Chapter

Microplastics and Environmental Health: Assessing Environmental Hazards in Haiti

Daphenide St. Louis, Ammcise Apply, Daphnée Michel and Evens Emmanuel

Abstract

Microplastics (MP) refer to all plastic particles that are less than 5 mm in size. Over the past decades, several studies have highlighted the impact of microplastics (MP) on living organisms. In addition to being pollutants themselves, these synthetic polymers also act as vectors for the transport of various types of chemicals in natural ecosystems. MP has been ubiquitously detected in a wide range of shapes, polymers, sizes and concentrations in marine water, freshwater, agroecosystems, atmospheric, food and water environments. Drinking water, biota, and other remote places. According to the World Bank, over 80% of the world's marine litter is plastic and the concentration of litter on Caribbean beaches is often high, with a high presence of single-use plastics and food containers. In its work, the World Health Organization (WHO) suggests an in-depth assessment of microplastics present in the environment and their potential consequences on human health, following the publication of an analysis of the state of research on microplastics in drinking water. It also calls for reducing plastic pollution to protect the environment and reduce human exposure. In Haiti, the bay of Port-au-Prince is the natural receptacle of all the urban effluents generated by human activities in the Metropolitan Zone. This urban wastewater carries household waste, sludge from pit latrines and sewage, industrial wastewater which largely contributes to the pollution of the bay. Furthermore, 1,673,750 tonnes per year of household waste, including 93,730 tonnes of plastic waste, are not collected. What are the environmental dangers represented by the MP contained in those wastes for living organisms in exposed tropical ecosystems? The purpose of this paper is: (i) to do a bibliographical review of the physical and chemical properties, as well as the toxicological profile of MP, (ii) to identify the environmental hazards associated with MP contained in urban waste in the metropolitan area of Port-au-Prince.

Keywords: microplastics, wastes, physical and chemical characteristics, natural ecosystems, fate, environmental hazards

1. Introduction

Synthetic polymers appeared at the end of the nineteenth century around the 1860s, but it was not until after World War II that the "rise of plastics" really began [1].

Plastic has become one of the most ubiquitous materials since its inception as a phenol-formaldehyde resin (i.e., bakelite) [2]. Basically, plastic was designed to improve the conditions of human life, but today it is becoming a real environmental concern [1].

Nowadays, plastic is ubiquitous in all environmental compartments (air, water, and soil) [3]. Simonneau et al., [4] report that rain and snow contain a significant number of MP, invisible to the naked eye and less than 5 mm in size. The presence of MP in soil ecosystems has been detected [5, 6]. Scientific literature reports the environmental occurrence of MP in surface waters [7], coastal sediments [8], beach sands [9], freshwater sediments [10], and deep-sea environments [11]. Indeed, the intensive exploitation of plastic associated with poor performance of waste management systems, including end-of-life collection and capture, have resulted in a massive accumulation of plastic waste in the environment [12]. The release of plastic materials into the environment is recognized as an important pollution related issue [13–15].

The proliferation of MP in the environment causes serious pollution all over the world [16]. According to their characteristics, namely, synthetic materials with a high content of polymers, solid particles, less than 5 mm, insoluble in water, and not degradable, they are easily introduced into the environment and persist there due to their low solubility [17]. Food chains are subject to significant pollution from the release of hydrophobic organic chemicals [18–22]. Being present in different aquatic ecosystems (surface water, oceans, estuarine waters, etc.), organisms are directly or indirectly exposed to microplatiscs [17]. Scientific literature reports negative impacts of microplastics on benthic organisms [23, 24]. The toxic effects of these pollutants have been studied on the feeding habits, growth and reproductive systems of several aquatic species [25–29]. Human beings are therefore exposed through the consumption of seafood, fish and crustaceans [30].

The purpose of this paper is: (i) to do a bibliographical review of the physical and chemical properties, as well as the toxicological profile of MP, (ii) to identify the environmental hazards associated with MP contained in urban waste in the metropolitan area of Port-au-Prince.

2. Methodology

Scientific and technical information from several world-wide documentation databases was used. Academic social networks, scientific databases such as Google Scholar, PubMed, academia.edu, researchgate.net, academic presses (springer.com, sciendirect.com, Wiley Online Library, ACS Publications, etc.) were consulted in this way as electronic data available on the sites of certain research universities. The search equations launched on the various sites consulted were implemented from the crossing of the following keywords: "Microplastics", "Microplastics (and) definition", "Microplastics (and) plastics", "Microplastics (and) thermodynamics", "Microplastics (and) Epidemiology", "Microplastics (and) physical and chemical properties", "Toxicological profile of microplastics", "Microplastics (and) Human health effects" , "Microplastics (and) Environment" , "Microplastics (and)) partition coefficient" , "Microplastics (and) Haiti", "Haiti (and) solid waste" , "Fate and Microplastics" , "Microplastics (and) Ocean" , etc.

The results obtained have been the subject of a critical examination. Each article read, referred the authors of this study for the reading of another article cited in the list of his references. We considered articles that were published from 2005 to 2021. The number of times cited (citations analysis).

3. Definition, composition, and physical and chemical characteristics of plastics

The term plastic refers to "a material which contains as an essential ingredient a high polymer and which, at some stage of its transformation into finished products, can be shaped by flow," [31]. However, elastomeric materials (also shaped by flow) are generally not considered plastics [32, 33].

Plastics are mainly produced from non-renewable substances, extracted from petroleum and natural gas [1, 34, 35], or renewable like sugar cane, starch, or vegetable oil or even of mineral origin like salt [36]. The evolution of plastic, correlated with its major strengths, makes it a substitute material, to the detriment of metals, for example [37]. Thus, the increase in plastic, and its multiple applications, place it at the forefront of market share, ahead of traditional materials [38].

The International Organization for Standardization (ISO) [31] recommends the use of the term "macromolecule" for individual molecules, the term "polymer" being reserved for a substance consisting of macromolecules, further stipulating that the term "high polymer" or more generally "polymer" denotes a product consisting of molecules characterized by a large number of repeats of one or more species of atoms or groups of atoms (constitutional units), linked in sufficient quantity to lead to a set of properties which hardly vary with the addition or elimination of a single or a small number of constituent motifs [31]. The denomination of "plastics" comes from the characteristic plasticity property of many polymer materials which can be deformed at will under the effect of temperature (the notion of temperature is relative here: certain plastics are deformable at room temperature) [39]. Thus, most of the plastic materials placed on the market result from complex formulation steps intended to give the macromolecules the desired properties of use. Adjuvants such as stabilizers and additives will be used to limit the degradation of the chains under the effect of heat, radiation, abrasion (antioxidants, mineral fillers, etc.) and give them specific properties (plasticizers, dyes, flame retardants, reinforcements ...) [39].

A main classification of plastics is based on the durability or non-durability of their shapes, or whether they are thermosets or thermoplastics [40]. According to Plastics Europe [36], plastics can be classified into various types. A typology of plastic as well as their applications and benefits are published on the website of this institution, which is an association of plastic manufacturers in Europe (**Table 1**).

3.1 Microplastics

Jiang et al. [40] note that the degradation of plastic waste generates microplastic (MP) or nanoplastic particles (NP); this division is based on the diameter of the plastic fragments or particles, MP being less than 5 mm in diameter and NP being 1 to 100 or 1000 nm in diameter [40]. The scientific literature on the diameter of plastic particles provides several information and divisions of microplastics. Arthur et al. [41] report when it was reported in 2004, the term microplastics was used to describe fragments of plastic approximately 20 μm in diameter. However, while these early reports referred to truly microscopic particles, they did not provide a specific definition of microplastic. In 2008, the United States National Oceanographic and Atmospheric Agency (NOAA) hosted the first International Microplastics Workshop in Washington and, as part of that meeting, formulated a broader working definition to include all particles. Less than 5 mm in diameter [41]. Other authors consider that particles>5 mm are macroplastics, mesoplastics 5 to>1 mm, microplastics 1 mm to>0.1 μm and nanoplastics as 0.1 μm [5].

Plastics	Description
Bio-based plastics	*Bio-based plastics are made in whole or partially from renewable biological resources. For example, sugar cane is processed to produce ethylene, which can then be used to manufacture polyethylene. Starch can be processed to produce lactic acid and subsequently polylactic acid (PLA).*
Biodegradable plastics	*Biodegradable plastics are plastics degraded by microorganisms into water, carbon dioxide (or methane) and biomass under specified conditions. To guide consumers in their decision-making and give them confidence in a plastic's biodegradability, universal standards have been implemented, new materials have been developed, and a compostable logo has been introduced.*
Engineering plastics	*Engineering plastics exhibit higher performance than standard materials, making them ideal for tough engineering applications. They have gradually replaced traditional engineering materials such as wood or metal in many applications because, not only do they equal or surpass them in their weight/strength ratio and other properties, but they are also much easier to manufacture, especially in complicated shapes.*
Epoxy resins	*Epoxy resins have been around for more than 50 years and are one of the most successful of the plastics families. Their physical state can be changed from a low viscosity liquid to a high melting point solid, which means that a wide range of materials with unique properties can be made. In the home, you'll find them in soft-drinks cans and special packaging, where they are used as a lining to protect the contents and to keep the flavor in. They are also used as a protective coating on everything from beds, garden chairs, office and hospital furniture, to supermarket trolleys and bicycles. They are also used in special paints to protect the surfaces of ships, oil rigs and wind turbines from bad weather.*
Expanded polystyrene	*Expanded polystyrene, or EPS, is widely used commodity polymer. It has been a material of choice for more than 50 years because of its versatility, performance, and cost effectiveness. It is widely used in many everyday applications, such as fish boxes, bicycle helmets and insulation material.*
Fluoropolymers	*Fluoropolymers are renowned for their superior non-stick properties associated with their use as a coating on cookware and as a soil and stain repellent for fabrics and textile products. They also contribute to significant advancement in areas such as aerospace, electronics, automotive, industrial processes (chemical and power sectors, including renewable energy), architecture, food and pharma and medical applications. The most well-known member of Fluoropolymers is PTFE (polytetrafluoroethylene).*
Polyolefins	*Polyolefins are a family of polyethylene and polypropylene thermoplastics. They are produced mainly from oil and natural gas by a process of polymerization of ethylene and propylene respectively. Their versatility has made them one of the most popular plastics in use today.*
Polystyrene	*Polystyrene is a synthetic polymer made from styrene monomer which is a liquid petrochemical. It is a thermoplastic polymer which softens when heated and can be converted via semi-finished products such as films and sheets, into a wide range of final articles.*
Polyurethanes	*Polyurethane (PUR) is a resilient, flexible, and durable manufactured material. There are various types of polyurethanes, which look and feel quite different from each other. They are used in a broad range of products. In fact, we are surrounded by polyurethane-containing products in every aspect of our everyday lives. While most people are not overly familiar with polyurethanes because they are generally 'hidden' behind covers or surfaces made of other materials, it would be hard to imagine life without them.*
Polyvinyl chloride	*Polyvinyl chloride (PVC) was one of the first plastics discovered and is also one of the most extensively used. It is derived from salt (57%) and oil or gas (43%). It is the world's third-most widely produced synthetic plastic polymer, after polyethylene and polypropylene. PVC comes in two basic forms: rigid (sometimes abbreviated as RPVC) and flexible.*
Thermoplastics	*Thermoplastics are defined as polymers that can be melted and recast almost indefinitely. They are molten when heated and harden upon cooling. When frozen, however, a thermoplastic becomes glass-like and subject to fracture. These characteristics, which lend the material its name, are reversible, so the material can be reheated, reshaped, and frozen repeatedly. As a result, thermoplastics are mechanically recyclable. Some of the most common types of thermoplastic are polypropylene, polyethylene, polyvinylchloride, polystyrene, polyethylenetheraphthalate and polycarbonate.*

Table 1.
Type of plastics [plastic Europe – Online].

Microplastics samples are usually sorted into different shapes according to observed morphology. The Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection (GESAMP) [42] recommends five general categories of recommends, including fragment, foam, film, line, and pellet. **Figure 1** presents the standardized size and color sorting system (SCS) for categorizing microplastics [43]. It is recommended the original data in these finer subdivisions with the recognition that subdivisions can be combined for ease of harmonizing and comparing data [42].

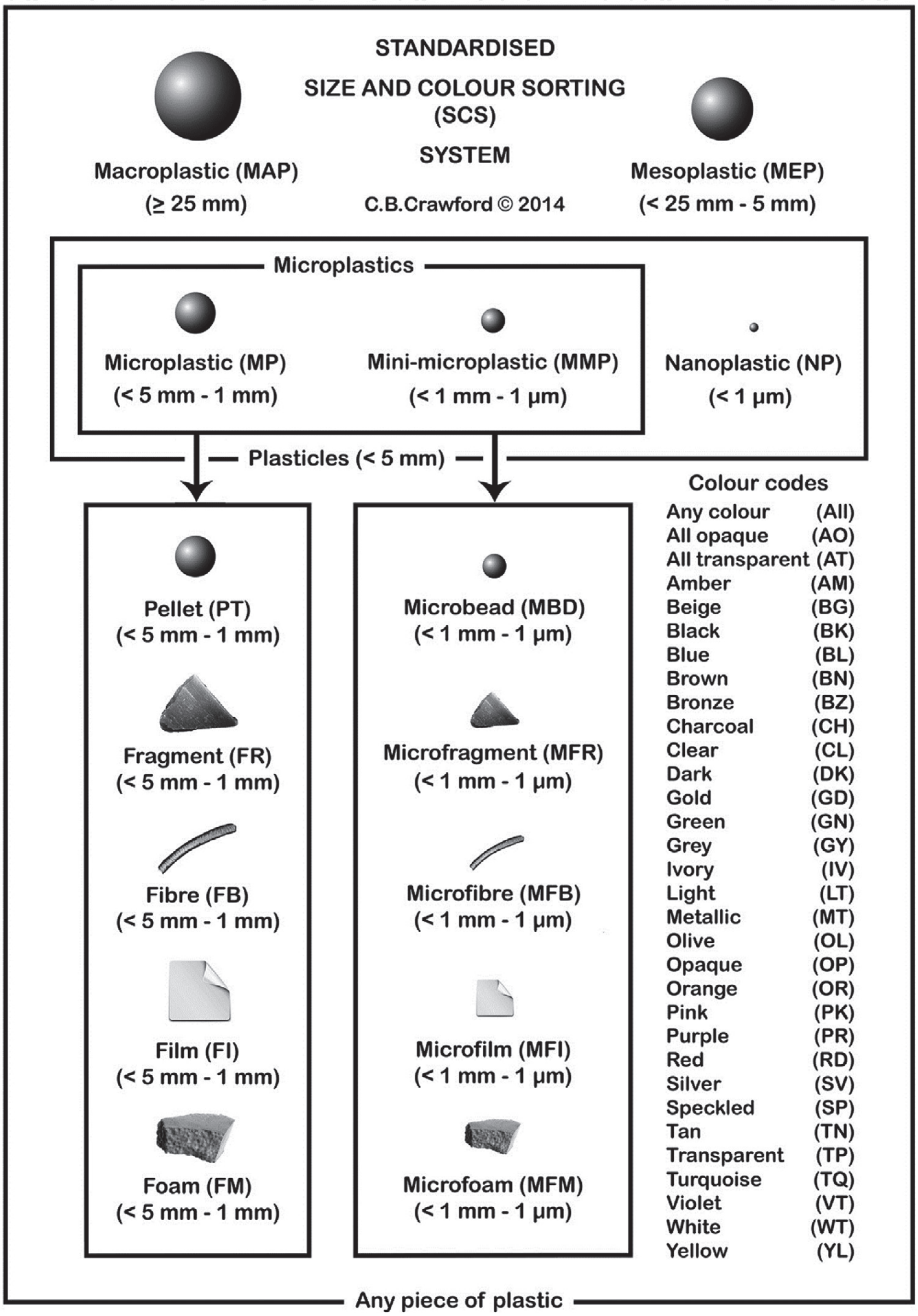


Figure 1.
The standardized size and color sorting (SCS) system [43].

According to Crawford et al. [43], the SCS system generates unique codes to process microplastic abundance data, requiring an efficient categorization system. **Table 2** presents a categorization of plastic according to size, while the **Table 3** gives the categorization of microplastics according to morphology.

There are many hundreds of different types of polymer and mixtures of polymer in commercial production, but the market is dominated by: polyethylene (as both

Category	Abbreviation	Size	Size definition
Macroplastic	MAP	≥25 mm	Any piece of plastic equal to or larger than 25 mm in size along its longest dimension
Mesoplastic	MEP	<25 mm–5 mm	Any piece of plastic less than 25 mm–5 mm in size along its longest dimension
Plasticle	PLT	<5 mm	All pieces of plastic less than 5 mm in size along their longest dimension
Microplastic	MP	<5 mm–1 mm	Any piece of plastic less than 5 mm–1 mm in size along its longest dimension
Mini-microplastic	MP	<1 mm–1 μm	Any piece of plastic less than 1 mm–1 μm in size along its longest dimension
Nanoplastic	NP	<1 μm	Any piece of plastic less than 1 μm in size along its longest dimension

Table 2.
Categorization of pieces of plastic based on size [43].

Abbreviation	Type	Size	Definition
PT	Pellet	<5 mm–1 mm	A small spherical piece of plastic less than 5 mm to 1 mm in diameter
MBD	Microbead	<1 mm–1 μm	A small spherical piece of plastic less than 1 mm to 1 μm in diameter
FR	Fragment	<5 mm–1 mm	An irregular shaped piece of plastic less than 5 mm to 1 mm in size along its longest dimension
MFR	Microfragment	<1 mm–1 μm	An irregular shaped piece of plastic less than 1 mm to 1 μm in size along its longest dimension
FB	Fiber	<5 mm–1 mm	A strand or filament of plastic less than 5 mm to 1 mm in size along its longest dimension
MFB	Microfibre	<1 mm–1 μm	A strand or filament of plastic less than 1 mm to 1 μm in size along its longest dimension
FI	Film	<5 mm–1 mm	A thin sheet or membrane-like piece of plastic less than 5 mm to 1 mm in size along its longest dimension
MFI	Microfilm	<1 mm–1 μm	A thin sheet or membrane-like piece of plastic less than 1 mm to 1 μm in size along its longest dimension
FM	Foam	<5 mm–1 mm	A piece of sponge, foam, or foam-like plastic material less than 5 mm to 1 mm in size along its longest dimension
MFM	Microfoam	<1 mm–1 μm	A piece of sponge, foam, or foam-like plastic material less than 1 mm to 1 μm in size along its longest dimension

Table 3.
Categorization of microplastics based on morphology [43].

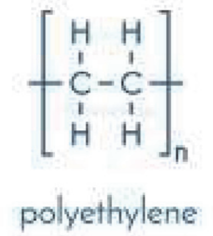
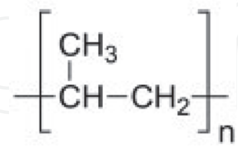
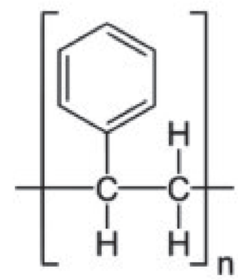
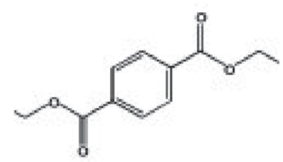
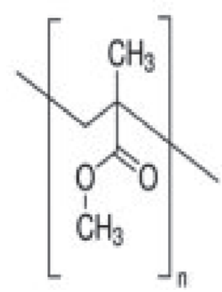
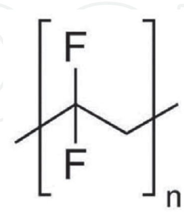
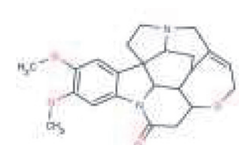
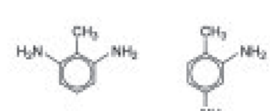
Polymers	Abbreviation	CAS #	Molecular formula	2D Structure
Polyethylene	PE	9002-88-4	$(C_2H_4)_n$	
Polypropylene	PP	9003-07-0	$(C_3H_6)_n$	
Expanded polystyrene	EPS	9003-53-6	$(C_8H_8)_n$	
Polyethylene Terephthalate	PET	25038–59-9	$(C_{10}H_8O_4)_n$	
Polymethylmethacrylate	PMMA	9011-14-7	$[(CH_2C(CH_3)(CO_2CH_3)]_n$	
Polyetrafluoroethylene	PTFE	9002-84-0	$(CF_2CF_2)_n$	
Polyamide (nylon)	PA	63428–84-2	$C2_3H_{26}N2O4$	
Polyurethane	PU	9009-54-5	$C_3H_8N_2O$	

Table 4.
Main polymers found in microplastics [32].

high-density HDPE, and low-density LDPE), polypropylene (PP), polyvinyl chloride (PVC), polyurethane (PUR), polystyrene (PS), and polyethylene terephthalate (PET). These six polymers make up about 80% of plastics production and are likely to form a large proportion of most marine litter (GESAMP, 2019). The most common human-produced and petroleum-derived polymers found in microplastics are listed in **Table 4**.

According to Lambert, et al. [16], "Microplastic" is an umbrella term that covers many particle shapes, sizes, and polymer types, and as such the physical and chemical properties of environmental microplastics will differ from the primary microbeads commonly used for ecotoxicity testing. In the **Figure 2** is presented the physical and chemical properties of MP, by concentrating particle size, particle shape, surface area and crystallinity, as well as chemical composition, while considering the type of polymer, additive compounds, and changes in surface properties) [16].

3.2 Legal and regulatory framework on MP

Microplastics are subdivided into two groups: primary microplastics and secondary microplastics [26]. The distinction between primary and secondary microplastics is based on whether the particles were originally manufactured to be that size (primary) or whether they have resulted from the breakdown of larger items (secondary) [44]. It is a useful distinction because it can help to indicate potential sources and identify mitigation measures to reduce their input to the environment. Primary microplastics include industrial 'scrubbers' used to blast clean surfaces, plastic powders used in molding, micro-beads in cosmetic formulation, and plastic nanoparticles used in a variety of industrial processes [44, 45]. In addition, spherical or cylindrical virgin resin pellets, typically around 5 mm in diameter, are widely used during plastics manufacture and transport of the basic resin 'feedstock' prior to production of plastic products. Secondary microplastics result from the fragmentation and weathering of larger plastic items. This can happen during the use phase of products such as textiles, paint, and tires, or once the items have been released into the environment [44]. The rate of fragmentation is controlled by several factors [46].

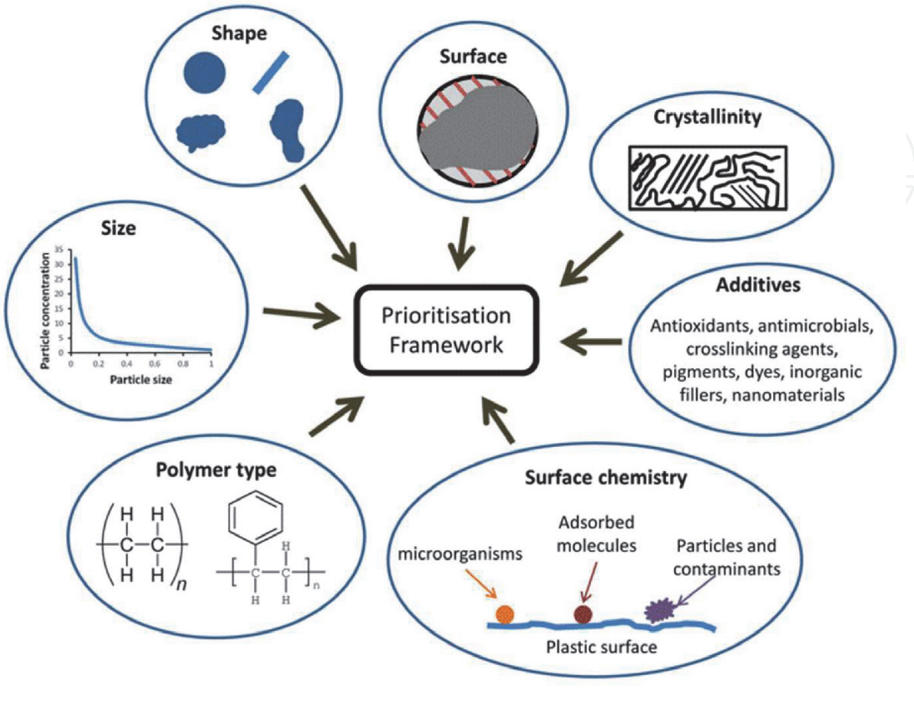


Figure 2.
Different microplastic physical and chemical properties to be considered in a prioritization framework [16].

Plastics can be lost to the environment across their entire value chain [47], which creates different opportunities (and challenges) to prevent leakage into technical and natural systems [48]. In this context, it is useful to frame the separate but interconnected issues of plastic pollution, which are nestled into one another [47]. A list of microplastic sources entering the environment is presented in **Figure 3**.

Some sources and pathways are interconnected (e.g., mechanical stress, plastic waste, plasticulture) and some sources are stand-alone (e.g., primary microplastics in products, targeted applications, or transportation losses), but collectively all sources are part of the puzzle of how microplastic enters the environment.

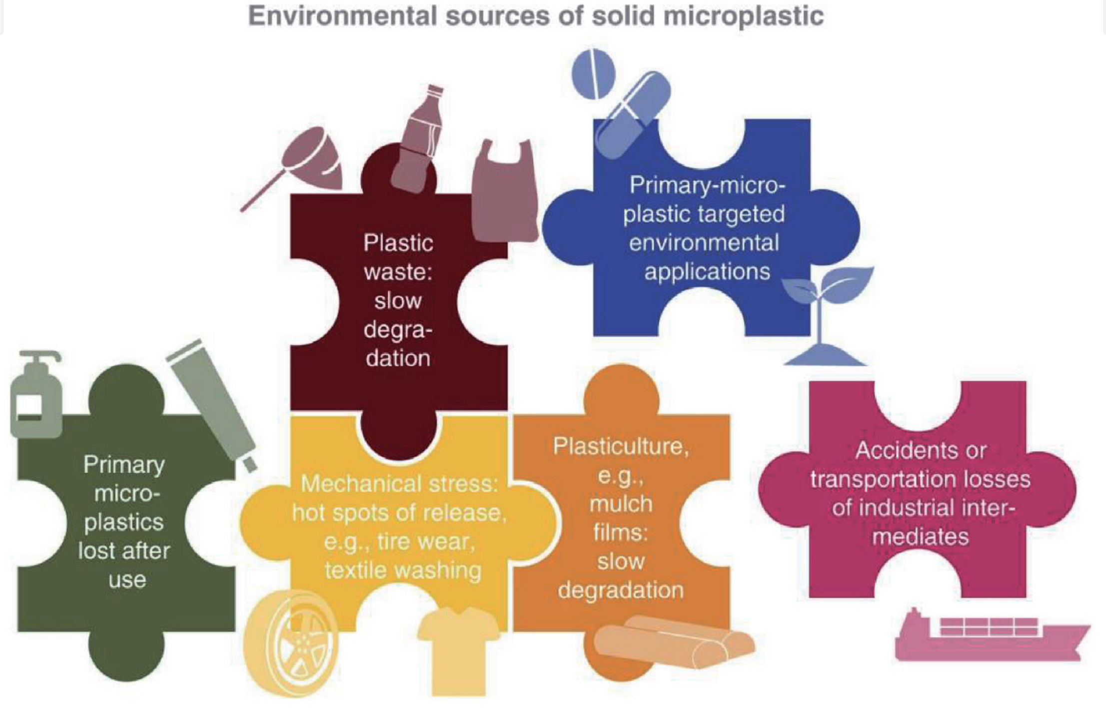


Figure 3.
Environmental sources of pollution by microplastic [47].

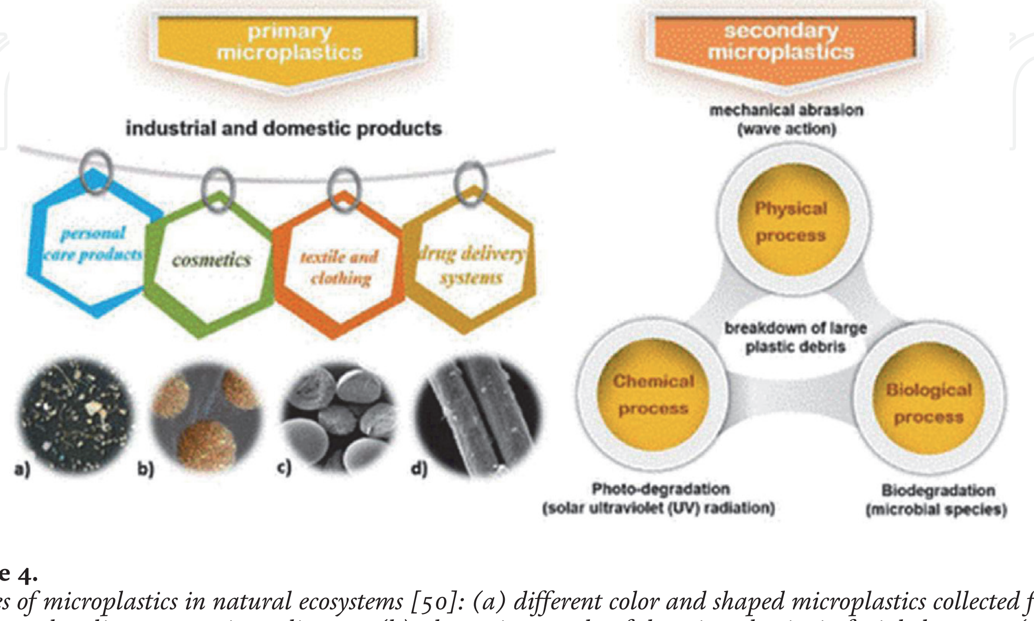


Figure 4.
Sources of microplastics in natural ecosystems [50]: (a) different color and shaped microplastics collected from seawater, shorelines, or marine sediments; (b) photomicrographs of the microplastics in facial cleansers; (c) scanning electron microscopy image of microbeads found in cosmetics; and (d) scanning electron microscopy image of a typical fiber from fabric [50].

Microplastics in the environment are generally supposed to be a heterogeneous aggregate of particles, which can be of both primary and/or secondary origins. However, whatever the group to which they belong, depending on their physical and chemical properties, the size and shape of the particles, the crystallinity, the surface chemistry and the composition of the polymers and additives, the toxicity of microplastics can be crucial for the environment [49]. In a critical review on the sources and instruments of microplastics in marine ecosystems, Wang & al [50] present a figure in which the landbased origins of primary and secondary MP are well explained (**Figure 4**).

Although there is no specific international marine legislation regarding microplastics so far, many proactive countermeasures have been taken – voluntary or legally binding practices at international, regional, and national levels [47]. Indeed, the available literature on marine pollution reports the existence of three global international conventions that deal with the problem of plastic waste in the marine environment at the beginning of the 1970s: (i) the United Nations Convention (UN) on the Law of the Sea [51], (ii) the International Convention for the Prevention of Pollution from Ships (1973) as amended by the Protocol of 1978

International instruments	Period	Specific contents
United Nations Convention on the Law of the Sea	1982	Part XII (Articles 192–237): protection and control of marine pollution from sea−/ land-based sources
MARPOL 73/78	1973	Annex V prohibits "the disposal into the sea of all plastics, cargo residues, fishing gear including but not limited to synthetic ropes, synthetic fishing nets and plastic garbage bags". (revised in 2011 and come into force in 2013)
London Convention	1972	To prevent the "deliberate disposal at sea of wastes and other matter from vessels, aircraft and other structures, including the vessels themselves". (Annex I, paragraph 2)
London Protocol	1996	To prohibit the dumping of any wastes or other matter including the export of waste to countries for dumping and incineration at sea except for the materials listed in Annex I. (Article 4.1.1, 5 and 6)
Basel Convention	1989	Include plastic waste and microplastics issues into the Basel Convention workstream at COP 13 (Plastic waste in Annex II Y 46 (Household wastes) and Annex VIII (Non-hazardous wastes))
United Nations Environment Programme – Regional Seas Programme and Global Programme of Action	2003	Regional activities in 12 regional seas
Manila Declaration	2012	Prevent marine litter from land-based sources and agree to establish a Global Partnership on Marine Litter (GPML)
G7 Summit	2014	G7 Marine Litter Action Plan
G20 Summit	2017	G20 Marine Litter Action Plan
United Nations Environment Assembly (UNEA) I	2014	Resolutions 1/6: put forward the issue of "Marine plastic debris and microplastics".
UNEA II	2016	Resolutions 2/11: measures to reduce marine plastic litter and microplastics
UNEA III	2017	Resolutions 3/7: combating the spread of marine plastic litter and microplastics.

Table 5.
Overview of current legislation, regulations and instruments related to microplastics [50].

(MARPOL 73/78) [52] and (iii) the Convention for the Prevention of Pollution by Dumping of Wastes and Other Matter (London Convention or LC, 1972) [53].

Table 5 shows an overview of current legislation, regulations and instruments related to microplastics. Considering the abundance of microplastics in the environment, their ability to absorb pollutants, their impact on living organisms, the health and environmental authorities in several countries have applied the precautionary principle by adopting a legal framework on MP. However, uncertainties and gaps in the evidence regarding the effects of microplastics on the environment and on human health prevent the adoption of more restrictive measures, with the precautionary principle - in line to the World Trade Organization (WTO) obligations on international trade - only playing a minor role [54]. Available information on current regional and national instruments related to microplastics is discussed in Wang & al. [50].

4. Impact of microplastics on living organisms in natural ecosystems

The global plastics production has increased from 1.5 million tons in the 1950s to 335 million tons in 2016, with plastics discharged into virtually all components of the environment [55]. The MPs present in the environment result from the successive breakdown of larger plastic pieces or from the direct input of micro- and nano-sized particles used in various industries and products available to consumers [56]. Indeed, during their production, industrial and domestic use, and after such processes, a considerable part of the plastics produced globally end up in the environment. Moreover, Plastics rarely biodegrade but through different processes they fragment into microplastics and nanoplastics, which have been reported as ubiquitous pollutants in all marine environments worldwide [55]. In fact, plastics represent one of the fastest-growing portions of the urban waste contributing to environmental contamination and pollution, with plastic debris accounting for approximately 60–80% of all marine litter, reaching 90–95% in some areas [55, 57–59].

4.1 Environmental occurrence

According to Lambert et al. [5] "Upon their release to the environment MPs are transported and distributed to various environmental compartments. The distances that an individual item will travel depends on its size and weight. Lightweight materials can be readily transported long distances via a windblown route or carried by freshwater to eventually accumulate in the oceans. During heavy rainfall events, roadside litter can be washed into drains and gullies, and, where the topography is favorable for it, can be carried to the sea". **Figure 5** shows a conceptual model illustrating degradation pathways for polymer materials [5].

Once in the environment MPs are degraded through abiotic or biotic factors working together or in sequence; these processes cause the polymer matrix to disintegrate, resulting in the formation of fragmented particles of various sizes and leached additives [5]. According to Lambert et al. [5] "there is a broad literature dealing with the degradation of various polymer types under various conditions. Most of these studies were performed in the laboratory and had a major focus on samples exposed to high-energy UV irradiation".

In the environment, MPs constitute a matrix of pollutants, composed of several monomers and polymers (PE, PP, EPS, PET, PMMA, PTFE, PA, PU, etc.), metal catalysts, additives: phthalates, retardants. Flame, bisphenols A and F, etc.), loading materials (talc, Ti dioxide), adsorbed environmental pollutants (organic and

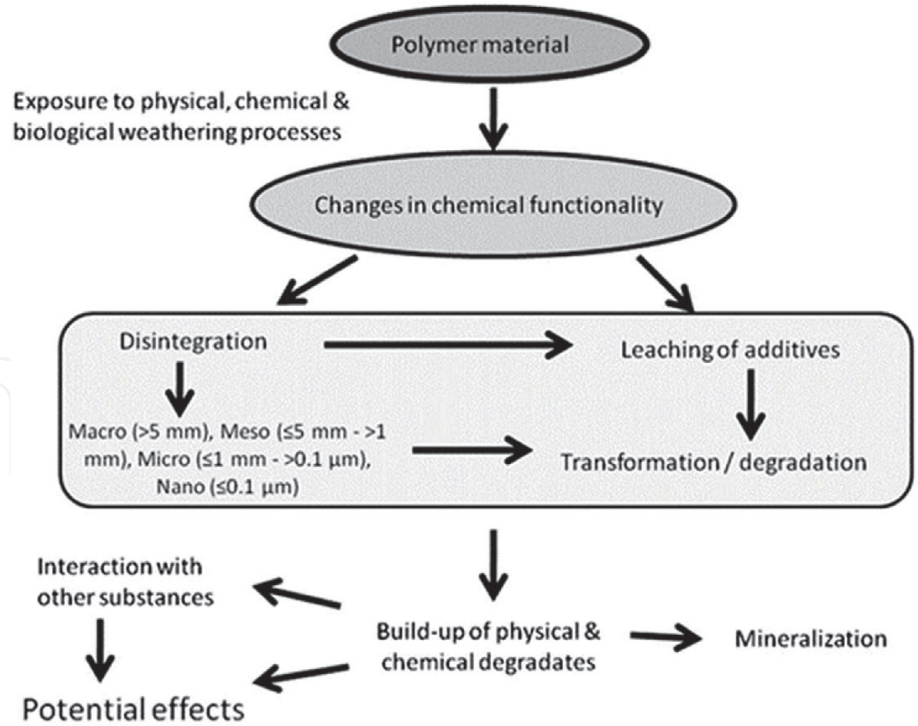


Figure 5.
Conceptual model illustrating degradation pathways for polymer materials [5].

inorganic, pathogenic agents, etc. The exposure of living organisms to MPs leads to consider the interactions between the combined effects of different pollutants. The characterization of exposure to microplastics will depend on: (i) the number of particles; (ii) size distribution, shape, surface properties, polymer composition and particle density; (iii) the duration of the exposure; (iv) the kinetics of absorption and desorption of contaminants, vis-à-vis the plastic and the organism; and (v) the biology of the organism [44].

4.2 Environmental effects

Microplastics have been detected in sediments, surface waters, estuarine and marine waters [60–62]. The negative effects of microplastics on algae, mussels, fish, and other organisms have been the subject of several studies and have shown [20, 63–66]. Given the difficulty for large filter-feeding organisms (fins, whales, ..) and zooplankton to differentiate between microplastics and food itself [27, 67], cellular intoxication has been documented by ingestion by inadvertently adhered microplastics with other pollutants [26, 25]. Flame retardants (chemicals derived from plastics) have been found in birds [29] and phthalates in whales and filter-feeding sharks [27]. Microplastics can affect growth and reproduction in daphnids [28].

Alimba and Faggio [55] observed effects of MPs on marine vertebrates and invertebrates, including asphyxiation by drowning, restricted diet and increased starvation, skin abrasions and skeletal injuries (which are the basis of intestinal mucosal damage, morbidity, and mortality), oxidative stress, altered immunological responses, genomic instability, endocrine disruption, neurotoxicity, reproductive abnormalities, embryotoxicity and transgenerational toxicity [55].

Present in an environment, MPs can mimic the natural food sources of living species [5]. 135 species of marine vertebrates and 8 species of invertebrates susceptible to entanglement, and 111 species of seabirds have been identified, among others, among the species that ingest plastic objects [67]. Other studies have shown that MPs wrapping loops are a threat to sea lions in California and fur seals in Australia, respectively [68, 69]. Plastic bags have been identified as the main type of debris ingested by sea turtles [70]. **Figure 6** shows a conceptual model illustrating the potential effects produced during the degradation of polymer-based materials [5].

4.3 Potential effects of microplastics on human health

The primary route of human exposure to MPs is the ingestion of foodstuffs, in particular seafood which has ingested microplastics [30], processed commercial fish [71], sea salt [72], honey [73], beer, food components [73]. Most of these food products are sometimes contaminated by the presence of impurities in processing materials and contaminants in packaging [74]. The second route of exposure is inhalation of air and dust containing MPs [30]. Due to their nutritional value, seafood plays an important role in human nutrition. Indeed, the consumption of seafood represents 6.7% of all protein and about 17% of animal protein in 2015 [75]. The risk of exposure is therefore great and increases with small fish eaten whole [46].

Several studies have highlighted the evidence for the presence of microplastics in several commercial aquatic species such as mussels, oysters, crabs, sea cucumbers and fish [76–78]. The results of this work suggest that humans are exposed to microplastics through their diet and the presence of microplastics in seafood could pose a threat to food safety [76]. The potential accumulation of microplastics in the food chain, especially in fish and shellfish (species of mollusks, crustaceans, and echinoderms) could have consequences for the health of human consumers [44]. In this trophic context, the fate and toxicity of microplastics in humans constitutes a major lack of knowledge which deserves special attention. The potential

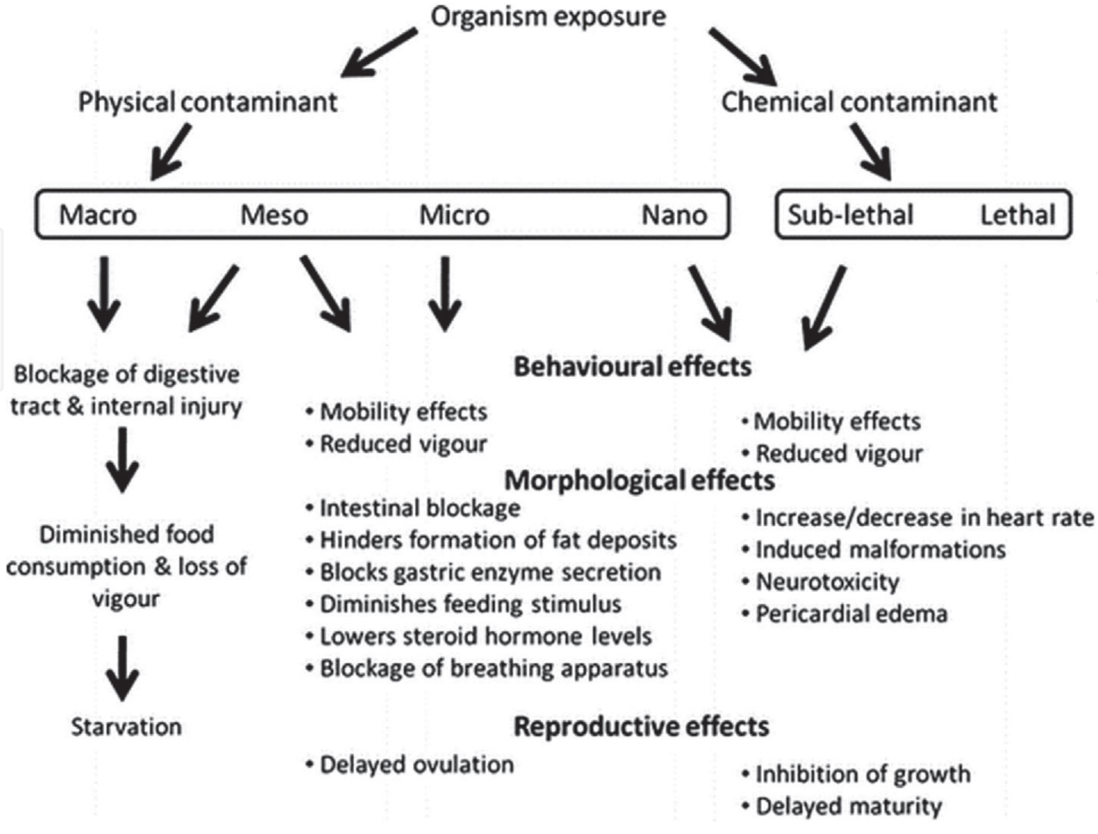


Figure 6.
Conceptual model illustrating the potential effects produced during the degradation of polymer-based materials [5].

accumulation of microplastics in food chains, particularly in fish and crustaceans (mollusks, crustaceans, and echinoderms), appears to be the main source of human exposure to microplastics [44]. Contamination of food products with MP could have consequences for the health of human consumers. In this trophic context, the fate and toxicity of microplastics in humans constitutes a major lack of knowledge which deserves special attention.

The translocation of microplastics from the intestine to the circulatory system and various tissues and cells in humans has been studied by several authors [44]. Indeed, Hussain et al. [79] have shown the absorption of PE particles captured in the lymph and the circulatory system from the gastrointestinal tract. Exposure of human macrophages to fluorescent microspheres of PS (1, 0.2 and 0.078 μm), demonstrated particle capture driven by non-endocytic processes (diffusion or adhesive interactions) [44].

5. Waste management, environmental pollution, microplastics and loss of biodiversity in Port-au-Prince

5.1 The issue of solid waste in Port-au-Prince

Urban cleanliness and its variations over time reflect the aspects of each civilization, […], the capacity of societies to legislate, to mobilize techniques and to organize the complexity of urban services [80]. In developing countries (DCs), however, the issue of urban cleanliness a priori highlights the weakness of urban managers and institutions in terms of their capacity to manage the growing and very heterogeneous flow of waste produced [81].

In Port-au-Prince, the capital of Haiti, solid waste management is practiced in a context of rapid population growth and extreme urban poverty [82]. Indeed, urban cleanliness and its variations over time highlight a clear discrepancy between the objective of the waste management service (making and maintaining the city clean) and the realities on the ground. The combination of the low rate of garbage collection and high human densities accentuates unsanitary conditions in the city and represents a risk factor not only in terms of human health but also of the environment. Also, vacant spaces, voids in the urban fabric of Port-au-Prince very quickly become public landfill spaces [81]. In this urban space, notes Lacour [83], urban cleanliness is established in the mix of most urban waste management systems where state and private services coexist, as well as public funds and international funding, through development organizations. In addition, the negative impacts (pollution, nuisance, proliferation of rodents and insects, risk of disease, etc.), linked to the size, nature, and unsuitable management methods of organic waste (landfill with other categories, combustion, etc.), are generally very pronounced [83].

The characteristics of the waste management system in Haiti have been defined as follows [84]:

- “At source, the general behavior tends to immediately remove unsorted waste. Consequently, the nearest (common) public space becomes the preferred outlet. This reflex is particularly predominant in rural and peri-urban areas and the precarious neighborhoods of so-called “low-standing” urban areas.

- The existence of an informal circuit, said to be rather pragmatic, compensates for the absence of an institutional waste management service in rural areas or the dysfunction of this service in urban areas. This circuit is characterized by a pre-collection by voluntary contribution, an individual (rural and peri-urban) or private (urban "medium standing" and "high standing") collection, waste disposal in non-dedicated spaces (vacant lots, gullies, etc.) spontaneously transformed into wild dumps.

- The total absence of a landfill site that meets environmental standards, in terms of waste categorization, development work for the control of discharges and the recovery of leachate and biogas, odor management, animal control, etc.

- The practices of recycling organic waste, by feeding pets and livestock (free and rope) are quite frequent at the level of pre-collection and collection points.

- The lack of information relating to the deposits of waste, in terms of their masses, their compositions and their bio-physico-chemical characteristics, through the seasons and rural, peri-urban and urban spaces, constitutes an obstacle to the implementation, the monitoring and anticipation of management strategies" [84].

5.2 The issues of plastic waste and microplastics in Port-au-Prince

According to the World Bank (2019) [85], in the Caribbean and elsewhere in the world, marine pollution is linked to poor waste management on land: illegal dumping, open burning or dumping of waste in streams. In addition, the quantity of plastics reaches a concentration of 200,000 pieces of debris per square kilometer in the northeast of the Caribbean. In this region of the world, about 85% of wastewater is discharged into the ocean without having been previously treated; and, in island countries more particularly - Bahamas, Greater Antilles (Cuba, Dominican Republic, Haiti, Jamaica and Puerto Rico) and Lesser Antilles - approximately 52% of households are not connected to sewers. However, 14 Caribbean countries (more than a third) have banned single-use plastic bags and / or styrofoam containers (**Figure 7**).

In Haiti, the government issued on August 9, 2012, a decree prohibiting the production, import, marketing, and use, in any form whatsoever, of polyethylene bags and expanded polystyrene objects (PSE or PS or Styrofoam) for single food

Figure 7.
Caribbean countries that have banned single-use plastic bags and/or expanded polystyrene containers [85].

use, such as trays, trays, bottles, sachets, cups and plates. On July 10, 2013, a second decree was issued to ban once again "the importation, production or sale of expanded polystyrene articles for food use". In support of the second decree, the ministries of the Environment, Justice and Public Security, Trade, and Industry as well as Economy and Finance announced in a note published in January 2018 that brigade's specialists will be deployed on the territory to force the application of the said decree.

To better approach the problem of plastic and microplastic waste management in Port-au-Prince, it is important to look at the waste management system. In Haiti, the National Solid Waste Management Service (*Service National de Gestion des Résidus Solides* (SNGRS)). This public institution has the status of an autonomous body, and an authority which extends over the entire territory of the country.

In the agglomeration of Port-au-Prince, there is a single space that has been officially designated to receive any type of waste. Due to the insufficient capacity of public actors to collect all waste, it ends up in different types of space according to different logics [86]. The uncontrolled presence of waste induces a certain number of potential nuisances. It is therefore necessary to consider the health risk classically associated with waste [87], as a vector of pathology and contamination of natural resources [86]. Beyond the environmental dangers generated by chemical substances and pathogenic microorganisms present in solid waste, the latter not only obstruct traffic routes, but are also a source of flooding by blocking irrigation canals and gullies (**Figure 8**).

Port-au-Prince's marine ecosystem is liable to suffer locally profoundly serious damages caused by the direct discharge of urban effluents [88]. Indeed, the discharge of contaminants in natural ecosystems, by example water bodies pose a significant concern to water quality and to the health of aquatic organism because of not only the varied types of pollutants that impact these systems, also because of the many ways pollutants can affect the health of aquatic organism [89].

With the tropical temperature of Haiti and the average daily duration (12 hours / day), the plastics present in the urban water canals could degrade more quickly by generating microplastics. Their discharge in the bay of Port-au-Prince exposes this ecosystem to environmental dangers [90], that of pollutants contained in wastewater, and that of climatic hazards, in particular the acidification of the oceans. The stress of benthic organisms (coral reefs, bivalves) should then be observed and monitored.

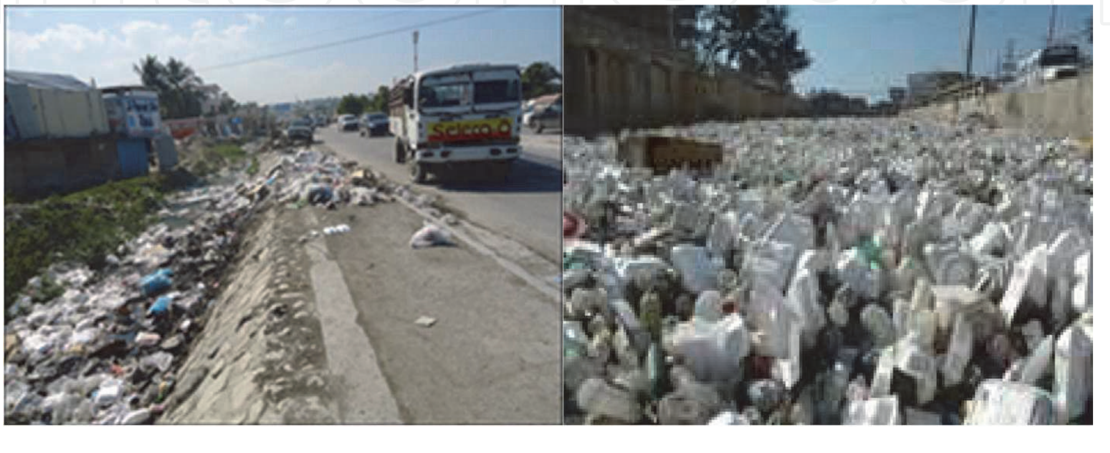


Figure 8.
Uncontrolled presence of waste in public spaces in Port-au-Prince. (left illustration - unauthorized deposit of household waste along a road [86]. Right illustration - unauthorized deposit of PSE or PS or Styrofoam waste in the largest urban water collector in Port-au-Prince).

6. Conclusion

The presence of microplastics in the environment first and foremost generates environmental health hazards, which need to be increasingly identified and assessed. Most of the research in the field of environmental pollution from microplastics has been carried out on aquatic ecosystems. There then arises the need to initiate research programs on terrestrial ecosystems.

The future of MPs in the environment represents real research challenges. Indeed, there is a lack of knowledge at the local and national level of the different flows. At the global level, the toxicological reference values have not yet been obtained. Human dose–response relationships need to be investigated on the basis of still possible animal species exposures.

The field of environmental assessment of MPs, in the Caribbean for example, a priori calls for transdisciplinary approaches. Indeed, this region of the world, thanks to its tropical climate and the Caribbean Sea, makes tourism one of its main development niches. Pollution from plastic waste exposes its economy to a risk of economic imbalance. In the case of Haiti, beyond the urgent need to review its public policies in terms of urban water and solid waste management, the pollution of ecosystems by MPs highlights the need to initiate real research work. in the field of marine ecotoxicology.

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Author details

Daphenide St. Louis[1,2,3], Ammcise Apply[1,2,4], Daphnée Michel[1,2,3] and Evens Emmanuel[3,4]*

1 Faculté des Sciences de la Santé, Programme de Maîtrise en Santé Publique, Université Quisqueya, Port-au-Prince, Haiti

2 Association Haïtienne Femmes, Science et Technologie (AHFST), Port-au-Prince, Haiti

3 Équipe de Recherche sur la Santé-Environnement (Ci-devant Laboratoire Santé-Environnement (LS-E)), Université Quisqueya, Port-au-Prince, Haiti

4 Équipe de recherche sur Changements Climatiques (ERC2), Université Quisqueya, Port-au-Prince, Haiti

*Address all correspondence to: evens.emmanuel@uniq.edu.ht

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