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Microplastics: Impacts on Environment and Human Health Hazards

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Authors' contributions

This work was carried out in collaboration between both authors. Author LNM designed the study, performed the statistical analysis, wrote the protocol, and wrote the first draft of the manuscript. Author KJM managed the analyses of the study and managed the literature searches. Both authors read and approved the final manuscript.

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Review Article

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ABSTRACT

Plastic waste is not biodegraded and can only be broken down, predominantly by physical processes, into small particles of micron to nanometre size. Microplastic pollution is becoming a major issue for human health due to the recent discovery of microplastics (MP) in most ecosystems. Microplastic have been found to have significant negative impacts on both human health and the environment. Plastic particles less than 150 µm can be ingested by living organisms, migrate through the intestinal wall and reach lymph nodes and other body organs. There are increasing concerns over the environmental and human health impacts associated to exposure to these pollutants. The long-term and irreversible risks to ecosystems and human health indicate for mitigation measures to be taken to halt the accumulation of plastics and microplastics in the environment. The surfaces of plastic fragments can be carrying disease-causing organisms andacts

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as a vector for diseases. The microplastics found in water and soil carry different types of contaminants and serve as carriers for bacteria and persistent organic pollutants. MP and nanoplastics may pose acute and chronic toxicity, carcinogenicity, developmental toxicity, and genotoxicity. This study conducts a review with primary objectives of MP, including their definition, ecological impacts with respect to direct and indirect effects; effects on aquatic biota, marine ecosystem, fresh water ecosystem, animal health and seafood, human health hazards; control measures; and knowledge gaps.

Keywords: Microplastics; toxic effects; human health; environment; ecological effects; seafood.

1. INTRODUCTION

Karimpour et al [1] stated that, “plastics are durable, lightweight, cheap to manufacture, and are suitable candidates for use in a wide spectrum of products. Global plastic production dramatically increased by 620% between 1975 and 2012”. “It is estimated that 4.8 to 12.7 million tonnes of plastic waste entered the ocean in 2010.With the present trends, annual plastic production is expected to reach 1124 million tonnes by 2050” [2]. “Plastics have brought a lot of benefits to modern life, driving the tremendous growth in plastic demand, because of their low cost, light weight, and durable character” [3].

“Plastic items are the major source of water pollution and a problem of growing concern. They have been reported in marine and freshwater environments, in urban wastewater and storm water, and elevated levels have been reported outside of wastewater treatment plants” [4]. “Release of plastics into the aquatic environment occurs through various land- and marine-based pathways, including rivers, atmospheric transport, beach littering, and directly at sea via aquaculture, shipping and fishing activities” [5, 6].

“Over the past couple of years, plastic ingredients in personal care and cosmetic products acts as a potential source of plastic pollution in the sea. Through various sources and routes, non-degradable plastic materials can be emitted to the marine environment. Plastic ingredients in products that are being used by consumers in households worldwide are contributing to the total abundance of particulate plastic litter in the ocean toda”y[7, 8].

Graca et al [9] stated that, “because of increasing global plastic production and production of synthetic polymers and their low biodegradability, plastic pollution has become a serious environmental problem.” “Continued plastics production, use, disposal, and leakage have led to a steady increase in the amount of plastics in the environment” [10]. “Due to growing global reliance on the plastics industry, plastic-derived pollution has become a threat to global ecology and a topic of international concern” [11,12].

GESAMP [13] reported that, “recently, considerable public attention has focused on microplastics particles from personal care products, which was mainly triggered by reports in news media”. “Concern about the quantity of plastic and microplastic debris in the ocean has grown rapidly in recent years, which has developed increased interest from governments, Intergovernmental Organizations (IGOs), regional seas organizations, the private sector, environmental NGOs, special interest groups, the media and the scientific community” [14,15].

Jassim [16] noted that, “due to increase in population worldwide, the consumption of plastic was increased and led to produce and generate microplastic waste”. “Plastic waste and debris can affect the life force, of the environment including cultural health and wellbeing” [17]. “Plastic pollution has attracted worldwide attention from governments, the public, the scientific community, media and nongovernmental organizations and has become a hot issue in current marine ecology and environmental research” [18, 19].

In the present work, currently available information on MP including their definition, ecological impacts with respect to direct and indirect effects; effects on aquatic biota, marine ecosystem, fresh water ecosystem, animal health and seafood; human health hazards; control measures; and knowledge gaps is critically evaluated.

Table1. Structure of the review paper

Section	Details
I	❖ Introduction, Goal of the present review paper
II	❖ Literature Search Methods
III	❖ Definition of 'Microplastics'(MPs)
IV	❖ Transformation of Macroplastics to Microplastic
V	❖ Ecological Impacts of Microplastics • Direct effects • Indirect effects • Effect on Aquatic Biota, Marine Ecosystem, Fresh water Ecosystem & Animal health • Impact on Seafood (Commercial Finfish, Shellfish, etc)
VI	❖ Human Health hazards of microplastics
VII	❖ Control Measures for Microplastics
VIII	❖ Knowledge Gaps

2. LITERATURE SEARCH METHODS

The review was carried out through extensive literature search, using electronic databases, and online search tools, such as EMBASE, Google Scholar, Medline, NCBI, PubMed, Science Direct, Scopus, and Web of Science databases. Data and information were collected from the thorough study of the journal articles, research papers, reports and various literatures. This review paper analysed a total of 41 research articles published in reputed journals. The keywords used for reviewing the literature were the ones that refer to the issues concerning the 'Microplastics'. For literature search, keyword "Microplastics" is combined with: definition, direct and indirect effects; effects on aquatic biota, marine ecosystem, fresh water ecosystem, animal health and seafood; human health hazards; control measures; and knowledge gaps.

3. DEFINITION OF MICROPLASTICS (MPs)

The definition used by GESAMP [13] is the only currently proposed definition that also covers the "nanoplastics". Earlier, "Micro-", "meso-", and "macro"-plastic debris were defined as <5 mm, 5–20 mm and >20 mm diameter, respectively, whereas "mega-" plastic debris would be >100 mm.

4. TRANSFORMATION OF MACRO-PLASTICS TO MICROPLASTIC (Figs. 1 & 2)

Plastic debris in the environment initially undergoes mechanical fragmentation to form the macroplastics, which is further disintegrated into the microplastics by the mechanism of oxidation, photodegradation or by the biodegradation (Fig. 1).

Table 2. Definition of Microplastics (MPs)

Authority	Definition of Microplastics
Lassen et al [20]	Persistent, solid particulates composed of synthetic or semi-synthetic polymers and physical dimensions of 1 μm - 5 mm originating from anthropogenic sources.
Lart [21]	Wide range of particles made from manmade polymers ranging in size from 10^{-9} m to 5 mm.
Wagner & Lambert [22]	Plastic particles whose longest diameter is in between 1 to <5 mm.
WHO [23]	Plastic particles with different densities, chemical compositions, shapes and sizes (<5 mm in length). A subset of microplastics <1 μm in length are referred to as 'nanoplastics'.
Yang et al [3]	Plastic fragments or particles with a diameter of less than 5 mm formed by fragmentation of larger plastics.
The Water Research Foundation [24]	Plastic particles under 5 mm in size (but seldom sampled <0.3 mm).

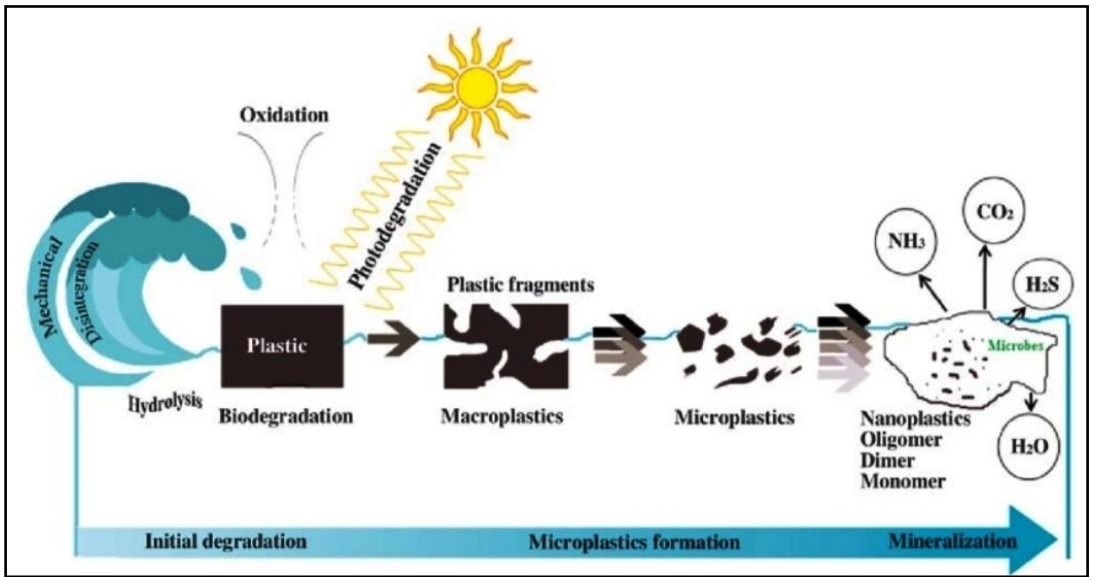

Fig. 1. Degradation of macroplastics to microplastics by oxidation, biodegradation & photodegradation
(Source: Sitharam [25])

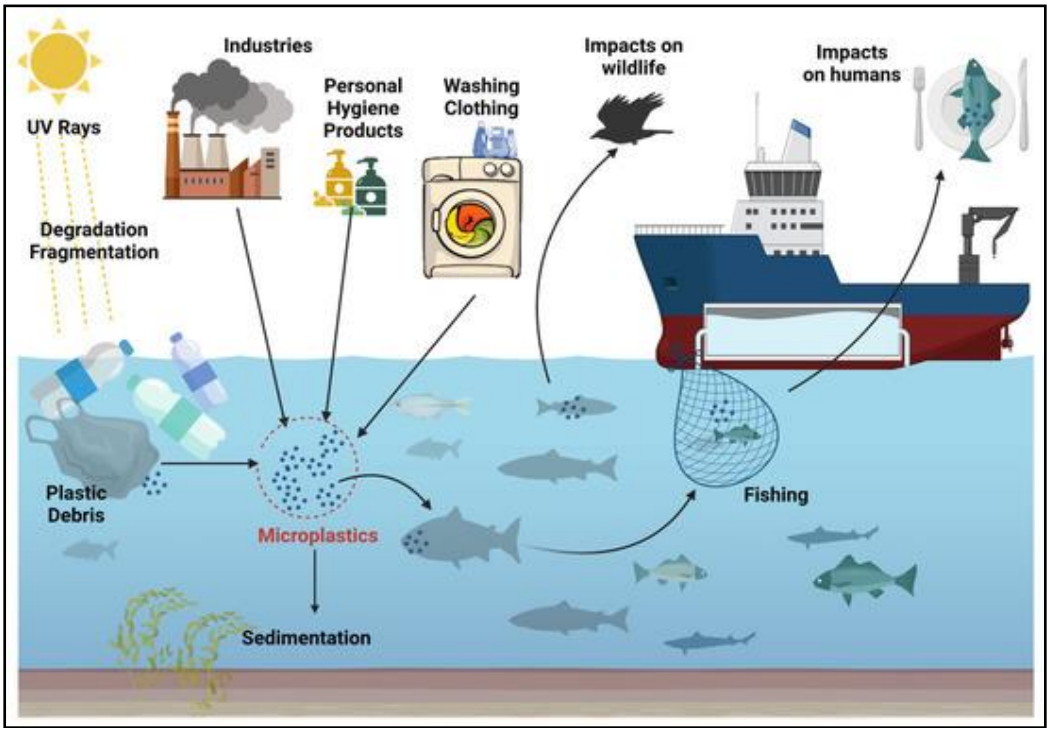

Fig. 2. Transformation of macroplastics to microplastics by UV rays, degradation & fragmentation
(Source: Ziani et al [26])

5. ECOLOGICAL IMPACTS OF MICRO-PLASTICS

"Manmade polymers are very persistent, widespread, and ubiquitous in the marine environment and become concentrated in areas of slow circulation in the middle of the 'oceanic gyres' which dominate the hemispheric circulations of the world's oceans" [21]. "Due to non-degradable nature, plastic has become very

difficult to handle & a real menace in aquatic ecosystem leading to pollution of biotic and abiotic components of environment" [18].

"MP are pervasive in lakes, oceans, and drinking water and they are ingested, inhaled, or absorbed throughout the food chain, from microscopic organisms to humans" [24]. "The potential hazards associated with MP come in three forms: physical particles, chemicals and microbial pathogens as part of biofilms. Plastic particles may cause impacts in the body, depending on a range of physicochemical properties of the particle, including size, surface area and shape" [23].

"MP pollution is one of the most persistent emerging environmental issues that are faced today. The world's oceans, freshwaters, soils and air are increasingly contaminated with tiny plastic fragments, particles, and fibres, raising concerns for the associated environmental and human health impacts" [8]. "MP may physically (mechanically) affect organisms, act as vectors for hydrophobic pollutants and as substrates for organisms, and affect sediment properties" [27].

5.1Direct Effects of Microplastics[3]

Direct effect of MP include: bioaccumulation in the digestive tract; biofilms of micro-organisms on the particles; ingestion by marine species; entry tissues or body fluids; translocation to the circulatory system; and uptake via the gills.

5.2 Indirect Effects of Microplastics

Indirect effect of MP include: adsorption of pollutants on the surface of the particles; effect on the physiology of organisms; and transfer of pollutants by microplastic particles in the body of marine fauna.

5.3 Effect of Microplastics on Aquatic Biota

Aquatic organisms such as planktons, copepods, zooplanktons, crabs, small fishes, turtles, fish larvae, sea birds and mammals were directly affected by MP. Bioaccumulation of MP results in diverse negative impacts on the body of biota such as: disruption and failure of organ system; death in extreme cases; respiratory and circulatory problems; rupturing of digestive system; and weakening of immune system and impotency.

5.4 Effect of Microplastics on Marine Ecosystem [7]

Marine ecosystem was negatively impacted by the MP by different ways such as: alteration in the feeding behaviour; decrease in growth rate; endocrine disruption; hormonal imbalance; injury to gill tissues and the intestinal tract; vector for pollutants; physical injury; oxidative stress; reduced energy allocation; damages in the alimentary canal; physical obstruction of feeding and digestion; reduced food consumption and reproductive outputs; and reproductive changes (reduction in the quality of oocytes, sperm swimming speed and fecundity).

5.5 Effect of Microplastics on Fresh Water Ecosystem [28]

Freshwater ecosystem is also affected by MP due to adsorption of persistent organic pollutants (POPs) and metals to MP. This results in alterations in the feeding and innate behaviour; hepatic stress, affects the growth and mortality; inhibition of hatching and reduced growth rates; and decrease in growth and reproduction.

5.6 Effect of Microplastics on Animal Health

Health of the aquatic fauna were seriously affected the MP due to entanglement; inhibited movement, invasion of foreign species, and ingestion resulting in difficulty in breathing and eating, impaired digestion, accumulation of toxins, and resulting in death.

5.7 Impacts of Microplastics on Seafood (Commercial Finfish, Shellfish)

MP have been reported in the tissues of both edible finfishes and shellfishes. Plastic infrastructure used widely in fisheries and aquaculture serve as source microplastics that may contaminate seafood products [14].

5.8 Microplastics in Commercial Fin Fishes

Accumulation of MP in the tissues alters the predatory behaviour of the fishes.

Bioaccumulation of contaminants (e.g. PCB, Polychlorinated biphenyls; PBDE, Polybrominateddiphenyl ether) in the tissues results in hepatic stress and changes in gene

expression. MP ingestion has been reported in commercial fish species, pelagic and benthic (bottom dwelling) fish such as: Pelagic, Bluefin tuna, Swordfish, Albacore, Atlantic herring, Sardine, European and Pacific Anchovies, Indian mackerel, Benthic/demersal hake, Blue whiting, Red mullet, small scale gurnard, and Common dolphin fish. Further, MP remain in the digestive tract of finfish and are transferred to other tissues.

5.9 Microplastics in Shellfish and other Species

In shell fishes, ingested microplastics range from 5 µm to 5 mm in size and is composed of fragments, pellets and fibres. It causes physical and/or chemical consequences to an animal upon exposure and possibility of transfer to human consumers since shellfish is eaten whole. MP have been observed in mussels, clams, oysters and scallops. MP are reported in mussels (*Mytilusedulis, Crassostreagigas*); crustaceans (*Carcinusmaenas, Nephropsnorvegicus*); gastropods (*Littorinalittorea, Patella vulgaris*); and echinoderms (*Tripneustesgratilla, Holothuria sp*.). Toxicity of MP cause reduction in function of the reproductive system and inflammation. MP are also transferred outside the gut into the hemolymph and the circulatory system.

6. HUMAN HEALTH HAZARDS OF MICROPLASTICS

Plastics are important in protecting food and beverages from damage and microbial contamination. In healthcare, plastics provide sterile equipment and hypoallergenic medical devices. But, plastics, microplastics and chemicals associated with plastics contaminate food, water, air, and affect human health [29]. Humans are exposed to plastics and the chemicals associated with them through diet and when breathing household dust, tyre dust and particles from burning plastics [30].

Pachkowski [31] reported that, humans are being exposed to microplastics from domestic, medical, and environmental sources. Microplastics from certain sources can have effects in humans. Plastic pollution is not just an eyesore, but a problem that causes extensive harm to our environment and to the health and wellbeing of people and animals (Fig. 3) [32].

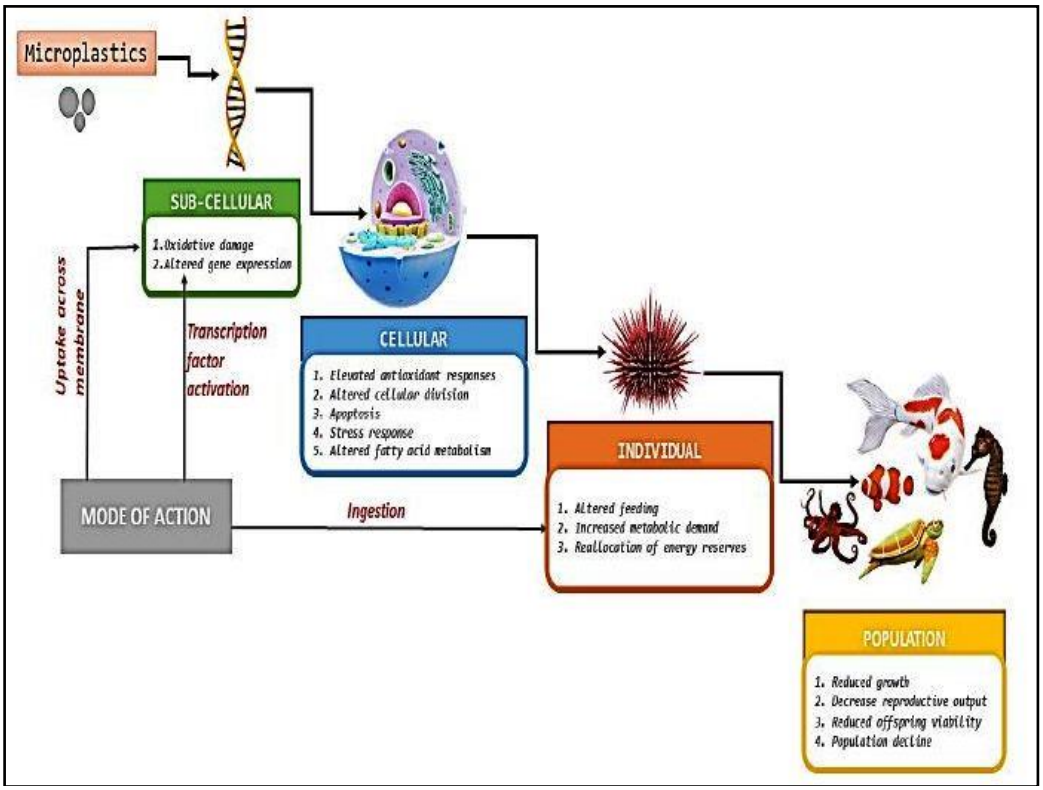

Fig. 3. Effects of microplastics on human at cellular and sub-cellular level
(Source: Thakur et al [33])

Plastic particles <150 µm can be absorbed by tissue, organs, and even cells. Microplastics may pose acute and chronic toxicity, carcinogenicity, and developmental toxicity. Nanoplastics may pose chronic toxicity, genotoxicity, and developmental toxicity. ABS (Acrylonitrile-butadiene-styrene), PAN (Polyacrylonitrile), PUR (Polyurethane), PVC (Polyvinyl chloride), and Epoxy resin are identified as the most toxic polymers [32].

6.1 Routes of Human Exposure to Microplastics

In human, routes of exposure for MP are ingestion (food, water), inhalation (air) and dermal contact. Also, consumption of contaminated foods and beverages: Bivalves, Finfish, Table salt (Harvested from the sea, lakes, or wells); Beverages (Bottled water, Tap water, Beer) is a major source of entry of MP in human. Other source of microplastics is laboratory contamination (airborne microfibers), processing or packaging of consumables, plumbing; as well as respiratory inhalation, skin contact, and ingestion [19].

6.2 Potential impact of Microplastics on Humans [34]

Physical & chemical characteristics of microplastics will influence the toxicological risk in human. The particle toxicity hazard of MP on humans include: biological responses (inflammation, genotoxicity, oxidative stress, apoptosis & necrosis); tissue damage, fibrosis and carcinogenesis; along with interaction of MP with gut microorganisms and affect human health. Exposure to micro-molecules adsorbed to MP affect human health through effects on gut microbiota [35].

6.3 Health Hazards of Polymers, Additives and Adsorbed Pollutant

Williams [36] stated that, MP was reported in various foods such as, fish, seafood, table salt, beer, honey, sugar, and tap water. Due to omnipresence of MPs in air, water, food, and consumer products, MPs surround us and human exposure can occur through inhalation, ingestion, and dermal absorption. The potentially hazardous effects of different types of micro- and nanoplastics to human health remain largely unknown [37].

According to Jassim [16], potential impacts of MPs on human health include: bioaccumulation in the human body; cancer, intestinal diseases, pulmonary diseases, cardiovascular disease, and gene expression disturbances [28]; carcinogenicity, cytotoxicity, neurotoxicity, immune system disruption, and transfer of MPs to other tissues [17]; carrier for chemicaladditives and pathogens; cause cellulardamage, neuro-inflammation in the brain

Table 3. Health hazards of polymers, additives and adsorbed pollutant

Polymer	Monomer(s)	Health hazard
Polyurethane	Ethylene oxide	Mutagenic, carcinogenic to humans
	Propylene oxide	Mutagenic, possibly carcinogenic to humans
	Toluene-dissocyanate	Irritant
Polycarbonate	Bisphenol A	Endocrine disruption, Reproductive and developmental effects
Polystyrene	Styrene	Genotoxic, probably carcinogenic to humans
Polyvinylchloride	Vinyl chloride	Carcinogenic to humans
Additive	Phthalates,Triclosan, PBDEs, Alkylphenols	Endocrine disruption
Adsorbed pollutant	PCBs	Carcinogenic to humans
	PAH	Some are carcinogenic to humans Developmental effects
	Organochlorine pesticides	Some are carcinogenic to humans Neurotoxicity, Endocrine disruption Reproductive/developmental effects
	Cadmium	Carcinogenic to humans, Renal toxicity
	Chromium	Carcinogenic to humans
	Lead	Neurotoxicity

(Source: Pachkowski, [31])

tissue and various neurological disorders [3]; concentrate in human body through inhalation of dust, consumption of food, or direct drinking water contaminated by microplastics; cytotoxicity (apoptosis, necrosis, tissue damage, fibrosis) and carcinogenicity; damage to human cells, allergic reactions, cell death, damaging cells, and inflammatory and immune reactions; oxidative stress, DNA damage, inflammation, and other health problems; impairs immune system and can cause autoimmune disorders; induce intestinal obstruction or tissue abrasion; inflammation and immune responses, adsorbed chemical pollutants, and toxicity via inflammation due to the bio-persistent nature of microplastics [38]; vector for diseases due to presence of pathogens on their surfaces; reproductive toxicity; and also toxicity to liver, spleen, heart, reproductive organs, brain, kidney, and intestine [39].

7. CONTROL MEASURES FOR MICRO-PLASTICS

Jassim [16] have suggested that, to irradiate the effect of the microplastic pollution, various practices should be followed such as: awareness on impact of MP on environment and human health; reduce consumption of meat and fish; legislation support to curb plastic production and waste; to avoid products containing micro-beads; reduce use of single-use plastics; use of active carbon filter on tap water; and use water filter for drinking water and avoid the bottled water.

8. EASY WAYS TO REDUCE PLASTIC WASTE

According to Badore [40], recycling can help reduce the amount of garbage that ends up in landfills, waterways and ecosystems, only a few types of plastics can be recycled by most municipal governments. The fraction that does get recycled still requires a lot of energy and water which just isn't a good proposition when it comes to single-use items. Plastic garbage that ends up in landfills and oceans take hundreds of years to degrade, and there's increasing concern about the toxins they release into the environment [41].

Badore [40] stated that, easy ways to reduce our plastic waste today include: bring your own shopping bag; stop buying bottled water; bring your own thermos to the coffee shop; choose cardboard over plastic bottles and bags; say no to straws; get the plastic off your face; skip the disposable razor; switch from disposable diapers to cloth; make your period waste-free; re-think your food storage; and shop in bulk (Fig. 4 & 5).

Fig. 4. Easy ways to reduce your plastic waste
(Source: Badore [40])

Fig. 5. 5R's (Reduce, Reuse, Recover, Recycle & Re-invest) for use of plastic

9. KNOWLEDGE GAPS

Knowledge gaps in the ecology of MP include: poor knowledge on cumulative impacts of microplastics with other stressors, environmental and human health risks posed by microplastics pollution of different environmental media, and cost-effectiveness of different mitigation interventions.

10. CONCLUSION

The study indicates that, quality-assured toxicological data are needed on the most common forms of plastic particles relevant for human health risk assessment. Detailed study on humans exposed to microplastics through a variety of environmental media, including food and air is necessary for better understanding of overall exposure to microplastics from the broader environment. Targeted, well-designed and quality-controlled investigation should be carried out to understand the microplastics in relation with the occurrence and sources of microplastic pollution and the uptake, fate and health effects of microplastics under relevant exposure scenarios. The students and young people can become familiar with the issues of microplastics as early as possible by including origins, types, effects, fates, and other related factors of microplastics in school and university curricula [38]. It is recommended to reduce the use of plastics, improve recycling programmes, reduce littering, improve circular solutions and decrease industrial waste inputs into the environment. Also, overall human community should be made aware of hazardous impacts of MP and minimal use of plastic on strict basis along with plastics should be discarded taking appropriate care. Further, the 5R's of responsibility regarding Reduce, Reuse, Recover, Recycle, and Re-invest must be practised regarding use of plastic.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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