Microplastics pollution studies in India: a recent review of sources, abundances and research perspectives - a comparison with global research

Karthikeyan Perumal (✉ pkarthikeyangold@gmail.com)

Alagappa University <https://orcid.org/0000-0002-8782-4146>

Subagunasekar Muthuramalingam

The Gandhigram Rural Institute Deemed University

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Abstract

Microplastics (MPs) are ubiquitous, persistent pollutants reported in abundance in all environments and biota. The main objective of this review is to identify the sources, distribution, and concentration of microplastics in all aquatic environments and biota in India. It is one of the least studied, with only 45 papers published on microplastics during 2013–2020 in the web of science. To define the concentration of microplastics in different aquatic environments such as 3096 items/kg in marine sediments, 106 items/kg in biota, 59 items/L in seawater, 175 items/kg in sea salt, 33.9 items/L in lake water, 336 items/kg in lake sediments, 288 pieces/m³ in river water, and 328 items/kg in river sediments. Hence we investigated MPs pollution in coastal and freshwater ecosystems such as rivers, lakes, and biota. However, knowing that many aquatic habitats and species were unexplored, we recommend extending investigations in all of the following areas. To reduce plastic consumption and its eventual threat to aquatic ecosystems, researchers should assess studies in each of these ways. Enforcing severe regulations, enhancing legal activities, well-planned comprehensive waste management plans, and spontaneous public engagement are also required to prevent land-based plastic pollution.

Introduction

[1] was the first to coin the term “microplastics” to express the small-sized (< 5mm) plastic particles in the oceans. Most results have been released on this matter globally. Environmental plastic debris is defined by solid-state, solubility, chemical composition, shape, size, color, and origin. Based on the dimension, plastics are graded as nano (1000 nm), micro (1000 mm), meso (10 mm), and macro (1 cm) [2]. Microplastic consists of primary microplastics manufactured in microscopic size for particular purposes (microbeads) and secondary microplastics derived from huge plastic debris degraded and fragmented by long-term chemical, physical, and biological environmental effects [3, 4].

Plastics became prominent a few years ago due to their resilience and functional affordability; however, plastic production rose from 15 Mt (1964) to 311 Mt (2014) and is predicted to double by the next twenty years. Unless the current increase in the manufacture and usage of plastic continues, by 2050, we will have far more plastics occupied in the ocean than fish [5]. Small types of plastic, commonly recognized as microplastic, are far more common as it is highly volatile due to their small size and can reach food chains and different ecosystems. Fishing contributes to microplastic pollution. Modern techniques in fisheries need plastics due to various advantages over conventional natural resources. Accidental loss, natural wear and tear of fishing products, and ancillary items such as gear ropes, nets, strapping bands, fish boxes, etc., tend to leave many plastic fibers and pieces [6]. Tourism and recreational activities mainly have single-use plastics in coastal areas, contributing to coastal microplastics [7]. Numerous studies on the toxicological impact of microplastic particles on several fish are accessible [8–15]. Reviews latest studies on the harmful consequences of fishes micro - and nano plastics ingestion [8]. In 1972, tiny plastic particles on the Sargasso Sea surface [16], many researchers have researched microplastics due to their harmful effects on the aquatic environment. Microplastics are identified in rivers, streams, oceans, the atmosphere, biota ecosystems, and aquatic ecosystems worldwide [17–55]. Microplastics were detected in marine biota in different parts of India [56–66]. Microplastics (MPs) are profuse in the marine environment, including marine sediments, beach, and seawater [67–91]; MPs in sea salt [92–94]; MPs in Island [95–97]; in riverine systems [98–99]; microplastic in lake water and sediments [100–101].

Twenty-five review papers were published related to microplastic in marine environments during 2010–2020. Research on microplastics using bibliometrics analysis [102], microplastic pollution in sedimentary marine environments [4, 103–111], microplastics and their ecotoxicological effects on biota [112–116], physical and chemical characteristics of microplastics [117–118] sampling, and analytical techniques of microplastics [119–124], Action plan for extenuating land-based plastic marine pollution [125].

The present review aims (i) to emphasize the findings on the concentration of microplastic in marine sediments, beach sand, seawater, sea salts, freshwater lake, riverine, and biota. (ii) Sources, identification, composition, and their distribution used in India, possibly one of the least studied with only forty-five papers published on microplastics during 2013–2020 in the Web of Science. (iii) to examine the characteristics of publication results, the distribution of subject grouping, and journals. (iv) to highlight the spatial distribution of microplastic in all aquatic environments and comparison with global research. (v) to discuss India's National marine litter policy and identify the research gaps to steer future research findings.

Methodology

Data sources and search criteria

In Scopus and Web of Science database, a systematic literature search was undertaken using a variety of keywords like "microplastic studies in India" OR "microplastics in biota" OR "plastic debris in marine environments" OR "microplastic in marine sediments" OR

"microplastic in beach sand" OR "microplastic in sea salt". The retrieved articles are screened, and only such microplastics works were chosen. It has resulted in 45 research articles published from 2013 to 2020, and these are taken up for detailed review. According to the following research topics, the articles are categorized into i) analytical methodologies, identifications, compositions, and distribution of microplastics used in India, which is one of the least studied with only forty-five papers published on microplastics during 2013–2020 are identified in the web of science (Fig. 1). Statistics indicate that the amount of MPs studies publications has grown steadily in the last five years.

Results And Discussion

Sources of microplastics

Microplastics differ in size, specific density, chemical composition, and shape [126]. They are present in day-to-day products such as cosmetics, paints, etc. (primary microplastics) or from the degradation of larger macroplastic debris by environmental factors (secondary microplastics) [111, 127, 128] (**Fig.2**). Microplastics are plastics with a diameter of less than 5 mm, a relatively significant component of this anthropogenic waste. These plastics can enter the environment in two forms: primary microplastics, which are manufactured to size, and secondary microplastics, formed when larger plastic particles break down [129]. Primary microplastics are manufactured for various domestic and industrial purposes. They are used in facial cleansers, hair coloring items, insect repellents, toothpaste, abrasives, synthetic clothing, cleaning products [4, 128, 130-133]. These products are described as open use products as they are washed off and drained in the environment [132]. Chang identified polyethylene beads used in facial cleansers varying from 60 to 800 μm and reported that roughly 5000 g of microplastics were drained annually in the waste stream. Secondary microplastics are formed when larger plastic debris at sea and land subjected to physical, chemical, and biological processes decreases the structural stability of macroplastic debris, resulting in fragmentation [4]. The fragmentation process is more active on beaches due to the presence of high UV light (photo-degradation), physical wave abrasion, supply of oxygen [4, 134], and turbulence [135]. If these fragments reach surface waters or deep habitats, colder temperatures and decreased UV light slow down the breakdown process [134]. The degradation persists until the particles become smaller and microplastic in scale [4, 135]. It is reported that about 245 tonnes of microplastics are generated per year, which ends up in water sources where they are absorbed and ingested by marine organisms [137, 138]. The mechanisms of fragmentation and degradation are essential in forming secondary microplastics, although they are incompletely defined. Microplastics have been found littering the environment at all stages of the plastic life cycle of the product, from producers to waste management. Microplastics can enter the marine environment through river systems, coastlines, ships, and platforms at sea, or wind-induced transfer in the atmosphere.

Waste Water Treatment Plants (WWTPs)

Significant microplastics are found in discharges from wastewater treatment plants (WWTPs), and most are released into the rivers. The principal purpose for WWTPs is to handle wastewater; however, they add a bulk amount of microplastics into the marine environment due to their improper disposal [139, 140]. In tertiary treatment, full recovery was reached, which was not expected when secondary treatment was used. Although most WWTPs use only secondary treatment, tertiary treatment performs better. Even then, tertiary treatment eliminates only 99.2% of microplastics.

Publication data

The original research articles in Marine Pollution Bulletin (40.74%), Science of the Total Environment (18.52%), Environmental Science and Pollution Research (7.41%), Chemosphere (5.56%), Environmental Pollution (5.56%), Environmental Geochemistry and Health (3.70%), Environmental Monitoring and Assessment (3.7%), Archives of Environmental Contamination and Toxicology, Journal of Cleaner Production, Environmental Forensics, Regional Studies in Marine Science, Journal of Environmental Science and Health C, Journal of Environmental Chemical Engineering, Water Air & Soil Pollution, and Marine Biological Association of India (1.85% respectively) category of Web of Science are preferred to explore microplastic and plastic research.

Spatial distribution of microplastics in India

The concentration, size, and spatial distribution of the microplastic in beach sand (38.64%), biota (27%), sediments (11%), island (7%), sea salt (4%), riverine (4%), lake (4%), and seawater (2%) were reviewed from the selected 44 papers.

Microplastics (MPs) in beaches, shores, and coastlines

The plastic debris concentration average is 204 items/kg, and about 100% of total plastic debris is 0.5 to 1 mm in size found in Silver Beach, Southern India [69]. The polymer types were PVC, PE, and NY identified using ATR-FTIR. The macro-meso-microplastic concentration of 3.77 items/m², 9.5 items/m², and 54 items/m² respectively, and their distribution of macro-meso-microplastics were 54.98%, 60%, and 41.17% and > 2.5 cm, 5-2.5 cm, 5 mm in size found in the beaches of Tuticorin Southern India [70]. The polymer types were PE, PP, PET, NY, PS, and PVC identified using ATR-FTIR. [71] reported that the MPs ranged from 60 to 126.6 items/L in water and from 50 to 103.8 items/kg in sediment, PE fibers (1-3 mm) and PP fragments (3-5 mm) were the most common forms of microplastics in the Tuticorin and Vembar groups of islands in the Gulf of Mannar, southeast India. [72] reported that the concentration of plastic debris average of 2275 items and about 100% of total plastic debris is 5.5 to 25 mm in size found in Marina beach in Chennai, India. The polymer types were LDPE, PE, PP, PA, and PC identified using ATR-FTIR, TGA-DSC, and SEM. The microplastic concentration of 414.35 items/kg, and about 100% of microplastic ranges from 100-1000µm in size found in the sediments of the Andaman beaches, India [73]. The polymer types were PP, PMM, PBR, PSF, poly (dimer acid-co-alkyl polyamine), PVC, NY-6, ABS, PBAN, PVF, PPO, and PVB identified using Raman spectral. The plastic debris concentration average of 22.4 kg dry weight/km² and their distribution of 40.6% in the Northeast Arabian coast, India [74]. The polymer types were identified: plastic bags, styrofoam cups, beverage bottles, bottle caps, plastic rope, net pieces, and food wrappers. The presence of plastic debris concentration of 2 g/kg in the seawater of South Juhu creek, Mumbai, India [68]. The microplastic concentration of 385 items/kg and their distribution of microplastics were 100% and 0.5 to 3 mm in size found in the sediments in coastal areas of Tamil Nadu [77]. The polymer types were PE, PP, NY, PEST, and PS identified using ATR-FTIR and SEM-EDAX.

[78] reported that concentration of microplastic concentration of 220 MPs/kg, 181 MPs/kg, 45 MPs/kg (Girgaon Mumbai, Tuticorin beach, and Dhanushkodi beach respectively), and their distribution of microplastics were 100% and > 1 mm in size found in the Arabian sea coast, Bay of Bengal coast, India. The polymer types were PET, PE, PVC, PP, PS, PEST, and PA identified using SEM-EDS, Fluorescence microscopy, and FTIR. [79] reported that plastic concentration of 0.55 kg/m² and their distribution of 73.8% in the beaches in Kerala Coast, India. The polymer type was plastic identified. [80] reported that the microplastic concentration of 191 items/kg, and their microplastic distribution is 70% and 5-1 mm in size found in the Nattika Beach, Kerala Coast, India. The polymer types were PE, PE+PP, PP, PS, and PCU identified using FTIR and SEM. [81] reported that plastic debris concentration of 8.96 kg/m and their distribution of 56.42% in the beach litter along with Chennai, East Coast of India. The food wrappers, cups, bottle and caps, thermocol/styrofoam, and food wrappers were identified. [82] reported that the microplastic concentration of 72.03 MPs/100g and their distribution of 56.32% and 300µm-1mm in size found in the beaches of Puducherry, India. The polymer types were PU, HDPE, PP, PS, and LDPE identified using Raman spectroscopy. [84] reported that microplastic concentration of 403 pieces and their distribution of 60.8 % and >1.01-200mm in size found in the Rameswaram beach, GoM, Southeast coast of India. The polymer types were polyethylene, polystyrene, nylon, and polyvinyl chloride identified using FTIR spectroscopy. [85] reported that plastic debris concentration of 505 pieces in the Nallathanni Island, SE of India. The polymer types were PS, PE, PC, PVC, and NY identified using FTIR spectroscopy.

[87] reported that plastic debris concentration was 3.24 kg and their distribution of 44.89% in the Marina beach, Chennai, India. [90] reported that plastic debris concentration of 7.49 g and their distribution of 55.33% and 1-5 mm in size found in the beaches in Mumbai, India. The polymer type was plastic identified. [91] reported that the concentration of plastic debris concentration of 3.24 g m⁻² and their distribution of 80% and 5-100 mm in size found in the beaches in Mumbai, India. The polymer type was plastic identified. [60] examined the presence of microplastic concentrations average of 134.29 items/kg in the sediments and 19.87 items/L in water, and their distribution of microplastics were 44% and 58% in sediments, and water respectively. The particle size range of 1-5mm, and 500µm-1mm (in sediment and water respectively) along the coast of the Tuticorin, Gulf of Mannar (GoM), India. The polymer types were PE, PP, PP-PE, PA, PET, PEST, PVC, PS, and PVA identified using FTIR-ATR, SEM, and EDAX. [64] examined the presence of microplastic concentrations average of 12.75 items/kg in sediments and 21.60 items/L in seawater, and their microplastic distribution is 100 and 100 %, respectively. The particle size ranges from 1-3 mm, and 0.5-1 mm respectively in the Roche Park, Coast of Tuticorin, Gulf of Mannar, Southeastern of India. The polymer types were PE, PP (*Magallana bilineata*), PE, PP, PEST, PA in sediments, and PE, PP in seawater identified using FTIR-ATR analysis. In quantities of plastic debris is the highest amount of 8.96 kg/m in marine beaches to prove that shoreline and recreational activities are the primary cause of beach debris litter along with Chennai, India [81].

[95] reported that microplastic concentration of 277.90 items/kg and their distribution of 49% and 0.01 - 3 mm in size found in the Island of Maldives, Indian Ocean. The three polymer types were PE, PP, and PS, identified using Celestron Digital Microscope. [96] examined the presence of microplastic concentrations of 0.93/m³ and 45.17 /kg (water, and sediments respectively) in the Port Blair Bay, Andaman Islands. The polymer types were ionomer surlyn, PEI, PAC, PPF, EVOH, PAN, NY, EVA, PI, PU, and PVC identified using FTIR-ATR. [97] reported that plastic debris concentration of 1029 items/m² and their distribution of 96% and > 1 mm in size found in the Island of the Maldives, Indian Ocean. The polymer types were PE, PP, PS, PU, PA, PVA, and PVC identified using ATR-FTIR spectroscopy.

[98] examined the presence of microplastic concentrations of 288 pieces/m³, 96 pieces/kg, 84.45 pieces/kg in water, sediments, and soil, respectively), and their distribution of microplastic is 86.51%. The particle size range of 1-5 mm and 0.3-1 mm in the Netravathi river, India. The polymer types PE, PET, PP, and PVC were identified using FTIR-ATR. Due to its widespread usage as packaging materials, higher polyethylene abundance is the primarily used plastic raw material in Indian industries [140]. Compared with other rivers, In Portugal's Antua River, microplastics abundance ranged from 13.5 to 52.7 mg/kg in March, and 2.6 to 71.4 mg/kg in October [141], higher than Haihe River [142] and marginally lower than Pearl River [143, 144]. [99] examined that MPs concentration ranges from 0.68 to 148.31 ng/g and 11-64 ng/g items/kg and their distribution of 70% and 5 to 10 mm in size found in the sediments of Ganga riverine, India. The polymer types were PET, PE, PP, and PS identified using FTIR. This degree of microplastic abundance was found to be smaller than other world rivers. Likewise, plastic debris concentration ranged from 228 to 3760 items/kg in the Rhine river [145], 178-544 items/kg in the Beijiing river [119], and 185-660 items/kg in the Thames river [32], which is less than previous.

The numerical fraction of microplastics in the Ganga was identified higher compared to the concentration of microplastic ranges from 0.60–160 items/kg in the Bloukrans river, South Africa [146]. This disparity in the concentration of meso and microplastics in these rivers is due to several factors, including pollutant loading, hydrodynamic state, and spatial location [147, 148]. Depending on these considerations, certain places were observed to have large concentrations of plastics relative to others. PET, PE, and PP were the most popular plastic forms in Ganga river sediments, while fibers (polyesters) and sheet or film were the most significant morphotypes. Microplastic waste highlighting fibers was recently emphasized compared to other morphotypes such as film and beads [149].

[75] reported that microplastic concentration of 343 items 50 g⁻¹ d.s. and their distribution of 100% and <5 mm in size found in the southernmost coast of India (Kanyakumari), India. The polymer types were fiber and fragment identified. [76] examined the presence of microplastic concentrations of 40.7 particles/m², 1.25 particles/m³, 22 particles in sediments, water, and fish, respectively), and their microplastic distribution is 96.10%. The particle size range of 0.3-0.6, 0.6-1.18, and 1.18-2.36 mm in Kerala, Southwest India. The polymer types PE, PP, PA, PS, PET, RY, CE, ABS, PVC, sediments, PE, PP, RY, PS, and CL in water, and PE, CE, RY, and PP in fish identified using FTIR-ATR, and FP-XRF. [86] reported that microplastic concentrations of 496 items m⁻² and their distribution of 91% and <5 mm in size were found in the Vembanad Lake, Kerala, India. The polymer types were PP, PE, and PS identified using Raman spectra. [88] reported that a microplastic concentration of 3000 pellets was found on the Goa coast, India. The polymer types were PE and PP identified using FTIR-ATR. [150] reported that microplastic concentration of 1200 pellets 2 to 5 mm in size found in the Chennai coast, India. The polymer types were PE and PP identified using FTIR-ATR.

[92] examined the presence of microplastic in sea salt, and their distribution of microplastic is 60%. Particle size of 100 µm was found in the Tuticorin coastal salt pan stations, Gulf of Mannar, South India. The polymer types PE, PP, CL, and NY were identified using µFTIR and AFM. In heavily polluted surface waters, MPs were also recently reported from Arctic sea ice, fish, sea birds, and sea salts. Only a small range of global studies have been carried out on the quantity and distribution of MPs in marine salts [151-155]. [93] reported that microplastic concentration of 72 items/kg and their distribution of 100% and 100 to 500 µm in size found in the sea salt in the Salt of Tuticorin, Southeast Coast of India. The polymer types were PE, PP, PEST, and PA identified using SEM-EDAX. The study shows that people consume around 216 MPs/year particles through sea salt if the average individual consumes 5 grams of salt per day.

[94] investigated the MPs concentration of 103 particles kg⁻¹ and their distribution of 80% and 2000 µm and 500 µm in size found in the sea salt in the Mumbai, Indian sea salts, Southeast Coast of India. The polymer types were PEST, PS, PA, and PE

identified using μ FTIR. Microplastic abundance in sea salts may be due to sea salt being a direct product of coastal water. The number of MPs in the salt samples tested by this analysis was smaller than in China and Spain's sea salts and well salt [156, 157]. Low-density MPs may also be transferred from surface soil to deeper soil levels horizontally and vertically through soil fractures as well as by earthworms, collembolan, and other species [158-161]. It may also be affected by airborne pollution [157, 162, 163].

[100] examined the presence of microplastic concentrations of 309 items/kg, 28 items/km², 5.9 items/L in sediments, and water respectively), and their microplastic distribution is 80%. The particle size range of -1 to 0.3 mm, 0.3-2 mm in the Veeranam lake, Tamil Nadu, India. The polymer types such as NY, PE, PS, PP, and PVC were identified using ATR-FTIR. [101] examined the presence of microplastic concentrations of 5.9 particles/L, 27 items/kg, in water and sediments respectively), and their distribution of microplastic is 99%. The particle size range of 0.33-2 mm in water, 2 mm in sediments of the Red Hills Lake, India. The polymer types were HDPE, LDPE, PP, and PS identified using ATR-FTIR, SEM. The causative factors of these microplastics are primarily attributed to the weathering phase degradation of plastic goods and even from fishing nets, as these are the significant contributors of microplastics in water and sediments [164-166]. A further probable route for microplastic is by dry deposition, by wind transport. The dust generated by, i.e., automotive emissions, tires [167] from the soil, deposition, and dispersion between the atmosphere, the environment, and the marine domain may also promote the transportation of microplastic [168]; however, this requires detailed analysis [169].

Ecotoxicological effects of microplastics on biota

Microplastic particles were found in many aquatic biota, such as fishes (*Anodontostoma chacunda*, *Arius arius* (11), *Carangoides armatus* (20), *Chirocentrus dorab* (20), *Coilia dussumieri* (10), *Cyanoglossus macrostomus* (126), *Decapterus russelli* (10), *Dussumieria acuta*, *Dussumieria elopsoidea* (10), *Eleutheronoma tetradactylum* (10), *Epinephalus diacanthus* (8), *Epinephalus merra*, *Escualosa thoracata* (10), *Harpodon nehereus* (20), *Istiophorus platypterus* (10), *Katsuwonus pelamis* (10), *Leiognathus equulus* (10), *Leiognathus splendens* (6), *Megalaspis cordyla*, *Mugil cephalus*, *Nemipterus japonicus* (20), *Nemipterus randalli* (38), *Pentapion longimanus* (20), *Piaractus brachipomus*, *Rastrelliger faughni* (10), *Rastrelliger kanagurta* (168), *Sardinella albella* (20), *Sardinella gibbosa* (41), *Sardinella longiceps* (144), *Saurida tumbil* (13), *Scomberomorus guttatus* (10), *Siganus javus* (29), *Sphyrna obtusata*, *Stolephorus indicus* (148), *Terapon puta* (33), *Thyssa dussumieri*, and *Thyssa mystax* (12); Shrimp (*Fenneropenaeus indicus* - 330), bivalve (*Perna viridis* & *Meretrix meretrix* - 50), mollusca (*Donax cuneatus* (225), *Perna viridis* (Linnaeus, 1758), oyster (*Magallana bilineata*), Annelida (*Sternaspis scutata*, *Magelona cinta* and *Tellina sp*), and zooplankton - copepods (100), chaetognaths (50), jellyfish (50), and shrimps (20), fish (72). Fourteen studies reported the intake of microplastics by aquatic species in India. From these researches, 1895 aquatic organisms were analyzed, and more than 95% of the species studied were infected by microplastic particles (**Table 1**).

Microplastics (MPs) invertebrates

Two primary mechanisms absorb microplastics into vertebrates: predators feed on food already infected with microplastics (through intake or external microplastic), or predators directly absorb microplastics from the water and sediments. Microplastics in different forms were found in 1470 no. of fishes (52 species) in India (**Table 1**).

Microplastics were present in the gut and intestine of fishes, namely as *Dardanelle longiceps* (123), *Rastrelliger kanagurta* (130), *Dardanelle gibbosa* (40), *Carangoides armatus* (20), *Stolephorus indicus* (127), *Epinephalus diacanthus* (8), *Saurida tumbil* (13), *Terapon puta* (13), *Nemipterus randalli* (38), *Leiognathus splendens* (6), *Cyanoglossus macrostomus* (106), and *Thyssa mystax* (12). The particle size range from > 1-5mm and 81.59% distributed in fishes of Kochi, southeastern Arabian Sea, India [56]. The polymer types were PE, PP, LDPE identified using Raman spectroscopy and FTIR. Average microplastic concentrations of 0.2002 items/g were found in gastrointestinal tracts of fishes and 13.4 items/L in seawater, and their distribution of microplastic is 34% and 64% (fish and seawater, respectively) [60]. The particle size range of <500 μ m, and 1-5mm (in guts and seawater respectively) in Tuticorin, Southeast coast of India. The polymer types were PE, PA, PEST, PS, PP, and PAC in fishes, and PE, PEST, PA, PS, PP, PD, PP-PE, and PLA in seawater identified using FTIR-ATR and SEM-EDAX. [57] examined the presence of microplastic concentrations average of 0.005 items/g in edible tissues and 0.054 items/g in inedible tissues of fishes, and their distribution of microplastic is 11.6% and 88.4% (edible and inedible tissues, respectively). The particle size ranges from 115-210 μ m and 136 to 4010 μ m (edible and inedible tissues respectively) in Kerala, India. The polymer types were PE, PP in edible tissues and PE, PP, EPDM, PS in inedible tissues of fishes identified using ATR- FTIR.

[61] reported the microplastic concentration is 26.01 items/g in the gut of the alien fish of *Piaractus brachypomus* (123). The particle size of 0.5mm and their distribution of 99% in the Ramsar, Vembanad lake, South India. The polymer types were PBT, PP, PET, and NY 6 identified using ATR-FTIR and Raman spectroscopy. The microplastic concentration of 20 items/g in the gastrointestinal tract of fishes such as *Coilia dussumieri* (10), *Decapterus russelli* (10), *Decapterus macarellus* (20), *Dussumieria elopsoides* (10), *Eleutheronoma tetradactylum* (10), *Escualosa thoracata* (10), *Nemipterus japonicus* (20), *Pentaprion longimanus* (20), *Rastrelliger faughni* (10), *Sardinella longiceps* (20), *Scomberomorus guttatus* (10), *Stolephorus indicus* (20), and *Terapon puta* (20) [62]. The particle size ranges from 1.3µm - 9.3mm, and their distribution of 8.95% in the Chennai and Nagapattinam, the Southeast coast of the Bay of Bengal. The polymer types were PA, PE, and PET identified using FTIR & SEM.

About 80% distribution of the microplastic is found in the intestine of *Rastriliger kanagurta* (20) and *Epinephalus merra* (20) [65]. The particle size ranges from 0.5 mm to 1 mm in the Tuticorin, Southeast coast of India. The polymer types were polyethylene & polypropylene identified using FTIR. [83] examined the microplastic concentrations of 46.6/m² in the gut of *Rastrelliger kanagurta* (17), *Siganus javus* (29), *Arius arius* (11), *Leiognathus equulus* (10), and *Mugil cephalus* (12) (Fishes), 9233mg/m² in sediments, and their distribution of microplastic are 60.1% respectively. The particle size ranges from 1-2.5mm respectively in the beaches of the Southeast coast of India. The polymer types were PE, PP, PS, and NY identified using FTIR-ATR analysis. Microplastic concentrations of 10.65 specimens in finfish & shellfish, and their distribution of microplastics were 45.83% in fishes such as *Alepes djedaba* (6), *Cynoglossus lida* (6), *Saurida tumbil* (9), *Gerres filamentous* (13), *Nemipterus peronii* (8), *Upeneus vittatus* (10), *Carangoides malabaricus* (4) (Adult), and *Carangoides malabaricus* (6) (Juveniles), and shellfish. The particle size range of 111.58 to 5094 µm in finfish & shellfish in the Port Blair Bay, Andaman Islands, India [96]. The polymer types were PEI, PAC, PPS, EVOH, PAN, NY, PEVA, PI, PU, PVC identified using FTIR-ATR.

In conditions of particles per organism, larger vertebrates have eaten higher concentrations of microplastics than fish. The highest microplastic abundance values were reported on southeast coast of India [96]. By examining microplastic abundance in fish from different studies in India, it is clear that microplastics abundance in Indian fish was of the same magnitude as in other countries. For particles per weight, microplastic was identified in *Istiophorus platypterus* showed in the Tuticorin, Southeast coast of India, which had an abundance of 0.0002 MP/g in the gut 1.10 MP/g in body, and 0.11 MP/ individual due to depth about >200m [93]. The depth of locations, the microplastic concentration of 0.2 MP/g in the gut, 0.008 MP/g in body, and 3.64 MP/ individual was found to be *Harpodon nehereus* due to depth above 1-3 m. In particles per weight, microplastic was found to be *Piaractus brachypomus* showed in the Ramsar, Vembanad Lake, south India, which had 26 % MP intake in fish [61].

Microplastics (MPs) in invertebrates

Microplastic toxicity has been observed in the ecological food web, influencing both the basal food web species and all kinds of species [114]. Indian invertebrate absorption of microplastic particles was studied in bivalves, shrimps, and other benthic species. At present, six studies analyzed the microplastic contamination in invertebrates in India, and 508 organisms are reported to be microplastic polluted (Table 1). Bivalves are of particular concern among these species since their extensive filter-feeding practices expose them to plastics in the waters [110, 170]. The confirmed rate of microplastic ingested by aquatic invertebrates was 58.58%. The microplastic abundance in marine invertebrates in India ranged from 0.04 to 3.78 and from 0.39 to 7.05 items/g. [57] Microplastic is 0.04 items/g (0.39 ± 0.6 items/shrimp) in the foregut and midgut of *Fenneropenaeus indicus* (Shrimp - 330). The particle size range from 500 to 1000 µm, and 30.9% are distributed in Cochin, Kerala, India. The polymer types were PA, PEST, PE, and PP identified using FTIR.

[58] reported the presence of microplastic is 3.78 g and 7.05 items/g (soft tissue and bivalve respectively) in the *Perna viridis* (90) and *Meretrix meretrix* (110). The particle size range of < 100 µm in the Pondicherry, India. The polymer types were PA, PEST, PE, and PP identified using Raman spectrum & Fluorescence microscope. [59] examined the presence of microplastic concentrations average of 0.95 items/g in clams (*Donax cuneatus* - 225), and their distribution was 41% *Donax cuneatus*. The particle size range of 100-250µm in clams in the Tuticorin coast of Gulf of Mannar (GoM), India. The polymer types were PE, PP, PP-PE, PA, PET, PEST, PVC, PS, RA, and PVA identified using FTIR-ATR, SEM, and EDAX. [63] examined that presence of microplastic concentration is 0.9/g in the tissue of *Perna viridis* (Linnaeus, 1758) (5). The particle size ranges from 5-30 µm, and their distribution of 87% in Chennai, the Southeast coast of India. The polymer type was PS

identified using DXR Raman spectroscopic. [64] examined the presence of microplastic concentrations average of 0.81/g in *Magallana bilineata* (oyster) (180), and their distribution of microplastic is 96%. The particle size ranges from 0.25 to 0.5 mm in the Roche Park, Tuticorin coast, GoM, SE India. The polymer types were PE; PP (*Magallana bilineata*) identified using FTIR-ATR analysis. [66] examined the distribution of microplastic 67% in the gut of *Sternaspis scutata*, *Tellina sp.*, and *Magelona cinta*. The particle size range of 20 µm in the Kochi, Southeastern Arabian Sea. The polymer types were polystyrene identified using a DXR Raman microscope.

[96] analyzed the microplastic concentration in 10.65 specimens, 0.12 pieces (finfish & shellfish, and zooplankton), and their distribution is 45.83 percent, 90% in finfish & shellfish, zooplankton, respectively. Port Blair Bay, Andaman Islands, the particle size spectrum is 111.58 to 5094 µm, 21.57 to 2225 µm (finfish & shellfish and zooplankton, respectively). Polymer forms were PEI, PAC, PPS, EVOH, PAN, NY, PEVA, PI, PU, and PVC were identified using FTIR-ATR. In terms of particles per individual, the highest concentration of microplastics was noticed in *Magallana bilineata* (oyster) collected in the Roche Park, Tuticorin coast, GoM, Southeastern India, which has an abundance of 29.19 items/ individual and 1.73 MPs items/g [64]. Similarly, the largest concentration of microplastics was found in oysters (*Crassostrea gigas*) obtained in Sangou Bay, Yellow Sea, with a concentration of 43-164 ind.⁻¹. By contrasting the abundance of microplastic in commercial invertebrates in China and other countries across the world, Chinese microplastic emission levels were found to be generally higher than in other countries.

Microplastics (MPs) size in different aquatic environments and biota

A primary element affecting the ingestion of microplastic particles is their small size, as many low-trophic species have little potential to turn plastic from food and feed upon it, which is reasonable in size [118, 171]. In general, size was also strongly linked to microplastics toxicity [172]. In the 53 reviewed papers, 35 researchers recorded the size spectrum (**Table 1**). The highest value varied from 9.3 mm to 5mm, and the minimum values ranged from 0.005 to 1mm. Most investigations have found microplastics in the size class of less than 1 mm (83 percent of biota articles). However, larger microplastics overshadowed particular fish research. For example, larger microplastics were identified in fish (0.0013-9.3 mm) from Chennai and Nagapattinam, Southeast Bay of Bengal [62], fish captured from the Kochi, southeastern Arabian Sea, India (particle size range from > 1-5mm [56], fish (inedible tissues) captured from Kerala, India (Size: 0.136 to 4.010mm [57], fish (gut) caught from the beaches of the southeast coast of India (Size: 1-2.5mm [83], Shrimp captured from the Cochin, Kerala, India (Size: 0.5-1 mm), the plastic debris size ranges from 0.5-25 mm in the beach sediments. In marine Chennai, the beach has been size in 5.5-25 mm in beach sediments [72]. The irregular plastic particles are produced mainly from dampening household plastic materials by urban drainage and partly by sea. Previous reports indicate a higher distribution of fragments and fibers than other sources in coastal sediments [173-175]. Polymer types such as PE, PP, and PS float on seawater and fly long stretches, located far from their primary origins [176].

Comparison of global research in microplastics

Microplastics in the China coastal regions

According to [177], the prevalence of microplastics in Jiaozhou Bay, Shandong Peninsula, northern China, ranges from 2.5 items/kg d.w. to 27.5 items/kg d.w., with nearly 80% of total microplastic ranging from 0.1 to 5 mm in size. The total microplastics in the sediment in Jiaozhou Bay were estimated to be 3.71 tonnes. The µ-FTIR spectroscopy analysis has been used to identify polymer types such as PMMA, PE, PA, PET, PU, RY, PP, and PE-PS. [178] explained that the East China Sea has an abundance of plastics ranging from 375.44 items/km² and nearly 95 % of total plastic ranging in size from 1.3 cm to 14.23 cm. The µ-FTIR spectroscopy was used to identify several polymer types such as PC, PVC, PP, PET, PE, and PS. [179] observed that the abundance of microplastics in the Sanggou Bay, China, varies from 1674 ± 526 items/kg and comprises 57.72 % microplastics with a size range of 0.5 mm. Particles were counted and photographed. PE, PP, PS, CL, and PC were identified by an optical microscope using µ-FTIR spectroscopy. [180] assessed the abundance of microplastics in the Nansha Islands, South China Sea, which ranged from 0.0556 ± 0.0355 items/m³ and accounted for almost 70% of total microplastics in the 3 mm range. [181] observed the abundance of microplastics in the Laizhou Bay, China, ranging from 461.6 ± 167.0 to 193 to 1053 particles/kg, with about 94.10 % microplastics in the 3 mm size range. µ-FTIR spectroscopy was used to identify the microplastics, mostly PEA, CP, PET, PP, PVA, PPA, and PVC. According to [182], the concentration of microplastics in the Chinese coastline is 309 ± 81 items/kg, with 71.5 percent of total microplastics with a size range of 2411 µm. µ-FTIR spectroscopy was used to identify several polymer types such as PP, PET, and RY. [183] studied the abundance of microplastics in the Hangzhou Bay, China, is 84.3 ± 56.6 items/kg, with almost 38% of total microplastic in the < 1.0 mm size range. They used µ-FTIR to identify polymer types, including PE, PP, PET, cellulose, and PP-PE. According to [184], the

concentration of microplastics in Haikou Bay, Northern South China Sea, ranging from 0.66 ± 0.58 n/50 g (d.w.), 17.00 ± 6.56 n/50 g (d.w.) and about 83.12% of total microplastic is 1 to 1.9 mm in size. FTIR was used to identify seven polymer types, including PP, PVC, PMMA, PS, PE, PP-PE, and PU.

According to [185], the Bohai Sea Coastline has a microplastic concentration of 458.6 ± 150.0 items/kg, with 77.1 % of total microplastic being $< 1500 \mu\text{m}$ in size. Using μ -FTIR, they were able to identify seven polymer types, including ABS, PE, PP, PA, PET, PS, and RY. In southern China, [186] identified an abundance of microplastics ranging from 2249 items/kg to 75% of total microplastics ranging from 3 mm in size. SEM and energy-dispersive X-ray spectroscopy studies were used to identify the microplastics, mostly made of PP, PE, and PS. According to [187], the abundance of microplastics in Sishili Bay, North Yellow Sea, China, ranges from 499.76 ± 370.07 items/kg, with about 86.37% of total microplastic ranging from $746.84 \pm 839.69 \mu\text{m}$ in size. FTIR spectroscopy analysis was used to identify polymer types such as PMMA, PE, PA, PET, PU, RY, PP, and PE-PS. [188] reported that the concentration of microplastics in the Zhubi reef in the South China Sea ranges from 1400 to 8100 items/ m^3 , with 80% of total microplastic in the 0.5 mm size range. They used SEM and a DXR2 micro-Raman spectrometer to identify two polymer types: PP and PA. [189] explained that the microplastic concentrations in the Yellow Sea and the East China Sea are 13.4 ± 0.6 particles per 100 g^{-1} , with 89 % microplastic in size range of $1000 \mu\text{m}$. Using μ -FTIR, they identified two polymer types: PP and PA. [190] investigated the abundance of microplastics in the Rudong Offshore Wind Farm, Yellow Sea, China, finding 2.58 ± 1.14 items/g and 68.7% of total microplastics ranging from 0.1 to 5mm in size. PPA, PVC, and PE were detected as microplastics in the samples. For the chemical identification of polymers, a micro-Fourier transform infrared spectroscope (μ -FTIR) was used. [191] observed that the abundance of microplastics ranges from 15–12,852 items/kg and that 61.3% of microplastics vary from 0.16 to 5.0 mm in size in Qinzhou Bay, China. FTIR spectroscopy was used to identify the three types of microplastics: PP, PE, and PS. In the Maowei Sea, South China, [192] reported that the microplastic concentrations vary from 520 ± 32 to 940 ± 17 items/kg, with around 75% microplastic in size range $< 1 \text{ mm}$.

[193] found that the concentration of microplastics on Guangdong, South China, coast ranged from 16,686 items/ m^2 . Microplastics ranged from 0.315 to 5 mm and were distributed at 83 % in the study location. Spectroscopy analysis was used to identify the microplastics, mostly made of PP and PE (FTIR and Raman). In the Changjiang Estuary, China, [194] found a concentration of microplastics of 121 ± 9 items per kg. Microplastics range in size from 1 to 5 mm. The μ -FTIR spectroscopy study revealed that the microplastics were RY, PEST, PAC, PE, PP, PD, and PS. [195] found that the concentration of microplastics in the estuaries of Jiaojiang, Oujiang, and Minjiang in China ranged from $100 \text{ n}/\text{m}^3$ to $4100 \text{ n}/\text{m}^3$ is 90%. Micro-Raman spectroscopy is used to identify the microplastics, mostly made of PP, PE, PVC, and PTFE. [196] reported the abundance of microplastics with a size range of 8714 (Items/kg in sediment). About 82% of microplastics with a size range of 5 mm have been detected in the Beibu Gulf and China Sea coastline. PP, PET, PEST, and PS were identified as four forms of microplastics. Fluorescence microscopes were used to count the number of microplastics. According to [197], the number of microplastics in debris on the northern South China Sea beaches ranged from 375 items/ km^2 to 42% of total microplastic size 5 mm.

Atlantic Ocean

[198] found 15,283 items/ km^2 of plastic in the Macaronesian region of the NE Atlantic. The size of microplastics in this area ranges from 1-5 mm. [197], studied the abundance of microplastics in Tenerife beaches was $3.5 \text{ g}/\text{m}^2$, with 78 % of total microplastic ranging in size from 1 to 2 mm (Canary Islands, Spain). FTIR spectrometry is used to determine the composition of microplastics such as polypropylene and polyethylene. [200], explained the abundance of microplastics ranges from $8.5 \text{ g}/\text{m}^2$ to $103.4 \text{ g}/\text{m}^2$, with 87 % microplastic size 5 mm was reported in Lanzarote's biosphere reserve in the combination of PE, PP, and PS. The chemical identification of polymers was made using Raman and FTIR spectroscopy. [201] The quantity of microplastics in the Mar Menor lagoon ranges from $186.1 \pm 8.1 \text{ g}$ and 84.2 % of the total microplastic size of 5.0 mm (SE Spain). FTIR spectroscopy is used to determine the composition of microplastics such as PEST, PVE, PP, PS, PE, PVCAP, and PE. [202] reported the microplastic content of 0-12,869 items/ m^2 on the beaches of the Canary Islands. Microplastics range from 1-5 mm and are distributed in 52.7 % of the total microplastic. [203] found a plastic abundance of $67 (\pm 76)$ MPs/kg in the French Atlantic coastline. Microplastics range in size from 50-100 μm , with 84% of the distribution. PP and PE constitute the majority of the microplastic composition. [204] found 7.49 g and $68.83 \text{ items}/\text{m}^2$ of microplastic in the Atlantic Ocean at Bremerhaven, Germany, and Cape Town, South Africa, with abundance values ranging from $1.15 \pm 1.45 \text{ particles m}^{-3}$. The research area has a distribution of 94% of microplastic. [205], the Atlantic Ocean contains 13 to 501 items m^{-3} of microplastics. The microplastic size ranged from 50-80 μm , with a 42 % microplastic distribution in the research region. Microplastic is made up of PE, and PP, which can be analyzed using FTIR. In

the Atlantic Ocean, [206] found 0.5 microplastics per 25 cm² (Porcupine Abyssal Plain, Lobe of Congo Canyon Atlantic and the Mediterranean Sea). Microplastics are found in sizes ranging from 75 mm to 161 mm. According to [207], the abundance of microplastics in Saint Peter and Saint Paul Archipelago, equatorial Atlantic, ranges from 0.34 to 20.81 g m⁻³, with microplastics ranging in size from 25mm. [208], analyzed that the microplastics are abundant in the South Pacific subtropical gyre, with 26,898 particles per km² and 88.8% of total microplastic ranging in size from 0.355 to 4.75 mm with the composition of PS fragments, pellets, PP/monofilament line, and film.

United States of America region

[209] explained that the concentration of microplastic in Virginia and North Carolina is 1410±810 per kg. Microplastics in the research area range in size from 5.0 to 0.5 mm, with a distribution of 93.91%. Using Raman microspectroscopy, the composition of microplastics was found to be fiber and PE, PS, NY, PP, PVBP, and PET. The Charleston Harbor Estuary, South Carolina, USA, [210] reported microplastic concentration to be 652 microplastics/ m². The microplastic size is ≥ 500 µm, and the distribution in the studied area is 26.2%. ATR-FTIR is used to determine the fiber composition of microplastic. In the sediments of Todos Santos Bay, Mexico, [211] found microplastic concentrations of 0.01 to 0.70 plastic particles/m³ (pp/m³). In the study area, particles with sizes ranging from 500 to 250 µm were identified. In Tampa Bay, Florida, [212] found 280 (±290) particles/kg microplastic concentration. The region has a microplastic size range of 5mm and a distribution of 42% of microplastic with the combination of fiber and PE and can be detected using a microscope (33×). On the sandy beaches of the Baja California Peninsula, Mexico, [213] found a microplastic concentration of 135± 92 particles kg⁻¹. The particle size of 1mm has been determined, and the microplastic distribution in this region is 91 %. The microplastics are separated using the density method, and the microplastics are identified using the ATR-FTIR. [214] found microplastic concentrations of 413.8 ± 76.7 and 221.0 ± 25.6 particles/ m² in beach sediments in the South Carolina estuaries (Charleston Harbor, Winyah Bay, and South Carolina, respectively). The particle sizes range from 63-149 µm, and their distribution in this area is 73 %. SEM was used to identify the four polymer types: NY, PEST, PE, and PP in the San Francisco Bay, California, USA, [215] observed a particle concentration of 700,000 particles/ km². In this region, microplastic with a diameter of 0.125-0.355 mm with the combination of PE and PP are identified using infrared or Raman spectroscopy. Microplastic concentrations of 69 g were found on tourist beaches in Huatulco Bay, on the Pacific coast of southern Mexico, as reported by [216]. [217] studied that the particle size is 5 mm with the microplastic concentrations of 4.0± 1.03 mg were found in barrier islands across the northern Gulf of Mexico. The particle size ranges from 2.5 ± 0.48 mm, with a microplastic distribution of 47.8% in this area. [218], analyzed the concentration of microplastic in the Canadian Lake Ontario nearshore is 500 particles per kg. In the study area, the microplastic size range is 2 mm. PMMA, PDMS, PU, ABS, PSS, PVAC, NY, and RPP. Raman spectroscopy and X-ray fluorescence spectroscopy were used to identify microplastics. [219] explained the Chesapeake Bay has a microplastic content of 560 g/km. Microplastics in the research area range in size from 0.3 to 5.0 mm, with a distribution of 93.91 % with the composition of synthetic fibers and polystyrene were identified using Raman microspectroscopy.

Mediterranean Sea

[220] reported the abundance of microplastic ranges from 182.66 ± 27.32 and 649.33 ± 184.02 kg⁻¹ and about 70 % of total microplastic ranges between 0.81 to 2.16 mm in size surface sediment microplastics and litter from North African coasts of Mediterranean sea. [221] studied the abundance of microplastics range of 280.3 ± 164.9 MPs/kg d.w. About 85% of the total microplastic size of 1.2 µm was found in the Spanish Mediterranean. The composition of microplastic such as fibers, fragments, and fibers was identified. [222] reported the concentration of microplastic ranges from 2073.3 ± 648.6 particles kg⁻¹ d.w. About 72% of total microplastic ranges from 1 to 5 mm in size are found in the Aegean and Mediterranean Seas, Datca Peninsula (Turkey). [223] reported that the concentration of microplastic ranges from 33 to 798 microplastics per kg. About 63% of total microplastic is 0.5 mm in size found in the northwestern Mediterranean sea. [224] studied the abundance of microplastics range of 734 g, and about 93% of the total microplastic size of 2 mm was found in the coastline of Northern Crete. The composition of microplastic such as PEST, PAHs is identified using GC-ITMS. [225] reported the abundance of microplastics ranges from 141.20 ± 25.98 to 461.25 ± 29.74 items kg⁻¹ and about 85.71% of total microplastic ranges between 0.1 to 5 mm in size found in the north Tunisian coast (Mediterranean Sea). [226] examined the abundance of microplastics ranges from 0.90 ± 0.10 MPs/g, and about 60 % of total microplastic is in the range of 2 mm in size is found in the Mediterranean Sea. [227] reported that plastic concentration of 24 to 1211 items/km² in the eastern Mediterranean and Black seas. Plastics were predominant in all study areas ranging from 45.2% to 95%. [228] reported a plastic concentration of 1462 m² on the island of Malta (Central Mediterranean). The distribution of plastic is 78.5% in the study area.

Baltic coast

[229] reported that concentration varied between 76 and 295 items per kg dry sediments in the southern Baltic Sea. Microplastic size is 500 μm , and the distribution of microplastic is 91% in this area. [230] studied that abundance of 88.10 microplastic particles per kg dry sediment was found at the Isle of Rugen, Baltic Sea. Microplastic size ranges from > 1 to 5 mm and > 0.63 to 1 mm in this region and 80% distribution. [231] reported that microplastic concentration of 7-5560 (42-1150) items per m^2 in the Baltic beaches of Kaliningrad region, Russia. Microplastic size ranges from 0.5-5 mm in this region. [232] studied that microplastic concentration of 0-27 particles kg^{-1} in beach sediments in the Southern Baltic Sea. The particle size ranges from 0.1 to 2.0 mm is identified the microplastic, and their microplastic distribution is 77% in this area. They identified six polymer types are PE-PP, PEST, PVC, PVCE, PAN, and PVA. [233] reported a microplastic concentration of 34 ± 10 items/kg in the Baltic Sea. The distribution of microplastic is 95% in this area. [234] deals with microplastic particle 0.07 ± 0.02 particles/ m^3 in the South Funen Archipelago, Baltic Sea. Microplastic size ranges from 0.3-0.63mm in this region. [235] reported microplastic concentrations of 0-7 particles/kg in beach sediments along the German Baltic coast. A microplastic size of 1.05 mm is identified. However, City discharges, industrial production sites, fishing activity, and tourism are the most likely sources for the highest microplastic concentrations.

Pacific Ocean

[236] reported that concentration microplastic is $34,039 \pm 25,101$ pieces/ km^2 of in the mid-west Pacific Ocean. The microplastic size ranges from 2.5 to 5mm, and 57.4 % distribution of microplastic in the study area. They identified several polymer types PE-PP, PS, PP, PEST, PET, and PMMA, are identified using Raman spectra. [237] reported that concentration microplastic is 240 items/kg in the Western Pacific Ocean. The microplastic size range is 1 mm, and 95% distribution of microplastic in the study area. The commonly identified polymers types are PP-PE, PET, and polychlorinated biphenyls identified using $\mu\text{-FTIR}$. [238] reported that concentration plastic is $0.5 \text{ items} \cdot \text{km}^{-2}$ ($135 \text{ g} \cdot \text{km}^{-2}$) of in the Pitcairn Islands Marine Reserve. The plastic size range is 5 cm in the study area. [239] reported that concentration microplastic is 6.2×10^4 items km^{-2} of in the northwestern Pacific Ocean. The microplastic size range is 0.3 and 5 mm, and 60 % distribution of microplastic in the study area. They identified seven polymer types, PEST, PE, PP, PS, PE-PP, PET, and PA, detected using SEM.

Sources of ocean plastic pollution

China is the largest polluting country in the world (29 percent) (**Fig.3**). China's population density, which produces over 8.8 million metric tons of mismanaged waste and around 3.53 million metric tons of thrown plastic waste into the ocean, is the leading cause of it contaminating the marine environment. In comparison to China, the rest of Asia accounts for 21% of plastic pollution. Plastic pollution in the ocean is primarily caused by ten river systems in Asia and Africa. The Yangtze, Yellow, Indus, Hai He, Ganges, Mekong, Amur, and Pearl are the eight river systems in Asia, while the Nile and the Niger are the two in Africa. The United States was ranked in the top twenty countries. Plastic waste accumulates in the maritime environment at a rate of 18 billion pounds each year. European countries cause plastic pollution (19%), NAFTA countries (18%), the Middle East/Africa (7%), and Latin America (4%). Plastic pollution from landfills accounts for 2% of all plastic pollution seen on beaches near coastal areas. Indonesia, the Philippines, Vietnam, Sri Lanka, and Egypt are among the top ten nations with poor plastic management, resulting in pollution [240-242]. Microplastics were found in the marine environment all over the world [243, 244]: they were found near dense metropolitan areas, rural areas, and in a variety of marine environmental systems, including beaches [245-246] and deep-sea sediments [27].

Cleaner sea

National Marine Litter Policy in India

India releases 600,000 tonnes of plastic waste annually into the oceans. It is necessary to develop the right clean-up technology to overcome marine plastic pollution. To regulate, identify and monitor the source of plastic litter along India's coastal line, the Union Ministry of Earth Sciences took an initiative to clean up the oceans by adopting National Marine Litter Policy and UN Environment's global 'Clean Seas Campaign' in 2018. This policy is about how do we reuse and recycle plastic for a cleaner sea. National marine litter Policy aims to (i) identify the path of plastics from source to sink and promote Reduce, Reuse and Recycle (3R's) concept to create awareness (ii) enumerating the plastic litter in marine sediments, water, and biota along the Indian coast (iii) to build a monitoring, management and mitigation procedures to overcome the impact of Microplastics to clean up oceans.

Research gap

Main criteria to tackle research gaps about microplastics in the marine environment.

1. Present an optimal and standardized size description of a microplastic, with additional size specifications for nano - and mesoplastics
2. Improve and adapt systematic, high-throughput microplastic sampling methodologies to effectively correlate the outcomes from various research areas
3. Establish effective methods to identify tiny microplastics and nanoplastics in water columns and sediments
4. Broaden understanding of the nature and behavior of microplastics and their consequences of fragmentation and bio-fouling in the water column.
5. Adapt methods to assess microplastic absorption by biota in the food web and extend the usage of sentinel organisms (e.g., Fulmars), and detect the abundance of microplastics in the marine environment.
6. Identify the impact of ingested microplastics (leached plastic additives, waterborne pollutants) on marine biota and recognize its transition within the food chain.
7. Determine the microplastic wastes emitted from wastewater treatment plants (WWTPs) that drains into the rivers.

Conclusion And Future Recommendations

In this review, 45 papers were collected from the Web of Science during 2013–2020, mainly focused on concentration, identification, size, and distribution of microplastic in different aquatic environments and biota. From previous research, it can be concluded that the sampling and detection of MPs in most research in the marine environment are performed in sediments, biota, and seawater. We have also targeted freshwater habitats such as lakes and rivers in India, which have different types and levels of MPs pollution. A new three-dimensional mathematical modeling analysis is proposed. The level of microplastics is abundant in the areas where the activity of industries and residents were placed near freshwaters. The majority of intakes of microplastics were accumulated in the gut and gastrointestinal tracts of biota. Furthermore, the role of Wastewater treatment plants in emitting microplastics into the nearby aquatic environment should be concentrated, and practical steps to be taken to set up tertiary treatment plants in India to reduce the microplastic pollution from WWTPs. Research gaps in establishing the practical techniques in identifying nanoplastics, the origin of microplastic sources, transportation through various aquatic environments from land-based plastic wastes, absorption of microplastics by biota, and their impact in the food web and food chain still has to be focused predominantly on the future studies.

The following conclusions are derived focused on these reviews

1. Evaluations of particles by physical diffraction of the light as FTIR and Raman methods have a drawback for small particle scale
2. Clear overview of MPs existence by determining the residence time of MPs within the stomach and gut of biota
3. Identification of MPs engagement with biota to avoid the related complications which could endanger the future health
4. Researchers have to concentrate on defining treatment therapies as the MPs identification is established in reasonable point
5. Future research can be geared at prevention, awareness, and mitigation approaches Cleaner sea to monitor and regulate the sources of plastic pollution along the coastal line

Abbreviations

ABS Acrylonitrile Butadiene Styrene; ATR-FTIR Attenuated Total Reflectance - Fourier Transform Infrared Spectrometry; CL Cellulose; CP Cellophane; EVA Ethylene-Vinyl Acetate; EVOH Ethylene vinyl alcohol; EVOH Ethylene Vinylalcohol; FTIR Fourier Transform Infrared Spectrometry; GC-ITMS Gas chromatography – Ion trap mass spectrometry; HDPE High-Density Polyethylene; LDPE Low-Density Polyethylene; MMA Polymethyl Methacrylate; NY Nylon; PA Polyamide; PAC Polyacrylic; PAHs Polycyclic Aromatic Hydrocarbons; PAN Polyacrylonitrile; PBAN Polybutadiene acrylonitrile acrylic acid; PBR polybutadiene; PC Polycarbonate; PCU Polycarbonate-Urethane; PD Polydiene; PDMS Polymethylsiloxane; PE Polyethylene; PEA Polyethylene Glycol Adipate; PEI Polyetherimide; PEST Polyester; PET Polyethylene Terephthalate; PEVA Polyethylene-Vinyl Acetate; PI Polyisoprene; PMM Polymelamine; PP Polypropylene; PPA Polyphthalamide; PPF Polyphenylene sulfide; PPO Poly perfluoroethylene oxide; PPS Polyphenylene sulfide; PS Polystyrene; PSF Polysulfide; PSS Polystyrene sulfonate; PTFE Polytetrafluoroethylenes; PU Polyurethane; PVA Polyvinyl Acetate; PVAc Polyvinyl Alcohol; PVAC polyvinyl/vinyl Acetate Copolymer; PVB Polyvinyl Benzoate; VBP Poly (4-vinylbiphenyl); PVC Polyvinyl Chloride; PVCA Poly 4-methylcaprolactam; PVCE Polyvinyl Chloride-Ethylene; PVE Polyvinyl Ester; PVF Polyvinyl formal; RPP Resin Polypropylene; RY Rayon; SEM Scanning Electron Microscopy; SEM-

Declarations

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Authors' contributions

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Tables

Table 1 shows the concentration, size, and distribution of microplastics in marine and biota environments

S. No	Location/ Environments	Sample type	MPs Range/ average	Size	Distribution (%)	Ingestion	Spectroscopy	Polymer types
	Kochi, Arabian Sea, India [56]	Fishes -24	-	> 1 - 5 mm	81.59	Gut, intestine	Raman spectroscopy & FTIR	PE; PP; LDPE
	Cochin, Kerala, India [57]	<i>Fenneropenaeus indices</i> (Shrimp - 330)	0.39 ± 0.6 items/shrimp 0.04 ± 0.07 items/g	500 - 1000 µm	30.9	Foregut and Midgut	FTIR	PA; PEST; PE; PP
	Pondicherry, India [58]	<i>Perna viridis</i> & <i>Meretrix meretrix</i> (bivalve -50)	1.8 g 0.18 g	< 100 µm	-	Mussels/ clams	Raman spectrum & Fluorescence microscope	PU;PVCA; PVC; PES; PVCA; PET; ABS; SBR; PVK; PET; PVC; PEVA
	Tuticorin, Gulf of Mannar (GoM), India [59]	<i>Donax cuneatus</i> (225)	0.95 items/g	100 - 250 µm	41	Clam	FTIR-ATR, SEM, & EDAX	PE; PP; PP-PE; PA;PET; PEST; PVC; PS; RA; PVA
		Sediments	134.29 items/kg	1 - 5 mm	44	-		
		Sea water	19.87 items/l	500 µm - 1 mm	58	-		
	Tuticorin, Southeast coast of India [60]	<i>Harpodon nehereus</i> (20), <i>Chirocentrus dorab</i> (20), <i>Sardinella albella</i> (20), <i>Rastrelliger kanagurta</i> (20), <i>Katsuwonus pelamis</i> (10), & <i>Istiophorus platypterus</i> (10)	0.2002 items/l	< 500 µm	34	Gastrointestinal tracts	FTIR-ATR and SEM-EDAX	PE; PA; PEST; PS; PP; PAC
		Sea water	13.4 items/l	1 - 5 mm	64	-		PE; PEST; PA; PS; PP; PD; PP-PE; PVA
	Kerala, India [57]	<i>Rastrelliger kanagurta</i> , <i>Megalaspis cordyla</i> , <i>Sardinella longiceps</i> , <i>Sardinella gibbosa</i> , <i>Stolephorus indicus</i> , <i>Dussumieria acuta</i> , <i>Thryssa dussumieri</i> , <i>Sphyraena obtusata</i> and <i>Anodontostoma chacunda</i>	0.005 items/g	115- 210 µm	41.1	Edible Tissues	ATR- FTIR	PE; PP
			0.054 items/g	136 to 4010 µm	7	Inedible tissues		PE; PP; EPDM; PS
	Ramsar, Vembanad Lake, South India [61]	<i>Piaractus brachypomus</i>	26.01 items/g	0.5 mm	99	Gut	ATR-FTIR & Raman Spectroscopy	PP; NY6; PET; PBT
	Chennai and Nagapattinam, Southeast coast of the Bay of Bengal [62]	Fish (190)	20 items/g	1.3µm - 9.3 mm	8.95	Gastrointestinal tract	FTIR & SEM	PA; PE; PET
	Chennai, Southeast coast of India [63]	<i>Perna viridis</i> (Linnaeus, 1758)	0.9/g	5-30 µm	87	Tissue	DXR Raman spectroscopic	PS
	Roche Park, Tuticorin coast, Gulf of Mannar, Southeastern India [64]	<i>Magallana bilineata</i> (oyster)	0.81/g	0.25 to 0.5 mm	96	Tissue	FTIR-ATR analysis	PE; PP
		Sediments	12.75 items/kg	1 - 3 mm	100	-		PE; PP; PEST; PA
		Seawater	21.60 items/L	0.5 - 1 mm	100	-		PE; PP
	Tuticorin, South east coast of India [65]	<i>Rastrilleger kanagurta</i> and <i>Epinephalus merra</i>	-	0.5 mm to 1 mm	80	gut	FTIR	PE; PP

	Kochi, Southeastern Arabian Sea [66]	<i>Sternaspis scutata</i> , <i>Magelona cincta</i> and <i>Tellina sp</i>	-	20 µm	67	gut	DXR Raman microscope	PS
Beach								
S. No	Location/ Environments	Sample type	MPs Range/ average	Size	Distribution (%)	spectroscopy	Polymer types	
	Silver Beach, Southern India [69]	Plastic debris	204 items/kg	0.5 to 1 mm	100	ATR-FTIR	PVC; PE; NY	
	Beaches of Tuticorin Southern India [70]	Macroplastics	3.77 items/m ²	> 2.5 cm	54.98	ATR-FTIR	PE; PP; PET; NY; PS; PVC	
		Mesoplastics	9.5 items/ m ²	5 mm - 2.5 cm	60			
		Microplastic debris	54 items/ m ²	5 mm	41.17			
	Tuticorin and Vembar groups of islands in the Gulf of Mannar, southeast India [71]	reported that the MPs ranged from 60 to 126.6 items/L in water and from 50 to 103.8 items/kg in sediment, PE fibers (1-3 mm) and PP fragments (3-5 mm) were the most common forms of microplastics						
	Marina Beach in Chennai, India [72]	Plastics debris	2275 items	5.5 to 25 mm	100	ATR-FTIR; TGA-DSC; SEM	LDPE; PE; PP; PA; PC	
	South Andaman beaches, India [73]	Sediments	414.35 items/Kg	100-1000 µm	100	Raman spectral	PP; PPM, PVF, PBAN; PSF; PPO; PVB; PVC; NY; ABS	
	North-east Arabian coast, India [74]	Marine debris	22.4 kg dry weight/km ²	-	40.6	-	Plastic bags, Food wrappers, Personal care products, Cups (Styrofoam), Beverage bottles, Plastic rope/ net pieces, Bottle or container caps	
	Beach sediments of coastal areas in Tamil Nadu India [77]	Sediment	385 items/kg	0.5 to 3 mm	100	FTIR-ATR SEM-EDAX	PE; PP; NY; PES; PS	
	Arabian sea coast, Bay of Bengal coast, India [78]	Beach sand	220 MPs/kg	> 1 mm	100	Fluorescence microscopy, SEM-EDS, and FTIR	PET; PE; PVC; PP; PS; PEST; PA	
		Beach sand	181 MPs/kg					
		Beach sand	45 MPs/kg					
	Beaches in Kerala Coast, India [79]	Plastics	0.55 kg/100m ²	-	73.8	-	Plastic	
	Nattika Beach, Kerala Coast, India [80]	Sediments	191 items/kg	5-1 mm	70	FTIR and SEM	PE; PE + PP; PP; PS; PCU	
	Chennai, East Coast of India [81]	Plastic debris	8.96 kg/m	-	56.42	-	Food wrappers; cups; bottle and caps; thermocol/styrofoam; food wrappers	
	Beaches of	Beach sediments	72.03 ± 19.16	300	56.32	Raman spectroscopy	PP; HDPE; LDPE; PS;	

	Puducherry, India [82]		microplastic particles/100 g	µm-1 mm			PU
	Beaches of southeast coast of India [83]	<i>Rastrelliger kanagurta</i> , <i>Siganus javus</i> , <i>Arius arius</i> , <i>Leiognathus equulus</i> , and <i>Mugil cephalus</i> (Fish)	46.6 ± 37.2 /m ²	1-2.5 mm	60.1	FTIR-ATR	PE; PP; PS; NY
		Beach sediments (25)	9233 mg/m ²				
	Beaches of Rameswaram, GoM, Southeast coast of India [84]	Sediment	403 pieces	> 1.01-200 mm	60.8	FTIR spectroscopy	PE; PS; NY; PVC
	Nallathanni Island, Gulf of Mannar Biosphere Reserve, Southeast coast of India [85]	Plastic debris	505 pieces	-	-	FTIR	PS; PE; PC; PVC; NY
	Four beaches in Mumbai coast, India [89]	Marine debris	3.24 kg	-	44.89	-	Plastic
	Beaches in Mumbai, India [90]	Plastic debris	7.49 g	1-5 mm	55.33	-	Plastic
	Urban beaches in Mumbai, India [91]	Plastic litter	3.24 g m ⁻²	5-100 mm	80	-	Plastic
Island							
S. No	Location/ Environments	Sample type	MPs Range/ average	Size	Distribution (%)	spectroscopy	Polymer types
	Island in the Maldives, Indian Ocean [95]	Sediment	277.90 items/kg	0.01-3 mm	49	Celestron Digital Microscope	PE; PP; PS
	The Port Blair Bay, Andaman Islands [96]	Finfish & Shellfish	10.65 specimens	111.58 to 5094 µm	45.83	ATR-FTIR	PEM; PAC; PPF; EVA; PAN; NY; EVA; PI; PU; PVC
		Zooplankton	0.12 pieces	21.57 to 2225 µm	90		
		Water	0.93 items/L	35.29 to 5010 µm	-		
		Sediments	45.17 particles/kg	46.72 to 5024 µm	-		
	Vavvaru Island of the Maldives, Indian Ocean [97]	Plastic debris	1029 items/m ²	> 1 mm	96	ATR-FTIR spectroscopy	PE; PP; PS; PU; PA; PVA; PVC
Riverine							
S. No	Location/ Environments	Sample type	MPs Range/ average	Size	Distribution (%)	Spectroscopy	Polymer types
	Netravathi River India [98]	Water	288 pieces/L	1-5 mm and 0.3-1 mm	86.51	FTIR -ATR	PE; PET; PP; PVC
		Sediment	96 pieces/kg				
		Soil	84.45 pieces/kg				
	Sediments of river Ganga, Eastern India [99]	Sediment	0.68 to 148.31 ng/g and 11.48-63.79 ng/g	5 mm to 10 mm	70	FTIR	PET; PE; PP; PS
Marine sediments							

S. No	Location/ Environments	Sample type	MPs Range/ average	Size	Distribution (%)	Spectroscopy	Polymer types
	Kerala, Southwest coast of India [76]	Sediments	40.7 particles/m ²	0.3 – 0.6; 0.6 – 1.18; 1.18 – 2.36	96.10	FTIR-ATR; FP-XRF	PE; PP; PA; PS; PET; RY; PUR; CE; ABS; PVC; PVFM
		Water	1.25 particles/L	and 2.36 –			PE; PP; RY; PS; CE
		Fish	22 particles	4.75 mm			PE; CE; RY; PL; PP
	Vembanad Lake, Kerala, India [86]	Sediments	496 items m ⁻²	< 5 mm	91	Raman spectra	PP; PE; PS
	Goa coast, India [88]	Sediments	3000 pellets	-	-	FTIR-ATR	PE; PP
	Chennai coast, India [150]	MPPs	1200 pellets	2 to 5 mm	-	ATR-FTIR	PE; PP
Sea salt							
S. No	Location/ Environments	Sample type	MPs Range/ average	Size	Distribution (%)	Spectroscopy	Polymer types
	Tuticorin Coastal salt pan stations, Gulf of Mannar, South India [92]	Sea salt	-	100 µm	60	µ-FT-IR and AFM	PE; PP; CL; NY
	Salt of Tuticorin, Southeast Coast of India [93]	Sea salt	72 items/kg	100 to 500 µm	100	SEM-EDAX	PE; PP; PEST; PA
	Mumbai, Indian sea salts [94]	Sea salt	103 particles kg ⁻¹	2000 µm and 500 µm	80	µ-FTIR	PP; PS; PA; PE
Lake (water & sediments)							
	Veeranam lake, Tamil Nadu, India [100]	Sediments	309 items/kg	-1 to 0.3 mm	80	ATR-FTIR	NY; PE; PS; PP; PVC
		Water	28 items/L	0.3 - 2 mm			
	Red Hills Lake, India [101]	Water	5.9 items/L	0.33 - 2 mm	99	ATR-FTIR, SEM	HDPE; LDPE; PP; PS
		Sediments	27 items//kg	2 mm			
Seawater							
	South Juhu creek, Mumbai, India [68]	Marine debris	2 g/kg	Macro	-	-	-

Abbreviations

ABS Acrylonitrile Butadiene Styrene; ATR-FTIR Attenuated Total Reflectance - Fourier Transform Infrared Spectrometry; CL Cellulose; CP Cellophane; EVA Ethylene-Vinyl Acetate; EVOH Ethylene vinyl alcohol; EVOH Ethylene Vinylalcohol; FTIR Fourier Transform Infrared Spectrometry; GC-ITMS Gas chromatography - Ion trap mass spectrometry; HDPE High-Density Polyethylene; LDPE Low-Density Polyethylene; MMA Polymethyl Methacrylate; NY Nylon; PA Polyamide; PAC Polyacrylic; PAHs Polycyclic Aromatic Hydrocarbons; PAN Polyacrylonitrile; PBAN Polybutadiene acrylonitrile acrylic acid; PBR polybutadiene; PC Polycarbonate; PCU Polycarbonate-Urethane; PD Polydiene; PDMS Polymethylsiloxane; PE Polyethylene; PEA Polyethylene Glycol Adipate; PEI Polyetherimide; PEST Polyester; PET Polyethylene Terephthalate; PEVA Polyethylene-Vinyl Acetate; PI Polyisoprene; PMM Polymelamine; PP Polypropylene; PPA Polyphthalamide; PPF Polyphenylene sulfide; PPO Poly perfluoroethylene oxide; PPS Polyphenylene sulfide; PS Polystyrene; PSF Polysulfide; PSS Polystyrene sulfonate; PTFE Polytetrafluoroethylenes; PU Polyurethane; PVA Polyvinyl Acetate; PVAc Polyvinyl Alcohol; PVAc polyvinyl/vinyl Acetate Copolymer; PVB Polyvinyl Benzoate; PVBP Poly (4-vinylbiphenyl); PVC Polyvinyl Chloride; PVCAP Poly 4-methylcaprolactam; PVCE Polyvinyl Chloride-Ethylene; PVE Polyvinyl Ester; PVF Polyvinyl formal; RPP Resin Polypropylene; RY Rayon; SEM Scanning Electron Microscopy; SEM-EDS Scanning Electron Microscopy - Energy Dispersive Spectroscopy; TGA-DSC Thermogravimetric Analysis & Differential Scanning Calorimetry.

Figures

Figure 1

No. of papers published in journals categories using the database Web of Science (Clarivate Analytics®) regarding MPs research in India

Figure 2

Sources of Microplastics (MPs) in the environment (IUCN 2017)

Figure 3

Sources of ocean plastic pollution