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Review Article

Microplastic in the Aquatic Environment and their Impact on Aquatic Organisms and Humans: A Review

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Abstract

Plastic which was first manufactured in the early 20th century became indispensable for human life in the second half of the 20th century as it makes daily life more manageable (buckets to the car of plastic were manufactured), but due to indiscriminate use in cleaning, packaging, cosmetics, pharmaceutical industry, automobile industry, construction etc. and mismanaged disposal has produces the number of unsolvable problems. Microplastics are plastic fragments of <5 mm size produced from plastic, textile fibres due to environmental factors. Microplastics detected in marine water, surface water, fresh water, wastewater, food, air, and drinking water (tap as well as bottled water) are the globally most hazardous environmental contaminants of the 21st century. Microplastic toxicity is not only due to particle size and chemicals but also due to pathogens present in the biofilm. On ingestion, these particles are accumulated in the intestinal wall, lymph nodes and other body organs in aquatic animals. Gastrointestinal ingestion (via seafood, water); pulmonary inhalation (via air) and dermal infiltration (via water) are the main pathways the human exposure. Developmental toxicity, neurotoxicity, genotoxicity, and carcinogenicity are reported in humans due to the accumulation of microplastic in the body. The toxicity depends on the particle size and composition of the polymer. The present study reports the different sources of microplastic and their distribution in aquatic environments (sea, fresh water, surface water, and wastewater) and their effect on aquatic ecosystems and their impact on human health.

Keywords: Microplastic; Ocean Water; Surface Water; Drinking Water; Aquatic Ecosystem; Human Health

Abbreviation

The present period (beyond 1990) can be termed the plastic age. Due to their durability, inertness, wide-scale usability, cost-efficiency, lightweight, convenience, hygiene and ease of processing plastic became the most used material by humans globally [1]. In 2021 globally 390.7 million tonnes of plastic and more than 100 million metric tons of textile fibres (consisting of 60% plastic fibres, 27% natural fibres and 6% cellulose fibres) were produced and are expected to reach 600 million tonnes by 2025. It is estimated that the global market will be 824 billion US dollars by 2030 from 627 billion US dollars in 2023. The plastics which are long-chain synthetic polymers are used not only to fulfil necessities (clothes, cosmetics, shampoos and toys etc.) but are also used in the medical field, in rockets and aircraft, electronics, grocery bags, forks, wrappers of eatables (chocolates, candy etc.) so nowadays for human plastic became indispensable. During the COVID-19 pandemic, approximately 129 million masks and 65 billion globes were used monthly enhancing the generation of plastic in aquatic and terrestrial environments. The market data denotes that more than one million plastic bottles per minute are produced globally and only 22% are recycled or incinerated.

The survey of literature denotes that 9-10% of the total plastic is recycled and 10-11% was incinerated and about 28-30% is used for a long period and the remaining about 50% is disposed of in terrestrial and aquatic environment [2]. As per the Ministry of Environment, Forest and Climate Change report in India, out of 25,000 tons of plastic used daily only 28-30% is recycled.

Plastic particles of less than 5mm in diameter are called microplastic. Worldwide microplastic particles have been reported in the ocean; the deep sea sediments, rivers, estuaries; surface, drinking water, sediments and food [3-6]. It is estimated that 14 million tons of plastic enter the ocean every year, which is 80% of all marine debris. A recent study has reported that 46000 pieces of microplastic float in our ocean in one square km, the total weight of microplastic in our ocean is 269000 tonnes [7]. Due to its small size, high surface area, and hydrophobic character, the microplastic particles in the water have caused adverse impacts on organisms including humans. Besides potentially toxic metals the persistent organic pollutants, pharmaceutical products, antibiotics and endocrine-disrupting chemicals are sorbed and released by microplastic particles [8]. The additives of plastic i.e. colorants, stabilizers, plasticizers, flame retardants and associated contaminants also became available to aquatic organisms due to microbial action and weathering of plastic [9]. The accumulation of microplastic in the aquatic environment also affects the ecosystem by limiting gas exchange between the sea surface and atmosphere Aquatic organisms including fish, birds, bivalves, crustaceans and other invertebrates ingest these microplastics and are transferred to aquatic and terrestrial food chain [10,11]. It is estimated that 11,000 pieces of microplastic are swallowed by a human who eats seafood. As per Times of India report dated July, 21, 2023 plastic kills one million seabirds annually and 100,000 marine lives are lost due to plastic entanglement every year. Sustainable Development of World, UN Environmental Programme (UNEP) has set an agenda for Sustainable Development to reduce significantly plastic pollution of marine mainly from land-based activities by 2025.

The review aims to summarize the microplastic concentration in ocean, river, surface, drinking water, aquatic animals and their impact on aquatic animals and humans.

Classification of plastic

Based on size the plastic debris is classified into 5 categories; (i) Megaplastic- particle size is >50 cm, (ii) Macroplastic- size of particle is 5-50 cm, (iii) Mesoplastic- particle size ranged from 0.5-5 cm, (iv) Microplastic- size of particles is <5 mm and (v) Nanoplastic- Particle size is of 100 nm.

Classification of microplastic

Microplastics based on their origin can be categorized into two:

- **Primary Microplastics**: Micro-sized synthetic polymers which are used in the manufacturing of synthetic clothes, chemical formulations, sandblasting media and in the maintenance of various plastic products are termed primary microplastic. Microbeads (<2 mm) used in cosmetics and health care are another type of primary microplastic. In the aquatic and terrestrial environment, the primary microplastic is released via domestic and industrial effluents, sewage discharge, spills, cosmetics, city dust, road markings, waste incineration, and airborne microplastic from textile industries, other industrial abrasives, pellets, film and fragments [12].
- **Secondary Microplastics**: The major percentage of microplastic present in aquatic and terrestrial environment is secondary microplastics and is fragmented product [13] of the macroplastic and the mesoplastic (i.e. discarded tyres, clothing, disposables and electronic items). Different environmental processes viz., as photo-degradation by sunlight, biodegradation by microbes, thermal degradation due to heat, thermo-oxidative degradation and hydrolysis (by air and water), mechanical transformation, wind, wave action and abrasion converts macroplastic and mesoplastic into microplastic [14]. The other source of secondary microplastic is the wastewater of the washing machines which contain synthetic fibres.

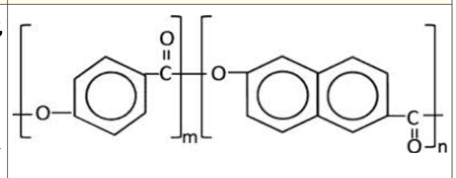
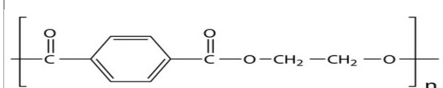
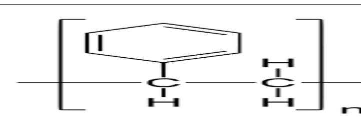
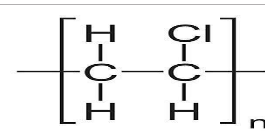
Major sources of accumulation of microplastics in aquatic systems are:

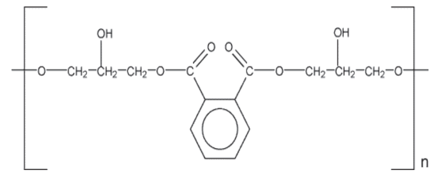
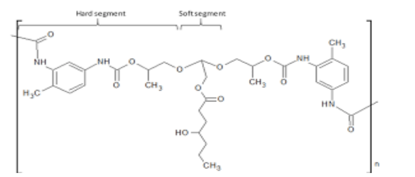
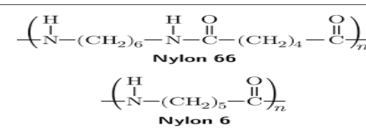
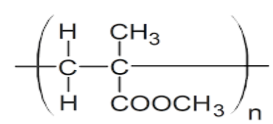
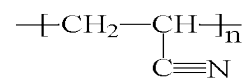
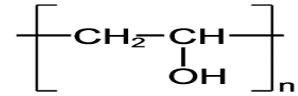
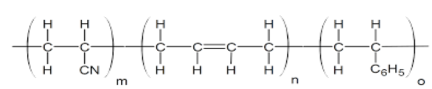
The major causes of the accumulation of microplastic in aquatic systems are domestic, industrial, coastal, and agricultural activities.

The Major sources are

(i) Industries manufacturing plastic products (in the form of pellets) (ii) Plastic bottles, bags and containers (iii) Plastic waste from households (iv) Sewage water and wastewater and sewage water treatment plants (v) Textile industry and wastewater generated from the washing of clothes. De Falco., et al. [15] have reported that during washing 124-308 mg of microfiber per kg of washed fabric (equal to 640,000 to 1,500,000 microfibers/kg) enter mainly in the aquatic environment (vi) Microbeads from the cosmetic industry and used cosmetics- Several researchers [16,17] have reported microplastic particles in the households, hotels, hospitals, and sports facilities including beaches wastewater streams. (vii) Fishing industry- Fishing nets, packaging etc. (viii) Abrasion of Tyres and road markings- Khan., et al. [18] research studies found that globally approximately 6 million tonnes of tyre-wear particles are generated (1.3 million tonnes in European countries only) which is 30-50% of total microplastic pollution. Globally most of water bodies, soil and ocean contain tyre-wear particles [19]. Rain and wind contaminate water bodies by the microplastic particles generated due to abrasion of road markings.

The list of most commonly used plastic polymers their uses and their chemical structures are recorded in Table 1.

Polymer	Nature and applications	Chemical Structure
Polyester	The global production of polyester a non-biodegradable polymer, with density, is 1.24-2.3 (sinks in water) in 2021 its global production was 65.3 million tonnes and it is expected that the global market will cross by 160 billion US dollars by 2027. The polyesters are used in clothing, home furnishings, tyres, Conveyor and safety belts, bottles, sprays, sports Gear, sportswear, covers, and tablecloths. bottles, recording tape etc.	
Low-density polyethene (LDPE)	LDPE is lighter than water (density is 0.92) and is non-biodegradable. In 2022 the global production was 134 million tonnes. It is expected that the global market for LDPE will be 200 billion US dollars by 2029. These polymers are used in shopping bags, water pipes, food wrap films etc.	---[CH_2-CH_2]n---- (where n maybe 1000 to 20,000)
High-density polythene (HDPE)	In the year 2022 the global production of non-biodegradable HDPE with density 0.96-0.97 was 193 million tonnes. It is expected that the global market for HDPE by 2029 will be 163 billion US dollars. HDPs are used in the making of toys, milk and detergent bottles, plastic bags, pipes wire insulation etc.	
Polyethene terephthalate (PET)	In 2021 PET was 82 million tonnes produced globally. The density of PET which is non-biodegradable is 1.37-1.45 (sinks in water). It is used in packing materials; bottles for soft drinks and other beverages jam jars, fillings of sleeping bags and pillows and as textile fibres.	
Polypropylene (PP)	Polypropylene which cannot be biodegraded is lighter than water (density is 0.85- 0.94) so floats on water. These are used in the manufacturing of drinking straws, laboratory equipment, packing materials, fibres, indoor-outdoor carpets; bottle caps, and heavy containers used in the microwave. The global production in 2018 was 56 million tonnes and is expected to become 88 million tonnes by 2026.	---[$CH(CH_3)$-CH_2]n----
Polystyrene (PS)	Polystyrenes which are used in disposable beverage/foam cups, in packing, Styrofoam, moulded objects such as forks, knives, and spoons, trays, video cassette cases, laboratory ware, electronic items and window in envelopes are non-biodegradable with a density of 1.01-1.08 (sinks in water). The annual production is expected to become 20.8 million tonnes by 2026 from 18.6 million tonnes in 2020.	
Polyvinyl chloride (PVC)	PVC which is used in shower curtains, raincoats, car seat covers, building and construction, clear food wrap, bottles, floor covering, garden hoses, and synthetic leather, water, drain and electricity pipes are non-biodegradable material heavier than water (density ranged from 1.16-1.584). The global production by 2028 is expected to become 78 million tonnes from 67 million tonnes in 2022. The global market will be 82 billion US dollars by 2030 (in 2021 it was 60.7 billion US dollars).	

Alkyd	The rate of biodegradation of the Alkyds is very slow, density ranges from 1.67 to 2.1 and is used in paints, varnishes, fibres and moulds for casting, commercial oil-based coatings. The global production is expected to become 0.24 million tonnes by 2023. The global market is expected of 39 billion US dollars by 2023.	
Polyurethane (PUR)	Polyurethane which can be biodegraded with the help of microbes has a very low density (0.1-0.6), floats on water and is used in building and construction, sports mats, foams, rigid and flexible fibres, and upholstery. The global production in 2021 was 24.7 million tonnes and is expected to reach 29.2 million tonnes by 2029.	
Nylon (Polyamide) (PA)	Polyamide (nylon) that can be biodegraded is used in sportswear, carpets, the automobile industry (windshield wipers, helmets), textile, fibres, racehorse shoes and moulded objects. The density of PA ranges from 1.02-1.15 (sinks in the water). The global production in 2021 was 5.87 million tonnes and is expected to become 10.4 million tonnes by 2027.	
Polymethyl methacrylate (PMMA)	As PMMA is lightweight, scratch resistant, less stress birefringence is widely used in the automotive industries to produce external, rear and indicator light covers, door entry strips, also used in electronics, glass replacement, paints, and household products. The global production is approximately 5.7 million tonnes and the global market will be 6.3 billion US dollars by 2027. The PMMA is non-biodegradable and its density ranges from 1.17-1.20.	 Polymethyl methacrylate: PMMA
Polyacrylonitrile (PAN)	The global production of PANs (non-biodegradable) that are used in automobile industries, textile industries, aerospace industry, high-temperature industrial plants, construction, medicines, packaging, electrical applications, recreation and sport is approximately 3.5 million tonnes. The market will be 9.8 billion US dollars by 2029. The density ranges from 1.09 to 1.20.	
Polyvinyl alcohol (PVA)	Polyvinyl alcohol is a chemically and thermally stable polymer with high strength and high optical transparency in water can be degraded, by fungi, Gram-negative and Gram-positive bacteria, are used in the textile, paper industry, and food packaging industries, acts as an optical polarizer. PVA whose global market is expected to reach 1.2 billion US dollars by 2025 is also used as coating and finishing agents, emulsifiers, wood, and leather. Its density is 1.19	
Poly Acrylonitrile-butadiene-styrene (PABS)	Acrylonitrile-butadiene-styrene whose global production is expected to reach 13.5 million tonnes by 2025 has applications in the Electronics industry, automotive sector and in pipes has a density of 1.02-1.08. These compounds have stronger physical structures so cannot be biodegraded.	
Polyvinyl acetate	The PVA is used as an adhesive in the building and construction industry, for wood, to seal surfaces such as paper, corrugated cartons, wallpapers, envelopes, textile finishes, cement additives, as a binder in the electronic industry, shatterproof glass, as a binder in nonwovens, packing has a density 1.19. The global output before the outbreak of covid-19 was 3.4 million tonnes. It is also used as the gum base of the Chewing gum.	$[-CH_2-CHOOCCH_3-]_n$

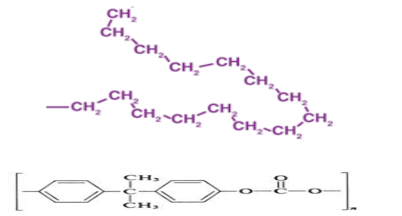
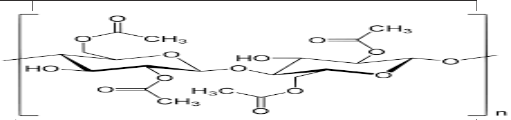
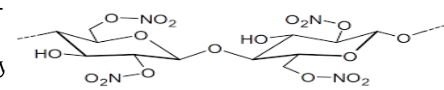
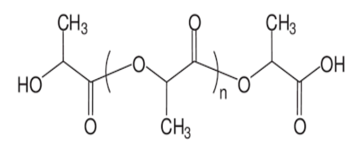
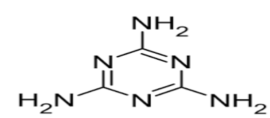
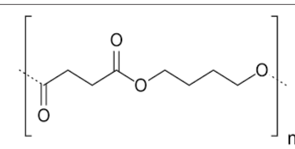
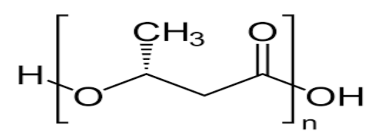
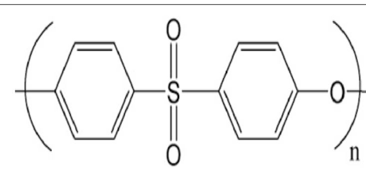
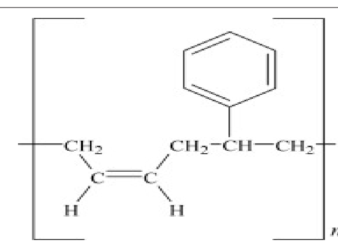
Polycarbonate (PC)	Polycarbonate contains a phenyl group on either side of the carbonate bond so enzymes cannot degrade them and are used in medical equipment, baby bottles, electronic components, construction materials, automotive, aircraft, railway, and security components, Data storage. The density of polycarbonate varies from 1.20-1.22. The global output in 2022 was 6 million tonnes with 8% growth.	
Cellulose acetate	• Cellulose acetate is an eco-friendly material easily biodegradabl polymer with a density of 1.28, in 2020 global output was 5.2 mill tonnes which is expected to become 9 million tonnes by 2030. Ce lulose acetate is used for cigarette filters, cosmetics and healthca membrane for water treatment, and film base for photographic films and fabric fibres.	
Cellulose nitrate	Cellulose nitrate (density 1.35) is used in the production of lacquers and coatings, printing inks, nail polish, explosives and foils. Cellulose nitrate is very slowly biodegraded. The global production is expected to be 305 kilo tonnes by 2025.	 Nitro Cellulose (NC)
Polylactic acid (PLA)	Polylactic acid has which is eco-friendly and easily biodegraded within 6-12 months. It is used in Packaging, manufacturing of plastic film, bottles and biodegradable medical devices (screws, pins, plates and rods) and shrink-wrap material. The density of PLA is 1.38	
Melamine	As melamine can tolerate heat more than any other type of plastic it is used for making, kitchenware, floor tiles, dry boards and fabrics. The non-biodegradable melamine has a density of 1.57. In 2026 the global production is estimated to be 2200 kilo tonnes.	
Polybutylene succinate (PBS)	The global output of polybutylene succinate that has mechanical endurance, ductility, toughness and impact resistance with a density of 1.26 and can be very easily biodegraded is expected to be 300 kilo tonnes by 2028. PBS is processed into films, bags and boxes, for food and cosmetic packaging, and in the biomedical industry for prosthetic materials, contact lenses, wound dressings, dental materials, implants and medical disposables.	
Polyhydroxyalkanoates	The density of polyhydroxyalkanoates, eco-friendly materials (very easily biodegraded) is 1.25. The global market in 2021 was 84.8 million US dollars and is used for packaging, latex, bio-implant material, heat-sensitive adhesives, and as a therapeutic carrier.	
Polyethyl Sulphones (PES)	PESs, aliphatic hydrocarbons have a density of 1.31-1.34, are high-performance thermoplastic and are resistant to acids, alkalis, oils, and grease and have good optical clarity. These compounds have moderate rigidity even at high temperatures and act as an electrical insulator, used in medical appliances. The global polysulphone market in 2021 was 2.1 billion US dollars and is projected to reach 3.4 billion US dollars by 2031.	
Styrene-butadiene rubber (SBR)	SBR synthetic rubber contains 75% butadiene and 25% styrene with a density of 0.98. Due to its resistance to crack and abrasion, it is used in the manufacturing of conveyor belts, shoe soles and heels, adhesives, roll coverings car tires, drive couplings, as a binder in lithium-ion battery **electrodes and haul-off pads etc. The global production in 2020 was** 8.17 million and is forecast to reach over 12 million tons in 2025.	

Table 1: Most commonly used plastic polymers their uses and their chemical structures are.

Microplastic in the aquatic environment

The survey of the literature indicates that there is no place on earth where plastic has not reached [20]. Microplastic particles are present not only in seawater but also in rivers, lakes, ground and surface water. Till 2001 studies were made only on seawater, recently Scientists have made research studies on the microplastic in freshwater, groundwater and wastewater. In Asian countries major studies have been made in China (10-31% of global studies).

Microplastic in seawater

A survey of literature shows that microplastic is present in ocean water and sediments of all five continents. It is reported that each year approximately 14 million tonnes of plastic enter the seawater. Weiss., et al. [21] have estimated that approximately 1.5 million metric tonnes of microplastic enter the ocean water via rivers. The concentration of microplastic in the coastal water or sediment was higher than in the open sea [22]. Caldwell., et al. [23] during their studies found that concentration of microplastic in Ligurian and Tyrrhenian lakes increased nine folds from 2018 to 2019. It is estimated that by 2100 the number of microplastic particles in the sea globally will be 9.6-48.8/m^3 (nearly 50 times as of today) [24]. The microplastic concentration in most of the oceans is uneven indicating that the concentration of microplastic depends on regional factors, the surrounding environment, ocean currents and meteorological conditions [25,26]. Gallo., et al. [26] have reported that 80-90% of marine plastic comes from terrestrial sources (remaining from fishing- commercial or recreational). Several researchers [27] have reported that microplastic concentration in seawater depends on population density and/or river input. The microplastic present in seawater is mainly composed of polyethene or polypropylene [28]. The concentration of microplastic in seawater is recorded in Table 2.

Source	Country	Particles in water	Composition	Reference
Coastal water	Bulgaria	46200/km^2	Fibre, fragment, film,	Berov and Klayn [49]
Lake water	Brazil	11.9-61.2 items/m^3	PP,PE; fragments	Bertoldi., *et al*. [50]
Lake water	India	28 items/km^2	Fibres, film	Bharath., *et al*. [51]
Lake sediment		309 items/kg		
Bay water	USA	32000 items/km^2	PE, PES, PP	Bikker., *et al*. [27]
Riverine water	Ghana	85-150 items/L	PP, PE, PS Nylon	Blankson., *et al*. [52]
Riverine Sediment		375-400 items/kg	Film, fragment	
Sea Water	Italy	1286-3814018 items/km^2	PE,PP, Polyester, PUR	Caldwell., *et al*. [53]
Sea water	Italy	1009-122817/m^3	PE,PP, Polyester, PUR	Caldwell., *et al*. [53]
Coastal Water	Korea	1400 items/m^3	PE,PP, Polyester	Cho., *et al*. [54]
Lagoon water	Turkey	33000particles/m^3	Fibre, fragment, film	Cullu., *et al*. [55]
Lake water	USA and Canada	<0.001-1.5 items/L	PE, PP	D'Avignon., *et al*. [4]
River water		0.002-0.017 items/L	Fibre, film	
Beach Sediments		50-391 items/kg	Fibre, fragment, film	
Lake Sediments		39-2783 items/kg	PE, PUR	
River Sediments		32.9-2110 items/kg	PE, PP, PES	
Sediments		25-300n/kg		
River water	France	1- 441x10^{-2}/L	PET, PP, PA, PET-PUR (and cellulosic fibres)	Dris., *et al*. [56]
River water	Germany	1-4 items/m^3	PE	Eibes and Gabel [57]
Pond water	Turkey	233particles/m^3	Film, fibres	Erdogan [58]
Bay of Bengal	India	16107-47077 items/km^2	PVC, PE,PS	Eriksen., *et al*. [59]
Lake water	Canada	0.2-0.58 particles/m^3	PE,PP, PUC; fragments, fibres	Felismino., *et al*. [60]

Lake water	Italy	0.82-4.41 x 10^{-3} items/L	fibres, fragments	Fischer., *et al.* [61]
Lake Sediments		112-234/items kg	PE,PP, fibres, fragments	
Antarctic Peninsula	Antarctica	0.47-1.43 items/1000m^3	Fragments	Gonzalez-Pleiter., *et al.* [62]
Hills Lake water	India	5.9 items/L	Fibre, fragment	Gopinath., *et al.* [63]
Hills Lake sediment		27 particles/kg		
Harbour Water	USA	6.6 items/L	Film, fibre, fragment	D'Avignon., *et al.* [4]
Bay water		30.8 items/L		
Lake water	Pakistan	14.2 items/L	PE, PP, PVC, PET Polyester	Irfan., *et al.* [64]
Lake Sediment		104 items/kg		
River water	Pakistan	1465-4251items/m^3	Fibres ,Fragments	Irfan., *et al.* [65]
River sediment		2854-8542/m^2		
Poyang Lake,	China	1,064 ± 90 items/m^3	PP, PVC, PE, PS, fibre	Jian., *et al.* [66]
Surface water	Turkey	1-13 items/L	PA, PET	Karaoglu., *et al.* [67]
Persian Gulf water		1500-46000 items/km^2	PE,PP,PS	Kor., *et al.* [68]
Lake water	India	18-29items/L	Fragments	Kumar., *et al.* [69]
Lake sediment	India, China	160-3800 items/kg	PE, PP, PVC, PS, PA	Lakshmanna., *et al.* [70]
River water	Vietnam	172,000- 519,000/m^3	PE, PP, PVC,PA	Lambert and Wagner [71]
River water	South India	0.038- 0.67 items/L	PE,PP	Lechthaler., *et al.* [72]
River water	Indonesia	9-23 items/m^3	Fibres and Films	Lestari., *et al.* [73]
Bay water	China	2.6-4.2 items/m^3	PE,PET,PP	Li Z,., *et al.* [74]
Bay sediment		330-500 items/kg		
Reservoir water	China	2225-7650 particles/m^3	PE, PP, PVC, PA, PET	Lin., *et al.* [75]
Rivers water	India-China	247-2686 items/m^3	Fibres, fragments, film	Liu., *et al.* [76]
Rivers sediment		0-933 items/m^2		
Lake water	Belgium	11.2-120.4 items/L	Fibres and fragments	Loayza., *et al.* [77]
Lake water	Nepal	1.4-3.5 items/L	Fibres and fragments	Malla-Pradhan., *et al.* [78]
Lake water	Siberia	4-26 items/L		Malygina., *et al.* [79]
Sea Water	Southern Caspian	0.246 items/m^3	PE, PET, PP	Manbohi., *et al.* [80]
Lakes water	Canada	230000-460000 items/km^2	Pellets, fragments	Mason., *et al.* [81]
Bottled water	USA	10.4 items/L	PP, nylon, PS, PE, PEST (polyester + polyethylene terephthalate	Mason., *et al.* [37]
River water	Slovenia	7-89 items/m^3	Film, fibre and fragment	Matjasic., *et al.* [82]
River sediments		40 items/kg	PE,PP,PS	
Lake water	Kenya	0.3-0.5 items/m^3	PP,PE polyester; fibres	Migwi., *et al.* [83]
River water	Vietnam	269693-863005 items/m^3	PE,PP	Oanh., *et al.* [84]
Bottled water (Plastic)	Germany	Single-use: 4889–5432 items/L ; Reusable: 90 – 16634 items/L; Glass: 813–35436 items/L	PS, PP, PE, PET, PA, PVC,ABS	Oßmann., *et al.* [38]
Lake water	Nigeria	201-8369 items/m^3	PET, PVC; Beads, pellets	Oni., *et al.* [85]

Sea water	Germany	0-1.8 items/m^3	PE, PP, PVC,PET, PUR	Ory., *et al*. [86]
Bay water	China	0.23-4.01 particles/m^3	Film, fragment and fiubres	Pan., *et al*. [87]
River water	South Korea	7-102 items/m^3	PE, PS, PTFE, Polyester,	Park., *et al*. [88]
River water	Bangla Desh	36000 items/m^3	PE, PP PS, PVC, Polyester	Parvin., *et al*. [89]
River Sediment		13607 items/kg		
Drinking Water (Raw)	Czech Republic	1473-3605 items/L	PE,PP,PS	Pivokonsky., *et al*. [26]
Treated		338-628 items/L		
River Estuary water	USA	244142 items/km^2	PE, PP, PET, PUR	Polanco., *et al*. [90]
Port water	South Africa	5-145 items/m^3	Film, fragments, fibres	Preston-Whyte., *et al*. [91]
Reservoir water	Indonesia	7100-459000 items/km^2	PE and PP	Ramadan and Sembiring [92]
Coast water	Southwest, India	1.25 items/m^3	PE,PP	Robin., *et al*. [93]
Offshore water	Scotland	0-91128 items/km^2	PE, PP, PS, PVC, PVA	Russel., *et al*. [94]
Sea Water	Finland	16.2 items/m^3	PE, PET, PP	Sainio., *et al*. [95]
River water	India	44-68 items/L	Fibres, fragments, foam, film	Sathish., *et al*. [96-97]
River Sediment		68-111 items/kg		
Lake water		26-42 items/L		
Lake sediment		34-62 items/kg		
Coastal water		64-114 items/L		
Coastal sediment		106-154 items/kg		
Marine protected areas water	Sri Lanka	0.276-0.515 items/m^3	PE, PP, PS	Sevwandi., *et al*. [98]
River water	Europe	5.57 items/m^3	PE,PP,PS,ABS, PA, PET, PMMA	Scherer., *et al*. [35]
River sediments		3.35x10^6 items/m^3		
Ocean water	Atlantic Ocean	1829 items/m^3	PE, PP, PS, PUR, PET	Silvestrova& Stepanova [99]
Bay water	Indonesia	0.61-0.62/m^3	Fibres, pellets, films beads	Suteja., *et al*. [100]
Surface water	Thailand	80-140 items/m^3	Fibres, pellets, films	Ta., *et al*. [101]
Sediment		91-125 items/kg		
Estuary Water	Malaysia	1687 items/m^3	PE,PP, PA	Taha., *et al*. [41]
Offshore water		1900 items/m^3	PE, PP	
Lake water	Turkey	5.25 particles/m^3		Tavsanoglu., *et al*. [102]
Dam Reservoir water	Malaysia	106-200 items/m^3	Fibres, fragment, film	Turhan [103]
Dam Reservoir sediment		760-1440/m^2		
Dam Reservoir Fish		0.41/fish		
Sea water	Finland	0.2-1.7 items/L	PE, PP, PS, PVc	Uurasjarvi., *et al*. [104]
River water	Canada	0.1 items/L	Fibres, films, fragments	
Treated Wastewater		0.07 items/L	Fibres, fragments	
Lake water	Switzerland	2.6items/L	Fibres	Velasco., *et al*. [105]
Sea water	Tunisia	66-1767 items/m^3	PE, PP, PS, PET	Wakkaf., *et al*. [106]

River water	China	14-17 items/L	PE, PP, PVC	Wang., *et al.* [107]
Pacific Ocean	Mid-west	6028-95335 items/km^2	PE,PET,PP, PMMA	Wang., *et al.* [108]
Lake water	China	67-933 items/m^3	Fibre, fragment, films	Xiong., *et al.* [109]
River water		67-600 items/m^3		
Aquaculture Pond water		100-1167 items/m^3		
Wastewater treatment Plants	China	1.47x10^6 particles daily	PE, PP, PS	Xuan., *et al.* [110]
River water	Nepal	180-262 items/m^3	Fibres, Films, Fragments	Yang., *et al.* [111]
River sediment		45-71 items/kg		
Lake waters	South America	0.3-1.9 particles/m^3	Pet, Fibres	Alfonso., *et al.* [112]
Black seawater	Turkey	0.12-7.62 particles/m^3	Films and fibres	Aytan., *et al.* [113]
Lake water	Mongolia	3.12-11.25 items/L	Polystyrene and polyethylene	Mao., *et al.* [114]
Aquatic animals				
Lake water Fish		34 particles/fish	Fibre, film, pellets	Atici., *et al.* [115]
Lake water Fish		10.7 particles/fish	Fibre, film, fragments,	Xu., *et al.* [116]
River water Fish		0.6 particles/fish	Fibre, film, pellets	Zhang., *et al.* [117]
Black Chinned Tilapia		2.25-2.5 items/fish	Fibres, Fragment, microbeads	Blankson., *et al.* [52]
Bagrid Catfish		Fibre, microfilm		
Mangrove fish		0.6-8/fish	Fibre, film, fragments and pellets	Huang., *et al.* [118]
Marine fish		1.58 item/fish	PE, PP, PS, Polyolefins, Synthetic rubber	Wotten., *et al.* [119]
		0.86 items/fish		
Marine commercial fish		1.3/fish	Fibre, film, fragments, rubber and pellets	Koraltan., *et al.* [120]
Oreochromis niloticus		94-174/fish	Fibres and Films	Lestari., *et al.* [73]
Barbonymus gonionotus		47-212/individual	Fibres and Films	Lestari., *et al.* [73]
Elongaria orientalis		27-89/individual	Fibres and Films	Lestari., *et al.* [73]
Marine Fish		4.11 items/fish;	PP, PET, PE Nylon	Mistri., *et al.* [121]
Marine Fish		5-6.5 items/fish	PE, PET, fibres, Nylon	Foo., *et al.* [122]
River Fish		1.85-3.5 items/fish	Fibber, film, foam	Khan and Setu [123]
Marine fish		0.81-2.06 items/fish	PP, fibre	Aytan., *et al.* [113]
Marine fish		1.1-1.9 items/fish	PP, fibre	Gundogdu., *et al.* [124]
Marine fish		3.72 items/fish	PET, PP, PE	Sparks &Immelman [125]
Hemiculter leucisculus		1.9–6.1 items/individual (in gut)	Fragments and pellets	Li., *et al.* [126]
Street Dust		307-1526 particles	PE,PP, Flakes, Fibres	Li., *et al.* [74]
Copepods		0.008-0.024 particles/individual	Films and fibres	Aytan., *et al.* [113]

Han River fishes		4-48/fish (intestine); 6.13/fish (gill)	Fibre and fragments	Park., *et al.* [88]
Oyster, Mussel, Manila Calm in Coastal water		1.1-2.5/animal	Fibre and fragments	Cho., *et al.* [54]
Procambarus clarkii		0.17-0.92/fish	Fibre and fragments	Zhang., *et al.* [117]
Sea Turtles		10-12.5-11/turtle	Fibres, Fragment; PP,PE,PET	Duncan., *et al.* [39]
Sea Turtles		2-10/turtle	Fibres, Fragment, and microbeads; PE, PP, PET	Duncan., *et al.* [39]
Mussels		1.1-6.4 items/mussel	PP, PE, LDPE, fibres, PVC	Li., *et al.* [127]
Compost from pulped food waste		1400	PP,PE,PS, Cellulose derivatives	Ruggero., *et al.* [128]
Compost from grocery store		300000	PES, PET, PE, PA, fibres	Golwala., *et al.* [129]
Fish meal		5-8items/g	Fibre	Wang., *et al.* [130]
Fish meal		216items/kg	Fragment, film, filaments	Karbalaei., *et al.* [131]
Fish meal		1600-2140/kg	Fibre, film, and fragment	Gündoğdu., *et al.* [124]
Edible sea salt		1400-1900 particles/kg	PE, PP,PET, nylon, PS	Yarnal., *et al.* [132]
Rock Salt				
Arctocephalus australis		9-45/individual	Fragments and fibre; PA and PET	Perez-Venegas., *et al.* [133]
Arctocephalus philippi		25-70/individual		
Otaria byronia		20-122/individual		
Baltic Sea fish		0.12-1.4/fish	Fibre and fragments	Sainio., *et al.* [95]
Estuary and offshore water fish		0.01-0.02/fish	Fibre and fragments	Taha., *et al.* [41]
Molluscs		1.0-8.5	Film, fibre and fragment	Ding., *et al.* [134]
Bivalves		0.5-3.3 items/individual	PVC, film, fragment and fibre	Ding., *et al.* [135]
Sea Turtles		3.5-11/turtle	Fibres, Fragment, microfilm and microbead; PE,PET,PVA	Duncan., *et al.* [39]
Zooplankton		0.6-4.55/m3	Fibre, particles, fragment	Liu [136]
Sea water fish		0.5-1.5 items/fish (gill);.1-3 items/fish (gastrointestinal tract); 0.05-0.11 items/fish (dorsal muscle)	Fibre, pellets, and fragments	Barboza., *et al.* [137]
Gill of *Trichopodus trichopterus*		223-385 particles/g WW	Cellophane.	Lestari., *et al.* [138]
Gill of *Rasbora argyrotaenia*				
Notopterus notopterus				
Neophocaena asiaeorientalis sunameri		16-24/individual.	Fibres, Fragment, and sheets; PP, PE,PET,PS, PC	Xiong., *et al.* [109]
Shellfish (sea food)		1.2-6/animal	Fibre, granules, film and fragments	Ding., *et al.* [139]

Table 2: Microplastics in water and food material.

Microplastic in freshwater

The literature review reveals that contamination of seawater by microplastic number of studies have been done in the last 50 years, but the information on contamination of freshwater (river, lake, drinking water) by microplastic is limited. The surface water is polluted by industries which have various applications of microplastic (medicines, cosmetics), the textile industry, household wastewater; cloth washing water, and sewage/wastewater treatment plants [29,30]. Rain and wind add microplastic to surface water generated due to abrasion of tyres and road markings [31]. Runoff from the dump site and waterways is another source of microplastic that contaminates surface water. Microplastic in surface water is in the form of pellets, microbeads, fibres, fragments, films and foams [10,32]. Amrutha and Warrier [30] during their studies have inferred that the abundance of microplastic in the river depends on anthropogenic activities and urban population. Crew., *et al*. [33]; Scherer., *et al*. [34] after their research studies reported that microplastic concentration on the riverbed was 4-5 times than in the water column. The microplastic in river water impacts river pollution index, and chemical oxygen demand [35]. The concentration of microplastic in surface water depends on climatic conditions [36]. The treated water bottles also contain 3-10 microplastic particles/L of the size 1-100 um [37]. The higher concentration of microplastic particles in water packaged in plastic bottles than in glass bottles from the same source suggests that the bottling process and packaging contribute to microplastic particles [38]. Polyethene, polypropylene, polyester, polyethene terephthalate are main contaminant of bottled water [38]. Table 2 denotes the concentration of microplastic in different surface water.

Microplastic in aquatic animals

As the microplastic in marine and surface water environment is increasing its availability to biota is also increasing. The presence of microplastic in the stomach of biota indicates that these organisms can ingest microplastic [39]. Ma., *et al*. [40] reported that the ingestion of microplastic by organisms depends on the shape, size, density, abundance, colour and aggregation of the microplastic particles. Copepods generally ingest lower-density particles while benthic invertebrates uptake high-density particles. In the zooplankton, the concentration of microplastic particles was 0.14-1 particle/individual [41]. In bivalves *Mytilus edulis* and *Crassostrea gigas* (which are generally consumed by humans), the microplastic particles were 1.5-7.6 items/individual. Doyle., *et al*. [42] have reported 2014 particles/g of wet soft body mass of gastropods. Rist., *et al*. [43] have predicted that by 2100 the number of microplastic particles consumed by humans by taking bivalves will be $6.6 x 10^4$ particles per year. Beer., *et al*. [44] found that one-third of microplastic particles present in the digestive tract of fish are plastic remaining are cellulose. The microplastic is also found in sea turtles and seabirds. The uptake of microplastic by seabirds depends on size, weight and habitat of seabirds; it was lesser in small body size seabirds (*Spheniscus penguins*) while higher ingestion was in *Cyclorhynchus auklets* that have large size. Zhao., *et al*. [45] during their studies found that 92.3% population of fish in Chinese coastal seas contains microplastic. Galloway., *et al*. [46] during their studies found that the digestive tract of *Dosidicus gigas* (giant squid) contains 93% microplastic. Nel., *et al*. [47]; Hurley., *et al*. [48] reported that midge larvae and oligochaete worms contain 370-1200 and 100-148 particles/g respectively.

Impact on aquatic animals

Microplastic is taken up by all the aquatic organisms viz., coral, bivalves, mussels, lugworms, oysters, turtles, sea lions, seals, penguins, whales, zooplankton, algae, fish, birds, amphibians, via drinking, feeding, swimming, respiration etc [140].

The planktons are essential for the marine habitat, as 1/3 of all marine fish species and numerous other organisms mainly feed phytoplankton and zooplankton (2). When the microplastic enters the cell wall of phytoplankton the reduction in chlorophyll absorption occurs [141] and in heterotrophic plants, these particles retain in the tissues which disturbs feeding and digestion [14]. Zooplankton interacts with tiny microplastic particles (as both have the same size). Corals accumulate microplastic in their digestive tract resulting in their death which affects negatively the biodiversity of the aquatic environment.

Microplastic is present in the guts of almost all aquatic animals (marine or freshwater). The number of microplastic particles in the gut of freshwater fish was more than that of marine water fish Coverton., *et al*. [142]. Accumulation of microplastic adversely impacts the reproduction, feeding habits and sperm and oocyte quality in oysters. Bessa., *et al*. [143] during their studies on Penguins in the Antarctic found that microplastic in the gut prevents the

Penguins from food consumption affecting their growth and development. The microplastic particles in aquatic organisms affect the activity of antioxidant enzymes causing oxidative stress, which reduces cell growth rate and normal physiological processes of cells. Due to oxidative stress muscle injury may also occur [144]. Microplastic in the organisms also inhibits the activity of the enzyme acetylcholinesterase [145] causing neurological damage to the organisms. The microplastic accumulation in the organs of the organisms also impacts the immune system. In fish, microplastic reduces cell viability and activity of immune cells and destroys the lysosome membrane. Enhanced mortality, reduced growth and swimming speed, physical impairment, and alteration in feeding behaviour, lipid accumulation, damage of reproductive organs, and disruption in gene expression are some other common effects of the accumulation of microplastic in aquatic organisms [146,147]. The adsorbents of microplastic (POP, Bisphenol-A; phthalates; toxic metals etc.) also adversely impact the aquatic organisms. Bisphenol-A and phthalates adversely impact the functioning of the thyroid gland in amphibians and larval growth is retarded. Phthalates in fish act as endocrine disrupters.

Impact on human

Due to persistence, hydrophobic nature, large surface area, presence of hazardous chemicals (amended during their production) and sorption of POP and potentially toxic metals, the microplastisc pose a health problem to humans. Human exposure to microplastic is via (i) inhalation (via lungs), (ii) ingestion (via the digestive system) and (iii) Dermal (via skin). Kor and Mehdinia [68] reported that in the human body microplastic particles enter by (i) Endocytosis and (ii) persorption. The survey of the literature denotes that the consumption of microplastic in India is much lesser (11 kg per year) than the average consumption of other Asian countries (36 kg per year). The average consumption per year by an American is 140 kg while in European countries is 92 kg/year. Senathirajah., *et al.* [148] during their studies inferred that the average global consumption by a human is 250g/year. Several researchers [1,149] after their studies have inferred that on average each citizenry ingests 39,000 - 52,000 particles and inhales 25000 particles per year. A citizen whose main drinking water source is bottled water consumes 9000 particles additionally; due to the development of microbial pathogens in the biofilms, such particles became more toxic. Energy drinks, wine, bottled tea and beer are also contaminated with microplastic particles: white wine from Italy contains 2563-5857 particles/L and beer from Germany contains 10-256 particles/L [150].

Consumers articles

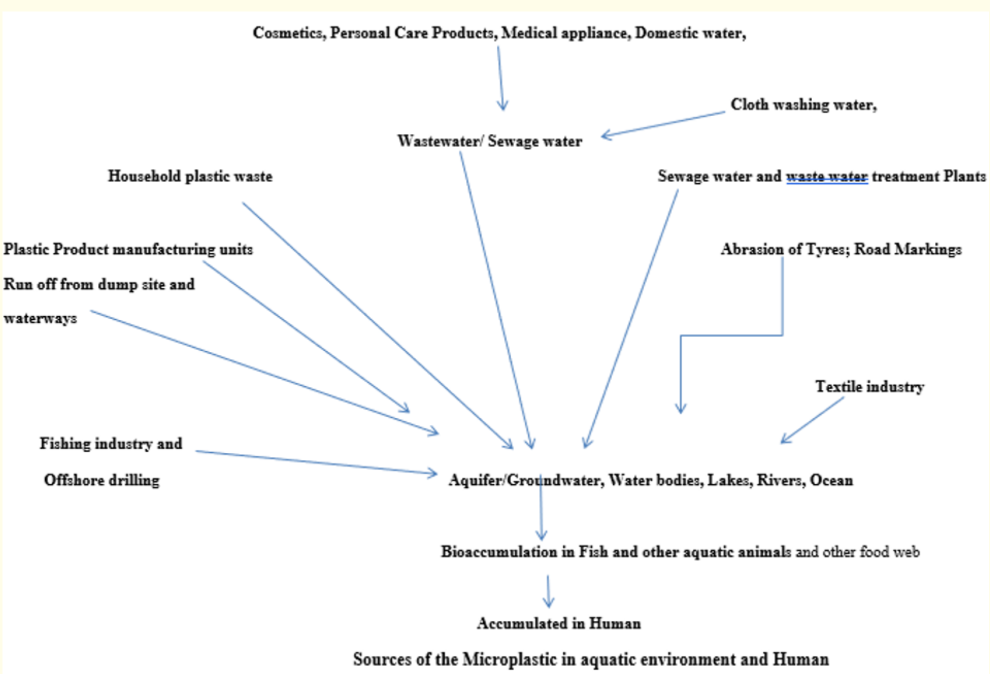


Figure 1

The shape, size, chemical structure and surface area of the microplastic particles are the major factors which affect adversely human health. Lymph nodes can absorb particles of the size 150 um and particles of the size 110 um are passed in the portal vein and organs. The inhaled microplastic particles cause inflammation in the lung tissues which may cause cytotoxicity and genotoxicity effects on the pulmonary epithelium and macrophages. It has been reported that workers in the textile industries are prone to lung diseases, pneumoconiosis, asthma, and allergic alveolitis [151,152]. Yang., *et al.* [153] and Lusher., *et al*. [154] reported that particles of the size 15-20 microns are transported to the lymphatic and cardiovascular systems. The food products viz., fish, bivalves, sugar, salt, and crustaceans are nowadays most contaminated by microplastic particles. The three main sources of microplastic ingestion by humans are bottled water, alcohol and seafood [152]. Microplastic particles of the size 100 um can pass through the gastrointestinal epithelium while particles of the size 10 um can cross the blood-brain barrier and can pass through the placenta. Prolonged exposure to microplastic in humans causes oxidative stress (due to more generation of reactive oxygen species) and abnormal activation of immune cells which results in immunodepression [153] and damage of neuron cells. When microplastic enters the circulatory system of humans it causes vascular inflammation, occlusions, blood cell cytotoxicity, reduced organ function, and enhanced chance of cancer [32,150-154]. Ormsby., *et al*. [155] reported that microplastic in bones activates osteoclasts. Rahman., *et al*. [151] during research studies found that the accumulation of microplastic in the human body lowers nutrient uptake, and alters the metabolic enzyme activity and energy consumption. Apoptosis, necrosis, fibrosis and damage of the tissue in the human body due to the accumulation of microplastic have been reported by Liang., *et al*. [156]. When the microplastic particles are accumulated in gonads it reduces reproductive capacity [157]. Organic compounds added during the manufacturing of plastic (viz, Bisphenol-A (BPA): bisphenone; PFAS and phthalates) and persistent organic pollutants sorbed on microplastic (PAH; PCB, DDT, toxic metals) magnify in the human body disturb the endocrine system, adversely affects the reproductive and immune system and carcinogenicity [158]. Pathogenic and non-pathogenic microbes' viz., *Folsomia candida*, *Pseudomonas aeruginosa*, *Legionella* spp., *Mycobacterium* spp., vibrio spp. and *Naegleria fowleri have been detected on the biofilm formed on microplastic [159,160]*. Dermal contact with microplastic via personal care products, face washes, hand cleaners, toothpaste, and facemask causes inflammation in the skin and cytotoxicity [14].

Conclusion

Microplastic in the water bodies mainly comes from terrestrial sources. The aquatic habitats viz., corals, planktons, fish, and seabirds ingest the microplastic particles assuming their food. Microplastics in the ocean and other water bodies negatively influence the health of the water bodies, aquatic organisms, food safety and quality, human health, and coastal tourism and also contribute to climate change. The present review which summarizes the recently published work denotes that globally all the water sources (ocean, river, surface water, drinking water, bottled water, and wastewater) are contaminated with microplastic particles. These particles not only adversely impact aquatic organisms (seafood) but also human health. In humans, the immune system, hormonal activities, and nervous system are impacted by microplastics and other associated chemicals. A few compounds are also carcinogenic. Awareness among the general public and proper and efficient plastic waste management is essential to minimize the adverse effects.

Small steps to curtail the risks of Plastic

At present time plastic cannot be completely avoided as it became an essential component of human life. For a better future, the following aspects are needed to strengthen.

- Single-use plastic articles must be banned globally and the plastic industry must follow the laws.
- There must be efforts to produce biodegradable plastic.
- There must be research studies to reduce the microplastic from aquatic sources.
- Discharge of plastic into water bodies must be prevented.
- Effective plastic waste management with high efficiency and low cost is the need of the hour.
- There must be monitoring and period check-ups of microplastics in water bodies.
- In personal care products and cosmetics in place of plastic microbeads other compounds must be used.
- As bottled water contains more microplastic particles than tap water so tap must be used for drinking and other purposes.
- As the harmful chemicals phthalates; styrene and bisphenols are present in plastic heating of food in plastic material must be avoided. So, it is better to use fresh food. American Academy of Paediatrics has suggested not washing plastic wares in dishwashers.
- Proper and regular vacuum cleaning is essential to minimise inhalation of the microplastic from household dust.

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Declaration

No original data have been used in this review all information is accessed from published work.

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