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RESEARCH PAPER

Presence of Microplastics in Freshwater Ecosystems: An Unheeded Emerging Concern – A Global Review

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ABSTRACT
Plastic production has inevitably increased in the past few decades and is one of the diverse material used in today's world. With this increasing production and wider use, the aquatic ecosystems have become the trash barrel for all kinds of plastic resulting in it becoming a looming spectre to the habitat and functions of both inland and offshore ecosystems. Plastic pollution is considered as an emerging global environmental concern which could significantly affect the biological diversity and may have potential to cause inimical effects on human health. These plastics have shown to gradually degrade into micro fragments and are reported to cause toxic effects on the aquatic organisms. In comparison to the studies on presence of microplastic in marine ecosystems, the studies on the presence of it in freshwater ecosystems have received relatively lesser attention although some studies have shown that the contamination is as grievous as that of in marine environment. This review article focuses on the literature available on the reports of microplastic occurrence, its distribution in freshwater ecosystems across the world and its insidious effects which are of emerging concern. The effect of such microplastic ingestion in both aquatic organisms and the potential health hazards due to such plastic consumption in humans have also been examined. The paper also discusses the existing knowledge gaps so that future research directions can be taken accordingly and the findings in this paper would significantly help all the countries across the world to understand the present plastic pollution scenario and work towards the mitigation of the same.
Keywords: Microplastics, freshwater ecosystem, emerging concern, toxic.

INTRODUCTION

Derived from the polymerization of monomers, plastics are the synthetic organic polymers whose large scale production began in 1950 (American Chemistry Council 2005). Plastic, the wonder material without which life seems unfeasible today, is one of the preeminent anthropogenic debris found in the aquatic ecosystems worldwide (UNEP 2018). Because of its cardinal use in daily life, plastic has become imperative to mankind (Andrady & Neal 2009). Although plastic has aided the world with unaccountable benefits but its indiscriminate disposal has led to massive environmental problems. The plastic pollution monitoring study in marine ecosystem has gained more assiduity than in freshwater ecosystem although the presence of it in the riverine ecosystem was long recognized and is now considered equivalent to the marine contamination (Williams and Simmons, 1996; Peng *et al*., 2017). The plastic debris find its way into the freshwater ecosystem through human littering, dumping of untreated industrial or agricultural wastes, careless abandoning of fishing nets and gears,

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untreated wastewaters and often due to the natural calamities too wherein the plastic debris are carried into the freshwater ecosystems as storm water discharge (Ziajahromi *et al.*, 2019; Horton *et al*., 2017; González *et al*., 2016; Van der wal *et al*., 2015). Lack of solid waste management programs in most of the cities have been one of the main causes of the immense amount of solid waste entering into the freshwater ecosystems (Guererro *et al*., 2012). As a result of this, the freshwater ecosystems which are linked to the coastal waters become the key source of transporting the plastics into the seas and oceans thereby contaminating the marine waters too (Van der wal *et al*., 2015).

Microplastic can be classified into primary and secondary microplastic (Andrady *et al.*, 2009). Primary microplastics are those which are present in the manufactured products like cosmetics, detergents, drug vectors, air-blasting media (Zitko and Hanlon, 1991; Patel *et al*., 2009; Gregory, 1996; Fendall and Sewell, 2009). Secondary microplastics are those which are derived from a parent plastic material due to breaking off in the process of gradual degradation through physical, chemical or biological degradation processes (Thompson *et al*., 2004).The microplastics may find its pathway into the freshwater ecosystem through various sources (Horton & Dixon, 2017). These small particles of microplastics are ingested by many freshwater organisms including both invertebrates and vertebrates (Park *et al.*, 2020; Wardlaw and Prosser, 2020; Nan *et al.*, 2020; Oliveira *et al.*, 2020; Khan *et al.*, 2020; Berglund *et al*., 2019; Batel *et al*., 2016; Jemec *et al*., 2016; Lei *et al*., 2018). The microplastics have shown to cause toxic effects and induce significant changes in many biomarkers at cell level and therefore are referred as “emerging contaminants” (Deng *et al*., 2017; Schirinzi *et al*., 2017). Moreover, the additives used in the plastic include plasticizers, flame retardants, antioxidants, surfactants, inorganic fillers, pigments, acid scavengers, thermal stabilizers, etc tend to adsorb the organic contaminants from the surrounding environment thereby increasing the exposure to a coalesce of toxins (Wagner *et al.,* 2014; Kärrman *et al.,* 2016). Most of the plastic materials also release estrogenic chemicals in the environment which are a potential health risk for humans (Yang *et al*., 2011; Gray 2008, vom Sal *et al*., 2005; Della Seta *et al*. 2006; Kabuto *et al*. 2004; National Research Council 1999; Newbold *et al*. 2004; Patisaul *et al*. 2006, 2009). Therefore the emerging concerns about microplastics in freshwater ecosystem are of a valid concern and calls for much more attention.

The present review elucidates substantial information about the occurrence, distribution and the toxicological effects of microplastics in freshwater ecosystem. While there is abundant research work on presence of microplastics in marine environment, the knowledge on the presence of it in freshwater ecosystems is still fragmentary and largely unexplored. Data on toxicological effects of microplastics on freshwater organisms are not sufficient. Such existing knowledge gaps are also discussed so that with the help of co-ordinated and concerted efforts the researchers may try to bridge the same.

MATERIALS AND METHODS

Compilation of peer reviewed literature was done using search engines https://link.springer.com, http://sciencedirect.com, http://scholar.google.com and https://www.webofknowledge.com/. Literature was searched using combined criteria consisting of “microplastics in freshwater ecosystem” or “inland water”, or “river”, or “lake, or “stream, or “reservoir, along with “toxicological effects of microplastics on freshwater aquatic organisms”. The following were taken into account from the relevant papers for this review: a) occurrence and fate of microplastics in various freshwater ecosystems (rivers, lakes, reservoirs, ponds, estuary, streams) across the world b) types and concentration of microplastics found in these freshwater ecosystems c) toxicological effects of ingestion of microplastics by the freshwater organisms. No limit in years was considered during the survey.

Occurrence and Distribution of Microplastics in Freshwater Environment

Due to the increasing urbanization and industrialization around the freshwaters, the occurrence of microplastics in surface water, sediment and biota of freshwater systems have been reported from various regions across the world even from the rural and remote areas (Klein *et al.*, 2018; Forrest *et al.*, 2019). Gopinath *et al.*, 2020 reported presence of microplastics in both sediment and water of Red Hills Lake, Chennai city, India with mean concentration of 5.9 particles/L in water and 27 particles/kg in sediment. The dominant type of polymers found here were polystyrene, polypropylene, low density polyethylene and high density polyethylene. This study also states that the water from this lake is being supplied to the residents of Chennai after treatment processes which does not include removal of microplastics. Therefore, the residents might be consuming this polluted water which can cause potential health hazards. In United Kingdom, microplastic presence was reported by Rowley *et al.*, 2020 from the water column samples of River Thames with a concentration of 24.8 per m^3 at Putney (upstream) and 14.2 per m^3 at Greenwich (downstream) and these concentrations are analogous to some of the highest recorded in the world. Observation of the microplastic particles obtained from this river indicated that packaging is the prime source and the degradation of plastic has occurred. Liu *et al.*, 2020 carried out a study in Haihe River, China to analyse the occurrence and characteristics of microplastics. Since this river flows through a metropolis and then into Bohai Sea, it is conclusive that microplastics in rivers forms a pathway of transport into the sea. Surface, middle and bottom waters of Surabaya River, Indonesia were sampled by Lestari *et al.*, 2020 to assess the occurrence of microplastics. The abundance of microplastics in the surface, middle, and bottom of the river ranged 1.47–43.11; 0.76–12.56; and 1.43–34.63 particles/m^3, respectively where low density polyethylene, polypropylene and polyethylene were found to be the major polymer group. High concentration of microplastics were found in the surface water which can be due to the density of the microplastic particles. Since, this river forms a major raw water source for the Surabaya city, presence of microplastics in the water of the river indicates a critical state and calls for immediate attention. Egessa *et al.*, 2020 studied the microplastic pollution in the surface waters of Lake Victoria, East Africa. Samples were examined from three sites in which the first site was in close proximity to landing beaches and recreational beaches with an urban or semi urban surrounding; second site was close to only fish landing beaches with a rural surrounding and third site was close to river inflows. Microplastic abundance was reported to be the highest from the first site (range: 103,333–329,167 particles/km^2 or 0.69–2.19 particles/m^3) and lowest from the third site (range: 2834–20,840 particles/km^2 or 0.02–0.14 particles/m^3). Secondary microplastics composed of polyethylene and polypropylene were predominant. Therefore, recreational activities can be a crucial source of contributing a huge load of microplastics into the freshwaters. A study in Wei River where abundance of microplastics in both water and sediment sample were quite abundant, showed that the distribution and accumulation of microplastics were influenced by the low water flow and high sand content but the reason for the same is not known (Ding *et al.*, 2019). Zhou *et al.*, 2020 observed presence of microplastics from surface urban waters of seven cities of Tuojiang River basin, China. All seven cities of the Tuojiang River basin showed presence of microplastics with a varied concentration from 911.57 ± 199.73 to 3395.27 ± 707.22 items/m^3

with fibers being the dominant among them. A significant positive correlation between gross domestic product of the secondary industries of cities in the Tuojiang River basin and microplastics concentration indicated the impact of the secondary industries on the microplastic pollution. This study also elucidated on the fact that water bodies with lower oxidation-reduction potential tended to have higher microplastic abundance. Microplastics in Brisbane River sediments were studied by He *et al.,* 2020. The study was conducted in different seasons and it was observed that low and high concentration of microplastic abundance mostly occurred in dry and wet seasons, respectively. The abundance here ranged from 0.18 to 129.20 mg kg^{-1}, or 10 to 520 items kg^{-1}. Interestingly, in contrary to the above study, the occurrence of microplastics in dry season (930 item/L) were found to be higher than in wet season (497 item/L) in Yellow River, China (Han *et al.,* 2020). Park *et al.,* 2020 studied occurrence of microplastics in Han River and its tributaries in South Korea. It was observed that the concentration of microplastics in the surface waters (0 m) was 0–42.9 particles/m^3 (mean: 7.0 ± 12.9 particles/m^3) compared to 20.0–180.0 particles/m^3 (mean: 102.0 ± 50.3 particles/m^3) at a depth of 2 m. Therefore, the microplastic abundance in this river was found to be affected by the depth. Jiang *et al.*, 2019 found that the abundance of microplastics ranged from 483 to 967 items/m^3 in the surface water and from 50 to 195 items/kg in the sediment of the rivers of Tibet Plateau. Polyethylene terephthalate, polyethylene, polypropylene, polystyrene, and polyamide were the significant polymers found. It was observed that the microplastic concentration was not only high in the developed areas where intensive human activities take place but also in the remote areas. Being a home to the headstreams of many great rivers, the microplastic pollution here requires more attention. Campanale *et al.,* 2019 studied incidence of microplastics in Ofanto River of Southeast Italy. Presence of microplastics in every surface water sample was observed. A spatial-temporal study was conducted here to understand the source and the fragmentation process of microplastics. The concentration ranged from 0.9 ± 0.4 p/m^3 to 13 ± 5 p/m^3 and the presence of black flake items indicated the source of microplastics to be of terrestrial origin associated to agricultural activities which is of prime use of land area in Ofanto valley. A study by Fan *et al.*, 2019 on Pearl River Catchment, China indicated microplastic presence in river water, river bed sediment, and estuarine sediment, also stated that the annual release of microplastics into the main river and its tributaries could be 15963 tons which is a menacing figure. Blair *et al.,* 2019 analysed microplastics in sediments of Kelvin River, UK. This was one of the first reports of microplastics in freshwaters of Scotland. The abundance of microplastics in the sediments ranged 161-432 $MPskg^{-1}$ with micro pellets as the predominating type. The study also suggested that diffuse sources of pollution might be transporting secondary microplastics to the river. Sarkar *et al.*, 2019 conducted a study of the sediments of River Ganga, India where abundance of microplastics were found to be 99.27–409.86 particles kg^{-1}. Considering River Ganga, which is the longest river in India and a lifeline to millions dwelling along its course, the presence of microplastics in the sediments of it surely have pulled the alarm for all. River Ganga is a source of potential drinking water to many rural communities therefore the incidence of microplastic presence alludes for immediate measures to identify the sources of such pollution and mitigate it. Table 1 summarizes some more studies on the presence of microplastics in freshwater ecosystems across the world.

Microplastic can enter the freshwaters through various sources, the most predominant among them being the waste water treatment plants (Blair *et al*., 2019; Mason *et al*., 2016; Talvitie, 2014; Edo *et al*., 2020). Although tertiary treatment and biological sewage treatment facilities (STFs) using anaerobic-anoxic-aerobic (A2O), sequence batch reactor (SBR), and the Media processes can remove 97% and 98% of the microplastic in effluents respectively, a considerable amount of it is still being discharged into the freshwaters (Blair *et al*., 2019; Lee and Kim 2018). The mean and median total annual emission of microplastics from WWTPs into rivers in Germany were reported to be 7.3×10^{12} items/year and 6.8×10^{12} items/year (Schmidt *et al.,* 2020). The other prominent source of microplastic in freshwater ecosystems is due to the storm-water discharge. A study in Denmark on the storm-water retention ponds indicated the presence of microplastics in those serving areas with commerce and industry (Liu *et al*., 2019). In this study, microplastic concentration ranged from the maximum being 127,986 items kg^{-1}; 28,732 $\mu g\,kg^{-1}$ and the minimum being 1511 items kg^{-1}; 115 $\mu g\,kg^{-1}$ in the sediments of ponds which serves the industrial areas. A study by Piñon-Colin *et al*., 2020 recorded the highest abundance of microplastics (66 and 191 particles L^{-1}) in industrial land use site and has concluded that storm-waters are an important source of transporting microplastics to the freshwater ecosystems. Microplastics may find its way into the freshwater bodies through atmospheric deposition as well (Dris *et al.*, 2016; Cai *et al*., 2017). A study in London showed deposition rate of 575 to 1008 microplastics/m^2/d with majority being fibrous in nature (Wright *et al*., 2020). Allen *et al.,* 2019 demonstrated that microplastic transport through air can take place up to 95km. It was found in their study that approximately 249 fragments, 73 films and 44 fibres per square metre got deposited on the mountain catchment (French Pyrenees) daily. Sewage sludge is still used often as landfilling and as fertilizers in agricultural processes, thereby the surface runoff may contaminate the rivers and lake with microplastics which in turn forms a pathway to transfer the same to the seas and oceans (Liu *et al.,* 2020; Kapp and Yeatman, 2018; Van der wal *et al*., 2015).Grbić *et al.,* 2020 examined the surface waters of Lake Ontario and the source waters to understand the source of microplastics to Great Lakes. Microplastic concentration of 0.9 particles L^{-1} were observed from agricultural runoff thereby forming a conduit of microplastic transport.

Due to the recent emergence of Covid-19 pandemic, some studies have found that random disposal of surgical masks and PPE kits can be a new potential source of microplastic pollution in the freshwater ecosystems. According to a WWF report, even if 1% of the total masks are disposed, it may lead to almost 10 million masks a month into the waters (Anon, 2020). Polymers such as polypropylene, polyurethane, polyacrylonitrile, polystyrene, polycarbonate, polyethylene, or polyester are mainly used in making the face masks, which is now being used by all as a precautionary measure (Potluri and Needham, 2005). An organization OceansAsia, reported the presence of face masks in highway and drainage in Ile-Ife, Nigeria, on May 5, 2020. Although usage of this mask is of utmost importance in the current pandemic situation but proper disposal management of the same should be done.

Due to different sampling techniques, unit of measurements, study of different samples of water, sediment and biota and their analysing techniques used, it has become increasingly difficult to compare the data from different parts of the world. Therefore, there is an urgent need for an universal criteria for both sampling techniques and reporting of the data on occurrence. Although the reports of microplastic occurrence in freshwater ecosystems have been quite significant and alarming in Asia than in rest of other continents (Figure 1), yet there is a necessity for more extensive spatial-temporal studies on the occurrence and source of microplastics in the freshwater ecosystems across the world in order to understand this global problem.

Table 1: Studies reporting microplastic pollution in various freshwater ecosystems across the world

Area Of Study	Sample Source	Sampling Method	Microplastic Concentration/ Abundance	Polymer Identification Method	Polymer Type	Citation
Ganges River, India	Surface water	Hand operated bilge pump	The average number of microplastics collected was 0.038 ± 0.004 MP/L	FTIR	Rayon	Napper *et al.*, 2021
Brahmaputra and Indus River, India	Shore sediment		Smaller size of microplastics 20–150 µm were more abundant (531–3485 MP/kg in the Brahmaputra River and 525–1752 MP/kg in the Indus River) than microplastics in size range between 150 µm and 5 mm (20–240 MP/kg in the Brahmaputra River and 60–340 MP/kg in the Indus River)	FTIR microscope		Tsering *et al.*, 2021
Kosasthalaiyar River, Adyar River, Chennai, Tamil Nadu & Muthirappuzhayar River, Munnar, Kerala	Surface water sample	Neuston net	The average MP concentrations per litre for the three different rivers were 0.67 particles/L at the Kosasthalaiyar River, 0.33 particles/L at the Adyar River and 0.20 particles/L at the Multhirappuzhayar River	FTIR	Polyethylene,polypropylene,polystyrene	Lechthaler *et al.*, 2021
Nine lakes across Patagonia, South America	Water	Horizontal Trawling	Mean concentration :0.9 ± 0.6 MPs/m^3	Raman Microscopy	Polypropylene, Polyethylene terephthalate, polyurethane,polystyrene	Alfonso *et al.*, 2020
Netravathi River, India	Water, sediment and soil	Stainless steel bucket, stainless steel spoon,	288 pieces/m^3 (water), 96 pieces/kg (sediment) and 84.45 pieces/kg (soil).	ATR -FTIR	Polyethylene (PE) and polyethylene terephthalate (PET)	Amrutha and Warrier, 2020
Donting Lake and its affiliated rivers, China	Surface water and sediment	Trawling using Nylon plankton Net	0.62–4.31 items/m^2 in plankton net samples, with 21–52 items/100 g dw in sediments	µ-FTIR	Fiber	Hu *et al.*, 2020
Veeranam Lake, Tamil Nadu,India	Water and soil sample	Van veen grab and Beaver Nylon Plankton net	Average MP concentration: 28 items/km^2	ATR-FTIR	Polyethylene polypropylene, polyvinyl chloride, polystyrene, and nylon	Bharath K *et al.*, (2020)
Rhine River	Surface water	Manta Trawl	0.04–9.97 MP/m^3 per sample	ATR -FTIR spectrometer	Polyethylene,polypropylene,polystyrene	Mani & Burkhardt-Holm 2020
Sabarmati River,Gujarat,India	Sediment	Stainless steel scoop	Range: 134.53 mg/kg (75-212μm) and 581.70 mg/kg (212-4mm)	SEM analysis	Plastic debris and fiber	Patel *et al.*, 2020
Lake Mead National Recreation Area, USA	Surface water, sediment	Microplastics net (HYDRO-BIOS)	Water surface: 0.44–9.7 particles/m^3 Sediment surface:87.5–1,010 particles/kilogram dry weight (kg dw)	Visual Microscopy	Fibers	Baldwin *et al.*, 2020

Area Of Study	Sample Source	Sampling Method	Microplastic Concentration/ Abundance	Polymer Identification Method	Polymer Type	Citation
			Sediment core concentrations: 220–2,040 particles/kg dw			
African lake	Sediment	Ekman grab sampler	70% of the plastic particles found here comprised of microplastics	ATR -FTIR analysis	Polyethylene, polypropylene and alkyd-varnish, polyethylene terephthalate, ethylene-propylene rubber and polyurethane_acrylic_rasin	Merga *et al.*, 2020
Zhangjiang River, China	River catchment area	Manta net	Abundance range: from 50 to 725 items/m^3 Average : 246 items/m^3	Stereomicroscopy and micro-Raman spectroscopy	Polyethylene and polypropylene.	Pan *et al.*, 2020
Qin River, China	Surface Water and Sediment	Phytoplankton nets, Grab dredge and 12V DC Teflon pump	In sediments, 0–97 items/kg. Microplastics of size ranging 1-5mm was found.	μ-FTIR	Polyethylene and polypropylene	Zhang *et al.*, 2020
Qiantang River, China	Surface Water	Stainless steel bucket	Abundance of MPs: (mean 1183 ± 269 particles/m^3)	FTIR spectroscopy	Polyamide, polyester, and polyethylene teraphalate	Zhao *et al.*, 2020
YongJiang River, China	Surface Water and sediments	12V DC Teflon pump	Abundances in surface waters and sediments ranged from 500 to 7700 n/m^3 and from 90 to 550 n/kg,respectively.	Stereo Microscope	Polyethylene and polypropylene	Zhang *et al.*, 2020
Maozhou River, China	Surface Water and Sediments	Stainless steel bucket and Box corer	Range : In Dry Season, 4.0 ± 1.0 to 25.5 ± 3.5 items/L in water and 35 ± 15 to 560 ± 70 item/kg and in wet season, water: 3.5 ± 1.0 to 10.5 ± 2.5 items/L; sediments: 25 ± 5 to 360 ± 90 item/kg	ATR -FTIR analysis	PE Polyethylene polypropylene (PP), water and sediments: 12.5%), polystyrene (PS, water: 34.5%; sediments 14.5%) and polyvinyl chloride (PVC, water: 2.0%; sediments: 15%).	Wu *et al.*, 2020
Manas River Basin, China	Surface Water	Grab sampling and stainless steel drums	Abundance : 21 ± 3–49 ± 3 items/L	Energy Disperse Spectroscopy and μ-FTIR	Polypropylene and polyethylene terephthalate	Wang *et al.*, 2020
Lake Naivasha, Kenya	Surface water	Zooplankton net	Average concentration: 0.183 ± 0.017 to 0.633 ± 0.067 particles/m^2 mean concentration: 0.407 ± 0.135 particles/m^2	Fourier transform infrared (FTIR) analysis using an IRAffinity-1S FTIR device	Polypropylene, polyethylene, polyester	Migwi *et al.*, 2020

Area Of Study	Sample Source	Sampling Method	Microplastic Concentration/ Abundance	Polymer Identification Method	Polymer Type	Citation
Victoria River, Australia	Surface water	Food-grade blue polypropylene jars	Abundance: 0.40 ± 0.27 items/L in surface water.	Leica M125 Stereo microscope	Polyester and rayon	Nan *et al.*, 2020
Yulin River, China	Surface Water	Teflon pump	1.30×10^{-2}, 1.95×10^{-1} and 3.60×10^{-1} items/L in the mainstream, tributaries and bays of the Yulin River, respectively.	Micro-Raman spectroscopy, X-ray photoelectron spectroscopy (XPS) and scanning electron microscopy (SEM)	Polyethylene, polypropylene, and polystyrene	Mao *et al.*, 2020
Tuul river, Mongolia	Sediment	Depth trolling net	603±251 items/kg	μ-FTIR	Polyester and polyamide	Battulga *et al.*, 2020
River Yongfeng, China	Sediment	Peterson Gravity Sampler	5-72 items/kg	ATR -FTIR analysis	Polyethylene, polypropylene , Polyethylene terephthalate, Polystyrene	Rao *et al.*, 2020
Nakdong River, South Korea	Surface water, mid water and sediment	Stainless steel beaker, submersible pump, Van Veen grab	Range: 293 ± 83 (upstream) to 4760 ± 5242 (downstream) particles/m^3 in water, and 1970 ± 62 particles/kg in sediment.	FT-IR spectroscopy	Polypropylene and polyester	Eo *et al.*, 2019
Wei River, China	Surface water and sediment	Glass bottle and grab grab (B-10104, Ravenep)	Concentration of microplastics: In surface water it varied from 3.67 to 10.7 items /L and in the sediments, the abundance of microplastics varied from 360 to 1320 items/kg.	A metallographic microscope with digital camera (MV5000(R/TR) and SEM	Polyethylene, P olyvinyl chloride and po lystyrene	Ding *et al.*, 2019
Seven water streams surrounding lagoon of Bizerte(Northern Tunisia)	Surface sediment	Stainless steel spatula	MP abundance was greatest at observed at Jedara stream (6920 ± 395.98 items/ kg dry weight), while the lowest mean value was 2340 ± 227.15 items/kg dry weight at Khima stream.	ATR-FTIR Analysis	Polyethylene , polypropylene	Toumi *et al.*, 2019
Pearl River Delta, China	Surface water	Surface water trawling	The number and mass concentrations of MPs were in the ranges of 0.005−0.7 particles m−3 and 0.004−1.28 mg/m^3.	ATR-FTIR Analysis	Polyethylene and polypropylene, polyamide, polystyrene, poly(ethylene) terephthalate, polyformaldehyde, acrylonitrile butadiene styrene, and poly(vinyl chloride)	Mai *et al.*, 2019

Area Of Study	Sample Source	Sampling Method	Microplastic Concentration/ Abundance	Polymer Identification Method	Polymer Type	Citation
Feilaixia Reservoir, Beijiang River, China	Surface water	Conical Plankton Net	Average abundance : 0.56 ± 0.45 items/m^3	μ-FTIR	Polyethylene (P E), polypropyle ne (PP), polyst yrene (PS), expanded polystyrene (EPS), polyvin yl chloride (PVC) and polyethyle ne terephthalate (PET)	Tan *et al.*, 2019
Lake Ulansuhai, Yellow River Basin, China	Surface water	12-V DC Teflon pump	Range : 1760 ± 710 and 10,120 ± 4090 n/m^3	FTIR spectroscope, SEM (scanning electron microscope) and EDS (energy-dispersive spectrometer)	Fibers	Wang *et al.*, 2019
Lake Ulansuhai, Yellow River Basin, China	Sediment	Van Veen grab	Concentration range : 24 ± 7 to 14 ± 3 n/kg	μ-FTIR and scanning electron microscopy/ energy dispersive spectroscopy (SEM/EDS)	Polyethylene, polyethylene terephthalate, polypropylene, and polyvinyl chloride	Qin *et al.*, 2019
Ciwalengke River, Majalaya district, Indonesia	Surface water and sediments	Grab sampling method using glass container Ekman grab sampler	Average microplastic concentration in surface water: 5.85 ± 3.28 particles per liter and in sediments: 3.03 ± 1.59 microplastic particles per 100 g of dry sediments.	Raman spectroscopy	Polyester and nylon	Alam *et al.*, 2019
Atoyac river basin, Puebla city, Mexico	Sediment	Trowel and Van veen grab	Total number of MPs in Zahuapan River, Atoyac River, Confluence zone and Valsequillo dam was 1633.34 ± 202.56, 1133.33 ± 72.76, 833.33 ± 80.79 and 900 ± 346.12 items/ kg respectively	SEM coupled with EDX	Films, fibers and fragment	Shruti *et al.*, 2019
Rhine River	Benthic midstream sediments	German Diving bell	Range: 0.26 ± 0.01 and 11.07 ± 0.6 × 10^3 MP/kg	FPA μFTIR microscopy	Acrylates, polyurethane, varnish (APV)	Mani *et al.*, 2019
Poyang Lake, China	Surface water, sediment	A steel sampler Van veen grab	Abundance of microplastics was respectively 5–34 items/L for surface waters, 54–506 items/kg for sediments	Micro-Raman spectroscopy	Polyethylene and polypropylene	Yuan *et al.*, 2019
Shanghai, China	Sediment	Quadrat	802 ± 594 (dw) items/kg	μFTIR	Polypropylene, Polyethylene, rayon, cotton + viscose, phenoxy resin, poly(vinyl stearate), 76% rayon + 24% PES	Peng *et al.*, 2018

Area Of Study	Sample Source	Sampling Method	Microplastic Concentration/ Abundance	Polymer Identification Method	Polymer Type	Citation
Saigon River, Vietnam	Surface water	Nets	172,000 to 519,000 items m^{-3} and 10 to 223 items/m^3	FTIR-ATR	Fibers (Polyester)	Lahens *et al*., 2018
Qinghai Lake, China	Surface water, lakeshore sediment	Trawl net and stainless-steel shovel	Abundance in lake surface water: 0.05×10^5 to 7.58×10^5 km^{-2} In inflowing river water: 0.03×10^5 to 0.31×10^5 items/km^2	Renishaw inVia Raman microscope And stereo microscope	Polyethylene and polypropylene	Xiong *et al*., 2018
Yangtze River Basin, China	Water and sediment	Steel bucket and Peterson sampler	0.5–3.1 items/L in water and 15–160 items/kg in sediment	μFTIR	Microfibers	Su *et al*., 2018
Antuã River, Portugal	Water and sediment	A motor water pump with a 0.055 mm mesh net and Van veen grab	Abundance: In water ranged from 5 to 8.3 mg/m^3 or 58–193 items/m^3 and from 5.8–51.7 mg/m^3 or 71–1265 items/m^3; In Sediment, ranged from 13.5–52.7 mg/kg or 100–629 items/kg and from 2.6–71.4 mg/kg or 18–514 items/kg	FTIR-ATR	Polyethylene and polypropylene	Rodrigues *et al*., 2018
West Donting Lake and South Donting Lake	Surface water and sediment	Large flow sampler and stainless shovel	Abundance: 616.67 to 2216.67 items/m^3 and 716.67 to 2316.67 items/m^3 in the lakeshore surface water of West Dongting Lake and South Dongting Lake, respectively Lake shore sediment: 320 to 480 items/m^3 and 200–1150 items/m^3.	Renishaw inVia Raman spectroscope	Polystyrene and polyethylene terephthalate	Jiang *et al*., 2018
Donting Lake and Hong lake, China	Surface water	12 V DC Teflon pump,	Concentration range: 900–2800 and 1250–4650 n/m^3	SEM and DXR2 Raman microscope	Polyethylene, polypropylene	Wang *et al*., 2018
Three Gorges Reservoir, China	Surface water and sediment	12 V DC Teflon pump and Van veen grab	Range in Surface water :1597 to 12,611 n/m^3 and in the sediments :25 to 300 n/kg wet weight (ww)	Micro-Raman spectroscopy, SEM	Polystyrene, polyethylene, polypropylene	Di and Wang, 2018
Vembanad lake, India	Sediment	Van veen grab	Range: 96 - 496 particles/m^2 ;mean abundance: 252.80 ± 25.76 particles/m^2	Micro Raman spectrometer	Low density polyethylene	Sruthy and Ramaswamy, 2017
Ottawa River, Canada	Surface water	Nearshore bottle sampling method and manta trawl	0.22 fragments per g dry weight	Stereomicrosco pe	Microbeads, microfibers	Vermaire *et al*., 2017
UK urban lake	Sediment	HTH gravity corer and transect	25 – 30 particles per 100g dried sediment	Binocular microscope (x40)	Fibers and films	Vaughan *et al*., 2017
Yarra River, Australia	Water	Manta net	158items/month	-	Polystyrene and cellophane	Kowalczyk *et al*.,2017
Maribyrnong, Australia River	Water	Manta net	122items/month	-	Polystyrene and cellophane	Kowalczyk *et al*.,2017

Area Of Study	Sample Source	Sampling Method	Microplastic Concentration/ Abundance	Polymer Identification Method	Polymer Type	Citation
Prairie Creek, California	Water	Conical net	Upstream sites : (3.8 ± 1.2 and 7.7 ± 2.0 microplastics/m^3 in 2015 and 2016, respectively) WWTP OF: (1.0 ± 0.2 and 1.0 ± 0.4 microplastics/m^3 in 2015 and 2016, respectively) downstream: (3.7 ± 0.3 and 0.9 ± 0.3 microplastics/m^3 in 2015 and 2016, respectively	-	Fibers and Fragments	Campbell *et al.*, 2017
River Thames Basin, UK	Sediment	Transect	660 items/kg	Raman spectroscopy	Polyethylene, polyester, polyethylene terephthalate, polypropylene, polystyrene, polyvinyl chloride, polyarylsulphone	Horton *et al.*, 2017
Lake Winnipeg, Canada	Water	Manta trawl	193,420 ± 115,567 items/km^2	SEM and Energy Dispersive X-ray Spectroscopy Oxford AZtec Energy Dispersive X-ray Spectroscopy system (EDS)	Not known	Anderson *et al.*, 2017
Beijiang River, China	Sediment	stainless-steel shovel and a wooden frame	178 ± 69 to 544 ± 107items/kg	μFTIR	Polyethylene, polypropylene, copolymer, paint particle	Wang *et al.*,2017a
Urban surface waters, Wuhan, China	Surface Water	12 V DC Teflon pump	Hanjiang River:2933 ± 305.5 items/m^3 Yangtze River: 2516.7 ± 911.7 items/m^3 Sha Lake: 6390 ± 862.7 items/m^3 Nantaizi lake: 6162.5 ± 537.5 items/m^3 Nan lake: 5745 ± 901.6 items/m^3	FTIR	Polyamide, polyethylene, polyethylene terephthalate, polypropylene, polystyrene	Wang *et al.*, 2017b
Salford Quays Basin, UK	Sediment	UWITEC gravity corer	Mean :(914 ± 844 particles kg−1 ; 1793 ± 1275 particles/m^2) and maximum: (2543 particles/kg; 3891 particles/m^2)	FT-IR spectroscopy	Polyethylene and polypropylene	Hurley *et al.*, 2017
Taihu lake, China	Surface water, sediment	Plankton net and a steel sampler	0.01×10^6– 6.8×10^6 items/km^2 in plankton net samples 3.4-25.8 items/L in surface water, 11.0-234.6 items/kg dw in sediments	m-FT-IR microscopy	Fiber and cellophane	Su *et al.*,2016

Area Of Study	Sample Source	Sampling Method	Microplastic Concentration/ Abundance	Polymer Identification Method	Polymer Type	Citation
Remote lakes in Tibet Plateau, China	Lakeshore sediment	Shovel	Abundance: 8 ± 14 to 563 ± 1219 items/m^2	Raman microscope spectroscopy	Polyethylene, polypropylene, polystyrene, po lyethylene terephthalate, and polyvinyl chloride	Zhang *et al.*, 2016
Ontario Lake, Canada	Lacustrine sediment,t ributary sediment and beach sediment	Glew gravity corer ,stainless steel Petite Ponar sediment grab, MOECC from sediment traps	980 items/kg (dw) in lacustrine sediment, 760 items/kg (dw) in tributary sediment and 140 items/kg in beach sediments.	Raman spectroscopy and X-ray fluorescence spectroscopy (XRF)	PE, PS, PU, PP, PVC, PSS, PET, PMMA, polyvinyl/vinyl acetate copolymer, PMMA-PS copolymer or mixture, ABS, nylon, phenoxy/ epoxy resin, polymethylsilo xane (silicone)	Ballent *et al.*,2016
Lake Hovsgol, Mongolia	Water	Transect	20,264 items/ km^2	-	Not Known	Free *et al.*,2014
Itchen and Hable River, UK	Water	Plankton net	1155 and 296 items/m^3 in Itchen and Hamble River respectively.	Thermo Fisher Nicolet iS10 Fourier Transform Infrared Spectrometer (FTIR)	Polyethylene, Polypropylene, Cellophane	Gallagher *et al.*, 2016
Ontario Lake, Canada	Lacustrine offshore	Mini box corer	10.5 items/m^2	FTIR	Polyethylene, polypropylene nitrocellulose	Corcoran *et al.*, 2015
Lake Bolsena and Lake Chiusi, Italy	Lakeshore sediment and surface water	Manta trawl, stainless steel frame	Abundance in surface water: 2.68 to 3.36 particles/m^3 (Lak e Chiusi) and 0.82 to 4.42 particles/m^3 (Lak e Bolsena). Abundance in sediment: Vary from mean values of 112 (Lake Bolsena) to 234 particles/kg dry weight (Lake Chiusi).	UV-microscope (PCE-MM200UV 365 nm), SEM	Fragments and fibers	Fischer *et al.*, 2016
Seine River, France	Surface water	Plankton net and manta trawl	3-108 particles/m^3 in Plankton net sample and 0.28-0.47 particles/m3 in manta trawl		Fibers	Dris *et al.*, 2015
St. Lawrence River, Canada	Sediment	Petite Ponar grab, single Peterson grab	13 832 ± 13 677 items/m^2	Not known	Polyethylene, polypropylene nitrocellulose	Castañeda *et al.*,2014
Lake Garda, Italy	Beach sediment	Random grid sample technique	1,108 ± 983 microplastic particles/m^2.	Raman spectroscopy	Polyamide, Polyethylene, polypropylene, polystyrene, polyvinyl chloride	Imhof *et al.*, 2013
Two urban rivers of South California	Water	Manta trawl	12,932 and 411 items/m^3 in Los Angeles and San Gabriel River respectively	-	Not Known	Moore *et al.*, 2011

EFFECTS OF MICROPLASTICS

IMPACT OF MICROPLASTIC INGESTION ON AQUATIC BIOTA

The study of presence and effect of microplastic in aquatic organisms is extremely crucial. Presence of microplastic in freshwaters and in aquatic organisms present a potential threat of contaminating the food web and also, many of these organisms are widely consumed by the human population too, thereby posing a potential health hazard for them as well (Wang *et al.*, 2019).

Limonta *et al*., 2019 showed that microplastics induced transcriptional changes, immune response and behaviour alterations in adult zebra fish (*Danio rerio*). Adult zebrafish was exposed to two concentrations of high-density polyethylene (HDPE) and polystyrene (PP) microplastics for 20 days. A correlation was found between alterations in the expression of immune system genes and the down-regulation of genes and epithelium integrity and lipid metabolism in the transcriptomic results. Tissue alterations and higher occurrence of neutrophils were also observed in gills and intestinal epithelium. Based on the transcriptomic and histological detection, it was hypothesized that the effects on mucosal epithelium integrity and immune response could potentially reduce the organism defence against pathogens. Malafaia *et al.,* 2020, reported developmental toxicity in zebrafish (*Danio rerio*) when exposed to polyethylene microplastics at different concentrations for different time periods. Lower hatching rate along with significant morphological changes were observed. Qiang and Cheng, 2019 noticed that swimming competence in larval zebrafish was decreased when exposed to microplastics. Increased SOD and CAT activities were observed in zebrafish when exposed to microplastics (Qiao *et al.,* 2019; Lu *et al.,* 2016). Disruption of oogenesis process, neurotoxicity, and abnormal behaviour were induced in zebra fish on acute exposure to microplastics (Mak *et al.*, 2019).

Elizalde-Velázquez *et al*., 2020 presented a study where *Daphnia magna* and *Pimephales promelas* were exposed to polystyrene microplastics for 5 days. Low bioconcentration factor and low bioaccumulation factor were observed for both the species. Jaikumar *et al.*, 2018 demonstrated acute sensitivity of three cladoceran species (*Daphnia magna, Daphnia pulex and Ceriodaphnia dubia*) to primary and secondary microplastics in combination with temperature. It was observed that there was an increase in sensitivity for *Daphnia magna* and *Daphnia pulex* between the temperatures 18℃ to 26℃. When *D.magna* and *D.pulex* were exposed to primary microplastics, the no effect concentration decreased from 10^5 particles/mL at 18℃ to approximately 47 particles/mL at 26℃ and from 10^5 particles/mL at 18℃ approximately 8 particles/mL at 26℃ respectively. For *C.dubia* it varied from 5×10^3 particles/mL at 18℃ to 500 particles/Ml at 26℃. Primary and secondary microplastics induced acute toxicity in all the species when exposed for 48-96 hr. Coady *et al.,* 2020 examined transcriptomic and apical responses of *Daphnia magna* when exposed to polyethylene microplastic for a span of 21 days. It was found that significant transcriptomic alterations were induced. Jemec *et al.,* 2016 showed that *Daphnia magna* which was exposed to microfibers could not recover from the induced stress even after 24hr incubation. Rehse *et al.,* 2016 and Ogonowski *et al.,* 2016 proved that secondary microplastics are more detrimental than the primary ones through his study in *Daphnia magna.* A reduced reproduction and feeding activity in *Daphnia magna* on exposure to primary and secondary microplastics were observed. Rosenkranz *et al*., 2009 observed disruption of filtration process in *Daphnia magna* on exposure to microplastics.

A study by Silva *et al*., 2021 exhibited effects of microplastic ingestion by a dipteran larvae *Chironomus riparius*. It was observed that ingested polyethylene microplastics induced oxidative stress and also decreased aerobic energy production. Total lipid reserves were also found to be depleted. Fish behaviour, neurological functions, metabolism, intestinal permeability and intestinal microbiome diversity when exposed to virgin microplastics and nanoplastics were observed to have been affected by Jacob *et al*., 2020. Gambino *et al.,* 2020 demonstrated the effect of microplastics on planarian tissue regeneration and cellular homeostasis. Specimens of *Dugesia japonica* were fed with a mixture of food and different sized plastics. It was observed that at least a part of microplastic was phagocytized by the enterocytes although regenerative ability was found to be unaffected. However, a significant reduction of the gut epithelium thickness and lipid content of enterocytes, together with the induction of apoptotic cell death, modulation of *Djgata 4/5/6* expression and reduced growth rate were observed under chronic exposure. Microplastics caused a disturbance in the planarian homeostasis which can be attributed to the fact that they are highly flexible to chemical and mechanical insults.

Xiao *et al.,* 2020, while studying the physiological and transcriptional responses of *Euglena gracilis*, a freshwater microalgae on exposure to polystyrene microplastics, observed that exposure to polystyrene microplastics induced superoxide dismutase, and oxidative stress. It reduced pigment contents and at the molecular level, it deregulated the expression of genes which are involved in cellular processes, genetic information processing, organism systems, and metabolisms. The elicited adverse effects may be due to KCS and CTR1 gene. Gushchina *et al.,* 2020 showed that polystyrene microplastics decreased two essential fatty acids linoleic and linolinic in common freshwater algae *Chlorella sorokiniana*. The FA composition of two major chloroplast galactolipids, monogalactosyldiacylglycerol (MGDG) and digalactosyldiacylglycerol (DGDG), were also affected which indicates that the conformational structure of photosynthetic complexes was changed thereby decreasing the photosynthesis.

Zwollo *et al.,* 2021 reported that rainbow trout (*Oncorhynchus mykiss*) when exposed to polystyrene microplastics, it affected developing B cells, reduced gene expression RAG1 and membrane form of immunoglobulin heavy chains mu and tau. Nile Tilapia (*Orechromis niloticus*), when exposed to microplastics showed significant increase in superoxide dismutase (SOD), catalase (CAT), total peroxides (TPX), malondialdehyde (MDA), DNA fragmentation, and oxidative stress index (OSI) activities whereas the activity of total antioxidant capacity (TAC) showed a significant reduction during post exposure phase (Hamed *et al.,* 2020). Microplastics induce overproduction of reactive oxygen among different species which cause DNA damage and an increase in oxidative stress. Increased superoxide dismutase (SOD) was reported in red tilapia by Ding *et al.*, 2018. Freshwater bivalve (*Corbicula fluminea*) showed increased lipid peroxide levels when exposed to microplastics in a study conducted by Oliveira *et al.,* 2018. An increased trypsin and chymotrypsin enzyme activities were observed in *Barbodes goinonotus* fry when exposed for a period of 96hr. This caused the thickening of mucosal epithelium (Romano *et al.,* 2017). Hindrance in survival rate, reproduction and body length along with induced oxidative stress due to microplastics were observed in *Caenarhabditis elegans* (Lei *et al.*, 2018). Accumulation of polystyrene microplastics in *Eriocheir sinensis* induced increased oxidative stress in the liver and affected the growth of *Eriocheir sinensis* too (Yu *et al.,* 2018). Significant changes in morphology were observed in *Hydra attenuate* by (Murphy and Quinn 2018). Changes in metabolic function, formation of tumour, and altered immune response were observed in *Oryzias latipes* (Medaka fish) when exposed to LDPE pellets (Rochman *et al*., 2013). Alteration of gene expression related to cell adhesion, xenobiotic metabolic process, brain development, and other functions in intestines was observed in medaka fish when exposed to polystyrene microplastics (Assas *et al.,* 2020). Effect of polyethylene on freshwater oligochaeta *Allonais inaequalis* was observed by Castro *et al.,* 2020. In this study, no significant changes were found under thermal stress, however due to the lack of sediment availability survival rates decreased.

Bioaccumulation of microplastics in amphibians who play a vital role in many freshwater and terrestrial food webs (Michael Walton, 2005; Whiles *et al.,* 2012) were reported only in two studies by Hu *et al*., 2016 and Hu *et al*., 2018. A study by Boyero *et al* 2020, on *Alytes obstetricans* using a microcosm experiment showed that high concentration of microplastics (1800 parts/ML) caused mortality of most tadpoles. It also reported reduced growth of tadpoles and showed the trophic transfer of microplastics from periphyton to tadpoles which could be further ingested by a predator.

Many studies have reported to have found metals in microplastics which could have been absorbed due to larger surface area however, effect of combined toxicity due to metals and microplastics are significantly lacking (Holmes *et al.,* 2012). Most of the studies focuses on the effect of microplastic ingestion on *Daphnia magna* and zebrafish. Extensive studies must be conducted on effect on other aquatic organisms as well so that a wider coverage can be obtained. Also, most of all toxicity studies use overdosed exposure conditions and they ignore that reports on the translocation of plastics into inner organs often rely on artefacts. Evidences of presence and detection of microplastics in freshwater organisms also have been reported from various parts of the world, some of them are listed below in Table 2.

POTENTIAL EFFECT OF MICROPLASTIC ON HUMAN HEALTH

Freshwater organisms like fishes and bivalves are consumed by humans. The organisms which ingest microplastics set off a route for the transport of these microplastics in human body which is a potential risk for human health. Microplastics are said to be an adsorbent of heavy and trace metals (Guan *et al*., 2020; Naqash *et al.,* 2020). In a study by Liao and Yang, 2020, it was observed that microplastics are a potential vector for chromium, which can have carcinogenic impact on humans, in an in-vitro human digestive model. Since most of the plastics release estrogenic chemicals, estrogenic activity can pose severe health hazard for humans (Yang *et al.,* 2011).

A study has found that microplastic content was higher in eviscerated fish than the excised organs indicating the fact that even if microplastics are removed from gills and viscera, the presence of it can be found in gut which can be transferred to human body when consumed (Karami *et al.,* 2017). Some studies have found that 90% of the ingested microplastic particles ingested were excreted out (Peixoto *et al.*,2019; Wang *et al.,* 2019). Particles which are less than 150µm may find its way into the lymph and circulatory system and those which are less than 20µm are likely to enter the organs and those lesser than this may move through cell membrane, placenta and blood-brain barrier (Barboza *et al.,* 2018; Peixoto *et al.,* 2019). A number of responses like immunosuppression, immune activation and abnormal inflammatory are triggered by the human body as a response to the presence of microplastic particles (Barboza *et al.,* 2018; Imran *et al.,* 2018).

Reports have also suggested that plastics like PVC, phthalates, polystyrene, polyethylene, polyester, Polyurethane foam, Tetrafluoro-ethelyne, can cause adverse effects on human. PVC can cause cancer, birth defects, genetic changes, skin diseases, chronic bronchitis, and liver dysfunction. Pthalates can cause endocrine dysfunction, asthma, reproductive issues. Polyethylene is said to have carcinogenic effects. Polyester causes respiratory tract irritation and acute skin rashes. Polyurethane foam can cause bronchitis, and on releasing toluene diisocyanatecan cause lung problems too (Endocrine Disruptors FAQ, 2001; Centres for Disease Control Report, 2001; Berkeley 1996; Goettlich 2001).

However, due to the lack of significant clinical evidence regarding the effects of microplastic ingestion in humans, an expository question regarding the long term effects of it in humans remain unanswered.

MICROPLASTIC AS A CHEMICAL HAZARD

Plastics are mixed with wide range of additives to enhance the physical properties (Browne *et al.*, 2013; Lithner *et al.*, 2009; Moore, 2008; Teuten *et al.*, 2009). Chemicals like bisphenol-A, phthalates such as di-n-butyl phthalate and di-(2-ethylhexyl) phthalate, polybrominated diphenyl ethers (PBDEs) which are associated with plastics are considered as endocrine disruptor (Hu*et al.*, 2005; Kim *et al.*, 2006; Lithner *et al.*, 2009; Oehlmann *et al.*, 2009; Rochman *et al.*, 2013; Teuten *et al.*, 2009). These chemicals tend to leach out of the plastics because they are weakly bound to the polymer (Horton *et al.*, 2017). Acute toxicity of leachates from plastic products comprising of polyethylene, polypropylene, PVC, acrylonitrile-butadiene-styrene, epoxy in *Daphnia magna* was observed by Lithner *et al.*, 2009; Schiavo *et al.*, 2020. Yang *et al.*, 2011 showed that additives and monomers which are used to manufacture plastic release estrogenic chemicals into the environment. Therefore plastic can act as a source of transferring chemical leachates to the aquatic ecosystems.

Microplastics may act as a vector and facilitate transfer of bioaccumulative and toxic substances (Batel *et al.*, 2016). He showed the transfer of benzo(a)pyrene in an artificial food chain where *Artemia* nauplii was loaded with polyethylene microplastics and was provided for zebra fish. The bioavailability of microplastics to fishes can also be affected by several factors like pH, suspended solid and conductivity (Tien *et al.*, 2020). Microplastics are found to bind to a number of hydrophobic organic chemicals like PAHs, PCBs, dioxins, metals (Besseling *et al.*, 2013; Mato *et al.*, 2001; Rochman *et al.*, 2013c). These hydrophobic organic chemicals are highly lipophilic in nature and therefore are more prone to adsorb organic matter from sediments and waters. In addition to this, hydrophobicity of polymer, large surface area, and biofouling indicate that these hydrophobic organic chemicals have sorption potential to plastics (Karapanagioti and Klontza, 2008; Teuten *et al.*, 2007. This phenomenon is more likely to occur in freshwater environment because of its propinquity to such usage of chemicals (Dris *et al.*, 2015b).

Table 2: Reports Of Occurrence And Detection Of Microplastic Particles In Freshwater Organisms

Location	Sample Species	Concentration Of Microplastics Found	Polymer Type	Citation
Liaohe Estuary, China	Surf clam (*Mactra veneriformis*), razor clam (*Sinonovacula constricta*), moon snail (*Neverita didyma*), and veined rapa whelk (*Rapana venosa*) belong to mollusks group; mantis shrimp (*Oratosquilla oratoria*), and swimming crab (*Portunus	Average microplastic abundance of 0.83 ± 0.99 to 3.87 ± 2.18 items/individual was detected across all species, including sandworm, mollusks, crustacean and fish, but they were not found in all individuals.	Polyethylene (PE), polypropylene (PP), and polyethylene terephthalate (PET)	Wang *et al.*, 2021

Location	Sample Species	Concentration Of Microplastics Found	Polymer Type	Citation
	trituberculatus) belonging to the crustacean group; spottedtail goby (*Synechogobius ommaturus*), seabass (*Lateolabrax japonicus*), and redeye mullet (*Mugil gaimardianus*) belonging to the fish group, sandworm (*Perinereis aibuhitensis*) belonging to polychaete			
Ponds of Central Europe, Poland	Common toad *Bufo bufo*, common frog *Rana temporaria*, water frogs *Pelophylax esculentus* complex, spadefoot toad *Pelobates fuscus* and tree frog *Hyla arborea*	53 (26%) tadpoles ingested a total of 71 MPs	Nylon, polyisoprene (6%), polyurethane (2%) and 1,2 polybutadiene	Kolenda *et al*., 2020
Central European lowland water	Freshwater fish (202 Gudgeons and 187 roaches)	452 MP-like particles were observed. 232 in gudgeon and 220 in roach. In gudgeon, the mean number of MP-like particles ± SD per individual was 1.15 ± 1.65, while in roach it was 1.18 ± 1.89	Fibers	Kuśmierek and Popiolek,2020
Ten Streams of Southern Brazil	294 Fishes of 13 species	Individuals of 10 species ingested microplastics	Fiber	Garcia *et al.*, 2020
Ticino River, North Italy	*Alcedo atthis*	10 out of 133 pellets were contaminated	Fiber	Winkler *et al.*, 2020
Grand River Watershed, Canada	Freshwater mussel (*Lasmigona costata*)	Microplastics detected in 71% mussels	Polypropylene-co-polyethylene	Wardlaw and Prosser, 2020
Han river, South Korea	Intestine of carp (*C. carpio*), crucian carp (*C. cuvieri*), bluegill (*L. macrochirus*), bass (*M. salmoides*), catfish (*S. asotus*), and snakehead (*C. argus*).	Concentrations of microplastic in the gills of fish ranged from 1 to 16 particles/fish (mean: 8.3 ± 6.0 particles/fish) Concentration of microplastics in the intestines of fish, which ranged from 4 to 48 particles/fish (mean: 22.0 ± 16.0 particles/fish)	Polytetrafluoroethylene , polyethylene, and rayon	Park *et al*., 2020

Location	Sample Species	Concentration Of Microplastics Found	Polymer Type	Citation
Nile River, Egypt	Digestive tract of Nile tilapia (*Oreochromis niloticus*) and catfish (*Bagrus bayad*)	75% of the fishes contained MPs. Average in Nile tilapia (*Oreochromis niloticus*) : 7.5 ± 4.9 items and average in Catfish (*Bagrus bayad*) : 4.7 ± 1.7 items	Polyethylene, polyethylene terephthalate and polypropylene	Khan *et al.*, 2020
Sorocaba river, Brazil	*Astyanax fasciatus, Astyanax lacustris, Crenicichla lacustris, Geophagus brasiliensis, Hoplias malabaricus, Hoplosternum littorale, Hypostomus sp., Hypostomus ancistroides, Hypostomus margaritifer, Prochilodus lineatus, Pterygoplichtys ambrosetti, Rhamdia quelen, Steindachnerina insculpta, Serrasalmus maculatus*	Microplastics were found in the stomach contents of four individuals: *Rhamdia quelen* (2 individuals), *Hoploster num littorale* (1 individual) and *Astyanax fasciatus* (1 individual)	Fiber	Oliveira *et al.*, 2020
African lake	*Clarias gariepinus, Cyprinus carpio, Carassius carassius, Oreochromis niloticus*	Out of 560 plastic particles, 74% were found to be microplastic. MP abundances per species were 77%, 61%, 71% and 69% in *O. niloticus*, *C. carassius*, *C. gariepinus* and *C. carpio*, respectively.	Polyethylene, polypropylene and alkyd-varnish	Merga *et al.*, 2020
Victoria River, Australia	*P. australiensis*	Abundance: 36% of shrimp (P. austraiensis) contained microplastics with an average of 0.52 ± 0.55 items/ind (24 ± 31 items/g).	Polyester and rayon	Nan *et al.*, 2020
Lake Mead National Recreation Area, USA	15 Stripped bass, 6 common carp and Quagga mussels	Shellfish microplastic concentrations ranged from 2.7–105 particles/organism, and fish concentrations ranged from 0–19 particles/organism.	Fiber, films, fragment and foam	Baldwin *et al.*, 2020

Location	Sample Species	Concentration Of Microplastics Found	Polymer Type	Citation
Municipal water supply lake, Southwestern Nigeria	109 samples of 8 species: *Coptodon zillii ,Oreochromis niloticus , Sarotheron melanotheron , Chrysicthys nigrodigitatus , Lates niloticus , Paranchanna obscura , Hemichromis fasiatus ,* and *Hepsetus odoe*	On average, 1–6 MPs were obderved per individual	Not known	Adeogun *et al.*, 2020
Swedish River, Northern Europe	Freshwater mussel (*Anodonta anatina*)	1620 fibres was observed. The average number of fibres across objects were 63.3 ± 29.6 SD in Värpinge and 38.0 ± 34.2 SD for Genarp. 196 microplastic particles in the mussels from the site in Värpinge, but only 51 particles in the Genarp mussels. Across objects, the mean number of particles was 12.2 ± 9.1 from Värpinge and 3.2 ± 3.5 from Genarp.	Microfibers and type of MPs not known.	Berglund *et al.*, 2019
Paraná river, La Plata Basin, Argentina	*Prochilodus lineatus*	All fishes were contaminated with atleast 1 MP. Number of items observed in digestive tracts of adult *P. lineatus* averaged 9.9 microplastic particles.	Films and fibers	Blettler *et al.*, 2019
Australian Urban Wetlands	Common noxious fish (*Gambusia holbrooki*)	19.4% of fish had microplastics present in their bodies with an abundance of 0.6 items per individual (items/individual) and 7.2% of fish had microplastics in their heads with an abundance of 0.1 items/individual	Polyester	Su *et al.*, 2019
Flemish River, Belgium	*Gobio gobio*	9% of the total fishes had ingested microplastics	Ethylene-vinyl acetate copolymer,polypropylene, polyethylene terephthalate, polyvinylchloride ,	Slootmaekers *et al.*, 2019

Location	Sample Species	Concentration Of Microplastics Found	Polymer Type	Citation
			cellophane, polyvinyl acetate and polyamide	
Poyang Lake, China	Wild crucian sample (*Carassius auratus)*	0–18 items per individual for wild crucians (*Carassius auratus*)	Polyethylene and polypropylene	Yuan *et al*., 2019
River of South wales	Baetidae, Heptageniidae and Hydropsychidae (Macroinvertebrates)	0.14 MP mg tissue^{-1}	Fibers. Types of microplastics not known.	Windsor *et al.*, 2019
Qinghai Lake, China	Fish samples	2 to 15 items per individual	Polyethylene and polypropylene	Xiong *et al*., 2018
Yangtze River Catchment	Tadpoles *Bufo gargarizans, Microhyla ornata, Rana limnochari* and *Pelophylax nigromaculatus*	Average of 0.17-2.73 particles in individual tadpoles of four species	PES and PP	Hu *et al.,* 2018
Bloukrans River system, South Africa	Bloodworm (*Chironomus* spp)	98%	Not known	Nel and Wasserman, 2018
Yangtze River Basin	*Corbicula fluminea*	0.3-4.9 items/g (or 0.4–5.0 items/individual)	Microfiber	Su *et al.,* 2018
Chi River, Thailand	*Labiobarbus siamensis, Puntioplites proctozyson, Cyclochelichthy repasson, Henicorhynchus siamensis, Labeo chrysophekadion,Mystus bocourti, Hemibagrus spilopterus, Laides longibarbis*	Percentage occurrence of microplastics in each species ranged between 50.0-86.7% with the highest in *Puntioplites proctozysron* (Smith's barb).	Fiber	Kasamesiri and Thaimuangphol 2018
River Thames, UK	*Rutilus rutilus*	33% of them contained 1MP	Polyethylene, poly propylene and polyester,	Horton *et al.*, 2018
Paris Conurbation	*Squalius cephalus*	5% of sampled livers contained microplastics	Fibers	Collard *et al.*, 2018
Lake Michigan, USA	74 Fishes of 10 taxa Round Goby, Bass, Emerald Shiner, Bannded killfish, Spotfin, shiner, Quiollback, Sand shiner, Fathead minnow, white sucker,Gizzard shad	10 (±2.3) to 13 (±1.6) microplastic particles fish^{-1}	Fibers and fragments	Mc Neish *et al.*, 2018

Location	**Sample Species**	**Concentration Of Microplastics Found**	**Polymer Type**	**Citation**
Freshwaters of China	*Carassius auratus, Hemiculter bleekeri, Hypophthalmichthys molitrix*, *Megalobrama amblycephala, Pseudorasbora parva, Cyprinus carpio*	95.7% of the freshwater fishes had microplastics	Cellophane	Jabeen *et al.*, 2017
River Thames, UK	*Platichthys flesus* & *Osmerus eperlanus*	75% in *Platichthys flesus* and 20% in *Osmerus eperlanus*	Acrylic, nylon, polyethylene and polyethylene terephthalate	McGoran *et al.*, 2017
Salfords Quay Basin, UK	Tubifex worms	129 ± 65.4 particles g^{-1} tissue.	Fibers	Hurley *et al.*, 2017
Prairie Creek, California	75 emerald shiners, 30 northern pike, 32 white suckers, 34 fathead minnows, and 10 five-spine stickelbacks	Among 181 fishes sampled, 73.5% of them ingested microplastics	Fibers and fragments	Campbell *et al.*, 2017
Canada	Freshwater birds	Average: 0.31 (± 3.1) items per bird	Not identified	Holland *et al.*, 2016
Brazos River Basin, USA	Sunfish	196 (45%) out of 436 sunfishes collected contained microplastics in their stomach	Microplastic threads	Peters and Braton, 2016
Taihu lake, China	Asian clams (*Corbicula fluminea*)	0.2–12.5 items/gm (ww)	Cellophane, polyethylene terepthalate, polypropylene, polyethylene, polyamide	Su *et al.*, 2016
River of South America	*Hoplosternum littorale*	88.6%	Fibers	Silva-Cavalcanti *et al.*, 2017
Lake Victoria, Tanzania	Nile perch (*Lates niloticus*) and Nile Tilapia (*Oreochromis niloticus*)	20% in both *Lates niloticus* and *Oreochromis niloticus*	Polyethylene, polyester, polyurethane, Polyethylene/polypropylene, copolymer, silicone rubber	Biginagwa *et al.*, 2016

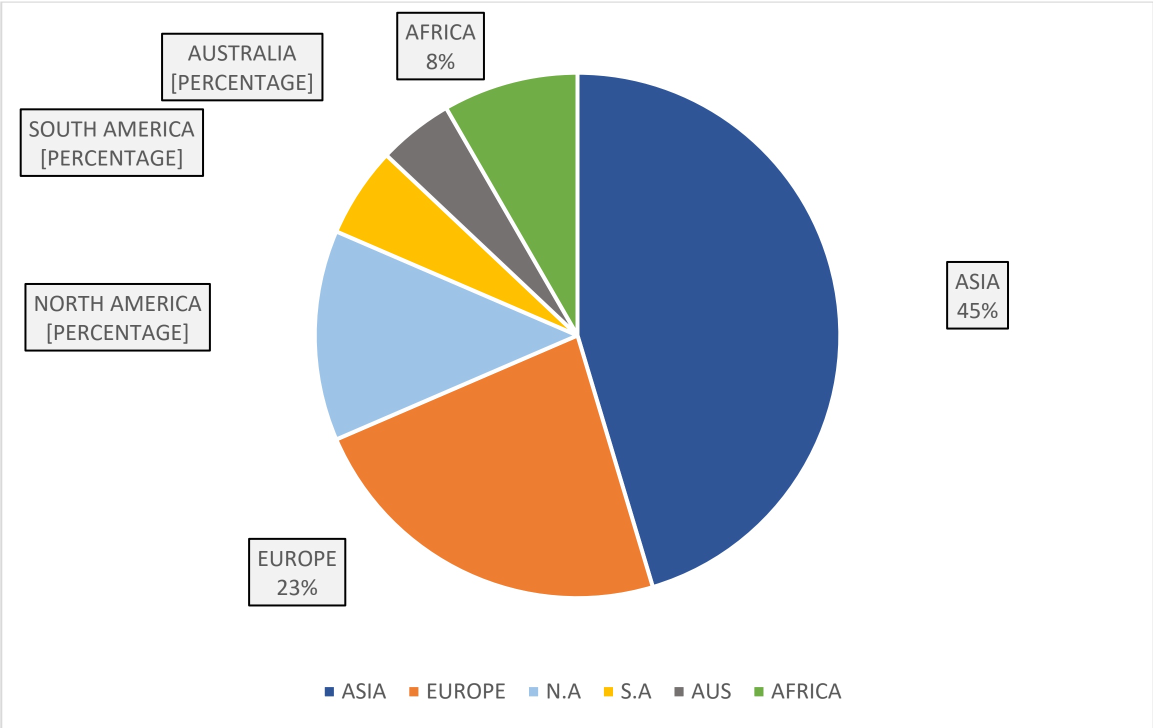

Fig 1: Percentage of Studies Reported on Occurrence and Detection Of Microplastics in Freshwater and Biota Across Different Continents

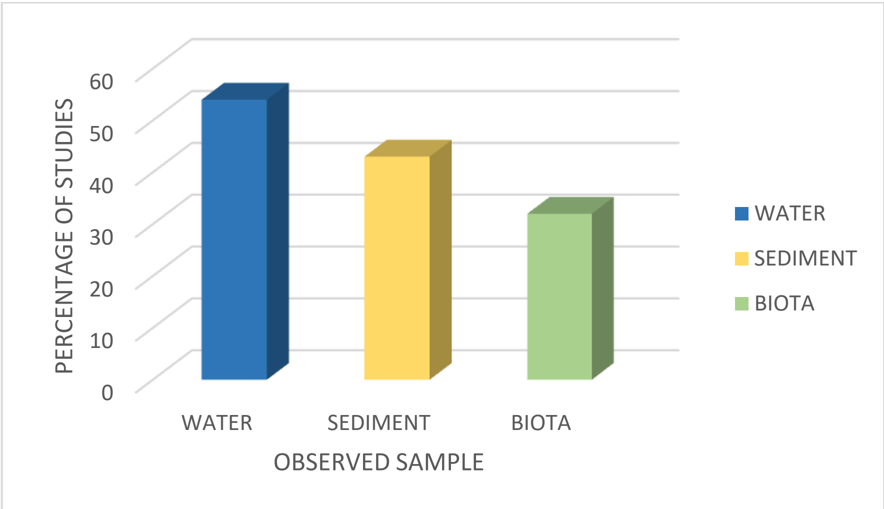

Fig 2: Percentage of Studies Reporting on Occurrence And Detection of Microplastics From Water, Sediment and Biota Samples

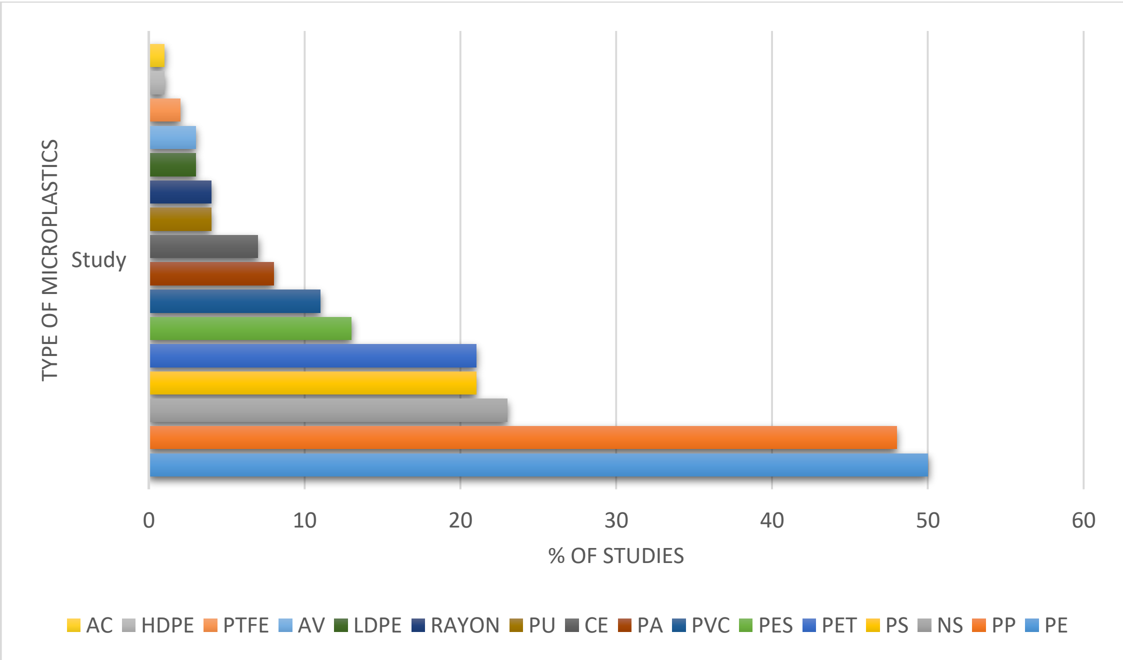

Fig 3: Comparison of Different Types of Microplastics Obtained From Different Studies Across The World. Different Types of Microplastics Cited Include: Pe: Polyethylene, Pp: Polypropylene, Ns: Not Specified, Ps: Polystyrene, Pet: Polyethylene Terephthalate, Pes: Polyester, Pvc: Polyvinyl Chloride, Pa: Polyamide, Ce: Cellophane, Pu: Polyurethane, Rayon, Ldpe: Low Density Polyethylene, Av:Alkyd-Varnish, Ptfe:Polytetrafluroethylene, Hdpe: High Density Polyethylene, Ac: Acrylic

DISCUSSION

Analysis of the available literature on presence of microplastics in freshwaters and the organisms dwelling in it shows the urgent need to expand the knowledge in this field. The environmental impact of microplastics is of emerging concern but most of the studies are focused exclusively on marine environment and marine organisms. The available data on microplastics in freshwater ecosystem (water, sediments and biota) is mostly fragmentary (Figure 2). Concern about the consequences of microplastics in freshwaters is quite legitimate and therefore scientists need to bridge the gaps of knowledge. Mentioned below are some of the areas where research needs to be prioritized:

1. Extensive and long term monitoring of microplastics in freshwater ecosystem needs to be done across the world to understand its current scenario and the extent of pollution cycle in the freshwater ecosystems. Also, an assessment of microplastic risk for an area is scarce (Zhou *et al.*, 2020). A plastic pollution risk index could be used to analyse and locate the areas where such pollution load is high and accordingly steps could be taken to reduce plastic input into the waters.

2. Effects of polyethylene, polypropylene, polystyrene, polyethylene terephthalate, polyester, polyvinyl chloride, and polyamide must be studied in wide range of organisms because of their high presence as detected from various studies reported in this paper (Figure 3).

3. Majority of the studies on microplastics focus only on quantifying the microplastics obtained and the polymer composition of the same. Study on the shape and size of microplastics are mostly scarce which can have greater implications in terms of determining the source and transport of the microplastics. For example, a study had

suggested that white microplastics indicate that such particles have undergone weathering process and has been there in the aquatic environment for a certain time (Pan *et al.*, 2019b).

4. Most of the studies on toxicity of microplastics in aquatic organisms have been done using overdosed exposure conditions. Therefore, this fails to give a correct idea about the effect of toxicity. Also, most of the studies conducted on toxicity of microplastics revolves around the same organisms like *Daphnia magna* and *Danio rerio.* Studies on a wide varierty of organisms or on edible fishes need more attention. Unless there is a wide range of data on the toxicological effects on different organisms, there will always be a persisting knowledge gap on the effects of micoplastics on freshwater biota.

5. Exact mechanism by which microplastics cause mortality, reduced growth or other significant effects on vertebrates remain poorly explored. Most of the studies demonstrate a probable or potential mechanism for such effects. Future research should address the mechanisms causing such harmful effects, interaction of microplastics with other stressors and their effect on ecosystem.

6. Microplastic particles have been found to act as vectors. However, very few studies have concrete evidences on the same. Since, heavy metals, trace elements are also now observed in the freshwaters, studies on the combined toxicity can be helpful to understand the possible health hazards on the flora and fauna due to it.

7. Information regarding impacts of microplastic ingestion on humans is clinically not proven. Extensive research is required in this field to understand how micoplastic loaded fish if ingested by humans can affect the later. The plastics are said to have carcinogenic impacts so whether it induces carcinogenic effects in humans too is not known.

8. Different sampling methods, analysis protocols and different units of measurement makes it difficult to compare the data from different regions of the world. A uniform method of reporting of data along with a standard protocol for microplastic analysis should be undertaken.

CONCLUSION

The impingement of microplastics in the aquatic environment are manifold. Both primary and secondary microplastics find their pathway into the aquatic ecosystems from point or diffuse sources. With the half-life of plastics ranging from years to centuries, these small fragments of microplastics are more likely to breakdown into further smaller fragments under various circumstances thereby providing with a larger surface area for interaction with chemicals and organic contaminants and increasing the probability to be up taken by aquatic biota (Jeong *et al.,* 2016; Lee *et al.,* 2013). Microplastics are responsible for physical, chemical and biological hazards. Therefore, the persisting problem of microplastics must be addressed solemnly. Discovering a suitable alternative to plastic materials and recycling of plastics are the most desirable means to reduce the pollution. Also, stringent management policies and legislative framework would also be helpful in preventing and reducing the input of plastics into the aquatic ecosystems.

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Life Science Reporting

No life science threat was practiced in this research.

Conflict of interests

The authors declare that there is not any conflict of interests regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/ or falsification, double publication and/or submission, and redundancy has been completely observed by the authors.

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