



Plastic pollution in Bangladesh: A review on current status emphasizing the impacts on environment and public health

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ABSTRACT

Invention of the plastics has largely been considered as a boon for the modern life due to their light weight, high strength, and versatile application while being cheaper than other alternative materials. However, with the low biodegradability, over consumption, and widespread mismanagement, plastics have now become ubiquitous in all the environmental compartments and are held responsible for causing enormous pollution to air, soil, and water bodies. Bangladesh is no different from this global scenario, though there has been a little effort to assess the amount of plastic waste and its consequence which is necessary to encounter this mounting threat effectively. Taking this into consideration, current study investigates the impacts of plastic pollution including its most threatening form microplastics on environment and human health in Bangladesh. The study is based on critical review of existing literatures from the global perspective. It has been found that a major percentage of the used plastic is mismanaged in Bangladesh, posing a great threat to the environment and human health. This article also put forward some recommendations to tackle this pervasive problem alongside the measures already taken by the government. Overall, this work is aimed at creating an urge among the researchers to study the plastic pollution in Bangladesh comprehensively and raising a concern among the appropriate authorities to develop policies and impose necessary actions against plastic pollution before it is too late.

Keywords: Bangladesh, Covid-19, Environment, Microplastics, Plastic pollution, Public health

1. Introduction

Plastic has become an inseparable part of human development although the first commercial use and large scale production was dated back to the 1950s [1]. Plastics are generally made from synthetic or semi-synthetic organic material. The raw materials of plastic are derived from cellulose, coal, natural gas, salt, crude oil; and most industrial plastics are made from petrochemicals [2]. According to associations of plastic manufacturers in Europe, about 20 types of plastics are used worldwide [3]. Few of the highly used plastics are high-density polyethylene (PE), low-density and linear low-density polyethylene (HDPE/LDPE), polypropylene (PP), polystyrene (PS), polyvinylchloride (PVC), polyethylene terephthalate (PET), and Polyurethane (PUR) resins; and polyester, polyamide, and acrylic (PP&A) fibers [3]. Plastic has diversified uses and consumed by a number of sectors worldwide (Fig. 1(a)) The principal consumer of plastics is packaging industry (consumes

almost 36% of the total world plastic production) [4]. Interestingly, this sector is also the highest contributor in the global plastic waste production (Fig. 1(b)) [4]. The low cost, durability, easiness in processing, lightweight, high thermal, and electrical insulation has made plastic attractive for its applications ranging from food packaging to electrical industries [5, 6]. However, the chemical bond of the monomers responsible for the durability of plastic makes it resistant to the different natural processes of degradation. The plastic waste does not decompose, rather they accumulate on landfill and marine environment [7]. Annually more than 300 million metric tons of plastics are produced in the world for various consumption [8] and an estimate of 10 percent by weight of the municipal waste stream is plastic [5]. Almost half of the total produced plastic waste are single used plastics constituting mainly plastic bags, straws, stirrers, and takeout clamshells [9]. Among the total annually produced plastics, 25 percent is incinerated, 20 percent recycled and the rest 55 percent are directly released in the environment [10].



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Received September 24, 2020 Accepted December 02, 2020

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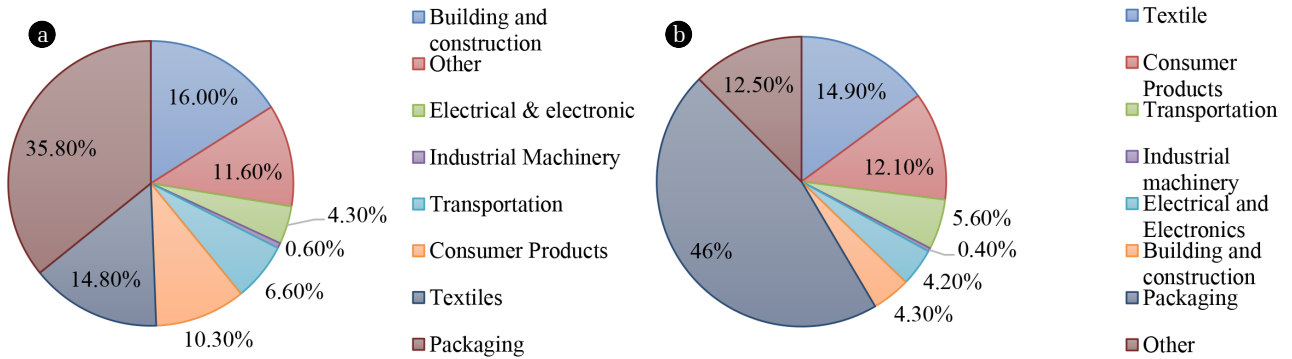


Fig. 1. (a) Plastic consumption by sector globally in the year 2018 (b) Plastic waste production by sector globally in the year 2018 [4].

In 2020, during the Covid-19 pandemic, the use of single plastics has increased many folds. Around 96% of the people worldwide are using different types of personal protection equipment (PPE) ranging from disposable mask and face shield, which are directly being disposed to environment and causing plastic pollution hazard [11]. These large amounts of plastic wastes can cause serious health and environmental hazards. The marine environment is largely affected by the plastic waste mainly the microplastics as they enter the food chain and causing fatality of animal from indigestion and stomach bloating problems. Microplastics are also present in fresh water system and can get incorporated in human food chain also [12]. The most common plastic waste management methods followed by countries like USA, Germany, Brazil, India are incineration and landfilling [13]. The plastics those are directly disposed in landfills are often burnt and approximately 10,000 g of dioxins/furans are annually released to the atmosphere and can cause serious health hazards such as headache, nausea, heart diseases, respiratory illness, and reproductive diseases [14, 15].

Bangladesh is a rapid developing country with a large population of 166 million. Despite the limitations raised by dense population, Bangladesh has a satisfactory economic growth. It has over three thousands small and big plastic industries at present and in the fiscal year 2017-18, plastic has been recognized as the 12th highest export earning sector in Bangladesh [16]. With the rapid development, the per capita consumption of plastics in Bangladesh has drastically risen from 2.07 kg in the year 2005 to 3.5 kg in 2014 [17] with a cumulative production of 3000 tons of plastic waste every day, which is the 8% of total generated waste [18]. Fig. 2 shows plastic waste production per person per day in different countries [10] and Fig. 3 shows the percentage of plastic waste directly released in environment in different countries [10]. Though the per capita consumption of plastics is not very high compared to the other developed and neighboring countries of Bangladesh, the percentage of contribution to mismanaged plastic waste in global total is very high (Based on 2010 data). Moreover, the per capita plastic consumption increased at a rate of 16.2% between the year 2005 and 2014, whereas the rate was around 25% throughout the world [17]. It has been estimated that the market size of plastic industries is near about USD 3 billion of which USD 2.2 billion is domestic and USD 0.8 billion is international and is expected to increase in future [19]. This growing market is anticipated to contribute to a large quantity of plastic waste, causing serious

threat to the environment. For example, the plastic wastes hinder the flow of water by blocking the drains and resulting in floods. These stagnant water in drains help in breeding of Aedes mosquito, which claims the life of thousands every year. The plastic waste accumulation largely affects the marine environment of the Bay of Bengal. In a survey, 6,705 pieces of plastic wastes are collected from four sea beaches of Cox's Bazar and of them 63% were found to be plastic [20]. These large plastic wastes have the potentiality to hamper the fish reproduction ability and destroys helpful organisms. Moreover, plastic debris in soil also have deleterious

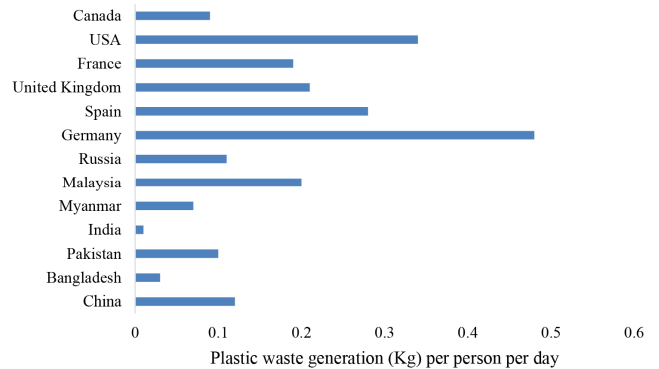


Fig. 2. Plastic waste generated by per person per clay in different countries [10].

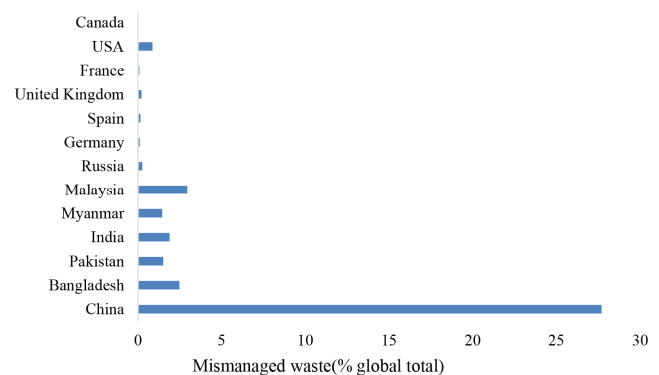


Fig. 3. Percentage of global mismanaged plastic waste contributed by different countries [10].

impact on the life of soil biota, soil environment and fertility, and ultimately on agricultural sector [21]. In order to mitigate the plastic pollution, Bangladesh government imposed a ban on poly bags on 1st March 2002 [22]. It is also providing tax exemption on account of recycling to inspire recycling of plastics and demotivating application of single used plastics. However, very little improvement has been observed over the years.

Though recycling is the best economic and environment friendly practice to get rid of this enormous plastic load, in Bangladesh recycling practices are still in nascent stage. Moreover, people find it easier to dump the plastic waste in open places or near roadside or in the river or sea shore rather than discarding them in a proper manner to be used for recycling [17]. For example, in 2014, national plastic consumption was 545,300 ton and the plastic waste available for recycling was about 50,213 tons, which implies that only 9.2 per cent of total plastic consumed in the country was available for recycling [23]. High cost associated with recycling, lack of available technologies and awareness about consequence of plastic pollution are the driving forces of landfilling or dumping of waste plastics in the water body such as channels, lakes, rivers and even to sea, which ultimately affect human health [17]. Currently, urban areas of Bangladesh generate 633,129 tons/year of plastic waste of which 51% plastic waste gets recycled and the recycling of the remaining could save USD 801 million every year [24]. However, recently the two city corporations of Dhaka city, Dhaka North and Dhaka South, have emphasized the plastic collection from the users, but most of them along with other waste get dumped in landfill. The plastic recycling companies in Bangladesh only export the recycled plastic flakes rather than making any products which holds a promising future [25]. Moreover, with the high calorific value of plastic waste ranging from 20 to 46 MJ/kg, it has been reported that about 5115–11,760 MWh/d electricity can be generated through gasification or incineration energy recovery from the daily plastic wastes [26]. Only recently, the government has initiated the installation of two waste-to-energy power plants in Dhaka, one at the Aminbazar landfill and the other at Matuail landfill, using daily waste produced, aiming at making it a habitable and a clean city [27].

In Bangladesh, there has been little effort to assess the amount of plastic waste in different environmental compartments and their associated impacts on the environment and human health. Therefore, this study aims to portray the scenario of plastic pollution in Bangladesh and the detrimental effect it has on the air, soil, and water and the public health, in light of the available worldwide and limited regional studies. Besides, this study will suggest some possible ways to curb the growth and impact of plastic pollution along with the measurements taken by the government. It is believed that this study will encourage the concerned authorities to think about the plastic pollution in a new way and to plan future plastic waste research and management strategies.

2. Classification of Plastic Materials

The Society of the Plastics Industry (SPI) made a detailed classification of plastic materials for plastic users and recyclers in 1988 [28]. An SPI code or number is molded into the bottom of the

plastic product so that the user can identify their desired material. The plastic materials are classified into following seven types, of which type 2, type 4 and type 5 are more compatible to use in terms of safety.

2.1. Type 1: Polyethylene Terephthalate

PET is the fastest growing plastic for food packaging applications because of its unique properties such as lightweight, hardness, toughness and resistance to grease, oil and heat. It can act as a good barrier of gas and moisture. These plastics are generally considered safe but sometimes engross odors and flavors from food items and beverages that are placed in them. The main disadvantages of these plastics are non-biodegradability and susceptibility to oxidation. PET plastics are used to make several domestic products such as beverage bottles, clothing and carpet fiber, medicine pots, rope etc. Items made from this plastic are usually recycled. The sleeping bags, pillow and carpet etc. are prepared from recycled PET materials.

2.2. Type 2: High-density Polyethylene

HDPE products are considered very safe because it inhibits the contamination of chemicals into food items. Now a days the use of these materials are increasing because of their lightweight, super-strong, long lasting, weather resistant and impact resistant properties. Various types of daily products such as containers for oil, milk, conditioners, shampoos, detergent and soap etc. are made from the HDPE materials. It is unsafe to reuse an HDPE bottle for storing food or drink because of health issues. These products are generally recycled into detergent bottles, flower pots and trash cans etc.

2.3. Type 3: Polyvinyl Chloride

PVC is used to make different types of pipes, tiles and electronics parts. Recently, PVC is substituting the place of traditional building materials due to its versatile properties such as lightweight, durability, cost effectiveness, corrosion resistance and easy process-ability. As it contains chlorine as its key ingredient it is biologically and chemically resistant. PVC plastic is generally not accepted by recycling programs.

2.4. Type 4: Low-density Polyethylene

LDPE is considered as a safe and healthy plastic because of its resistance to impact, moisture, and chemicals. The durability and flexibility properties of LDPE have increased its uses to make different daily items such as sandwich bags, food wraps, beverages bottles, and plastic grocery bags. It is infrequently recycled so it should be reused or repurposed rather than throwing them away after one use.

2.5. Type 5: Polypropylene

PP is strongly resistant to water, soap, detergent, acid and bases which increases its strength and durability. It can use for versatile applications as it withstands higher temperatures. It can be made translucent, opaque or various colors during manufacturing. It is used to make lunch boxes, butter containers, yogurt pots, sauce bottles, ketchup bottles, plastic bottle caps and medicine packaging etc. PP is occasionally recycled and it can be recycled into car battery cases, lumber and manhole steps etc.

2.6. Type 6: Polystyrene

PS is a thermoplastic polymer that is widely used to prepare solid plastic material as well as rigid foam material. This plastic is considered unsafe as it leaches potentially toxic chemicals when exposed to heat. It is used to make different types of daily items such as tea cups, coffee cups, plastic boxes and cutlery, egg cartons and packing foam. It is commonly recycled though it is difficult to do because it may take hundreds of years to decompose when not recycled.

2.7. Type 7: Other

Code 7 is used to indicate remaining kinds of plastic which is not included by the above six codes. Two types of recognized plastics such as Polycarbonate and bio-plastic polylactide are included in this category. These types of plastics are not usually recycled.

3. Effect of Plastic Pollution on Environment

Plastic products are mostly manufactured from crude oil derivatives and come with low manufacturing cost due to the immense technological progress in this sector. Other than the low cost, the features that the plastic products are of light weight and high durability have made them domineering over other materials of construction, such as wood or metal, and are the reason of their ubiquitous presence in our daily life. On average, the growth rate of the plastic manufacturing industry in Bangladesh is 20 percent per year and is still continuing to mount [29]. The widespread access to plastic products made humans' life easier and smarter on one hand and on the other hand led them to encounter long lasting environmental pollution from escalating waste generation due to over production and consumption. Since the most commonly used plastics are non-biodegradable and disposable, they accumulate in landfills or natural environment when goes unchecked and contaminate different environmental compartments: air, soil, and water. This polluted environmental bodies from irrevocable use of plastic and their unmanaged disposal affect not only human life but also other life creatures which ultimately end up to jeopardizing mankind.

Plastic materials have got wide usage in several sectors, such as packaging, consumer products and household applications, building and constructions, textiles, transportation, electrical and electronic equipment etc. However, among the plastic materials produced, very few get recycled and the rest of it is subjected to either incineration or dumping in landfill or natural environment. A recent data shows, of approximately 6,300 Mt waste generated worldwide up to 2015, only about 9% was recycled, 12% was incinerated, and almost 79% was routed to landfills or natural surroundings [30]. Bangladesh is no different from this global scenario of plastic waste fate. In our county, most of the used plastic products are discarded after their first use and due to improper management, they find their way in roads, drains, canals, rivers, and roadside open landfills. According to a study conducted by Waste Concern, a Bangladeshi social business enterprise that promotes resource recovery from waste, concluded that approximately

Table 1. Principal Types of Plastic Materials Found in Discarded Waste

| Plastic types | Usage |
|---------------|--|
| HDPE | Trash bags, milk jugs, shopping bags |
| LDPE | Bags, food wrap, plastic film |
| PVC | Bottles, packaging, container, plumbing and sewage pipes, floor and furniture coverings |
| PET | Beverage bottles and containers |
| PS | Hot beverage cups, thermally insulated take-home boxes, food containers, e.g., trays for carrying meat and egg, insulating materials |
| PP | Yogurt containers, diapers, straws, wrapping films, butter tubs, special bags |

0.8 million tons of plastic waste is generated per year in Bangladesh of which 36% is recycled while 39% is landfilled and the rest 25% goes unchecked and finds its way into marine environment [31]. Various types of plastics are found in this discarded waste of which the most predominant are listed in Table 1 ([32, 33])

Regardless of plastic types, the major contribution to environmental pollution comes from those are of single use purpose, such as packaging materials which is held accountable for around 36% of the global plastic consumption [34]. Mainly plastic bags made of polyethylene are held responsible for current uptick in plastic waste generation. Some 14 to 15 million pieces of polythene bags are used every day in Dhaka city alone and get discarded in trash, garbage, or litter after their first use [35]. Moreover, the concept of microbusiness has led to increase in the production of personalized products that in turn increased the use of packaging plastics. However, these plastic materials are not made of only polymer, rather various types of additives are added to it through different polymerization processes in order to improve physical and chemical properties. Various types of crosslinking agents, antistatic agents, antioxidants, flame retardants, UV and visible light stability improvers, heat stabilizers, plasticizers, and coloring pigments are used as additives during plastic manufacturing [36]. Upon subjected to frequent abrasion or long time sunlight exposure in municipal waste sites and roadsides, these additives and degraded plastic products can get released slowly into the environment posing potential toxic effects. For example, one compound of special concern is diethylhexyl phthalate, which has long been used as plasticizer is considered to be source of human carcinogen and endocrine disruptor to various organisms [37, 38].

3.1. Air Pollution

The most damaging effect by plastic litter to surrounding air can be attributed to intentional or incidental open-fire burning. In most cases, incineration of the plastic wastes is done to reduce the volume which causes not only environmental pollution but also energy loss since valuable fuel could be extracted from plastics through pyrolysis [39]. The air pollution is caused by the noxious fumes released into the atmosphere during plastic combustion. Plastic burning generates highly toxic gases such as hydrogen chloride, hydrocyanic acid, carbon monoxide, carbon dioxide, and sulfur dioxide, volatile organic compounds such as toluene, xylene, ben-

zole, and benzaldehyde, heavy metals, polycyclic aromatic hydrocarbons (PAHs), sulfur and nitrogen containing PAHs, polychlorinated dibenzodioxins, polychlorinated biphenyls (PCBs), polychlorinated dibenzofurans, naphthalene, phenanthrene, and dioxins [40-43]. Polyhalogenated dioxins and furans are considered one of the most hazardous anthropogenic pollutants [44]. However, the combustion products significantly depend on the types of plastics, types of additives and fillers added to it, polymerization reaction conditions, combustion temperature, and availability of oxygen. In addition to the release of poisonous gases, incineration of plastic wastes leaves charred ash and soot in the form of very fine particles [32]. In some studies, open-air burning was simulated by controlled combustion of various plastic materials and the results of this studies confirmed that toxic heavy metals, such as Pb, Cd, Cr, Ni, Zn, Cu, and lithophilic metals, such as Ca, Si, Na, Mg, Al, P, Fe were present to various extents in particulate soot and bottom ash [32, 40, 45]. Plastic additives which are comprised of organometallic compounds are mostly responsible for toxic metal emission [46].

In their experiment on burning of some rubbers and plastics, Wagner and his co-worker found more than 92% of the particulate matter to be in the respirable range i.e. less than 10 μ m in aerodynamic size termed as particles of concern [40]. They also identified that the sulfur used in vulcanization of rubber to improve the hardness of the products was responsible for release of SO₂ during combustion. Ashes, soot and various powders formed during incomplete combustion of plastic wastes deposit on plants and soil. Rainfall and floods can wash away these toxic substances and cause them to incorporate in the soil and water body, exerting further damaging effects by becoming integrated into the food chain. Some of the contaminants can chemically react with water and the resulting unwanted products may alter the pH threatening the usual functioning of aquatic ecosystems. Among the types of plastic waste types, incineration of PVC poses the greatest threats. On an average, combustion of PVC generates up to 2 mg/g phosgene, a serious health hazard that was also used as a chemical weapon during World War I [47]. This also reacts with the condensing vapor during combustion and form hydrogen chloride, which is also a toxic compound. Waste in landfill areas are also often found to contain some biodegradable plastics that undergo microbial degradation by several microbes including bacteria such as *Pseudomonas*, nylon-eating bacteria, and *Flavobacteria*. The breakdown of these plastics release considerable amount of methane, a very powerful greenhouse gas that contributes significantly to global warming [48].

With the rapid technological advancement, growing consumption of electronic and electrical products and subsequent waste generation have been found to exacerbate the plastic pollution even more. The effect is more pronounced in developing countries like ours due to overall high consumption, low recycling techniques and practice, and illegal transboundary business of electrical products from developed to developing countries [49, 50]. Combustion products of these waste electrical and electronic equipment (WEEE) embrace the environmental fate similar to that of other plastics. The ashes and smokes from burning of WEEE were found to carry heavy metals, polybrominated diphenylethers, polychlorinated dioxins and furans and their bromine versions, mixed halogenated

compounds like polybrominated-chlorinated dibenzo-p-dioxins and polybrominated-chlorinated dibenzofurans [51, 52]. Copper (Cu) is used in most of the electrical wiring which acts as a suitable catalyst for dioxin formation and can contribute to formation of so when the wire is coated with PVC [53]. Transport of dust and smoke by air can contaminate other areas also. Leung et al. [54] reported significant amount of polybrominated diphenyl ethers (PBDE), frequently used as flame retardants, in rice crop soils of Guiyu, India and linked it to the nearby WEEE open burning activities. This indicates the toxic products released due to the burning activities remain persistent in soil and vegetation and by incorporating in the food cycle they may enter in biota.

Presence of toxic gases in air derived from plastic burning is deleterious to both human and animal health, when exceeding a tolerable limit. They may cause skin and eye irritation, respiratory tract diseases, nervous system disorders, brain and digestive system impairment, reduction in immunity to diseases, and in their ultimate form can lead to cancer [47]. Despite the proved drawbacks, the use of plastics especially the one for packaging purposes continue to rise that end up in generating more and more waste. Hence, the open-air burning of plastic material and their toxic emissions is of growing concern in areas of municipal solid waste where open-fires occur intentionally or accidentally. In winter, the case of incineration in local municipalities increases since the unprivileged people warm themselves by burning road side waste that contains significant amount of plastic materials.

3.2. Water Pollution

The most discernible effect of plastic pollution has been observed on water bodies. Most of the mismanaged plastic waste from open landfills and roadsides get trapped into drains and canals, where they are deposited by air, rain water and even by direct dumping. Moreover, plastic waste discarded by tourists during riverside recreational activities and by passengers on river transport systems can accumulate on surface and bed of the river. The greatest threat is from single use plastic-mostly bags, packaging, bottles-that are thrown away immediately after use, and the different shapes and sizes of un-recycled plastic materials. This plastic waste has caused the sewage systems to fall apart, by clogging the natural passage way of water and choking the drainage system. The city of Dhaka used to have 65 canals that drained rainwater to surrounding rivers including the Buriganga, Turag and Shitalakhya, but the number has now dropped to only 43, died mostly by being converted into dumping zone [55], while some others are increasingly narrowed day by day due to plastic accumulation. The blockage of the drainage and sewage system is responsible for waterlogging and artificial flooding during the monsoon season. Most of the streets of Dhaka and Chottogram city remain inundated for several days after heavy rainfall, causing inhabitants to live in unhygienic environment, an increase in mosquito-borne diseases such as dengue and malaria, traffic congestion, and damage of the roads and road side establishments. Moreover, the plastic waste can accumulate on the surface of river, imposing obstacles to the movement of some popular transport mediums of the country, such as boats, steamers, and launches. They can also decrease the navigability by being deposited on the river bed. River transport plays a significant role

in country's economy by providing a cheap and reliable way of conveying goods for different industries throughout the country. Besides, the surface accumulation of plastic can block sunlight from reaching the aquatic plants that live on photosynthesis and cause them to die. The decomposition of these organics by microbes can lead to reduced dissolved oxygen which in turn can cause other aquatic biota including fish to die and their subsequent degradation can deplete the oxygen even more. In addition, marine mammals, turtles, fish, bird and several other organisms are known to become entangled in or ingest large items of plastic including bags and bottles, causing suffocation, starving, and drowning [56]. How much severe the situation is can be surmised from a recent incident in Philippines where a whale was washed up dead with 40 kilograms of plastic bags in its stomach [57].

Most of the discarded plastic wastes route their way to different water bodies including ponds, lakes, rivers, and ultimately get into ocean. It has been reported that around 50 to 80% of the waste gathered on seashore, ocean surface, and seabed consisted of different types of plastics [58]. Earlier, marine pollution was attributed solely to plastic waste expelled from coastal lands, width ranging from 50 to 200 Km [59, 60]. But it is now believed that terrestrial plastic debris over long distance to sea, travelled by river networks, is also responsible [61], since the rivers connect most of the land areas to oceanic environment through their branch like networks, from small rivers to large rivers and then to oceans. A staggering 8 million tons of plastics end up in the world's oceans every year [62]. According to a study by Lebreton *et al.* [63], river transport can be held accountable for 3-19% of the marine plastic and is a way of expelling $0.8-1.5 \times 10^6$ t/y plastic waste into ocean from inland areas. Some 72,845 tons of plastic are released into oceanic environment each year by Ganges, Meghna, Brahmaputra (GBM), which account for roughly 3.5% of the plastic present in top ten plastic polluting rivers [64]. The GBM is a transboundary river system consisting of five countries: Bangladesh, Bhutan, China, India, and Nepal [65] and thus contribute to transboundary plastic pollution in Bangladesh through the Bay of Bengal. The distribution of plastic debris in oceanic environment is influenced by a variety of factors, such as regional air and current direction, seaboard geography and population density, coastal activities, point of entries into the marine environment, e.g., nearby urban areas and trade routes. In a recent survey by the Department of Environment under the Ministry of Environment, Forest and Climate Change found that plastic waste constitutes more than 60% of the litter found in the four sea beaches Laboni and Inani in Cox's Bazar, and Ananda Bazar and Patenga in Chittagong of Bangladesh [66].

The impact of plastic waste on marine environment is mostly assessed based on the presence of so-called microplastics, a frequently pronounced term which is still a nascent area of research. The term microplastics was first introduced in 2004 [67] and later its wide accepted definition was prescribed as plastic fragments that are smaller than 5 mm [68], though several experimental findings confirm that most of them reside in the range of several micrometers [69]. They can conform a wide range of sizes and shapes including one dimensional fiber, two dimensional flat fragments, and three dimensional spherules [70]. Based on the source of occurrence, microplastics can be classified into two genres: primary

and secondary. Primary microplastics come in the form of resin pellets that are used either as raw material for manufacturing different plastic products or as ingredients of personal care products, cosmetic products, exfoliate scrubs etc. [69, 71]. Whereas, secondary microplastics originate from large plastic detritus or macroplastics through their disintegration into minute fragments by various chemical, physical, and biological actions, such as UV radiation from sunlight, temperature, mechanical abrasion at soil surfaces, wave action, microbial attack, repeated use etc. [69, 72]. Another potential way of microplastics entering the environment is through textile fibers. A recent study reported around 30,000-465,000 microfibers were discarded from per m² of textile garments which is equivalent to 175-560 microfibers/g [73]. Hence, with the readymade garments industry sector responsible for 84% of export earnings and 20 million employments, Bangladesh is at high risk of being polluted by microplastics from garments and textile industries that contribute 11.17% to country's Gross Domestic Product (GDP) [74]. Besides, plastic emissions from vehicle transport, including tire wear and tear, brakes, road markings, are another potential source of microplastics in the environment [75].

With the surge in plastics usage, microplastics concentration in the marine environment continues to rise along with the increasing threat to the marine life as well. Microplastics have been detected on seashores and seabeds of six continents, with fibers being the most predominant shape [7, 76]. Findings from numerous studies on the presence of plastic fragments in the oceanic water system worldwide have been compiled in Table 2.

Whatever the origin, microplastics embrace the same fate in the marine environment and impose the similar and same extent of detrimental effect on marine biota, and ultimately on human life. With their progressive fragmentation to smaller size, microplastics become increasingly available for ingestion by a wide range of marine organisms and it has been demonstrated that a considerable amount of ingested plastic was found in various marine creatures including fish, seabirds, decapod crustaceans, amphipods, lungworms, and barnacles [92]. Table 3 depicts some of the marine biota that have been found to ingest microplastics in considerable amount. These marine biota mistake microplastics for natural prey due to the similarity in size, shape and color of the microplastics and the natural food source. The lower trophic organisms indiscriminately ingest and accumulate microplastics and by being preyed on by the higher trophic one microplastics get incorporated into the food chain, accelerating the biomagnification of microplastics along the food web [93]. A study showed, in North Pacific Central Gyre, small plastic fragments are mistaken for natural food source by a low-trophic, mesopelagic family fish the Myctophidae which are in turn preyed upon by squid, tuna, whales, seabirds and fur seals and thus facilitate their way to various compartments of the oceanic food chain including the one for human [94]. However, higher trophic organisms may also absorb plastic directly. For instance, findings of the study by Fossi *et al.* [95] suggested that the Mediterranean fin whale *Balaenoptera physalus*, one of the largest filter feeders on the planet, may assimilate microplastics both directly and indirectly from the water and plankton, respectively. Ingestion of microplastics by marine biota may lead to adverse physical conditions, such as internal abrasion,

Table 2. Microplastics in Marine Water System

| Location | Compartment | Microplastics concentration | Reference |
|--------------------------------|-------------------|--|-----------|
| Northeastern Pacific Ocean | sub-surface water | 279 ± 178 (particles/m ³) | [77] |
| Yellow Sea | surface water | 0.13 ± 0.20 (particles/m ³) | [78] |
| Western English Channel | surface water | 0.27 (particles/m ³) | [79] |
| Jiaozhou Bay, China | surface water | 46 ± 28 (particles/m ³) | [80] |
| | sediment | 15 ± 6 (particles/kg) | |
| North Atlantic Ocean | deep-sea water | 70.8 (particles/m ³) | [81] |
| Baltic Sea | surface water | 8.6 ± 2.5 (particles/L) | [82] |
| Italian Minor Island | surface water | 0.3 ± 0.04 (particles/m ³) | [83] |
| Bohai Sea, China | surface water | 0.33 ± 0.34 (particles/m ³) | [84] |
| Ross Sea (Antarctica) | sub-surface water | 0.17 ± 0.34 (particles/m ³) | [85] |
| Arctic polar water | surface water | 0.34 (± 0.31) (particles/m ³) | [86] |
| | sub-surface water | 2.68 (± 2.95) (particles/m ³) | |
| Southern North Sea | sediment | 2.8-1,188.8 (particles/kg) | [87] |
| | surface water | 0.1-245.4 (particles/m ³) | |
| North Yellow Sea | surface water | 545 ± 282 (particles/m ³) | [88] |
| | sediment | 37.1 ± 42.7 (particles/kg) | |
| Northwestern Mediterranean Sea | surface water | 112 × 10 ³ (particles/km ²) | [89] |
| Hangzhou Bay, China | surface water | 0.14 ± 0.12 (particles/m ³) | [90] |
| | sediment | 84.3 ± 56.6 (particles/kg) | |
| Jinhae Bay, Korea | surface water | 88 ± 68 (particles/L) | [91] |

blockage in the alimentary canal, false satiation leading to low food intake, abnormal swimming and lethargy, pathological stress, oxidative stress, compromised immune response, complication in reproduction, and liver metastasis [96-99]. The ingested microplastics can also be translocated from the gut into the circulatory system of the muscle or other body tissues [98]. In addition, some oceanic creatures were found to show anomalies in gene expression which has been tethered to ingested microplastics [100]. In a study, adult zebrafish were exposed to environmentally relevant concentrations of microplastics mixture comprised of HDPE and PS, and the result indicated a loss in tissue integrity and a striking alteration in gene expression related to immune response and metabolic pathways in liver [101]. Besides, binding of plastic beads on nanometer range can result in inhibited photosynthesis and oxidative stress in algal species by blocking sunlight and air [102].

Apart from the physical damage, consumed small plastic detritus can introduce toxic chemicals in living organisms in two ways [132, 133]. Firstly, the chemicals used as additives, such as phthalates as plasticizers and PBDE, might leach out during post-ingestion period from the disintegrating plastic debris. Though these chemicals are meant to improve the properties of plastics, but their presence in living organisms is associated with carcinogenic and endocrine disrupting effects [134]. Secondly, the microplastics can act as a vector for carrying different hydrophobic organic contaminants into the marine biota. Their large surface to volume ratio makes them susceptible to accumulation of persistent organic pollutants (POPs), such as PCBs, dichlorodiphenyldichloro-

ethylene, PBDEs, PAHs, and phenanthrene, even in a more concentrated manner than in the surrounding water [135]. Their low density allows them to travel a long distance along with the contaminants and to become available to living creatures in a marine environment where the actual concentration of POPs is low. Upon ingestion by marine biota, the microplastics release these toxic pollutants which can cause impairment of the immune regulatory system including endocrine disruption, delayed ovulation, and hepatic stress [136, 137]. However, apart from marine biota, human being also consumes microplastics, mainly in an indirect way through the consumption sea foods, and can face detrimental health issues. A well number of studies have reported the presence of microplastics in several sea fish and shellfish and found to affect human health miserably when consumed [138, 139]. Efforts to quantify the presence of microplastics in marine species of Bangladesh has largely been neglected until very recent time, though the pace is not in an expected manner. It has been reported that 500–20,000 microplastics/km were floating on the surface water of the Bay of Bengal [140]. In another study, researchers reported a total of 443 microplastic items in the intestines of three marine species of Bay of Bengal, namely *Harpadon nehereus*, *H. translucens* and *Sardinella gibbosa*, on average ranging from 3.20 to 8.72 items per species [141]. Again, two shrimp species (*Metapenaeus monocerous* and *Penaeus monodon*) in the Bay of Bengal were found to ingest 22 different types of microplastics [142]. These findings suggest that microplastics are also present in our marine environment and related research should be augmented by considering

Table 3. Microplastics Ingestion by Marine Biota

| Types of marine biota | Species | Location | Amount of microplastic ingested | Reference |
|-----------------------------------|--|--|------------------------------------|-----------|
| Deposit and detritus feeders | <i>Arenicola marina</i> (lugworm) | French–Belgium–Dutch coastline | 1.2 ± 2.8 particles/g | [103] |
| | <i>Nephrops norvegicus</i> (decapod crustacean) | Clyde Sea (north), Scotland, UK | - | [99] |
| | Benthic holothurians (sea cucumbers): <i>Thyonella gemmate</i> , <i>Holothuria floridana</i> , <i>Hamataliwa. grisea</i> and <i>Cucumaria frondosa</i> | Florida and Maine, USA | - | [104] |
| | <i>Hediste diversicolor</i> | Italy | 57 ± 9 particles per individual | [105] |
| | <i>Yoldiella antarctica</i> | Terra Nova Bay (Ross Sea, Antarctica) | 1.6 particles per individual | [106] |
| | <i>Aequiyoldia eightsii</i> | | 2.2 particles per individual | |
| | <i>Thyasira debilis</i> | | 2.7 particles per individual | |
| | <i>Orchomenella franklini</i> | | 0.3 particles per individual | |
| | <i>Oweniidae sp.</i> | | 0.4 particles per individual | |
| | <i>Gammarus setosus</i> | Kongsfjorden, Spitsbergen, Svalbard | 72.5 particles per individual | [107] |
| Filter and suspension feeders | <i>Megaptera novaeangliae</i> (The humpback whale) | Den Helder and the island Texel in The Netherlands | 45 particles per individual | [108] |
| | <i>Balaenoptera physalus</i> (fin whales) | The Mediterranean Sea and the Sea of Cortez (Gulf of California, Mexico) | - | [109] |
| | <i>Mytilus edulis</i> (mussel) | French–Belgian–Dutch coastline | 0.2 ± 0. particles g ⁻¹ | [103] |
| | <i>Cetorhinus maximus</i> (Mediterranean basking shark) | Italy | - | [110] |
| | <i>Ascidia spp.</i> | Gulf of La Spezia, Italy | 0.62 particles/g | [111] |
| | <i>Crassostrea gigas</i> (bivalve oyster) | | 0.11 particles/g | |
| | <i>Mytilus galloprovincialis</i> (bivalve mussel) | | 0.05 particles/g | |
| | <i>Anomia ephippium</i> (bivalve) | | 0.12 particles/g | |
| | <i>Mytilus edulis</i> | | Atlantic Ocean | |
| | <i>Crassostrea gigas</i> | 0.47 ± 0.16 particles/g | | |
| <i>Cyamiocardium denticulatum</i> | Terra Nova Bay (Ross Sea, Antarctica) | 0.7 particles per individual | | |
| <i>Perkinsiana milae</i> | | 0.6 particles per individual | [106] | |
| Echinoderms | <i>Tripneustes gratilla</i> (sea urchin) | - | - | [113] |
| | <i>Paracentrotus lividus</i> (sea urchin) | - | - | [114] |
| | <i>Lytechinus variegatus</i> (sea urchin) | - | - | [115] |
| Zooplankton | <i>Centropages typicus</i> (copepod), <i>Calanus helgolandicus</i> (copepod), <i>Brachyuran</i> (decapod crab), <i>Porcellanidae</i> (decapod crab), and <i>Temora longicornis</i> (copepod) | A coastal site located in the western English Channel 12 km south of Plymouth, UK. | - | [92] |
| | <i>Neocalanus cristatus</i> (calanoid copepod) and <i>Euphausia pacifica</i> (euphausiid) | Northeast Pacific Ocean | 2-7 particles per individual | [116] |

Table 3. Continuation

| Types of marine biota | Species | Location | Amount of microplastic ingested | Reference |
|---|--|---|--|-----------|
| Fishes | <i>Sardina pilchardus</i> (European pilchard), <i>Pagellus erythrinus</i> (common pandora), and <i>Mullus barbatus</i> (red mullet) | Northern Ionian Sea (Mediterranean Sea), Europe | 1.5-1.9 particles per fish | [117] |
| | <i>Scyliorhinus canicula</i> (small-spotted catshark), <i>Merluccius merluccius</i> (European hake), and <i>Mullus barbatus</i> (red mullet) | Spanish Atlantic and Mediterranean coasts | 1.56 ± 0.5 particles per fish | [118] |
| | <i>Dicentrarchus labrax</i> (European bass), <i>Diplodus vulgaris</i> , and <i>Platichthys flesus</i> (European flounder) | Mondego estuary (Portugal) | 1.67 ± 0.27 particles per fish | [119] |
| | <i>Coilia ectenes</i> | Yangtze estuary, East China Sea and South China Sea | 4.0 ± 1.8 particles per fish | [120] |
| | <i>Larimichthys crocea</i> (large yellow croaker) <i>Thamnaconus septentrionalis</i> | | 4.6 ± 3.4 particles per fish 7.2 ± 2.8 particles per fish | |
| Turtles | <i>Caretta caretta</i> (loggerhead sea turtles) | Sardinia (Western Mediterranean Sea) | 19.58 ± 10 particles per individual | [121] |
| | | North Atlantic subtropical gyre | 15.83 ± 6.09 particles per individual | [122] |
| | Green sea turtles | Southern Brazilian coast | Between 3 and 134 particles per individual | [123] |
| | <i>Chelonia myda</i> | Great Barrier Reef | 7 particles per individual | [124] |
| Sea birds | <i>Macronectes giganteus</i> (southern giant petrel) | | 117 particles per individual | [123] |
| | <i>Puffinus puffinus</i> (manx shearwater) | Southern Brazilian coast | 13 particles per individual | |
| | <i>Spheniscus magellanicus</i> (magellanic penguin) | | 2 particles per individual | [125] |
| | <i>Alle alle</i> (little auks) | Off East Greenland | 9.5 particles per individual | |
| | <i>Fulmarus glacialis</i> (northern fulmar) | Labrador Sea | 1.9 ± 3.9 particles per bird | |
| <i>Uria lomvia</i> (thick-billed murre) | Nunavut, Canada | 0.89 ± 1.09 particles per bird | [127] | |
| | Nunavut, Canada | 0.33 ± 0.92 particles per bird | [127] | |
| Mammals | <i>Rhincodon typus</i> (whale shark) | La Paz Bay, Gulf of California | - | [128] |
| | <i>Tursiops truncatus</i> (bottlenose dolphins) | South Carolina, USA | Between 123 and 422 particles per individual | [129] |
| | <i>Halichoerus grypus</i> (grey seals) | Gweek, Cornwall (United Kingdom) | 0.87 ± 1.09 particles per individual | [130] |
| | <i>Mesoplodon mirus</i> (True's beaked whale) | Ballyconneely, Connemara, Co. Galway, Ireland | 88 particles per individual | [131] |

it as a potential threat to public health. However, In Bangladesh, a very few scientific research works have been done regarding plastic pollution. To date 18 works on plastic pollution have been published in peer reviewed journals, among them only three are on microplastics. This may be reasoned to the lack of knowledge, proper wealth, well equipped lab facilities, inequity in funding, regional issues, etc [143]. A big collaboration is needed between national and international researchers to overcome this situation. However, researches about the more dangerous form of plastics-nanoplastics-have not done so far.

While there has been a lot of studies, though insufficient, on the source and fate of microplastics in marine environment, but their fate in continental aquatic environment or in fresh water

ecosystems has largely been neglected. However, the few studies that have been done to date confirm that microplastics are also noticeably present in fresh water system and causing deleterious impact on aquatic biota likewise in marine environment. Several authors investigated the sediments and surface water of different lakes, rivers, and reservoirs around the world and found a considerable amount of microplastics in fresh water system that is reported in Table 4. The tremendous amount of microplastics estimated in fresh water system of several developed countries implies that the scenario is even more dangerous in developing countries like Bangladesh, though no apparent effort has been taken to quantify it.

The most abundant polymers were PS, PE, PA, and PVC and

Table 4. Microplastics in Fresh Water System

| Location | Compartment | Microplastics concentration | Reference |
|--|--------------------|---|------------|
| Lake Geneva (Switzerland) | Surface water | 48,146 particles/km ² | [144] |
| Laurentian Great Lakes (USA) | Surface water | 43,157 particles/km ² | [145] |
| Lake Hovsgol (Mongolia) | Surface water | 20,264 particles/km ² | [146] |
| Greater London (Great Britain) rivers | Surface water | 3.3 to 9.9 particles/L | [147] |
| San Gabriel and Los Angeles Rivers (USA) | Surface water | 0.01 to 12.9 particles/L | [148] |
| Danube River (Central Europe) | Surface water | 316.8 ± 4,664.6 items/1,000 m ³ | [149] |
| Seine River (France) | Surface water | 3 to 106 particles/m ³ | [70] |
| Chesapeake Bay (USA) | Surface water | 260,000 particles/km ² | [150] |
| Lake Qinghai (China) | Surface water | 0.05 × 10 ⁵ to 7.58 × 10 ⁵ particles/km ² | [151] |
| Lake Maggiore (Italy) | Surface water | 3.83 × 10 ⁴ ± 20,666 particles/m ² | [152, 153] |
| | Sediments | 1,100 ± 2,300 particles/m ² | |
| Lake Iseo (Italy) | Surface water | 4.04 × 10 ⁴ ± 20,333 particles/m ² | [152] |
| Lake Constance (Europe) | Surface water | 61,000 ± 12,000 particles/km ² | [153] |
| | Sediments | 320 ± 220 particles/m ² | |
| Lake Neuchâtel (Switzerland) | Surface water | 61,000 ± 24,000 particles/km ² | [153] |
| | Sediments | 700 ± 1,100 particles/m ² | |
| Lake Zurich (Switzerland) | Surface water | 11,000 ± 2,600 particles/km ² | [153] |
| | Sediments | 460 ± 350 particles/m ² | |
| Lake Brienz (Switzerland) | Surface water | 36,000 ± 23,000 particles/km ² | [153] |
| | Sediments | 2,500 ± 3,000 particles/m ² | |
| Lake Bolsena (Italy) | Sediments | 1,922 ± 662 particles/m ² | [154] |
| Lake Chiusi (Italy) | Sediments | 2,117 ± 695 particles/m ² | |
| Lake Qinghai (China) | Lakeshore sediment | 50 to 1292 particles/m ² | [151] |
| Lake Geneva (Switzerland) | Lakeshore sediment | 2,656.25 to 5,018.75 particles/m ² | [144] |
| Lake Huron (Canada, USA) | Lakeshore sediment | 4.75 ± 11.83 particles/m ² | |
| Lake Erie (Canada, USA) | Lakeshore sediment | 1.54 ± 1.01 particles/m ² | [155] |
| Lake St. Clair (Canada, USA) | Lakeshore sediment | 1.72 ± 2.64 particles/m ² | |
| Lake Garda (Italy) | Lakeshore sediment | North shore: 1,108 ± 983 particles/m ² South shore: 108 ± 55 particles/m ² | [156] |
| Lake Ontario (Canada, USA) | Lakeshore sediment | 980 particles/kg dry weight | [157] |
| St. Lawrence River (Canada) | River sediment | 13,832 particles/m ² | [158] |
| Thames river (United Kingdom) | Sediment | 18.5 ± 4.2 to 66 ± 7.7 particles /100 g | [159] |
| Rhine River (Germany) | Surface water | 892,777 ± 1,063,042 particles/km ² | [160] |
| | Sediment | 1784 to 30,106 particles /m ² | [161] |
| Seine River (France) | Surface water | 0.28 to 0.47 particles /m ³ | [162] |
| Po River (Italy) | Surface water | 2,043,069.8 ± 336,637.4 particles/km ² | [163] |
| Tamar Estuary (United Kingdom) | Surface water | 0.028 particles /m ³ | [164] |

their origin was tethered to fragments of larger plastic particle, industrial pre-production pellets, and facial cleaner and other personal care products. In a rigorous study, Schmidt et al. [61] analyzed sample from 79 sites covering 57 rivers and detected microplastics in 98.5% of the samples with mean and median concentration

of ~37,700 and ~13/1,000 m³, including zero detections. Potential sources of fresh water pollution by microplastics include effluent from waste water treatment plant (WWTP), runoff from industrial plastic production sites, urban, and agricultural areas, and atmospheric fallout. Laundry washing machines are also responsible

for discharging a large amount of microplastics into wastewater in fibrous form, with one study estimating that around 1,900 fibers are discarded from a single wash [7]. In a study, the downstream outlet of a WWTP in the North Shore Channel in Chicago (USA) was found to contain around 9.3 times microplastics than in the upstream, which depicts the contribution of WWTP in discharging microplastics to fresh water system [165]. Microplastics can accumulate in agricultural lands from widespread plastic mulching used in farming and atmospheric fallout of the airborne particles originated in nearby areas [166]. They can also appear in farming land through another potential source of microplastics: sewage sludge, typically used as fertilizer and for landfilling [167]. Apart from polluting soil compartment, these microplastics contaminate the waterbody through surface runoff to canals and rivers by irrigation or rain water. Alike marine biota, aquatic biota also ingest and accumulate microplastics and encounter the same adverse effects. Hurt et al. [139] investigated two fish species, 72 gizzard shad and 24 largemouth bass, in two agricultural reservoirs in the midwestern U.S.A. and found microplastics in 100% of the fish sample. In another study, 83% of a fresh water fish species *Hoplosternum littorale* were observed to have microplastics in their gut, mostly microfibers [168]. Thus, the microplastics in fresh water fish, being a crucial part of human food web, may pose more threat to human health than the seafood as the former ones are more frequently consumed. Apart from fresh water or sea fish, humans are also consuming microplastics from other food sources that includes table salt, sugar, honey, and beer [169-171].

Often scientists positively correlate microplastics abundance with human population density [7], which infers that Bangladesh, being a very populated country, is at a high risk of being polluted by microplastics, specially the water bodies. However, till now, there has been little or no systematic study to assess the amount of microplastics in different environmental compartments nor the impact of microplastics on living creatures. With the rivers and water bodies occupying 5% of the land surface [172], Bangladesh needs more rigorous assessment of the plastic presence in water bodies and take necessary steps to prevent further pollution since this environmental compartment is crucial for maintaining ecological balance. Apart from environmental and ecological damage, substantial amount of economic cost is also associated with the plastic wastes stuck in water bodies as they require frequent clean-up activities.

3.3. Soil Pollution

With 79% global plastic waste dumped in landfills, soil compartment is also at high risk of contamination by being a sink of microplastics [173]. A recent study estimated that the amount of microplastics that enter into agricultural land of Europe and North America varies from 63 to 430 thousand tons and from 44 to 300 thousand tons per year respectively, and interestingly this figure outnumbers the emission of microplastics to ocean surface [174, 175]. Apart from plastic mulching, sewage sludge, and atmospheric deposition, microplastics can be introduced to soil through landfilling [176], wastewater irrigation system [177], tire wear and tear [178], actions of soil organisms [166, 179], such as grinding in gizzard and subsequent release through excretion process, scraping or chewing off, and incorporation by digging process. They can

be vertically transported from surface to deep soils by the burrows of anecic earthworms, deep-dwelling earthworms feeding on surface and excreting far below the surface, agronomic activities (plowing and harvesting), plant root elongation, and water infiltration, and then be dispersed laterally by the movement of geophagous earthworms, soil microarthropods, mosquitoes, mites and collembolan, and digging mammals, such as gophers and moles [21, 180-183]. Apart from migration within the soil, the microplastics can be transported to surrounding air and water bodies by the action of wind, rain water, irrigation water, and flooding. Bangladesh is flooded each year during the monsoon, facilitating the migration of plastic debris from land to water compartment.

The interaction between microplastics and soil may bring about serious impact on the health of soil, crop and soil biota, ultimately threatening human health. However, few information has been explored about it by the researcher community so far [21]. Sometimes, the effects of microplastics on soil have been found to be inconclusive and dependent on microplastics types. With the presence of PS fibers in soil, it was found that water holding capacity increased and bulk density decreased significantly, but there was no conclusive trend in case of PE and PAA in soil [184]. Whereas in another study with PS fibers, there was no change in bulk density of the soil and the water holding capacity decreased [185]. Besides, it has been shown that microplastics can promote accumulation of humic-like substances responsible for improved soil stability, nutrient availability, and water holding capacity [186]. On the other hand, it was reported that the presence of microplastics may reduce the hydraulic conductivity or permeability of the soil which ultimately may affect the soil microbial activity as well as soil fertility [187]. Moreover, their presence can create channels in soil that may lead to increased water evaporation and soil desiccation, suppressing the plant growth [188]. Thus, substantial uncertainty exists about the effect of microplastics on soil, and it needs further investigation to assess the exact impact of microplastics on soil. However, microplastics can significantly affect the activity of some crucial soil enzymes, such as urease, fluorescein diacetate hydrolase, and phenol oxidase that are responsible for maintaining soil nutrients: dissolved carbon, nitrogen, and phosphorus at a desired level, and thus compromise the soil fertility [186, 189]. Again, it has been demonstrated that prolonged exposure of high level of microplastics in soil can augment the accumulation of dissolved organic matter (DOM) that enhance the release of soil nutrients [186]. Sometimes, these contaminants make other pollutants less available to soil biota and plants, exerting some protective role [190]. However, the change in soil nutrient, moisture, and porosity may alter the flow of oxygen in soil causing a decrease in indigenous microorganisms [191, 192]. The deposited mulching films in soil can inhibit microorganisms because of the presence of carbonyl groups [193]. Owing to high surface to volume ratio, microplastics can adsorb POPs, heavy metals, antibiotics, and various other toxic substances, and act as a vector to spread them across the terrestrial areas [194, 195], a scenario also observed in marine environment. Increased accumulation of DOM also enhance the transformation and mobility of contaminants in soil and increase their availability to soil [192]. Like marine and aquatic environment, soil microplastics can incorporate in food chain and can be transferred from lower trophic organisms to higher trophic

one. The higher trophic biota is likely to consume more microplastics, thus facilitating the biomagnification along the food chain [196]. In terms of affecting the organisms, microplastics in the soil embrace the similar fate as in the marine environment and are ingested by soil organisms and retained in their different tissues. For instance, microplastics have been found in liver, gut, and kidney of mice, earthworm casts, chicken feces, and snails [197-199]. Apart from that, ingestion of microplastics cause false satiation, energy scarcity, decreased growth and reproduction, intestinal obstruction, alteration of biochemical responses, such as decreased immune responses, metabolic disorder, and anomalies in gene expression in soil animals [200-202].

Since the microplastics negatively affect the soil fertility and enzyme, it is expected that the microplastics have detrimental effect on plant community, though research findings in support to this phenomenon is still not sufficient. Nonetheless, existing studies report that microplastics have significant impact on plants (such as wheat, perennial ryegrass, cress, spring onion), causing growth inhibition, genotoxic and oxidative damage [21]. Moreover, microplastics can impair the assimilation and transportation of nutrients in plants by damaging the connection between cells and blocking cell wall pores, resulting in low water transport, leaf growth, and production [203]. In their study, Qi et al. [66] found microplastic residues from polyethylene and biodegradable mulch films to have negative effect on growth of wheat (*Triticum aestivum*). In another study, spring onion (*Allium stulosum*) were studied in the presence of microplastics and found to be noticeably affected in terms of water content, C/N ratio, leaf nitrogen content, root properties (length, diameter), mineralization rate, and root symbioses [204]. Agriculture in Bangladesh contributes about 16.5% of the GDP and nearly 87% of the rural inhabitants draw their income from agricultural activities, directly or indirectly [205]. Again, fisheries and livestock contribute 30 to 40% of the agricultural sector which is about 7 to 8% of country's GDP, of which 3.57% comes from fisheries and 1.53% from animal husbandry [206]. The agricultural land in Bangladesh covers about 9.1 million hectares which is 70% of the country's total land area [207]. Thus farming, fisheries and livestock sector plays a vital role in socioeconomic development of Bangladesh through ensuring food security, economic growth, and employment generation for poor and marginal people. With the proved global impact of microplastics on soil and plants, it can be expected that microplastics are also present in our soil and posing the same threat to the soil biota and plants. If the threat is unchecked for a long time, agricultural crops will see a decrease in production that will risk feeding such a big population of our country and will substantially jeopardize country's economy. In addition, livestock and fishes may face microplastics in their food sources in soil and water compartment and can have detrimental consequences, which may in turn endanger their production as well as nation's economy. Therefore, it is urgent that comprehensive research should be done to quantify the amount of microplastics in our soil and how they are affecting soil fertility, food crops (rice, wheat, tea), other plants, and soil animals (mainly domestic animals).

3.4. Plastic Pollution during Covid-19 Pandemic

It is expected that during the current pandemic situation arose due to novel coronavirus (SARS-CoV-2), responsible for a severe

respiratory syndrome known as COVID-19 [208], the scenario of plastic pollution in Bangladesh will get worsened even more due to the mismanagement of safety products that are largely made of polymers. With the uncertainty in vaccine availability for this highly contagious Covid-19, health professionals from across the world made it compulsory for people to use PPE masks, gloves, and googles to avoid contact as well as infection. That's why the demand for PPE increased tremendously worldwide. For instance, it has been estimated that 129 billion face masks and 65 billion gloves would be necessary each month to protect citizens across the world [209]. These PPE are typically made of PP, polyurethane, PAN, PS, polycarbonate, PE, polyester, PET etc [210, 211]. All of these PPE are meant for single use to avoid further contamination which led to a drastic increase in medical waste all over the world, overloading the capacity of the waste treatment facility. For instance, Spain and China observed a 350% and 370% increase in medical waste, respectively than what produced during the normal situation [212]. According to Environment and Social Development Organization (ESDO), In Bangladesh, during the first month of official lockdown to prevent corona virus outbreak, around 14,500 tons of hazardous plastic waste emerged, comprising of face masks, hand gloves and polythene bags. After the emergence of Covid-19, about 5796 ton plastic waste generated in a single month of which 3076 ton generated in Dhaka city, capital of the country, alone [213]. Managing this unprecedented level of plastic waste pose a great challenge for countries, especially developing nations like Bangladesh. These wastes are, in part, likely to undergo uncontrolled incineration, releasing GHGs, heavy metals, dioxins, PCBs and furans [214]. Another big portion will find their way into rivers and oceans, followed by sewage and canal blockage, and continue to degrade to microplastics that will easily be mistaken for food by the biota. Besides, because of their elastic components, masks also have increased risks of entanglement for a wide variety of fish, animals and birds [215]. Moreover, the use of single used plastic bags has also increased parallelly during this pandemic to ensure safety against cross contamination from reuse of plastic bags during home delivery and carrying groceries. Their use also increased due to relief activities to support people who became jobless in this situation. It has been estimated that demand for global plastic packaging is expected to increase by 40% due to Covid-19 situation [209]. Overall, if these large amounts of contaminated single use plastics go unmanaged, they will create an immediate outbreak of second phase of the virus and in the long run, they will continue to pollute air, soil, and water compartment. Hence, an immediate action is sought for safe management of the mounting safety plastic wastes generated in this pandemic situation.

4. Effect of Plastic Pollution on Public Health

According to UN report on environment that plastic items never decomposed fully, they just reduce their size (particle). Those tiny particles come into human body with travelling very short distance [216]. These particles can travel a long distance and remain in the environment for a long time. Moreover, burning of these plastics can release toxic gases and particles in the air that can be inhaled by human. It has been estimated that adults and children intake

on average 1063 and 3223 microparticles per year, respectively, through dust inhalation [217]. Because of environmental pollution, 234,000 people died in around Bangladesh where 80,000 are in urban areas, a World Bank 2018 statistics showed [218]. The monomeric building blocks of plastics (bisphenol A), their additives (plasticizers) or a combination of the two (antimicrobial polycarbonate) can raise the human health risks [219]. Bisphenol A (BPA) which is the constituent of polycarbonate plastics, also used as an additive to polyvinylchloride (PVC). The first BPA was synthesized in 1891 [220]. Some monomers leaves unbound at the polymerization of BPA. Beverage and food containers can be released BPA molecules into drink and food over time. The factors that are responsible to leach the monomer at elevated temperatures into food which are repeatedly washing, storing in acidic and basic items, reuse of water bottles, baby bottles, dental filling, household electronic items, and sports equipment [220-223]. The heavy metals released during plastic burning act as soil contaminant due to their low solubility and resistant to microbial degradation, risking human metabolism by entering the human food chain [224]. As an endocrine disruptor BPA can interfere natural body's hormones with the production, secretion, action, transport, function, and elimination. Moriyama et al. [225] demonstrated that BPA weaken thyroid hormone transcriptional activity by forming T_3 binding to the thyroid hormone receptor. BPA binds to both nuclear receptor $ER\alpha$ and $ER\beta$. It can mimic the behavior of estrogen. The exposure of BPA has been caused a number of health issues like reproductive disorders (affect egg maturation, interfere endocrine function, puberty, ovulation, lead to infertility). The maturing of the oocyte is affected by BPA. Some studies found that higher level of BPA in the serum decreased probability of mature oocytes. This higher concentration of BPA causes polycystic ovary syndrome in women which leads to dysfunction of menstrual cycle, hirsutism, and infertility [226]. BPA exposure in adult population also increases the risk of cardiovascular (CV) disease (heart attack, coronary artery heart disease, angina, peripheral artery disease, hypertension), type 2 diabetes, rapid changes in immune system, body weight, anxiety, etc. [227]. The molecular mechanisms for CV disease might be involved with rapid signaling of estrogen receptor and alteration of cardiac Ca^{2+} through phosphorylation, handling protein expression, oxidative stress, ion channel inhibition and genome modifications [228]. Persistent free radical carbon and oxygen centered free radicals are also released and are considered to have adverse effects on human lungs when inhaled [32]. Nancy Cardoso et al. [229] also found that serum concentrations of testosterone reduced by the effect of BPA. Scientists also suggested that BPA could stimulate the risk of prostate, breast and other cancers due to its estrogen like properties. The chemotherapy of breast cancer is also affected by it [230]. The unconjugated BPA levels are in the range of 0.1 to 10 g/L in human blood and tissues [231, 232]. Centers for Disease Control and Prevention reported that a survey on 394 American adults showed that most of them have detectable levels of BPA in urine [233]. The daily amount of BPA in terms urine levels are greater for males than females (53.8 and 41 ng/kg/d) and in children and adolescents (64.6 and 71 ng/kg/d) in terms of geometric means, this exposure rate decreases as age increases up [234]. The reference dose of BPA for humans (U. S. EPA) observed a value of 50 $\mu\text{g/kg/d}$ after taking necessary safety. This reference

rate was measured on the scale of the lowest observable adverse effect level [235]. Phthalates (a large group of compounds) which is used as plasticizers for PVC, introduced in market 75 years ago. The main exposures of phthalates are plastic tubing, gloves, bags, toys, home decoration products, Beautification products, etc. [236]. The direct route of human exposures to phthalates are dialysis, extracorporeal membrane oxygenation, blood transfusions, ingestion of contaminated materials [237-239]. Like BPA, Phthalates also responsible for the hormonal imbalance into human body [240]. It can also affect the childbearing mother, fetus and new born baby. Though the toxicity of phthalates is less than BPA, still it's harmful for human body. Along with BPA and Phthalates, other plastic additives, commonly used polymers cause the human health problems and ecological imbalance. So the people of all ages, person who are closely contact with those exposures have been affected highly by health problems.

5. Organizational and Governmental Policies against Plastic Pollution in Bangladesh

The legislation against plastic bags was first implemented in Bangladesh. ESDO is the pioneer organization for banning plastic bag in Bangladesh. In 1990, it took an initiative for writing articles in the national dailies about the threats of plastic pollution in order to draw the attention of general public and to increase their awareness about its severity [241]. In 1993, Ministry of Environment and Forest (MOEF) considered the movement against plastic pollution and took an initiative to ban the manufacturing and usage of polythene bags but it was not accepted by the parliament. In 1997, ESDO again raised their voice and initiated "Plastic Bag-free day" [242]. In 1999, the MOEF initiated Sustainable Environment Management Program for making a plan to remove polythene shopping bags by campaigning against it. The authorized members of the program suggested for taking a complete study on the manufacturing, advertising and usage of polythene shopping bags as well as recommended to consider the socio-economic impacts before making the ultimate decision.

The Ministry then motivated the general people by campaigning everywhere to stop the usage of polyethylene bags and publicized that January 1, 2002 shall be the cutoff date for manufacturing and usage of polyethylene shopping bag in Bangladesh [241]. In 2002, the law of section 1 under the Bangladesh Environment Conservation Act was revised. The production and uses of polythene shopping bag was forbidden according to Rule 6ka of Clause-5 under Section-9 [200].

- According to rule 6ka, the penalty and punishment will be
- For production, import and marketing: 10 years sentence of vigorous prison, or 1 million taka fine, or both punishments together.
 - For sale, exhibition for sale, store, distribution, transportation or use for commercial purpose: 6 months sentence of vigorous prison or 10 thousand taka fine, or both punishments together [241].

In 2018, Transparency International Bangladesh raised their voice for stronger implementation of law to impede illegal manufacturing, advertising and uses of plastic to stop environment pollu-

tion [243]. The National 3R strategy for waste Management was initiated by Ministry of Environment and Forests to decrease the amount of waste material which may reduce the plastic waste by increasing the reuse and recyclability of used plastic [202]. The 3R policy i.e. reduce, reuse and recycle can minimize the plastic pollution in an efficient way. However, Bangladesh government is still trying to enforce the law by placing mobile courts at marketplaces in different time of the year. [244].

6. Recommendations for a Possible Way Out

Though there has not been enough study on the amount of plastic waste generation and their fate and impact on different environmental compartments of Bangladesh, we can conclude citing the limited regional studies and the huge amount of global studies that the country is and will continue to be at high risk of plastic pollution, if necessary actions are not taken immediately. This pollution is directly and indirectly harming the entire creature from human kind to a zooplankton through polluting the entire environment. Moreover, without checking the plastic production and proper management of the generated waste, it would be quite difficult to achieve the sustainable development goal set by United Nations in 2015 to ensure a poverty and pollution free peaceful planet Earth by 2030 [34]. In response to that, the country has already taken some measures, but it appears that the plastic use and subsequent pollution have not been curbed yet in an expected manner. Hence, to deal with this global problem in a sustainable way, the following suggestions are proposed:

- Raising awareness among the end users against plastic use by concerning them about the detrimental effects of it through advertisement on media and activities by government and non-government agencies.
- Introducing reward based plastic collection program to encourage people not to dump plastic waste here and there.
- Enhancing collaborative research between universities and research institutes to assess the plastic waste in different environmental compartments and their consequences.
- Increasing the research opportunities and funding for searching biodegradable polymer and economically viable alternatives to plastic products, especially packaging plastics.
- Preferential tax treatments, easy bank loan, duty free importation of tools and machineries for industries and businesses related to production of biodegradable alternative to plastics.
- Exploiting the country's huge potential for jute production in manufacturing cost effective biodegradable alternatives to plastics and providing incentives for these kinds of businesses.
- Providing subsidy for plastic recycling industries rather than plastic manufacturing businesses.
- Imposing high tax on plastic related businesses, from importing raw material to selling the end products. High price will refrain public from using plastic products.
- Consideration of plastic recycling and eco-friendly alternative to plastic production businesses as a sustainable solution to country's worsening unemployment problem.
- Inclusion of plastic waste collection points at every potential source of plastic pollution including road and river transport

system, institutions, offices, shopping centers etc.

- Increasing the capacity of municipalities to collect maximum quantity of plastic waste.
- Strict implementation of existing regulatory laws to stop the use of plastic bags.
- Developing national action plan for monitoring and management of plastic wastes at the point of sources.

7. Conclusions

Plastic materials are considered an inevitable part of our daily lives because of their wide-ranging uses owing to their low cost, light weight, high durability, and easy availability. But they have now become a global threat due to their long lasting negative effect on every compartment of the environment-air, soil, and water. Due to their non-biodegradability they persist in the environment for an unbelievably long time and migrate from one compartment to another and then get incorporated in human food chain, causing adverse consequence on human health. Moreover, the toxic chemicals released when plastics are subjected to physical and chemical actions are also a health hazard. In this work, the impact of plastic waste on Bangladesh in terms of its environment and human health has been delineated by critically reviewing the existing studies on plastic pollution in different regions of the world as well as available little local studies. It has been demonstrated that the over whirling usage of plastic is also affecting the environment and public health of our country significantly. This review paper also identified some potential sources of plastic pollution in our country and it is expected that during the Covid-19 situation the pollution scenario will get worsened in an unexpected manner. The article ended by prescribing some possible ways to lessen the impact of plastic pollution in a sustainable manner that followed citation of necessary measurements already taken by the government. It is believed that this work will make the researcher community feel the necessity to conduct a comprehensive study on plastic pollution in Bangladesh and to search potential eco-friendly alternatives to plastics and assist the policy makers to make fruitful policies to curb the plastic pollution.

Author contributions

S.H. (Lecturer) conceived, wrote, and revised the manuscript. M.A.R. (Lecturer) conceived, supervised, wrote and revised the manuscript. M.A.C. (Lecturer) wrote the manuscript. S.K.M. (Lecturer) wrote the manuscript.

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