World Journal of Biology Pharmacy and Health Sciences

eISSN: 2582-5542

Cross Ref DOI: 10.30574/wjbphs

Journal homepage: https://wjbphs.com/

(Review Article)

Microplastics as potential source for environmental pollution: An updated review on Indian scenario Post Covid -19

Darakhshan Khan, Tasneem Husain, Gulafsha Kassab and Sharique A Ali *

Postgraduate Department of Biotechnology, Saifia College of Science, Bhopal 462001 India.

World Journal of Biology Pharmacy and Health Sciences, 2022, 12(03), 094–106

Publication history: Received on 28 October 2022; revised on 05 December 2022; accepted on 07 December 2022

Article DOI: https://doi.org/10.30574/wjbphs.2022.12.3.0229

Abstract

Technological advancement has tremendously accelerated the promotion of microplastics in our environment. In early 2020, the COVID-19 pandemic accelerated the production and use of plastics in the form of facemasks, face shields and PPE kits across the globe has intensified and becomes a new environmental challenge. As scientific knowledge is limited concerning the source, exposure, toxicity, and bioavailability of microplastics in the surroundings, this review has been aimed to provide comprehensive information about microplastics present in the environment with special emphasis on their deposition and related increasing menace in India, during and after the COVID 19 period. We have focussed on the 5 key research needs, involving (1) the occurrence and abundance of microplastics (2) sources, fate, and occurence of microplastics in different media (water, air and soil), (3) toxicological implications of microplastics on human beings, (4) scenario of microplastics disposal during COVID-19 pandemic and (5) major challenges and future directions to curtail them. We suggest that addressing these knowledge gaps will lay the groundwork to counteract such environmental issues which are important to prevent them from exacerbating. Combating microplastic contamination can be achieved through an intensive and combined effort of all, including the stakeholders, researchers, educators, media and policymakers. We can join the effort to manage plastic in the environment by refusing, reducing, reusing and recycling the plastic products, to prolong every item's life cycle as far as possible. A start would be a focus on limiting the use of single-use plastic products, especially if alternatives are readily available.

Keywords: Microplastics; Plastic pollution; Plastic microbeads; Bioaccumulation; Biomagnification

1. Introduction

Environmental pollution is a wide-reaching problem, and it is likely to influence the health of human populations considerably. Most of the seabed is made up of plastics resulting from the waste collected on the coasts and in the sea [1]. When plastic gets released into the environment it undergoes degradation, which leads to serious issues. Atmospheric agents, such as waves, abrasion, ultraviolet radiation, and photo-oxidation combined with bacteria can degrade plastic fragments into micro and nano-sized particles, called microplastics and nanoplastics.

Microplastics (MPs) are defined as plastic particles less than 5 mm in size [2]. Microplastics have been detected in environments and media as varied as oceans, rivers, sediments, sewages, soil, and even table salts [3,4]. Microplastics accumulated in the earth's environment adversely affect wildlife, habitat, aquatic habitat, and human beings[5].A report by the World Health Organization on "Microplastics in drinking water" encourages extensive research to assess their hazardous effects [6]. There is evidence of the presence of microplastics in the human placenta and that prenatal exposure to microplastics affected the early development of neonates [7].

* Corresponding author: Sharique A Ali; ORCID-ID: 0000-0002-0378-7385; E-mail:drshariqueali@yahoo.co.in

Even excessive use of face masks, Personal Protective Equipment kits (PPE kits) made up of plastics during the pandemic times (Covid-19) created a huge amount of wastage of microfibres (as microplastics) that is detrimental to our environment[8]. Research into the extent and consequences of microplastics in the environment is significant in light of growing shreds of evidence confirming the seriousness of this issue. Therefore, there is a great need to address microplastics induced toxicity that is both inevitable and essential. Moreover, the toxicological problem with these microplastics is their non-biodegradable materials, which then get washed down the drain and end up accumulating in water bodies via the natural phenomenon of biomagnification and bio-accumulation [9].

The increasing attention of research on microplastics is attributable to their longevity, which enables long-distance distribution from their source and consequent accumulation in water bodies [10]. In India, the presence of microplastics has also been reported in different lakes of India [11,12]. Microplastics have been accumulated by aquatic animals and can also transfer from one species to another species by the process of biotransformation and bioaccumulation. In a study, microplastics can be accumulated from algae (*Scenedesmus sp.*) to zooplankton (*Daphnia magna*) to goldfish (*Carassius carassius*), with noticeable effects on the feeding behaviour of (*C.carassius*) exposed to microplastics [13]. This study shows the 'natural' trophic transfer of microplastic and its translocation to the hemolymph and tissues of a crab. Globally, these aquatic animals are consumed by human beings as a source of proteins and concentrated in the food chain through a process called biomagnification, subsequently contaminating the fish and wildlife species that human beings can be consumed by which microplastics can enter into the cell through the cell membrane disrupting the cell organelles.

Microplastics can also act as a vector for many contaminants such as BPA, PCB, and heavy metals, which is detrimental to both terrestrial and aquatic habitats. The sorption rate of these pollutants on plastic debris can vary among polymers: shape, crystallinity, surface functional groups and ageing of particles affect the sorption capacity of pollutants [14,15]. For example, polyethylene pellets have a higher affinity for polychlorinated biphenyls (PCB) than polypropylene. The higher affinity of polyethylene is the result of the larger volume of the inertial cavities, which allows the diffusion of compounds into the polymer [16]. Espinosa *et al.* investigated the in vitro effects of microplastics polyvinylchloride (PVC) and polyethylene (PE) on gilthead seabream (*Sparus aurata*) and European sea bass (*Dicentrarchus labrax*), resulting continue exposure of fish to PVC or PE microplastics could impair fish immune parameters in the fish leucocytes [17]. Yang et al. investigated polystyrene microplastics in mice systems based on toxicity-based modelling to quantify organ-bioaccumulation and biomarker responses for mice and establish a TBTK/TD framework for mechanistically assessing potential from mice size-specific MPs exposure that would offer a tool-kit for health risk assessment perspective [18]. Reviewing the literature, it becomes evident that the present state of information on microplastic exposure and its various toxicological effects shows lacunae in scientific knowledge of microplastic-induced toxicity in animals and human beings.

2. Types and Sources of Microplastics

Microplastics are divided into two types: primary and secondary microplastics. Primary microplastic is synthetic microbeads developed for domestic and industrial purposes. These microbeads are used as raw materials in the plastic industry for the production of cosmetics, detergents, and other hygiene and personal care products. These primary microplastic particles that get released into rivers from water treatment plants will subsequently enter into the sea on a global scale and are mostly unknown, thus critical for evaluating the acute and chronic effects of microplastics [19].

About 93% of the microbeads used in personal care products and cosmetics contain microplastics such as polyethylene (PE), polypropylene (PP), polymethyl methacrylate (PMMA), polyethylene terephthalate (PET), and nylon [20]. These microbeads can eventually transport to wastewater treatment plants that enter the oxidation ponds and sewage sludge These microplastic particles may pass through filtration systems and sink into the water bodies and affect aquatic habitats [14,21].

Secondary microplastics are plastic particles derived from macro-plastics fragmentation through photo-degradation, mechanical abrasions, and physical and biochemical reactions. It includes fishing nets, industrial resin pellets, domestic items, and other discarded plastic debris [22,23,24]. Other sources of microplastics include effluent treatment plants, landfills, irrigation, industrial wastewater, and domestic usage [25,26,27]. According to Geyer *et al.* yearly plastic production has tremendously increased in international markets from 2 million tons to 381 million tons in 2015, 42% of which were used as single-use packaging [28]. It was estimated that the excessive use of plastic could increase its waste to 155-265 million tons per year by 2060 [29]

Most of the research on microplastics has been focussed on marine waterbodies, less than 4% of microplastic related studies have been reportedly associated with freshwater [30]. This shows the scarcity of research and information but also reveals the abundance of microplastics in freshwater and its dispersion in freshwater is extremely heterogenous [31]. Microplastics can accumulate over time in the sediments of different water bodies [32]. Microplastics are considered an emerging global problem but only (22.9%) of countries have engaged in microplastic research. This creates a lacuna of information on microplastics abundance and distribution on a global scale.

3. Physical Characteristics of Microplastics: Shape, Size and Colour

Microplastics in the environment appear in a wide range of shapes and sizes in the form of spheres, beads, pellets, foam, fibres, fragments, films, and flakes. The shape of microplastic particles depends on their actual form and the degradation and erosion processes of these plastic particle surfaces with time in the environment. These shapes of microplastics are used to infer their origin and pathway because certain shapes may be more prolifically shed from particular products. Besides, the texture of particles indicates that mechanical abrasion and chemical weathering might play a key role in the degradation of microplastics in the environment [33]. For example, Microfibres used to make synthetic clothes could get fragmented from the exposure of larger plastic items to UV light [34]. Particle size and shape are the important aspects that can help to determine the interaction of pollutants with biota and its environmental providence [35]. The influence of shape and size on atmospheric transport is currently unknown and it requires further research. Specific shapes or sizes of microplastics may have a higher potential to cause physical harm to organisms, with smaller angular particles passing membrane barriers more easily than particles presenting regular surfaces or longer edges. Exposure to microplastics induced significant size-dependent effects, such as reduced growth rate, reduced life span and increase in reproduction time. These findings suggested that microbead toxicity was size-dependent and the smaller the size of the microbeads more it is toxic to the organisms. Antioxidant-related enzymes and mitogen-activated protein kinase (MAPK) signalling pathways were activated in response to microplastics exposure in a size-dependent manner, thus indicating serious kinds of shocks to organisms at the cellular level.

The colour of microplastic particles helps to categorize the potential sources of plastic fragments and potential pollutants during sample preparation. In previous studies, microplastics have been reported in different colours, including red, orange, yellow, brown, tan, off-white, white, grey, blue, green, and so on [33,36]. In a study, Xiong *et al.* investigated the effect of size, colour, and shape of microplastic particles on goldfish (*Carassius auratus*). The result suggested that microplastic particles with food-like colours could be ingested more than microplastics with other colours by goldfish [37]. Recently, Pegado *et al.* studied the ingestion of microplastics (MPs) by Longnose stingrays in the Western Atlantic Ocean and found fibres were the most frequent item (82%), blue was the most frequent colour (47%), and Polyethylene Terephthalate (PET) was the most frequent polymer recorded (35%), as identified by 2D imaging - Fourier Transform Infrared (FTIR) [38]. These diverse types of microplastics in the environment, which differ in shape, colour, and size, have different likelihoods of ingestion by aquatic animals indicating the growing problem of microplastics pollution.

4. Distribution of Microplastics in Different Medium of the Environment

4.1. Microplastics in Water

Water is a key source for our living on earth. It is the foremost part of the biosphere. We know that 75% of our whole earth is filled with water, and it is our responsibility to save our water bodies and aquatic lives from the risk of global warming. In the last few years, different studies have reported an increase in the number of killings of marine animals (birds, turtles, mammals) due to plastic ingestion and strangling by abandoned (ghost) fishing nets. Fossi *et al.* reported the presence of organochlorine compounds in fin whales suggesting that MPs might have potential effects on them [39]. Nevertheless, the mechanism of microplastic metabolism and its effect on aquatic organisms need to be explored.

The distribution of microplastic particles was also reported in freshwater bodies. The possible sources of the accumulation of microplastics in the freshwater ecosystem are wastewater plants [40], which can potentially transfer the polluted microplastics from seawater to the river and descent into lakes. In a study, Luo *et al.* suggested that the microplastic pollution of small freshwater bodies is more serious than estuarine and coastal waterbodies [41]. Meanwhile, the properties of microplastics can be quite heterogeneous. The order in globally detected polymers is polyethylene (PE), polypropylene (PP), polystyrene (PS), polyvinylchloride (PVC), polyethylene terephthalate (PET), which probably reflects the global plastic demand and a higher tendency for PVC and PET to settle as a result of their higher densities [42].

Microplastic accumulated in water bodies can also act as a vector for contaminants such as polycyclic aromatic hydrocarbons (PAH), heavy metals, and antibiotics [43]. Wang *et al.* investigated the effects of exposure of polyethylene microplastics to air, water and soil on their adsorption behaviours for copper and tetracycline [44]. Ašmonaitė *et al.* compared the polystyrene (PS) and polyethylene (PE) to act as vectors for hydrophobic organic chemicals (HOCs) in fish Three-spined stickleback (*Gasterosteus aculeatus*) after ingestion and found polystyrene (PS) and polyethylene (PE) microplastics mediated higher chemical transfer and accumulation of model HOCs [45]. Present studies show that microplastics can serve as a vector for other contaminants. However, more research is needed to achieve an indistinct understanding of the underlying factors influencing the sorption capacity and bioaccumulation behaviours. Progressive research coupled with management could determine the future production, consumption, and leakage of microplastics into the environment.

4.2. Microplastics in Air

Airborne microplastic pollution represents the newly emerging threat which creates a great emergency to deal with it. These microplastics can originate from different sources, such as synthetic materials washed off clothes during laundry cycles, such as polyester and polypropylene, abrasions to vehicle tires on the road that cause tiny tire shreds to fly off, erosion of everyday plastic or synthetic objects, like the soles of shoes and cooking utensils, runoff from plastic components used to develop and mark roads, coatings used on marine equipment and infrastructure, such as container ships, the plastic microbeads used in personal care products, such as plastic microdermabrasion beads in face wash. According to National Oceanic and Atmospheric Administration NOAA study, microplastics get generated as a by-product of sewage treatment, which sinks into the ocean where microplastics then evaporate into the atmosphere in huge volumes [46]. Cai *et al.* investigated the characteristic of microplastics in the atmospheric fallout from Dongguan city, China and found dust particles emission and deposition between the atmosphere, land surface, and aquatic environment were associated with the transportation of microplastics [47]. Dris *et al.* found a concentration of microfibres (synthetic plastic) ranging from 190 to 670 fibres/mg in domestic dust [48]. Catarino *et al.* estimated microfibre exposure from dust fallout of 13,731–68,415 airborne particles/year/capita in a household [49].Gaston *et al.* investigated airborne microplastics inside and outside of buildings in coastal California by filtering known volumes of air through glass fibre filters, suggesting polyvinyl chloride dominates indoor air, followed by polyethylene (PE) and μFT-IR showing polystyrene dominates followed by polyethylene PE and polyethylene terephthalate PET [50]. The ubiquity of airborne microplastic points to significant new potential sources of plastic inputs to terrestrial and marine ecosystems and raises concerns about inhalation exposure of microplastic particles to human beings both indoors and outdoors.

4.3. Microplastics in Soil

Agricultural soils are particularly prone to exposure to microplastic, as several pathways for plastic addition and incorporation exist in agroecosystems. Intensive farming and less organic matter in the soil can lead to declining soil health and structure. On the other hand, contamination of microplastics in the soil can create more stress on the agroecosystem [51]. Plastic mulching is extensively used in agricultural fields to increase yields, fruit quality and water-use efficiency. However, potentially promote soil degradation and soil water repellency. [52,53]. Many countries have been facing the problem of microplastics in agronomies such as., Europe, China, Bangladesh, Australia, Mexico, India, and Switzerland (54,55,56,57). Recent research has identified the risk of biomagnification of microplastics from terrestrial agriculture to the human food chain [58,59]. Thus, microplastics are considered an imminent hazard to food safety and sustainable agriculture.

Microplastics have specific morphology and properties rendering to their polymer types (e.g., flexibility, roughness, resistance, and durability) [60]. For example, polyurethane, a polymer used to produce flexible foams, has the potential for soil biology as millions of tons of this plastic are produced annually, potentially increasing its concentration in the soil [61]. Other microplastic shapes, such as foams or fragments, can be incorporated into the soil due to littering, street runoff, or wind deposition [62]. Lazano *et al.* have reported that microplastic particles can affect plant traits and soil physical and biological properties depending on their polymer types and shapes [63]. Microplastics can also interrupt the natural carbon cycle by influencing soil microbial processes, plant growth, or litter decomposition [64]. Therefore, more research is needed to understand the ubiquitous effects of microplastics on the functioning agricultural and terrestrial ecosystems.

5. Toxicological Implications of Microplastics on Human-beings

Microplastics have been observed in many food substances like salt, branded milk, fish and other seafood, and tea from teabags [65]. One of the most prevalent microplastic entry points into the human body system is the ingestion of microplastics contaminated food [66]. Seafood is a nutrition-rich source for human beings. Microplastics potentially get transferred from seafood to human beings by biomagnification, which poses a greater risk to human health. Danopoulos *et al.* reported microplastic contamination in seafood (*Mollusks, crustaceans, fish and Echinodermata*) for

Human consumption and estimated the annual human microplastic uptake to be close to 55,000 microplastic particles [67].

In a study, Prata *et al.* reported that exposure to microplastic particles through ingestion, inhalation and dermal contact cause particle toxicity. The failure of the immune system to remove these particles can lead to chronic inflammation and an increased risk of neoplasia [68]. Ranjan *et al.* reported that three coffees in disposable paper cups are enough to make us ingest about 75 thousand microplastic particles. The commonly used paper cups have a thin layer of plastic which, in contact with the hot liquid, researchers observed about 25,000 micron-sized microplastic particles [69]. The daily use of plastic feeding bottles and plastic water bottles is the potential release of microplastics (MPs), which threaten the health of infants and children. Recent studies suggested that exposure to microplastics is detrimental to early child development. It can cause male infertility, making them a potential hazard to reproductive success [70,71].

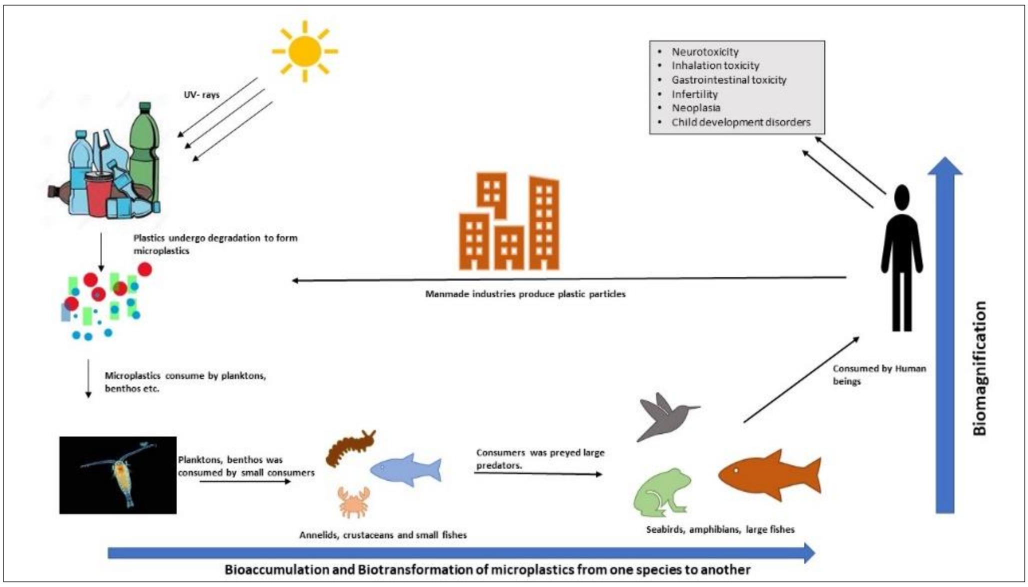

Figure 1 Bioaccumulation, Biotransformation and Biomagnifcation of Microplastics

6. Microplastic distribution in India

India has a long coastline of 7,517 km, contributing to ecological wealth, biodiversity and economy. In India, thousands of tons of garbage composed of plastics, glass, metals, and fibres can reach the oceans, and plastic litter contribute a large portion (~60%) every year. In India, the distribution of microplastics has been reported by many researchers. In 2016, microplastics found in the sediments of Vembanad Lake, a Ramsar site in India [72]. Similarly, Veerasingam *et al.* examined the distribution, abundance, weathering and chemical characteristics of microplastics on the beaches of Goa and their transportation to the coast during the southwest monsoon [73]. Gopinatha *et al.* has been quantified microplastic in Red Hills Lake of Chennai city, Tamil Nadu and found high-density polyethylene, low-density polyethylene, polypropylene, and polystyrene [74]. Narmadha *et al.* examined the presence, quantification and identification of microplastics in the ambient air from urban and rural sites of Nagpur and identified the polymers of polyethylene, rayon, rubber fibres, polystyrene, polyaniline, polyolefin, and chlorinated polyvinyl chloride [75]. Similarly, Bharath *et al.* have examined the quality and quantity of microplastic contaminants in water and soil samples at Veeranam lake in Tamil Nadu, India. They found that collected water and sediment samples deposited with polymer-type of plastic particles were nylon (39%), polyethylene (23%), polystyrene (19%), polypropylene (15%), and polyvinyl chloride (4%) (Bharath *et al.,* 2021). The present state shows a scenario of microplastics is susceptible and microplastics are an emerging problem for waterbodies in India.

In 2021, Selvam *et al.* evaluated heavy metals (cadmium, manganese, lead, arsenic and copper) adsorption capacities of different microplastic polymers (Polyamide, polyester, polypropylene, polyethylene, polyvinyl chloride and cellulose) in groundwater and surface water from coastal south India [76]. This study indicates that future research strategies to be made to reduce the environmental risks of particulate plastics as a potent vector for transportation of toxic trace elements and the subsequent impact on human health through the OSPRC framework (Origins, Sources, Pathways, Receptors and Consequence). Additionally, microplastics having found in riverine like the Indus, Brahmaputra, Ganga, the coast of Kanyakumari, and the different regions of the Himalayas [77,78,79,80]. Thus, the present literature has shown evidence of the wide distribution of microplastic in different regions of India.

7. Scenario of Microplastic Disposal During COVID-19 Pandemic

World Health Organization (WHO) declared COVID-19 as a pandemic in 2020. Corona Virus 2019 as COVID-19 is a virus that causes pneumonia in people with the severe acute respiratory syndrome (SARS) (SARS-CoV-2). The virus gets transmitted through direct contact with respiratory droplets of an infected person (generated through coughing and sneezing) and touching surfaces contaminated with the virus. COVID-19 virus causes an inflammatory response in an infected person that induces severe damage to alveolar cells, culminating in substantial fluid accumulation [34]. As a result, numerous steps have been implemented around the world to prevent the virus from spreading further.

The most effective preventive approach is lockdown (staying at home), travel limitation, and isolation. However, countries are concerned that the global economy will weaken and a catastrophe would erupt. As a result, the people and governments of various countries were forced to lift the lockdown and pursue other possibilities. They use disposable face masks and implement social distancing, sanitation, proper personal hygiene (hand washing), and avoiding social gatherings [81].

Before COVID-19, disposable face masks were used by healthcare professionals and researchers, who are skilled to used and disposing of them to prevent occupational hazards. But, with the global spread of the COVID- 2019 wearing face masks has become the new normal for every human being. COVID-19 acts as a catalyst for already existing issues with microplastics. The surge in the production and usage of face masks across the globe has intensified a new environmental challenge, plastic particle waste in the environment. Developed countries have been extensively using face masks since the emergence of COVID-19 worldwide, and developing countries are using them in mass. Due to improper disposal, these face masks eventually pass through the waterways from where they can reach the freshwater and marine environment, adding to plastics in the aquatic medium [82,83].

For instance, plastic packaging materials, drinking bottles, and fast-food containers are leading sources of microplastic pollution globally. Similarly, disposable face masks (single use) that get to the environment (disposal in landfill, dumpsites, freshwater, oceans or littering at public spaces) could be an emerging new source of microplastic fibres, as they can get fragmented into small particles under environmental conditions. The other implication of these extensively disposed face masks in the environment is the possibility of acting as a medium for disease outbreaks, as plastic debris is known to proliferate microbes such as invasive pathogens [84,85]

COVID-19 acts as a catalyst for already existing issues with microplastics. In a study, Abbasi *et al.* reported that the extensive use of face masks during the COVID-19 pandemic causes microplastic pollution and potential health concerns in the Arabian Peninsula, contributing to up to 32-235 thousand tons of microplastics [86]. In 2021, Ardusso *et al.* reported COVID-19 pandemic repercussions on plastic and antiviral polymeric textile causes pollution on beaches and coasts of South America [87]. Akhbarizadeh *et al.* also assessed the presence of PPE wastes and their microplastics along the coastline of Bushehr port, the Persian Gulf [88].

De-la-Torre *et al.* reported the occurrence and distribution of COVID-19-associated PPE along the coast of the overpopulated city of Lima, Peru and suggested that the inappropriate disposal, landfilling, and incineration of PPE plastic wastes will reach the marine environment is exacerbating pollution in the aquatic ecosystems,[89].

In another, Gallo Neto *et al.* reported the presence of an adult-size PFF-2 protective mask within the stomach of the Magellanic penguin (*Spheniscus magellanicus*) on Juquehy Beach, Brazil [90]. Therefore, the awareness of Covid-19 prevention is intense across the globe and will indeed be admirable if the consciousness on the protection of our environment through reduction and elimination (where possible) but, the proper management of disposable face masks should be carried along. Otherwise, microplastic pollution may be the next world pandemic.

India is the second-most populated country after China and the second worst-hit nation by the coronavirus disease 2019 (COVID-19) after the United States of America (As of November 9, 2020). Due to the improper biomedical waste management system and lack of resources, India faces severe consequences during COVID-19. Untreated and improperly managed biomedical waste material is a potential source of microplastic pollution. According to the Central Pollution Control Board's annual report [91], India creates roughly 9.4 million tonnes of plastic garbage per year, of which 5.6 million tonnes are recycled and 3.8 million tonnes are left uncollected/littered (9400 tonnes of waste/day) in the land [92]. Developing countries such as India are already dealing with waste management concerns [93], and the garbage generated by the COVID-19 pandemic phase has exacerbated the situation. With hospitals, quarantine wards, health care or medical institutions, and other departments in India producing roughly 517 tonnes of biomedical waste per day [94] hospitals are predicted to generate nearly six times more biomedical waste during the COVID-19 pandemic.

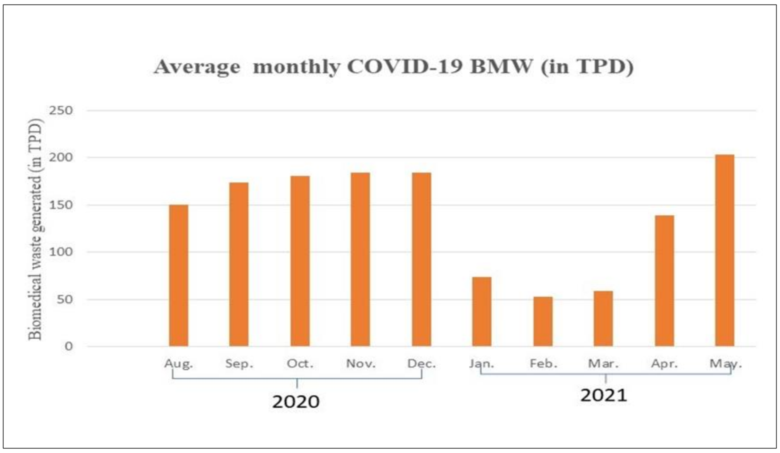

Figure 2 Average monthly generated COVID-19 biomedical waste (BMW) in India

(Source: Central Pollution Contrl Board Report (CPCB), 2020-2021)

India has become the second-largest producer of PPE Kits. Before the Coronavirus pandemic, India used to import the majority of PPE kits from outside but the viral outbreak coupled with demand for PPE kits pushed the country to manufacture indigenously. With the ramped-up production of PPE kits, India has become a producer of PPE kits and become the second largest producer of PPE Kits globally, with a daily production of more than 5 lakh PPE kits [95].

Nevertheless, it also increases the burden of plastics on the environment. Every day 25 lakhs PPEs are required to fight against COVID-19 [96]. For instance, the demand for plastics is increasing by 40% in packaging and 17% in other applications, including medical uses. For example, masks, sanitizer bottles, personal protective equipment, food packaging, and water bottles. Life came to be concealed in a plastic shell. Safety concerns related to shopping in supermarkets during COVID-19 led to a preference of consumers and providers for fresh food packaged in plastic containers (to avoid food contamination and to extend shelf-life) and the use of disposable food packaging and plastic bags to carry groceries. Also, the consumables used for the coronavirus testing kits that are made up of plastics, give rise to plastic waste generation. Researchers have considered single-use plastic as a hidden pandemic. The pandemic halted and, in some cases, reversed much of the microplastic remediation progress [97].

The issue of plastic pollution and microplastic generation continues to compound as the COVID-19 pandemic drives global demand for disposable, safe solutions. E-commerce sales have a projected growth rate of more than 20% in 2020 because economic shutdowns and home quarantine orders have created additional plastic waste with packaging. In a report, Plastic packaging shipped with the 7 billion packages delivered in 2019 generated 465 million pounds of waste. As a result, 22.4 million pounds of that plastic packaging ended up in waterways and marine ecosystems [98,99].

8. Major Challenges and Future Directions

The goal to minimize the impact of plastic debris leakage into the environment has become a global challenge. Industries play an important role in environmental contamination. It releases chemicals and additives into the environment. Industries can also indirectly generate secondary microplastics and can use primary microplastics for their manufacturing processes is decisive. Additionally, seafood constitutes one of the important sources of protein worldwide,[100]. Trophic transfer of microplastics that are swallowed by seafood (Bivalves, molluscs, crustaceans, fishes) is a potential pathway for microplastics to enter a living ecosystem. Further research on microplastic bioaccumulation, biotransformation and biomagnification can bridge the gaps in scientific knowledge and help to understand the underlying mechanisms and molecular targets of microplastic toxicity which will certainly contribute to the global efforts to combat microplastics induced toxicity. There is also scarce research which can demonstrate human health risks and considerate exposure, dose-dependent relationship, mechanism of toxicity, and interaction with other pollutants. Also, there are limited possibilities of risk assessment of microplastics inducing toxicity. There is also a lack of information about microplastic accumulation in the organs or tissues.

Additionally, stakeholders and policymakers have to reform the policies, plans, and guidelines as a significant and practical way of solving problems of escalating plastic waste management to control the environmental transmission of the COVID-19 Pandemic [101]. If plastic emissions into the environment continue at current rates, there may be widespread risks associated with microplastics to aquatic ecosystems within a century [102], with potentially concurrent increases in human exposure.

In response to concerns about the impact of plastic and microplastic pollution, public engagement and political commitment have increased. More than 60 countries are already taxing or banning single-use plastics, primarily plastic bags [103]. Nevertheless, we should also take microplastics as a serious issue of man-made environmental change. Plastic pollution is a visible example of how humans and the environment interact and unveils our relationship with the environment. What kind of environment do we want, and how do we want to live? We need to explore the intersections between global risks, power relations, and societal relations with the environment if we want to bring sustainable transformation.

9. Conclusion

Microplastics have adversely affected the environment by contaminating air, soil and water. Our existing knowledge is limited regarding the source, exposure, toxicity, and bioavailability, of microplastics in the environment. Therefore, more investigation is needed to understand its potential source and pathway of bioaccumulation and elimination. Experimental research and observations can consciously measure the variations and responses of microplastics in the environment. Combating microplastic contamination will be achieved through an intensive and combined effort of all, including stakeholders, researchers, educators, media and policymakers. We can join the effort to manage plastic in the environment by refusing, reducing, reusing and recycling plastic, in that order, to prolong every item's life cycle as far as possible. A start would be a focus on limiting the use of single-use plastic products with a short lifetime, especially if alternatives are readily available.

Compliance with ethical standards

Acknowledgments

The authors are thankful to the Secretary and Principal of Saifia Science College, Bhopal, India for providing the necessary facilities.

Disclosure of conflict of interest

All authors have declared there is no conflict of interest and all authors have carefully read the manuscript and approved for submission.

References

[1] de Souza Machado AA, Kloas W, Zarfl C, Hempel S, Rillig MC. Microplastics as an emerging threat to terrestrial ecosystems. Global Change Biology. 2018; 24(4):1405-1416.

[2] Hartmann NB, Rist S, Bodin J, Jensen LH, Schmidt SN, Mayer P, Meibom A, Baun A. Microplastics as vectors for environmental contaminants: Exploring sorption, desorption, and transfer to biota. Integrated Environmental Assessment and Management. 2017; 13(3):488-493.

[3] Karami A, Golieskardi A, Keong Choo C, Larat V, Galloway TS, Salamatinia B. The presence of microplastics in commercial salts from different countries. Scientific Reports. 2017; 7(1):1-1.

[4] Kosuth M, Mason SA, Wattenberg EV. Anthropogenic contamination of tap water, beer, and sea salt. PLoS One. 2018;13(4): e0194970.

[5] Miraj SS, Parveen N, Zedan HS. Plastic microbeads: small yet mighty concerning. International Journal of Environmental Health Research. 2021;31(7):788-804.

[6] Microplastics in drinking-water. Geneva: World Health Organization; 2019. Licence: CC BY-NC-SA 3.0 IGO.

[7] Ragusa A, Svelato A, Santacroce C, Catalano P, Notarstefano V, Carnevali O, Papa F, Rongioletti MCA, Baiocco F, Draghi S, D'Amore E, Rinaldo D, Matta M, Giorgini E. Plasticenta: First evidence of microplastics in human placenta. Environment International. 2021; 146:106274.

[8] Dharmaraj S, Ashokkumar V, Hariharan S, Manibharathi A, Show PL, Chong CT, Ngamcharussrivichai C. The COVID-19 pandemic face mask waste: A blooming threat to the marine environment. Chemosphere. 2021; 272:129601.

[9] Sharma S, Chatterjee S. Microplastic pollution, a threat to marine ecosystem and human health: a short review. Environmental Science and Pollution Research. 2017; 24(27):21530-21547.

[10] Klein S, Worch E, Knepper TP. Occurrence and Spatial Distribution of Microplastics in River Shore Sediments of the Rhine-Main Area in Germany. Environmental Science & Technology. 2015; 49(10):6070-6.

[11] Gopinath K, Seshachalam S, Neelavannan K, Anburaj V, Rachel M, Ravi S, Bharath M, Achyuthan H. Quantification of microplastic in Red Hills Lake of Chennai city, Tamil Nadu, India. Environmental Science and Pollution Research. 2020; 27(26):33297-33306.

[12] Bharath KM, Srinivasalu S, Natesan U, Ayyamperumal R, Nirmal KS, Anbalagan S, Sujatha K, Alagarasan C. Microplastics as an emerging threat to the freshwater ecosystems of Veeranam lake in south India: A multidimensional approach. Chemosphere. 2021; 264(Pt 2):128502.

[13] Cedervall T, Hansson LA, Lard M, Frohm B, Linse S. Food chain transport of nanoparticles affects behaviour and fat metabolism in fish. PLoS One. 2012; 7(2): e32254.

[14] Wang J, Zheng L, Li J. A critical review on the sources and instruments of marine microplastics and prospects on the relevant management in China. Waste Management & Research: The Journal for a Sustainable Circular Economy. 2018;36(10):898-911.

[15] Rodrigues JP., Duarte AC, Santos-Echeandía J, Rocha-Santos T. Significance of interactions between microplastics and POPs in the marine environment: A critical overview. TrAC Trends in Analytical Chemistry.2019; 111:252-260.

[16] Velez JFM, Shashoua Y, Syberg K, Khan FR. Considerations on the use of equilibrium models for the characterisation of HOC-microplastic interactions in vector studies. Chemosphere. 2018; 210:359-365.

[17] Espinosa C, García Beltrán JM, Esteban MA, Cuesta A. In vitro effects of virgin microplastics on fish head-kidney leucocyte activities. Environmental Pollution. 2018; 235:30-38.

[18] Yang YF, Chen CY, Lu TH, Liao CM. Toxicity-based toxicokinetic/toxicodynamic assessment for bioaccumulation of polystyrene microplastics in mice. Journal of Hazardous Materials.2019; 15(366):703-713.

[19] Cole M, Lindeque P, Halsband C, Galloway TS. Microplastics as contaminants in the marine environment: A review. Marine Pollution Bulletin.2011; 62(12), 2588–2597.

[20] Eriksen M, Mason S, Wilson S, Box C, Zellers A, Edwards W, Farley H, Amato S. Microplastic pollution in the surface waters of the Laurentian Great Lakes. Marine Pollution Bulletin.2013; 77(1–2):177–182.

[21] UNEP (2015) Plastic in Cosmetics, ISBN: 978-92-807-3466-9 pp33

[22] Barnes DK, Galgani F, Thompson RC, Barlaz M. Accumulation and fragmentation of plastic debris in global environments. Philosophical Transactions of the Royal Society B: Biological Sciences. 2009; 364(1526):1985-98.

[23] Galgani F, Hanke G, Werner S, De Vrees L. Marine litter within the European Marine Strategy Framework Directive. ICES Journal of Marine Science. 2013; 70(6): 1055– 1064.

[24] Gewert B, Plassmann MM, MacLeod M. Pathways for degradation of plastic polymers floating in the marine environment. Environmental Science: Processes & Impacts. 2015;17(9):1513-21.

[25] Kole PJ, Löhr AJ, Van Belleghem FGAJ, Ragas AMJ. Wear and Tear of Tyres: A Stealthy Source of Microplastics in the Environment. International Journal of Environmental Research and Public Health. 2017;14(10):1265.

[26] Li J, Green C, Reynolds A, Shi H, Rotchell JM. Microplastics in mussels sampled from coastal waters and supermarkets in the United Kingdom. Environmental Pollution. 2018; 241:35-44.

[27] Corradini F, Meza P, Eguiluz R, Casado F, Huerta-Lwanga E, Geissen V. Evidence of microplastic accumulation in agricultural soils from sewage sludge disposal. Science of The Total Environment.2019; 671:411–420.

[28] Geyer R, Jambeck JR, Law KL. Production, use, and fate of all plastics ever made. Science Advances. 2017; 3(7): e1700782.

[29] Lebreton L, Andrady A. Future scenarios of global plastic waste generation and disposal. Palgrave Communications. 2019 ;5(1):1-1.

[30] Wagner M, Lambert S. Freshwater microplastics: emerging environmental contaminants? Springer Nature; 2018.https://doi.org/10.1007/978-3-319-61615-5_1

[31] Peng G, Zhu B, Yang D, Su L, Shi H, Li D. Microplastics in sediments of the Changjiang Estuary, China. Environmental Pollution. 2017; 225: 283–290.

[32] Martin J, Lusher A, Thompson RC, Morley A. The Deposition and Accumulation of Microplastics in Marine Sediments and Bottom Water from the Irish Continental Shelf. Scientific Reports. 2017;7(1):10772.

[33] Rochman CM, Brookson C, Bikker J, Djuric N, Earn A, Bucci K, Athey S, Huntington A, McIlwraith H, Munno K, De Frond H, Kolomijeca A, Erdle L, Grbic J, Bayoumi M, Borrelle SB, Wu T, Santoro S, Werbowski LM, Zhu X, Giles RK, Hamilton BM, Thaysen C, Kaura A, Klasios N, Ead L, Kim J, Sherlock C, Ho A, Hung C. Rethinking microplastics as a diverse contaminant suite. Environmental Toxicology and Chemistry. 2019; 38 (4):703-711.

[34] Liu Q, Xu K, Wang X, Wang W. (2020). From SARS to COVID-19: What lessons have we learned? Journal of Infection and Public Health. 2020; 13(11):1611–1618.

[35] Hüffer T, Metzelder F, Sigmund G, Slawek S, Schmidt TC, Hofmann T. Polyethylene microplastics influence the transport of organic contaminants in soil. Science and the Total Environment. 2019; 657:242-247.

[36] Bergmann M, Wirzberger V, Krumpen T, Lorenz C, Primpke S, Tekman MB, Gerdts G. High Quantities of Microplastic in Arctic Deep-Sea Sediments from the HAUSGARTEN Observatory. Environmental Science & Technology. 2017;51(19):11000-11010.

[37] Xiong X, Tu Y, Chen X, Jiang X, Shi H, Wu C, Elser JJ. Ingestion and egestion of polyethylene microplastics by goldfish (Carassius auratus): influence of color and morphological features. Heliyon. 2019; 5(12): e03063.

[38] Pegado T, Brabo L, Schmid K, Sarti F, Gava TT, Nunes J, Chelazzi D, Cincinelli A, Giarrizzo T. Ingestion of microplastics by Hypanus guttatus stingrays in the Western Atlantic Ocean (Brazilian Amazon Coast). Marine Pollution Bulletin. 2021;162: 111799.

[39] Fossi MC, Marsili L, Baini M, Giannetti M, Coppola D, Guerranti C, Caliani I, Minutoli R, Lauriano G, Finoia MG, Rubegni F, Panigada S, Bérubé M, Urbán Ramírez J, Panti C. Fin whales and microplastics: The Mediterranean Sea and the Sea of Cortez scenarios. Environmental Pollution. 2016; 209: 68–78.

[40] Klein M, Fischer EK. Microplastic abundance in atmospheric deposition within the Metropolitan area of Hamburg, Germany. Science of The Total Environment.2019; 685: 96–103.

[41] Luo H, Xiang Y, He D, Li Y, Zhao Y, Wang S, Pan X. Leaching behavior of fluorescent additives from microplastics and the toxicity of leachate to Chlorella vulgaris. Science of The Total Environment. 2019; 678:1-9.

[42] Koelmans AA, Mohamed Nor NH, Hermsen E, Kooi M, Mintenig SM, De France J. Microplastics in freshwaters and drinking water: Critical review and assessment of data quality. Water Res. 2019; 155:410-422.

[43] Woodall LC, Sanchez-Vidal A, Canals M, Paterson GL, Coppock R, Sleight V, Calafat A, Rogers AD, Narayanaswamy BE, Thompson RC. The deep sea is a major sink for microplastic debris. Royal Society Open Science. 2014 Dec 17;1(4):140317.

[44] Wang Y, Wang X, Li Y, Li J, Liu Y, Xia S, Zhao J. Effects of exposure of polyethylene microplastics to air, water and soil on their adsorption behaviors for copper and tetracycline. Chemical Engineering Journal. 2020; 404: 126412.

[45] Ašmonaitė G, Tivefälth, M., Westberg, E., Magnér, J., Backhaus, T., & Carney Almroth, B. Microplastics as a Vector for Exposure to Hydrophobic Organic Chemicals in Fish: A Comparison of Two Polymers and Silica Particles Spiked With Three Model Compounds. Frontiers in Environmental Science.2020; 8.

[46] NOAA, National Centers for Environmental Information, Monthly National Climate Report for Annual 2020, published online January 2021, retrieved on December 1, 2022 from https://www.ncei.noaa.gov/access/monitoring/monthly-report/national/202013.

[47] Cai L, Wang J, Peng J, Tan Z, Zhan Z, Tan X, Chen Q. Characteristic of microplastics in the atmospheric fallout from Dongguan city, China: preliminary research and first evidence. Environmental Science and Pollution Research. 2017 ;24(32):24928-24935.

[48] Dris R, Gasperi J, Mirande C, Mandin C, Guerrouache M, Langlois V, Tassin B. A first overview of textile fibers, including microplastics, in indoor and outdoor environments. Environ Pollut. 2017; 221:453-458.

[49] Catarino AI, Macchia V, Sanderson WG, Thompson RC, Henry TB. Low levels of microplastics (MP) in wild mussels indicate that MP ingestion by humans is minimal compared to exposure via household fibres fallout during a meal. Environmental Pollution. 2018; 237:675-684.

[50] Gaston E, Woo M, Steele C, Sukumaran S, Anderson S. Microplastics Differ Between Indoor and Outdoor Air Masses: Insights from Multiple Microscopy Methodologies. Applied Spectroscopy. 2020;74(9):1079-1098.

[51] Ng EL, Huerta Lwanga E, Eldridge SM, Johnston P, Hu HW, Geissen V, Chen D. An overview of microplastic and nanoplastic pollution in agroecosystems. Science of The Total Environment.2018;627:1377-1388.

[52] Steinmetz Z, Wollmann C, Schaefer M, Buchmann C, David J, Tröger J, Muñoz K, Frör O, Schaumann GE. Plastic mulching in agriculture. Trading short-term agronomic benefits for long-term soil degradation? Science of The Total Environment.. 2016; 550:690-705.

[53] Bläsing M, Amelung W. Plastics in soil: Analytical methods and possible sources. Science of The Total Environment. 2018; 612: 422–435.

[54] Fuller S, Gautam A. A Procedure for Measuring Microplastics using Pressurized Fluid Extraction. Environmental Science & Technology. 2016 ;50(11):5774-80.

[55] Scheurer M, Bigalke M. Microplastics in Swiss Floodplain Soils. Environmental Science & Technology 2018;52(6):3591-3598

[56] Huerta Lwanga E, Mendoza Vega J, Ku Quej V, Chi JLA, Sanchez Del Cid L, Chi C, Escalona Segura G, Gertsen H, Salánki T, van der Ploeg M, Koelmans AA, Geissen V. Field evidence for transfer of plastic debris along a terrestrial food chain. Scientific Reports. 2017;7(1):14071.

[57] Liu M, Lu S, Song Y, Lei L, Hu J, Lv W, Zhou W, Cao C, Shi H, Yang X, He, D. Microplastic and mesoplastic pollution in farmland soils in suburbs of Shanghai, China. Environmental Pollution.2018; 242: 855–862.

[58] Sarkar DJ, Sarkar SD, Manna RK, Samanta S, Das BK. Microplastics pollution: An emerging threat to freshwater aquatic ecosystem of India. Journal of the Inland Fisheries Society of India.2020; 52 (1).

[59] Guo JJ, Huang XP, Xiang L, Wang YZ, Li YW, Li H, Cai QY, Mo CH, Wong MH. Source, migration and toxicology of microplastics in soil Environment International. 2020; 137:105263.

[60] Espí, E, Salmerón A, Fontecha A, García Y, Real AI. PLastic Films for Agricultural Applications. Journal of Plastic Film and Sheeting.2006; 22(2):85-102

[61] Lithner D, Larsson A, Dave G. Environmental and health hazard ranking and assessment of plastic polymers based on chemical composition. Science of The Total Environment. 2011; 409(18), 3309–3324.

[62] Allen S, Allen D, Moss K, Le Roux G, Phoenix VR, Sonke JE. Examination of the ocean as a source for atmospheric microplastics. PLoS One. 2020 ;15(5): e0232746.

[63] Lozano YM, Carlos AT, Gabriela O, Maaß S, Zhao T, Rillig M. Effects of microplastics and drought on soil ecosystem functions and multifunctionality. Journal of Applied Ecology. 2021; 58 (2).

[64] Rillig MC, Hoffmann M, Lehmann A, Liang Y, Lück M, Augustin J. (2021). Microplastic fibers affect dynamics and intensity of CO2 and N2O fluxes from soil differently. Microplastics and Nanoplastics.2021; 1,3.

[65] Souza VGL, Fernando AL. Nanoparticles in food packaging: Biodegradability and potential migration to food—A review. Food Packaging and Shelf Life. 2016; 8:63-70

[66] Smith M, Love DC, Rochman CM, Neff RA. Microplastics in Seafood and the Implications for Human Health. Current Environmental Health Reports. 2018;5(3):375-386.

[67] Danopoulos E, Twiddy M, Rotchell JM. Microplastic contamination of drinking water: A systematic review. PLoS One. 2020;15(7):e0236838

[68] Prata JC, da Costa JP, Lopes I, Duarte AC, Rocha-Santos T. Environmental exposure to microplastics: An overview on possible human health effects. Science of The Total Environment. 2020;702: 134455.

[69] Ranjan VP, Joseph A, Goel S. Microplastics and other harmful substances released from disposable paper cups into hot water. Journal of Hazardous Materials. 2021; 404: 124118.

[70] Ragusa A, Svelato A, Santacroce C, Catalano P, Notarstefano V, Carnevali O, Papa F, Rongioletti MCA, Baiocco F, Draghi S, D'Amore E, Rinaldo D, Matta M, Giorgini E. Plasticenta: First evidence of microplastics in human placenta. Environment International. 2021; 146:106274.

[71] D'Angelo S, Meccariello R. Microplastics: A Threat for Male Fertility. International Journal of Environmental Research and Public Health. 2021;18(5):2392.

[72] Sruthy S, Ramasamy EV. Microplastic pollution in Vembanad Lake, Kerala, India: The first report of microplastics in lake and estuarine sediments in India. Environmental Pollution. 2017; 222:315-322.

[73] Veerasingam S, Saha M, Suneel V, Vethamony P, Rodrigues AC, Bhattacharyya S, Naik BG. Characteristics, seasonal distribution and surface degradation features of microplastic pellets along the Goa coast, India. Chemosphere. 2016; 159: 496–505.

[74] Gopinath K, Seshachalam S, Neelavannan K, Anburaj V, Rachel M, Ravi S, Bharath M, Achyuthan H. Quantification of microplastic in Red Hills Lake of Chennai city, Tamil Nadu, India. Environmental Science and Pollution Research,. 2020; 27 (26) :33297-33306.

[75] Narmadha, V. V., Jose, J., Patil, S., Farooqui, Mohd. O., Srimuruganandam, B., Saravanadevi, S., & Krishnamurthi, K. (2020). Assessment of Microplastics in Roadside Suspended Dust from Urban and Rural Environment of Nagpur, India. International Journal of Environmental Research, 14(6).

[76] Selvam S, Jesuraja K, Venkatramanan S, Roy PD, Jeyanthi Kumari V. Hazardous microplastic characteristics and its role as a vector of heavy metal in groundwater and surface water of coastal south India. Journal of Hazardous Materials. 2021;402: 123786.

[77] Singh N, Mondal A, Bagri A, Tiwari E, Khandelwal N, Monikh FA, Darbha GK. Characteristics and spatial distribution of microplastics in the lower Ganga River water and sediment. Marine Pollution Bulletin. 2021; 163:111960.

[78] Ajay K, Behera D, Bhattacharya S, Mishra PK, Ankit Y, Anoop A. Distribution and characteristics of microplastics and phthalate esters from a freshwater lake system in Lesser Himalayas. Chemosphere. 2021; 283:131132.

[79] Tsering T, Sillanpää M, Sillanpää M, Viitala M, Reinikainen SP. Microplastics pollution in the Brahmaputra River and the Indus River of the Indian Himalaya. Science of The Total Environment. 2021; 789:147968.

[80] Sundar S, Chokkalingam L, Roy PD, Usha T. Estimation of microplastics in sediments at the southernmost coast of India (Kanyakumari). Environmental Science and Pollution Research. 2021 ;28(15):18495-18500.

[81] Bauchner H, Fontanarosa PB, Livingston EH. Conserving Supply of Personal Protective Equipment-A Call for Ideas. JAMA. 2020 May 19;323(19):1911.

[82] Shukla S, Khan R, Saxena A, Sekar S. Microplastics from face masks: A potential hazard post Covid-19 pandemic. Chemosphere. 2022;302: 134805

[83] Rab S, Javaid M, Haleem A, Vaishya R. Face masks are new normal after COVID-19 pandemic. Diabetes & Metabolic Syndrome: Clinical Research & Reviews2020;14(6):1617-1619.

[84] Reid AJ, Carlson AK, Creed IF, Eliason EJ, Gell PA, Johnson PTJ, Kidd KA, MacCormack TJ, Olden JD, Ormerod SJ, Smol JP, Taylor WW, Tockner K, Vermaire JC, Dudgeon D, Cooke SJ. Emerging threats and persistent conservation challenges for freshwater biodiversity. Biological Reviews Cambridge Philosophical Society. 2019; 94(3):849-873.

[85] Fadare OO, Okoffo ED. Covid-19 face masks: A potential source of microplastic fibers in the environment. Science of The Total Environment. 2020; 737: 140279.

[86] Abbasi S, Khalil AB, Arslan M. Extensive use of face masks during COVID-19 pandemic: (micro-)plastic pollution and potential health concerns in the Arabian Peninsula. Saudi Journal of Biological Sciences.2020; 27(12): 3181–3186.

[87] Ardusso M, Forero-López AD, Buzzi NS, Spetter CV, Fernández-Severini MD. COVID-19 pandemic repercussions on plastic and antiviral polymeric textile causing pollution on beaches and coasts of South America. Science of The Total Environment. 2021;763: 144365.

[88] Akhbarizadeh R, Dobaradaran S, Nabipour I, Tangestani M, Abedi D, Javanfekr F, Jeddi F, Zendehboodi A. Abandoned Covid-19 personal protective equipment along the Bushehr shores, the Persian Gulf: An emerging source of secondary microplastics in coastlines. Marine Pollution Bulletin. 2021; 168:112386.

[89] De-la-Torre GE, Rakib MRJ, Pizarro-Ortega CI, Dioses-Salinas DC. Occurrence of personal protective equipment (PPE) associated with the COVID-19 pandemic along the coast of Lima, Peru. Science of The Total Environment. 2021 Jun 20;774: 145774.

[90] Gallo Neto H, Gomes Bantel C, Browning J, Della Fina N, Albuquerque Ballabio T, Teles de Santana F, de Karam E Britto M, Beatriz Barbosa C. Mortality of a juvenile Magellanic penguin (Spheniscus magellanicus, Spheniscidae) associated with the ingestion of a PFF-2 protective mask during the Covid-19 pandemic. Marine Pollution Bulletin. 2021 May; 166:112232.

[91] CPCB Biomedical Waste Management Rules, 2016 (Issue 1). Central Pollution Control Board, New Delhi, Govt of India. 2016. https://cpcb.nic.in/uploads/Projects/Bio-Medical-Waste/Biomedical_Waste_Management_Rules_2016.pdf

[92] MoEFCC . 2018. Plastic Waste Management Rules. Ministry of Environment, Forest and Climate Change. New Delhi: Govt of India.

[93] Srivastava V, Ismail SA, Singh P, Singh RP. Urban solid waste management in the developing world with emphasis on India: challenges and opportunities. Reviews in Environmental Science and Bio/Technology. 2015; 14:317–337.

[94] Anwer M. Faizan M. Solid Waste Management in India Under COVID19 Pandemic: Challenges and Solutions. International Journal of Engineering and Technical Research. 2020; 9: 368-373.

[95] Ministry of Housing &amp. Urban Affairs Government of India . 2019. Plastic Waste Management Issues, Solutions & case Studies. New Delhi.

[96] Aayog NI. Empowered Group 6 Engages CSOs/NGOs/Industry/Intl Organisations in India's fight against COVID-19. Press Bureau of India. 2020 May 4.

[97] Ammendolia J, Saturno J, Brooks AL, Jacobs S, Jambeck JR. An emerging source of plastic pollution: Environmental presence of plastic personal protective equipment (PPE) debris related to COVID-19 in a metropolitan city. Environmental Pollution. 2021 Jan 15; 269:116160.

[98] Hossain R, Islam MT, Shanker R, Khan D, Locock KE, Ghose A, Schandl H, Dhodapkar R, Sahajwalla V. Plastic waste management in India: Challenges, opportunities, and roadmap for circular economy. Sustainability. 2022;14(8):4425.

[99] Staub C. Country lockdowns bring 'unprecedented implications.' Resource recycling. 2020. https://resource-recycling.com/plastics/2020/04/01/country-lockdowns-bring-unprecedented-implications/

[100] Barik NK. Freshwater fish for nutrition security in India: Evidence from FAO data. Aquaculture Reports. 2017 Aug 1;7:1-6.

[101] Shammi M, Tareq SM. Environmental catastrophe of COVID-19: disposal and management of PPE in Bangladesh. Global Social Welfare. 2021 Jun;8(2):133-6.

[102] SAPEA, (2019). A scientific perspective on microplastics in nature and society. Berlin: Scientific Advice for Policy by European Academies (https://www.sapea.info/topics/ microplastics/, accessed 1 July 2019). doi: 10.26356/microplastics.

[103] UNEP. (2018). SINGLE-USE PLASTICS: A roadmap for sustainability. https://wedocs.unep.org/bitstream/handle/20.500.11822/25496/singleUsePlastic_sustainability.pdf?isAllowed=y&sequence=1