

Microplastic in Freshwater Environment: A Review on Techniques and Abundance for Microplastic Detection in Lake Water

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Abstract

Microplastic particles have been detected in water sources such as in oceans, lakes and rivers worldwide, which have received much attention in recent years. This review includes a summary of the analytical techniques such as sampling, processing and identification used by researchers to evaluate microplastic in lake water from 35 studies. Microplastic abundance and its morphological characteristics were also compared. Bulk sampling and volume-reduced sampling were almost equally implemented during sample collection. During sample processing, digestion were followed by 85.71 % of the researcher's using hydrogen peroxide (H₂O₂) to degrade the organic matter present in the sample. Though density separation is the most common approach to extract microplastic from sediment sample, this was not the case in lake water as only 31.43 % used this method. Fibers were the most dominant shape and the maximum abundance of microplastics were found to be in < 0.5 and < 2 mm² size class. Most studies reported microplastic to be of polyethylene (PE) and polypropylene (PP).

Keywords: Microplastics, Lake, Abundance, Sources, Analytical techniques, Polymer, Globally

Introduction

Plastic are synthetic or semi-synthetic polymers which are versatile material. As it is affordable, light weight and durable it has become an integral part of modern world which provide job to nearly 1.5 million people in Europe [1]. Numerous use of plastic include packaging materials (40.5 %), building and construction materials (20.4 %), automotive parts (8.8 %), electronic gadgets (6.2 %), household articles, leisure and sports equipment (4.3 %), agriculture tools (3.2 %) and others (16.6 %) [1]. On the other hand, substantial amount of plastic waste enters the environment due to inappropriate management and misuse of plastic [2]. According to United Nations Environment Programme [3] over 8.3 billion tons of plastic has been manufactured since 1950s. Between 1950 - 2015, around 60 % of the plastic manufactured has ended up in dumping ground or natural surrounding and only 9 % of the plastic produced has been recycled [4]. Due to COVID-19 pandemic, every minute around 3 million face masks are discarded globally which finally makes its way to the environment, fresh water habitat and marine ecosystem [5]. Plastic in course of time convert into small- sized particles of less than 5 mm called as microplastic [6].

Microplastics can be classified as primary and secondary microplastics. Primary microplastics are plastic pieces which are smaller than 5 mm before making its way to the environment [7]. Primary source of microplastic includes industrial grinders for sandblasting [8], plastic pellets as raw materials in plastic factory or personal care products such as facial and body scrubber containing microbeads [9,10]. Secondary microplastic results as the action of UV rays disintegration or washing machine [11], wave abrasion [12], and biodegrading by microorganisms [13]. Secondary sources of microplastic includes fishing nets, industrial raw materials pellets, household goods and other discarded plastic waste [14]. Microplastic have a negative consequence on food intake, survival, growth and reproductive output [15-17]. Microplastics adsorb hazardous organic pollutants from the surrounding soil and aquatic ecosystem and may transfer to

the organism [18]. Once ingested it results in neurotoxicity and oxidative stress [19,20] and disrupt the energy metabolism [20]. In human, excessive inhalation of airborne microfibers is associated with health hazards, such as lesions in the respiratory system [21] and increase carcinogenic risk [5,21].

Freshwater is the life line of all living organism. Studies concerning microplastic pollution in freshwater environment has increased recently. From 2019 to September 2020, 64 research articles has been published in freshwater environment which was just 4 studies in 2013 [22]. To date, few reviews have been published on freshwater microplastic focusing on effects on aquatic organisms [12,23-26], analytical techniques [22,24,25,27-29], occurrences and sources [24,25,28,30,31], outline the knowledge gap and future research needs [14,26,32,33]. In spite of the available review on freshwater microplastics, there is only 2 reviews dealing entirely with lake system. Thus, this paper intends to (1) compare detail methods used for microplastic sampling, extraction, and detection in lake water (2) summarize the abundance and characteristics of microplastics found in lake water from different locations globally. Knowledge of microplastic contamination in freshwater lake is in its early stage. Therefore this review may be helpful for those who are new to this field in determining the suitable sampling technique, reliable extraction and identification method for accessing microplastic pollution.

Materials and methods

Extensive literature survey was performed using database of web of science (all database) in February 2022. The search keywords included were “microplastic” and “surface water” and “lake” (in any topic, title or text words). A total list of 199 publications were generated from the year 2001 to the beginning of February 2022. Thirty-five articles relevant to microplastic in lake water and 6 review paper related to lake were selected for this review. From the available studies, information regarding 1) widely used procedure for sample collection, extraction, and identification techniques and 2) microplastic abundance and characteristics in lake water were retrieved and processed.

Results and discussion

Analytical methods for microplastics in freshwater

Sampling methods for microplastics

In order to quantify microplastic in freshwater environment, sampling is the first crucial step. The common sampling methods are volume-reduced sampling and bulk sampling [34]. In volume-reduced sampling, the amount of water sample is reduced during sample collection. A flow meter is used during water sampling to determine the total volume filtered through the mesh by which overall volume of water can be calculated [24]. Manta trawl and plankton net are the commonly used sampling tools in volume-reduced sampling. Zooplankton net, trawl, and pump filtration are also used in volume-reduced sampling. In bulk sampling, volume of water is not reduced during sampling. Steel bucket and Teflon pump are used for collecting bulk sampling. In 16 studies, water sample was collected by volume-reduced sampling technique, fifteen by bulk sampling and in 4 studies both the methods was followed for sample collection. The choice of sampling method depends on the research question [35], availability of the financial resources and the study compartment [22] as it has a significant influence on the overall analysis of the result [29].

From the published studies, various mesh sizes are used ranging from 20 μm to 335 μm (**Table 1**). Overall, in 31.43 % of the studies, the mesh size ranges from 300 - 335 μm (**Table 1**). 300 - 335 μm mesh is the common mesh size used by the researchers [24,25,27,28]. Lindeque *et al.* [36] recently compared sampling mesh size of 100, 333 and 500 μm with microplastic abundance. Their study found that mesh size 100 μm can collect 2.5 times more particles compared to 333 μm and 10 times more than 500 μm mesh size. This shows that underestimation of microplastic abundance is possible if bigger mesh size is used. So in order to capture the smaller size microplastics, net of mesh size 20 μm is recommended to give a clear idea of microplastic load in the water bodies.

Sample preparation/processing

After the sampling, for better identification and quantification of the microplastic present in the sample, it should be processed which include organic matter digestion, density separation, and filtration.

Table 1 Summary of analytical method used for detection of microplastic from lake water.

Study area	Collection tool	Cutoff size in μm	Extraction	Identification	References
Lake Hovsgol, Mongolia	Manta trawl	333	30 % H_2O_2 +Fe(II); density separation (NaCl)	Light microscope	Free <i>et al.</i> [37]
Six Largest Swiss Lake	Manta trawl	300	35% H_2O_2 +Fe(II)	Stereomicroscope; ATR-FTIR	Faure <i>et al.</i> [38]
Lake Bolsena & Lake Chiusi, Italy	Manta trawl	300	HCl; density separation (NaCl)	UV microscope; SEM	Fischer <i>et al.</i> [39]
Taihu Lake, China	Plankton net; 5 L Bulk sample	333	30 % H_2O_2	Stereomicroscope; μ -FTIR; SEM/EDS	Su <i>et al.</i> [40]
Lake Winnipeg, Canada	Manta trawl	333	30 % H_2O_2 +Fe(II)	Dissecting microscope; SEM	Anderson <i>et al.</i> [41]
20 Major Lake, Wuhan City, China	20 L Teflon pump & stainless-steel sieve	50	30 % H_2O_2	Stereomicroscope; FTIR; SEM	Wang <i>et al.</i> [42]
West Dongting & South Dongting Lake, China	30 L large flow sampler & stainless-steel sieve	45	30 % H_2O_2 +Fe(II); density separation (ZnCl_2)	Stereomicroscope; μ -Raman	Jiang <i>et al.</i> [43]
Qinghai Lake, China	Trawl net	112	30 % H_2O_2 ; density separation (Potassium formate)	Stereomicroscope; Raman	Xiong <i>et al.</i> [44]
8 Urban Lake, China	40 L Bulk sampler & stainless-steel sieve	45	30 % H_2O_2 +Fe(II)	Stereomicroscope; μ -Raman; SEM	Yin <i>et al.</i> [45]
Poyang Lake, China	20 L Bulk sampler & stainless-steel sieve	50	30 % H_2O_2	Stereomicroscope; μ -Raman	Yuan <i>et al.</i> [46]
Lake Kallavesi, Finland	Manta trawl Pump filtration	333	NaOH+Sodium dodecyl sulfate	Stereomicroscope; μ -FTIR	Uurasjarvi <i>et al.</i> [47]
Red Hill Lake, India	Plankton net	120	H_2O_2 +Fe(II); density Separation (NaCl)	Stereomicroscope; ATR-FTIR; SEM	Gopinath <i>et al.</i> [48]
Ox-bow Lake, Nigeria	50 L Teflon pump & stainless-steel sieve	-	30 % H_2O_2	Stereomicroscope; μ -FTIR	Oni <i>et al.</i> [49]

Study area	Collection tool	Cutoff size in μm	Extraction	Identification	References
Veeranam Lake, India	Plankton net	20	30 % H_2O_2	Microscope; ATR-FTIR	Bharath <i>et al.</i> [50]
Lake Guaiba, Brazil	Zooplankton net	60	35 % H_2O_2 +Fe(II); density separation (NaI)	Stereomicroscope; μ -FTIR & μ -Raman	Bertoldi <i>et al.</i> [51]
Subalpine Lake, Italy (Maggiore, Iseo, Garda)	Manta trawl	300	Manual separation	Stereomicroscope; ATR-FTIR	Sighicelli <i>et al.</i> [52]
Lake Naivasha, Kenya	Plankton net	150	H_2O_2 +Fe(II)	Dissecting microscope, ATR-FTIR	Migwi <i>et al.</i> [53]
Lake Ulansuhai, China	20 L Teflon pump & stainless-steel sieve	48	30 % H_2O_2	Stereomicroscope; FTIR; SEM/EDS	Wang <i>et al.</i> [54]
Dongting & Hong Lake, China	20 L Teflon pump & stainless-steel sieve	50	30 % H_2O_2	Dissecting microscope; Raman	Wang <i>et al.</i> [55]
Poyang Lake, China	20 L steel bucket & Neutron net	38	30 % H_2O_2 ; density separation (NaCl+NaI)	Multifunctional digital microscope; μ -FTIR; SEM	Jian <i>et al.</i> [56]
Rawal Lake, Pakistan	2 L bulk sample	-	30 % H_2O_2	Light microscope; FTIR	Irfan <i>et al.</i> [57]
Lake Mead & Mahava, USA	Microplastic net	-	30 % H_2O_2 +Fe(II); density separation (Lithium metatungstate)	Stereomicroscope	Baldwin <i>et al.</i> [58]
Wuliangshuai Lake, China	20 L bulk sample & sieve	75	30 % H_2O_2	Metallographic microscope; ATR-FTIR; SEM	Mao <i>et al.</i> [59]
Gehu Lake, China	Submersible pump	48	H_2O_2 +Fe(II); density separation (NaCl)	Stereomicroscope; FTIR	Xu <i>et al.</i> [60]
Nine lakes, Patagonia, Argentina	Trawl	38	30 % H_2O_2	Stereomicroscope; Raman	Alfonso <i>et al.</i> [61]
Süreyyabey Dam Lake, Turkey	Microplastic nets	330;100	30 % H_2O_2 +Fe(II); density separation (NaCl)	Dissecting microscope; ATR-FTIR	Tavsanoğlu <i>et al.</i> [62]
Lake Simcoe, Canada	4 L bulk sample; Manta net	335	Manual	Microscope; FTIR/Raman	Felismino <i>et al.</i> [63]

Study area	Collection tool	Cutoff size in μm	Extraction	Identification	References
Crater Lake, Erzurum, Turkey	10 L bulk sample		Manual	μ -Raman; SEM	Comakh <i>et al.</i> [64]
Three Gorges Reservoir, China	25 L Teflon pump	48	30 % H_2O_2	Dissecting microscope; μ -Raman	Di and Wang [65]
Lake Sassolo, Switzerland	5 L bulk sample	63	30 % H_2O_2	Optical microscope; FTIR	Velasco <i>et al.</i> [66]
Renuka Lake, India	3 L UWITEC water sample	NA	NA	Dissecting fluorescent microscope; Stereomicroscope; ATR-FTIR and Raman	Kumar <i>et al.</i> [67]
Lake Erie and Lake Ontario, Canada	Manta trawl	333	30 % $\text{H}_2\text{O}_2 + \text{Fe(II)}$	Dissecting microscope; SEM/EDS	Mason <i>et al.</i> [68]
Western Lake Superior, Canada	Manta net	333	30 % $\text{H}_2\text{O}_2 + \text{Fe(II)}$; NaCl	Microscope; pyr-GC/MS; FTIR	Hendrickson <i>et al.</i> [69]
Six Lakes, Southern Siberia, Russia	5 L bulk sample	NA	NA	SEM/EDS	Malygina <i>et al.</i> [70]
Phewa Lake, Nepal	5 L bulk sample	75	30 % $\text{H}_2\text{O}_2 + \text{Fe(II)}$	Stereomicroscope	Malla-Pradhan <i>et al.</i> [71]

Digestion of organic matter

In order to remove the organic matter from the sample matrix, chemical degradation (oxidizing, acidic and alkaline digestion) or enzymatic degradation can be performed [27]. Degradation step was followed by 85.71 % of the reviewed studies. Hydrogen peroxide (H_2O_2) was mainly used for the removal of organic matter (28 studies) along with Fe (II) solution. This Fenton's reagent helps to generate powerful oxidizing agents catalytically which is efficient to remove much of the organic matter from the water sample. Acid digestion by hydrochloric acid (HCl) [39] and alkali digestion by sodium hydroxide (NaOH) along with sodium dodecyl sulfate (SDS) was used for organic matter digestion [47]. Enzymatic degradation has not been used by any researchers in these reviewed studies. Compared to chemical degradation, enzymatic degradation causes no damage to microplastic and has good efficiency to remove organic matrix. However, the cost of enzyme is high and time consuming [24,27].

Density separation

The type of polymer determines the density of the microplastic [29,34]. Density separation is widely used method to isolate microplastic from the sample [25]. However, in lake water only 31.43 % (of the 35 papers reviewed) has adopted these techniques. Different types of separating solution are used for density separation. Saturated sodium chloride (NaCl) with a density of 1.2 g/cm^3 are used only in 6 lake water [37,39,48,60,62,69]. NaCl is widely used separating solution as the cost is low and non-toxic [29] but only low density microplastic can be extracted [72]. Jiang *et al.* [43] used zinc chloride (ZnCl_2) solution of density 1.5 g/cm^3 to extract microplastic however, care should be taken while using this chemical as it is hazardous and corrosive [24]

Other density separating solution used are potassium formate (density = 1.54 g/cm^3) [44], sodium iodide (NaI) [51], and lithium metatungstate (density = 1.6 g/cm^3) [58]. However, Jian *et al.* [56] used a combination of NaCl and NaI as a density separation. Filtration is the final step in sample processing. The supernatant from density separator is passed through filter paper under vacuum filtration. In some case sieve is used as filtering medium.

In lake water, the samples are processed almost in a similar manner for both bulk and volume-reduced samples. From the reviewed studies, the general laboratory processing of sample includes sieving, digestion, density separation, filtration and visual sorting but the order of steps may differ among studies.

Microplastic identification

After the processing of microplastic, it is necessary to spot and specify the suspected microplastic. In all reviewed studies, visual inspection is a crucial step to detect microplastic either with unaided eye or with the help of microscope [34]. Visual inspection is carried out with the aid of stereomicroscope in 68.57 % of the reviewed studies on lake water. Three researchers used light microscope [37,57,66], multifunction digital microscope [56], metallographic microscope [59], and UV microscope [39] were also used. Three study did not specify the type of microscope used [50,63,69]. If protocol for visual identification [34,73] is adapted, it can be a reliable tool to identify microplastic particles up to 500 μm [74] yet it cannot detect the polymer of plastic. Therefore, spectroscopy technique like FTIR and Raman spectroscopy is trustworthy for the confirmation of unknown polymer particles [24]. From 35 reviewed studies (Table 1) on lake water, polymer identification was carried out using FTIR (17 studies), Raman spectroscopy (8 studies), and both FTIR and Raman spectroscopy (3 studies). Some studies have used scanning electron microscope (SEM) to study the surface morphology of microplastic.

FTIR is mechanically simple which gives accurate output and is a non-destructive detection method with an extensive polymer database [24]. The polymer verification is achieved by comparing the spectra with the known reference spectra. Attenuated total reflectance (ATR)-FTIR can examine microplastic particles > 500 μm whereas, micro-FTIR can analyze smaller plastic particles up to 10 μm [75]. Raman spectroscopy analysis, the sample by using monochromatic light to excite the molecules causing scattering of the beam which gives the structural information of the sample. Raman spectroscopy can detect microplastic to a size range 1 to 20 μm [25] and in few cases it provide the analysis of microplastic down to 500 nm [76]. Other thermoanalytical technique like pyrolysis gas chromatography/mass spectrometry (pyr-GC/MS) and thermogravimetric analysis-mass spectrometry (TGA-MS) has been applied for microplastic identification [77]. However, only 1 study [69] has applied pyr-GC/MS. Availability of the instrument, cost factor and the researcher's objective determine the option for the technique to proceed.

Table 2 Comparison of abundance and characteristics of microplastic in lake water.

Location	Abundance	Polymer	Category	Size class	References
Lake Hovsgol, Mongolia	20,264 particles/km ²	Not identified	fragments, film, line/fiber	0.355 - 0.999 mm 1.00 - 4.749 mm	Free <i>et al.</i> [37]
Six Largest Swiss Lake	91,000 particles/km ²	PP, PE, PS	fragments, pellets, cosmetics beads	< 1 mm	Faure <i>et al.</i> [38]
Lake Bolsena & Lake Chiusi, Italy	0.82 - 4.42 particles/m ³ (Bolsena) 2.68 - 3.36 particles/m ³ (Chiusi) 0.01×10 ⁶ - 6.8×10 ⁶	Not identified	fragments, fibers, fibers (Chiusi)	< 0.5 mm	Fischer <i>et al.</i> [39]
Taihu Lake, China	items/km ² (Plankton net) 3.4 - 25.8 items/L	Cellophane, PET, Polyester	fibers	0.1 - 1 mm	Su <i>et al.</i> [40]
Lake Winnipeg, Canada	193,420 items/km ²	Not identified	fibers, films	-	Anderson <i>et al.</i> [41]
20 Major Lake, Wuhan City, China	1,660.0 ± 639.1 items/m ³ to 8,925 ± 1,591 items/m ³	PET, PP	fibers	< 2 mm	Wang <i>et al.</i> [42]
West Dongting & South Dongting Lake, China	616.67 - 2,216.67 items/m ³ W. Dongting 716.67 - 2,316.67 items/m ³ S. Dongting	PS	fibers	< 0.5 mm	Jiang <i>et al.</i> [43]
Qinghai Lake, China	0.05×10 ⁵ - 7.58×10 ⁵ items/km ²	PP, PE	sheet	0.1 - 0.5 mm	Xiong <i>et al.</i> [44]
8 Urban Lake, China	2,425 ± 247.5 to 7,050 ± 1,060.66 items/m ³	PP	line	< 2 mm	Yin <i>et al.</i> [45]

Location	Abundance	Polymer	Category	Size class	References
Poyang Lake, China	5 - 34 items/L	PP, PE	fibers	< 0.5 mm	Yuan <i>et al.</i> [46]
Lake Kallavesi, Finland	0.27 ± 0.18 particles/m ³ (Manta trawl) 1.8 ± 2.3 (> 300 µm), 12 ± 17 (100 - 300 µm), 155 ± 73 (20 - 100 µm) particles/m ³	PP, PE	fibers, fragments	0.02 - 0.1 mm	Uurasjarvi <i>et al.</i> [47]
Red Hill, India	5.9 particles/L	HDPE, LDPE, PP, PS	fibers, fragments	2 mm	Gopinath <i>et al.</i> [48]
Ox-bow Lake, Nigeria	1,004 - 8,329 items/m ³ (dry)	PET, PVC-Dry	beads and pellets	1 - 3 mm	Oni <i>et al.</i> [49]
Veeranam Lake, India	201 - 8,369 items/m ³ (rainy)	PVC-raining	pellets	0.51 - 1 mm	Bharath <i>et al.</i> [50]
Lake Guaiba, Brazil	28 items/km ² with range 13 - 54 items/km ²	Nylon, PE, PS	fibers, fragments	1 - 0.3 mm	Bertoldi <i>et al.</i> [51]
Subalpine Lake, Italy (Maggiore, Iseo, Garda)	11.9 ± 0.6 - 61.2 ± 6.1 items/m ³	PP, PE	fragments	0.1 - 0.25 mm	Bertoldi <i>et al.</i> [51]
Lake Naivasha, Kenya	40,000 particles/km ² (Iseo); 39,000 particles/km ² (Maggiore); 25,000 particles/km ² (Garda)	PE, PS, PP	fragments	-	Sighicelli <i>et al.</i> [52]
Lake Ulansuhai, China	0.183 ± 0.017 - 0.633 ± 0.067 particles/m ² Mean 0.407 ± 0.135 particles/m ²	Polyester, PP, PE	fibers	-	Migwi <i>et al.</i> [53]
Dongting & Hong Lake, China	1,760 ± 710 - 10,120 ± 4,090 items/m ³	PE, PS, polybutylene terephthalate	fibers	< 2 mm	Wang <i>et al.</i> [54]
Poyang Lake, China	900 - 2,800 items/m ³ (Dongting)	PE, PP	fibers	0.33 mm	Wang <i>et al.</i> [55]
Rawal Lake, Pakistan	1,250 - 4,650 items/m ³ (Hong)	PP, PVC, PE, PS	fibers	< 0.5 mm	Jian <i>et al.</i> [56]
Lake Mead & Mahava, USA	1,064 ± 90 items/m ³	PE, PP, PET	fibers, fragments	< 1 mm	Irfan <i>et al.</i> [57]
Wuliangshuai Lake, China	0.142 items/0.1 L	Polyester, PVC	fragments	< 1 mm	Baldwin <i>et al.</i> [58]
Gehu Lake, China	0.44 - 97 particles/m ³	Not identified	fibers	0.355 - 1 mm	Baldwin <i>et al.</i> [58]
Nine lakes, Patagonia, Argentina	3.12 - 11.25 items/L	PS, PP, PE, PVC	fibers	< 2 mm	Mao <i>et al.</i> [59]
Süreyyabey Dam Lake, Turkey	1.51 - 22.22 number/L	Polyester, PP	fibers	0.1 - 0.5 mm	Xu <i>et al.</i> [60]
Lake Simcoe, Canada	0.9 ± 0.6 microplastics/m ³	PET	fibers	≤ 1 mm	Alfonso <i>et al.</i> [61]
Crater Lake, Erzurum, Turkey	4.09 particles/m ³ (in 330 µm mesh)	PET, PET & PVC blend	fibers	-	Tavsanoğlu <i>et al.</i> [62]
Three Gorges Reservoir, China	5.25 particles/m ³ (in 100 µm mesh)	Polyurethane, Polyester, PE, PP	fibers, fragments	-	Felismino <i>et al.</i> [63]
	0.25 ± 0.22 particles/L (grab)				
	0.40 ± 0.39 particles/m ³ (manta)				
	-	Not identified	-	-	Comakh <i>et al.</i> [64]
	1,597 - 12,611 numbers/m ³	PS, PP	fibers	< 0.5 mm	Di and Wang [65]

Location	Abundance	Polymer	Category	Size class	References
Lake Sassolo, Switzerland	2.6 microplastics/L	PE, PP	fibers	-	Velasco <i>et al.</i> [66]
Renuka Lake, India	21 ± 13 particles/L	PE, PP	fragments	-	Kumar <i>et al.</i> [67]
Lake Erie and Lake Ontario, Canada	460,000 particles/km ² (2012 - 2014) 230,000 particles/km ²	Not identified	pellets, fragments fragments	0.355 - 0.999 0.355 - 0.999	Mason <i>et al.</i> [68]
Western Lake Superior, Canada	37,000 ± 27,000 particles/km ²	PVC, PE	fibers	-	Hendrickson <i>et al.</i> [69]
Six Lakes, Southern Siberia, Russia	4 - 26 microplastics/L	Not identified	foam, fragments, films	31 - 16 nm	Malygina <i>et al.</i> [70]
Phewa Lake, Nepal	1.51 particles/L (rainy season) 2.96 particles/L (winter season)	Not identified	fibers	< 1 mm	Malla-Pradhan <i>et al.</i> [71]

Table 3 Microplastic abundance of lake water expressed in range across the world.

Lake	Lower range	Upper range	Unit
Qinghai Lake, China	5,000	758,000	km ²
Taihu Lake, China	10,000	6,800,000	km ²
Taihu Lake, China (bulk)	3,400	25,800	m ³
Poyang Lake, China	5,000	34,000	m ³
Wuliangsu Hai Lake, China	3,120	11,250	m ³
Lake Ulansu Hai, China	1,760	10,120	m ³
20 major lakes Wuhan, China	1,660	8,925	m ³
Ox bow Lake, Nigeria (rainy)	201	8,369	m ³
Ox bow Lake, Nigeria (dry)	1,004	8,329	m ³
8 Urban Lake, China	2,425	7,050	m ³
Hong Lake, China	1,250	4,650	m ³
Dongting Lake, China	900	2,800	m ³
South Dongting Lake, China	716.67	2,316.67	m ³
West Dongting Lake, China	616.67	2,216.67	m ³
Lake Guaiba, Brazil	11.9	61.2	m ³
Lake Mead & Mahava, USA	0.44	9.7	m ³
Bolsena, Italy	0.82	4.42	m ³
Chiusi, Italy	2.68	3.36	m ³
Gehu Lake, China	1,510	22,220	m ³
Three Gorges Reservoir, China	1,597	12,611	m ³
Plain and Mountainous Lake, Siberia, Russia	4,000	26,000	m ³

Table 4 Microplastic abundance of lake water expressed in average across the world.

Lake	Average abundance	Unit
Lake Naivasha, Kenya	407,000	km ²
Winnipeg, Canada	193,420	km ²
Six largest Swiss Lake	91,000	km ²
Subalpine Lake, Italy Iseo	40,000	km ²
Subalpine Lake, Italy Maggiore	39,000	km ²
Subalpine Lake, Italy Garda	25,000	km ²
Lake Hovsgol, Mongolia	20,264	km ²
Veeranam Lake, India	28	km ²
Lake Erie, Canada	460,000	km ²
Lake Ontario, Canada	230,000	km ²
Western Lake Superior, Canada	37,000	km ²
Poyang Lake, China	1,064	m ³
Lake Kallavesi, Finland	0.27	m ³
Red Hill Lake, India	5,900	m ³
Rawal Lake, Pakistan	1,420	m ³
Nine Lakes, Argentina	0.9	m ³
Sureyyabey Dam, Turkey (mesh size 330 µm)	4.09	m ³
Sureyyabey Dam, Turkey (mesh size 100 µm)	5.25	m ³
Lake Simcoe, Canada (grab sample)	250	m ³
Lake Simcoe, Canada (manta)	0.40	m ³
Sassolo, Switzerland	2,600	m ³
Renuka Lake, India	21,000	m ³
Phewa Lake, Nepal (rainy/ wet)	1,510	m ³
Phewa Lake, Nepal (winter/ dry)	2,960	m ³

Microplastic abundance and characteristics in lake water

Microplastic abundance in lake water

Table 2 shows the outline of microplastic abundance in lake water globally. Out of 35 reviewed studies 18 were from Asia, 8 from Europe, 7 from America while 2 studies were carried out in Africa. China is leading in microplastic research (12 articles). Comparison of studies between various regions shows lack of standardized methods for sampling making it difficult for comparison. Therefore, there is an urgent need to develop a standardized method for sampling and unit of result expressed. For better comparison of microplastic abundance among studies, the year of sampling is to be considered. To compare concentration of microplastic between various localities, the data obtained were differentiated based on units expressed as items/km² and items/m³. Similarly, items/m² were converted into items/km² and items/L into items/m³ for easy comparison (**Tables 3** and **4**).

To compare the abundance of microplastics in lake water, the studies that used the same mesh size (300 - 333 µm) and same reported units (items/ km²) were compared. Taihu Lake, China reported extremely the highest level of microplastic concentration in lake water worldwide ranging from 10,000 - 6,800,000 items/km² [40]. High population density around the vicinity of the lake, enormous amount of effluent and garbage discharge by rivers and non-point source into the lake is the cause of large concentration of microplastics in Taihu Lake [40].

Lake Erie and Lake Ontario, Canada also reported a high quantity of microplastic concentration of 460,000 and 230,000 particles per km² respectively [68]. Also, the abundance of microplastic concentration was high in Lake Winnipeg, Canada (193,420 particles/km²) [41]. Lake Naivasha, Kenya reported high

average microplastic abundance of 407,000 particles/km² [53]. Intense anthropogenic activities, shallow nature of the lake having no clear outflow of water and the use of smaller mesh size (150 µm) are the reason behind the high concentration of microplastic in Lake Naivasha [53]. Likewise, Faure *et al.* [38] explored 6 largest Swiss Lake and found an average microplastic abundance as 91,000 particles /km². Similarly, among the 3 Subalpine Lake, Iseo, Maggiore and Garda, the average concentration of microplastic were 40,000, 39,000 and 25,000 particles/km² respectively [52]. Even the remote mountain Lake Hovsgol situated in Mongolia was found to have relatively high abundance of microplastic (20,264 particles/km²) as a result of improper waste management system [37]. However, Veeranam Lake, India reported a low concentration of microplastic (28 items/km²) [50].

With regards to units expressed in volume for microplastic concentration, the highest abundance was recorded in Poyang Lake, China which ranged from 5,000 - 34,000 items/m³ [46]. In Taihu Lake, China bulk sampling captured 3,400 to 25,800 items/m³ of microplastic [40]. Similarly, other lakes in China like Gehu Lake, Ulansuhai Lake, Wuliangshuai Lake and 3 Gorges Reservoir also showed high concentration of microplastic pollution (**Table 3**). In general, intense human activities, plastic and domestic waste disposal, fishery related activities are the reason behind high microplastic load in surface water lakes of China. The lowest microplastic abundance was observed in Lake Bolsena, Italy which ranges from 0.8 - 4.42 items/m³ [39]. As there is wide variation in the lower and upper limit range, it is better to express the result as average concentration for microplastic abundance so that inter comparison could be made among various studies across the world. As for the result expressed as average microplastic concentration, Renuka Lake, India was found to have the highest microplastic concentration as 21,000 ± 13,000 particles/m³ [67] followed by Red Hill Lake, India (5,900 items/m³) [48]. Among the review studies Lake Kallavesi of Finland was found to have the lowest microplastic concentration of 0.27 items/m³ [47]. Oni *et al.* [49] studied Ox-Bow Lake in Nigeria for 2 seasons and found the level of microplastic higher in dry season than raining season which was also the case of Phewa Lake, Nepal [71] (**Table 4**)

Characteristic of microplastic in lake water

Shape and size

In the environment microplastic is found in an array of shape and sizes. Fibers, fragments, films, pellets, lines, sheets, foam and beads are the different shapes of microplastic reported in this review study. **Figure 1** shows the percentage distribution of microplastic by shape. Fibers was found to be the most dominant shape detected in lake water (71.43 %). Fibers are the most common shape of microplastic encountered in fresh water sediments [28,77] and water [28]. The likely sources of fibers to surface water includes domestic effluent [78], disintegration of fishing nets and lines [79], and atmospheric deposition [58]. Next to fibers, fragments accounted for 37.14 % and the sources of fragments to the lake are mainly due to disintegration of plastic and cosmetic products [51]. Likewise, beads and pellets together accounted 14.29 % of the total microplastic particles in all 35 studied lake water. Oni *et al.* [49] reported beads and pellets as the dominant shape of microplastic in Ox-Bow Lake linked to rural culture where beads making is important part of their life and some use them as tools in fishing. Whereas, pellets are connected to plastic industries located nearby the study area.

The smallest size distribution and composition of microplastics precisely depends on the overall sampling methods [24,34]. From these reviewed studies it was found that the most prevalent size range of microplastic differ greatly among studies. Eleven out of 35 studies expressed the dominant size class in range. Whereas, 15 studies reported the upper size limit in which maximum number of microplastic was obtained in < 0.5 and < 2 mm size class (**Table 2**). Nine reviewed studies did not mention the size class. Different sizes of microplastic particles may be linked with the variation in the sampling methodology as different mesh sizes are used [28]. Therefore standardized method for microplastic sampling is recommended.

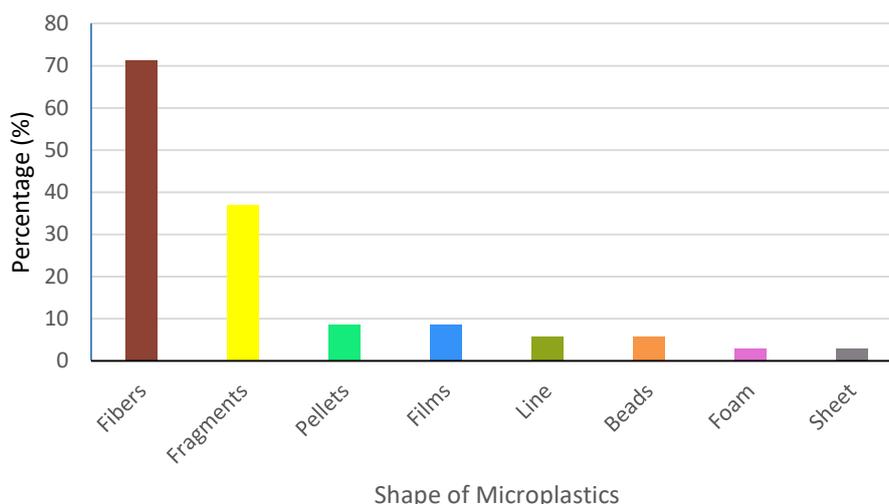


Figure 1 Percentage composition of microplastic by shape in lake water.

Chemical characterization of microplastic

For determining microplastic pollution chemical composition is the point of reference [80]. FTIR and Raman spectroscopy can be helpful to identify the chemical composition of microplastic which may be able to trace the possible sources of microplastic in freshwater [81]. Twenty-seven out of 35 studies reported the polymer composition of microplastic. In lake water, polypropylene (PP) and polyethylene (PE) was found to be main polymer types (54.29 and 51.43 % respectively) followed by polystyrene (PS) and polyethylene terephthalate (PET/polyester) which accounts for 25.71 % each. Of the total plastic demand globally by resin type, PE and PP accounts for 30.3 and 19.7 % respectively [1]. Hence, this could be the prime factor for the dominant of these 2 polymers in surface water as a result of mismanagement of plastic waste. Other types of polymers recorded in this review study were polyvinyl chloride (PVC), nylon, cellophane, polybutylene terephthalate, PET and PVC blend, and polyurethane. Percentage composition of polymer from reviewed study for lake water is given in **Figure 2**.

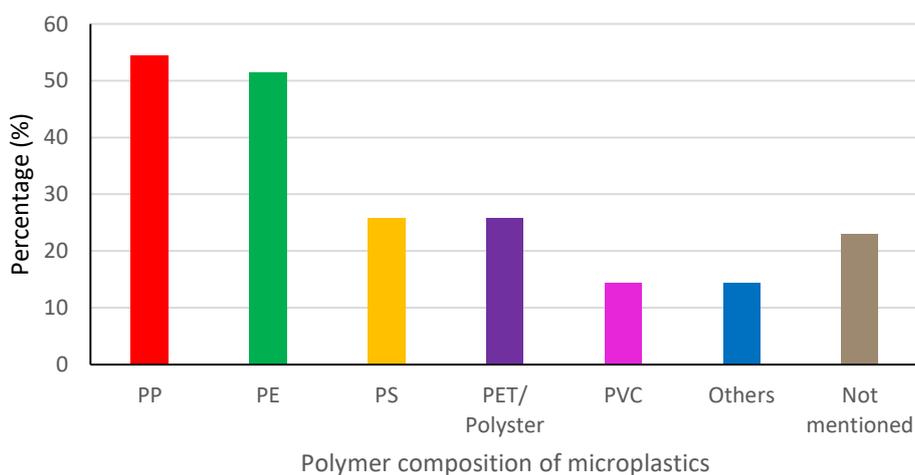


Figure 2 Polymer composition by percentage in lake water.

Conclusions

Microplastic pollution have now become the subject of interest to researchers, policy makers and even the general public. These microplastic pollutants is a serious threat not only to the marine environment but also to the freshwater bodies which has direct connection to human life. However, there is confined knowledge about microplastic in lake water which should be explored further in terms of its occurrence, characteristics and effects to aquatic organisms. The present review shows that there is no standardized method for microplastic sampling and processing which may bring variation in the results. Moreover, inter-study comparison of data is difficult when there is no uniformity in the reported unit so researchers should express the result of microplastic concentration both as average concentration and range. There is urgent need for scientist around the globe to set the standards for microplastic pollutant in marine and freshwater habitat so that researchers know the status of water body of their study site. This in turn helps to create awareness in general public about the negative consequences of microplastic pollution in turn will be a step ahead to tackle these emerging pollutants.

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