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DISCUSSION PAPER

# RIVERINE MICROPLASTIC POLLUTION IN ASEAN COUNTRIES

## - CURRENT STATE OF KNOWLEDGE -


Pham Ngoc Bao[1], Yukako Inamura[1], Amila Abeynayaka[2]
Pankaj Kumar[1], Bijon Kumar Mitra[1,3]

1: Adaptation and Water Area, IGES
2: IGES Centre Collaborating with UNEP on Environmental Technology (CCET), IGES
3: Integrated Sustainability Center, IGES


IGES
Institute for Global Environmental Strategies

# Executive Summary

*Water pollution caused by microplastics generated from land-based sources (e.g. as tire-wear particles, broken road markings, synthetic textile microfibre from washing, microbeads from personal care products, discharged domestic wastewater from households, and others) is attracting attention in many countries and regions around the world as an emerging environmental problem, not only at national and regional level, but also worldwide. Microplastics released from these sources often flow directly or indirectly into surrounding aquatic environments such as rivers and lakes, and eventually enter the ocean. The adverse impacts of microplastics on ecosystems and aquaculture organisms have been well-reported, and they may gradually cause potential adverse effects on human health as well. Unfortunately, in most member states in the Association of Southeast Asian Nations (ASEAN), basic knowledge about the occurrence, ingestion and impacts of riverine microplastics pollution on ecosystem and human health is very limited. As a result, appropriate and effective countermeasures to control the emission of microplastics have not yet been established. This Discussion Paper presents a concise and insightful review of the current state of knowledge on the occurrence, ingestion and impacts of microplastics on ecosystems and human health. Moreover, due to the transboundary nature of plastic litter issues, any solutions implemented in single country will not be sufficient to address these regional and transboundary issues. The paper calls for collective efforts from all the ASEAN Member States to address issues along the plastic value chain through the circular economy approach, from raw material extraction, design, production, distribution, responsible plastic consumption (especially single use plastic products), collection/reuse/repair, to the recycling stage and final disposal.*

Plastics in a river

# 1. Introduction

Human society has been sustained by consuming resources, and plastic has become one of the materials we use to maintain a convenient and comfortable lifestyle. Plastic was invented in the early 1800s as a substance for tooth filling and as a reinforcing material (British Plastic Federation, 2021). Since the first appearance of polyvinyl chloride (PVC) in the early 1900s, plastic has been used in many products, and its low cost, convenience and durability created strong demand from the manufacturing and packaging industries (Ryan, 2015). Because of this huge demand, the annual global production of plastic has seen a massive increase from 2 million tonnes per year in 1950 to 381 million tonnes per year in 2015. More than 70% of the total amount of plastic was produced after 1990 (Geyer et al., 2017). It has been reported that the ASEAN region, comprised of member states of the Association of Southeast Asian Nations, accounts for about 20% of global plastic production (Borongan et al., 2018). The ASEAN countries with the largest growth in plastic production and consumption are Indonesia, Malaysia, the Philippines, Singapore, Thailand and Viet Nam. Four ASEAN countries (Indonesia, the Philippines, Thailand and Viet Nam) and China are estimated to contribute to about half of the world's marine plastic litter generation (Geyer et al., 2017).

In addition, the 'takeaway food culture', 'e-commerce activities' and 'sachet economy' are growing in the region, leading to an increased use of plastics. Consumer preferences are also shifting from traditional fresh foods to packaged foods, while at the same time, shopping on digital platforms is on the rise (The World Bank, 2021). Consequently, this convenience and versatility has resulted in an increase in plastic waste, with mismanaged plastic waste emerging as an environmental problem. The scientific community has made great efforts to spread awareness about the environmental consequences from this plastic pollution, but in absence of any strict regulations, irrational consumption and littering has continued, resulting in severe damage to global aquatic ecosystems (Alegado et al., 2021; Bean, 1987).

Microplastics (MPs) are currently a great concern as they exist in water, sediments, fauna and even flora (Kalčíková, 2020). However, there is no all-inclusive definition which accurately encompasses the criteria that could potentially describe microplastics. These small-size plastic pieces, with a size less than 5mm, are produced as synthetic raw materials or generated as a result of the breakdown and fragmentation of larger pieces of plastic. MPs are divided into two categories, primary and secondary, based on their origin. Primary MPs enter the environment directly. Secondary MPs derive from the breakdown of larger plastic pieces in the environment. This environmental degradation of plastic is governed by the synergic effects of photo- and thermo-oxidative degradation, abrasion and biological activities (Amila Abeynayaka et al., 2020; Barnes et al., 2009). Figure 1 shows the categorisation of plastic debris. Primary MPs are comprised of tire-wear particles, broken road markings, synthetic textile microfibres from washing, microbeads from personal care products and land-based accidental pellet releases. Secondary MPs are made up of decomposed macroplastic debris originating from roads, domestic wastewater systems and municipal waste dumps. These MPs originate from various environmental sources through multiple pathways: road runoff, wastewater systems, wind movement, and marine activities. (Boucher & Friot, 2017).

MPs released from these sources often flow directly or indirectly into surrounding aquatic environments such as rivers, and eventually enter the ocean. However, there is still not much scientific evidence on the potential negative impacts of MPs on ecosystems and aquaculture organisms, or on the implications of microplastics toxicity on human health, and as such, the issue is not well-understood in most ASEAN countries. In addition, basic knowledge is quite limited about the occurrence and status of MP pollution, particularly riverine MP pollution, and the impact on ecosystems and human health. As a result, appropriate and effective countermeasures to control the emission of MPs have not yet been established.

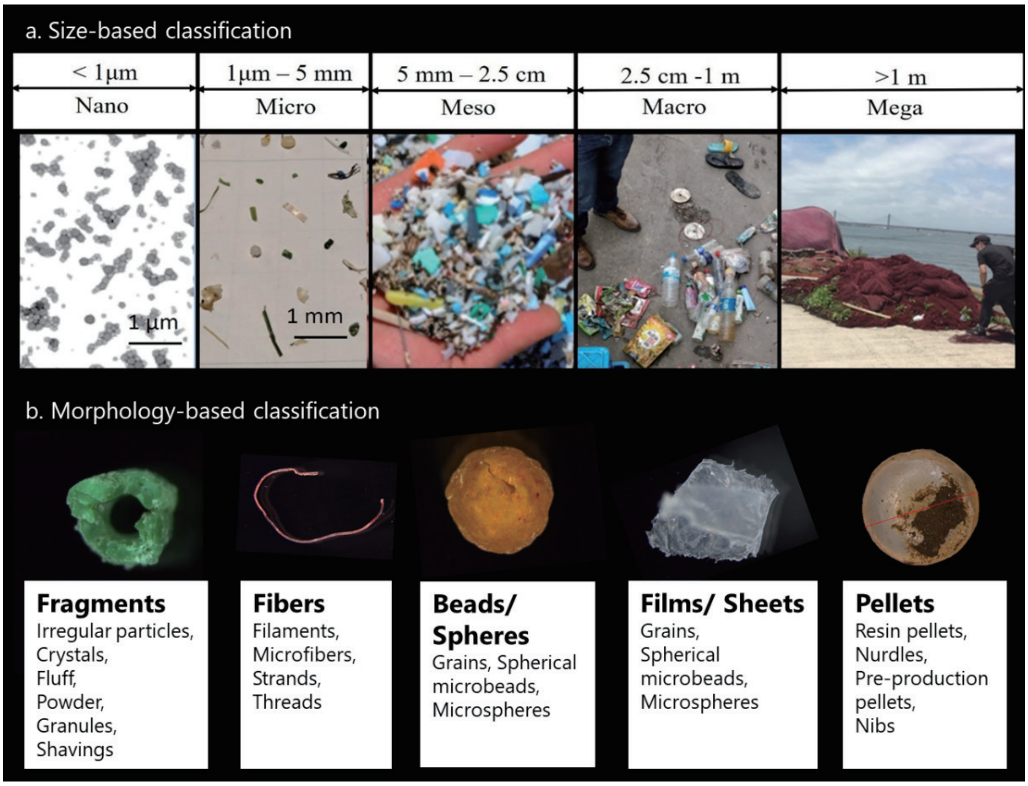


**Figure 1.** Characteristics for categorising plastic debris. a) Size-based classification (modified from Abeynayaka et al 2021) and b) Morphology-based classification (Source: Abeynayaka et al., 2021; Lusher et al., 2017; Pirika, 2021)

This discussion paper aims to provide a concise review of the current state of knowledge on the occurrence, ingestion and impacts of MPs on ecosystems and human health. It also initiates discussion and dialogues on how to minimise the discharge of MPs into aquatic environments, particularly into rivers, either through effective end-of-pipe wastewater treatment technologies, or changing lifestyles and consumption habits for products/materials containing MPs.

# 2. Occurrences, pathways and impacts of microplastics on ecosystems and human health

## 2.1. Occurrence of microplastics in aquatic environments, particularly rivers

Figure 2 shows the pathways taken by MPs as they enter freshwater and marine environments from land-based sources such as direct littering, wastewater treatment plants (WWTPs) and households (HHs). While scholars have revealed evidence of MP pollution in water, particularly in oceans, national governments also began to address the issue by implementing various measures. For example, Belgium, Canada, France, Italy, New Zealand, Republic of Korea, Sweden, Taiwan, the United Kingdom and the United States have all imposed bans on adding MPs to personal care products (PCPs) prior to 2017. Moreover, regional economic and political unions such as the European Union (EU) and ASEAN also initiated different actions for managing MPs (Kadarudin et al., 2020; Kentin & Kaarto, 2018).

Several empirical studies show the occurrence of MPs in water bodies including the Arctic and the Antarctic Oceans, rivers and lakes around the world (Constant et al., 2020; A. L. Lusher et al., 2015; Phuong et al., 2021; Sarijan et al., 2021; Waller et al., 2017; Zeri et al., 2021). A significant amount of plastic has been produced and disposed of in Asia. It has been reported that 15% of the total solid waste by mass was plastic waste in Asia, and half of this amount reach the ocean from land-based sources, contributing to global MPs issues (Alegado et al., 2021). Indeed, studies conducted in ASEAN countries found large amounts of MPs in rivers (Lahens et al., 2018; Sarijan et al., 2021). Studies found that synthetic materials have become the dominant clothing material in recent times, and during the COVID-19 pandemic, single-use plastics have become preferred items, implying that, without action, MP pollution is not likely to be mitigated anytime soon (Arkin et al., 2019).

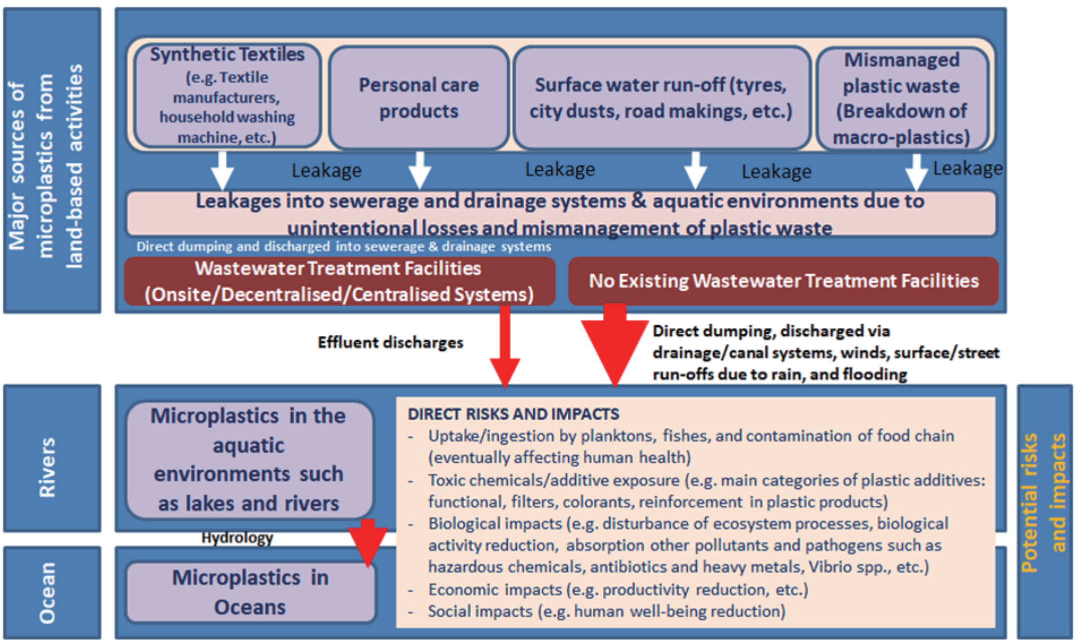


**Figure 2.** Pathways for microplastics to enter riverine systems and reach oceans

## 2.2. Major sources, fate and human exposure pathways of MPs

Primary MPs are produced as small synthetic raw materials for abrasive components in PCPs including cosmetics and toothpaste as well as industrial raw materials. Microfibers are particles from synthetic textiles such as polyester, acrylic and nylon, which are shed when clothes are washed, and enter freshwater systems. Secondary MPs are generated due to the fragmentation of larger plastic pieces that are used for activities such as food packaging, beverage bottles, industrial materials, household goods, synthetic fibres, and many others (Hann et al., 2018; Lim, 2021; Sundt et al., 2014). These MPs are thought to reach the ocean by falling from the air (atmospheric fall-out), being swept away by rain (run-off), or draining into ditches and rivers (Dris et al., 2016). Septic tank systems and WWTPs are also found to be major sources of MPs (Leslie et al., 2017; Miller et al., 2017).

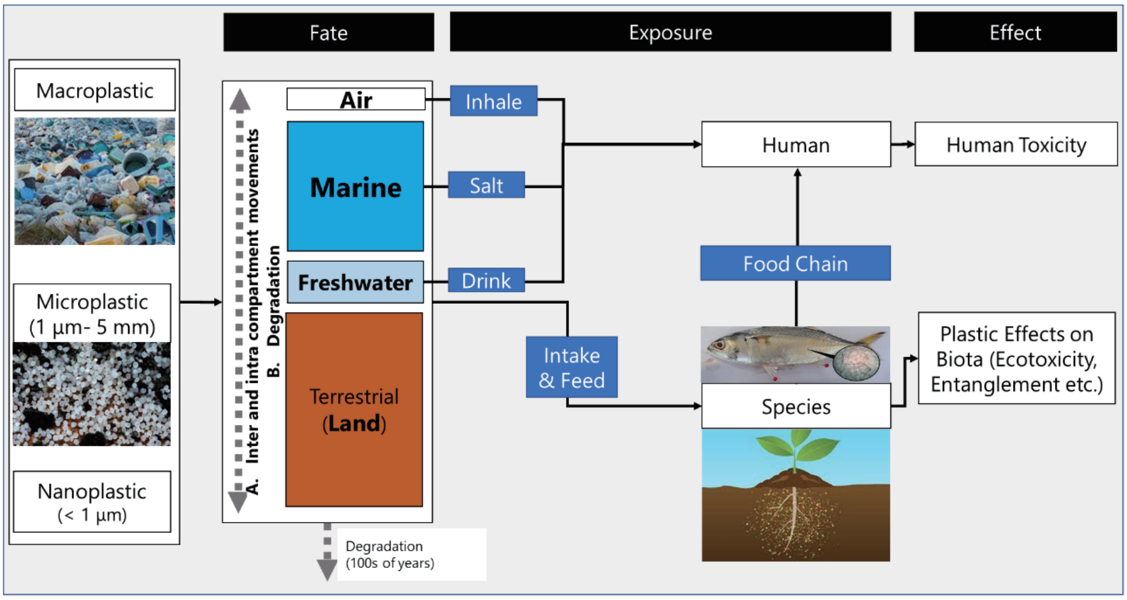


**Figure 3.** Fate of plastics and human exposure pathways (modified from Abeynayaka & Itsubo, 2019; Abeynayaka, 2021)

Once plastics enter the environment, they move within a compartment or move between compartments by various means (Figure 3 illustrates the major compartments and exposure pathways of MPs). Simultaneously degradation causes plastic to break into smaller components. Due to its longer half-life, the longevity of plastic is estimated to be hundreds to thousands of years. Hence, complete breakdown and removal from systems takes hundreds of years (Barnes et al., 2009). Human exposure pathways are mostly associated with inhalation, ingestion through drinking water, food web-associated ingestion, and dermal intake, and MPs will eventually reach the intestines (Prata et al., 2020). Thus, the absorption of harmful substances is a great concern (Ahechti et al., 2020; Fu et al., 2021).

**Do you know?**

- ✓ *Each person inhale around 121,000 particles of microplastic and nanoplastic per year.*
- ✓ *One person may ingest about 52,000 particles of microplatic and nanoplastic per year.*
- ✓ *Microplastics may accumulate in the human liver and kidney*
- ✓ *Microplastics have been found in human stools, suggesting particles may be widespread in the human food chain*
- ✓ *Microplastics are also found in the human placenta*

(Source: UNEP, 2021)

## 2.3. Ecosystem and human health risks

Currently, studies on MPs mainly investigate the occurrence, distribution and ingestion by biota, as well as analysis of physical morphologies in the aquatic ecosystems. The adverse effects of plastic litter in ecosystems have been widely discussed in existing literature (Bellasi et al., 2020; Horton et al., 2018). Plastic contaminants in freshwater are a threat to ecosystems as well as a potential health hazard to humans (Jemec et al., 2016; Redondo-Hasselerharm et al., 2018; Su et al., 2018).

Microplastics can be ingested by plankton at the bottom of the aquatic food chain allowing plastics to move to the next level of the chain, eventually affecting humans. Transparent microplastics along the Surabaya River in Indonesia, for instance, make it more susceptible to ingestion by aquatic biota as it is similar in colour to original prey (Lestari, et.al., 2020). The presence of anthropogenic plastic debris in fish and shellfish was found in grocery markets in Indonesia, indicating that plastics have already infiltrated marine food webs via sea products (Rochman et al., 2015).

A study on potential microplastics in fish from the Surabaya River showed that microplastics were found in 72% of fish samples (103 Surabaya fish samples from 9 species of fish) (Kristanto, 2018). In addition, the herbivorous and polyphagous fish groups had the highest incidence of microplastics, occurring in 67% -100% of the studied fish.

In another study carried out by the University of California, Davis, and Hasanuddin University in Indonesia, 76 fish samples across 11 different species were collected from markets in Makassar, Indonesia. The study revealed that anthropogenic debris (plastic or fibrous material) was found in 28% of individual fish (in their guts) and in 55% of all species (Rochman et al., 2015). In another study conducted in Japan, microplastics were detected in the digestive tracts of 49 out of 64 Japanese anchovies (Engraulis Japonicus), 77% of sampled fishes in Tokyo Bay (Tanaka & Takada, 2016). Among detected microplastics, polyethylene (PE) and polypropylene (PP) account for 52.0% and 43.3%, respectively. The results from this study also indicated that most of the detected plastics were fragments (86.0%), and 7.3% were beads or microbeads, similar to those found in facial cleansers.

Although the effects of microplastic ingestion on human health are not fully understood, microplastics are known to travel through the human digestive tract and into human organs. In addition, microplastics can contain toxic contaminants (e.g. bisphenol A, phthalate plasticizers, carcinogens, polybrominated flame retardants and heavy metals), which are either derived from the plastic itself or absorbed from the surrounding environment. The exposure may cause cancer, neurological and immune system damage, as well as having other effects, if the particles themselves are toxic or if they absorb toxic substances (Arkin et al., 2019; Smith et al., 2018). Table 1 summarises the potential human health effects of MPs and associated chemicals.

A recent study reported that the presence of MPs in human placentas may lead to adverse pregnancy outcomes including preeclampsia and fetal growth restriction (Ragusa et al., 2021). This study observed the presence of microplastic fragments ranging from 5 to 10 μm in size, with spheric or irregular shape in placentas (5 in the fetal side, 4 in the maternal side and 3 in the chorioamniotic membranes), which are possibly used for manmade coatings, paints, adhesives, plasters, finger paints, polymers and cosmetics and personal care products (ibid.).

Table 1. Potential human health effects due to exposure to plastic-associated chemicals.
(Source: Nikiema et al., 2020)

| Affected organs (or potential health issues) | Potential human health impacts |
|---|---|
| **Brain/Nervous system** | Neuro-developmental disorders (Attention deficit hyperactivity disorder (ADHD) Autism, Neurobehavioral, IQ, Cognition |
| **Thyroid** | Hormonal (Thyroid disease, Thyroid cancer) |
| **Reproductive system** | Polycystic ovarian syndrome, Endometriosis, Male sub-fertility, Reduced sperm quality, Delayed time to pregnancy, Abnormal PAP smears, Pregnancy-induced hypertension, and/or pre-eclampsia |
| **Respiratory system** | Asthma |
| **Heart** | Cardiovascular disease |
| **Metabolic diseases** | Type 2 diabetes, childhood obesity; increased waist circumference; serum lipid levels, e.g. total cholesterol and LDL cholesterol |
| **Antibody responses** | Decreased antibody response to vaccines |
| **Pregnancy outcomes - offspring** | Gestational length; birth weight; delayed pubertal timing; genital structure (ano-genital distance); and pubertal onset |

# 3. Status of riverine microplastic pollution in ASEAN countries

## 3.1. Why do we need to focus on riverine microplastics?

It has been reported that between 1.15 and 2.41 million tonnes of plastic debris are being discharged from rivers into the oceans every year around the world, with 86% of this debris emanating from Asian rivers (Lebreton et al., 2017). Rapid economic growth, changes in urban lifestyles and consumption patterns, high ratio of poorly managed plastic waste (about 70% in Asia, based on 2010 data, according to Jambeck et al. (2015)), and frequent heavy rainfalls in the region are considered to be major reasons behind high plastic pollution in oceans, generating from Asia. It has been reported that the top 20 rivers polluted with plastic debris were mostly located in Asia (with seven rivers located in ASEAN countries), accounting for more than two-thirds (67%) of the global annual plastic input (Lebreton et al., 2017). Rivers are considered to be one of the major pathways for land-based plastic waste, mainly coming from single-use plastic items. The waste reaches the world's oceans (Schmidt et al., 2017), and it is further broken down into microplastics after 20 to hundreds of years, causing a threat to biodiversity (Barra & Leonard, 2018; Sarkar et al., 2021). Figure 4 shows examples of the time it takes for some typical single-use plastic items to decompose. In light of the this, it is important to further investigate the fate and flow mechanisms of MPs in the riverine system to design a robust management system.


**Figure 4.** Time required for decomposing single-use plastic items (Source: Rhodes, 2018; Stanes & Gibson, 2017; WWF, 2021)

## 3.2. Detection of microplastics in river water, raw and treated water/wastewater samples

It is reported that there were between 15 and 51 rillion microplastic particles floating in surface waters around the world in 2015 (Lim, 2021). Since these particles travel between the sea and land, people may be ingesting plastic from everywhere (ibid.). Reports on ASEAN countries have shown that the Ciwalangke, Surabaya and Citarum Rivers in Indonesia, the Chao Phraya River in Thailand, and the Cherating River in Malaysia are hotspots for MP pollution (R. Kumar et al., 2021). Besides these major rivers, MPs were also detected in canals and tributaries in Viet Nam (Lahens et al., 2018). In the Philippines, the abundance of MPs in five major river mouths namely the Cañas, Meycauayan, Parañaque, Pasig, and Tullahan rivers draining into Manila Bay varied from 1,580–57,665 particles/m3 in surface waters and 514–1, 357 particles/kg in dry sediments (Osorio et al., 2021). Plastic fragments are the most dominant form across all samples taken from these rivers. This may be attributed to indiscriminate waste dumping and mismanaged plastic waste as evidenced by the amount of macroplastics observed during sampling. Plastic film was also significantly abundant in all samples especially in the Cañas and Pasig Rivers as the mouths of these two rivers were surrounded by large residential settlements, where direct littering and rampant garbage dumping were observed. Most film was detected as low-density polyethylene (LDPE) (ibid.).

Despite the significant addition by ASEAN countries to plastic pollution in the oceans, there are still not many detailed studies about status quo of MPs in different riverine systems (Alegado et al., 2021). Furthermore, most of the existing studies investigated occurrence, distribution and morphologies, whereas it is the exact fate of MPs from source to ocean that needs further investigation.

The management of plastic waste on land is of utmost importance; however, MPs, particularly secondary MPs, are found in the effluent from WWTPs (Liu et al., 2020; Zeri et al., 2021). The literature suggeted that advanced wastewater treatment technologies, which include tertiary treatment processes (e.g. membrane bioreactor (MBR), sand filtration, etc.) could remove most MPs with removal efficiency of between 89.17 % and 97.15 %. Moreover, MPs removed at WWTPs were white colour microfibres, 0.1 – 0.5 mm in size (Xu et al., 2019). These MPs were rayon, polyethylene terephthalate (PET), polypropylene (PP), polyethylene (PE), polystyrene (PS) and PE-PP from laundry and industry, and were mainly found in samples of influent and sludge at WWTP, but also found in the effluent (Lee & Kim, 2018).

MPs have also been found in raw and treated water at two water treatment plants in Indonesia, with a concentration of 26.8-35 and 8.5-12.3 particles/L, respectively. The MPs were made up of 93-95% fibre in the raw water, and 84-100% fibre in the treated water. The MPs dominant size in the raw and treated water was 351-1,000 µm, with percentages of 45-50% and 36-69%, respectively. The dominant polymer types of MPs in the raw water were PE, PP, and LDPE. The water treatment plants I and II had a total MP removal efficiency of 54% and 76%, respectively (Radityaningrum et al., 2021).

## 3.3. Technologies for the removal of MPs at wastewater treatment plants

Due to their low density and small particle size, microplastics are easily discharged into the wastewater drainage systems. Therefore, municipal wastewater treatment plants (WWTPs) have been shown to be the main recipients of MPs before they are discharged into natural water environments (Ngo et al., 2019). Consequently, it is important to develop appropriate wastewater treatment technologies to reduce MP leakages from WWTPs to nearby aquatic environments. Although the literature indicates that advanced WWTPs with tertiary treatment processes (e.g. membrane bio-reactors) could efficiently remove MPs, it is a fact that WWTPs in operations are not necessarily advanced. Moreover, not many households in the ASEAN region are connected to centralised sewage treatment plants, indicating the possibility of more MPs leaking from human activities directly to freshwater and marine environments. Neither centralised and decentralised wastewater treatment systems are specifically designed to remove MPs, but they do remove other organic and inorganic pollutants. Therefore, it is vital to take this fact into account in the design and installation of new or modified wastewater treatment technologies in the near future. In the case of centralised WWT systems, Figure 5 shows how efficiently microplastics can be removed from various treatment processes, if the wastewater treatment facility is operated properly (Nikiema et al., 2020). These results provide a rough understanding of the removal efficiency of microplastics by different treatment processes and may serve as a basis for developing new or appropriate technologies to remove MPs from effluent at WWTPs. The literature investigating MP removal from decentralised wastewater treatment systems is limited. Decentralised WWTPs are the major method for water treatement in the ASEAN region, so it is essential to study MP removal in decentralised systems in order to to reduce MPs in the riverine system.

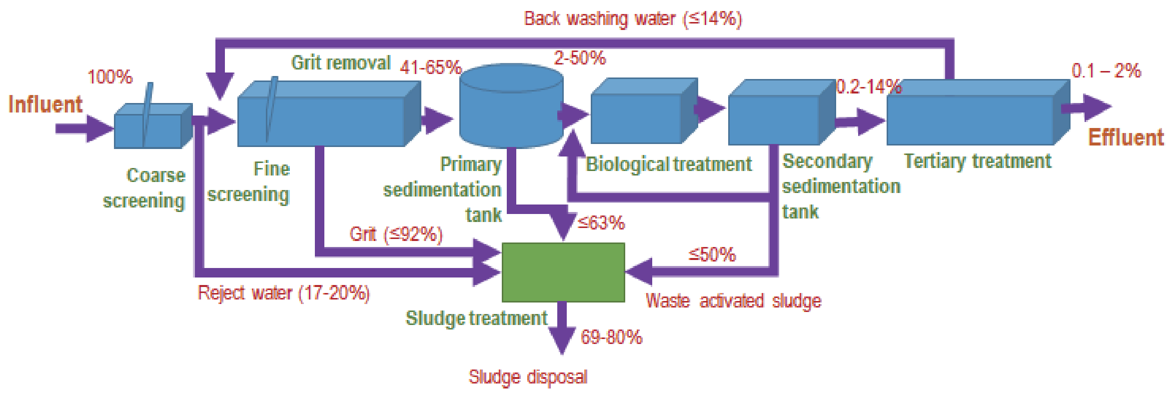


**Figure 5.** Average microplastics flow in both liquid and sludge across different treatment processes within a wastewater treatment plant (Source: Nikiema et al., 2020)

Detecting smaller MPs is a challenge. Fibres are found to be one of the major MPs in rivers as well as in WWTPs (Bujaczek et al., 2021; Uurasjärvi et al., 2020), but sampling and lab analysis of MPs below 100 μm are not easily done, thus recent studies highlighted the possibility of underestimating the concentration of MPs in WWTP effluents (Ben-David et al., 2021; Abeynayaka at el., 2020). Establishing a practical sampling and analysis method for the smaller particles is also needed.

# 4. ASEAN national and regional frameworks for tackling plastic pollution

Rapid urbanisation, economic growth and significant changes in production and consumption patterns have contributed to the growing problem of riverine and marine plastic litter as well as microplastics, not only at national level but also at the regional level in ASEAN. Since ASEAN Member States (AMS) are connected by oceans and rivers (e.g. Mekong River), it is necessary to establish regional and national policies in concordance with neighbouring countries' policies. Moreover, due to the transboundary nature of plastic litter issues, any single country solution will not be sufficient. There is a strong need for regional collective efforts, strong commitments from AMS, and new initiatives with adequate funding mechanisms to be implemented through region-wide collaborations.

Consequently, AMS formalised their commitment in June 2018 to combating marine debris through the adoption of the Bangkok Declaration on Combating Marine Debris in ASEAN Region, and subsequently, the ASEAN Framework of Action on Marine Debris, which highlights the need for regional and national actions with four key pillars, namely (i) policy support and planning; (ii) research, innovation and capacity building; (iii) public awareness, education and outreach; and (iv) private sector engagement. In May 2020, AMS also launched the ASEAN Regional Action Plan for Combating Marine Debris in the ASEAN Member States, which emphasised the need to address microplastic pollution in the region.

At national and city level, great efforts are also underway to tackle both riverine and marine plastic pollution, with special attention on regulating or planning for the elimination of single-use plastic products and plastic packaging. For example, in

October 2018, the Government of Malaysia released its Roadmap to Eliminate Single-use Plastics 2018 - 2030, announcing a policy to eliminate plastic straws and plastic bags by 2030. In Thailand, the Government announced a Roadmap on Plastic Waste Management 2018-2030, with the aim of reducing and halting the use of plastic and replacing it with environmentally-friendly materials. Accordingly, three plastic products, including plastic cap seals for water bottles, oxo-degradable plastics and plastic microbeads, would be banned in Thailand. The use of four other types of plastic, including plastic bags less than 36 microns in thickness, styrofoam food boxes, plastic straws and single-use plastic cups, will stop by 2022. By 2027, 100% of plastic waste will be reusable.

Similarly, in Indonesia, the Phipppines and Viet Nam, many actions have been taken by both central and local governments to reduce plastic pollution, addressing both macro and microplastics pollution in aquatic environments.

## 5. The Way Forward

For effective implementation of the ASEAN Framework of Action on Marine Debris and the the ASEAN Regional Action Plan for Combating Marine Debris, there is a need for strong political will from all AMS to solve the issue. It is said that "Prevention is always better than cleaning up" , considering time and resources spent on a solution. Moreover, it is crucial to address various issues along the plastic value chain through the circular economy approach, from raw material extraction, design, production, distribution, excessive plastic consumption (especially single use plastic products), collection/reuse/repair, to the recycling stage. These stages are all essential to solve this national, regional and global issue.

It is widely well-recognised that private financing can play a major role in providing not only financial but also operational solutions to these challenges (e.g. research on plastic alternatives, materials and product design, and business model innovation). This can gradually complement public sector investments to reduce the use of plastics, increase recycling, and promote a circular economy (The World Bank, 2021). Meanwhile, it is expected that the scientific community will provide sufficient scientific evidence that supports policymakers in developing effective measures and evidence-based policies.

Furthermore, the following are recommended actions for all ASEAN countries to take, based on the findings from this paper, for establishing an MP-free water environment.

- Install and optimise the performance of wastewater treatment facilities in ASEAN countries
- Strictly control the discharge of wastewater containing microplastics into aquatic environments
- Develop national quality standards related to microplastics pollutants (standards for both effluent and drinking water)
- Properly manage plastic waste to avoid leakage into the water environment by improving municipal solid waste collection, treatment and management services
- Reduce the use of single-use plastic products and replace them with alternative products
- Introduce an appropriate policy approach of Extended Producer Responsibility to mitigate MP pollution, especially in aquatic environments.
- Identifying alternative solutions to reduce leakages of MP from textiles, personal care products, and tire-wear particles emissions

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**Institute for Global Environmental Strategies (IGES)**

2108-11 Kamiyamaguchi, Hayama, Kanagawa, 240-0115, Japan

Tel: 046-855-3700 ／ Fax: 046-855-3709

E-mail: iges@iges.or.jp　URL: https://www.iges.or.jp/