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Microplastics pollution: An emerging threat to freshwater aquatic ecosystem of India

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Abstract Recently, there has been global concern about the occurrence of microplastics (MPs) and their associated ill effects on natural ecosystems. These MPs have detrimental effects on the aquatic biota and possible hazards to human health also. Hence, they have been included in the class of "contaminant of emerging concern" (CEC). They are being studied widely in the marine environment; their sources, fate, and ill-effects to marine life also. Recently it has been considered that rivers of the developed and developing countries, especially India and China, are the biggest sources of plastic pollution to the marine environment. However, till now very little data exists on the inland freshwater ecosystems. This paper reviews the occurrence and distribution of MPs in the inland open waters of India. It was found that MPs occurence are heavily studied in the coastal ecosystem of India. Although, freshwater ecosystems, like lakes, rivers and reservoirs are not touched. Only few rivers like Ganga, Netravathi, Sabarmati are studied for their MPs contamination. The study in the Ganga river showed that MPs load is less as compared to other reported rivers. It was also found that the MPs level in Ganga sediment is correlated with different pollution parameters viz. total phosphate, specific conductivity, and BOD.

Key words Microplastics: River Ganga; Pollution parameter; Contaminant; Ecosystem

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Introduction

In recent time, there has been great attention on the distribution and effect of plastic debris including microplastics (MPs) in the natural ecosystems. They have been identified as one of the significant indicators of the anthropocene (Waters *et al*., 2016) and included in the list of "Contaminant of Emerging Concern" (CEC) besides other chemical pollutants due to their ability to cause potential threats to the biosphere. The term MPs commonly refers to plastic particles whose longest diameter is < 5 mm (Andrady, 2011; Browne *et al*., 2011). However, recently the term has been suggested to include only plastic particles < 1 mm (Lambert *et al*., 2014). Above this ranges the plastic particles were termed as mesoplastic (>1 to = 5 mm) and macroplastics (> 5 mm) (Lambert *et al*., 2014). But at present, the upper limit of MPs is widely accepted to be 5 mm in view of the small size that can be readily ingested by the organisms (GESAMP, 2015). The MPs are present in the environments for many years now, as reported by early researchers in 1970s (Carpenter *et al*., 1972; Colton *et al*., 1974; Gregory, 1977), however, they have not been studied extensively till the early 2000s thus qualifying them as CEC (Lambert *et al*., 2014; Wagner *et al*., 2014).

In 2018, the world production of plastic reached 359 million tonnes, an increase of 15.43 % from 2014 (Plastics Europe, 2019). China and Japan are the two leading plastic producing countries, accounting for 30% and 4% of the global plastic production, respectively (Plastics Europe, 2019). However, in 2014 it was estimated that the per-capita plastic consumption in Asian countries (China: 45Kg/person; India: 9.7 Kg/person) is low as compared to the USA (109 Kg/person) and Europe (65 Kg/person) (Tatastrategies, 2014). But the Asian countries are suffering most in generating mismanaged plastic waste and load of plastic waste in their natural ecosystem is considered to be huge (Jambeck *et al*., 2015). Thus, it is highly likely that MPs abundance in the Asian river systems is enormous as compared to river systems of other continents. A recent predictive model has highlighted that among the rivers, Yangtze of China contributes the highest annual plastic debris discharge (0.33 million tonnes per year) to the marine system followed by the Ganga of the Indian subcontinent (0.12 million tonnes per year) (Lebreton *et al*., 2017). Similarly, various literature report on extraction of MPs in both marine and terrestrial ecosystems and it is now a well-established fact that they are ubiquitously distributed around the world. The occurrence of MPs has been extensively studied in the marine ecosystem, including estuaries, lagoon, seafloor, etc. (Cole *et al*., 2011). However, their abundance study and fate analysis in the freshwater system, especially the riverine ecosystem is still in the infancy stage covering only a few major rivers of the world. It was reported that only 3.7% of the total publications on MPs contains the term “freshwater” (Lambert and Wagner, 2018).

A worldwide estimate on the occurrence of plastic litter, including MPs, dumped into the marine water shown that the river is the one of main sources of plastic pollution carrying more than 2 million tonnes of MPs per year (Leberton *et al*., 2017). Moreover, it was reported that riverine transport of plastic debris accounts for 80% of the release from land to the marine environment (Andrady, 2011; Tanaka and Takad, 2016). Since there is extensive report on the bad effect of plastic debris on the habitat properties of the ecosystem including harm to the biological diversity (Anju *et al*., 2019), it is very much essential to understand the behaviour of the plastic debris in the river ecosystem. Moreover, as the small plastic debris was reported to have trophic transfer potential (Hurley *et al*., 2018; Anonymous, 2017), they have enormous effect on the ecological health through the ingestion process by the different organisms of the aquatic food chain (Cole *et al*., 2014). It is reported that less dense and floating MPs are mostly associated with lower organisms (phytoplankton and zooplankton) whereas, benthic invertebrates (amphipods, polychaete worms, mollusks and echinoderms) shows more tendency towards dense MPs (de Sá *et al*., 2018). The higher vertebrates such as fishes also engulf MPs through the process of prey-predation relationships in

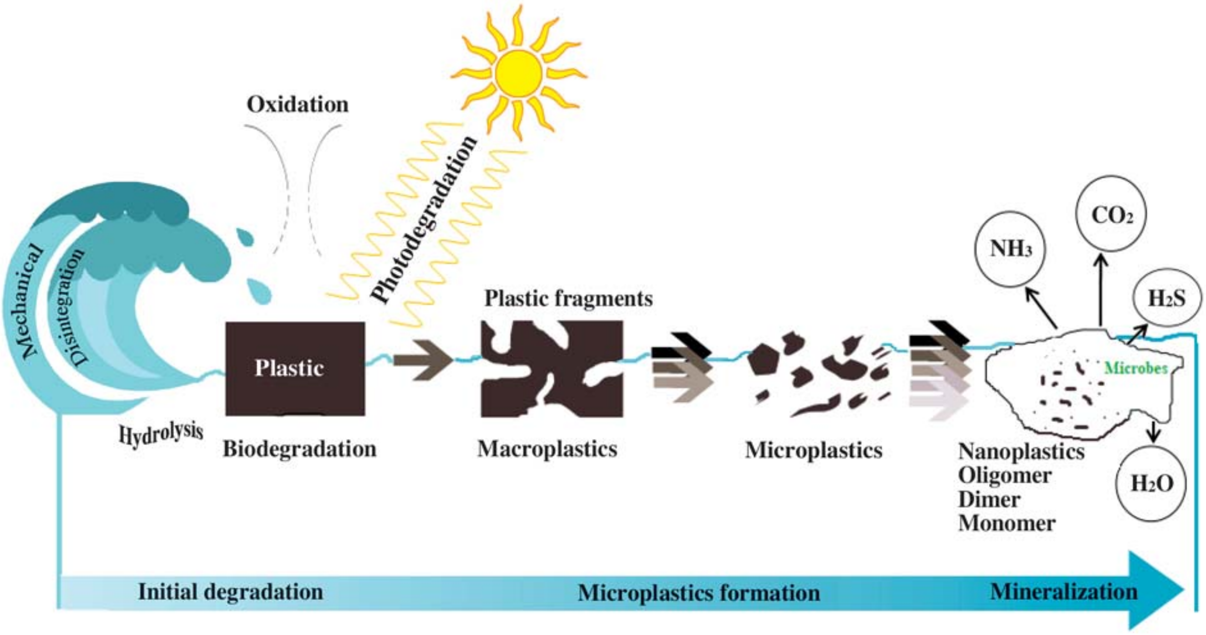

Fig. 1. Degradation pathways of plastic materials in flowing water bodies with various degradation processes involved until complete mineralization (Sarkar *et al*., 2020a)

the aquatic environment (Mohsen *et al*., 2019). Besides, MPs are also reported to have the potential to accumulate hydrophobic organic pollutants like persistent organic pollutants (POPs), polyaromatic hydrocarbon (PAHs), polycyclic biphenyls (PCBs) and other chemical mixture in their polymer structure, like flame retardants, additives, and plasticizer (Fries *et al*., 2017; Kwon *et al*., 2017). In this regard, it is very much essential to estimate the spatial distribution of different plastic fragments in the natural streams to alert and avoid plastic pollution in the environment. In the Antuã River of Portugal, the abundance of MP ranged from 2.6–71.4 mg/kg (2600-71400 ng/g) (Rodrigues *et al*., 2019). MPs occurrence was also estimated in other rivers *viz.* Rhine River (228-3760 items/kg), Beijiang River (178 to 544 items/kg) sediments, Thames River (185-660 items/kg, 2 times), and Bloukrans River, South Africa (0.60–160 items/kg) (Woodall *et al*., 2015; Klein *et al*., 2015; Wang *et al*., 2017).

The most common type of plastic debris (mesoplastic) found in the river sediments was polyethylene (PE), polypropylene (PP), and polyethylene terepthalate (PET). These plastic chemical types were reported extensively as dominant plastic debris in the coastal plain river network in eastern China (Kataoka *et al*., 2019) and Saigon River, Vietnam (Wang *et al*., 2018), Yangtze River, China (Xiong *et al*., 2019). The most important morphotypes of the plastic particles were found to be fibers (polyesters) and sheet or film. MPs pollution highlighting fibers was emphasized recently as compared to other morphotypes like film and beads (Rodrigues *et al*., 2019). These fibers in the Ganga sediment might have been coming from garment washing through effluents from municipal sewages (Lahens *et al*., 2017). Asian river contributes 86% of the total global plastic input (Lebreton *et al*., 2017). A recent report by United Nations Environment Program on "Single-use plastics: A Roadmap for Sustainability" underscores the annual environmental damage to the global marine ecosystem at $13 billion. In addition, authors have also opined that August is the peak period for plastic inputs in river Ganga with 44500 tonnes per month whereas, the river discharges <150 tonnes per month from December to March.

MPs pollution in the Indian inland waters

MPs pollution study in India is still in the nascent stage. Only a few studies are available both in the terrestrial and fresh water ecosystems. However, in coastal ecosystems many studies are available. MPs pollution on the sandy beaches of Tamil Nadu coast of India was studied and it was found that beaches adjacent to rivers exhibited relatively higher MPs abundance as compared to those influenced by tourism and fishing activities. Out of the total detected debris, plastic fragments were the maximum (47–50%), followed by line/fibres (24–27%) and foam (10–19%) materials (Karthik *et al*., 2018). In another report MPs pellets were studied in the beaches of Goa, and their transport to the coast during the southwest (SW) monsoon was studied (Veerasingam *et al*., 2016). White coloured MPs pellets were found to be the most abundant with PE and PP as the dominant polymer types. The effect of the flood on the distribution, surface features, polymer composition and age of microplastic pellets in surface sediments along the Chennai coast from March to November 2015 were studied and it was found that a huge quantity of fresh MPs was washed through Cooum and Adyar rivers from land during flood (Veerasingam *et al*., 2016). On the Kerala coast, MPs abundance was also studied in the beach sediments, water, and fishes. The study concluded that MPs abundance was 1.25±0.88 items/m^3 in coastal waters and 40.7±33.2 items/m^2 in beach sediments and high MPs were found on the southern coast of the state. MPs abundance in the Puducherry coast in India was studied and found 72.03±19.16 items/100g dry weight of sediments (Dowarah and Devipriva, 2019). MPs were also reported from the sediments of Rameswaram Island, Gulf of Mannar, India (Vidyasakar *et al*., 2018). MPs abundance along Silver Beach, Southern India was studied and revealed that white-colored (44%) and irregularly-shaped (82%) plastics were prevalent in the study area (Vidyasakar *et al*., 2020). MPs abundance in the recreational beaches of Mumbai, India was estimated to be 7.49 g and 68.83 items/m^2 (Jayasiri *et al*., 2013). The occurrence of MPs and heavy metals in the water and sediment of corals, sea grass-beds, and near-shores of Rameswaram Island, India was studied and found that the mean concentration of MPs was the greatest in the coral reef site (96 ± 51 items/L; 259 ± 88 items/kg) followed by the seagrass site (94 ± 55 items/L; 203 ± 75 items/kg) and the near-shore site (95 ± 63 items/L; 193 ± 75 items/kg) (Jeyasanta, *et al*., 2020). Estimation of MPs in sediments at the southernmost coast of India (Kanyakumari) showed that the highest concentration (150 particles/50 g d.s.) was in tourist beach followed by the harbors (99 particles/50 g d.s.) (Sundar *et al*., 2020).

The occurrence of MPs in the Vembanad Lake, a Ramsar site in India, was assessed and found to be in the range of 96–496 items m^{-2}. Low-density polyethylene (LDPE) was identified as the dominant type of polymer in lake extracted MPs (Sruthy and Ramasamy, 2017). In another study at Vembanad Lake, found MPs in the range of 13–54 items/km^2 in surface water (mean value, 28 items/km^2), 92–604 items/kg sediment (mean value, 309 items/kg) (Srinivasalu *et al*., 2020). An attempt was made to study the distribution and source of MPs contamination in Red Hills Lake, a freshwater system supplying water to the North of Chennai city which showed that concentration of MPs (fibers, 37.9%; fragments, 27%; films, 24%; pellets, 11.1%) in water samples was 5.9 particles/L and 27 particles/kg in sediment (Gopinath et al., 2020). In another study, source-to-sink characterization of MPs (5 mm–0.3 mm) in an Indian river, namely the Netravathi River was done and it concludes that all the river samples were contaminated with MPs with a mean numerical abundance of 288 items/m^3 (water), 96 items/kg (sediment) and 84.45 pieces/kg (soil) (Amrutha and Warrier, 2020). Quantification of MPs in Sabarmati river sediments (Gujarat, India) was done and it was found to be 134.53 mg/kg (75–212 im) and 581.706 mg/kg (212–4 mm) dry weight of sediment (Patel *et al*., 2020).

However, till now, not much study is available on the major river system of India like Ganga. Originating from Gangotri, the Ganga flows through a number of industrial cities and effluent points, mainly in the lower stretch, to reach the Bay of Bengal. The river harbours more than 650 million people through her basin and is designated as one of the most heavily populated basins in the world (Shukla *et al*., 2018). On her course, river Ganga carries inland debris pervasive of wastage from rayon industries, paint industries, dairy, and milk manufacturing units. Hence, the zone thought to be received plenty of inland wastes/litters including microplastics. Thus ICAR-Central Inland Fisheries Research Institute, Kolkata (ICAR-CIFRI) has attempted to measure the abundance of MPs (with various categories of size and shape) in the sediments in the lower stretch of river Ganga.

It was found that all the selected sites of river Ganga were contaminated with both mesoplastics and MPs. The MPs abundance was further grouped into two categories viz. 5 mm to 850 µm and 850 to 63 µm, and both the two size groups have shown their presence in sediment samples irrespective of their sampling location of the lower Ganga (Figure 2). The plastics particles investigated in the present study are categorized into two size classes namely, mesoplastics (> 5 mm) and MPs (< 5 mm) (Xiong *et al*., 2019). The average meso and MPs mass concentration in the sediment samples ranged from 0.68-148.31 ng/g (Mean ± SE ~ 52.88 ± 59.92 ng/g) and 11.48-63.79 ng/g (Mean ± SE ~37.56 ± 16.50 ng/g), respectively. The number fraction of plastic debris were estimated (Figure 3) and it was found that the number of mesoplastic was found more in Godakhali (215.43 items/kg) followed by Fraserganj (182.37 items/kg) > Patna (46.03 items/kg) > Buxar (11.70 items/kg) > Barrackpore (10.97 items/kg) > Nabadwip (9.42 items/kg) > Bhagalpur (4.37 items/kg). Though mesoplastic content was found highest in Fraserganj, the highest MPs in the size fraction of 850-63 µm was found more in Buxar (352.18 items/kg) followed by Fraserganj (327.47 items/kg) > Bhagalpur (130.92 items/kg) > Barrackpore (115.22 items/kg) > Patna (80.38 items/kg) > Godakhali (76.43 items/kg) > Nabadwip (44.64 items/kg).

The plastic matters were also classified into five morphotypes namely, fibers, filaments, film, foams/beads, and fragmented plastics (Figure 4). The study showed the presence of all five categories of plastics in Buxar, Patna, Bhagalpur, Barrackpore, and Godakhali. The highest mass fraction of fiber type was found in Patna whereas the mass fraction of monofilament was found only in Fraserganj and Godakhali. Fibrous plastic debris was found in almost every site whereas the foam/beads morphotype was found in only Buxar. Based on the Fourier-transform infrared spectroscopy (FT-IR) analysis of the plastic fraction (10-5 mm), extracted from the selected sites, the percent composition of the mesoplastics based on chemical nature was detected. The maximum contribution was found from PET (39%) followed by polyethylene (30%). The polypropylene was found to contribute 19% of the total mesoplastics whereas the PS contribution was found to be very less (1%). The FT-IR spectrum of the fragmented MPs (< 5 mm) showed that the MPs fragments from Barrackpore, Godakhali, and Fraserganj are dominated with polyesters having characteristic bands at 1717-1738 cm^{-1} (corresponding to >C=O stretching vibration) whereas MPs fragments from Buxar, Patna, Bhagalpur and

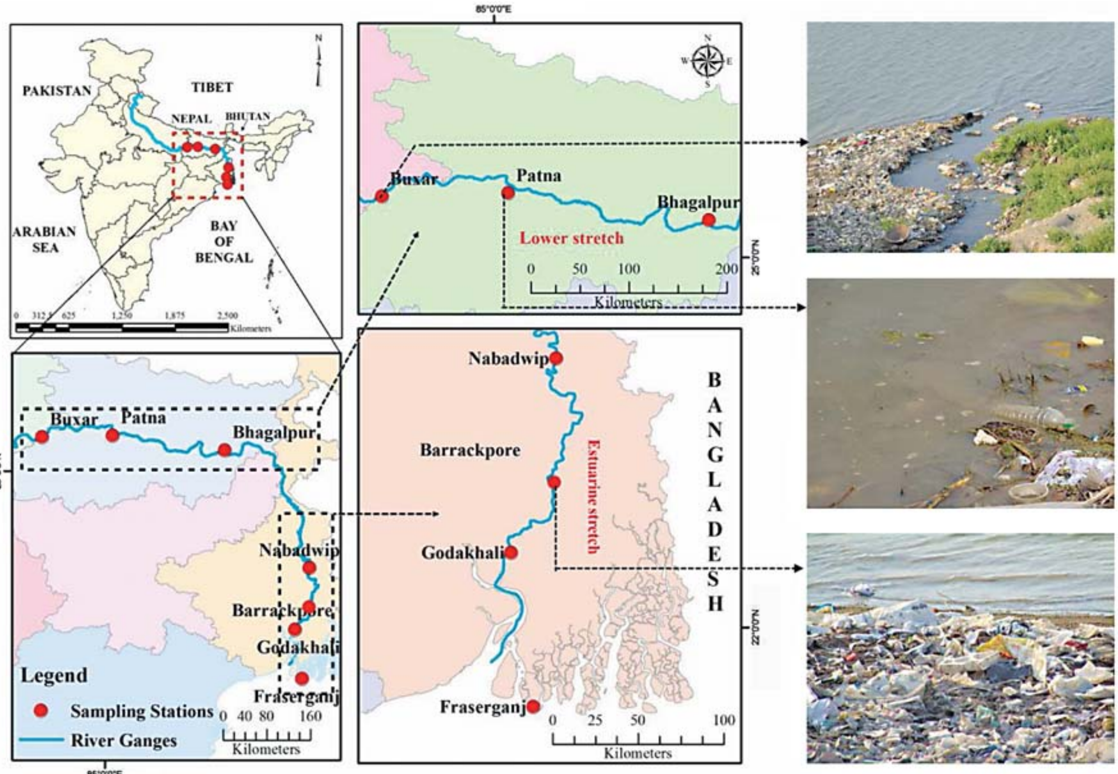

Fig. 2. Sampling locations in the river Ganga. Sampling locations along the river are marked with red dots: Buxar, Patna, Bhagalpur, Nabadwip, Barrackpore, Godakhali, and Fraserganj (Sarkar *et al*., 2019)

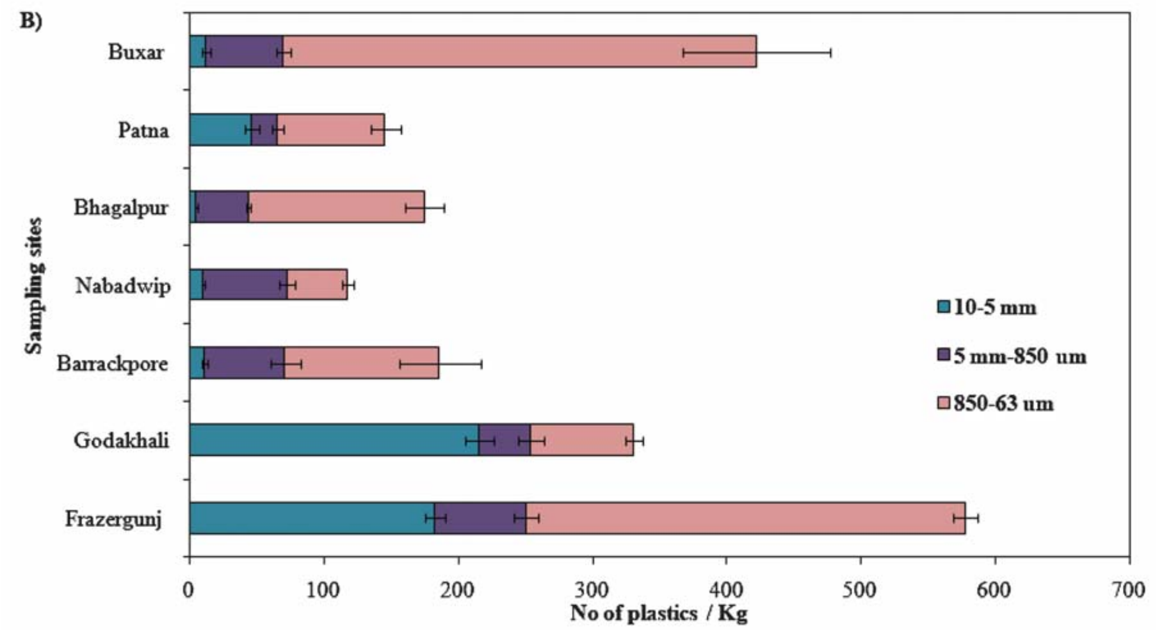

Fig. 3. Numeric abundance (items/kg) of plastic particles in the Ganga river sediments (Sarkar *et al*, 2019)

Nabadwip were dominated with polyethylene or polypropylene and or with synthetic polymer-rich with ether functional group (900-1092 cm^{-1}).

The abundance of the MPs at Ganga sediment samples were correlated with different physico-chemical parameters of sediment to understand the significant parameters contributing towards the higher occurrence of MPs in certain sites of Ganga (Figure 5, A). The physico-chemical parameters of the sediments *viz.* pH, specific conductivity, total Nitrogen, available Nitrogen, available Phosphate, and Organic Carbon were estimated along with percent sand, silt, and clay. The biplot of principal component analysis (PCA), the PC1 and PC2 altogether can explain 75.6% variability in the data, shows that the parameters which mostly influence the MPs content in the Ganga sediments are specific conductivity (r = 0.5326) and available phosphate content (r = 0.4834) (Figure 5, A). Similarly, the abundance of the MPs was correlated with the quality parameters of the water *viz.* BOD, DO, total suspended solids, turbidity, specific conductivity, available nitrogen, total nitrogen, available phosphate, and velocity (Figure 5, B). The biplot of PCA (explaining 72 % of the total variation) showed that the most two important parameters which influenced the MPs concentration in the sediment were BOD and available phosphate (Figure 5 B).

Aquatic ecotoxicity of microplastics

MPs are omnipresent in nature and remain scattered in the water column based upon its shape and density which is further accessed by the aquatic biota of multiple trophic strata (Cole *et al*., 2011, Foley *et al*., 2018). Less dense and floating MPs are mostly found in lower organisms (Phytoplankton, zooplankton) whereas, benthic invertebrates (amphipods, polychaete worms, molluscs, and echinoderms) show a higher tendency towards dense MPs (de Sá *et al*., 2018). Concurrently, fibre, and fragments (600 -1000 µm) are mostly detected in field animals. The higher vertebrates such as fishes, birds, and mammals also engulf MPs through the process of prey-predation relationships in the aquatic environment. Hence, the mechanism of MP toxicity has become more relevant in assessing an organism's health. Fishes with neurotoxic disorders (96 h; 1–5 ìm; 0.184 mg L^{-1}), freshwater crustacean amphipod *Hyalella azteca* with decreased growth and reproduction competency (240 h and 1008 h; 10–27 ìm; 0–10^8 particles L^{-1}) (Au *et al*., 2015), marine mussel *Mytilus galloprovincialis* with oxidative stress and genotoxicity when exposed to PE MPs (168 h; <100 ìm; 20,000 mg L^{-1}) (Avio *et al*., 2015) are few examples of toxic implications of MPs. MPs are also found to alter morphological appendages and haemolymp proteome in blue mussel (*Mytilus edulis*) in reef habitat (Green *et al*., 2019).

Estuaries are the hotspot for MPs occurrence and mangroves, being located in the estuarine zone, are no more left out. A study by CSIR-NIO, Goa has confirmed that tourism activities are responsible for the occurrence of MPs residues along the coastline (Anonymous, 2019). The occurrence of MPs was investigated in two fishes species namely *Rastrilleger kanagurta* and *Epinephalus merra* bought from Thirespuram and Punnakayal fish landing sites at Tuticorin (Kumar *et al*., 2018). Thirty percent of landed fish was found to contain MPs (PE and PP) in the test fish gut with microfibers (red, black, and translucent colors) as a major component (80%) and micro-fragments (20%). MPs abundance was also investigated in the *Harpodon nehereus*, *Chirocentrus dorab*, *Sardinella albella*, *Rastrelliger kanagurta*, *Katsuwonus pelamis,* and *Istiophorus platypterus* collected from Tuticorin, southeast coast of India and found that MPs content ranged from 0.11 ± 0.06 to 3.64 ± 1.7 items/ individual (Sathish *et al*., 2020). MPs were isolated from the soft tissues of the commercially important bivalve *Perna viridis*, Chennai, southeast coast of India, and identified as polystyrene (Naidu, 2019). The study highlighted that the filter-feeding coastal bivalves are at the highest risk due to bioaccumulation of MPs generated from anthropogenic activities. MPs in the Indian edible oyster, *Magallana bilineata* collected from the Tuticorin coast, Gulf of Mannar, India was studied and found that the mean abundance of MPs in oysters was 6.9±3.84 items/individual and 0.81±0.45 items/g of tissue (Patterson *et al*., 2019). MPs in the edible (muscle and skin) tissues of nine commercially important pelagic fish species from Kerala, India was studied and the average abundance of MPs in edible tissues was 0.07 ± 0.26 items/fish (Daniel *et al*., 2020).

Concern for fisheries

Plastic debris especially MPs fragments, fibres, beads,

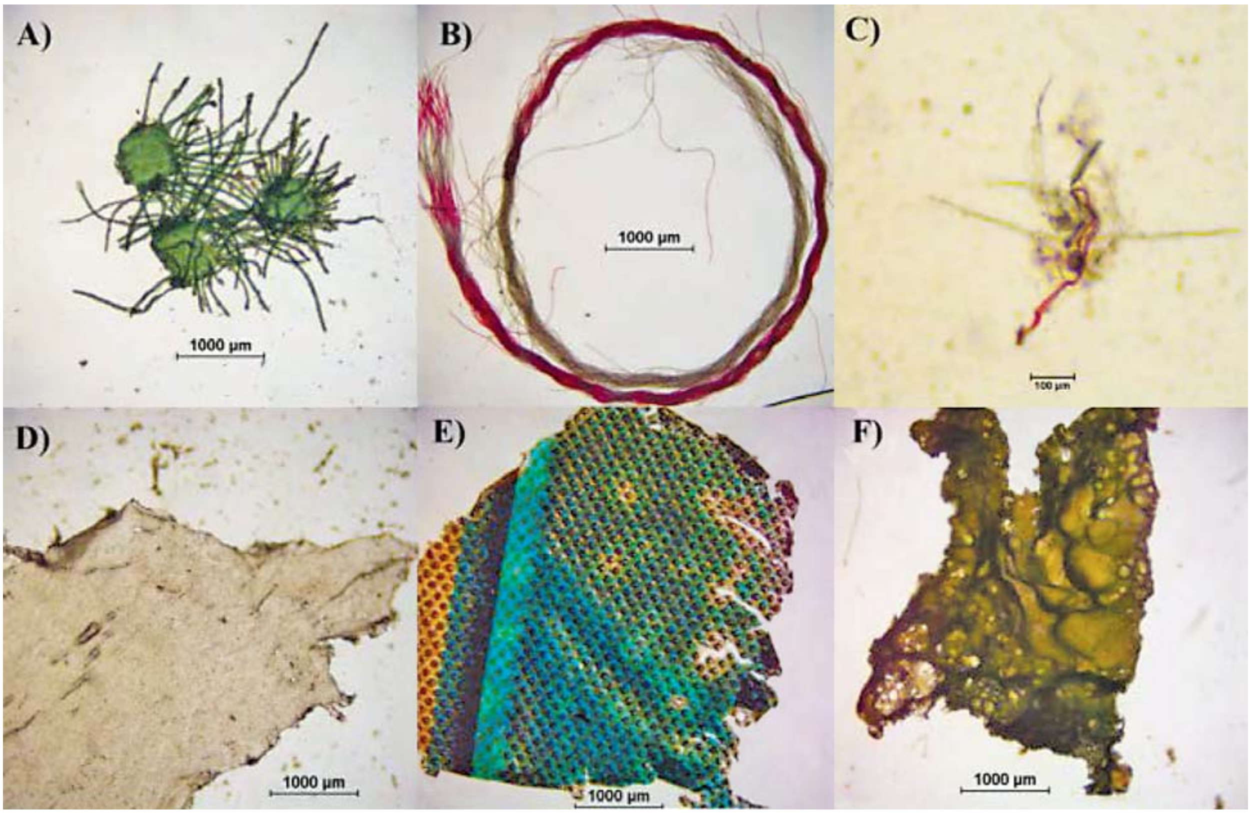

Fig. 4. Microscopic image of different microplastics extracted from the seven location of Ganga; Fibers (A, B and C), Film (D and E) and Foam (F) (Sarkar *et al*, 2019)

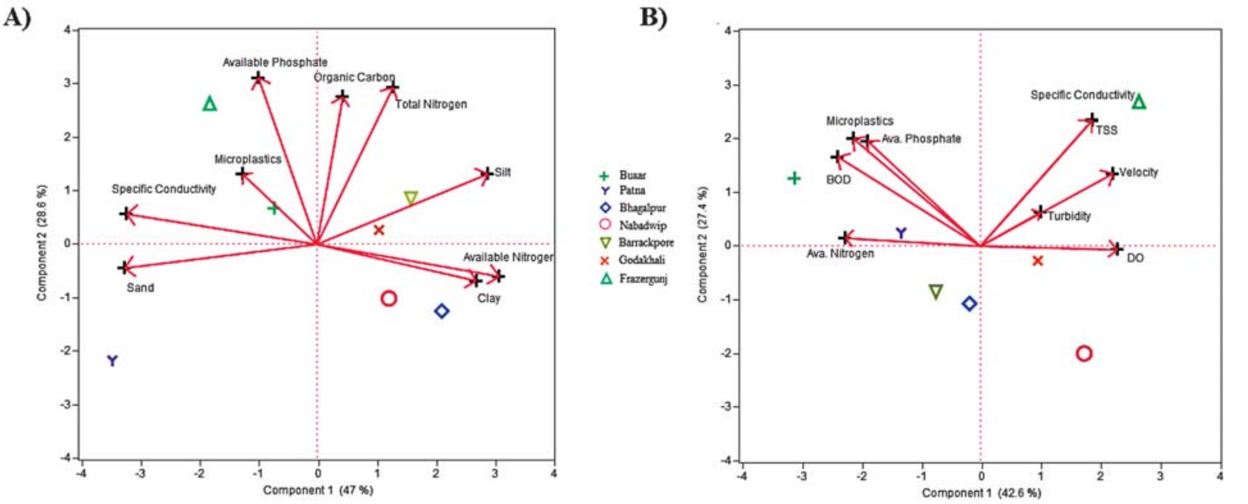

Fig. 5. Principal component analysis of microplastics (> 5 mm) with different physic-chemical parameters of sediments (A) and water (B) collected from different locations (Sarkar et al., 2019)

Fig. 6. Plastic debris during fish catches at Godakhali (Source: ICAR-CIFRI)

etc. are found to damage fishes by its toxic effects. Moreover, abandoned and discarded fishing gear which is formally known as ghost fishing, also accounts for marine litter (640000 tons) in terms of nylon net which drifts a long distance and hence keeps on entangling many large animals and mammals as well (Faulder, 2018). Seabirds, turtles also become the worst victim of this marine litter problem. Researchers also have observed traces of MPs on regular basis in the filter feeder mussel, fish flesh. Researchers from Cochin University of Science and Technology (CUSAT) have traced MPs fibres in the gut of red line torpedo barb, *Sahyadria chalakkudiensis* from Periyar river, South India. The authors reported that discards from eco-tourism industries and abandoned fishing net materials in upper stretches of Periyar river might be resulting in fragments of microplastics contaminations in fishes (Anju *et al*., 2019). Fishes have accidentally engulfed plastic particles along with their preferred food items. A recent study by ICAR-CIFRI also confirms that microplastics are present in the guts of Indian Major Carps (IMC) when sampled in the sewage fed wetland systems (unpublished).

Direct link to human health and management strategies

Members of the Centre for Environmental Science and Engineering (CESE) have reported 626 MPs particles from the popular Indian salt. In fact, a study by IIT, Bombay has shown that edible salt of the Indian market also contains traces of MPs. Moreover, researchers from CESE have reported quantified fractions of MPs viz. fragment (63%) and fibers (37%) in Indian table salt (https://greencleanguide.com/most-table-salts-sold-in-india-are-likely-to-contain-microplastics-from-polluted-seawater-iit-study/). Plastic waste (management and handling) rules, 2011 ban use of poly bags by setting pricing mechanism and also by recycling. Later on, new rules on plastic waste management, 2016 emphasize upon the ban on plastics below 50 µm. Flood-driven MPs flushing has been suggested as an effective tool for eradicating the abundance of microbeads on river catchments (Hurley *et al*., 2018). Authors also opined that fluvial processes have the capacity to clean MPs contaminated river channel beds rapidly and assigning a new pace to understand the global sediment system fully. In search of a solution to plastic pollution, waste-to-energy (WTE) plants are incinerating municipal waste to convert to energy. On the contrary, the second solution is promoting bioplastics as a potential alternative to polythene bags. These bioplastics are oxi-biodegradable plastics, hydro-biodegradable plastics, and biodegradable plastics. Researchers have indicated that the use of edible starch and vegetable oil to produce biodegradable bags may be reflected in implications on food security (Colwill *et al*., 2012). Another solution is the invention of plastic-eating bacteria. However, such research are always becomes critical than what is anticipated. The increasing rate of plastic waste problems can be overcome by use of conventional biodegradable material such as reused cotton, paper, wood made from novel materials like vegetable fibres and cellulose. Although the per-capita plastic consumption is low (11 kg per year) in India as compared to America (109 kg per year) (Source: Federation of Indian Chambers of Commerce and Industry (FICCI)), the condition may create an alarming situation for the sustenance of aquatic organisms.

Conclusion

Although MPs are ubiquitously distributed all over the world, their distribution study is mainly focused on marine ecosystems. Studies on MPs abundance and their harmful effect in inland open waters are still in infancy stages. Though some studies in river systems are being done, studies in wetland and reservoir systems are completely lacking. MPs transport through inland open waters and their further transformation into smaller particles possess tremendous ill effect to aquatic biota and finally to human health. The river Ganga in India was found to carry a huge amount of MPs in its sediment at the lower stretch, however its MPs load was found to be less as compared to the other rivers of the world. The study also implies that MPs abundance at different sites of river Ganga is associated with anthropogenic activities and has a significant correlation with pollution parameters like available phosphate, specific conductivity, and BOD. The study indicates that Indian rivers are at the risk of plastic pollution and requires immediate attention from policymakers. More efforts should be given on monitoring plastic pollution in the Indian rivers with special emphasis on its impact on aquatic biodiversity.

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