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

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Abstract

**Purpose:** Microplastics (MPs) are ubiquitous, persistent pollutants that are reported in abundance in all environments and biota. This review highlights the identification, distribution and concentration of microplastics in all aquatic environments and biota in the India region which is one of the least studied with only forty-four papers published on microplastics during 2013-2020 in the web of science.

**Results:** The present review focuses on 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/m^2 in river water, and 328 items/kg in river sediments.

**Conclusion:** Consequently, we studied the distribution and occurrence of pollution from MPs in coastal and freshwater environments such as rivers, lakes and biota. Therefore, we propose extending studies in all the above areas of microplastics knowing that there are many unique aquatic habitats and species that are yet unexplored. For future research, we suggest new methods for sampling MPs in all marine ecosystems and biota. Assessing research in each of these ways will allow suggesting a microplastic threshold level and devising control initiatives to minimize plastic consumption and its eventual hazard to the aquatic ecosystem. Moreover enforcing strict laws, enhancing legal initiatives, well-planned comprehensive waste management policies and spontaneous public engagement are essential to create awareness of marine plastic pollution and reduce the adverse effects of land-based plastics.

**Background, Aim, And Scope**

[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 were 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 owing to its resilience and functional affordability; however, plastic production rose from 15 Mt (1964) to 311 Mt (2014), and within the next twenty years it was predicted to get doubled. 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 recognised as microplastic are far more common as it is extremely volatile due to its small size, and has the ability to 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 a large number of plastic fibers and pieces [6]. Tourism and recreational activities in coastal areas mainly have single-use plastics, contributing to coastal microplastics [7]. Numerous studies on the toxicological impact of microplastic particles on a number of fish are accessible [8-15]. Reviews latest studies on the harmful consequences of micro- and nano plastics ingestion of fishes [8]. In 1972, small plastic particles on the Sargasso Sea surface [16], many researchers have been involved in researching microplastics owing to their harmful effects on the aquatic environment. Microplastics have been identified in rivers, streams, oceans, atmosphere, and aquatic ecosystems across the world [17-47]. MPs have been investigated worldwide in biota ecosystems [48-55]. Microplastics have been 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 bibliometric 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 impact of microplastic particles on a number of fish are accessible [8-15]. Reviews latest studies on the harmful consequences of micro- and nano plastics ingestion of fishes [8]. In 1972, small plastic particles on the Sargasso Sea surface [16], many researchers have been involved in researching microplastics owing to their harmful effects on the aquatic environment. Microplastics have been identified in rivers, streams, oceans, atmosphere, and aquatic ecosystems across the world [17-47]. MPs have been investigated worldwide in biota ecosystems [48-55]. Microplastics have been 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].

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) identification, composition, and their distribution used in the India region, which is possibly one of the least studied with only forty-four 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. (v) to discuss the National marine litter policy in India and to 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 were screened, and only such microplastics works were chosen. This has resulted in 44 research articles, published from 2013 to 2020, and these were taken-up for detailed review (Fig.2). According to the following research topics the articles are categorized into (i) analytical methodologies, identifications, compositions, and distribution of microplastics used in the India region, which is possibly one of the least studied with only forty-four papers published on microplastics during 2013-2020 are identified in the web of science (Fig. 3). (ii) to examine the characteristics of publication results, the distribution of subject grouping, and research gap. (iii) to highlight the spatial distribution of microplastic in all aquatic environments and biota. Statistics indicate that the amount of MPs studies publications has grown steadily in the last 5 years.
Results And Discussion

Sources of microplastic

Microplastics differ in their 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] (Fig.4).

Primary microplastics

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 etc [4, 127, 128-130]. These products are described as open use products as they are washed off and drains in the environment [129]. Chang, on the other hand, 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

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, 131] and turbulence [132]. If these fragments reach surface waters or deep habitats, colder temperatures and decreased UV light makes the breakdown process to slow down [131]. The degradation persists until the particles become smaller and microplastic in scale [4, 133]. It has been 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 [134, 135].

Waste water treatment plants (WWTPs)

Significant amounts of microplastics are found in discharges from waste water treatment plants (WWTPs), and most are released out into the rivers. The predominant purpose for WWTPs is to handle waste water; however, they add a bulk amount of microplastics into the marine environment due to their improper disposal [136, 137]. In Tertiary treatment, full recovery was reached, which was not expected when secondary treatment has been 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 (Table 1).

Spatial distribution of microplastic in India

In this part, we have selected 44 papers of beach sand (38.64%), Biota (27%), sediments (11%), island (7%), sea salt (4%), riverine (4%), lake (4%), and seawater (2%) of concentration, size, and spatial distribution of microplastic in the entire environment (Fig. 5 and Table 2).

Microplastic (MPs) in beaches, shores, and coastlines

The concentration of plastic debris average of 204 items/kg and about 100% of total plastic debris is 0.5 to 1 mm in size found in Silver Beach, Southern India [70]. The polymer types were polyvinyl chloride, polyethylene, and nylon 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 [71]. The polymer types were PE, PP, PET, NY, PS, and PVC identified using ATR-FTIR. [73] 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 100-100μm in size found in the sediments of the Andaman beaches, India [74]. The polymer types were PE, melamine, polybutadiene, polysulfide, poly (dimer acid-co-alkyl polyamine), PVC, NY-6, acrylonitrile butadiene styrene, poly (butadiene-acrylonitrileacrylic acid), polyvinyl formal, poly (perfluoroethylene oxide), polyvinyl benzoate, and epoxy epichlohydrin 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 [75]. The polymer types were plastic bags, styrofoam cups, beverage bottles, bottle caps, plastic rope, net pieces, food wrappers were identified. The presence of plastic debris concentration of 2g/Kg in the seawater of South Juhu creek, Mumbai, India [69]. The concentration of 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 [78]. The polymer types were PE, PP, NY, PES, and PS identified using FTIR-ATR, and SEM-EDAX.

[79] 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, polyester, and polyamides identified using SEM-EDS, Fluorescence microscopy, and FTIR. [80] reported that concentration of plastic concentration of 0.55 kg/100m² and their distribution of 73.8% in the beaches in Kerala Coast, India. The polymer type was plastic identified. [81] reported that concentration of microplastic concentration of 191 items/kg, and their distribution of microplastic 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. [82] reported that concentration of plastic debris concentration of 8.96 kg/m and their distribution of 56.42% in the beach litter along Chennai, East Coast of India. The food wrappers, cups, bottle and caps, thermocol/styrofoam, and food wrappers identified. [83] reported that concentration of 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 polyurethane, HDPE, polypropylene, polystyrene, and LDPE identified using Raman spectroscopy. [85] 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. [86] reported that plastic debris concentration of 505 pieces in the Nallathanni Island, SE of India. The polymer types were polystyrene, polyethylene, polycarbonate, polyvinyl chloride, and nylon identified using FTIR spectroscopy. [88] reported that concentration of plastic debris concentration of 3.24 kg and their distribution of 44.89% in the Marina beach, Chennai, India. [91] 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. [92] reported that 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 that 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, RA, and PVA identified using FTIR-ATR, SEM, and EDAX. [65] examined the presence of microplastic concentrations average of 12.75 items/kg in sediments, and 21.60 items/L in seawater, and their distribution of microplastic 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, polyester, polystyrene, and nylon identified using FTIR-ATR analysis. In quantities of plastic debris is highest amount of 8.96 kg/m in marine beach to prove that shoreline and recreational activities are the primary cause of beach debris litter along Chennai, India [82].

[96] reported that microplastic concentration of 277.90 items/kg and their distribution of 49% and 0.01 - 3 mm in size found in the Beaches of Puducherry, India. The three polymer types were poly (ethylene; propylene; styrene) identified using Celestron Digital Microscope. [97] examined that presence of microplastic concentrations of 0.93/m³, and 45.17 /kg (water, and sediments respectively). The particle size range of 35.29 to 5010 µm, and 46.72 to 5024 µm (in water, and sediments respectively) in the Port Blair Bay, Andaman Islands, India. The polymer types were ionomer surlon, poly ethereimide, acrylic (Acryl Fiber), polyphenylene sulfide, ethylene vinyl alcohol, acrylonitrile, nylon, ethylene-vinyl acetate, polyisoprene, polyurethane, PVC identified using FTIR-ATR. [98] reported that plastic debris concentration of 1029 items/m² and their distribution of 96% and > 1 mm in size found in the Vavvaru Island of the Maldives, Indian Ocean. The polymer types were polyethylene, polypropylene and polystyrene, but polyurethane, poliamide, polyvinyl alcohol and polyvinyl chloride identified using ATR-FTIR spectroscopy.

[99] 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 Nettavathi river, India. The polymer types PE, PET, PP and PVC 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 [138]. The 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 7.14 mg/kg in October [139], higher than Haihe River [140] and marginally lower than Pearl River [141, 142]. [100] 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 riverine sediments of Ganga, 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 [143], 178-544 items/kg in the Beijiang 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 [144]. 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 [145, 146]. 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 fibres (polymers) and sheet or film were the most significant morphotypes. Compared to other morphotypes such as film and beads, microplastic waste highlighting fibers was recently emphasised [147].

[76] 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. [77] examined that presence of microplastic concentrations of 40.7 particles/m², 1.25 particles/m³, 22 particles in sediments, water, and fish respectively), and their distribution of microplastic is 96.10%. The particle size range of 0.3-0.6, 0.6-1.18, and 1.18-2.36 mm in the Kerala, Southwest coast of India. The polymer types PE, PP, PA, PS, PET, PP, PUR, alkyd; CE; ABS; PVC; PVFM sediments, PE; PP; alkyd; Ry; PS; CE in water and PE; CE; Ry; PL; PP in fish identified using FTIR-ATR, FP-XRF. [87] reported that microplastic concentration of 496 items/m³ and their distribution of 91% and < 5 mm in size found in the Vembanad Lake, Kerala, India. The polymer types were Polymers; Polypropylene; polyethylene, and polystyrene identified using Raman spectra. [89] reported that microplastic concentration of 5500 pellets found in the Goa coast, India. The polymer types were PE and PP identified using FTIR-ATR. [148] reported that microplastic concentration of 1200 pellets 2 to 5 mm in size found in the found in the Chennai coast, India. The polymer types were Polyethylene and Polypropylene identified using FTIR-ATR.

[93] examined the presence of microplastic in sea salt, and their distribution of microplastic is 60%. The particle size of 100 µm in the Tuticorin coastal salt pan stations, Gulf of Mannar, South India. The polymer types PE, PP, CL, and NY identified using μ-FT-IR and AFM. MPs were also recently reported from Arctic sea ice, fish, sea birds and sea salts in heavily polluted surface waters. Only a small range of global studies have been carried out on the quantity and distribution of MPs in marine salts [149-153]. [94] 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 polyethylene, polypropylene, polyester, and poliamide
identified using SEM-EDAX. The study shows that people consume around 216 MPs/year particles through sea salt if the average individual has 5 g daily salt intake.

[95] 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 polyesters, polystyrene, polyamide, polyethylene identified using μ-FTIR. [102] examined that 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 [162-164]. A further probable route for microplastic is by dry deposition, by wind transport. The dust generated by, i.e., automotive emissions, tyres [165] from the soil, deposition and dispersion between the atmosphere, the environment and the marine domain may also promote the transportation of microplastic [166], although this requires detailed analysis [167].

**Ecotoxicological effects of microplastics on biota**

Microplastic particles were found in many aquatic biota, such as fishes (Anodontostoma chacunda, Arius arius [11], Carangoides amatus [20], Chiroteuthis dorab [20], Colilia dussumieri [10], Cyanoglossus macrostomus [126], Decapterus russelli [10], Dussumieraca acuta, Dussumieraca eloposoides [10], Eleutheronoma tetractylym [10], Epinephalus diancus [8], Epinephalus mera, Escualosora thoracata [10], Harpodon neheverus [20], Istiothorax platypterus [10], Katsuwonus pelamis [10], Leiothtus equulus [10], Leiothtus splendens [6], Megalasplys cydola, Mugil cephalus, Nemipterus japonicas [20], Nemipterus randalli [38], Pentaprion longimanus [20], Piaractus brachyomus, Rastrelliger faughni [10], Rastrelliger kanagurta [168], Sardinella albella [20], Sardinella gibbosa [41], Sardina ricaphias [144], Saurida tumbi [13], Scomberomorhcus guttatus [10], Siganus javus [29], Sphyraena obtusa, Stolephorus indicus [148], Terapon puta [33], Thryssa dussumier, and Thryssa mystax [12]; Shrimp (Fenneropenaeus indicus - 330), bivalve (Perna viridis & Meretrix meretrix - 50), mollusca (Donax cunetlceus -225, Perna viridis [Linnaeus, 1758], oyster (Magallana bilineata), Annelida (Stemaspis scutata, Magalena 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 analysed and more than 95% of the species studied were found to be infected by microplastic particles (Table 3).

**Microplastics (MPs) in vertebrates**

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 3).

Microplastics were present in the gut and intestine of fishes namely as Dardanelle longiceps [123], Rastrelliger kanagurta [130], Dardanelle gibbosa [40], Carangoides amatus [20], Decapterus indicus [127], Epinephalus diancus [8], Saurida tumbi [13], Terapon puta [13], Nemipterus randalli [38], Leiothtus splendens [6], Cyanoglossus macrostomus [106], and Thryssa mystax [12]. The particle size range from > 1-5mm and 81.59% distributed in fishes of Kochi, south eastern Arabian Sea, India [57]. 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) [61]. The particle size range of <500 μm, and 1-5mm (in guts, and seawater respectively) in the Tuticorin, Southeast coast of India. The polymer types were polyethylene, polyamide, polyester, polystyrene, polypropylene and acrylic in fishes, and polyethylene, polyester, polyamide, polystyrene, polypropylene, polydine, PP-PE, and PLA in seawater identified using FTIR-ATR and SEM-EDAX. [58] 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 μm, and 136 to 4010 μm (edible and inedible tissues respectively) in the 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.

[62] reported the concentration of microplastic is 26.01 items/g in the gut of the alien fish of Piaractus brachyomus [123]. The particle size of 0.5mm and their distribution of 99% in the Ramsar, Vembanand lake, South India. The polymer types were PBT, PP, PET, and NY 6 identified using ATR-FTIR and Raman spectroscopy. Microplastic concentration of 20 items/g in the gastrointestinal tract of fishes such as Colilia dussumieri [10], Decapterus russelli [10], Decapterus macarellus [20], Dussumieraca eloposoides [10], Eleutheronoma tetractylym [10], Escualosora thoracata [10], Nemipterus japonicas [20], Pentaprion longimanus [20], Rastrelliger faughni [10], Sardinella longiceps [20], Scomberomorhcus guttatus [10], Stolephorus indicus [20], and Terapon puta [20] [63]. The particle size ranges from 1.3μm - 9.3mm and their distribution of 8.95% in the Chennai and Nagapattinam, Southeast coast of the Bay of Bengal. The polymer types were PA, PE, and PET identified using FTIR & SEM.

About 80% distribution of microplastic found in the intestine of Rastrelliger kanagurta [20], and Epinephalus mera [20] [66]. The particle size ranges from 0.5 mm to 1 mm in the Tuticorin, South east coast of India. The polymer types were polyethylene & polypropylene identified using FTIR. [84] examined the
microplastic concentrations of 46.6/m² in 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 is 60.1% respectively. The particle size ranges from 1-2.5mm respectively in the beaches of SE 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 peroni (8), Opehenus 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. [97] the polymer types were ionomer surlin, poly ethenamide, acrylic (Acryl Fiber), polyphenylene sulfide, ethylene vinyl alcohol, acrylonitrile, nylon, ethylene-vinyl acetate, polisoprene, polyurethane, poly vinyl chloride identified using FTIR-ATR.

In conditions of particles per organism, larger vertebrates have eaten higher concentrations of microplastics than fish. Highest microplastic abundance values were reported in India's southeast coast [97]. By examining microplastic abundance in fish from different studies in India, we found 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 abundances of 0.0002 MP/g in gut, 1.10 MP/g in body, and 0.11 MP/ individual due to depth about >200m [94]. In terms of depth of locations, microplastic was concentration is 0.2 MP/g in gut, 0.008 MP/g in body, and 3.64 MP/ individual found to be Harpodon neheurus due to depth above 1-3 m. In conditions of 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 [62].

Microplastics (MPs) in invertebrates

In the ecological food web, microplastic toxicity has been observed to influence 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 have analyzed microplastic contamination in invertebrates in India and 508 organisms have been reported to be microplastic polluted (Table 3). Among these species, bivalves are of particular concern since their extensive filter-feeding practices expose them to plastics in the waters they visit [110, 168]. The confirmed rate of microplastic ingested by aquatic invertebrates was 58.58%. The highest microplastic abundance in aquatic invertebrates in India ranged 0.04 to 3.78 and from 0.39 to 7.05 items/g. [58] reported the presence of microplastic is 0.04 items/g (0.39 ± 0.6 items/shrimp) in the foregut and midgut of Fenneropenaeus indices (Shrimp - 330). The particle size range from 500 to 1000 μm and 30.9% distributed in Cochin, Kerala, India. The polymer types were poly (amide, ester, ethene, and propylene) identified using FTIR.

[59] 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 poly (amide, ester, ethene, and propylene) identified using Raman spectrum & Fluorescence microscope. [60] examined that presence of microplastic concentrations average of 0.95 items/g in clams (Donax cuneatus - 225), and their distribution of microplastics were 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. [64] 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 the Chennai, Southeast coast of India. The polymer type was PS identified using DXR Raman spectroscopic. [65] examined that presence of microplastic concentrations average of 0.81/g in tissue of 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. [67] examined that distribution of microplastic 67% in the gut of Stemiospis 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 DXR Raman microscope.

[97] analysed the concentration of microplastic in 10.65 specimens, 0.12 pieces (finfish & shellfish and zooplankton) and their distribution is 45.83 percent, 90% in finfish & shellfish, zooplankton respectively. The particle size spectrum in Port Blair Bay, Andaman Islands, is 111.58 to 5094 μm, 21.57 to 2225 μm (in finfish & shellfish, and zooplankton, respectively). Polymer forms were ionomer surlin, polyethenamide, acrylic (Acryl Fiber), polyphenylene sulphide, ethylene vinyl alcohol, acrylonitrile, nylon, ethylene-vinyl acetate, polisoprene, polyurethane, FTIR-ATR polyvinyl chloride. In term of particles per individual, the highest concentration of microplastics was noticed in Magallana bilineata (oyster) (180) collected in the Roche Park, Tuticorin coast, GoM, Southeastern India which has an abundance no. of MPs 29.19 items/ individual and no. of 1.73 MP items/g [65]. In similar that, the largest concentration of microplastics was found in oysters (Crassostrea gigas) obtained in Sangou Bay, Yellow Sea, with a concentration of 43-164 ind. 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 main 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 would feed upon it which is reasonable in size [119, 169]. In general, size was also strongly linked to microplastics toxicity [170]. In the 53 reviewed papers, 35 researches recorded the size spectrum (Table 3). The highest value varied from 9.3 mm to 5mm, and the minimum values varied from 0.005 to 1mm. Twelve biota experiments determined size groups. Most experiments have found microplastics in the size class of less than 1 mm (83 percent of biota articles). However, larger microplastics overshadowed certain sh research. For example, larger microplastics were identified in fish (0.0013-9.3 mm) from Chennai and Nagapattinam, Southeast Bay of Bengal [63], fish captured from the Kochi, south eastern Arabian Sea, India (particle size range from >1-5mm [57], fish (inedible tissues) captured from the Kerala, India (Size: 0.136 to 4.010mm [58], fish (gut) captured from the beaches of southeast coast of India (Size: 1-2.5mm [84]. Shrimp captured from the Cochin, Kerala, India (Size: 0.5-1 mm; Daniel et al., 2020), the plastic debris size ranges from 0.5-25 mm in the beach sediments. In marine Chennai beach has been size in 5.5-25 mm in beach sediments [73]. 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 fibres than other sources in
coastal sediments [171-173]. Polymer types such as polyethylene, polypropylene, and polystyrene float on seawater and fly long stretches, having been located far from their primary origins [174].

Cleaner sea

National Marine Litter Policy in India

India releases 600,000 tonnes of plastic waste annually into the oceans. We need to develop the right clean-up technology to overcome the marine plastic pollution. In order to regulate identify and monitor the source of plastic litter along the India's coastal line the Union Ministry of Earth Sciences took an initiative to clean up the oceans by adopting National Marine Litter Policy along with UN Environment's global 'Clean Seas Campaign' on 2018. This policy is about how do we reuse and recycle plastic for cleaner sea. National marine litter Policy aims in (i) identifying the path of plastics from source to sink and promoting 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 pertaining to microplastics in the marine environment.

1. Present a optimal and standardised size description of a microplastic, with additional size specifications for nano- and mesoplastics
2. Improve and adopt 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 behaviour of microplastics in the water column, together with the consequences of fragmentation and bio-fouling.
5. Adapt methods to assess microplastic absorption by biota in the food web and extend usage of sentinel organisms (e.g., Fulmars) to detect microplastic abundance 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 waste water treatment plants (WWTPs) that drains into the rivers.

Conclusion And Future Recommendations

This is first time from India this kind of review paper were written in the microplastic pollution in different aquatic environment and biota. In this review 44 papers were collected from Web of Science during 2013-2020, mainly focused on concentration, identification, size and distribution of microplastic in different aquatic environment and biota. From previous research it can be concluded that the sampling and detection of MPs in majority of research in the marine environment performed in sediments, biota, and seawater. We have also targeted the freshwater environments such as lakes and rivers in India which has different types and level of MPs pollution and a new 3 dimensional and mathematical modelling analysis is proposed. The level of microplastics is abundant in the areas where activity of industries and residents were placed near to fresh waters. The majority intakes of microplastics were accumulated in gut and gastrointestinal tracts of biota. Furthermore the role of Waste water treatment plants in emitting microplastics into the nearby aquatic environment should to be concentrated and effective steps to be taken to setup tertiary treatment plants in India to reduce the microplastic pollution from WWTPs. Research gaps in establishing the effective techniques in identifying nanoplastics, 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 in the future studies.

Focused on these reviews, following conclusion can be derived

1. Evaluations of particles by physical diffraction of the light as FTIR and Raman methods have 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 to define treatment therapies as the MPs identification is established in reasonable point
5. Future research can be geared at prevention, awareness and mitigation approaches
6. Cleaner sea to monitor and regulate the sources of plastic pollution along the coastal line

Declarations

Authors' contributions

Karthikeyan Perumal: Conceptualization, Supervision. Investigation, Methodology, Writing - original draft, Writing - review & editing, Subagunasekar M: Software; Data analysis; Investigation.

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Tables

| S. No | Name of the Journals | Abstracing/ Indexing* | Cite Score | Impact factors | No. of Papers | Percentage of Papers |
|-------|----------------------|------------------------|------------|----------------|---------------|---------------------|
| 1     | Marine Pollution Bulletin | SCI  | 6.7 | 4.049 | 22 | 40.7 |
| 2     | Science of The Total Environment | SCI | 8.6 | 6.551 | 10 | 18.52 |
| 3     | Environmental Science and Pollution Research | SCI | - | 3.056 | 4 | 7.41 |
| 4     | Chemosphere | SCI | 8.8 | 5.778 | 3 | 5.56 |
| 5     | Environmental Pollution | SCI | 9.3 | 6.792 | 3 | 5.56 |
| 6     | Environmental Geochemistry and Health | SCI | - | 3.472 | 2 | 3.70 |
| 7     | Environmental Monitoring and Assessment | SCI | - | 1.903 | 2 | 3.70 |
| 8     | Archives of Environmental Contamination and Toxicology | SCI | - | 2.400 | 1 | 1.85 |
| 9     | Journal of Cleaner Production | SCI | 10.9 | 7.246 | 1 | 1.85 |
| 10    | Environmental Forensics | SCI | - | 0.726 | 1 | 1.85 |
| 11    | Regional Studies in Marine Science | SCI | 2.3 | 1.883 | 1 | 1.85 |
| 12    | Journal of Environmental Science and Health C | SCI | 3.517 | 1 | 1.85 |
| 13    | Journal of Environmental Chemical Engineering | SCI | 6.7 | 4.300 | 1 | 1.85 |
| 14    | Water, Air, & Soil Pollution | SCI | - | 1.900 | 1 | 1.85 |
| 15    | Marine Biological Association of India | CrossRef | - | - | 1 | 1.85 |
Table 2 No. of papers published in different aquatic environment/ Biota in microplastic/plastic debris

| S. No | Environments          | No. of Papers |
|-------|-----------------------|---------------|
| 1     | Biota                 | 12            |
| 2     | Beach sand           | 17            |
| 3     | Island               | 3             |
| 4     | Riverine             | 2             |
| 5     | Marine sediments     | 4             |
| 6     | Sea salt             | 3             |
| 7     | Lake (water & sediments) | 2          |
| 8     | Sea water            | 1             |

Table 3 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, south eastern Arabian Sea, India [56] | Fishes -24 | *Fenneropoeaues indicus* (Shrimp - 330) | 0.39 ± 0.6 items/shrimp | > 1-5 mm | 81.59 | Gut, intestine | Raman spectroscopy & FTIR | PE, PP, LDPE |
| Cochin, Kerala, India [57] | *Perca viridis* & *Meretrix meretrix* (bivalve -50) | 1.8g | < 100 µm | - | mussels/ clams | Raman spectrum & Fluorescence microscope | PU, PVCA, PVC; PE; PVCA; PET; ABS; SBR; PVK; PET; PVC; PEVA |
| Pondicherry, India [58] | *Perna viridis* | 0.95 items/g | 100-250µm | 41 | clam | FTIR, SEM, & EDAX | PE, PP, PP-PE, PA, PET; PEST; PVC, PS; RA; PVA |
| Tuticorin coast of Gulf of Mannar (GoM), India [59] | Sediments | 13.429 items/kg | 1-5mm | 44 | - | - | - |
| Tuticorin, Southeast coast of India [60] | Fish | 0.2002 items/l | <500 µm | 34 | gastrointestinal tracts | FTIR-ATR and SEM-EDAX | polyethylene, polyamide polyester, poly styrene, polypropylene and acryl |
| Kerala, India [57] | *Rastrilliger kanagurta, Megalaspis cordyla, Sardinella longiceps, Sardinella gibbosa, Stolephorus indicus, Dussumieria acuta, Thryssa dussumieri, Sphyraena obtusata and Anodontostoma chacunda* | 0.005 | 115-210µm | 41.1 | edible tissues | ATR-FTIR | PE; PP |
| Ramsar, Vembanad Lake, South India [61] | *Piaractus brachypomous* | 26.01 items/g | 0.5mm | 99 | gut | ATR-FTIR & Raman Spectroscopy | PP, Nylon 6, PET & PBT |
| Chennai and Nagapattinam, Southeast coast of the Bay of Bengal [62] | Fish (190) | 20 items/g | 1.3µm - 9.3mm | 8.95 | gastrointestinal tract | FTIR & SEM | PA; PE; PET |
| Chennai, Southeast coast of India [63] | *Perna viridis* (Linnaeus, 1758) | 0.9/g | 5-30 µm | 87 | tissues | DXR Raman spectroscopic | PS |
| Roche Park, Tuticorin coast, Gulf of Mannar, Southeastern India [64] | *Magallana bilineata* (oyster) | 0.81g | 0.25 to 0.5 mm | 96 | tissue | FTIR-ATR analysis | PE; PP |
| Seawater | 12.75 items/kg | 1-3 mm | 100 | - | - | - |
| Seawater | 21.60 items/L | 0.5-1 mm | 100 | - | - | - |
| Tuticorin, South eastern coast of India [65] | *Rastrilliger kanagurta and Epinephalus merra* | - | 0.5 mm to 1 mm | 80 | gut | FTIR | Polyethylene & Polypropylene |
| Kochi, Southeastern Arabian Sea [66] | *Sternaspis scutata, Magelona cinta and Tellina sp* | - | 20 µm | 67 | gut | DXR Raman microscope | Polystyrene |
| S. No | Location/Environments                  | Sample type          | MPs Range/average | Size          | Distribution (%) | spectroscopy            | Polymer types                                      |
|-------|----------------------------------------|----------------------|-------------------|---------------|------------------|-------------------------|---------------------------------------------------|
| 1     | Silver Beach, Southern India [84]      | plastic debris       | 204 items/kg      | 0.5 to 1 mm   | 100              | ATR-FTIR               | polyvinyl chloride, polyethylene, nylon           |
|       | Beaches of Tuticorin Southern India [70]| macroplastics        | 3.77 items/m²     | > 2.5 cm      | 54.98            | ATR-FTIR               | PE, PP, PET, NY, PS, and PVC                      |
|       |                                        | mesoplastics         | 9.5 items/m²      | 5 mm - 2.5 cm | 50               |                         |                                                   |
|       |                                        | microplastic debris  | 54 items/m²       | 5 mm          | 41.17            |                         |                                                   |
| 2     | 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                              |
| 3     | South Andaman beaches, India [73]      | sediments            | 414.35 items/Kg   | 100-1000 µm   | 100              | Raman spectral         | poly(dimer acid-co-al polyanine, polypropylene, melami polyvinyl form, polybutadiene, polybutadiene-acrylonitrile, acrylic acid, polysulfide, poly(perfluoroethylene oxide), polyvinyl benzoate, polyvinyl chloride, nylon, epoxy epichlorhydrin acrylonitrile butadiene styrene |
| 4     | North-east Arabian coast, India [74]   | Marine Debris        | 22.4 kg dry weight/km² | -          | 40.6             |                         | Plastic bags, plastic sheet, Personal care products, CTA (Styrofoam), Beverages bottles, Plastic rope/ / pieces, Bottle or container caps |
| 5     | 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                               |
| 6     | 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, polyester, polyamides |
| 7     | Beach sand                             | 181 MPs/kg           |                   |               |                  |                         |                                                   |
| 8     | Beach sand                             | 45 MPs/kg            |                   |               |                  |                         |                                                   |
| 9     | Beaches in Kerala Coast, India [79]    | Plastics             | 0.55 kg/100 m²    | -             | 73.8             |                         | Plastic                                           |
| 10    | Nattika Beach, Kerala Coast, India [80]| Sediments            | 191 items/kg      | 5-1 mm        | 70               | FTIR and SEM           | PE, PP + PP, PP, PS, PC                           |
| 11    | Beach Litter along Chennai, East Coast of India [81] | Plastic debris      | 8.96 kg/m²        | -             | 56.42            |                         | Food wrappers; cups; bottle and caps; thermocol/styrofoam; food wrappers |
| 12    | Beaches of Puducherry, India [82]     | Beach sediments      | 72.03 ± 1.16%     | 300 µm - 1 mm | 56.32            | Raman spectroscopy     | Polypropylene, HDI LDPE, Polystyrene Polyurethane |
| 13    | Beaches of southeast coast of India [83]| Rastrelliger kanagurta, Siganus javus, Arius arius, Leiognathus equulus, and Mugil cephalus (Fish) | 46.6 ± 37.2 m² | 1 - 2.5 mm | 60.1              | FTIR-ATR               | PE, PP, PS, NY                                    |
| 14    | Beaches of Rameswaram, GoM,            | Sediment             | 403 pieces        | >1.01 - 200 mm| 60.8             | FTIR spectroscopy      | polyethylene, polysterene, nylon, and polyvinyl   |
| Island | Location/Environments | Sample type | MPs Range/ Size | Distribution (%) | Spectroscopy | Polymer types |
|--------|------------------------|-------------|----------------|-----------------|-------------|---------------|
| Nallathanni Island, Gulf of Mannar Biosphere Reserve, Southeast coast of India [85] | Plastic debris | 505 pieces | - | - | FTIR | Polystyrene; Polyethylene; Polycarbonate; Polyvinyl chloride; Nylon |
| Marina beach, Chennai, India [87] | 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 | Location/Environments | Sample type | MPs Range/ Size | Distribution (%) | Spectroscopy | Polymer types |
|--------|------------------------|-------------|----------------|-----------------|-------------|---------------|
| 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 |
| Sediments of river Netravathi River India [98] | water | 280 pieces/m³ | 1-5 mm and 0.3-1 mm | 86.51 | FTIR-ATR | PE; PET; PP; PVC |
| Marine sediments | Sediments | 40.7 particles/m² | 0.3-0.6; 0.6-1.18; 1.18-2.36 and 2.36-4.75 mm | 96.10 | FTIR-ATR | PE; PP; PA; PS; PET; RY PUR; alkyd; CE; ABS; PVC; PVFM |
| Vembanad Lake, Kerala, India [86] | sediments | 496 items m⁻² | <5 mm | 91 | Raman spectra | Polymers; Polypropylene; polystyrene; polyamide; polyvinyl alcohol and polyvinyl chloride |
| Goa coast, India [148] | Sediments | 5500 pellets | - | - | FTIR-ATR | PE; PP |
| Chennai coast, India [88] | MPPs | 1200 pellets | 2 to 5 mm | - | ATR-FTIR | Polyethylene; Polypropylene |

| Riverine | Location/Environments | Sample type | MPs Range/ Size | Distribution (%) | Spectroscopy | Polymer types |
|----------|------------------------|-------------|----------------|-----------------|-------------|---------------|
| Netravathi River India [98] | water | 280 pieces/m³ | 1-5 mm and 0.3-1 mm | 86.51 | FTIR-ATR | PE; PET; PP; PVC |
| Sediments | sediment | 96 pieces/kg | - | - | - | - |
| Sediments | soil | 84.45 pieces/kg | - | - | - | - |

| Sea salt | Location/Environments | Sample type | MPs Range/ Size | Distribution (%) | Spectroscopy | Polymer types |
|---------|------------------------|-------------|----------------|-----------------|-------------|---------------|
| Tuticorin Coastal salt pan stations, sea salt | - | 100 µm | 60 | µ-FT-IR and APM | PE; PP; CL; NY |
### Gulf of Mannar, South India [92]

| Material                          | Type | Mass Density (items/kg) | Diameter (µm) | Method | Plastics |
|-----------------------------------|------|-------------------------|---------------|--------|----------|
| Salt of Tuticorin, Southeast Coast of India [93] | sea salt | 72 | 100 to 500 | SEM-EDAX | Polyethylene; polypropylene; polyester; polyamide |
| Mumbai, Indian sea salts [94]    | sea salt | 103 | 2000 and 500 | µ-FTIR | Polysters; polyethylene; polyamide; polyester |

### Lake (water & sediments)

| Location                                      | Material                | Type | Mass Density (items/kg) | Diameter (µm) | Method | Plastics                                      |
|-----------------------------------------------|-------------------------|------|-------------------------|---------------|--------|-----------------------------------------------|
| Veeranam lake, Tamil Nadu, India [100]        | Sediments               |      | 309                     | 1-0.3 mm      | 80     | ATR-FTIR                                      |
|                                              | Water                   |      | 28                      | 0.3 - 2 mm    |         |                                              |
| Red Hills Lake, India [101]                  | Water                   |      | 5.9                     | 0.33-2 mm     | 99     | ATR-FTIR, SEM                                 |
|                                              | sediments               |      | 27                      | 2 mm          |         |                                               |

### Sea water

| Location                                      | Material | Type | Mass Density (items/kg) | Diameter (mm) | Method | Plastics                                      |
|-----------------------------------------------|----------|------|-------------------------|---------------|--------|-----------------------------------------------|
| South Juhu creek, Mumbai, India [68]          | marine debris |      | 2g                      | macro- and mega plastic | -     |                                              |
|                                               | Sea water |      | 2g                      | macro- and mega plastic | -     |                                              |

### Figures

**Figure 1**

Paper collection and critical review of microplastics/plastic debris research framework
Figure 2

Spatial distribution of the authors of papers published in the past decade (2013-2020)

Figure 3

No. of papers published in journals categories using the database Web of Science (Clarivate Analyticals®) regarding MPs research in India
Figure 4

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

Figure 5

Spatial distribution of microplastics in different aquatic environment in India