA & PA	digestive tract	(Ningrum & Patria, 2022)
Fish	3 pieces/fish	Filament, Round, Angular	PBDE	gastrointestinal tract	(Andreas et al., 2021)

*There is currently no standardized unit for reporting microplastics in fish. Therefore, the units shown are presented as reported in the original studies.

Table 2.3 Summary of studies reporting the MPs in bivalves.

Species	**MPs Concentration**	**Shape**	**Polymer type**	**Accumulation Organ**	**Sources**
Bivalve	2.23 ± 1.04 items/ind (cultured) 1.29 ± 1.19 items/ind (wild).	Fibre, Fragment, Film, Foam, Bead	PE & PP	Soft tissues	(Zin et al., 2022)
Bivalve	0.31–2.50 (*Perna viridis*) 0.93–4.27 (*Atrina pectinata*)	Filament, Film, Foam, Pellet, Fragment	PE, PS, PET & Thermo Polyurethane	Soft tissues	(Malto & Mendoza, 2022)
Bivalve	0.29 ± 0.14 items/ind	Fiber	PP & PE	Soft tissues	(Nam et al., 2019)
Bivalve	4–20 items/g ww	Fiber	PA	Soft tissues	(Khoironi et al., 2018)
Bivalve	86.27 – 557.98 particles/g.	Filament	1	tissues	(Ibrahim et al., 2016.)

** There is currently no standardized unit for reporting microplastics in fish. Therefore, the units shown are presented as reported in the original studies.*

In addition, the concentration of MPs in aquatic organisms can also vary depending on the environment they inhabit. Organisms in areas with high levels of microplastic pollution, such as near urban centers or near industrial sites, have been found to have higher concentrations of MPs than those in more pristine environments (Alfaro-Núñez et al., 2021, Bajt, 2021). Ingestion is the primary route of microplastic accumulation in aquatic organisms. The ingestion of MPs can cause physical harm, such as blockages in the digestive tract or perforation of the gut wall. This can lead to reduced nutrient uptake, impaired growth and development, and increased mortality in the affected organisms (Issac and Kandasubramanian, 2021, Nanthini devi et al., 2022).

Aquatic species can ingest MPs through several physiological pathways and subsequently transport them to different tissues or organs, including the stomach, and digestive system (Xu et al., 2020). Studies on ecotoxicology have revealed the accumulation of MPs in a wide range of aquatic species. In a study conducted by Curren et al. (2020), it was discovered that the number of MPs varied between 13.4 and 7050 items in the collected samples. Notably, *F. indicus* had the highest prevalence of MPs among the observed species. Another study conducted by Pradit et al. (2021) during the COVID-19 pandemic lockdown period, the researchers investigated the presence of MPs particles in the gastrointestinal tracts of fish and shrimp specimens collected from Songkhla Lake. The mean occurrences of MPs particles per stomach in fish and shrimp were 2.73 ± 0.15, 4.11 ± 1.12, and 3.78 ± 1.12, respectively. A study conducted by Ibrahim et al. (2017) reported on the comparison of microplastic ingestion between two fish species from different habitats. The study discovered that there is a present of MPs in both wild and cage cultured Lates calcarifer fish in estuarine environments. Wild species have a higher abundance of MPs compared to cage-cultured species, a phenomenon that can be attributed to variations in habitat dynamics and feeding behaviour. The presence of MPs in fish was shown to be directly linked to the concentration of MPs in water, suggesting that fish are primarily exposed to MPs that are present in the water (Park et al., 2020). Nevertheless, environment has a crucial role in influencing the concentration of MPs in fish (Park et al., 2020).

In the environment, MPs constitute particles with a diverse range of chemical components, including hazardous substances. It has been shown that exposure to MPs and chemical pollutants can cause severe toxicity in various kinds of organisms (Ha & Yeo, 2018). Moreover, when disposed of in the environment, they absorb a variety of toxins from the surrounding atmosphere (Khalid et al., 2021).

2.2.4 Effect of Microplastics on Aquatic Organisms

MPs are a grave environmental concern, and they have been found to be risky to aquatic organisms ranging from small zooplankton to large marine mammals (Hernandez-Gonzalez et al., 2018; Moore et al., 2020; Xiong et al., 2018), both physically and chemically (Li et al., 2021, Vivekanand et al., 2021).

2.2.4(a) Physical Effect of Microplastics on Aquatic Organisms

Physical health effects on aquatic organisms can include a range of negative impacts on their behaviour, growth, and survival. For example, MPs can cause physical damage to an organism's digestive system, leading to reduced nutrient absorption and malnourishment. They can also cause blockages in the organism's digestive tract, which can lead to starvation or even death. MPs can also have indirect impacts on aquatic organisms. For instance, MPs can alter an organism's behaviour, such as reducing their ability to swim or migrate. This can have negative effects on the organism's survival, as it can impact their ability to forage for food, find mates, or avoid predators. Furthermore, MPs can impact the growth and development of aquatic organisms. This is because they can interfere with the normal functioning of an organism's endocrine system, which can impact their reproductive success and overall fitness.

When aquatic species consume MPs, it builds up in their bodies, causing particulate or chemical toxicity. This accumulation leads to disturbances in their metabolism, feeding habits, growth, and reproduction. The level of toxicological risk varies for each species (Issac & Kandasubramanian, 2021). In a study conducted by Rainieri et al. (2018), zebrafish (Danio rerio) were used to investigate the effects of consuming food containing both MPs and persistent organic pollutants (POPs). The results showed that zebrafish fed with this diet had higher levels of hepatocyte vacuolization compared to those ingesting feed containing only POPs. Furthermore, zebrafish that were simultaneously exposed to MPs and persistent organic pollutants (POPs) exhibited noticeable skin abnormalities. Another study by Sussarellu et al., (2016), found that polystyrene MPs had negative effects on the reproduction and feeding of oysters. This was due to changes in their food intake and energy distribution. Oysters exposed to micro sized polystyrene showed a decrease in the number of eggs produced, as well as a reduction in oocyte quality and the motility of sperm. Fish that ingest zooplankton polluted with MPs take more than twice as long to consume 95% of the provided food compared to fish that consume MPs-free zooplankton.

In addition, the presence of MPs in the digestive tract can also lead to inflammation and damage to the intestinal walls, which can impair the organism's ability to absorb nutrients and defend against pathogens. This can ultimately lead to weakened immune systems and increased susceptibility to disease (de Sá et al., 2018). Another physical health effect of microplastic ingestion is the potential for suffocation or entanglement. This is particularly relevant for organisms that filter large amounts of water, such as bivalves and some species of plankton. MPs can clog the organism's gills or other filtering structures, leading to reduced oxygen uptake and potential suffocation (Feiock, 2020). Additionally, small organisms such as zooplankton and larval fish can become entangled in microplastic fibers or fragments, which can impede their movement and feeding. Additionally, MPs can have chemical effects on aquatic organisms. When MPs are ingested, they can release chemical additives and contaminants that are adsorbed on their surface into the digestive tract of the organism. These chemicals can leach out of the MPs and enter the organism's tissues, potentially causing toxicity and other adverse effects (Badea et al., 2023). For example, according to a study published by the National Center for Biotechnology Information, polystyrene MPs have been found to release a toxic substance called BPA when ingested by zebrafish (Martínez-Álvarez et al., 2022). Furthermore, MPs can also absorb and concentrate other chemical pollutants such as polychlorinated biphenyls (PCBs) and polycyclic aromatic hydrocarbons (PAHs), which are known to be toxic and persistent in the environment (Du et al., 2021).

2.2.4(b) Chemical Effect of Microplastics on Aquatic Organisms

MPs can have a devastating effect on aquatic organisms, due to the presence of chemicals known as plasticizers that are used to enhance the flexibility and durability of plastic materials. These plasticizers can leach out of MPs and enter the bodies of aquatic organisms, where they can mimic the effects of hormones such as estrogen and testosterone. This disruption of hormone signalling can lead to developmental abnormalities, reproductive impairments and changes in behaviour and physiology (Ma et al., 2019).

Bisphenol A (BPA), for instance, can mimic oestrogen and disrupt reproductive function in fish whereas phthalates have been linked to developmental and behavioural difficulties in certain aquatic organisms. BPA released from Polyvinyl chloride (PVC)