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REVIEW ARTICLE

Current scenario and challenges of plastic pollution in Bangladesh: a focus on farmlands and terrestrial ecosystems

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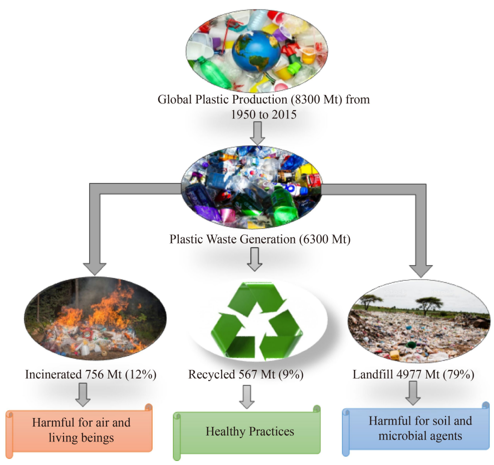
HIGHLIGHTS

- A global snapshot of plastic waste generation and disposal is analysed.
- Effect of plastic pollution on environment and terrestrial ecosystem is reviewed.
- Ecotoxicity and food security from plastic pollution is discussed.

GRAPHIC ABSTRACT



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ABSTRACT

Plastic is considered one of the most indispensable commodities in our daily life. At the end of life, the huge ever-growing pile of plastic waste (PW) causes serious concerns for our environment, including agricultural farmlands, groundwater quality, marine and land ecosystems, food toxicity and human health hazards. Lack of proper infrastructure, financial backup, and technological advancement turn this hazardous waste plastic management into a serious threat to developing countries, especially for Bangladesh. A comprehensive review of PW generation and its consequences on environment in both global and Bangladesh contexts is presented. The dispersion routes of PW from different sources in different forms (microplastic, macroplastic, nanoplastic) and its adverse effect on agriculture, marine life and terrestrial ecosystems are illustrated in this work. The key challenges to mitigate PW pollution and tackle down the climate change issue is discussed in this work. Moreover, way forward toward the design and implementation of proper PW management strategies are highlighted in this study.

1 Introduction

Plastic pollution is now a worldwide concern on account

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of its ubiquity and vital ecological effect on agricultural land and marine environment as well as on human beings. Since 1950s, there has been around 4900 MT, accounting for up to 60% of global plastic production, discarded and accumulated in landfills or in the natural environment (Reis et al., 2019). The main source of plastic waste is from both residential commercial activities that is usually collected and transported to the landfill sites (i.e., for recycling, incinerating, or discarding). Another massive source of PW is from intensive and semi-intensive agricultural practices that involves plastic materials such as covering films, shading nets, mulching, packaging, wrapping material, etc. (Briassoulis et al., 2013). Moreover, in most cases, plastic debris ends up journey to landfill sites or in marine environment causing soil and water pollution (Chae and An, 2018; Corradini et al., 2019). Furthermore, air pollution from spreading odour, microorganisms, and pathogens is usually caused by open dumping and incinerating of plastics (Rillig, 2012; Nizzetto et al., 2016). The pollutants also latched into rivers, canals, or other nearby marine environments through rain, storm or by the placement of landfill sites (Browne et al., 2015; Li et al., 2016). Though there are several studies on plastic pollution in aquatic environments, only few studies have been carried out to address such issue in the terrestrial ecosystem, in which farmlands are still overlooked. Thus, addressing the adverse effects of plastic contamination on both terrestrial ecosystems and aquatic environments needs to pay more attention.

Effective and sustainable routes of management (i.e., collection, sorting, recycling, and treatment) the plastic waste is critical to eliminating the challenges of pollution by these types of waste. This should be done at a global scale; however, sustainable waste management strategies draw the borderline between developed and underdeveloped countries (Horodytska et al., 2019). In developing countries, lack of proper laws, policies and legislations coupled with poor infrastructure to manage PW hinders the implementation waste management (Hossain et al., 2021; Prata et al., 2022). Other key factors including outdated or inefficient technologies, lack of support in technical services, and most importantly financial backup to implement waste management strategies also contribute to poor management practices of debris (Hossain et al., 2021). Thus, open dumping, landfilling, and burning in the open air are common PW management practices in developing and under-developed countries (Mourshed et al., 2017). As a result, the communities from such countries are the worst sufferer of plastic contamination and consecutive natural disasters (global warming, greenhouse gases or GHGs emission) (OECD, 2019) that are closely linked with the unwise dumping of plastics. Therefore, this process of waste management system ultimately entangles the total ecosystem inland and marine life. Moreover, it has been reported that plastic litter causes the spread of microorganisms of various fatal diseases and even causes the death of human beings and wildlife (Williams et al., 2019).

This write-up is going to deal with the potential challenges of plastic contamination and its adversity on agricultural lands and ecosystems in the context of Bangladesh. Bangladesh is an agri-based country with 87700 km^2 of cultivable land. It has numerous rivers throughout the country coupled with tropical monsoon climate that is a great condition to develop the agri industries (FAO, 2014). Along with these agri industries, Bangladesh occupies 0.6% share of the USD 570 billion global plastic market (Ministry of Industries, 2020), with more than 2 million employees involved in the plastic industry directly or indirectly (Ahamed, 2014). While dealing with natural calamities and the management of different types of solid wastes, mismanaged plastics are now a serious concern for Bangladesh. According to an estimation, 633129 t/a of PW are generated only from suburban areas of Bangladesh, and this scenario pulls Bangladesh in 10th rank among the top 20 mismanaged PW generated countries throughout the globe (WasteConcern, 2016). The plastic waste production increases significantly during the COVID-19 pandemic when a rocket demand in the use of masks, hand gloves, and regular polythene production. It is estimated that an additional amount of 14500 tons of PW (including masks and hand gloves, alongside regular polythene production) were produced in a month from March 26 to April 25 after first COVID-19 case was detected and among these waste (where 3076 t have been produced only in Dhaka, the capital city of Bangladesh). However, waste management practices and techniques to curb this huge threat of plastic pollution are still not in satisfactory condition. Dumping on open spaces or burning are the common solution to deal with the plastic pollution, whereas these open dumping sites have a detrimental effect on soil biota, fertility and overall soil health, and ultimately on the agri sectors. Moreover, the burning of PW also generates toxic gases like CO_x, NO_x as well as contributes to GHG emissions (de Souza Machado et al., 2018b; Guo et al., 2020). The polluted aquatic environment linked up with these landfill sites causes threatens to fish reproduction ability and damages to helpful organisms in aquatic biota (Thushari and Senevirathna, 2020). Last but not least, mismanaged plastic may lead to clogging of drainage systems that may cause local flooding, and thus poses a serious threat to wildlife in land and water.

Some previous research works (Islam, 2012; Ahamed, 2014; WasteConcern, 2016; Mourshed et al., 2017; Ahmed, 2019; Kabir et al., 2021) highlight the generation scenario of PW and its effects on the environment. It is noteworthy that Bangladesh is an agro-based country and a large number of its total population directly and indirectly depend on agriculture; hence, it is important to effectively address the effects of PW on agricultural land, water as well as on total ecosystem. This study sheds light on the scenario of plastic pollution and its adverse effect in the context of agricultural farmlands and the terrestrial ecosystem of Bangladesh. The generation of PW and its dispersion pathways to environment contributing to both global and Bangladesh perspectives are comprehensively studied in this work. The effect of PW on agricultural land, water as well as on food quality and food security are also emphasised in this study. Moreover, the adversity of plastic-oriented medical waste and its role during and post-pandemic situations are highlighted in this paper. Moreover, a way forward is presented in the conclusion section to address the key challenges of managing PW and reducing environmental pollution from this hazardous waste.

2 Global plastic utilisation, disposal and management—an environmental concern

2.1 Overview

The plastic production and consumption increase considerably with the world's population, consumption of different goods and waste generation rate also increases according to per capita income. Plastic, among other sorts of waste, is regarded most hazardous waste because of its non-degradable qualities and the subsequent effect on the environment (Gall and Thompson, 2015; Mourshed et al., 2017; Bläsing and Amelung, 2018; Chae and An, 2018). It is pointed out that per capita plastic consumption rate is approximate 43 kg in consideration of the global aspect, and highly populated, low-income countries are the major consumers and producers of this huge volume of plastics (Jensen, 2018). Only EU has produced 29.1 million tons (Mt) plastic waste and only 32.5% plastic waste was recycled in 2018 (Rahman and Bhoi, 2021), (when the EU GDP was $15978.72B) (macrotrends) and 61% of the total generated plastic wastes were from packaging industry. In the EU, within 14 years (2005 and 2018), plastic packaging waste generation has increased by 21% to 17.2 Mt. In 2019, the global total amount of plastic production was circa 370 Mt (PlasticsEurope, 2021). Among which, only Asia accounts for 51%, Europe 16%, North America 19%, Latin America 4%, Middle East and Africa accounts for 7%, Countries of the Commonwealth of Independent States (CIS) 3% (PlasticsEurope, 2021).

According to statics from 2015, plastic consumption amount accounted for 0.13% to 0.75% of the Asia-Pacific region's total material consumption (Lebreton and Andrady, 2019; StatisticsTime, 2022), where imported fossil fuels are used to manufacture plastic and depicts how, as per capita income rises, so does plastic usage (Jain, 2020). Increasing the amount of PW generation according to highly populated continents is shown in Fig. 1.

The polymer type and longevity of the finished products determined the PW generation, though; therefore, primary plastic manufacturing does not immediately reflect it. Fig. 2 demonstrates the distribution of plastic production by sector in 2015, where 42% (Ritchie and Roser, 2018) of plastics entered the usage phase, and the most prevalent application of plastic globally has been identified in packaging sector (Geyer et al., 2017).

In line with plastic production and consumption, PW management is not backed up by the proper management strategies. It is estimated that within 66 years (1950–2015), circa 8300 Mt of fresh plastics were manufactured around the world, resulting in roughly 6300 Mt of PW, of which approximately 9% was recycled, 12% were burnt, and 79% eventually ended up in different landfills (Geyer et al., 2017). Fig. 3 illustrates the chronological life cycle of plastics from generation to dumping during the period 1950 to 2015.

Apart from that, one of the major sources of primary microplastic (microplastics or MPs is a segregated or broken plastics from larger plastic waste which is less than five millimetres or 0.2 inches in diameter) contamination is the use of sewage sludge from municipal

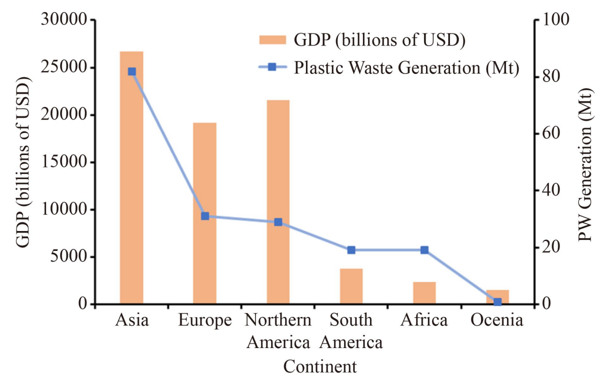

Fig. 1 Amount of PW generation on each continent in 2015.

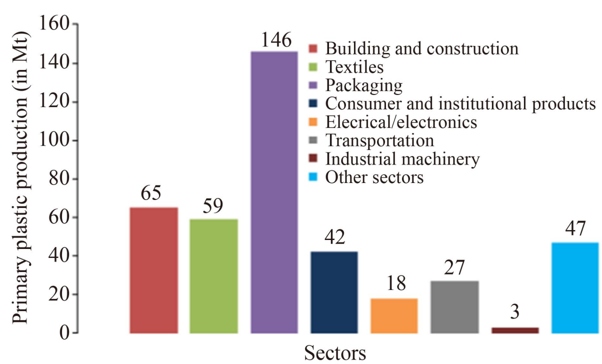

Fig. 2 Primary plastic production by industrial sector, from 1950 to 2015.

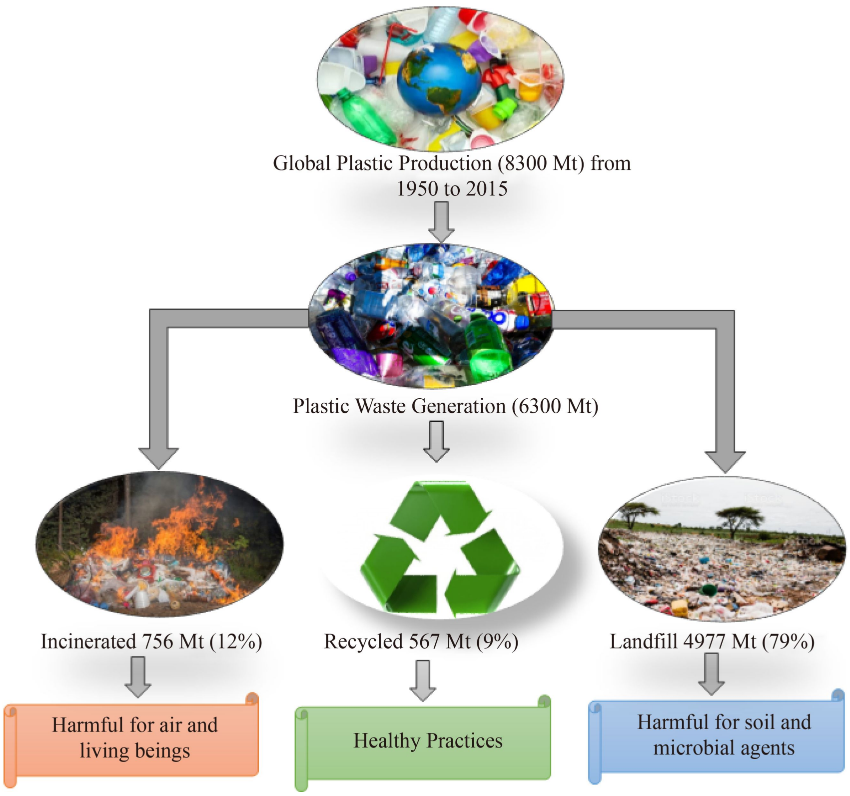

Fig. 3 Fate of plastic production and its effect on the environment.

wastewater treatment facilities as a fertiliser for agricultural land (Horton et al., 2017). It is estimated that about 125 to 850 t of MPs per million inhabitants are mixed up annually in agricultural lands in Europe (Henry et al. 2019) [REF: Henry B, Laitala K, Klepp IG (2019). Microfibres from apparel and home textiles: prospects for including microplastics in environmental sustainability assessment. Science of The Total Environment, 652:483-94]. Each year, roughly, European and North American farmlands then incorporate 63000–430000 t/a and 44000–300000 t/a of MPs, respectively (Nizzetto et al., 2016). Moreover, during municipal solid waste (MSW) collection, processing, transportation and landfilling, secondary MPs are also generated (Horton et al., 2017; Chen et al., 2022; Sun et al., 2022). Using agricultural plastics, such as polytunnels, silage bailing and plastic mulches, also creates secondary MPs through sunlight; fragmentation on land is then enhanced, which has a greater impact on this plastics pollution (Rillig, 2012; Steinmetz et al., 2016; Horton et al., 2017). According to the European Commission, the EU market is enumerated to be 100000 t/a for plastic mulch and only 32% of plastic is accumulated at the end of use, with the rest either landfilled or burnt (Sarvi et al., 2017). In addition, natural factors and disasters like storms, floods, and wind contributes to the dissemination of MPs, either across land, or from land to water and vice versa (Zylstra, 2013).

2.2 Effect of plastic pollution on the environment

2.2.1 Soil

2.2.1.1 Impact of micro-plastic on soil's physicochemical properties

Soil aggregation ability, bulk density, water retention capacity, mineralisation, stabilisation, and disintegration of soil aggregates are harmed by the dispersion of MPs; this is likely to have negative impact on soil microorganism evolution (de Souza Machado et al., 2018a). MPs existed in phytotoxic compounds may have a deleterious impact on plant roots and soil fauna by forming a hydrophobic barrier in the soil (Ma et al., 2022; Pushan et al., 2022; Zhang et al., 2022a). In addition, Bisphenol A (BPA), a chemical, released by plastic after entering into soil, creates toxicity (Bläsing and Amelung, 2018; Rillig et al., 2019a). It is also alarming that plastic mulching, a common practice in crop fields, seems to be a leading source of soil health deterioration, nutrient and carbon stock loss, and releases toxic additives that promote soil infertility (Domagała-Świątkiewicz and Siwek, 2013; Zhang et al., 2015). Along with the pitfalls associated with traditional thermoplastics (e.g., PVC, PET, polyethene, or polystyrene), other polymer-grounded accoutrements, similar to microparticles deduced from CTR (car tire rubber), are causing concern

(Wagner et al., 2018). CTR is considered as one of the utmost contributors to plastic pollution, particularly in roadside farmland. CTR may be injurious to human health and to the environment specially soil, as it contains different types of harmful chemical substances like carbon black, clay, silica, sulphur (pigments, oils, resins, and short fibres) (Rodgers and Waddell, 2005; Turner, 2016).

2.2.1.2 Impact on the microbiota in the soil

MPs have an impact on soil microbes, ultimately disturbing mineralisation rates and affecting root-colonising symbionts by altering soil pH (Sarker et al., 2014; Vallespir and Ursell, 2019). Interestingly, protists have a crucial role in delivering MPs into the food chain (Rillig et al., 2019b), and MPs have been discovered to be able to pick up protists from aquatic habitats (Christaki et al., 1998).

Fig. 4 illustrates the impacts of MPs on growth of plants under different mechanisms (i.e., immobilisation of nutrients, pollutant transport or adsorption, and direct toxicity as well). The transportation of the MPs on agricultural soil also causes minor soil texture and structural change, bulk density change, increased soil water evaporation, and decreased nutrient contents by microbial immobilisation; however, MPs are directly toxic to root traits and growth and nutrient absorption.

Moreover, MPs can be easily transferred to different layers of soil and cause a fundamental change in the chemical composition of soil as well as affect the growth of microorganisms. With the dispersion of MPs to deeper soil layers, the earthworms' health is affected and also causes heavy contamination of groundwater (Chae and An, 2018). From a previous study, it is reported that polybrominated diphenyl ether (PBDEs) produced from polyurethane foam (less than 75 mm) can be deposited in earthworm bodies which means MPs have the ability to penetrate into the soil ecosystem and accumulate in soil invertebrates (Gaylor et al., 2013). Hence, it can be said that MPs have a great impact on soil organisms which ultimately affects soil biota. As a result, both yield and quality of agri-products is reduced if the soil gets contaminated by plastic wastes.

2.2.2 Water

Bangladesh is one of the worlds' largest river networks containing country, with more than 700 rivers and watercourses with tributaries, totalling around 24140 km. Mismanaged plastic trash is considered as one of the primary pollutants among various types of solid waste; that is why Bangladesh has been rated 10th among the top 20 mishandled plastic waste-generating countries throughout the world (Chowdhury et al., 2021). Almost all discarded PWs end up their journey either by leaking from landfill sites or direct dumping into water bodies (ponds, lakes, rivers, and eventually in the ocean).

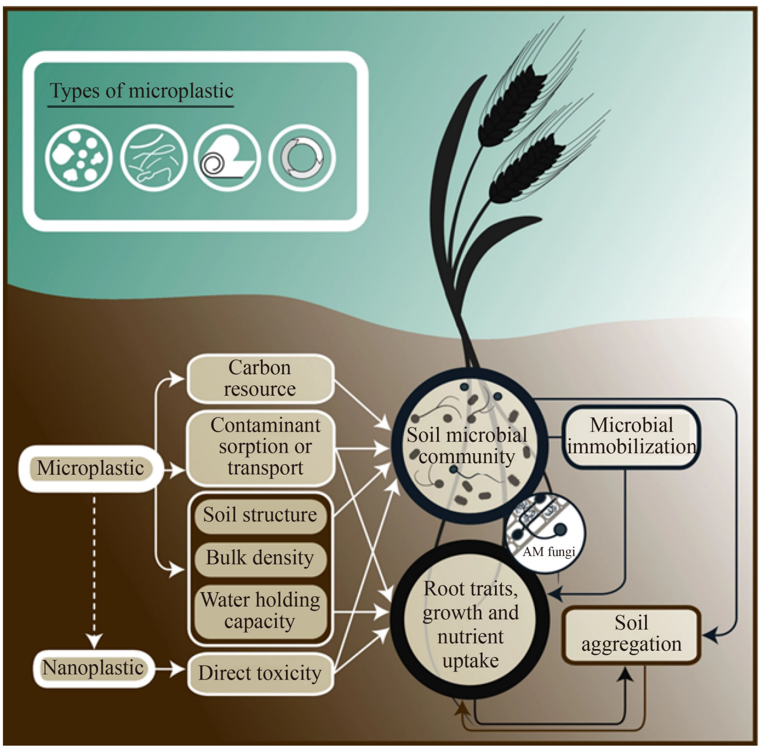

Fig. 4 Effects of MPs on Soil biota and soil properties (Rillig et al., 2019b).

Different sorts of plastic made up 50% to 80% of the total waste collected on the shoreline, ocean surface and bottom (Barnes et al., 2009). For example, for each waste litter found on four big beaches (Laboni, Inani, Ananda Bazar and Patenga) in Bangladesh, plastic contamination accounts for more than 60% of the litter (Qi et al., 2018). This issue should be addressed to protect biodiversity in the marine tourism area which is growing up and contributes considerably to local economic development.

Among different types of plastic litter, plastics in microform usually release hazardous organic pollutants like dichlorodiphenyltrichloroethane, polybrominated diphenyl ethers etc., that are found in water during manufacturing, consequently increasing their concentration in water (Issac and Kandasubramanian, 2021). Though additive-free MPs are not perilous to aquatic organisms chemically, they have a negative impact on physical health, like bowel obstruction in long-term (Udayakumar et al., 2021). In the next step, fragmented or degraded size of MPs during wastewater treatment are infiltrated and then direct discharge into water resources. As a result, negative impacts on the environment caused by MPs contamination are including (Issac and Kandasubramanian, 2021):

- Poor growth and variance in food habits of species because of large volume of MPs intake (Horton et al., 2018)
- Hazardous substances and additives (i.e., plasticisers, antioxidants, flame retardants, pigments etc.), from plastic production entered into the body tissue of aquatic organisms if they are properly untreated before dumping to the marine environment (Botterell et al., 2019)
- MPs surface may absorb extra pollutants at a larger concentration due to weathering, prolonged self-life, and hydrophobic characteristics, and finally serve as a contaminant transporter into aquatic organisms (O’donova et al., 2018)

Consumption of small plastic particles can introduce toxic chemicals into living organisms in two ways, in addition to physical harm (Oehlmann et al., 2009; Talsness et al., 2009; Hossain et al., 2021). Using addictive chemicals (i.e., phthalates as plasticisers) helps to improve the qualities of polymers; however, their presence in biological creatures causes carcinogenic effects and endocrine disruption (Teuten et al., 2009; Chen et al., 2022; Lu et al., 2022). MPs could play the role as a carrier of various hydrophobic organic substances into marine species, making them more vulnerable to the build-up of persistent organic pollutants (POPs) (Bakir et al., 2014). Due to their lightweight, they have the ability to travel a vast distance with other contaminants and create trouble for the water ecosystem.

2.2.3 Air

Most common PW management implies open landfills and burning without any kind of sorting (to categorise recyclable and reusable materials) that causes the most damaging effect on the surrounding environment and air quality. Incineration or open burning is a common solution for treatment high volume and mass of mixed plastics content, but it consumes fossil fuels for the burning and exhausts great deal of GHG to the environment causing air pollutions and climate change (Pinto et al., 1999). The effects of plastic adulteration on the air and surrounding environment can be summarised as follows:

- When plastic is burned, harmful smoke is released into the environment, resulting in highly hazardous gases (Hossain et al., 2021)
- Poisonous gases are released as a result of the combustion of PWs, which are reduced to ash and ink in the form of tiny particles (Valavanidis et al., 2008)
- Toxic heavy metals (Cd, Pb, Cr, Ni, Cu, Zn) and lithophilic metals (Ca, Si, Na, Mg, Al, P, Fe) are produced by open-air burning and induces many fatal diseases in living creatures (Wagner and Caraballo, 1997; Font et al., 2004; Valavanidis et al., 2008)
- Burning of PVC releases phosgene (up to 2 mg/g PVC) which is considered a serious health deteriorative agent (a dangerous chemical weapon used to during the first world war) while breathing (Ágnes and Rajmund, 2016)
- Irritation of the skin and eyes, respiratory tract infections, nervous system abnormalities, brain and gastrointestinal tract damage, and a decline in disease immunity ultimately led to cancer (Ágnes and Rajmund, 2016)
- The breakdown of landfilled plastics by several microbes, bacteria (for instance, *Pseudomonas*, a well-known nylon-eating bacteria) and flavo-bacteria release a large amount of methane which is considered one of the leading gases of global warming (Biello, 2011)
- In some cases, Li-ion, and lead-acid batteries boxes are dumped and burned that causing serious damage to soil with the dispersion of aqua regia from batteries to soil

Consequently, the unplanned and uncategorised open combustion of plastic materials and their carcinogenic outflow is now a rising concern. In developing countries like Bangladesh, this type of solid waste management (open burning) has been carried out mainly by the informal sectors or local vendors, and their number is quite large and significant in the total waste management sector.

2.2.4 Marine life

Effects of plastic contamination on marine biota and ecosystems (a wide range of organisms, including microbiota, invertebrates, and vertebrates) at different levels are found (Thiel et al., 2018). MP (< 1 m) MPs have the eventuality to interact with submarine organisms in all trophic situations, causing a variety of negative consequences (Kühn et al., 2015; Barboza et al., 2019). Hundreds of papers have reported on contact between marine litter and approximately seven hundred marine species in the following decades (Gall and Thompson, 2015). Plastics account for more than 80% of total marine litter. It is estimated that around 5.25 trillion particles of plastic trash, with 269000 t floating and 4 billion microfibers per square kilometre below the surface of our seas (Ferries, 2021). Agriculture runoff, untreated sewage, fertiliser, and pesticide discharges contribute up to 80% of global marine pollution, while ten rivers alone account for 90% of global ocean trash. Every year, 100 million marine animals die because of this plastic contamination (Ferries, 2021).

Plastic contamination has an influence on marine species through entanglement, absorption, bioaccumulation, and alterations in habitat integrity and function. While microplastic wastes are considered as a major source of entanglement, many marine species ingest macro and MP wastes (Vegter et al., 2014; Cai et al., 2022; Shan et al., 2022). Moreover, plastic contamination has an impact on marine organisms at all levels of the food chain, from plankton to whales (Dhineka et al., 2022; Gong et al., 2022). For example, after getting stranded on a West Seattle beach, a couple of sweatpants, golf balls, rubbish, along with more than 20 plastic bags, tiny towels, medical gloves, plastic fragments, and duct tape were discovered in the stomach of a grey whale (Associated Press, 2010).

Up to 13 million metric tons of different polymers are expected to remain in the ocean per year (Reddy, 2018). Bisphenol A (BPA) and phthalates leached products of plastic are listed as implicit endocrine-dismembering chemicals because they have the capability of disrupting hormone regulation in both humans and wildlife (Klika, 2015). BPA, phthalates, and BFRs are among the additives that harm the aquatic species (Canesi and Fabbri, 2015), as presented in Table 1. On the other hand, the exposure of leached plastic cumulative fusions has gotten far lower attention. Knowledge about their fate and goods is also limited. The permeability of the polymer matrix, gaps between polymer molecules, physicochemical properties of the additives, properties of the surrounding medium (e.g., salinity, temperature, pH), and time all play a role in additive leaching from plastic materials (Kwan and Takada, 2016). This limits the ability to identify and quantify the chemical composition of leachates, as well as establish a probable connection between the observed toxin and specific leachate ingredients. Nonetheless, leachate exposure has negative effects on a variety of organisms, including fish, photosynthetic bacteria, and *Daphnia* spp., brown mussels, barnacle nauplii (Lithner et al., 2009; He et al., 2011; Tetu et al., 2019).

The aqueous leachates from plastic materials have an effect on microalgae's growth like *Raphidocelis subcapitata* and *Skeletonema costatum*, as well as in *Mytilus galloprovincialis*. Apart from aquatic ecosystems that are exposed to plastic debris on a daily basis, with varying effects on the health of aquatic microorganisms, plants, and animals, the risk of exposure for terrestrial species has also emerged (Fabbri et al., 2014).

From the previous reports, it has been illustrated that traces of plastics were found in the stomach of 95% (while performing tests on 1295 seabirds) seabirds (northern fulmar) corpses in the North Sea (Van Franeker et al., 2011) and also during the investigation of sighting photographs for the past 29 years, 83% of 626 North Atlantic right whales became entangled in rope or nets (Knowlton et al., 2012).

2.2.5 Ecosystem

Humankind, the key components of the whole ecosystem, can significantly control the balance of ecosystem through their activities. Unwise and unplanned dumping of plastic into environment from different man-made sources causes severe disturbance to ecosystem and its constituting bodies (de Souza Machado et al., 2018a). As discussed above, MPs are a segregated portion of plastic, and they are easy to disperse in environment and continue to exist, particularly in the environment of poor light and oxygen (i.e., soil), for over 100 years (Horton et al., 2017). As a result, MPs interact with soil microorganisms by impacting their fitness and soil function through their biophysical environment (Lwanga et al., 2016; Lwanga et al., 2017; Zhu et al., 2018). Other terrestrial creatures also undergo extensive alterations in the biophysical environment under the presence of MPs; consequently, they interfere with plant-pollinator interactions (Liebezeit and Liebezeit, 2013). Another study unveiled that MPs have potential to be preferentially preserved in

Table 1 Ecotoxicity of plastic waste

Item	Availability	Effect
Car Tire Rubber (CTR)	Land	Harmful to overall environment as it contains chemical substances such as carbon black, clay, silica, sulphur, etc.
Bisphenol A (BPA) and phthalates	Land and water both	Endocrine disruptive substances have the potential to alter hormone regulation in both wildlife and people.Shows harmful effects on aquatic species also.
Leachate Exposure	Water	Negative effects on a variety of organisms, including fish, photosynthetic bacteria, and *Daphnia* spp., brown mussels, barnacles.

earthworms and transmit to other organisms through food chain (Chae and An, 2018). Furthermore, the wastes from incomplete combustion of PWs such as ashes, smut and various powders accumulate on plants and soil, which are washed away by rainfall and floods and absorbed into the food chain, causing further perilous effects (Hossain et al., 2021). Researches have been also carried out to address the detrimental effects of MPs on essential plants and pollinator ecological functions (de Souza Machado et al., 2018a). However, the impacts of micro and NPs on marine environments at the ecosystem level have been uncertain yet, although they might include changes in nutrient availability and food chains and also changes in the microbial populations that develop on plastics (Zettler et al., 2013). Another interesting information is that under typical environmental conditions, the adding disposal rate (now predictable at more than 8 Mt per time) and variability slow declamation rates of plastic beget a periodic loss in an ecosystem that's performing in periodic profitable losses of about USD 2.5 billion globally (Beaumont et al., 2019).

2.3 Strategies to manage PW

Waste management can be classified on the basis of pre- and post-consumption of goods. Pre-consumption or production state mainly addresses the quality (physical and chemical properties) of goods in accordance with the laws and regulations of each country, whereas post-consumption steps mainly articulate the recycling and sustainable dumping of waste. Table 2 summaries the existing laws and legislations on PW management for several countries and regions. It can be observed that developing and underdeveloped countries are still in the state to strengthen their laws to effectively manage the plastics wastes while they are living in the environment condition of plastic contamination. In underdeveloped countries, the waste management sector is greatly reliant on informal sectors, which are generally the poorest and most vulnerable members of society, and they make their living by collecting and selling commodities to trash aggregators.

It is also alarming that among 191 countries throughout the world, only 55 countries follow the rules and legisla-

Table 2 Existing laws and its significances in different countries (UNEP, 2018)

Country	Existing laws and significance		
	Level	Legislation	Impact
Bangladesh	National	Ban on polyethene plastic bags (2002).	The public's immediate reaction was good. Unwillingness of law enforcement authorities and the unavailability of low-cost alternatives, the usage of polymer bags surged after a few years.
India	National	Non-degradable plastic bags (< 50 μm) are prohibited (2016).	Information is not available.
	Local-Punjab	Single-use plastic (SUP) carry handbags and buckets are prohibited from being manufactured, stocked, distributed, sold, or used.	Information is not available.
	Local-West Bengal	From 2001 forward, several restrictions were imposed. West Bengal has imposed a total ban on plastic bags < 40 μm in some places.	Information is not available.
France	National	Prohibition on all plastic bags except biodegradable bags was amended in 2017 to include lightweight SUP carrying bags (< 50 μm and < 10 L).	Information is not available.
Rwanda	National	All polymer bags are prohibited from being manufactured, used, imported, or sold.	The restriction resulted in illegal market for plastic bags in the first phase. Plastic bags are gradually being replaced with paper bags.
Sweden	National	Supermarkets are required by law to educate customers about the negative impacts of plastic on the environment.	Information is not available.
Ireland	National	Impose a tariff on a customer for the use of plastic bags. The goal is to reduce usage to no more than 21 bags/person per year.	Plastic bag use went down by more than 90% in the first year after the fee was implemented.
China	National	Non-decomposable plastic bags < 25 μm are prohibited, and consumers must pay a fee for thicker bags.	Plastic bag usage has decreased by 60% to 80% in Chinese shops.
	Local-Hong Kong	Levy on the consumer.	Only a few chains and outlets have been affected as a result of the deployment. The levy was expanded to over 100000 business holders in 2015. Within the first year, 25% fewer bags were discarded in landfills.
USA	Local-Washington	Levy has been imposed on purchaser (USD 0.05) for plastic bags.	According to a poll conducted in 2014, the average weekly usage of plastic bags reduced from 10 to 4.
Canada	Local-Leaf Rapids	In Leaf Rapids, plastic bags are prohibited.	Information is not available.
	Local-Montreal	Plastic bags < 50 μm are prohibited in Montreal.	Information is not available.
United Arab Emirates	National	The Environment Agency-Abu Dhabi (EAD) has unveiled a strategy to eliminate SUP from the emirate by 2021.	Information is not available.

tion about manufacture, import and retail distribution of plastic goods (UNEP, 2018). More than 15 million people lead their life unhealthy with no social protection (Kaza et al., 2018). In Bangladesh, MSW management is primarily carried out by city corporation authorities along with some third-party organisations and a few numbers of non-governmental organisations. However, those organisations are unable to cope with this huge quantity of MSW management. Therefore, developed countries are well organised in managing PW through their technological and infrastructural advancement. Plastic properties or quality (thickness, composition) dictates its biodegradability, whereas frequency of use (single or multiple) indicates the volume of unintentional PW generation. In this way, cotton bud sticks, drink stirrers, plates, straws, cutlery, and balloon sticks are all single-use plastic products and are restricted in some markets by the EU in 2021 (Herberz et al., 2020). Table 3 also listed some specific countries to illustrate the laws regarding plastic utilisation (plastic thickness, beads, frequency of use) and dumping (strategies, management and significance of legal action).

3 Scenarios of PW generation and dispersion in Bangladesh

3.1 Sources of plastic in Bangladesh

Despite the fact that Bangladesh is one of the most populous countries in the South Asia (around 1265 per sq. km), around 87000 t of share of plastic (SUP) waste generated each year of which 86% of the MSW is still being dumped in landfills sites (Khan, 2020). In Bangladesh, the SUP waste is mainly from municipal areas with nearly 80% of total SUP waste over the country. Although the major fraction (about 78%) of SUP waste is generated in municipal areas of Bangladesh, rural areas also generate a notable amount (about 22%) due to rapid advancement in industrialisation and agricultural sectors (Wing, 2020). Fig. 5 represents a breakdown of plastic generation sectors in Bangladesh and their relative contribution to the total single-use plastic generation. Sachets, which are constructed entirely of non-recyclable polymers, are becoming a more common source of single-use plastic in both countryside and suburb regions, and food and personal care goods, such as small shampoo moisturiser, ketchup and toothpaste, are commonly packaged in them. If non-biodegradable plastic products are discarded directly into environment, they will exist in there and get broken down into smaller particles called MPs over a longer period of time (hundreds or even thousands of years) depending on the surrounding environmental abiotic (UV irradiation, heat, chemicals, mechanic stress) and biotic (enzymatic oxidation, hydrolysis) factors along with characteristics of plastic (Kalogerakis et al., 2017; Zhang et al., 2021). As discussed in Section 2, these MPs remain in the soil and water for a long time, posing a serious threat to soil health and eventually contaminating the food chain (Yi et al.,

Table 3 Strategies to manage plastic pollution in different countries (UNEP, 2018)

Country	Plastic bag bans /restrictions	Thickness thresholds for plastic bags	Require recycling within the regulation of plastic bag	Bans and restrictions on single-use plastic	Recycling mandated	Micro-beads prohibition law	Voluntary approaches to control micro-beads
Bangladesh	Yes	30 microns or less	No	No ban	No	No	Information is not available.
India	No	Minimum 50 µm	Yes	No ban	Yes	No	Information is not available.
France	Yes	Under 50 µm	No	Ban on free distribution	No	Cannot sell	Govt. statements of support for phase-out or ban of Micro-beads.Private company and/or association honorary industry get rid of action.
Rwanda	Yes	Not applicable	No	No ban	No	No	Information is not available.
Sweden	No	Not applicable	Yes	No ban	No	Cannot sell	Govt. statements of support for phase-out or ban of microbeads.Eco-leveling.
Ireland	Yes	Not applicable	No	No ban	Yes	No	Govt. statements of support for phase-out or ban of microbeads.
China	Yes	Information not available	No	Ban on import	No	No	Private company and/or association honorary industry get rid of action.
USA	No	Not applicable	No	No ban	No	Can not manufacture, sell, package and import.	Information is not available.
Canada	No	Not applicable	No	Ban on manufacture	No	Can not manufacture, sell and import.	Private company and/or association honorary industry get rid of action.
United Arab Emirates	Yes	Not applicable	No	Ban on manufacture and import	No	No	Information is not available.

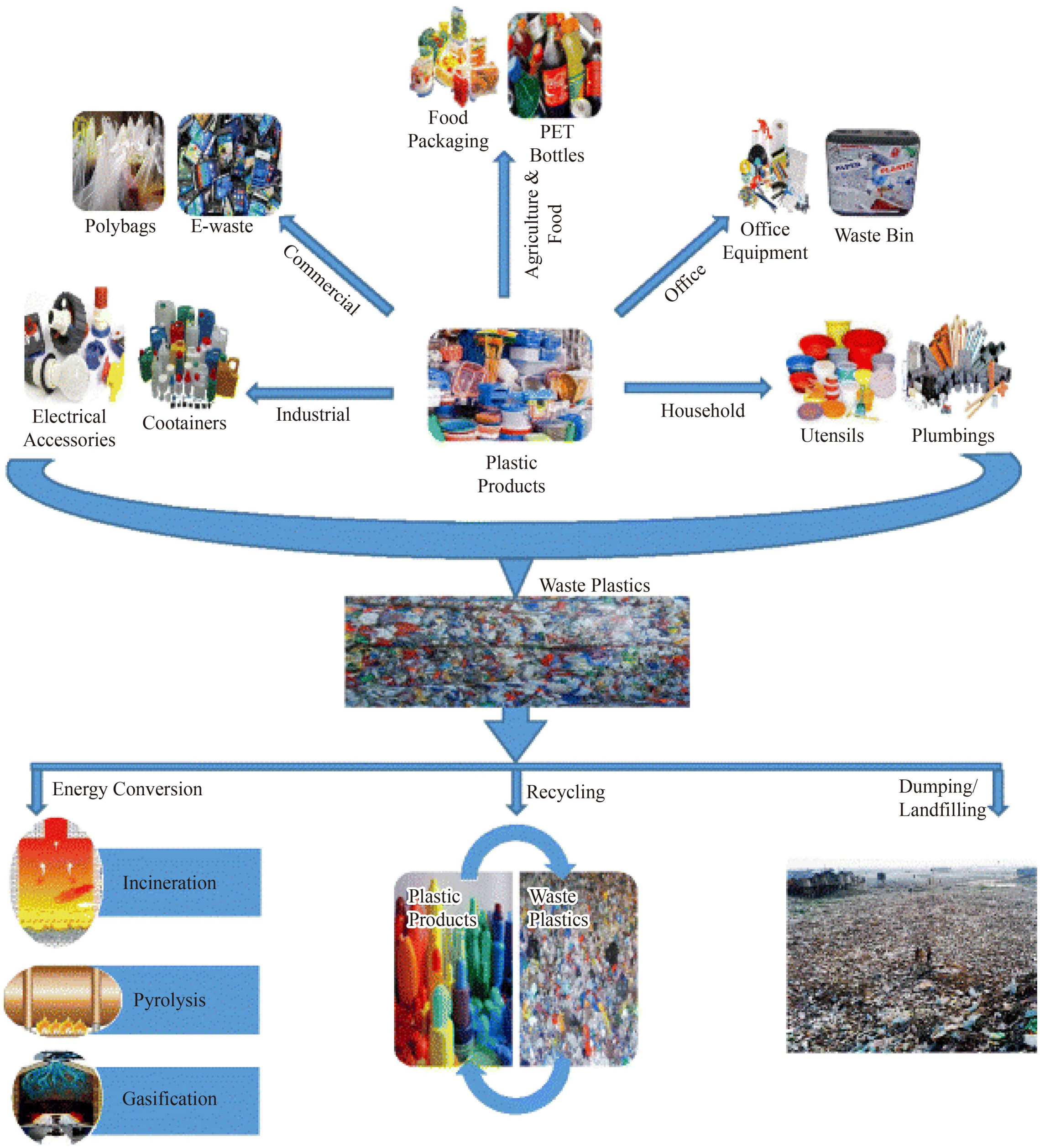

Fig. 5 PW generation sources and their management in Bangladesh (reused with permission Mourshed et al. (2017)).

2008). In the perspective of Bangladesh, SUPs are commonly used in homes, restaurants, hotels, airports, superstores, and grocery stores, among other places, due to low prices, lack of reasonably priced alternatives and weak law enforcement authorities (Hossain et al., 2021). However, the majority of food packets are composed of non-recyclable plastics.

Mismanaged production and use of plastic in various industries, offices, and business sectors, mainly packaging, set Bangladesh as one of the biggest plastic-polluted countries (Mannan, 2021). There are 3000 plastic manufacturing industries in Dhaka and Chittagong; among them, almost 98% belong to the Small-Medium Enterprises (SMEs) with around USD 74 million of domestic market size (Islam, 2012). In a lecture on plastic adulteration at a symposium in 2018, UNDP Programme Specialist Arif M Faisal noted that plastic manufacture generates greenhouse gases and causes global warming, as well as damaging land and water (Islam, 2019).

Nonetheless, lack of waste collection and sorting staff, limitations in technical and infrastructural abilities and above all, poor waste management strategies and skills are key factors in plastic contamination in Bangladesh. The fatality of waste plastic can be imagined from clogged city drains and rivers (e.g., Buriganga, Turag etc.) as a result of mismanaged dumping of plastics and poor management of it. It is noteworthy that Bangladesh produces 3000 t of PW per day and contributes almost 8% of the total debris generation (Islam, 2019). In a single day, approximately 14 million polythene materials (mostly packaging bags) are used in Dhaka (Bangladesh's capital city), while around 250 t of non-recyclable items, such as straws and plastic cutlery, are marketed in Old Dhaka (a part of Dhaka) alone (Islam, 2019). All of these mismanaged waste systems often go into rivers and get deposited eventually in the ocean, posing a serious threat to sea biodiversity (Islam, 2019). It is estimated that daily, there is approximately 73000 t of PW following flows of three main rivers (Padma, Jamuna and Meghna) and then end up their journey in the Bay of Bengal (ESDO, 2016; Rahman, 2018). ESDO warned polythene bags and PW as a serious threat to the total environment of the country (Ferdous, 2021). About 80% of Bangladeshi people use plastic bags as their daily habits despite being aware of their detrimental effect, which results from the poor application of laws and regulations.

3.2 Different types of plastic available in Bangladesh

In Bangladesh, plastic products are getting acquainted with mass people after independence in 1971. Plastics of different types like PTE, HDPE, LDPE, PVC etc., are being used to manufacture different sorts of products that are widely used in our daily life. In the following Table 4, detailed characterisation is given for varying types of plastics with their corresponding applications.

During the COVID-19 pandemic in 2020 and 2021, it is estimated that around 14500 t of plastics waste were generated throughout the country from health care centres and hospitals, of which over 200 t (average) of medical debris are produced on a daily basis only in Dhaka (Report, 2020). Although a few hospitals dump their garbage in a ditch and burn it in their backyards, most of it appears to end up in the open or in landfills. Thus, MWs, along with plastics which are dumped randomly at the roadside, may get scattered into roadside farmland and leading to soil pollution. Moreover, the highly infectious wastes flowing into the river easily pollute the marine environment causing negative effects on its habitats as well as farmland through irrigation systems.

3.3 Dispersion pathway of plastic

The main sources of MSW generations are from households, industries, hospitals/clinics, convenient shops, shopping centres, restaurants/canteens, and slaughterhouses (Mourshed et al., 2017). Other sources come from tourist sites, recreational centres, and institutes are minor

Table 4 Display of different types of plastic products used in Bangladesh (Mourshed et al., 2017; Mia et al., 2018; Masud et al., 2019; Mahmud, 2021)

Types of plastic	Characteristics	Uses
Polyethylene terephthalate (PET)	➢ Totally rigid or flexible ➢ Highly resistant to Chemical and weather ➢ A rampant barrier against H_2O and gas ➢ Melting temperature is 260–280 °C ➢ Its density is 1.38–1.51 g/cm^3	Soda, fruit juice, water, cooking oil bottles, packing trays, frozen ready-meal trays, first-aid kit blankets, polar fleece and so on.
High density polyethylene (HDPE)	➢ Incredibly strong considering its density which is 0.959 g/cm^3 ➢ Solid material ➢ Can tolerate high temperatures (Melting temperature is 210–270 °C) and strong chemicals	Mostly used to make containers for cleaning solution and soap. In addition, containers for food and beverages, bottles of cleaning products, pipes, chopping boards, and some shoe components.
Polyvinyl chloride (PVC)	➢ Exceptionally resistant to bio-chemical attack ➢ Management is easy so as converting into desired shape ➢ It is one of the most versatile ➢ Melting temperature is 160–210 °C, and density is 1.384 g/cm^3	Widely used to make sewage pipes. Furthermore, in the construction, health care device making, electronics device like cable making, automobile sector and so on.
Low density polyethylene (LDPE)	➢ Highly non-reactive material at general living temperatures ➢ It can endure temperatures of up to100 °C ➢ Melting temperature is 180–240 °C, and density is 0.925 g/cm^3 ➢ It is certainly more resilient	Various containers and trays making, bottles for drug preservation and transport, wash bottles, computer hardware components, moulded equipment for laboratory use.
Polypropylene (PP)	➢ Enough strong and flexible ➢ It has too much high tolerance against high temperatures (Melting temperature is 200–280 °C) ➢ Its density is 0.905 g/cm^3	Mostly known as food-safe materials. It is considered as most thermoplastics. In addition, use to manufacture hot juice and yogurt containers, jars, pallets etc.
Polystyrene	➢ Thermoplastic polymer ➢ When exposed to high temperatures, it excretes potentially harmful compounds ➢ Melting temperature is 170–280 °C ➢ Its density is 1.05 g/cm^3	Use to make teacups, boxes, egg containers and packaging foams etc. However, as it releases toxic chemicals in response to high heat, it should not be used to serve or preserve hot food items like soup.
Biodegradable plastic	➢ Alternative to traditional plastic bag ➢ Decomposed within 3–4 months in soil ➢ Tensile strength of Sonali bag is 1.6 higher than of PP/PET bags ➢ Elongation at break is 35.52% ➢ Named as Sonali bag with cellulose as main component that prevents CO_2 emission ➢ Environment friendly	Used as packing materials for food, clothes or any other materials.

sources of MSW, but they pollute environments and cause health hazards in both direct and indirect manners. However, due to widespread applications of plastics, they are now present in all types of solid wastes and because of being non-biodegradable in character, plastic poses major threats to the environment and total ecosystem (Rahman et al., 2013).

As shown in Fig. 6, PW in the dumping yard or landfills coming from residential, hospitals and industrial areas can contaminate the near rivers, ponds or agricultural fields. Moreover, plastics are embarking into river, pond, argilcultural land by air and flood unintentionally. Plastic which has been accumulated already in river, are dispersing through irrigation water and flood, especially in the rainy season.

3.3.1 Households and municipal

In Bangladesh, there is over 522 suburban areas that produces significant amount of MSW (Uddin et al., 2011). Solid wastes from domestic households contribute to about 90% of total municipal waste, of which over 80% is organic (Ahmed et al., 2010). Excessive plastic consumption is caused by rapid population expansion, urbanisation, and industrialisation, resulting in increasing solid waste, and plastic constitutes a significant portion of this MSW. For instance, plastic solid wastes account for around 15% of total 70 t of solid garbage processed in the Jashore municipal (Kabir et al., 2021). More specific example can be found in recent study conducted in that almost half of residents in Tangail Municipal, Bangladesh discarded over quarter of plastic waste in their total generated waste every day. Another 33.5% of the residents produces less than a quarter, and 18% of them dumps one-third of their total produced garbage (Islam et al., 2021). In developing nations like Bangladesh often do not have appropriate strong waste management policies or technologies, waste collection services (e.g., in Bangladesh, very few amounts of plastic are collected manually by ‘Tokai’ or street waste pickers) from the damping site, which is not adequate in the context of PW collection of government or non-government organisations to manage their wastes properly.

Bangladesh also lacks specific guidelines, education, legislations and policies to effectively manage MSW, including plastics, in terms of considering it hazardous waste, even though PW management in municipal areas is still in its infancy (Mourshed et al., 2017; Masud et al., 2019). This mismanaged PW explain for the reasons of current polluting farmland, mainly ponds and lakes situated inside the municipal area.

3.3.2 Hospital

Plastics are the main components of various medical tools and devices (i.e., syringes, surgical gloves, inflatable splits, insulin pens, IV tubes, catheters, surgical gloves, etc.). Such products are usually single use to avoid the transmission of infectious diseases while reducing the need for sterilisation and reusing tools. Commodity polymers such as Polystyrene (PS), polypropylene (PP), polyethene (PE), and PVC account for over 70% of the market for disposable medical equipment. Moreover, in high-end medical applications, high temperature and

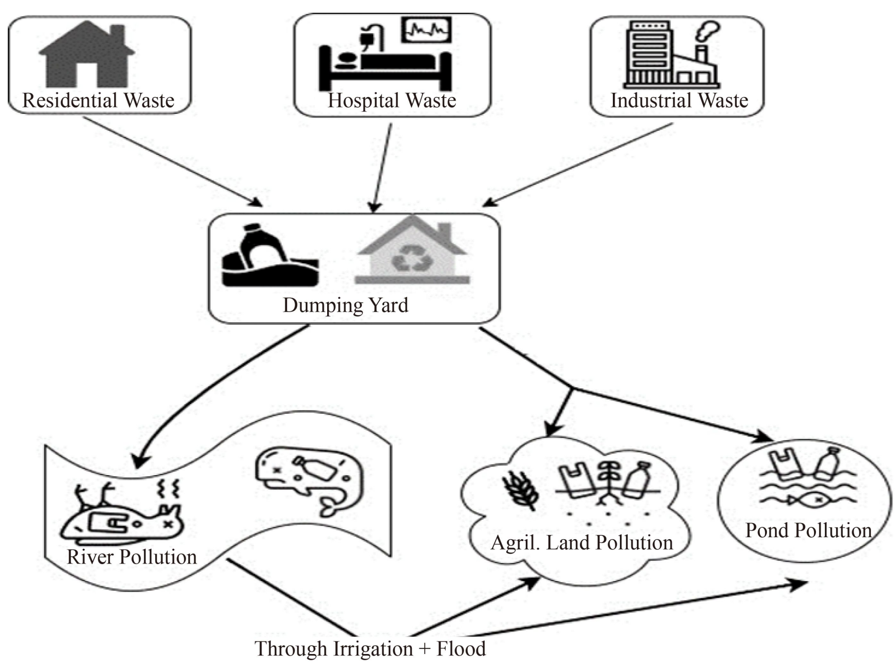

Fig. 6 Attribute dispersion pathway of PW.

thermoplastic elastomers are also being utilised (McKeen, 2014). Thus, plastic is considered one of the most significant components of healthcare waste because of the widespread use of plastic in hospital equipment.

Healthcare centres across the USA generate approximately 14000 t of waste daily, among them up to 25% made up of plastic products. But the fact is that a lot of unmanaged medical PW materials are burnt or disposed of in landfills (Linnenkoper, 2019). A study conducted in 2006 shows that all the surveyed HCE (DMCH, BMCH, General Hospitals, Private Clinics, Diagnostic Centers) in Dhaka produce around 5562 t of MW, of which PW accounts for 3.83% (213 t) (Hassan et al., 2008). MW management in Bangladesh is underdeveloped due to a lack of national chemical strategies and regulations (Syed et al., 2012). Poor waste management accelerates the chance of disease transmission both directly via uncollected or discarded debris and indirectly through polluting water and crops (Sarkodie and Owusu, 2021).

Bangladesh is the world's 2nd largest country which manufactures ready-made clothes, and garment sectors produce a huge quantity of MSW (Haider, 2007). Toxic solid wastes are generated by many pharmaceutical companies, which poses a tremendous effect on public health. Apart from clinical and non-clinical waste, another two categories of MW have been identified, they are kitchen waste and laboratory waste, which are also responsible for environment pollution, especially toxic laboratory waste. A large volume of MW originated from different government and non-government medicals that possess about 15%–22% hazardous waste (Hossain and Alam, 2013). The average amount of trash material generated per bed in a single day in hospitals and clinics was estimated to be 1 kilogram (Nasrin, 2016). MW accounts for roughly 5.7% of total waste and is collected daily by the Dhaka City Corporation authority. It may contaminate the entire lot when combined with other trash (Nasrin, 2016).

The hospital and clinical wastes are to blame for the city corporation's environmental deterioration and the rise of infectious diseases such as viral hepatitis, pneumonia, gangrene, typhoid etc. Moreover, MWs are not properly managed and are mixed up with residential solid trash before being disposed of at the municipal corporation's common disposal site. Throughout the year, hospital waste with extremely toxic and infectious materials mixed up with water across the country, resulting in severe biological pollution of rivers and croplands. Poor waste management raises accelerate the chance of disease transmission both directly via uncollected or discarded debris and indirectly through polluting water and crop (Sarkodie and Owusu, 2021). Inadequate waste management strategies are estimated to cause about 400000 to 1 million fatalities per year in developing nations moreover productivity losses because of sickness (Manlove et al., 2004).

In Bangladesh, there is a Medical Waste Management and Processing Rules- 2008, but a safe disposal system has not yet been established to manage the hazardous as well as infectious MW generated from different health care centres (Sejan, 2020). Reduced water quality, increased sedimentation, narrowing, cordoning, diversions, dry-ups, commercialisation, so-called development projects, unplanned re-excavations, and slow flows all contribute to pollution and river death (Matin, 2017). According to a report, in Dhaka City alone, 206.2 t of MW is generated in a single day (Report, 2020). MW generation has risen by up to 40% due to a higher production rate from the pharmaceutical and medical sectors to meet the COVID-19 pandemic demand (Yu et al., 2020). So, the situation regarding the use of COVID-related plastics in Bangladesh is also an arduous task to manage. Due to the prolonged lockdown, recycling sectors stopped their activity. With the poor management system of MW, Bangladesh was struggling with plastic waste pollution; this becomes more pronounced during the COVID-19 pandemic period when the dumping of plastic wastes from health care systems rocket increase. According to the data provided by ESDO, about 14500 t of PW have been discarded within a single month between March and April 2020. Dhaka city alone, where high rate of covid infected cases, was responsible for 30766 t of PW (Amin, 2020). The production of one-time plastic was also increased to meet the demand for personal protective equipment (PPE), such as gloves, masks, and disinfectant bottles, as well as packaging material (Silva et al., 2021). Used hand gloves were the major source of PW with total of 5877 t (~1216 million discarded gloves), of which 3039 t are made of plastic. Plastic shopping bags are considered as the second-biggest source of PW, accounted for 5796 t of waste, of which 1592 t are from discarded surgical masks, and about 900 t came from hand sanitiser bottles.

3.3.3 Industrial

With the rapid advancement in science and technology, electronic products manufacturing companies also developed new devices consisting of plastic materials with incredible features to attract people in each corner of the world. Also, the standard of living, attraction to new technologies, or to grab some changes in lifestyle make people tempted to take something new and discard old ones. In this manner, electronic product consumption has rapidly increased, with a nearly equal quantity wasted (Masud et al., 2019). Due to hazardous chemicals (like batteries, PCB boards, heavy metals, etc.), handling e-waste made of plastic is becoming a serious issue. For instance, small automobile service stations dump old tyres (made from a variant of plastic) as scrap and burning these discarded tyres with plastics as mixed wastes has become one of the biggest environmental problems (Dobrotă et al., 2020).

Around 7000 small-medium-large companies in Dhaka dump tons of the untreated hazardous waste directly into rivers, canals, and low-lying regions, causing water pollution and affecting the ecosystem (Ahmed, 2019). In 2005, Dhaka City Corporation area alone produced 3315 t of solid waste per day, of which 4.15% is made of plastic; thus, the rate of PW production stands at 137.5 t/d (Mourshed et al., 2017). In Bangladesh, 1176 industrial manufacturers have been detected as the worst polluters, alongside numerous small polluter units (Khan, 2009). It is noteworthy that Textile industries are one of important sector for development in economics of Bangladesh with about 4.62 thousand textile factories being operating and discarding a significant quantity of MP fibres. In the Dhaka capital city, wastewater from nearby textile manufacturers (source of MP fibre) dumped to rivers (Buriganga, Balu, and Turag) has been killing the ecosystem from these rivers; as a result, Bangladesh's government has classified such rivers to be "biologically dead" as they contain no Dissolve Oxygen at all (Khan, 2010). Just of being costly, industry owners are not willing to establish Effluent Treatment Plant (ETP); consequently, farmers are unable to cultivate their land and to grow crops near the bank of the mentioned polluted rivers. Similarly, the state of Balu and Turag rivers, according to officials from the Department of Environment, is in extremely dangerous condition. The rivers polluted by oil and chemicals inthe Buriganga continue unabated (Rahman, 2011). According to the study, the riverbank near Keraniganj has a thick deposit of chemicals, engine oil, and other garbage components because of dumping waste without treatment (Alam, 2009).

The wastewater from the washing facilities of a ready-made clothing business is gushing into neighbouring water bodies. Another research found that 67.7 million gallons of industrial liquid pollutants are daily discharged into the environment (Parveen, 2007). From 2002–2005, a study by the Department of Energy focused on11149 industrial units, among them 524 units falling into the red category under the Environmental Conservation Rule (ECR) 1997 (Kamruzzaman, 2014). Among the 524 red-listed industrial units mentioned above, 417 were discovered to have built their own ETP, whereas 105 had no ETP at all (IMF, 2013). As a result, industrial liquid wastes are discharged into Buriganga, Balu, Turag, and Sitoulakha, causing significant water contamination.

3.3.4 Argo based

The use of plastic in agriculture, also called as plasticulture, is growing quickly across the world, including in Bangladesh. PVC pipes are used in deep tube-well (DTW) and shallow tube wells (STW) to pump out underground water, for mainly irrigation purposes. Moreover, flexible PVC pipes are used as a conveyer of water from STWs and DTWs and as polybags for growing seedlings. Plastic tubes, drippers and water tanks are used in a drip irrigation system. Polyethene and polypropylene are broadly used as mulching materials to inhibit weed growth, reduce volatilisation of fertiliser, reduce evaporation etc. By 1999, plastics had been applied as mulching materials over 12 million hectares of agricultural land throughout the world, although in 1948, plastics were used in agriculture instead of glassware just to minimise the expense (Roy, 2012).

In case of growing some kinds of vegetables and small fruits in protected agriculture or to create an artificial greenhouse, plastic sheets are used to cover on the top of the bamboo or iron frame that protect them from adverse conditions like excessive rainfall, over-temperature, wind, insects and pathogens attack and so on. All of these efforts ultimately help to grow different varieties of plants (vegetables, fruits, flowers, etc.) throughout the year as well as ensure proper quality. However, most of the farmers in Bangladesh lacks proper awareness about side effects of plastic contamination on their own lands; they are used to discharging plastic bottles and packets of pesticide, seed and fertiliser randomly on farmland which leads to pollution of farmland. Therefore, the application of plastics in different forms in agricultural sectors has become a great concern in this small country, and it should be addressed accordingly.

4 Effects of plastic waste on agriculture

4.1 Impacts of plastic wastes on soil quality and plant growth

Different forms of discarded plastics like macroplastics, nanoplastics (NPs), which are fragmented products of larger plastic, have detrimental effects on the soil's physical properties along with soil water balance, soil microbiology (microflora and microfauna) and soil environment, so as on root (even larger plastic particles may create stumbling blocks physically in root proliferation especially in field crop lead to yield loss) and tissue of plants as plant usually uptake almost all nutrients from soil media (Rillig, 2012; de Souza Machado et al., 2018a). Due to the huge amount of plastic used in farmland, macroplastics fragments also are probably common in agricultural soils (Piehl et al., 2018; Huang et al., 2020). A research work conducted in American horticultural farmland found 1535 plastic macroplastics within 286 m^2 of land (McKay et al., 2022). However, macroplastics is less harmful to soil health than micro and nano plastic particles (Qi et al., 2018; Zhang et al., 2022b). Nevertheless, on crop yield and the condition of the soil health, macroplastics likely to have a considerable detrimental impact (Gao et al., 2022). Another study revealed that NPs reduce the overall biomass of experimented plant named *Arabidopsis thaliana* (Gigault et al., 2018). Plants living in the soil contaminated with NPs have shorter roots and grow up in a smaller resulting in poor nutritional value (Sun et al., 2020). Another group of researchers experimentally investigated on spring onion in soil with primary MPs (tiny plastic particles specially manufactured in micron size for commercial purposes like making cosmetics or personal care products), secondary MPs (derived from the fragmentation of larger plastic items like water bottles) and without MPs. They found that plant performance, and consequently agroecosystems and terrestrial ecosystems, may be harmed by widespread plastic contamination in soil. It is also reported that high bulk density due to granular polythene causes a reduction in soil water infiltration, reduction in aeration and poor penetration, which has a negative effect on crop production (Atuanya et al., 2012). Microorganisms tend to absorb nano-plastic particles, which is then attached to root tissues or enter inside them, causing a changing in structure of root cells (de Souza Machado et al., 2018a; de Souza Machado et al., 2019). This harmful particle finally reaches human beings through consuming crops (Stubenrauch and Ekardt, 2020).

4.2 Impacts of PWs on surface water quality

Communication between plastic micro fragment concentration and water quality is interlinked. However, the concentration of micro fragments and characteristics of water quality are both highly variable over time (Kataoka et al., 2019). According to the World Bank, three rivers (Ganges, Padma, and Jamuna) which pass through India and Bangladesh have the world's second-worst plastic polluted water media (Hasnat et al., 2018). Approximately 30000 t of plastic garbage was discovered in only four rivers surrounding the capital city of Dhaka; among of them, Buriganga is the highest polluted river (Tarnnum, 2020). A study on the river Buriganga's water quality is presented in Table 5, where the pollution mainly occurs from the direct or indirect latching of MSW from landfill stations and industries (Fatema et al., 2018).

The MP concentrations show a positive association with BOD (Biochemical Oxygen Demand which is considered a water pollution indicator) but DO (Dissolved Oxygen which is the amount of oxygen dissolved in the water available in living aquatic organisms) has a negative relationship (Kataoka et al., 2019). Thus, irrigation water from the above-mentioned rivers is becoming unusable soon if the plastic contamination continues getting worse as this rate.

5 Plastic pollution and food security aspects

Several evidence proves that plastic, in microform, has been dispersed into many relevant aquatic organisms and species like fish and shellfish. The study showed that 80% of the *Decapterus muroadsi* (Carangidae) had ingested plastic fragments which are collected from Rapa Nui, the coastal area of South Pacific subtropical gyre (Ory et al., 2017). A research on 26 different species of fish, which are collected from diverse habitats in the Red Sea, showed that 14.6% of the sampled fish were contaminated with plastic debris (Baalkhuyur et al., 2018). Another group of researchers had found plastic particles in two farmed bivalves. The presence of MPs had been proved to have an average of 0.36 ± 0.07 particles/g to 0.47 ± 0.16 particles/g *Mytilus edulis* and *Crassostrea gigas*, respectively (Van Cauwenberghe and Janssen, 2014). Although there have been several studies on marine ecosystems, a terrestrial ecosystem has not been full-fledged yet. The presence of plastic in soil may affect plant biomass, the elemental composition of plant tissue, and root traits alongside microbial activities (de Souza Machado et al., 2019). Moreover, microparticles plastic have been detected in drinking water beer, tap water (Kosuth et al., 2018), table salts (Renzi and Blašković, 2018), canned food (Karami et al., 2018) and, honey and sugar (Liebezeit and Liebezeit, 2013), branded milk, tea from teabags (Schymanski et al., 2018; Kutralam-Muniasamy et al., 2020). Food availability, accessibility, utilisation and stability are the four main pillars of food security that are important in the food security aspect. However, plastic in many marine species

Table 5 Water quality analysis of Buriganga (Fatema et al., 2018)

Water parameters (Mean)	Standard value for water			After Pollution (Buriganga) (Year 2018)
	Drinking water	Inland water	Irrigation water	
Temperature (°C)	20–30	40	20–30	22.80 to 31.40
DO (mg/L)	⩾ 6	4.5–8.0	⩾ 5	0.22 to 2.74
pH	6.5–8.5	6.0–9.0	6.5–8.5	7.61 to 8.97
Electrical conductivity (μS/cm)	–	1200	700–3000	180 to 598
TDS (mg/L)	1000	2100	450–2000	–

also has effects on food availability and utilisation (De-la-Torre, 2020). After taking synthetic polymers, marine organisms cannot digest through an enzymatic reaction, causing plastic particles to be retained in the gut (Guzzetti et al., 2018); this may block the food passages (Tourinho et al., 2010), causing compact feeding and lower weight. In addition, the presence of plastic fragments has a detrimental effect on photosynthetic activities and growth in microalgae (Sjollema et al., 2016). Plastic in agricultural soil also hinders the growth of helpful bacteria and reduces fertility of soil (Nasrin, 2016).

6 Effect of plastic pollution on climate change and global warming

Polyethene is the most used synthetic plastic material throughout the world and is considered as one of the major sources of methane gas generation, particularly when it is exposed to solar radiation (Royer et al., 2018). Along with morphology and density, average molecular weight, which varies with the length of the polymer chain, and thus, the number of exposed branched molecules, is a factor to determine this type of hydrocarbon emission (Mohanan et al., 2020). In addition to the emission from automobiles, MSW dumping sites, coal stockpiles, and mines (gas and oil) are considered as vital sources of methane generation in Bangladesh (Clark et al., 2021).

Among different types of toxic gases, methane gas is responsible for increasing temperature significantly. Because methane is 80 times more dangerous than CO_2 in the context of temperature retention capacity, methane emissions are considered as the main source for the countrywide heatwave and rising average temperature; consequently, climate is getting changed rapidly (Opu, 2021; Basak and Meena, 2022). Another alarming fact is that on April 17, by using ESA's Sentinel-5P and Sentinel-2 satellites, a Canada-based emission tracking company named GHGSat Inc. identified Matuail Sanitary Landfill (where almost 65% of total waste generated in Dhaka is disposed of) situated near the capital city Dhaka as the origin of methane gas (Hai and Ali, 2005; Clark et al., 2021). It is estimated that about 4000 kg of methane was emitted in an hour, the equivalent to the amount of fuel to run 190000 traditional cars (Opu, 2021). According to the GHG emissions-tracking institute (GHGSat Inc.), "We have for the first time been able to attribute emissions in Bangladesh to a specific source. The situation remains a mystery, and we will continue to monitor the area" (EARTH.ORG, 2021). It is also noted that landfill site spreads over 181 acres and accepts about 2500 t of waste each day, but unfortunately, this site does not record any data or prediction about the possible methane gas emission (Waste360, 2021). However, the climate is being changed rapidly not only in Bangladesh but also in other areas of the world, causing downfall of agricultural production. Global warming may lead to be inundated the agricultural land. As Bangladesh is one of the most climate-vulnerable countries in the world, it has become aware of its methane emissions, and according to the short-lived climate pollutants reduction plan 2018, measures to reduce methane emissions could reduce them by up to 17%–24% by 2030 and up to 25%–36% by 2040 (EARTH.ORG, 2021; Waste360, 2021).

7 Biodegradable plastic: alternative to traditional plastic

Form of plastics that can be degraded into H_2O, CO_2, and biomass by the activities of living organisms, typically microbes—are said to be biodegradable. Biodegradable plastics are not as harmful as traditional plastic (PVC, PET etc.). As an alternative to non-biodegradable plastic, polybutylene adipate terephthalate (PBAT) is being used because its unique characteristics differ from plastic. PBAT is made by reaction of three chemicals mainly ($C_6H_{10}O_4$, $C_4H_{10}O_2$, and $C_8H_6O_4$), 100% biodegradable in nature with no residual effect (Tullo, 2021).

Many countries have embraced packaging materials that are biodegradable; for instance, leaves, paper, wooden sticks, or plant stems are used as alternatives to SUP (Kershaw, 2018). As Bangladesh is the second largest jute-producing country and jute (also considered as golden fibre of Bangladesh) has great potential to be a substitute element for plastic bags. It has already been proved as a strong alternative to plastic bags by one of the prominent scientists Mubarak Ahmad Khan (who developed the Eco-friendly Poly Bag, well-known as Sonali bag in Bangladesh) (Sun, 2018). From Bangladesh's perspective, "Sonali Bag" may be the best alternative to non-biodegradable plastic. Chemical composition of Sonali Bag is unlike non-biodegradable plastic. Sonali bag is composed of cellulose extracted from jute, biodegradable synthetic polymer and a cross linker to create chemical bond (Sun, 2018). Lack of mass awareness, insufficient financial backup and long-term strategic planning are the main limitations behind the alternate adoption.

8 Conclusions and way forward

A proper PW management strategy is now indispensable to safeguard and conserve the environment and surrounding ecosystems from the perilous impacts of PW. The above discussion addresses the fatal effect of PW on living beings as well as the long-term consequences on agricultural industries together. However, while discussing the generation and effect of PW on the environment, it is also important to shed light on the areas of interest in managing this huge ever-expanding pile of hazardous waste. However, traditional waste management facilities, lack of technological advancement, infrastructure development, and financial constraints are barriers to the systematic planning and enforcement of waste management methods in Bangladesh. It is also important to address these challenges more specifically to implement feasible waste management strategies.

Dumping or landfilling of plastic is the most common scenario to reduce the large volume of PW, which mainly undergoes without any sorting or characterising. This disposal not only causes serious infertility to the soil by destroying soil microorganisms but also contaminates ground odour and spreads serious viral diseases. Also, the open burning of this plastic causes serious air pollution and environmental hazards. In addition, dispersion of MPs in soil and ground also causes serious damage to agricultural lands and natural resources. On the other hand, due to the availability of land, many countries discourage this technique of solid waste management. Thus, adequate financial measures should be taken to set up a transfer and sorting station (to segregate recyclable and non-recyclable items), establish processing units to recover valuable items and ensure proper safety and security for the stuff associated with waste management. Moreover, a well-planned landfill site requires the convenient transportation of wastes along the waste characterisation unit to ensure material recovery in a cyclic rather than linear manner.

A higher level of recycling, reuse, repair, and remanufacturing can add value to the waste plastic with low addition of virgin ingredients (fossil fuels) and energy. These steps towards reuse also decrease the waste volume and lower the emission of greenhouse gases, MPs, etc. Moreover, recycling activities also promote a circular economy by boosting the informal sectors to manage waste in developing countries. However, incineration is also used to process mixed PW as most of the PW in Bangladesh is found as non-characterised or in mixed conditions. Nowadays, this PW is breaking down and being used in cement industries, road carpeting, fuel extraction through pyrolysis etc. However, recovering energy or products from this waste in comparison to applying energy to process them to get the final output is a crucial factor in adopting any of that energy conversion or product conversion technologies. Moreover, it is time to rethink the wide-scale application of plastics, as, in the end, it is difficult to manage this hazardous waste. Avoid unnecessarily or over-packaging household, commercial, industrial, official, agri and food products. Introducing suitable alternatives and avoiding the use of single-use plastic can be a way to cut off the ever-increasing amount of PW. Therefore, rethink actually backed the overall waste management policy as it is important to rethink before using plastics at a large scale for every aspect of daily life as well as to consider the complexity incurred with the disposal of PW.

MSWs are collected without any grading by untrained staff and dumped the MW as general waste or mixed waste in some unauthorised dumping zone without proper treatment or even no treatment (Mutahara et al., 2012). It is evident that this disposal of MW poses a great threat to the surrounding environment as these MW can spread out different types of fatal diseases when they come in contact with the environment (through the air, water bodies, etc.). However, those engaged with this MW management are also at great risk, as they don't have proper training, equipment and knowledge to manage MW, and the scenario is getting even worse in pandemic situations. Untrained waste pickers working all over the country are at serious risk of getting affected by coronavirus because of lacking PPE. There is a severe risk of coronavirus outbreak if used gloves, facemasks, and other PPE are not treated properly. Therefore, a policy paradigm change toward a strategic, cutting-edge MW management system is necessary. Also, extensive efforts should be put in place to manage the massive increase in MW during COVID-19 to minimise the ever-increasing environmental and public health risks. Thus, it is essential to dispose of the MW on the spot or use a steriliser to disinfect the equipment before disposing of it to the environment. Along with the characterising and sorting of the MW, using a sealed bag and colour tagging with proper levelling (indicating the treatment process) can be a big help in managing MW.

Conveying the proper information and techniques for mass consumption by the wider public for waste management is the first and foremost criterion for developing a well-managed waste management hierarchy. Maintaining data log of the PW generation, collection, sorting and recovery are needed to adopt a feasible and long-term waste management policy. It is also important to quantify and analyse microplastic abundance and distribution in the environment. Different methods are presented to understand the toxicity level of MPs on soil, water and environment bodies, where fluorescence staining and quantification method is considered one of the cheap and reliable strategies to analyse samples on both large environmental and small laboratory scales (Liu et al., 2022). However, sufficient data and careful laboratory sample analysis is the prime concern in implementing this method.

Mass awareness among the people is needed about the effect of PW and its dispersion to the environment in different forms. Media (both online and offline), seminars, and workshops can be a great help in this regard. Moreover, for developing countries like Bangladesh, it is quite difficult to reach out to remote areas with adequate information and technologies to manage hazardous waste as well as to manage or back up any mismanagement that happens in this regard. Thus, along with the municipality areas, large institutional waste management technologies are needed to cover remote areas. In addition, the government should step forward to design a waste management policy with sufficient financial backing so that people get the options to choose alternative plastics and also find a suitable way to dispose of the waste PW in an environmentally friendly manner.

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