Microplastics: Devastation and destination in aquatic ecosystem

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Summary

Plastic pollution is a major global issue due to its non-biodegradability and persistence in nature. Plastics take thousands of years to degrade and can be converted into microplastics which are very harmful to all living biota due to their extensively small size (≤ 0.5 mm). Even though microplastics are not completely separated during wastewater treatment in plants (WWTPs). MPs are converted from highly stable and different kinds of polymers like polystyrene, polyethylene, etc., and radically distributed across the globe including the Arctic and Polar regions which fascinate scientists and researchers in addressing the issue. Due to the microscopic dimension of plastics, MPs has been entering through various pathways into the food webs of various aquatic fauna and indirectly or directly affecting the ecosystem including human health. Therefore, MPs are an inevitable and emerging threat especially for the aquatic ecosystems. This review discusses briefly the types, sources, chemical properties, and effects of MPs on aquatic biota.

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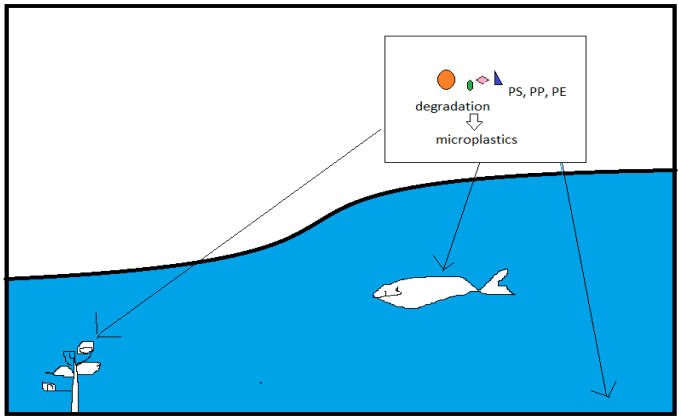
INTRODUCTION



In modern scenario, the plastics are one of the most user-friendly materials and now becoming nearly indispensable due to its vast application spectra since the emergence of first synthetic plastics in beginning of the 20th century. Plastics are of high molecular mass derived from natural, organic feedstocks such as natural gas, and crude oil by polymerisation or polycondensation processes.[22] There has been a significant raise in global production of plastics in the last sixty years but inappropriate disposal and waste management of plastics waste is of great environmental concern. Plastics may take decades or even more time to degrade and disintegrate eventually by progressive of physical, chemical and biological events to higher surface area to volume particles. These plastic of microscopic dimensional size less than 5 mm is termed as Microplastics (MPs) by Thompson in 2004 and found to spread in the environment with final destination is water bodies.[47] These MPs are the polymers like polyethylene, polyethylene terephthalate, polystyrene, polychlorinated biphenyls, etc.[32, 60] MPs have been reported in Polar Regions, tropical regions, the east, the west, coastal areas, open seas, sea surface and deep seas.[14] From further studies, MPs are also found in Arctic snow.[34] MPs is also present in Antarctic region but there is lack of data to define its effect properly.[57] The concentrations of MPs are increase with decrease in size.[18] It can be extremely difficult to remove microplastics through treatment process that are lost into the environment and have been accumulating in the environment ever since the origin of plastic materials. Moreover, plastic can absorb organic pollutants from surrounding and serve as vector for transfer of chemical and microbial contaminants for

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organism, once this plastic degrades in to micro sized plastic it releases the toxic chemicals.[26]

Sources and classification of MPs

Origins of MPs can be characterized and classified on basis of sources as primary and secondary. Primary sources include plastic pellets, nurdles, beads, fibers, and powders used as industrial materials, personal care products and cleaning additives. MPs are used in personal care products and in cosmetics as silicones, functionalised polymers, hydrophilic and film-forming agents. They provide the silky texture and stability to the products. These MPs have size in the range of 420 µm. These are called microbeads, which are directly drained in the water resources after usage.[25, 55] They are microbeads released from cosmetics and personal care products like facials, scrubs, toothpaste, shampoos and exfoliants.[46] They have variable size (0.5 mm - 1 mm) and shapes like ellipses, ribbon, sphere, fiber and thread.[32, 52, 51] Secondary microplastic sources: They are produced from the degradation of large sized plastic debris by action of UV radiations, oxidation and friction.[2, 6] Secondary microplastics are abundant in globe marine and coastal environments. During washing of clothes, which are commonly made of polyester, nylon, acrylic fibres, these fibres are released as secondary MPs in to wastewater. These MPs are further fragmented in to nanoplastics due to ageing and degradation processes.[24] MPs also released from municipal waste, agriculture, industrial, road run off and even from waste water treatment plants (WWTP).[41] They retain in the environment for a long period due to their special characteristics.[2, 27, 11] These MPs has been dispersed among various habitat and greatly affecting the aquatic ecosystem.[51] Around 1401 marine species interact with marine plastic.[48] Research investigation revealed that 16.80% of the specimens had ingested MPs of an approximate dimension of 0.34 mm.[4] Literature revealed that most of filament type (PET) MPs are ingested and concentration in living organism.[5] These MPs are ingested by the many aquatic organisms, which serve as food. These microplastics affect the aquatic fauna in many ways, MPs enters in the organisms like zooplankton, crustaceans, fishes, seabirds through gastrointestinal tracts and gills.[2] The amount of MPs increases in fishes with their length and fishes having large stomach have more ingested MPs.[4] These MPs affect their reproduction rate, growth rate, survival rate, immune system, abnormal metabolism, alteration in behavior, affect their circulatory system and change in their energy budget.[11, 28, 36] MPs affect the aquatic flora also like aquatic diatoms, duckweeds, chlorella, sea grass, macro algae. The absorption of these MPs (mainly polystyrene) effect the rate of photosynthesis, growth rate, reproduction rate and increase the production of reactive oxygen species. These plants may be food and habitat for many aquatic species and their life is also affected. These MPs affected the entire food web and affects the organism at each tropic level.[32, 52, 3]

Classification of Microplastics

MPs are classified into five types as fibres, microbeads, fragments, nurdles and foam as presented in Fig. 1.

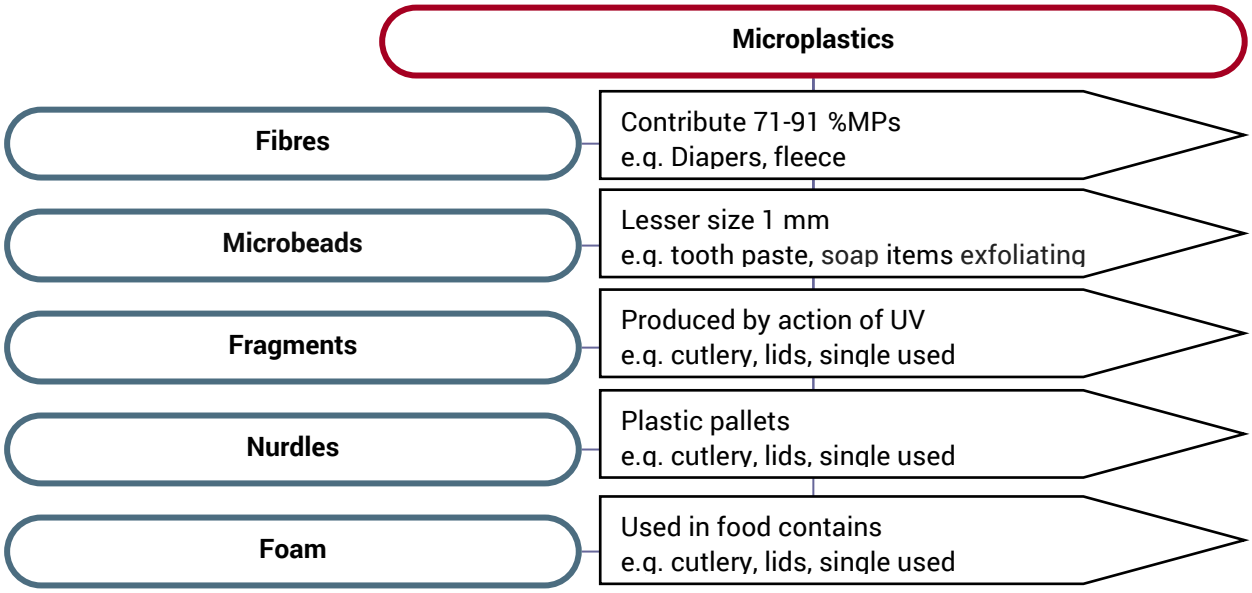

Fig. 1: Classification of microplastics (MPs)

Fibers constitute about 71% of MPs in the great lakes and it is assumed that MPs fibers contribute 91% of sea water debris.[56] It comes from things like diapers, fleece clothing and cigarette butts, clothing materials like cotton or wool, fleece microfibers are not biodegradable. Microbeads: These have size less than 1mm, micro beads are present in facial cleansers, exfoliating soap products, and toothpaste (just one tube of toothpaste can contain 300,000 micro beads). Produced from breakdown of larger plastics and further converted in to smaller pieces by action of UV radiations. It includes cutlery, lids and single used plastics. Nurdles are small plastic pellets used to make plastic items. Sometimes they leaked during transportation and end up in to storm drain before emptying in to nearby water body.[21] Styrofoam (extended polystyrene is known as Styrofoam[55] is used in food containers, coffee cup and packing materials. Chemicals release from Styrofoam mix in to food items or beverages and affecting human health. On heating Styrofoam increase the exposure. Just like micro beads and fragments, Styrofoam broke in to smaller pieces and release in to water bodies and most of the municipalities do not recycle Styrofoam.[21]

Plastic speciation in MPs

These MPs are found to disintegrate from various types of polymers and includes PE, PET, PP, PS, PVC, PCB, PA, ES, ABS, PTFE, PMMA and PUR.[47, 17] Among them polyethylene and polystyrene are used widely in personal care product, kitchen appliances, disposable drinking cups, packaging material and thus there is a great risk of them present in the environment.[53]

Table 1: Spectrum of commonly used plastic classes and their disintegration process into MPs

Plastics forming MPs	Chemical formula	Uses	Process of disintegration		
Polyethylene(PE)	$(C_2H_4)_n$	Packaging, bags, films	Physical Process (Abrasive/ Mechanical)	Chemical Process (Thermal /UV photochemical)	Biological Process (Microbial degradation/Animal digestion)
Polyethylene terephthalate(PET)	$(C_{10}H_8O_4)_n$	Textiles, drink bottles			
Polypropylenes(PP)	$(C_3H_6)_n$	Straws, food containers, bottlecaps			
Polystyrene(PS)	$(C_8H_8)_n$	Plates, cutlery, toys			
Poly vinyl chloride(PVC)	$(C_2H_3Cl)_n$	Pipes, fencing, flooring, shower curtains			
Polychlorinated biphenyls(PCB)	$(C_{12}H_{10-x}Cl_x)_n$	Lubricants, coolants in transformers, capacitors and other electrical equipments			
Polyamide(PA) nylon	(CO-NH)	Fishing lines and net, toothbrush bristles			
Polyoxymethylene(POM)	$(CH_2CH_2O)_n$	Automotive parts, glass frames, fasteners			
Acrylonitrile-butadiene-styrene(ABS)	$(C_8H_8.C_4H_6.C_3H_3N)_n$	pipe systems, musical instruments			
Polytetrafluoroethylene(PTFE)	$(C_2F_4)_n$	Used as non-stick coating of cookwares			
Polymethylmethacrylate (PMMA)	$(C_5O_2H_8)_n$	Lenses, shatterproof windows, paint			
Polyurethane(PUR)	$(C_{27}H_{36}N_2O_{10})_n$	Automotive, furniture and bedding, refrigerators and freezers			

These plastic are lightweight, durable, versatile, corrosion and flame resistant, highly cost effective, low thermal and heat conductivity which make them highly efficient for any purpose.[51, 29, 40]

Destination of MPs

Micro sized plastics are found to exist as a part of aquatic life and matter of concern to the marine environment since 1970. So to address the seriousness of the current issue in 2018 the United National Environment Program has declared the theme as “Beat plastic pollution” on World Environment Day.[22, 7, 40] The total plastic production across the world is increased from 1.7 million in 1950 and over 350 million tons in 2018. In 2014, plastic production is 300 million tons and the total microplastics production in world’s ocean is in between 15 and 51 trillion which

approximately weigh between 93,000 and 236,000 metric tons.[10] It is estimated that total plastic production is reached to 33 billion tons by 2050 and also estimated that 4.85 trillion MPs is dispersed across the oceans till today.[60, 28] A recent studies suggested that 7000 to 35000 tons of plastics have been floating in open oceans.[22] Lebrelon et al. (2019)[18] revealed the trend about a global mass budget for positively buoyant MPs debris has been estimated much higher in coming years due to heavy production and consumption in plastic economy across wide application spectra (Fig. 2).

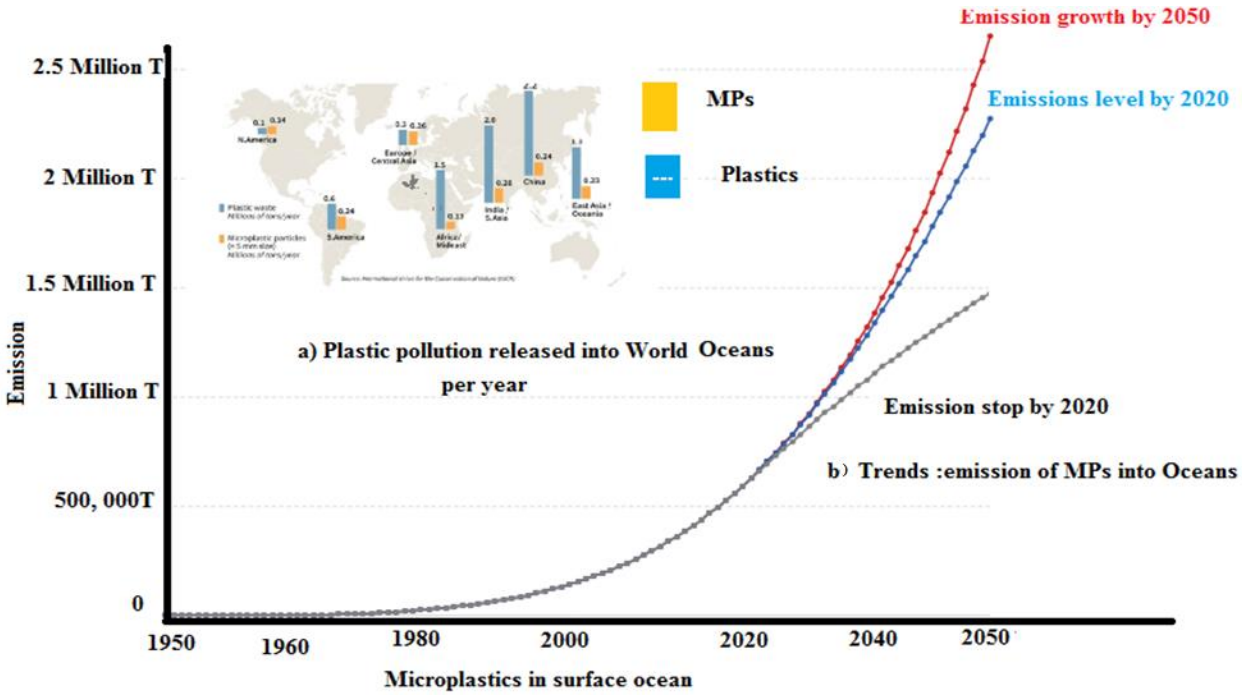

Fig. 2: Global scenario of Plastics pollution and emission of Microplastics

Sources and transport of MPs into aquatic environments

It is generally considered that 75–90 % of marine plastic originates from land-based and the rest (about 10–25 %) originates from ocean-based sources.[46] MPs are transported and dispersed throughout the oceans, including beaches, in deep-sea and coastal sediments, and on surface waters from the Arctic to the Antarctic from remote locations.[55] In Antarctic region, MPs reached through scientific research centers, tourist vessels.[57] The oceans have been used as dustbin for dumping of plastic and thus effect the marine life and convert marine areas in to plastic soups (UN Environment 2018). MPs enters in to aquatic environment through fresh water and marine water ecosystem. Most of the MPs with dimension ≤1 µm has been released from flue gases by combustion, rubber from tyres, glass etc. which are regularly dumped in to marine environment.[23] They enter into the water through urban runoff, from agriculture waste (through pesticides as pesticides also contain MPs), recreational activities, from industrial waste and also from overflow of sewage sludge (Nel 2018).[57, 20, 16, 8, 45] MPs enter in to the fresh water through WWTPs (wastewater treatment plants) and the WWTPs plays important role in MPs pollution.[44, 39]

Devastation of MPs in aquatic ecosystem

The MPs are found in both freshwater and marine water. Once these MPs enter in the aquatic system they present in each level *i.e.* in surface water, water column, benthic sediments. Due to their variable size, color and densities these MPs are found in different trophic level in aquatic biota.[58] The MPs are consumed by both marine and fresh water organisms. They affect them both physically and chemically.[33] The MPs are ingested by aquatic fauna due to their very small size and absorbed on the surface of aquatic flora due to which it affect entire aquatic biota

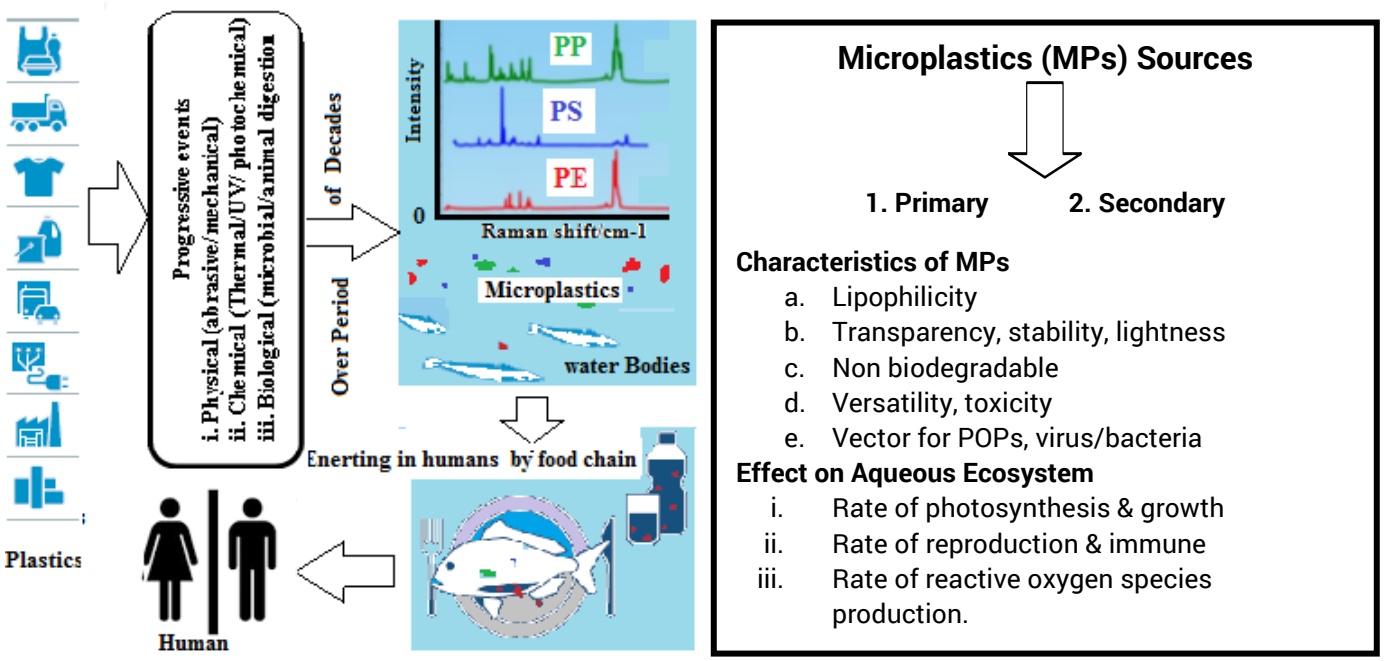

Fig. 3: Microplasitcs formation and penetration into food chain/web and its effects

through food chain even upto human being [Fig. 3].[46, 32]

Effect of MPs on aquatic biota (Table 2)

On entering in the aquatic ecosystem these MPs are ingested by aquatic fauna, from small vertebrates to large predatory mammals all have been infected by MPs.[58] Around 331 species of marine water are found to be containing plastic from 1960s to 2015.[37] From recent studies revealed that plastic is ingested by both pelagic and benthic fishes.[5, 13] The different investigation showed that microplastic is ingested and accumulate in filter feeding bivalves, which can affect their physiological activities. MPs present in digestive track and gills of mussels and stick on their foot, mantle and gonads.[35] MPs accumulate in the gastrointestinal tract of the fishes, but it could not effects the larval development, growth and their metabolism.

Table 2: Effect of MPs on aquatic biota

Species	Organ	Effects
Fauna: Mussels, longnose lancetfish, pelagic & benthic fishes (232 species of fishes), polar cod	Digestive track, gills in filter feeding bivalves, stomach, cell wall, gonad, visceral, mantle, adductor and endocrine gland	mortality risk, reduce feeding activities, inhibit growth and development, cause oxidative stress, reduce immunity, endocrine disruption, disturb testrogen and oestrogen secretion energy disturbance, neurotransmission dysfunction and also genotoxicity
Flora: macrophytes, (sea grass) Chlorella pyrenoidosa, duckweed	Cell wall, thyakoids, roots and leaf	Morphological & physiological effect the thylakoids and also damage the cell wall, damage root length, root number, reduce the chlorophyll content in leaf and damage leaf

Invertebrates have little effect of high concentration of MPs.[38] Plastic enters in the fishes from anthropogenic waste like cans, horse shoes and ropes. The first reported case of plastic in fishes is recorded in 1964, it is found that 62.5% of longnose lancetfish (*Alepisurus ferox*) contained plastic. In 2015, almost 92 species of fishes are found with ingested plastic and more recently this number increases to 232 species of fishes are found with ingested plastic.[36] MPs have the ability to increase mortality risk, reduce feeding activities, inhibit growth and development, cause oxidative stress, reduce immunity, endocrine disruption, energy disturbance, neurotransmission dysfunction and also genotoxicity.[4, 13] Chemicals like as bisphenol A, phthalates, nonylphenol

and polybrominated diphenyl esters are added to MPs during manufacturing processes to increase their stability and make them more durable. These chemical are not bound with MPs polymers and leach from the product and enters in the water body and become available for organisms, these chemicals interfere with the biological activity of fishes and enters in their cells and cause endocrine system disruption.[5] Once MPs are ingested they can cause damage to digestive tract and tubules, in addition to this physical harm to marine biota, MPs serve as vector of hydrophobic POPs (persistent organic pollutants), OCPs (organochlorine pesticides), PAHs (polyaromatic hydrocarbons), viruses and bacteria and after ingestion of these contaminated POPs they enters in the whole marine web.[1, 49] The microbeads after ingested by oyster change their feeding behavior and reproductive ability and also affect their offsprings.[14, 59]

Effect of MPs on aquatic flora

MPs accumulate on the surface of aquatic plants and affect their morphological and physiological character. MP are found on the surface of marine macrophytes, like seagrass and macroalgae and enters in the marine food web.[52] MPs present on fresh water algae Chlorella pyrenoidosa cause physical damage and oxidative stress.[12] MPs distort the thylakoids and also damage the cell wall of chlorella pyrenoidosa. Chlorella can reduce the MPs effect through thickening of cell wall.[42] Phytoplankton are the important primary producer and important for oxygen production and nitrogen and phosphorus biogeochemical cycle.[42] In marine water microalgae are primary producers, but the nano and micro sized plastic particles absorb on their surface and inhibit their photosynthetic activity as the larger pore size (>20 mm) of typical algal cell wall so the MPs can easily penetrate inside them.[54] Now, we discuss the effect of MPs on vascular plant (duckweed) they are the primary producers and serve as food for fishes. They also provide habitat to many organisms.[31] MPs are attached to the roots. MPs do not affect their growth process, but MPs with sharp edges can affect their root length and damage their root membrane.[18, 32, 43] However, at the same time when MPs enter in the aquatic system and comes in contact with plants they colonized by diverse microbial life that develop a biofilm and this biofilm cover the sharp edges of MPs and protect duckweed from harm.[50, 30]

Most plausible remedial measures

Plastics take thousand of year to degrade and can be converted into microplastics which are very harmful for all living biota due to their extensively small size (≤ 0.5 mm). Even the microplastics are not completely separated during waste water treatment in plants (WWTPs). Therefore different remedial and legal tools can be adopted to reduce the MPs level includes biotechnology and engineering tools (Fig. 4).[61] There are certain legal procedures which are formulated and adopted to decrease MPs release.

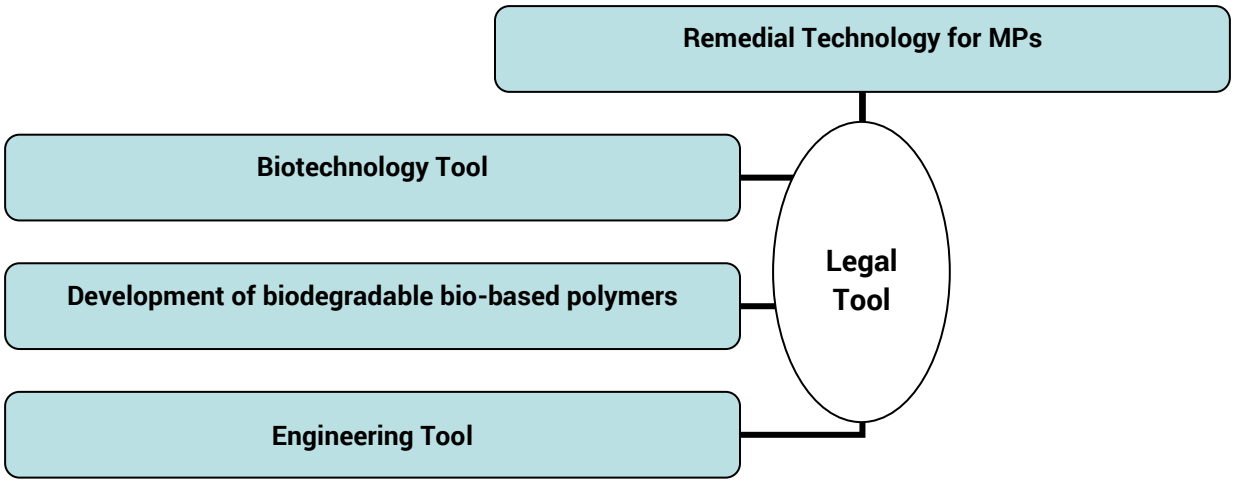

Fig. 4: Remedial measures for MPs

Since 2017, US banned the use of microbeads in cosmetic products and many other country like Austrilia, European Union (EU), Canada also thinking about to do the same, because microbeads used in cosmetics are the main cause of MPs pollution. Regarding the secondary source of MPs there is restriction on the consumption of single-use plastics, especially plastic bags and straw. Already, 73 countries have banned the utilization of single-use plastics.[47] Some initiative steps are taken by EU, like in 2030 all plastic packaging are recyclable and unwanted consumption of single-use plastic is decreased and intentional use of plastic is banned.[19]

Many remediation technologies are used to reduce plastic from pollution from water ecosystems, restriction in the use of MPs and parallel cleaning of oceans is done.[47, 19, 62, 9]

Conclusion

Microplastics (MPs) pollution is a one of major global issue due its non-biodegradability and radically distributed, persistence at micro and nano level across the globe including Arctic and polar the aqueous ecosystems. Even the microplastics are not completely separated during wastewater treatment in plants (WWTPs). Most of the MPs are of highly stable polymers like polystyrene, polyethylene and due to microscopic dimension of plastics, MPs are mistily consumed as food by aquatic fauna and effect the biota including human health through food web. But there is major problem is that there is no proper method to calculate the amount of MPs in water body. In this review, we reviewed the sources, destination and devastation effect of MPs on fishes, mussels, oysters, bivalves and on many other aquatic animals, but in aquatic flora we studied only few plants like duckweed, algae, phytoplanktons. To reduce the effect of MPs some legal procedure formulated and enforced by some countries and banned the MPs in the personal care product. Many countries trying to adopted the alternate of MPs to reduce its products and stop the unnecessary use of plastics leading to microplstics.

Declaration of interests

The authors have no conflict of interest to declare.

Data sharing

All relevant data are within the manuscript.

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