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REVIEW ARTICLE

Public and Environmental Health Effects of Plastic Wastes Disposal: A Review

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Abstract

Since 1950 to 2018, about 6.3 billion tonnes of plastics have been produced worldwide, 9% and 12% of which have been recycled and incinerated, respectively. Human population increase and consistent demand for plastics and plastic products are responsible for continuous increase in the production of plastics, generation of plastic waste and its accompanied environmental pollution. We have reviewed in this paper, the most relevant literatures on the different types of plastics in production, the hazardous chemical constituents, prevailing disposal methods and the detrimental effects of these constituents to air, water, soil, organisms and human health viz-a-viz the different disposal methods. Papers that reported environmental and public health effects of plastic constituents but not plastics directly were also reviewed. Varieties of plastics used in the production of many consumable products including medical devices, food packaging and water bottles contain toxic chemicals like phthalates, heavy metals, bisphenol A. brominated flame retardants, nonylphenol, polychlorinated biphenylethers, dichlorodiphenyldichloroethylene, phenanthrene etc. An estimated 8 million tonnes of plastic is yearly released into the ocean, leading to degradation of marine habitat which eventually affects aquatic organisms. Long term usage and exposure of plastics and plastic products to high temperature can lead to leaching of toxic chemical constituents into food, drinks and water. Indiscriminate disposal of plastics on land and open air burning can lead to the release of toxic chemicals into the air causing public health hazards. This paper also presents recommendations for global prevention and control of plastic wastes.

Keywords

Plastic waste, Environmental contamination, Pollution, Public health, Toxic chemicals

Introduction

Plastics are made up of synthetic organic polymers which are widely used in different applications ranging from water bottles, clothing, food packaging, medical supplies, electronic goods, construction materials, etc [1]. In the last six decades, plastics became an indispensable and versatile product with a wide range of properties, chemical composition and applications. Although, plastic was initially assumed to be harmless and inert, however, many years of plastic disposal into the environment has led to diverse associated problems. Environmental pollution by plastic wastes is now recognized widely to be a major environmental burden [2,3], especially in the aquatic environment where there is prolong biophysical breakdown of plastics [4,5], detrimental negative effects on wildlife [6,7], and limited plastic removal options [5,7,8].

In many instances, sheeting and packaging plastics are disposed of after usage, however, because of their durability, such plastics are located everywhere and persistent in the environment. Research on the monitoring and impacts of plastic wastes is still at the infancy stage, but thus far, the reports are worrisome. In human occupational and residential environment, plastics made of petrol-based polymer are present in high quantity. At the end-of-life of these plastics, they are usually land-filled together with municipal solid waste. Plastics have several toxic constituents among which are phthalates, poly-fluorinated chemicals, bisphenol A (BPA), brominated flame retardants and

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antimony trioxide which can leach out to have adverse effects on environmental and public health. Plastics in electronic waste (e-waste) have become a serious global environmental and public health concern due to its large production volume and the presence of inadequate management policies in several countries. Reports from China, Nigeria, and India indicated that plastic hazardous substances from e-wastes can migrate beyond the processing sites and into the environment [9-11].

Global Production of Plastics and Generation of Waste

In modern life, plastics are ubiquitous. Its early usage dated back to 1600 B.C., at the time when human hands shaped natural rubber and polymerized into different useful objects in prehistoric Mesoamerica [12]. Diverse usage and manufacturing of plastics and plastic products began in 1839 when polystyrene (PS) and vulcanized rubber were discovered [13]. Production of bakelite which is the first truly synthetic polymer was in 1907 in Belgium [14], however, by 1930, bakelite was everywhere, especially in fashion, communication and electrical and automotive industries [15]. It took a decade after this for mass production of plastics to begin and it has constantly expanded ever since.

As at 2008, the annual plastic production was estimated to be 245 million tons globally [16]. At present, single-use packaging is the largest sector, accounting for almost 40% of the overall plastic usage in Europe [17], this is followed by consumer goods, materials for construction, automotive, electrical and agriculture applications at 22%, 20%, 9%, 6% and 3%, respectively [15]. It was estimated in 2015, that the highest rate of production is in Asia (with 49% of total global output, with China as the largest world producer (28%), followed by North America and Europe at 19% each. In terms of production, the rest regions are of lesser importance although not necessarily in terms of plastic consumption [15].

Current World Production Rate of Plastics

Globally, plastic production was estimated to be 380 million tonnes in 2018. Since 1950 to 2018, plastics of about 6.3 billion tonnes have been produced worldwide, 9% and 12% of which have been recycled and incinerated, respectively [18]. Plastics of about 5 million tonnes are yearly consumed in UK alone, with only about one-quarter recycled, and the rest landfilled. It has been suggested by researchers that by 2050, oceans might contain more plastics than fish in terms of weight [19]. Yearly, approximately 500 billion plastic bags are used out of which an estimated 13 million tonnes ends up in the ocean, killing approximately 100,000 marine lives [18].

Future Projection of Production of Plastic

Plastic productions has increased in twenty-fold since 1964. Globally, approximately 311 million tonnes of plastics were produced in 2014, expected to double in about 20 year time and possibly quadruple by 2050 [20]. International Energy Agency World Energy Outlook in 2015 estimated that, the largest application, plastic packaging (26% of the overall volume), is envisaged to have continuous strong growth, which might double within 15 years, with a possibility of fourfold increase by 2050, to about 318 million tonnes yearly, which is higher than the whole plastic industry today.

Plastic Types

There are different types of plastics based on

Table 1: Types of plastics, their properties and common uses.

Symbols	Types of plastics	Common uses	Properties	Recycled into
1 PETE	Polyethylene terephthalates	Soft drinks, water bottles, containers, salad dressing, biscuit trays and salad domes.	Clear, tough, solvent resistant, barrier to gas and moisture, softens at 80 °C.	Pillow and sleeping bag filling, clothing, soft drink bottles, carpeting, building insulation
2 HDPE	High density polyethylene (HDPE)	Shopping bags, freezer bags, buckets, shampoo, milk bottles, ice cream containers, juice bottles, chemical and detergent bottles, rigid agricultural pipe, crates.	Hard to semi-flexible, resistant to chemicals and moisture, waxy surface, opaque, softens at 75 °C, easily coloured, processed and formed	Recycling bins, compost bins,
3 V	Polyvinyl Chloride (PVC)	Cosmetic container, plumbing pipes and fittings, electrical conduct, blister packs, wall cladding, roof sheeting, bottles, garden hose, Shoe soles, cable sheathing, blood bags and tubing.	Strong, tough, softens at 80 °C, can be clear, can be solvent welded.	Compost bin
	Plasticized Polyvinyl chloride PVC-P.		Flexible, clear, elastic, can be solvent welded.	

4 LDPE	Low density polyethylene (LDPE)	Refuse bags, Irrigation tubings, mulch film, cling wrap, garbage bags, squeeze bottles.	Soft flexible, waxy surface, translucent, softens at 70 °C, scratches easily.	Bin liners, pallet sheets
5 PP	Polypropylene (PP)	Microwave dishes, lunch boxes, packaging tape, garden furniture, kettles, bottles and ice cream tubs, potato chip bags, straws	Hard and translucent, soften at 140 °C, translucent, withstands solvents, versatile.	Pegs, bins, pipes, pallet sheets.
6 PS	Polystyrene (PS) Expanded polystyrene (PS-E)	CD cases, plastic cutlery, imitation glassware, low cost brittle toys, video cases/foamed polystyrene cups, protective packaging, building and food insulation	Clear, glassy rigid, opaque, semi-tough, soften at 95 °C, Affected by fat, acids and solvents, but resistant to alkalis, salt solutions, Low water absorption, when not pigmented is clear, is odour and taste free. Special types of Polystyrene (PS) are available for special applications.	Recycle bin
7 OTHER	Other	Automotive and appliance components, computers, electronics, cooler bottles, packaging	Includes all resins and multi-materials (e.g. laminates) properties dependent on plastic or combination of plastics	Recycle bins

Source: [21].

their constituents and type of materials used in their production. Table 1 shows the different types of plastics, their properties and common uses [21].

Polyethylene Terephthalate (PET)

Polyethylene terephthalate (PET) is a type of plastic which is smooth, transparent and relatively thin. It is also called stomach plastics. PET is commonly used during disposable salad dressing, juice, mouthwash, vegetable oil, cosmetics, soft drinks, margarine and water bottles production, because it is anti-inflammatory and fully liquid. PET is also anti-air, preventing entrance of oxygen into it [1]. Antimony trioxide, an inorganic compound, is used as a catalyst for the production of PET and rubber vulcanization [18]. Plastics made from PET must be prevented from high temperatures so as to prevent the leaching of some toxic additives such as acetaldehyde, antimony and phthalates. Antimony is a possible human carcinogen [1]. Generally, PET is manufactured for single use only [1].

High-density polyethylene

Worldwide, the most used plastic is polyethylene. High-density polyethylene is a heat-resistant plastic produced from petroleum. It is a major constituent of refrigerators, detergent bottles, toys, milk containers, varieties of plastic grocery bags, etc. No phthalates or BPA is present in high-density polyethylene. High-density polyethylene container is generally considered safe for drink and food because it has no reported health risk even though some studies showed that a long time exposure of the plastics to sunlight can make it harmful [1].

Polyvinyl Chloride (PVC)

Polyvinyl Chloride (PVC), a type of heat-resistant polymer, is used for packaging fruit juice, cooking oil, etc. PVC is considered highly toxic due to the presence of chemical constituents like heavy metals, dioxins, BPA and phthalates. Depending on non-plasticization, PVC is flexible due to the presence of phthalates. Phthalates are harmful to humans. The entire PVC life cycle which include the production, usage and disposal are capable of causing severe environmental and public health risks, hence, its usage has considerably reduced. However, due to cost-effectiveness and versatility, PVC remains very popular in the production of consumer goods. PVC have been reported to cause chronic bronchitis, birth defects, genetic changes, cancer, skin diseases, deafness, vision failure, ulcers, liver dysfunction and indigestion [1].

Low-density polyethylene

Low-density polyethylene is heat resistant, fragile, flexible and rigid. It is commonly used in packaging of milk, frozen foods and juices. Because the plastic does not have any component that is harmful to human body, its usage is termed safe for beverages and food [1].

Polypropylene

Polypropylene, a type of plastics, is strong and semi-transparent. It is heavier and stronger than polyethylene. It is used for packaging medicine, yogurt, ketchup, beverage, etc. Plastics made of polypropylene have no harmful substances and like polyethylene, polypropylene containers are considered safe for humans as packages for food and beverages [1].

Polystyrene

Polystyrene, a type of petroleum-based plastic, contains benzene which is carcinogenic to humans [1]. Polystyrene is commonly used in the production of insulators and packaging materials. Products from styrene are hazardous to health. Report of Dowty, et al. [22] showed that a long-term exposure to small quantity of styrene can be neurotoxic and causing cytogenetic, carcinogenic and hematological effects. The International Agency for Research on Cancer (IARC) has categorized styrene as a human carcinogen [1].

Polycarbonate

Polycarbonates are used for packaging consumer goods such as reusable bottles. It contains BPA. Due to exposure to high temperature, BPA can be leached from polycarbonated container into the drink or food stored in them. Because BPA's health risk has been reported in several studies, the usage of polycarbonated plastics have greatly decreased [1].

Size of plastics: Macro and microplastics

Size of plastics can be used for their classification, aside the plastic types and their chemical composition. There are two major classification of plastics at sea: 1) Macro (these are plastics higher 20 mm in diameter) and; 2) Micro (plastics which are less than 5 mm in diameter) plastics. Of these two plastic sizes, the microplastics are the major pollutants documented for deteriorating the ecosystem. This microplastics are either produced by design and are called primary microplastics, or they are formed as a result of degradation of macroplastic called secondary microplastics [23,24].

The major issues in plastic waste centered around the microplastics due to an increase difficulty in their monitoring and a greater effect at the physical and chemical levels on environmental and public health, because of their higher volume-to-surface area ratio [25]. Inadequate waste management and indiscriminate dumping are the major routes of entry of microplastics into the marine environment [26]. Direct production of microplastics such as plastic pellets is common, as such are used in fabricating larger items as raw material, however, microplastics can also be produced through mechanical disintegration of larger plastics or plastic products. This is the case in the breakdown of plastic ropes to finer filaments such as microfibers.

Environmental release of large quantities of microplastics is in form of cosmetic products and cleaning ingredients such as toothpaste and microbeads in face-wash. Because of the health effects of microplastics, countries like Canada, USA and others are now phasing out their usage in certain personal care products. Reports of recent research suggest that the detrimental effects of microplastics especially microbeads, micro plastic fibres and degraded macroplastics in aquatic environment might be higher than that of macroplastics [27-29], although studies and legislations to manage plastic pollution are still inadequate.

Management of Plastic Wastes

Landfilling

Approximately 10% of household waste is plastics and mostly end up on the landfill [30]. Even though landfilling is the commonest waste management conventional approach in many countries, however, scarcity of space for landfills is becoming a major problem. For example, historically, landfilling was attractive in the UK because it is relatively cheap and simple without necessarily requiring treatment, cleaning or separation. In 1999, 65% (8.4 million tonnes per annum) of the overall household waste recoverable plastics were sent to landfill in Western Europe [31], but at present in the UK, plastic waste landfilling is the least favoured waste management option. There is a growing environmental and public health concern about the potential effects of landfills because of the types and quantities of toxic chemicals and their potential for leaching at landfill sites [32]. It is now a government policy in the UK to reduce the amount of wastes landfilled (e.g. Landfill Directive European Commission 1999/31/EC) which has been difficult to materialize as an estimated 60% of England's municipal wastes is still sent to the landfills compared to an estimated of 20% and 37% in Germany and France, respectively [33].

Environmental pollution and risks to public health can be reduced if the landfills are well-managed, although there are possibilities of soil and groundwater contamination by disintegrated plastic byproducts and additives that can persist in the environment on long-term basis [34,35].

Plastic incineration

An alternative to landfilling of plastic waste is incineration, but growing concerns exist about the potential atmospheric release of hazardous chemicals during the process. For instance, plastic waste fumes release halogenated additives and polyvinyl chloride, while furans, dioxins, and polychlorinated biphenyls (PCBs) are released from incineration of plastics into the environment [36]. The disadvantage of combustion of plastics is the air pollution caused by the noxious fumes released into the atmospheres. The combustion heater of the flue systems is permanently damaged by plastics during plastic incineration and the products of this plastic combustion are detrimental to both humans and the environment. Compounds of low molecular weight can vaporize directly into the air thereby polluting the air and based on their varieties, some may form a combustible mixture, while others may oxidize in solid form.

Incineration of plastics is usually accompanied with

Table 2: Compounds generated during the incineration of polyvinylchloride and their harmful effects.

Compound	Health effect(s)
Acetaldehyde	It damages the nervous system, causing lesions.
Acetone	Irritates the eyes, the respiratory tract.
Benzaldehyde	Irritates the eyes, skin, respiratory system, limits brain function.
Benzole	Carcinogenic, adversely effects the bone marrow, the liver, the immune system.
Formaldehyde	Serious eye damage, carcinogenic, may cause pulmonary oedema.
Phosgene	Gas used in the WWI. Corrosive to the eyes, skin and respiratory organs.
Polychlorinated dibenzo-dioxin	Carcinogenic, irritates the skin, eyes and respiratory system. It damages the circulatory, digestive and nervous system, liver, bone marrow.
Polychlorinated dibenzofuran	Irritates the eyes and the respiratory system, causes asthma.
Hydrochloric acid	Corrosive to the eyes, the skin and the respiratory tract.
Salicyl-aldehyde	Irritates the eyes, the skin and the respiratory tract. It can also affect the central nervous system.
Toluene	Irritates the eyes and the respiratory tract, can cause depression.
Xylene	Irritates the eyes. It can also affect the central nervous system, reduces the level of consciousness and impairs learning ability.
Propylene	Damages the central nervous system by lowering of consciousness.
Vinyl chloride	Carcinogenic, irritating to eyes, skin and respiratory system. Effect on the central nervous system, liver, spleen, blood-forming organs.

Source: Nagy and Kuti [36].

the formation of chark, and the coking extent is dependent on the conditions of incineration [37]. Gaseous release in the process of plastic and plastic composite products incineration are very dangerous. For example, Table 2 shows the compounds release during the incineration of PVC and the health effects of these compounds. In the process of incineration of plastics, soot, ashes and different powders are produced, which eventually settles on plants and soil, with the potential to migrate to the aquatic environment. Rainfall can make some of these toxic compounds to sink into the soil, contaminate the ground water or absorbed by plants growing on this soil, thus, becoming incorporated into the food chain. Some of these plastic incineration products can chemically react with water and the resulting compounds can alter the pH thereby change the functioning of aquatic ecosystems.

Due to the potential pollution impact on the environment, plastic incineration is less employed for waste management in comparison to recycling and landfilling. Notable exceptions to this are European countries like Sweden and Denmark, as well as Japan, with massive incinerator facilities for managing municipal solid waste including plastics. However, countries like Hungary has enacted regulations, 29/2014. (XI. 28.) Regulation of the Ministry of Agriculture on waste incineration, which allow for only licensed plastic waste incineration plants to incinerate plastics, while all other forms of burning plastic waste are banned [37]. An advantage of plastic incineration is the recovery of energy from the plastic wastes [30].

Recycling of plastics

Reprocessing of recovered plastic scraps or wastes into usable products is called plastic recycling. Most plastics are non-biodegradable in nature, hence, the fundamental work is reduction of waste emissions, effective management and recycling of resulting wastes [38,39]. Recycling of plastics is a major aspect of the worldwide efforts in minimizing the yearly 8 million tonnes of plastics in the waste stream entering the Earth's ocean [8,40]. According to Hopewell, et al. [30], plastic recycling terminology is complex due to varieties of recovery activities and recycling. There are four main categories of recycling which are: primary (which involves the mechanical reprocessing of plastics into a new product with equivalent properties), secondary (which involves the mechanical reprocessing of plastics into a product with lower properties), tertiary (which involves the recovery of the chemical constituents of the plastics) and quaternary (which involves energy recovery from the plastics).

In comparison to the lucrative metal recycling but similar to the low value of glass recycling, recycling of plastics is often more challenging because of low density and low value. Also, there are several technical issues to deal with when recycling plastic. Melting together of different plastic types often cause phase-separation similar to oil and water, and they set in these layers. The resulting phase boundaries is responsible for structural weakness in the final product(s), which has limited the application of this polymer blends. This is the case with polyethylene and polypropylene, which are the two plastics commonly manufactured, and therefore has limited their use for recycling. Of recent, block copolymers has been proposed as a form of macromolecular welding flux [41] or molecular stitches [42] in other to overcome this challenge of phase-separation during plastic recycling [43].

There can be increase in the percentage of plastics with the possibility of full recycling instead of the large quantity generated as wastes if package good manufacturers reduce their mixing of packaging materials and eliminate contaminants. In view of this, a design guide has been issued by the Association of Plastics Recyclers for recyclability of plastics [44]. There has been an increase in the volume of post-consumer plastics recycled since 1990, although it is still incomparable to other items like corrugated fiberboard (approximately 70%) and newspaper (approximately 80%) [45]. For example, in US, the post-consumer plastic wastes generated in 2008 was approximately 33.6 million tons, out of which 6.5% (2.2 million tons) were recycled, while 8% (2.6 million tons) and 86% (28.9 million tons) were burned and landfilled, respectively [46].

Some governments use policy to encourage postconsumer recycling, such as the EU Directive on packaging and packaging waste (94/62/EC). This subsequently led Germany to set-up legislation for extended producer responsibility that resulted in the die Gru¨nePunkt (Green Dot) scheme to implement recovery and recycling of packaging. In the UK, producer responsibility was enacted through a scheme for generating and trading packaging recovery notes, plus more recently a landfill levy to fund a range of waste reduction activities. As a consequence of all the above trends, the market value of recycled polymer and hence the viability of recycling have increased markedly over the last few years, Globally in 2015, about 9% of the 6.3 billion tons plastic wastes generated had been recycled, while 12% and 79% were incinerated and landfilled, respectively [14]. However, in 2016, the global rate of recycling grew to about 14% of the total generated plastic waste [47]. Major contributors to this increment include countries like Japan, where plastic waste recycling rose from 39% (1996) to 83% (2014) according to their Plastic Waste Management Institute [48].

Environmental pollution by plastic wastes

Distribution of plastic waste is associated with human populations. Increase in human population has led to increase demands for plastics and plastic products. Indiscriminate disposal of wastes from plastics and plastic products can lead to environmental pollution which is evident in several ways including environmental natural beauty deterioration [49], entanglement and death of aquatic organisms [50,51], sewage system blockage in towns and cities especially in developing countries [52], resulting in creating conducive environment for breeding mosquitoes and other disease causing vectors and production of foul smells [53], reduction in water percolation and normal agricultural soils aeration thus causing reduced productivity in such lands [54].

Land Pollution

In human occupational and residential environment, plastic products are present in large volume. Pollution by plastics and plastic products can damage and contaminate the terrestrial environment and can be subsequently transferred to the aquatic environment. There is a shortage of data on the volume of plastic wastes on land in comparison to the voluminous data which exist on plastic debris in marine habitat, despite the fact that about 80% of plastic waste present at sea originates from land-related sources [55]. Dumping of plastics on land or landfilling plastics leads to abiotic and biotic degradation of the plastics, where plastic additives (e.g. stabilizers, harmful colorant moieties, plasticizers and heavy metals) can leach and eventually percolate into various aspects of the environment, thereby causing soil and water contamination. Reports have shown that microplastics [56] as well as synthetic polymer fibres are still detectable five years after they have been applied to sewage sludge and soils [57]. Chlorinated plastics are capable of leaching out toxic chemicals into the soil and subsequently seep into the underground water or surrounding aquatic system thereby polluting the ecosystem. Methane, a dangerous greenhouse gas, which significantly contributes to global warming is released during microbial biodegradation of plastics [58].

Water Pollution

Approximately 165 million tonnes of plastic wastes were estimated to be present in the oceans of the world in 2012 [59], while an average of 8 million tonnes of plastics are annually released into the ocean [8], with about 5 trillion plastic pieces floating on the ocean [60]. Typically, plastics in the oceans can degrade within a year but not completely. During this plastic degradation process, toxic chemicals like polystyrene and BPA can be released into the water [59] causing water pollution. Wastes found in the oceans are made up of approximately 80% plastics. Plastic debris which are floating on the ocean can be rapidly colonized by sea organisms and due to persistence on the ocean surface for a long period of time, this mayaid the movement of 'alien' or non-native species [61-63]. Contaminants from microplastics are bioavailable for many marine lives because of their presence in benthic and pelagic ecosystems and their small sizes [64]. Within the marine ecosystem, plastics have been reported to concentrate and sorb contaminants present in the seawater from different other sources. Examples of such contaminants are persistent organic pollutants like nonylphenol, PCBs, dichlorodiphenyldichloroethylene (DDE) and phenanthrene, with potential to accumulate in several fold on the plastic debris compared to the surrounding seawater [65]. More than 260 species of marine organisms such as turtles, invertebrates, seabirds, fish and mammals ingested or are entangled in or with plastic debris, leading to reduced movement, feeding, reproductive output, ulcers, lacerations and eventual death [63,66].

Air Pollution

Carbon dioxide and methane are released into the air when plastic wastes which were landfilled finally decompose. During the decomposition of solid waste in landfills in 2008, an estimated CO_2 equivalent ($eqCO_2$) volume released into the atmosphere was 20 million tonnes. CO_2 is also released into the atmosphere during the burning of plastics and plastic products, and this CO_2 is capable of trapping radiant heat and hinder it from escaping from the earth causing global warming [67]. Air pollution is one of the major environmental threats to public health, and it is responsible for more than 6 million deaths associated with environmental pollution [68]. Open burning of plastics and plastic products releases pollutants such as heavy metals, dioxins, PCBs and furans which when inhaled can cause health risks especially respiratory disorders. The role of plastics in air pollution in the developing and poor countries of the world cannot be overemphasized, and the impact on the future generations may be massive [68].

Effects of Plastic Wastes on Animals

Food supplies for human consumption can be adversely affected if animals are poisoned by toxic constituents from wastes of plastics and plastic products [69]. Indeed, report of threat to survival of large marine mammals have been documented due to large amount of plastic wastes entering the world oceans [70].

Animals are exposed to plastic wastes majorly through ingestion and entanglement, however, ingestion is more frequent than entanglement. Most animals in the oceans mistaking plastic wastes dumped in the ocean for food, thereby ingesting them. Furthermore, entanglement in plastic products like nets can cause harm, damage and even death in marine animals. Reports have shown that more than 260 different species of vertebrate and invertebrate animals ingest plastics or are entangled by plastic or plastic products, with more than 400,000 deaths of marine mammals [69]. Marine pollution by plastic wastes majorly affects sea turtles and other species whose main food are jelly fishes because they often confuse discarded plastic bags for jelly fish. A similar situation is common in sea birds which can confuse microplastics for cuttlefish or with fishes, which can mistake plastic wastes for their natural prey [63]. Ingestion of plastic wastes is capable of causing obstruction and physical damage to bird's digestive system, reduce the digestive ability of the system leading to starvation, malnutrition and eventually, death.

Many birds, turtles, fishes, seals and other marine animals have died by drowning or suffocation as a result of entanglement in plastic debris. Entanglement has been observed to cause health risks in estimated 243 species of marine lives, often ending in fatalities. Animal entanglement by plastic debris also contributes to death from predators, as the animals are unable to untangle themselves and escape [71]. Coral reefs have been damaged by dragging nets and other plastic products along sea beds [63]. Often times, discarded fishing nets also called "ghost nets" trap marine animals, leading to starvation and death. Table 3 shows the effects of different types of plastics on animals and the mechanism(s) of action.

Table 3: Effects of plastic wastes on animals and their mechanism(s) of action.

Species	Specie variant	Plastic type	Effects
Sea Bird	Greater Shearwater	Plastic bottle cap	Starvation due to gastrointestinal obstruction
	Magellanic penguin	Fragments, line and straws	Stomach perforation
Sea Turtles	Green sea turtles	Plastic bags and other debris	Impediment of hatchling movement towards the sea, exposure to predators
	Leatherback turtle	Plastic bags and debris	Blocked and injures cloaca, impedes laying of eggs
Fish	Bigeye tuna	Fragment line	Ingestion of plastic fragments
	Japanese medaka	Particulate plastic	Hepatic stress from exposure to plastic pollutant
	Orchid dottyback	Plastic bags	Leached nonophenol additives caused mortality
	Larva Perch	Microplastic particles	Inhibited hatching, decreased growth rate and altered behavior
Mammals	Fur seal	Plastic particles	Bioaccumulation of particulate plastic from prey fish
	Sperm Whale	Plastic bags and debris	Stomach rupture and starvation
	Australia Sea lion	Plastic fishing gear	Entanglement caused mortality
Invertebrates	Urchin larva	Polyethylene pellets	Plastic leachates caused abdominal development
	Mussels	Microplastic particles	Accumulation of microplastic in circulatory system
	Oyster	Microplastic particles	Interference with energy uptake and reproduction
	Norway lobster	Plastic strands and particles	Ingestion and accumulation of plastics in the gut

Source: Worm, et al. [15].

Public Health Effects of Plastic Wastes

It is generally believed that plastic polymers are lethargic and of little concern to public health, however, different types of additives and the residual monomers possibly retained from these polymers are responsible for the suspected health risks [72]. Most of the additives present in plastics are potential carcinogens and endocrine disruptors [18]. Ingestion, skin contact and inhalation are the main routes of exposure of humans to these additives. Dermatitis have been reported from skin contact with some of the additives present in plastics [73]. Microplastics are major contaminants that can bioaccumulate in the food chain after ingestion by a wide range of freshwater and marine lives leading to a public health risk [74]. Human consumption of animals exposed to microplastics and plastic additives can be detrimental. Biomonitoring studies on human tissues have shown that plastic constituents persist in human population through the measurement of environmental contaminants [73].

Public Health Effects of Plastic Additives

Different additives are used in the production of plastics and they have been reported to have various detrimental effects on humans. Table 4 shows the different types of additives use in plastic production, their effects and the types of plastics [75].

Bisphenol A (BPA)

Inner linings of food cans, reusable water bottles, and baby bottles are manufactured using BPA. In 2003, an estimated global output of BPA was greater than 2.2 million metric tonnes annually [76]. As a result of repeated usage of beverage and food containers over a long period of time, BPA molecules can leach from the plastics into the drinks and food. The process of BPA leaching from plastics is accelerated by storing acidic or basic items that can breakdown plastic polymers, exposure of the plastic container to high temperature, and by repeated washing of the plastic container [77,78]. BPA is an endocrine disruptor which mimics oestrogen in females. Women exposed to BPA have damaged health system such as polycyclic ovarian syndrome, obesity, recurrent miscarriages, endometrial hyperplasia and sterility [79-81]. BPA alters thyroid hormone axis gene expression, thereby altering its biological functions like metabolism and development. Also, BPA increases thyroid hormone receptor transcriptional corepressor activity causing a decreasing in thyroid hormone receptor activity. This alteration to thyroid axis causes hypothyroidism [82]. Exposure of children and women of reproductive age to elevated concentration of BPA is of great public health concern because of the higher vulnerability of children and developing foetus to BPA compared to adults exposed to similar concentration [83]. Studies have reported a strong association between the concentration of urinary BPA and liver enzyme abnormalities, cardiovascular disease and type 2 diabetes [84]. Also, BPA associated neuro-behavioural disorders (e.g. autism),male's abnormal urethra/penile development, female early sexual maturation and increase in hormonally-mediated cancers (e.g. breast and prostate cancers) have been reported [85-87].

Phthalates

Phthalates, also called 1, 2-benzenedicarboxylic acids, consist of a diverse groups of diesters of phthalic acid which are produced in large volumes from the 1930s. In industrial applications, particularly in the manufacture of food packaging, raincoats, medical devices, toys, hoses, vinyl flooring and shower curtains, high molecular weight phthalates (e.g. di(2-ethylhexyl) phthalate (DEHP)) are commonly used [88-90]. Phthalates with low molecular weight especially

Table 4: Different additives used in plastic production, their effects and the plastic types.

Toxic Additives	Uses	Public health effect(S)	Plastic types
Bisphenol A	Plasticizers, can liner	Mimics oestrogen, Ovarian disorder	Polyvinyl chloride (PVC), Polycarbonate (PC)
Phthalates	Plasticizers, artificial fragrances	Interference with testosterone, sperm motility	Polystyrene (PS), Polyvinyl chloride (PVC).
Persistent Organic Pollutants (POPs)	Pesticides, flame retardants, etc.	Possible neurological and reproductive damage	All plastics
Dioxins	Formed during low temperature combustion of PVC	Carcinogen, interferes with testosterone	All plastics
Polycyclic aromatic hydrocarbon (PAHs)	Use in making pesticides	Developmental and reproductive toxicity	All plastics
Polychlorinated biphenyls (PCBs)	Dielectrics in electrical equipment	Interferes with thyroid hormone	All plastics
Styrene monomer	Breakdown product	Carcinogen, can form DNA adducts	Polystyrene
Nonylphenol	Anti-static, anti-fog, surfactant (in detergents)	Mimics oestrogen	PVC

Source: [76].

dibutyl phthalate (DBP) and diethyl phthalate (DEP) are used as solvents in the manufacture of products such as lacquers, coatings, varnishes and personal-care products (e.g. cosmetics, perfumes and lotions) [91]. Lack of chemical bound between phthalates and the plastic matrix makes it easy for phthalates to leach out and contaminate the environmental [92,93]. Due to the presence of phthalates in many consumer goods, there is widespread human exposure to phthalate.

Phthalates are endocrine disruptors with anti-androgenic activity [94]. Children and infants are mostly exposed to phthalates because of their frequent mouthing of objects like plastic toys and fingers, and direct skin contact with phthalate contaminated substances. Ingestion of phthalates in breast milk, cow milk, or food packaging materials are the main routes of exposure in breast feeding infants [95]. Using personal care products frequently can increase the rate of exposure to phthalates of low molecular weight, indeed, report have shown that men who recently used aftershave and cologne have increased phthalate exposure, while infants that used certain infant-care products such as shampoos, lotions and powders also showed increased exposure [96]. High phthalate concentration alters hormone levels thus causing birth defects in rodents exposed to certain types of phthalates. Butyl benzyl phthalate have been reported to cause rhinitis and eczema in children and has been classified as possible class-Chuman carcinogen in the 1986 US EPA guidelines [96].

Brominated flame retardant

In the production of plastics, brominated flame retardants are raw materials used for safety purposes. The most commonly used brominated flame retardants in plastic production are tetrabromobisphenol A (TBBPA) and polybrominateddiphenyl ethers (PBDEs). These are present in a variety of plastic products such as electronic thermoplastics (e.g. computers, phones and televisions) and textiles [97]. About 5-30% by weight of plastic products are PBDEs and they are not chemically bound to the polymer making it possible for PBDEs to leach out and contaminate surrounding environment [98]. PBDEs and TBBPA are hormone disruptors, altering the activities of thyroid hormones and oestrogen, thereby causing impaired development of both the nervous and reproductive systems [93]. Plastic materials which contain TBBPA have been reported to leach TBBPA [99], and contaminating sewage sludge [100], fish, bird, sediments, soils [101] and air [102]. High concentration of PBDEs have been observed in serum, breast milk and adipose tissue in exposed individuals. On a pro-kilogram basis, children have a higher exposure rate to PBDEs than adults [103].

Polychlorinated biphenyls (PCBs)

Marine food web has been continuously polluted with polychlorinated biphenyls (PCBs) for the last-70years, particularly in seabirds [104]. PCBs ingestion may cause reproductive disorders, enhance disease proliferation, alters hormone levels and death [104,105]. PCBs can contaminate marine food web through the plastic bits and it has been shown that PCB is detrimental to marine life even at very low concentrations [106]. The study of Ryan, et al. [107] showed the presence of PCBs in the tissue of great shearwaters (Puffinus gravis) after ingestion of plastic particles.

Recommendations on Reduction and Control of Plastic Wastes

Many countries are laboring on controlling environmental pollution by plastic wastes by reducing plastics and plastic product's production, prohibition of excessive packaging, litter capture and recycling. In the struggle against plastic pollution, the following recommendations might be helpful:

Policy making

To combat and curb persistent environmental pollution by plastics, there is need for realistic policies which must be properly followed and enforced. This should include the need for global convention on environmental pollution by plastics to mandate plastic producers to declare all ingredients in their plastic products and put a warning on the products for consumers about the potentially health effects of such constituents. Policies to classify some of the harmful ingredients in plastic products should be enacted. Successful precedents exist including the 1989 reclassification of chlorofluorocarbons (CFCs) as hazardous (Montreal Protocol) and persistent organic pollutants in 2004 (Stockholm Convention) [107]. This led around 200 countries to completely stop the production of CFCs in the next 7 years and 30 other dangerous chemicals.

This type of reclassification might also stimulate research into new and harmless alternatives, which will improve our plastic waste management, and hinder continuous buildup of plastic wastes in the environment. It is also important for government to enforce and implement regulations that will check production, consumption, usage and eventual disposal of plastics, irrespective of their hazardous status. The 3Rs: Reduce, Reuse, and Recycle must be employed at all stages so as to prevent zero diversion to landfills and indiscriminate disposal to the environment [108].

Plastic waste management and recycling

In reducing toxic effects of plastic wastes on the environment and public health, waste management plays a major role. For global reduction of plastic litters and ocean pollution, there is need for improvement in proper plastic waste collection, treatment and disposal [8]. Inadequate management of landfills will make way for harmful chemicals in plastic wastes to leach into the environment, polluting the soil, air and underground water.

Proper wastewater management will prevent microplastics from entering the environment from the landfills. Most treated wastewaters are discharged into rivers or oceans, therefore, there is need for a ban such as Annex V to the International Convention for Prevention of Pollution from Ship (MARPOL) agreement, which will prevent plastic waste disposal into the sea [109,110].

Education and public awareness

Efforts must be made to educate the general populace on the potential environmental and public health effect of pollution by plastic wastes. This will go a long way to reduce the pollution rate and preserve the quality of the environment. There is need for people to be aware of the chemical constituents of plastic products and their health effects. Educational curriculums at different levels must include ways of plastic pollution reduction and waste management systems as information resources.

Bioplastics as alternative

Bioplastics is a plastic produced from cellulose that is made of wood pulp by a British chemist in the 1850s. Now, bioplastics can be produced from different biodegradable and non-biodegradable materials including weeds, hemp, plant oil, potato starch, cellulose, corn starch, etc. [111]. Sugar-based bioplastics can biodegrade under normal conditions for composting [18]. Bioplastics are environmentally friendly since they require less fossil fuels during production in comparison to other types of plastic [111].

Although bioplastics have been used commercially in just few applications, they are widely used in consumer goods for items that are disposable like cutlery, bowls, pots, crockery, straws and packaging [112]. In principle, bioplastics can replace petroleum-derived plastics in many applications, however, the problem lies with the cost and performance of bioplastics. If there are no specific regulations globally to limit the use of conventional plastics, there may be no favourable usage of bioplastics. For example, Italy has since 2011 enacted law that made it compulsory for biodegradable plastic bags to be used for shopping [113]. In the production of bioplastics, substitute for fossil fuel resources like wood, cellulose, sugar and starch are used. This has made bioplastic production more sustainable and environmentally friendly in comparison to conventional plastic production [114]. The production of bioplastics decreases consumption of non-renewable energy and reduces the emission of greenhouse gases [114].

We believed that the problem of plastic waste generation and the accompanied environmental and public health effects can be handled if globally, manufacturers can embrace the use of bioplastics. The biodegradability with little or no toxic products left behind will go a long way to protect our natural environment from the menace of conventional plastic wastes, protect our world's organisms and make the world safer for humans.

Conclusion

Researches on worldwide production of plastics and the accompanied environmental pollution have shown that plastic wastes have constituted a major environmental issue. The effect of plastic wastes on marine organisms, humans and the environment at large is of public concern, and calls for the need to salvage the ecosystems and lives therein. Despite the fact that plastics are very useful in everyday life, the toxic chemicals used in the production need to be thoroughly monitored so as to ensure environmental and health safety. Reducing community's exposure to toxicants from plastic wastes will increase the chances of having a clean environment and healthy society. There is a urgent need for government agencies and health authorities to enact and enforce environmental laws that will monitor production, usage and disposal of plastics. In addition, some harmful chemical constituents used in the production of plastics (e.g. phthalates, BPA, etc) should be banned in consumer goods and in plastic products that are in direct contact with food, beverages and children.

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