A Review on Microplastics - An Indelible Ubiquitous Pollutant

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Abstract: With the advent of the 20th century, the usage of plastics and the plastic manufacturing industries have risen sharply. Plastics have become an irreplaceable part of our day-to-day life as most of the gadgets/consumables that we use are made of plastic. The improper disposal and management of plastics have impacted our planet negatively by polluting the soil and water. Furthermore, plastics are not biodegradable and persist in nature for a longer duration. The emerging issue with plastics persisting in the environment is the formation of microplastics. Any plastic particles whose length is less than 5mm are classified as microplastics. Owing to their small size, these microplastics can pollute with ease. The widespread presence of such microparticles has deleterious effects on the ecosystem and affects the life contained in it. This review focuses on the different sources of the microplastics, their classification, the various means by which microplastics are distributed in the environment, its isolation, detection, and characterization of microplastics from the environmental samples, the toxicological effects of microplastics on different life forms, and control and clean-up of microplastics from the environment.

Keywords: plastics; microplastics; eco-toxicology; environment; clean-up; human health; marine pollution.

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1. Introduction

Plastics are synthetic organic polymers that are derived by the polymerization of monomers extracted from gas or oil. Plastics are preferred and over manufactured due to their inert, durable, lightweight, and corrosion-resistant properties. These properties led to the extensive use of plastics with inexhaustible applications [1]. The plastics' chemical inertness made them more resistant to the complete degradation by the conventional degradation process and made them stand over the centuries without complete degradation [2]. Annually, millions of metric tons of plastics are produced globally for diverse purposes. It is alarming to know that a considerable portion of these plastics is discarded after their purpose [3]. Geyer *et al.* [4] estimated that from the plastics that are being generated as wastes, only about 9% of them are being recycled. About 12% of these wastes are being burned, and the remaining 79% of these plastics end up in the natural environment. Accumulation of the plastics occurs either by direct dropping or dumping of plastic litter on land or at sea or being blown from landfill sites, or by losses in transport and accidents. These plastics then end up in marine habitats worldwide, thus polluting them. The major concerns about these accumulating plastics are that they are non-biodegradable and can persist in the environment for centuries [3, 5]. Several groups of plastics like Polyethylene, Polypropylene,

Polystyrene, Poly(ethylene terephthalate), and Poly(vinyl chloride) are commonly utilized by the industries [6]. Not only the scale of production but the great durability of plastics being produced, poor recycling rates, and mismanagement of plastics have resulted in the accumulation of plastic debris everywhere on the earth [1, 7-8].

Despite its durability and inertness, recent studies have indicated that these plastics could be degraded when they are exposed to certain factors. In the environment, atmospheric agents like ultraviolet radiation, waves, corrosion, and photo-oxidation in combination with bacteria break these plastics into micro and nanosized particles [9]. These micro-sized plastics have a small size and low density, allowing them to persist in the environment for longer, transforming into a growing environmental hazard [10]. Therefore, Microplastics emerged as the global challenge in which the major concern involved the disposal of these smaller particles from the ecosystem [11]. In general, Microplastics are defined as a heterogeneous mixture of differently shaped materials referred to as fragments, fibers, spheroids, granules, pellets, flakes, or beads whose size ranges between 0.1 and 5,000 μ m [12]. Their shape can be flat, oblong, cylindrical, and disk-shaped pellets. Some are spherical to ovoid with rounded ends [13, 14]. In general, microplastics are composed of polyethylene terephthalate (PET), nylon, polyvinyl chloride (PVC), and polystyrene (PS) [15].

In the beaches, prolonged weathering of the macro plastics resulted in the degradation by surface embrittlement and microcracking, making these particles easily carried into the water by wind or wave action [6]. Microplastics released into the ocean or other water bodies have a higher chance of ending up in the food cycle of marine life by indirect consumption. This, in turn, pollutes the seafood that we consume [12]. These microplastics are found in sediments of both marine and lacustrine environments [16]. But the ill effects of the microplastics in our diet are yet unknown [17]. It is of alarming concern to note that recently microplastics have become a greater threat to the terrestrial ecosystem. When these microplastics interact with the biota, it causes changes in the geochemistry and biophysical environment. This, in turn, leads to an alteration of the ecosystem as a whole [18].

Studies have shown a greater accumulation of microplastics has affected the countries in Africa, Asia, North America, Europe, and South Africa [19]. Microplastics reserve the frontline of current environmental pollution as they can easily migrate from the environment to living organisms' including mammals [9,20]. The most challenging part of dealing with microplastics is the identification of microplastics in the environment and their characterization. This is due to the fact that they can be easily mystified with organic or other types of compounds of similar origin. The other major challenge faced with microplastics is the removal of its remanents from the environment [21]. Also, microplastics act as vectors for microorganisms, heavy metals, and toxic chemicals, which pose health risks [22-25].

The objectives of this review include the classification of microplastics, the plethora of sources of microplastics that end up in the environment, the various micro plastic isolation techniques, the effect of microplastics on the environment and the health of living organisms, and the various measures to control the microplastics from reaching the environment.

2. Microplastics and its classification

Plastics are considered one of the most omnipresent and long-lasting pollutants. Recent concern in the usage of plastic is its fragmentation and accumulation on the earth's surface. Accumulation of plastics is due to their low recycling rate and long durability. The accumulated large pieces of plastic will gradually degrade into microplastics [26]. Plastic pollutants were https://biointerfaceresearch.com/

classified as macro-debris whose size is greater than 20 mm diameter, meso-debris whose size ranges between 5 and 20 mm, and mega-debris where the size is greater than 100 mm (Figure 1) [7]. Macro-plastics are mostly in the form of smaller fragments, which are readily visible to the naked eye [27]. Microplastics have been considered pollutants since the turn of the century. Microplastic is attributed to small plastic fragments, granules, and fibers [1]. It is difficult to define and classify microplastics as inconsistencies exist between studies, making it difficult to create a scientific standard. Moore [28] divided the plastic debris into two classes based on their sizes in which the macro plastics are larger than 5 mm while the microplastics are smaller than 5 mm. Graham and Thompson [29] defined microparticles are particles with diameters less than 10 mm, whereas Barnes et al. [7] and Betts [30] defined them to have less than 5 mm. Derraik [9] proposed the size to be between 2 and 6 mm, Ryan et al. [31] suggested diameters less than 2 mm, and several works of literature recommended the size of these particles to be less than 1 mm [32-34]. Recent studies indicated that some plastic particles present in the ecosystem measured to be much smaller, i.e., in nanometer-scale (<1 µm), and were termed "Nanoplastics" [35]. Based on the origin, microplastics are classified as primary microplastics, secondary microplastics, and nano plastics [36].



Figure 1. Classification of plastic litter based on their size as microplastics, macroplastics, mesoplastics, and megaplastics.

2.1. Primary microplastics.

Primary microplastics can be defined as small-sized plastics and are presented as microplastics by design. Primary microplastics are produced directly from the consumer products like cosmetics or indirectly during the manufacture of plastics, i.e., precursors for virgin resin pellets or nurdles [5, 37-39]. Microbeads used in cosmetics, pre-production pellets, or the discharge from the washing machine to the wastewater containing acrylic textile fibers from the clothes were directly inputs of primary microplastics [40- 41]. The two major components that are

present in the micro debris include (i) the broken fragments from larger objects and (ii) the thermoplastic feedstock like resin pellets and powders [28]. The emission of primary microplastics by the individual country depends upon the population and economy of the nation. Wang *et al.* [39] estimated that the mainland of China is the highest accumulator of these microplastics. It is predicted that each individual in China uses up to 538 g of microplastics in a year. These microplastics are generally the by-products of particulate emissions released from industrial production, i.e., plastic dust from plastic products [42]. Primary microplastics are also found in the most commonly utilized products used in daily life [19, 39].

2.2. Secondary microplastics.

Secondary microplastics are formed from larger plastic debris due to combined actions of chemical, physical, biological, thermal, photic, and chemical processes [19,43]. Secondary microplastics are described as weathered, embrittled, irregularly sized and shaped, degraded chunks of plastics [44]. The fragmented microplastics are mainly in the form of angular, rounded, sub-angular, and subrounded. These are also represented in the form of sharp, rough, degraded, and broken edges [14]. Masiá *et al.* [5] reported that secondary microplastics are derived from the degradation of the larger sized plastics by exposing them to high temperature and UV radiation. It can also be reported due to a combination of mechanical forces and the photochemical process triggered by sunlight [40]. Weathering of plastics causes large-sized plastic material to break down into smaller fragments. This is also affected via combined processes involving mechanical and chemical weathering, causing the embrittling of larger plastics to secondary microplastics [42, 45]. This breakdown seen in microplastics results in an increased surface area that influences the growth of biofilms over these microplastics [46]. Polyethylene type of plastics is found to be more susceptible to be broken down via mechanically related weathering processes than polypropylene related plastics [47].

2.3. Nano-plastics.

Nanoplastics are tiny plastics of sizes less than 100 nm. Nanoplastics are generated during the fragmentation and weathering of microplastic debris and can also originate from engineered material [12]. Exposure of plastic debris to solar radiation catalyzes the rate of the photo-oxidation process, making them more brittle. Abrasion and wave action further degrades the plastics fragmentation to micro-sized $(0.1 - 1000 \ \mu m)$ and nanosized ($\leq 0.1 \ \mu m$) particles [48]. Nanoplastics are discovered under marine debris, but more research is required in this unexplored area to characterize these particles. The major concern revolving around these nano plastics is that they could not be purified by the conventional purification methods, making their detection in the samples nearly impossible. This makes it quite difficult to develop standard protocols to detect these nanoparticles from the environment [49]. Another concern is that the effect of these nanoparticles on the health of humans is still undiscovered. Other undiscovered studies on these nanoparticles include their effects in the cooking processes, whether upon ingestion these microplastics can be degraded to nano plastics in the gastrointestinal tract, and the plausible consequences of the nano plastics when they enter into the body. This is because of the toxicity effects shown by some engineered nanomaterials. Also, there are no existing standard protocols methods to detect the nano-plastics in food, especially seafood [12].

3. Distribution of Microplastics

3.1. Distribution of microplastic in soil.

There is very little knowledge on the source of microplastics and their occurrence in the soil. Studies have shown the role of earthworms in the formation of secondary microplastics. This occurs due to the ingestion and digestion of the normal plastics by the worms. This makes the plastics brittle leading to the formation of smaller fragments [50]. The other possible source of microplastic pollution in the farmland was speculated to be road dust, garbage, industrial plastics, soil sedimentation, and atmospheric deposition [51]. The microplastics are accumulated in the soil by the direct discharge via plastic mulching, or the fertilizer application of plastic containing compost and the indirect effect made by the input of untreated wastewater, sewage, as well as flooding with river and lake water contribute the major pathway for the plastic into the soil [52]. In practice, mulching results in a higher amount of plastic debris accumulation, which further accumulates in the agricultural soil [53]. Also, the composition and nature of microplastics varied between the different layers of the agricultural soil. Highly dense microplastics remained in the depths of the soil when compared to the soil surface [54]. Polyester and polypropylene were the commonly occurring type of microplastics seen in the soil [55].

3.2. Distribution of microplastic in air.

Pollution by airborne microplastics poses a new challenge. Based on the study conducted using a Breathing Thermal Manikin, it was predicted that humans were highly exposed to indoor airborne microplastics [56]. Very few studies are available to speculate the effects of airborne microplastics on humans [57]. Dris *et al.* [58] did a comparative investigation on the fibers in the indoor and outdoor air, as well as indoor settled dust. They reported that the fiber concentrations in the outdoor air were significantly lower than in the indoor air. In their study, Trainic *et al.* [59] reported the presence of microplastics made of polysilicone, polyethylene, polystyrene, and polypropylene in the remote North Atlantic Ocean's marine atmosphere. Two-thirds of the total textile fibers produced are synthetic and plastic fibers. Fibrous types of microplastics undergo photo-oxidative degradation. These degraded particles further undergo fragmentation when combined with the wind shear. This degrades the microplastics into fine particles and is eventually exposed to the air [60]. Airborne microplastic particles were observed over terrestrial, coastal locations, and remote marine atmosphere [59]. As the microplastic particles are less dense than soil, they can be airborne and easily travel longer distances than natural dust particles [61].

3.3. Distribution in marine and freshwater ecosystem.

In the marine environment, microplastic pollution has become a major global environmental challenge [62]. The ever-growing concern in the marine environment is due to plastic debris discharge. The presence of microplastics in these marine environments is ascribed by the plastic wastes disposed of by the people and industries in the nearby areas. The event of plastic degradation is slower in the marine ecosystem compared to the plastic wastes present in the land. The growing population demands more seafood, which increases the rate of commercial fishing. This indirectly indicates the growing requirement for plastic fishing gear [63]. Abandoned, lost, or discarded fishing gear (ALDFG) adversely affects the coastal and marine ecosystem [64]. To overcome the drawbacks of using natural fibers for fishing, the fishing industry has transitioned towards the usage of plastic nets. Nylon, Polypropylene and polyethylene

are primarily used in fishing gear applications [65]. Plastic facilities are the main source of microplastics in surface seawater, and intensive mariculture was identified as the major source of this microplastic pollution. For example, it contributed to nearly 62.76% of microplastic pollution in Sanggou Bay [62]. Yang *et al.* reported that fibers with particle size less than 1 mm are dominant in freshwater sediment samples. Also, the most frequent type of microplastics includes either PE or PS [66].

In recent decades, Plastic litter in the marine ecosystem has been a major global environmental concern affecting all parts of our oceans [38]. Fiber-type microplastics are commonly reported [17]. Engineered microplastics are introduced into aquatic environments by direct discharge or accidental spills after use [38]. Microplastics have been observed on the shore, sea surface, and seabed from the coast to the open ocean, including the Arctic Sea and Atlantic waters to the north of Scotland [38,67]. Microplastics have been reported in surface waters, shorelines, and seabed from the coast to the open ocean globally [67]. Plastic fishing gears such as Buoy, line, net, and other fishing gears and also plastics such as Bucket, Bottle, foamed polystyrene, plastic bag/film, and miscellaneous plastics were observed in the shorelines of South Africa, Chile, the Hawaiian Archipelago and Atlantic coast of North America contributes majorly for the microplastic pollution [68].

Rivers can act as the vector for the cause of microplastic pollution in the ocean. A study conducted by Rech *et al.* [69] concluded that rivers carried large amounts of anthropogenic litter from inland sources to the ocean and coastal beaches of the southeast Pacific region. The floating spherical microbeads labeled as polyethylene or polypropylene used in cosmetic/cleaning products and wastewater contributed to the presence of primary microplastics in freshwater bodies [70]. Microplastics are also being detected in freshwaters of Europe, North America, and Asia. The types of forces involved in the transport of microplastics in freshwater are similar to that of the marine ecosystem [71].

3.4. Distribution of microplastics in ice.

Microparticles from terrestrial regions that runoff to the marine regions pose a great threat to the polar regions, coastal areas, oceans, seas, rivers, and lakes [19]. In recent decades, the pollution of microplastics in the Arctic Ocean posed a major concern as the melting of ice released a substantial quantity of microplastics into the ocean [67]. Higher concentrations of microplastics are observed in the artic ice when compared to the surface seawater as it impacted the properties of sea ice present. East Antarctic fast sea ice is the potential reservoir for microplastic debris in the Southern Ocean with an average of 11.71 particles/L. Polyethylene, polypropylene, and polyamide-type microplastics were commonly identified [72]. Geilfus *et al.* [73] performed the microcosm experiment to evaluate the change in distribution and effects in sea ice conditions by adding microplastics. The experiment revealed that the higher concentrations of microplastics resulted in increased ice salinity and changes in sea ice albedo by affecting the depth of light penetration, thereby altering the photochemical and photobiological processes in sea ice. But these microplastics did not affect the growth of sea ice and its total thickness over the timescale. It is also assumed that the presence of microplastics in the arctic surface water is readily incorporated in ice during the initial stages of ice formation. It remains in the ice until the event of melting.

3.5. Distribution in sewage.

In municipal and surface water, effluents of washing machines are the major source of microplastics [21]. Synthetic fibers released from the clothes are released into the sewage along with wastewater effluent. These sources account for the occurrence of microplastic fibers in municipal sewage treatment plant sludge and effluent [74]. Secondary microplastics arising from polyester, acrylic, and polyamide fibers from washing clothes present in the household effluent are majorly found at sewage disposal sites [71]. A study showed the occurrence of Microplastics in high concentrations found in sewage treatment sludges in Great Britain. The forensic evaluation estimated that waste effluent from the washing machines from a single garment produced an average of more than 1900 fibers/wash [75].

Settling tanks are not designed to capture lighter microparticles like polyethylene and nylon. Hence these particles do not settle with flakes by the activated sludge layer. In addition, these types of particles are not removed by the primary settlement process nor by the addition of flocculants and coagulants. The usage of microbeads in personal care products and synthetic fibers in the textile industry has a greater impact on aquatic ecosystems. Another possible way that can lead to microplastic emission in the sewage is that rainwater washes out some plastic wastes from roads, sewages, wearing tires, and construction materials that finally make their way to sewage treatment plants [76].

4. Isolation of Microplastics from the Sample

Different methods have been developed for determining microplastics in water and other sediments [40].

4.1. Sieving.

Microplastics can be isolated by selective sampling from the marine environment through direct visualization on the sediment's surface [14]. The protocol involves sieving sediment samples from the top layer of the beach through a set of nested sieves. The smaller plastic particles are sorted out by using the Tyler sieves, and the remaining particles were oven-dried at 65° C. Only the plastic particles in the range of 1–15 mm in size were retained from each sieve tray. Preliminary sorting allows the sorting of plastics based on sizes and simplifies the detection of microplastics. Further sorting helps to separate the microplastics into fragments, foams, pellets, lines, and films [52].

4.2. Density separation.

In general, the density of microplastics ranges between 0.8 and 1.4 g/mL. The ranges of the density of common microplastics are polypropylene (0.85-0.94g/mL), polyethylene (0.92-0.97g/mL), and polystyrene (0.05 to 1.00 g/mL), whereas the free-floating plastic films may slightly have a higher density [63]. The sand and the marine sediments have a comparatively greater density of about 2.65 g/mL than the microplastics. This difference in density contributes to separating smaller plastic particles from the denser sediment samples by mixing the samples with a saturated solution and shaking the sample for a certain period [14]. The solutions used for density separations are sodium polytungstate solution with a density of 1.4g/mL [77], seawater, saline NaCl solution [14], tap water [78], and hypersaturated saline of 1.2 g/mL [79]. Among these solutions, tap water is suitable for floating any plastics previously floating on the sea [78].

Polyethylene, polypropylene, and foamed forms of polystyrene microplastic types float in fresh and seawater. The solid form of Polystyreneolid form floats in a hypersaturated saline solution. Plastics that float in sodium polytungstate solution are polyvinyl chloride (PVCs), polyethylene terephthalate (PETs), and nylon [79]. Microplastics of Light density polyethylene type (LDPE) were removed efficiently from soil samples by floatation method using distilled water. Three-time floatation or an ultrasonic method was required to extract the microplastics from the soil. LDPE and polypropylene microplastics can be effectively extracted from the soil sample by a repetitive floatation process [54]. Higher separation of microplastics (95.5 \pm 1.8%) from the sediments was achieved when Munich Plastic Sediment Separator (MPSS), a density separator used to quantify plastic particles, was employed [50,80].

4.3. Pressurized fluid extraction.

Pressurized Fluid Extraction (PFE) is a technique utilized to quantitatively extract plastic particles whose size is less than 30 microns. Pressurized fluid extraction uses dichloromethane and methanol solvents and is operated at a cell temperature of 180°C at a pressure of 1500 psi to identify the microplastics present in municipal wastes and soil samples. By applying heat, the microplastics are isolated from sample impurities by comparing the change in shape before and after heating. PFE can efficiently identify the microplastics compared to the techniques like flotation [52,81]. Furthermore, evaluation of the microplastics can be done with the empirical model [54].

4.4. Detection of microplastics.

Micro- and nanoplastic particles are extremely complex and diverse in terms of their size, shape, density, polymer type, surface properties, etc. [82]. The characterization of micro/macro plastics is important to determine their distribution and impact on the environment. The dense plastic debris in contact collides with a higher impact with sediment particles than lighter microplastics. The variation between these smaller plastics arises due to their multiple shapes, size, origins, and surface characteristics of microplastics. The modern instrument techniques for the characterization of microplastics are Raman and Fourier-transform infrared spectroscopies and microscopy; pyrolysis and thermal desorption by gas chromatography and other imaging techniques [21]. For microplastic characterization and identification, mass-based and particlebased techniques are frequently employed. Mass-based techniques include thermal extraction desorption-gas chromatography/mass spectrometry (TED-GC/MS), **Pyrolysis** gas chromatography-mass spectrometry (Py-GC/MS), Matrix-assisted laser desorption/ionization -Time of Flight – Mass spectroscopy (MALDI-ToF – MS), quantitative Nuclear Magnetic Resonance (qNMR), Differential scanning calorimetry (DSC) and High-Performance Liquid Chromatography (HPLC) are employed. Particle-based techniques include Attenuated total reflection- Fourier transform Infrared spectrometry (ATR-FTIR), micro - Fourier transform Infrared spectrometry (µ-FTIR), µ-Raman spectroscopy, Coherent anti-Stokes Raman scattering (CARS), Near-infrared spectroscopy (NIR), Stimulated Raman scattering (SRS), and Time of Flight - Secondary Ion Mass Spectrometry (ToF-SIMS) [82, 83].

Typically, microplastics are examined using Raman spectroscopy, Fourier-transform infrared (FTIR) spectrometer, and a laser infrared imaging system [56]. The application of FTIR spectroscopy enables the identification of the different types of plastic [33]. The number of microplastics present in the sample could be identified by combining the microscope and FTIR

method [84]. Laser Direct Infrared imaging technique is used to identify the size and the type of microplastics. Rummel *et al.* [46] reported using flow cytometry to detect microplastics from environmental biofilms. Microplastics could be counted using optical microscopy, and the photograph can be observed by direct microscopic visualization. The authentic number of microplastics was evaluated by conforming to the μ -FTIR analysis [62]. Sun *et al.* [85] reported using AxioCam Hrc connected to a stereomicroscope to count and image the microplastics from the seawater and zooplankton samples. Each microplastic's length, width, and size composition were measured manually using ImageJ software. The chemical composition of the microplastics was analyzed by the μ -FTIR microscope (detection limit -10 μ m). Similar reports on the use of Stereomicroscopy and μ -FTIR were reported by Zhou *et al.* [86]. Zhang *et al.* [54] determined the number and size of microplastics using a camera that was connected to a microscope.

Ragusa *et al.* [9] morphologically characterized microparticles by a 100x objective (Olympus MPLAN 100x/0.90) lens. Raman spectroscopy was performed, and the obtained spectra were compared with the SLOPP Library of Microplastics and KnowItAll software of spectral library. Similarities (>80%) of the Hit Quality Index (HQI) were considered satisfactory. Liu *et al.* [87] confirmed the presence of microplastics by identifying the polymer using micro-transformed infrared spectroscopy under the transmittance mode. The polymer composition of the microplastics was detected with the use of the spectra database of Hummel Polymer and Additives and Polymer Laminate Films. For the quantification and measurement of microplastics, nano measures were used.

5. Effects of Microplastics

The various harmful effects of microplastics on humans, birds, marine organisms, agriculture, and soil are outlined in Figure 2.

5.1. Effects on human beings.

Microplastics have exhibited ecotoxicological effects such as cytotoxicity, neurotoxicity, mortality, reproductive impairment, genotoxicity, biotransformation of enzymes, physical and behavioral effects, oxidative stress and damage, and effects on blood and hemolymph [76]. Humans are exposed to microplastic particles via drinking water, food, and air via ingestion, inhalation, and dermal absorption [21-22, 89 -90].



Figure 2. The harmful effects of microplastics on soil and living beings.

The ingestion of plastics in the form of microplastics facilitates the transportation of hazardous chemicals into the organisms. The larger surface area of this type of plastic has the greater transportation of contaminants [2]. It was estimated in a study that, on average, humans may ingest about 0.1 -5g of microparticles through several exposure routes [91]. Ragusa *et al.* [9] reported microplastic fragments (size $\sim 10 \ \mu m$) being detected in the placenta of humans. These microplastics are comprised of stained polypropylene and microplastics remnants from manufactured coatings, paints and finger paints, adhesives and plasters, polymers, cosmetics, and personal care products. The isolation of the microplastics from the human placenta reveals the drastic exposure of humans to the plastic environment [9].

Schirinzi *et al.* [92] evaluated the cytotoxicity effect of microplastics by testing oxidative stress and cell viability. Polyethylene (PE) and Polystyrene (PS) type microplastics were employed for the study using human cell lines like T98G cerebral cells and HeLa epithelium cells. After a period of exposure of about 24h on cell lines, the information on oxidative stress effect of microplastics (10 ng/mL to 10 μ g/mL) was assessed. Dose dependant results were observed. In the oxidative stress study, the generation of reactive oxygen species (ROS) by polyethylene and Polystyrene microplastics significantly affected T98G cerebral cells. Also, Polystyrene type presented the oxidative stress effect on HeLa epithelial cells with an increase in ROS. In the cell viability study, polyethylene and polystyrene type microplastics did not produce the cytolysis effect on tested cells.

The intensive microplastic pollution in mariculture poses a major threat to seafood. When humans consume these products, there is a fair chance of developing health problems [62]. These particles are found to have the capability to cross biological barriers and exert toxic effects. These plastic particles have a larger surface area favorable for several organic pollutants to be adsorbed on the surface resulting in bioaccumulation and bio-amplification [49]. Fibrous microplastics have been observed in atmospheric fallouts. These microplastics result in lung inflammation by stimulating the biological response [60].

5.2. Effects on birds.

In a study, Zhao *et al.* [93] found that 16 out of 17 terrestrial birds were identified to have a microscopic anthropogenic litter (size - 0.5 to 8.5 mm) in their gastrointestinal tracts. On further examination, the microscopic anthropogenic litter was found to be Natural fibers (37.4%), plastic fibers (54.9%), and fragmented plastics (7.7%).

In the terrestrial food web, if the birds were found to have higher densities of microplastics than their aquatic counterparts, it could be potentially due to microplastic ingestion by direct intake or indirect consumption via trophic transfer. Larger quantities of microplastics were found in red-shouldered hawk's gastrointestinal tracts indicating that the species is much more affected by plastic pollution [94].

5.3. Effects on the marine ecosystem

Microplastics are paramount to marine plastic debris. A study on microplastic pollution in surface seawater from Sanggou Bay, China, showed that over 96.15 kg of microplastics were present on the sea surface water [62]. Microplastics are very small in size and easily ingested and accumulated by aquatic animals or through trophic transfer, leading to harmful effects [85,95-96]. Jeong *et al.* [97] reported size-dependent toxicity of microplastics in the monogonont rotifers

where smaller microplastic particles induced more toxicity than the larger ones. Also, microplastics of very small size were easily ingested and accumulated by aquatic animals, which led to harmful effects [85]. Li *et al.*, in their study, reported that microplastics were more ingested by swallowing-feeding fish than filtering-feeding and sucking-feeding fish [98]. The more recognized problems of the plastic debris associated with ingestion, entanglement, and suffocation that were suffered by the associated marine organisms ranging from zooplankton to cetaceans, seabirds, and marine reptiles [99].

5.4. Effects on terrestrial ecosystem.

5.4.1. Effects on agriculture and soil.

Contamination of Microplastic in agroecosystems is a threat of global importance. Farmlands that have been mulched are found to contain a greater amount of microplastics than non-mulched land. The microplastics, whose origin is from fibers and films, dominated the mulched land. The characteristic feature of these microplastics was that they were relatively larger when compared to the microplastics found in irrigation water [86]. These microplastics pose a great threat as they can change soil's biochemical and physical properties [87]. Substantial use of plastic mulching and compost exploits the farmland by exposing the land to microplastics, resulting in the breakdown of plastic debris in farmland soils into smaller sizes of fragments [51]. Thus, organic fertilizers act as the possible vector for introducing microplastic particles in the farmland [11]. The utilization of sewage sludge for agricultural application is common in developed regions has a greater contribution to the accumulation of microplastics in agricultural lands. It is to be noted that North America and Europe process over 50% of sewage sludge for agricultural use [100].

Plastics are not degraded naturally by the usual mineralization process. This nonbiodegradable nature of plastics contributes to the persistent nature of microplastic [77]. Liu *et al.* [51] investigated farmland soil in Shanghai. Their investigations concluded that the topsoil region contains larger microplastics and higher concentrations. The majority of these microplastics were found to be polypropylene (50.51%) and polyethylene (43.43%). Deeper regions of the soil layer contained microplastics with higher densities and weight [54]. Liu *et al.* [87] noted the changes in Chinese loess soil that was incubated with microplastics. These results suggest that the accumulation of microplastics in the soil affects the composition of dissolved organic matter and enzymes activity.

6. Mitigating Microplastic Pollution

Several strategies need to be implemented to control the amount of microplastic reaching the environment and clean up the microplastics that already exist in the environment. Few of the strategies are discussed here.

Dawson *et al.* [20] reported an Antarctic krill that has the capability to degrade the polyethylene type of microplastics by decreasing its size via digestion. The data showed that the ingested microplastics were around 31.5 μ m in size. The digested fragments measured less than 1 μ m in diameter. This physical size alteration of microplastics to nano plastics introduces the significant connection between zooplanktons and microplastic degradation. Microplastics that are present in the air are being inhaled by humans during breathing [60]. This can greatly impair the respiratory health of the individual. It was found that wearing N-95 masks considerably decreased the inhalation of spherical and fiber microplastics even after the disinfectant treatment. N-95 masks

reduced the inhalation of spherical type microplastics significantly by twenty-five times compared to the exposure without a mask [56].

Wastewater contains a considerable amount of microplastics. The wastewater treatment plants process the wastewater for the production of biosolids. This involves several processing steps such as drying, pasteurization, composting, etc. But these steps were found to be quite ineffective in removing microplastics [100]. But on the other hand, Laboratory scale treatment of wastewater treatment showed some promising leads. The application of a combination of coagulation and ultrafiltration processes effectively removed microplastics, thereby preventing them from reaching the have the freshwater ecosystem [21]. Removal of Microplastics from wastewater streams using electro-coagulation (EC) technique had been evaluated using Polyethylene microbeads. It was observed that the polyethylene microbeads were removed with a removal efficiency of > 90%. The maximum removal (99.24%) was observed at pH 7.5 [101].

After the primary and secondary treatment, the final wastewater effluent was found to be the reservoir of a mass volume of microplastics after the wastewater treatment processes. This effluent is directly discharged into the aquatic environment. In these effluents, the small size and fiber-like microplastics were the most common types of microplastics seen pre and post-treatment. Membranes, electrodeposition, and coagulation are the frequently used technologies used in the final treatment of effluents. One of the studies indicated that using a membrane bioreactor (MBR) to remove the microplastics from the wastewater is a promising approach. In a study, MBRs were tested to remove microplastics from four different municipal wastewater. It exhibited an efficacy of 99.4% removal. The removal efficacy is higher when compared to other processes such as rapid sand filter (97%), dissolved air flotation (95%), and disc filter (98.5%) [102].

As discussed earlier, they can form biofilms due to their large surface area. Biofilm formation on the microplastics influences the vertical transportation and release of associated chemicals. Additionally, the biofilm formed may have the capability to degrade the polymers [46]. In a study, Commercial polycaprolactone diol from wastewater treatment liquor was treated under aerobic and denitrifying conditions. This resulted in surface modifications on the samples suggesting an optimistic potential to remove microplastics from wastewater [21].

Another strategy is to use bioengineering-based solutions to search for new biodegradation routes for classical plastics by using a consortium of bacteria and fungi. This can also involve the extracellular enzyme-like carboxylesterases produced by these organisms, which can hydrolyze the microplastics. Recently certain microorganisms have been reported to degrade plastics like the bacterium *Ideonella sakaiensis*, which can break down PET, and marine fungus *Zalerion maritimum*, which can degrade PE. But despite several strategies being developed to control microplastic pollution and remediation, the techniques are still in infancy under developmental stages at laboratory scale only. Countries' governments should impose strict legislation to alleviate the current situation. Since 2017, the use of microplastics in cosmetic products has been banned in the United States, and some legislative measures have already been in action to decrease the exposure of microplastics [21]. The world needs to move to a more sustainable and circular economy in order to palliate the alarming environmental situation of the century.

7. Conclusions

Microplastics are ubiquitous pollutants that are of great concern. Over the past decade, more inputs and expanding scientific interest helped understand microplastics and their interactions with various ecosystems. Despite advancements, certain fundamental questions remain unanswered. Humans have developed advanced instrument and analytical techniques, yet https://biointerfaceresearch.com/

no standard protocols are available regarding the isolation, identification, and characterization of microparticles from the ecosystem. Many of the studies are limited to laboratory scale as this will not give a reliable parameter to estimate the damage caused by the microplastics in-field conditions. It is not clear whether these microplastics cause any health effects on humans and other living biota. Whether these microplastics can act as carriers for toxic pollutants and accumulate in the tissues is still unknown. Such gaps in scientific knowledge need to be addressed. Governments need to impose strict regulations in order to limit the usage of microplastics to curb the further pollution of these particles in the ecosystems. Even though being a Gordian knot, strategies need to be developed to remediate the omnipresent microplastics present in the environment. This would ensure further damage caused by these particles could be mitigated.

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Conflicts of Interest

The authors declare no conflict of interest.

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