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Microplastics Contamination in the Environment: An Ecotoxicological Concern

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Abstract: The accumulation of plastic products in the terrestrial and aquatic environment is one of the major concerns in recent years. The quality of the ecosystem is affected globally due to the large production, ubiquitous usage, and poor plastic waste disposal. Plastic debris is categorized based on its size as macroplastics, mesoplastics, microplastics, and nanoplastics, respectively. Microplastics are the emerging contaminant that occurs in varying shapes like tiny beads, spheres, films, fragments, fibres, and filaments. The use of microplastics in cosmetics and abrasion from large plastic items including textile fibres and tyres are suspected to contaminate the environment when it reaches the aquatic ecosystem. Indian coastal waters are polluted by microplastics owing to industrialization, overpopulation, tourist and maritime activities. Many species of fishes, reptiles, birds, and mammals are directly threatened by entanglement or ingestion, and some marine mammals consume a large amount of microplastic debris by raptorial feeding thereby leads to trophic transfer. Humans are considered as the most exposed organisms than other vertebrates as they occupy at the top of the food chain. Certain government legislations have been put forth to ban some products that are considered as the major contributor to plastic debris. Recently, the use of bioplastics is increased all over the world to replace microplastics in industrial and commercial products. However, there is little awareness of the microplastic pollutants among the public, thus the main motive of this review is to provide public awareness and responsibility to limit the use of plastics that adversely damage our environment.

Keywords: Plastic pollution; Plasticene; Microplastics; Bioplastics; Environmental risks

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Introduction

There is an increasing concern about the adverse health outcomes associated with microplastic pollution. The available scientific information on the toxic environmental

chemicals is voluminous, of variable suggestions and quality, which create chaos for the decision-makers. Intending to expedite the evidence-based literature analysis, the authors undertook systematic review methods to strengthen the resources on the nature of pollutants, their occurrence, effects, and regulations. Among the total of more than 2300 articles reviewed by the authors, about 617 articles were found focused on the current scenario of global plastic pollution. Further screening of reviews into the mainstream on the environmental issues and toxic impacts on various organisms from microbes to humans narrowed it to cite 206 journal articles that include articles from the year 1972 onwards, however, most of the references cited were from 2014-2020.

Aquatic ecosystems are the water-based environment that occupies three-fourth of the entire earth's surface. Human interventions such as agricultural practices, urbanization, industrialization, over-exploitation of resources, and habitat destruction are known to damage the quality of the aquatic environment. Anthropogenic contaminations include industrial and chemical wastes discharged into the water bodies as a result of accidental spillage, intentional dumping from wastewater, untreated effluents, and industrial leakage. The abundance of microplastic contamination has been positively correlated with a population density that indicates the direct effects of human activity. The major pollutants include industrial solvents, volatile organic compounds, radioactive materials, heavy metals, agrochemicals, fuel combustions, household products, personal care products, nanomaterials, biomaterials, antibiotics,

drugs, pharmaceutical products, micro-plastics, and so on.

Aquatic pollution also occurs naturally due to volcanic eruption, evaporation, or lack of hygiene. In addition, pollution also occurs from the various point or non-point sources due to anthropogenic activities. Collection of sewage and untreated wastes from a different location, and discharging at a particular region in the water bodies form the direct or point sources whereas the disposal of contaminants from industries, agricultural fields, and urban areas that are brought through the rainwater run-off is the indirect or non-point source of pollution. In the current situation, 844 million people lack access to clean water globally, and in India 0.4-0.5 million children aged less than five years die each year due to water-borne diseases (Mudur, 2003). The Indian Council of Scientific and Industrial Research (CSIR) and the National Institute of Oceanography (NIO) reported the accumulation of microplastics in Indian coastal areas, rivers, and estuaries during the monsoon.

1. *Types of pollutants:*

Based on human interventions, pollutants are broadly classified as organic and inorganic. Organic pollutants are derived from plant or animal sources whereas inorganic pollutants are of mineral origin (Siantar *et al.*, 1994). Similarly, on the origin, presence, release, and existence in the water resources, pollutants are classified as conventional and emerging pollutants. Conventional pollutants include domestic and industrial wastes such as biochemical oxygen demand, pH, heat, nutrients, pathogens, and suspended soils that can be treated by the municipal treatment plant. High levels of arsenic, nitrate, and

fluoride in the groundwater and drinking water are the conventional pollutants that affect human health (Chen *et al.*, 2017).

Emerging pollutants are not usually new chemicals but they may be present in the environment for a long time, however, their adverse effects have been recognized recently. The emerging water pollutants are the synthetic or naturally occurring chemicals that are suspected to cause adverse ecological and health effects in organisms. According to the NORMAN network, there are 1036 listed emerging pollutants comprising biocides, pesticides, gasoline, surfactants, flame retardants, pharmaceuticals, artificial sweeteners, personal care products, xenoestrogens, engineered nanomaterials, microplastics, and so on. In addition, several micropollutants enter into the natural aquatic ecosystems, and are recently detected in the drinking water which can cause harmful effects on ecosystems or humans (Bolong *et al.*, 2009; Clarke and Smith, 2011). The occurrence of emerging pollutants was reported in all aquatic bodies including rivers, lakes, streams, estuaries, drinking water, rainwater, groundwater, sewage, seawater, and oceans.

2. *Plasticene - Plastics as pollutants:*

Plastic pollution is considered one of the major concerns in recent years as it targets both terrestrial and aquatic environments. Plastic is multipurpose, tough, weightless, flexible, moisture resistant, slowly degrading and relatively economical product first introduced in the 1950s. Plastics are synthetic polymers derived from natural materials such as cellulose, natural gas, coal, crude oil, and salt by polymerization or polycondensation process (Derraik, 2002; Thompson, 2006).

However, in 1907 the first fully synthetic plastic named Bakelite was synthesized, which was more durable, heat resistant, and ideally a good insulator. The worldwide production of plastic has increased from 1.5 to 359 million metric tons in the 1950s to 2018, respectively (Alimba and Faggio, 2019). In India, annually 9.46 million tons of plastic wastes were generated, and are more abundant as litters in the shores of urban areas than rural areas (Jayasiri *et al.*, 2013).

The surge in plastic production, multipurpose usage, and poor waste disposal management poses a serious concern to plastic pollution on the quality of the ecosystem globally. The first report on plastic pollution in the ocean was reported in the scientific literature during the early 1970s. The plastic wastes reach the aquatic ecosystems from the landfills by leaching, rainwater run-off, intentional or unintentional disposal thereby cause a plastic surge in the aquatic bodies. It has been estimated that 80% of marine plastic debris originates from land, in which 21 to 42% of global plastic wastes are stored as landfills (Gregory, 2009). Plastic decomposes very slowly where it breaks down into small pieces, and based on the size, the plastic debris are classified as a macro (> 25 mm), meso (5–25 mm), large micro (1–5 mm), small micro (20 µm–1 mm), and nanoplastics (1–1000 nm), respectively (Gigault *et al.*, 2018).

2.1. *Macroplastics:*

Macroplastics are large-sized plastic debris that includes plastic chairs, plane, boat and car parts, footballs, fishing nets, traps, and so on, which are released intentionally or unintentionally into the environment. The land-based macroplastics form 80% of plastic

litters in the aquatic environment, which are thrown as garbages or enter through rainfall or by frequent shipping activities. Large-sized plastic items can be seen floating on the surface of both marine and freshwater environments as well as found littering in the shorelines. In the terrestrial environment, macroplastics affect the hydrological cycle, biogeochemical cycling of elements spreads harmful diseases, affects soil fertility, harms crops and cultivation, and acts as carcinogens when the unsorted plastic wastes are burned improperly. Accumulation of macroplastics in the environment causes major impacts such as habitat damage, entanglement, and ingestion of plastics by biota thereby causing suffocation and disruption of digestion in birds, fishes, and mammals that finally leads to death (Thompson *et al.*, 2004).

Macroplastics, especially floating objects reach the marine environment by large winds, and also due to high urban population, tourism, disposal of galley untreated plastic debris, accidental loss, as rainwater run-off from rivers and other freshwater bodies, or by deliberate discarding. Macroplastics occupy all marine matrices such as sea coast, surface waters, water columns, seafloor, sediments, and in biota (Turra *et al.*, 2014). An increase in plastic debris across the marine ecosystems leads to aesthetic issues, economic loss, and hazard for marine industries like shipping, fishing, and aquaculture (Derraik, 2002; Barnes *et al.*, 2009; Sivan, 2011). The adverse effects on aquatic organisms include injury and death of marine birds, mammals, fish, and reptiles as the entangled organisms suffer from reduced mobility and feeding that lead to drowning, suffocation, and strangulation (Fischer *et al.*, 2015; Li *et al.*, 2016).

2.2. Mesoplastics:

Mesoplastics are large microplastics usually in the form of plastic resin pellets having granulated cylindrical or disc-shaped. Hard and foam plastic fragments, plastic floats, needles, and films are categorized under mesoplastics, which are used as raw materials or 'nurdles' in industries by melting and remolding into various shapes (Gundogdu and Cevik, 2017). The accidental spillage of nurdles occurs from the production site, manufacturing, or during transportation, which is then carried to the aquatic ecosystems through the surface runoff, streams, lakes, or rivers, and finally reaches the ocean (Ogata *et al.*, 2009). Recreational beaches of India are mostly dominated by the presence of mesoplastic debris in which Styrofoam was the dominant source (Jayasiri *et al.*, 2013). The stoke drift transports mesoplastics more efficiently than microplastics thereby affect the pelagic life of the sea and pollute the surface samples of the aquatic ecosystems (Iwasaki *et al.*, 2017).

2.3. Microplastics:

The term 'microplastics' was introduced in the mid-2000s to describe small plastic particles with a size of a maximum of 5 mm composed of mixtures of plastic polymers and their functional additives. They exist in varying shapes like tiny beads, spheres, films, fragments of irregularly shaped particulates, fibres in the form of plastic threads in clothing, and as filaments. Microplastics are known to exist in several environmental compartments including soil sediments, water column, surface layers, terrestrial and aquatic ecosystems in the form of microbeads, plastic wastes, textile fibers, car tyres, polystyrene

containers, packaging, construction coating, tapes, and fishing equipment and so on (Carpenter *et al.*, 1972; Cole *et al.*, 2011).

2.4. Nanoplastics:

Nanoplastics are unintentionally produced particles, comprising a mixture of different polymers, sized between 1 and 1000 nm that exhibit colloidal property (Gigault *et al.*, 2018). It exists in different shapes such as spherical, angular, long, and thin fibers contaminating air, soil, and water. Nanoplastics also act as a carrier of potentially toxic chemicals and microorganisms (Mato *et al.*, 2001; Teuten *et al.*, 2009; Oberbeckmann *et al.*, 2015). Nanoplastics associate directly with dissolved organic and inorganic colloids to form both stable and unstable aggregates (Hotze *et al.*, 2010). Nanoplastics are found in water, beverages, food products including the human diet, fish meal, and also exist in edible animal species thereby find a way into the human food chain where they undergo bioaccumulation in mammalian and human tissues posing significant environmental and health concerns (Prust *et al.*, 2020).

3. Microplastics, an emerging contaminant:

Microplastics are categorized under the emerging contaminant that raised global concern in recent years. The abundance of microplastics and their usage and distribution throughout the environment is becoming a major concern, which forced to denote the current era as 'plasticene' or the age of plastics (Haram *et al.*, 2020). It refers to the geological implications of plastic pollution stating the ocean globally as the 'plastic soup' (Reed, 2015).

Recent literature stated several lexicons related to plastic pollution, which includes the

terms such as 'epiplastic' – the life living on floating plastics (Reisser *et al.*, 2014), 'plasticized' – to make or mould plastics using plasticizers (Eriksen, 2014), 'plastisphere' – the living micro or macrobiotic community colonizing plastic (Zettler *et al.*, 2013), 'plastivore' – the organisms that ingest plastics (Irigoin, 2018), 'plastic cycle' – the movement of plastic materials across abiotic and biotic compartments, including human (Bank and Hansson, 2019), 'plasticrust' – plastic debris of varying size, color, and thickness attached to tropical or subtropical intertidal shores (Gestoso *et al.*, 2019), 'pyroplastic' – the melted plastic debris found on beaches (Turner *et al.*, 2019), 'plastic confetti' – multicolored plastic fragments formed by the degradation of large plastic products (Corcoran *et al.*, 2014), 'plastitrash' – waste materials made of plastic products (Felger, 2000).

Based on the origin, microplastics are classified as primary and secondary microplastics. The primary microplastics are manufactured polymers in the form of pellets usually of the spherical or cylindrical structure and used as microbeads in marine coatings, road markings, tyres, synthetic textiles, cosmetics, and personal care products such as toothpaste, facial scrubs, and soaps (Zitko and Hanlon, 1991; Hidalgo-Ruz *et al.*, 2012). Using air blasting technology, the primary microplastics are extensively used as acrylic, melamine, or polyester scrubbers to remove rust and paints in industries, machinery, engines, and boat hulls (Derraik, 2002; Browne *et al.*, 2007). However, the repeated use of microplastics as scrubbers reduces the size and cutting power, which ultimately contaminates the environment by binding with heavy metals such as lead,

cadmium, and chromium (Derraik, 2002). In Ljubljana, Slovenia of Yugoslavia about 112,500,000 microbead particles contained in cosmetics are released into the freshwater habitat making the microbeads concentration of 21 particles/ m³ that are likely to accumulate in the organisms (Kalcikova *et al.*, 2017).

The breakdown of large pieces of plastics over time into small pieces by various physical, chemical and biological factors are termed secondary microplastics. The degradation of plastics that occur by fragmentation and weathering, photo-degradation, or microbial activities from household plastics, industrial products, disposed car tyres, and paint flakes are then released into the environment as micro or nanoplastics (Nizzetto *et al.*, 2016). Microplastics have a large surface area to volume ratio and the unique chemical composition allows them to carry contaminants such as heavy metals (Ashton *et al.*, 2010; Cole *et al.*, 2011; Brennecke *et al.*, 2016).

4. Occurrence and distribution of microplastics – a global outlook:

An increase in the manufacture and production of microplastics gained popularity in replacing the natural materials used in industrial, domestic, and other household items such as stone, bone, wood, ivory, tusk, horn, and metals (Science History Institute, 2018). Several reports are demonstrating that the global release of primary microplastics at approximately 1.5 million tons per year is the major source of plastic pollution in the ocean (Jambeck *et al.*, 2015). The land-based activities including tourism, maritime activities, and road run-off release 98% of

primary microplastics into the environment whereas only 2% like floods, intentional release through effluents, fishing, and recreation contribute from the sea-level activities (Boucher and Friot, 2017).

Littering and mismanaged wastes also add the major entry of microplastics into the aquatic ecosystems. Besides, deliberate use of microplastics in the form of microbeads in cosmetics, and abrasion from large plastic items including textile fibres and tyres are suspected to contaminate the environment. Some of the microplastics like polypropylene are less dense than the seawater thus it floats, and is carried by currents widely across the ocean (Salvado *et al.*, 2012; Tubau *et al.*, 2015). The distribution of microplastics across Asia, Africa, and European continents are comparatively higher than the other continents and hence emphasized in this section. Asia, the largest and densely populated continent faces the potential risk of microplastics pollution in the terrestrial ecosystem, inland water bodies, and marine environments. China and Japan are the two leading countries of Asia contributing 26% and 4% of the world's total plastic production, respectively, which is nearly half of the global production while the other Asian countries accounted for only 16% of the world's production (Plastics Europe, 2015). Thus Asia stands in the top rank of plastic production but the consumption rate is relatively low in comparison with other developed countries. It was reported that plastic consumption per capita is 9.7 and 45 kg/person in India and China, respectively than 65 and 109 kg/person in Europe and the United States (Tata Strategic, 2014).

The environmental release of micro-

plastics is more abundant in Asian countries since the mismanaged plastic wastes varied between 1 and 27.7% thereby polluting the Asian inland water bodies (Wu *et al.*, 2018). The microplastics in the form of expanded polystyrene were found abundant in the coast of eastern and south-eastern Asia while polyethylene and polypropylene occupy almost all parts of Asia (Lee *et al.* 2013; Fok and Cheung, 2015). The first report of microplastics in the lake and estuarine sediments of India showed that the distribution of polyethylene dominated at 26-91% than other plastic items (Sruthy and Ramasamy, 2017). The unintentional spillage from ships releases 3000 different micropellets in the northern and southern coast of Goa (Veerasingam *et al.*, 2016). The wind and ocean currents transport microdebris during the rainy season towards the north to the south coast of the Bay of Bengal, India (Eriksen *et al.*, 2017). The presence of microplastics like polypropylene, polyethylene, nylon, and cellulose was identified in coastal salt pan stations of the Gulf of Mannar, Tuticorin, Tamil Nadu and South India (Selvam *et al.*, 2020). Microplastic particles have been identified in the 25 beaches along the South coast of India including Gujarat, Chennai, Mumbai, and Kerala, in which polyethylene and polypropylene were found abundant both in the beaches and 75 fish guts of five species (Karthik *et al.*, 2018). Indian sea salts contained polyesters, polystyrene, polyethylene terephthalate, polyethylene, and polyamide (Seth and Shriwastav, 2018).

Table salts, the main edible commodity, obtained from seawater are contaminated with microplastics mainly with polyethylene terephthalate, polyethylene, and cellophane

from 15 brands of salts from Chinese supermarkets (Yang *et al.*, 2015). In the coast and sand of bathing beaches in Qingdao, China the distribution of microplastics occurs from various sources including the textile, tourism, and packaging industries (Luo *et al.*, 2019). Microplastic pollution examined in the Guangdong Province reported the abundance of 3183 items/m³ in the Beijing River and 7571 items/ m³ in the Pearl River Delta, and omnivorous fish samples had 6.8 and 6.2 items/ individual, respectively (Wang *et al.*, 2020).

Microplastics in the form of microbeads of varying size and shape were found in the marine water of Japan (Isobe, 2016), and surprisingly about 342.2 billion items of microbeads were recorded in the Hong Kong beaches (Cheung and Fok, 2016). The intertidal mudflats of Hong Kong are biologically diverse so that it retains more microplastics like polyethylene, polypropylene and polyethylene terephthalate that are discharged locally from the sewage treatment plants (Lo *et al.*, 2018). The polymers of microplastics such as polypropylene, polyethylene, and polystyrene have been identified as inflow from urban areas into the rivers of Japan transported through rainwater, flood, or strong wind (Kataoka *et al.*, 2019). In densely populated urban areas of Japan including Nagoya, Osaka, and Tokyo, the value of plastic inputs from land to sea estimated using water balance analyses ranged from 210-4,776 tons/year (Nihei *et al.*, 2020), which was comparatively lower than the estimated values of plastic inputs from previous reports that ranged between 21,000-57,000 tons/year (Jambeck *et al.*, 2015). Besides, plastic additives including plasticizers and flame retardants

were identified as tracers of microplastic sources in road dust and road markings of highly populated and traffic density areas of Japan (Kitahara and Nakata, 2020).

Microplastic contamination including paint resin particles, spherules, expanded polystyrene, sheets, alkyd and polyacrylate/styrene, and other microplastic samples such as phenoxy resin, polypropylene, polyester, polyethylene, synthetic rubber, and other polymers were predominant on the coast of Jinhae Bay and Geoje of South Korea (Song *et al.*, 2015). A survey conducted in Korean coastal waters found the abundance of microplastics near urban areas, and the polymer composition differed by depth, based on the size and density of particles, with a high load of low-density microplastics in the bottom water samples as a result of biological interactions (Song *et al.*, 2018). A recent water sample analysis conducted in the surface water from six semi-enclosed bays and two coastal waters in Korea found the region-specific occurrence of microplastics due to differences in human activities near urban and rural areas, but the distribution of microfibers was uniform throughout the study area (Kwon *et al.*, 2020).

The occurrence, concentration, and distribution of microplastics in Australian aquatic ecosystems are more abundant by the production of 327,000 tons of dry biosolids every year. Many marine animals die owing to plastic ingestion and entanglement, particularly turtles, and 60% of seabirds are found with plastic trapped in their gut that represents 14% of bird's body weight. Besides, other marine animals such as corals, cetaceans, and zooplanktons ingest plastics that concern to bioaccumulate and undergo trophic transfer encountering ghost nets in

Australia's northern waters and freshwater bodies in Victoria (Nan *et al.*, 2020).

Microplastic accumulations in the African water bodies are notable in the marine, estuary, freshwater lakes, rivers, and inland waters. The main sources of plastics were considered due to human activities such as urban wastes, fishing, and tourism. A large variety of polymers, including polyethylene, polypropylene, and silicone rubber were recovered from the organisms inhabiting the African Great Lake systems as Lake Victoria, River Congo, and the Nile (Khan *et al.*, 2018). The major African freshwater bodies namely River Nile, Niger, Congo, Zambezi, Limpopo, and Orange discharges 170-41,000 m³/sediments of microplastics, similarly, major lakes including Nasser, Chad, Turkana, Victoria, Tanganyika, and Malawi represented major pollution (Osman and Kloas, 2010). The abundance of microplastics along the marine ecosystems has been documented in the early 1980s and its amplification in recent years as evidenced by the incidence of plastic ingestion by marine species like fishes and birds. The presence of plastic particles in the digestive tract of marine organisms in the form of cosmetic microbeads, fibers, plastic powders, and pellets represents the mismanagement of solid plastic wastes into the aquatic ecosystems of African countries (Lederer *et al.*, 2015). Thus the distribution and accumulation of microplastic particles are more prominent in the proximity of the urban-industrialized coastline in South Africa (Collins and Hermes, 2019), and the spatial differences in microplastic loads depend largely on the water currents (Nel *et al.*, 2017).

In Europe, microplastics are identified from the surface waters of Swiss, Italy, and

Hungarian natural and excavated lakes (Faure *et al.*, 2015; Fischer *et al.*, 2016; Bordos *et al.*, 2019), and in the sediments of the Belgian marine environment (Claessens *et al.*, 2011). The abundance of microplastics pollution has been identified in Central European lakes that lie in small, densely populated areas while lakes of Scandinavia and Finland, located in northern Europe are low polluted as they are less populated (Uurasjarvi *et al.*, 2019). The presence of microplastics in the sediments, snow, and ice of the Vesijarvi lake and Pikku Vesijarvi pond near the city of Lahti, Finland identified polyamides (53.3%), polyethylene and polypropylene (17.1%), and natural fragments like cellulose (45.8%) and wool (18.8%) aroused from stormwaters, sport and recreational activities (Scopetani *et al.*, 2019). Spain, the second-largest country in Western Europe also faces microplastic contamination in the sea products like commercial Spanish table salt that ranged from 0-680 microplastics/kg, among which polyethylene-terephthalate, polypropylene, and polyethylene were predominant (Iniguez *et al.*, 2017). The European Chemical Agency (ECHA) has recently restricted the use of intentionally added microplastics concentration to 0.01% in consumer, medical, and construction products, paints and coatings, printing inks, and so on. The proposed restriction helps to reduce the use of polymers, and check for ineffective and inappropriate disposal. The final opinion of the Risk Assessment Committee (RAC) and the Socio-Economic Analysis Committee (SEAC) is to assess the identified risks, benefits, and costs of the proposed restriction by ECHA, which then are expected to enter into the force in 2021 (Clausen *et al.*, 2020).

5. *Polymers of microplastics:*

The common polymers used in microplastics are polyethylene terephthalate (PET), polyvinyl alcohol (PVA), polyethylene (PE), polypropylene (PP), polyamide (PA), polystyrene (PS), and polyvinylchloride (PVC). The fate of microplastics in the environment depends on the density of polymers used. The polymer also influences the nature of floating and distribution in the water column and its subsequent interaction with the biota (Wright *et al.*, 2013a). Some polymers like PVC are identified to sink into the bottom of oceans as their density is more than seawater, while the low-density polymer like PE and PP tend to float in the water column (Lobelle and Cunliffe, 2011). The density of polymers undergoes modifications due to several processes such as fragmentation, degradation, and leaching of additives. The reduction in the molecular weight and mechanical integrity of polymer occurs by the degradation reactions including thermal or photo-oxidation, hydrolysis, and biodegradation through microbial activity (Singh and Sharma, 2008).

PET is the most widely recycled, synthetic, polyester family of polymer resin produced by the polymerization of ethylene glycol and terephthalic acid. FDA approved PET as safe for contact with food and beverages as it does not contain bisphenol A and phthalates. The unique properties of PET prevent the attack of microorganisms, however, *Ideonella sakaiensis*, a bacterium, is known to possess the ability to biodegrade PET as it contains the enzyme PETase that breakdown PET into its monomers (Palm *et al.*, 2019). PVA is used in biomedical applications such as contact lenses, artificial organs, drug delivery systems, wound dressing, and wound management (Kamoun *et al.*, 2017), which experience

certain allergic reactions including inflammation, itching, rashes in the eyes, face, tongue, and throat followed by dizziness and trouble in breathing (DeMerlis and Schoneker, 2003).

PE also shows some adverse effects on the ecosystem as it takes a long time for the breakdown, and contributes to global warming and climate change. PE is safe and non-toxic in solid form but toxic if absorbed or inhaled in liquid or vapor form causing dermal and ocular irritation (Sheftel, 2000). However, PP at high concentration elevates the levels of cytokines and histamines thereby stimulated unwanted immune responses (Hwang *et al.*, 2019). The presence of plastic polymers in the children's toys, art materials, child care articles, and school supplies cause potential health effects on children that prompted for the permanent prohibition by the United States Consumer Product Safety Commission (Babich *et al.*, 2020), but not in other countries, including India.

PA that is released from nylon flock processing plant was known to develop lung pathologies like lymphocytic bronchiolitis and peribronchiolitis with lymphoid hyperplasia characterized by lymphoid aggregates leading to severe pneumonitis. The symptoms include dyspnea, cough, and restrictive ventilatory defect with a reduction in lung diffusing capacity (Eschenbacher *et al.*, 1999). PS also causes serious health problems to humans as the landfills containing polystyrenes take at least 500 years to decompose. Besides, it contains benzene and styrene as a monomer, which is neurotoxic and carcinogenic to humans (Kik *et al.*, 2020). The drastic increase in the production and use of PS also contributes to marine pollution, environmental contamination, and global

warming. In addition, PVC is the known endocrine disruptor that leaches from food packaging into food cause the toxicity of polymers (Hale *et al.*, 2002).

6. *Microplastics in the aquatic environment:*

Microplastic particles exist in all environmental compartments globally, of which, the major concern is in the aquatic ecosystem as it provides direct and indirect economic benefits. The occurrence and accumulation of microplastics in aquatic ecosystems have been reported by scientists and researchers worldwide. After an overview of the databases available, selective literature was pooled to demonstrate microplastics contamination in the water bodies. However, currently, few pieces of literature are available concerning the source, transport, and distribution of microplastics in the aquatic ecosystems, and thus the comparability of literature used in this section is limited. Usually, the land-based plastic wastes enter the freshwater bodies mainly through rainwater runoffs, transport, and intentional discharge of untreated wastewater effluents. Rivers play a major role as the main transport vector of plastic debris from terrestrial sources. Wastewater discharged from domestic and effluents from urban wastewater treatment plants also find its way into the freshwater environment. The distribution of plastic items in the form of plastic bottles, fishing gears, bags, foams, beads, cigarette butts, plastic pieces, net, rope, string, cord, styrofoams, bottle caps, and industrial packagings identified from the beach sediments contributed to the 'great garbage patches' in the aquatic ecosystems (Mani *et al.*, 2015).

The occurrence of microplastics in the marine compartment has been documented

since the 1970s. There are four main routes of microplastics exposure to organisms including entanglement, contact, ingestion, and inhalation. However, in the case of marine organisms entanglement and ingestion are of major concern. Some of the microplastics are found in the deep oceans that depend on the density of plastic debris. Besides the denser plastics, some of the low-density microplastics may also sink to the bottom that was based on the presence of negatively buoyant polymers. The addition of fillers or foams during processing and hollow-shaped objects helps for easy float while biofouling and aging increase the density of floating material thereby enhances the sinking behavior (Kaiser *et al.*, 2017). Microplastics find their way to humans along with the ingestion of edible macroalgae as it is an important functional food in East Asia including China, Korea, and Japan (Feng *et al.*, 2020). Many factors including the force derived by the wind and buoyancy along with the barotropic tidal currents influence the transport and distribution of microplastics throughout the open ocean globally, which takes the time scales from months to years resulting in worldwide marine microplastic pollution (Sterl *et al.*, 2020). The presence of microplastics in the gastrointestinal tract and muscles of adult benthopelagic fish *Serranus scriba* caught from the southern part of the Mediterranean Sea threaten the transfer of microplastics into humans (Zitouni *et al.*, 2020).

7. Effects of microplastics:

Plastics are chemically inert substances as they do not penetrate the cell membrane of organisms but most of the plastic additives are lipophilic, hence penetrate the cell thereby causing toxic effects. The degree of biofouling

and composition makes the microplastics less dense than water so they float as surface microlayer (Reisser *et al.*, 2015). Some of the lipophilic toxicants adsorb and concentrate on the hydrophobic surface of plastics by electrostatic attraction forming a micelle-like structure (Verla *et al.*, 2019). The toxicants associated with microplastics by adsorption act as a vector for uptake into organisms through water or sediments, and get accumulated in the food chain. Several factors determine the rate of adsorption of microplastics to the chemicals that include glass transition temperature, the free volume within the polymer, mobility and crystalline nature of polymer chains, the distance between the polymer chains, degree of crosslinking, surface-to-volume ratio, etc. Some of the environmental contaminants such as PCB, DDE, BPA, and NP, etc. are known to adsorb with microplastics by forming high-affinity polymer matrix (Mato *et al.*, 2001; Gerdes *et al.*, 2019; Liu *et al.*, 2019).

The environmental conditions such as pH, ionic strength, temperature, and salinity determine the length of polymer-matrix sorption. Desorption of adsorbed and absorbed chemicals depends on partition ratio, binding strength, sorption capacity, surface polarity, pore size, surface area, planarity, diffusion rate, etc., and using weathering or fragmentation the chemicals are known to release into the environment (Koelmans *et al.*, 2016; Ziccardi *et al.*, 2016). Besides the vector of contaminants or additives, microplastics are widely used in medicine for drug delivery and in personal care products like cosmetics. Microplastics act as vectors in the medical field for the delivery of antibiotics such as sulfadiazine, tetracycline, ciprofloxacin, trimethoprim, and

amoxicillin (Cole *et al.*, 2011; Li *et al.*, 2018). Microplastics in the form of microbeads, micro-exfoliates, granules, and spheres are used in cosmetics since the 1980s in the form of microplastic scrubbers and cleansers (Fendall and Sewell, 2009). Such products can directly reach water bodies as the part of medical waste and human feces, which in turn recycle to human through the food chain causing several toxic effects in many organisms, including cancers in humans.

7.1. In microbes:

Plastics are ubiquitous in the environment from offshore to coastal areas, rural to urban, surface water to the ocean floor, and from microbes to humans. Microplastics are known to exchange between terrestrial and aquatic habitats, and vice-versa as evidenced by the presence and crossing of microplastics into different life stages of mosquito that live in different habitats such as larva of feeding type to non-feeding pupa to flying terrestrial adult that reveals the spread from aquatic systems to terrestrial habitat (Rhodes, 2019). Microplastics provide long-lasting buoyant substrates for many aquatic organisms including algae, fungi, and bacteria to disperse over long distances (Goldstein and Goodwin, 2013). Some of the algal species responsible to cause toxic algal blooms are known to flourish on the surface of microplastics, which in turn get transferred to humans through the consumption of filter-feeding bivalves resulting in several shellfish poisoning syndromes (James *et al.*, 2010).

Some plastic polymers are hydrophilic, they form rapid biofilms around the immediate water surface so that micro and macro-organisms adhere to them leading to biofouling (Andrady, 2011). Biofouling occurs

through the adsorption of dissolved organic molecules, attachment of bacterial cells, unicellular eukaryotes, and larvae and spores (Lobelle and Cunliffe, 2011). Microplastics serve as a vector for various toxic chemicals, metals and other pollutants thereby provide habitat for the growth of bacterial pathogens by co-selection that involves cross-resistance and co-resistance. The role of microplastics in the spread of antibiotic-resistant bacteria in different sites was reported from King George Island, Antarctica (Lagana *et al.*, 2019). The major genetic strategies of bacteria to resist antibiotics are mutational resistance and horizontal gene transfer. Microplastics enhance the horizontal transfer of antibiotic resistance genes in aquatic ecosystems. The same mechanism helps the microbes to resist different toxic compounds including metals and other chemicals in the pollution site (Munita and Arias, 2016).

The presence of microplastics in the microbial habitat could change the community structure as well as microbial functions thereby influence the ecological functions of microbial communities in aquatic ecosystems. Microplastics become the habitat for microorganisms where they enrich and cause greater toxicity to organisms than ordinary microplastics. For instance, *Vibrio* bacteria are less dense in seawater but have a high density on the surface of microplastics that dominate all microorganisms, and enter into other organisms along with microplastics causing colonization and ingestion (Lu *et al.*, 2019). Thus co-contamination of microplastics, metals, and antibiotics results in the development and spread of multiple drug-resistant human pathogens through a co-selection mechanism (Imran *et al.*, 2019). Besides bacteria, zooplankton also plays an

important role in the ingestion of microplastics. The virus is known to survive on the surface of plastics up to 5 d under room temperature and in aerosol for up to 3 h, and recent research proposes that SARS-CoV-2 can accommodate in the form of viral biofilms on microplastics surfaces, and can be deposited more than 100 Km long-distance (Enyoh *et al.*, 2020).

7.2. In invertebrates:

Man-made polymer-based microplastics are abundant in aquatic ecosystems, and the leaching of additive chemicals occurs either by weathering or fragmentation processes. Based on the chemical composition and presence of organic and inorganic additives, the adverse effects of plastic leachates vary from moderate to highly toxic in the invertebrates of freshwater ecosystems. The physico-chemical features of leachants such as permeability of the polymer matrix, space between polymer molecules, nature of the additives, pH, temperature, and salinity of the surrounding medium, and exposure duration are known to influence the fate and effects on the dwelling organisms. The larvae of the marine polychaete worm *Galeolaria caespitosa* ingest neutral-density polymer microspheres of 3-10 mm size (Bolton and Havenhand, 1998). Microplastic stuck in gills may also lead to difficulty in oxygen intake and lead to hypoxia conditions (Pacheco *et al.*, 2018). Benthic invertebrates such as polychaetes were another group of the organism which is found to ingest microplastic as they have a filter-feeding mechanism (Wright *et al.*, 2013b).

The pelagic copepod, *Calanus helgolandicus* on the consumption of microplastics in the form of polystyrene beads altered the feeding behavior, fecundity, and

survival along with energetic depletion over time (Cole *et al.*, 2015). The process of biofouling, fragmentation, and sedimentation of plastics into small-sized and irregularly-shaped polyethylene microplastics allowed ingestion into the dipteran *Chironomus riparius* that significantly impaired the life history traits of the larvae (Silva *et al.*, 2019). Plastic and car tyre rubber leachates such as PET, PP, PS, and PVC microplastics altered gamete fertilization, embryonic development, larval motility, and survival in the Mediterranean mussel, *Mytilus galloprovincialis* (Capolupo *et al.*, 2020).

The presence of microplastic particles in the digestive tube of amphipod, *Cryptorchestia garbinii* detected using Nile red, a lipophilic fluorescent stain, suggested the ingestion of plastic debris confused with food particles (Iannilli *et al.* 2020). The effects of microplastics examined in planaria, *Dugesia japonica* altered the regenerative ability, reduced thickness of the gut epithelium, and lipid content of enterocytes, along with the induction of apoptosis, modulation of Djgata 4/5/6 expression, and also reduced the growth rate (Gambino *et al.*, 2020).

The feeding habit of different freshwater invertebrates vary depending on the size and availability of microplastics with the ingestion of 6-180 particles per h in *Daphnia magna*, followed by *Chironomus riparius* ingesting 226 particles per h, *Physella acuta* about 118 particles per h, *Gammarus pulex* intake 10 particles per h and *Lumbriculus variegatus* consumed 8 particles per h with a maximum size of 1-90 µm microplastics (Scherer *et al.*, 2017). The nematode worm, *Caenorhabditis elegans* exposed to 1 and 5 µm of microplastics at 10^7 to 10^{10} particles/m² for 72 h induced toxic effects on lifespan and

affected defecation rhythm of the intestine at physiological, genetic, and molecular levels (Shang *et al.*, 2019). In the zooplankton, *Daphnia magna* reduction in body size and alteration in reproduction and malformations observed raise concern on the entry of microplastics into food webs (Besseling *et al.*, 2014). *Daphnia pulex* exposed to polystyrene for 21 d slowed the growth rate, reproductive ability, and reproductive pattern and changed the sex ratio (Zhang *et al.*, 2020). Microplastic contamination in the juvenile *Daphnia* revealed modifications in the body length, width, and tail spine length whereas adult showed alterations in the expression of stress-related genes such as HSP60, HSP70, and GST, as well as the genes involved in body function and body composition namely, Sarco/endoplasmic reticulum Ca^{2+} -ATPase gene (Imhof *et al.*, 2017). A study conducted at Leiden University, Netherlands reported a reduction in the total population and biomass of *Daphnia magna* exposed to microplastics under the laboratory condition thereby affect the population dynamics of the freshwater ecosystems (Bosker *et al.*, 2019).

Surprisingly, several mosquito species including *Culex pipiens* ingest and adsorb microplastics based on their size followed by ontogenic transfer from larval, pupal to the adult stage without causing mortality presenting a potential pathway for dispersal of microplastic debris into terrestrial environments (Al-Jaibachi *et al.*, 2019; Cuthbert *et al.*, 2019). The presence of microplastics in three species of freshwater insects like *Chironomus*, *Siphonurus* and *Lestes viridis* collected from the Gulf of Guinea in Nigeria, Africa recorded the highest diversity of plastic debris in the form of ethylene butylene styrene, acrylonitrile

butadiene styrene, chlorinated polyethylene, polypropylene, and polyester (Akindele *et al.*, 2020). Environmentally relevant concentrations of microplastics in sediment induced harmful effects on the development and emergence of *Chironomus tepperi*, with profound effects in the particle size, ranging between 10-27 μm (Ziajahromi *et al.*, 2018).

Polystyrene microplastics exposed to the freshwater mussel *Dreissena polymorpha* altered the behavior and oxidative stress response based on the size of particles indicating the stressor effect of the pollutant in the aquatic ecosystems (Weber *et al.*, 2020). Incorporation of polyvinyl chloride and polyethylene terephthalate to caddisfly, *Lepidostoma basale* under laboratory condition reduced stability and are more prone to predation thereby limited the survival causing instability of food web in the aquatic ecosystems (Ehlers *et al.*, 2020).

Crustaceans are being considered the most affected organism due to their high rate of microplastic consumption as revealed in many studies. *Nephrops norvegicus*, the decapod crustacean, ingest microplastics at 83% in the form of filaments, and 62% were in the form of tightly tangled balls (Murray and Cowie, 2011), and are translocated from the intestines to tissues and the hemolymph in crab, *Carcinus maenas* within 24 h of ingestion (Farrell and Nelson, 2013). Ingestion of polystyrene nanoparticles also affects the feeding habits and physiology in the brine shrimp larvae *Artemia franciscana* (Bergami *et al.*, 2016).

The presence of microplastic fibers, polystyrene beads, colorant particles like dyes, and pigments in the bivalve *Perna viridis* collected from the harbor waters of Chennai,

India, damaged intestine, altered feeding behavior, growth rate, and reproduction (Naidu *et al.*, 2018). Blue mussel, *Mytilus edulis* can able to uptake large amount of polystyrene that get accumulated in the gut and 10 µm size can be easily translocated into the circulatory system (Bouwmeester *et al.*, 2015). Several such studies are reporting the presence, accumulation, and translocation of microplastics on mussels harvested from coastal areas (Von Moos *et al.*, 2012; Goldstein and Goodwin, 2013; Van Cauwenberghe and Janssen, 2014). Microplastics exposure also induced DNA fragmentation in mussels *Mytilus galloprovincialis* (Avio *et al.*, 2015).

7.3. In terrestrial animals:

The raw material used in plastic manufacturing in the form of fibers, pellets, spherules, disc, granules, beads, etc is representative of microplastic litters. Many species of fishes, reptiles, birds, and mammals are directly threatened by entanglement or ingestion, which in turn obstruct the digestive system. The presence of microplastics in regurgitated pellets of the common kingfisher, *Alcedo atthis* collected along the Ticino River, North Italy examined between March and October 2019 from 54 transects using micro-FTIR and SEM-EDS illustrated the presence of plastic ingestion by the top carnivores such as fish-eating birds and impact of microplastic pollution in food webs of freshwater ecosystems (Winkler *et al.*, 2020). Ingestion of microplastics by tadpoles of the common midwife toad, *Alytes obstetricians* limited feeding and growth, induced gut blockage, and altered cardiac activity thereby demonstrated the key role of amphibians in the major transfer path of microplastics from freshwater to terrestrial food webs (Boyero *et al.*, 2019). The presence of micro-fiber in the feces and

feather brushings of southern African duck species indicates that the foraging behavior affects plastic ingestion (Reynolds and Ryan, 2018).

7.4. In fishes:

Evidence of microplastics ingestion in the stomach of several freshwater fishes in the Amazon rivers' documented the presence of plastic polymers in the form of the lost and discarded fishing gear, mainly the plastic polymers including polyester, polyethylene terephthalate, and polyamide released from plastic bottles, bags and threads ultimately harm the health and food security of humans (Andrade *et al.*, 2018). The omnivorous and bottom-dweller freshwater fish were more likely to ingest plastic debris where the minute size, coloration, and buoyancy get attracted as their natural prey (Zheng *et al.*, 2019). Most of the studies focused on the ingestion and accumulation of microplastics in the gastrointestinal tracts, gills, liver, intestine leading to growth retardation, defect in energy and nutrient metabolism, immune and endocrine disruption, oxidative stress, neuronal imbalance, genotoxicity, etc.

Plastic debris ingested through diet is known to disrupt the functions of the endocrine system by the down-regulation of choriogenin gene expression in males, and vitellogenin, choriogenin, and the estrogen receptor gene expressions in females of Japanese medaka *Oryzias latipes* (Rochman *et al.*, 2014). The fishing nets and other nylon products discarded in the mudbank region in Alappuzha District, Kerala, India, was known to enter into the gut of two main species of anchovies namely *Sardinella longiceps* and *Stolephorus commersonnii* in the form of microplastics that threaten human health on

fish consumption (Kripa *et al.*, 2014). The occurrence of microplastics in the range between 11 and 26% was observed in the digestive tract of wild gudgeons, *Gobio gobio* from 11 different sites of French rivers (Sanchez *et al.*, 2014). Polystyrene microplastics accumulated in the gut, gill, liver of the zebrafish *Danio rerio*, and histopathological analysis showed the inflammation and lipid accumulation in fish liver, oxidative stress, and disturbed lipid and energy metabolism (Lu *et al.*, 2016). The occurrence of microplastics in gastrointestinal tracts, gills, liver, and brain of *Oreochromis niloticus* and *Lates niloticus* collected from Lake Victoria, Tanzania revealed the potential impacts of microplastics on the ecosystem and biota (Biginagwa *et al.*, 2016).

Microbeads and microfibers are known to retain in the gastrointestinal tract of the goldfish, *Carassius auratus* showing 90% retention for 33.4 h, but there was no trace of net bioaccumulation in the gut or any tissues (Grigorakis *et al.*, 2017). Polystyrene microplastics are found to accumulate in the gastrointestinal tract and gill tissue in the adult zebrafish that led to the thinning of the muscularis layer in the gut followed by hyperactivity and shortage of energy-supplying substances (Chen *et al.*, 2020). Accumulation of different shapes of microplastics observed in zebrafish caused intestinal injury and dysbiosis of gut microbiota (Qiao *et al.*, 2019; Chen *et al.*, 2020). In another study, zebrafish exposed to polystyrene microplastics decreased body weight and caused metabolic disorder as a result of satiety and low intake of nutrients (Zhao *et al.*, 2019). Histological analysis performed in Japanese medaka *Oryzias latipes* after exposure to polystyrene microplastics

showed cellular alterations in the gastrointestinal tract, spleen, and kidney causing glomerulopathy and nephrogenesis (Zhu *et al.*, 2019). Mostly the plastic polymers such as polypropylene and polyethylene of black color accounted for 25% of ingestion whereas only 13% of the white-transparent fragments were accumulated in the gut of the fish (Baalkhuyur *et al.*, 2020).

The baseline survey of micro and mesoplastics from the gastrointestinal tract of 17 commercial fishes collected from the Southeast coast of the Bay of Bengal, India showed the presence of 20 plastic particulates in the form of polyethylene, polyamide, and polyester polymers causing serious threat to human consumption (Karuppasamy *et al.*, 2020). Fish that ingest microplastics shows adverse effects on growth, reproduction, and survival. Several species of cetaceans that live along the coast of Ireland presented signs of entanglement and ingestion of microplastics, composed of 83.6% fibers and 16.4% fragments in the digestive tract, and most of them were fisheries-related items (Lusher *et al.*, 2018). Ingestion of microplastics of various size and shape to the goldfish, *Carassius auratus* experimentally caused weight loss, and most of the plastic debris without being ingested are chewed and expelled that resulted in inflammation of liver tissues and damages to the gastrointestinal tract (Jabeen *et al.*, 2018). High intake rates of microplastics in the Western Atlantic predatory fish, *Cynoscion acoupa*, was associated with trophic transference in addition to the direct ingestion, and also suggested that longer filaments of riverine origin and smaller filaments of oceanic inputs were actively ingested by juveniles and sub-adults (Ferreira *et al.*, 2018).

Microplastic uptake in fish also depends on the feeding characteristics where *Neogobius melanostomus*, a zoobenthivore had the highest concentration of gut microplastic of about 19 particles/fish than the other fish groups measured (McNeish *et al.*, 2018). A sampling study conducted from 15 rivers at 17 locations in Flanders, Belgium noted that among 78 specimens of gudgeon, *Gobio gobio* investigated, 9% had ingested at least one microplastic item mainly of seven different types of polymers (Slootmaekers *et al.* 2019). Exposure to microplastics in early juvenile Nile tilapia caused haemato-biochemical alterations that may lead to anemia and cause mortality in the fish (Hamed *et al.*, 2019).

Microplastics are known to retain in the gut of juvenile guppy, *Poecilia reticulata* thus impaired digestive performance, stimulated immune response, and induced microbiota dysbiosis in the gut by reducing the activities of digestive enzymes and stimulating the expression of immune cytokines were noted (Huang *et al.*, 2020a). Polyethylene microplastics ingested during the embryonic and larval stage of zebrafish, *Danio rerio* induced transient and extensive change in larval gene expression without apparent immediate effects on larval development and physiology (LeMoine *et al.*, 2018). A biomonitoring study conducted in the Greater Melbourne Area of Australia noted the presence of microplastics in the body of the fish, *Gambusia holbrooki*, and interestingly found that the female individuals ingested more microplastics than males under the controlled laboratory conditions (Su *et al.*, 2019). Polystyrene microplastics exposed to guppy, *Poecilia reticulata* declined the activity of Na⁺/K⁺-ATP stating the interference in osmotic balance of gills, while the activity of

catalase was at the highest index (Huang *et al.*, 2020b).

Polystyrene microplastics exposed to adult zebrafish accumulated in the gastrointestinal tract and gill but were not detected in muscle and brain tissues. There was no oxidative stress and histological changes, however, induced behavioral abnormalities such as hyperactive swimming in the fish (Chen *et al.*, 2020). On contrary, microplastics caused the overproduction of reactive oxygen species and alterations in the antioxidants parameters resulting in oxidative stress and DNA damage in Nile tilapia *Oreochromis niloticus* (Hamed *et al.*, 2020). Polyvinyl microplastics when exposed through diet induced oxidative stress and hepatic damage in *Clarias gariepinus* (Iheanacho and Odo 2020a), and caused variations in hematology, antioxidant enzymes, lipid peroxidation, and acetylcholinesterase activity in African catfish *Clarias gariepinus* (Iheanacho and Odo, 2020b). The impact of polyvinyl chloride microplastics was noted in *Cyprinus carpio* by altering the antioxidant-related gene expression (Xia *et al.*, 2020). Besides, nanoplastics also induce neurobehavioral dysregulation, reproductive impairment, and oxidative damages in zebrafish at the molecular level, which in turn reduce the survival fitness in the aquatic ecosystem (Sarasamma *et al.*, 2020). In a comparative study, it was found that nano-sized microplastics easily enter through the epidermis into the muscle tissues and damage muscle and nerve fibers, inhibit acetylcholinesterase activity, and affected larval movement than micron-sized microplastics in the larva of goldfish *Carassius auratus* (Yang *et al.*, 2020).

The toxic effects of microplastics and their bioaccumulation in the gastrointestinal tract have been studied in detail in many fish species while relatively few studies focused on the impacts in other tissues. Moreover, hardly a very less number of researches evaluated the toxicological impacts of microplastics on the environmentally relevant concentrations. Thus more studies are required for assessing the toxicity of microplastics in various animal models for a better understanding at the ecosystem level.

7.5. In aquatic mammals:

Marine mammals such as seals, whales, and dolphins consume a large amount of microplastic debris using raptorial feeding strategy thereby lead to trophic transfer (Hocking *et al.*, 2017). Antarctic fur seal *Arctocephalus tropicalis* that consumed the species of fish, *Electrona subaspera* contained plastic particles of size ranging from 2 to 5 mm in their feces that reflected the trophic transfer of microplastics (Eriksson and Burton, 2003). Similarly, the stomach and intestine of the harbor seal *Phoca vitulina* also contained plastic debris (Rebolledo *et al.*, 2013). The microplastics trapped in the stomach result in physical trauma including alteration in the normal feeding behavior before death (Lusher *et al.*, 2017).

Baleen whales are found to ingest microplastics than large plastic debris because of the selective filter-feeding than the toothed whales that are entangled by plastics (Baulch and Perry, 2014). The gut passage time, retention time, and excretion rate of microplastics in Baleen whales mainly depend on the size and type of plastics, the composition of stomach contents, and gastrointestinal tract (Fossi *et al.*, 2014). A

study conducted on the coastal dolphins suggested that those who live in the seabed consume more microplastic debris than the surface dwellers (Di Benedetto and Ramos, 2014). The number of microplastics consumed by the sperm whales in the North Sea was about 322 polymers of various sizes (Unger *et al.*, 2016), and the humpback whales ingested about 45 microplastic particles, which include PE, PP, PVC, PA, and PET (Besseling *et al.*, 2015).

8. Microplastics threat on human health:

Humans are considered as the most exposed organisms than other vertebrates as they occupy at the top of the food chain. The microplastics that form biofilm around the surface of the microorganisms get transferred into the food chain and enter the human (Mincer *et al.*, 2016). Thus microplastic can disperse the microbial community over a large distance across the ocean. Use of high throughput sequencing techniques revealed the presence of a bacterial community that is responsible for pathogenesis in corals, humans, and fishes (Jiang *et al.*, 2018). In another study the presence of a fish pathogen *Aeromonas salmonicida* on microplastics was identified in marine water, this pathogen also causes human infection by the consumption of infected fishes (Rummel *et al.* 2017). One of the studies conducted in Baltic seas found the presence of human bacterial pathogens like *Vibrio cholerae*, *Vibrio parahaemolyticus*, and *Vibrio vulnificus* on the surface of polystyrene, polyethylene, and polypropylene microplastics (Kirstein *et al.*, 2016). Effects of microplastics at different biological organizations such as biochemical, enzymatic, reproductive, developmental, genetic, and molecular levels are needed to be focused on various organisms, including humans.

9. Regulations and safety measures:

There is little or no awareness about microplastic pollutants among the public than macroplastic contamination. There were many management strategies and guidelines provided by various organizations including The United Nations Expert Panel of the United Nations Environmental Programme that engage over 40 million people from 120 countries to educate the public on the awareness to decrease the usage of plastic products, encourage recycling, and to evaluate disposal facilities (UNEP, 2014).

A bill has been imposed in California to ban the single-use of plastic bags, and Scotland banned around 650 million bags from entering into the waste stream (Plastic Pollution Coalition, 2016a, b). The federal administration of different countries such as Canada, Austria, Australia, Belgium, Luxembourg, Netherlands, Germany, and Sweden also imposed the ban for the use of microbeads in personal care products like facial scrubs, washing detergents, creams, and toothpaste (Perschbacher, 2016). In India, The National Green Tribunal (NGT) directed the government to monitor the use of microbeads in cosmetics. In May 2017, the Bureau of Indian Standards (BIS) classified microbeads as unsafe for use in cosmetics but still used in many national and international brands including herbal products, consisting 50% in the face wash and 67% in the facial scrubs (Miraj *et al.*, 2019). According to the recent survey of the Central Pollution Board of India, 6 million tons of plastic waste is produced in India annually from cosmopolitan cities like Delhi, Chennai, Kolkata, and Mumbai producing 690, 429, 426, and 408 tons per year, respectively. The risk of microplastics in the environment can be

avoided by using plastic items synthesized by biodegradable materials, maintaining proper plastic waste management, and recycling.

Plastic debris as an environmental contaminant is an emerging international issue in recent years. Currently, microplastics in the environment are eliminated by conventional destructive thermal treatment like pyrolysis, by decomposition in the absence of oxygen, or by combustion/burning in the presence of oxygen (Geyer *et al.*, 2017). Recently, microplastic pollution is monitored in the Ottawa River, located in Canadian provinces, by engaging citizen scientists as a volunteer network in collaboration with microplastics researchers. However, citizen science has been criticized as it faced publication issues, and other limitations including bias, potential error, reliability of data collection, training or oversight, lack of appropriate protocols, and concerns of replicability, comparability, and completeness. Despite the limits, citizen science offered an inexpensive method to improve microplastic monitoring programs (Forrest *et al.*, 2019).

There are certain legislations put forth by the government to ban some products that are considered as the major contributor to plastic debris. It includes a ban for single-use plastics like straws, cups, plates, and bags, avoids the use of plastic microbeads in personal care products, and to promote the use of safe alternatives in the market.

10. Do bioplastics replace plastic wastes?

Bioplastic is the biological plastic or bio-based plastic, made of biodegradable material that is obtained from renewable sources such as agricultural byproducts, recycled food waste, vegetable fats and oils, wood, grass, algae, etc. Most widely used bioplastics include starch-

based, protein-based, cellulose-based, and lipid-derived polymers. The bioplastics which are derived from food crops are called first-generation feedstock, and those derived from non-food crops are second-generation feedstock whereas algae and seaweed-derived bioplastics are the third-generation feedstock (Chen and Patel, 2012). Bioplastics are widely used as microbial control agents in agricultural and horticultural crops (Accinelli *et al.*, 2015).

The production and demand of bioplastics are increasing tremendously all over the world to replace microplastics used for industrial and commercial purposes. However, the research on the effects of bioplastics is in its infancy, and it is understood that biodegradable plastics are not fully degradable; however, their persistence in the environment is not studied. Bioplastics also face many challenges before they get recycled so a well-managed system can make them economically useful to society.

Conclusion

The plastic-dependent lifestyles of modern and educated societies are the major contributors to the microplastic pollution on the Earth. The primary focus of the review is to provide awareness to the urban population on the influence of microplastic pollution, their ecological toxicity to terrestrial and aquatic organisms, and humans. Improved detection and characterization techniques in research may help for the prevention and control of microplastic contamination. Community awareness and a new education system make the public conscious of this problem. Besides, encouraging more research globally can alleviate the ecological consequences of plastic pollution mainly

through an environmentally friendly approach. The conclusions of the review are to alert the need for more responsible use of plastics, especially by urban communities, and to promote more strict regulations by the governments of developed and developing nations for the production, handling, and discharge of the enduring chemicals.

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