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A Review on Microplastic in Freshwater Lake Sediments from Asian Countries: Methods and Abundance

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Abstract

This review paper summarizes the methods used for measuring microplastic in freshwater lake sediments and also compares the distribution and characteristics of microplastic in freshwater lake sediment in Asia. Bulk sampling using Van Veen grab or stainless steel shovel was the most common sampling tool used for sediment sampling. Density separation using sodium chloride (NaCl) is the most common process for the extraction of microplastic from lake sediments. For microplastic quantification, the common preliminary technique is visual counting aided by an optical microscope. Whereas, spectroscopy like Fourier transform infrared spectroscopy (FTIR) and Raman spectroscopy is the most commonly used technique for polymer identification. High abundance of microplastic reaching 11 to 3153 items/ kg was observed in the lakeshore sediment of Poyang Lake, China. In the lake bottom sediment of Ulansuhai Lake, the concentration of microplastic was low (24±7 to 14±3 items/kg). Polyethylene and polypropylene was the widely used polymer in Asia.

Keywords Microplastic, freshwater, lake sediment, abundance, Asia

1. Introduction

In modern society, plastic has occupied every sector of development activities to make life safe and comfortable. Effectual sewerage system, access to safe water, sustainable transport, universal network, economical and healthful medical care, and food safety are not possible without the use of plastic. With its wide application global production has increased to 368 million tons in 2019 (PlasticsEurope, 2020). Huge consumption and fast disposal of plastic are leading to assemblage of plastic litter (Strungaru et al., 2019). This has raised growing concern due to its negative environmental impact (Yang et al., 2021). The small bits of ingested microplastic cause bioaccumulation and further result in dangerous consequences for the overall growth and development, metabolic activities, reproductive ability, and survival of freshwater organisms (Galloway et al., 2017; Lu et al., 2016; Rochman et al., 2013).

In the environment, plastic occur in various sizes as mega-plastic (>100 mm), macroplastic (>20 mm), meso-plastic (20-5 mm), and microplastic (<5 mm) (Barnes et al., 2009). Microplastics are defined as plastic particles with a small size of <5 mm (Arthur et al., 2009). Depending on the mode in which they are generated, microplastic can be classified as primary and secondary. Microplastic manufactured in small size (<5 mm) used in medicine, cosmetic products, and detergents is called primary microplastic (Cole et al., 2011). Secondary microplastic is formed due to the breakdown of large plastic particles as a result of UV radiation, mechanical activities, physical, chemical, and biological interaction (Browne et al., 2007; Cole et al., 2011).

Initially, microplastic pollution studies were focused on the marine territory but now microplastic studies in freshwater habitats are progressing (Horton et al., 2017). Sediment is a vital long-term sink of microplastic (Li et al., 2020). About 6300 million tons of plastic debris have been produced between 1950 to 2015, out of which 79% have been piled up in dumping grounds or the surrounding (Geyer et al., 2017). To date, handful of studies report the evidence of the presence of microplastics in freshwater sediments (Yang et al., 2021), so the data on lake sediment is scarce (Gopinath et al., 2020).

Though, Asia accounts for 51% of the world's plastic production (PlasticsEurope, 2020) it is far behind in microplastic pollution studies. Thus, this review aims to compile available freshwater lake sediment data from Asian countries and (1) summarize the method used for collection, extraction and microplastic detection in lake sediments, and (2) compare the abundance and characteristics of microplastic in lake sediments of freshwater.

2. Methodology

A literature review was conducted using the Web of Science Core Collection in April 2021. A combination of keywords was used in our research as "microplastic" and "freshwater" and "lake" sediment. A total of 146 peer reviewed publications were found. It covers the span from 2001 to the beginning of 2021. 11 studies precisely related to microplastic in freshwater lake sediments from Asian countries, 4 reviews on freshwater sediments, and 2 reviews on the freshwater environment were selected for this study. All necessary details regarding methods, microplastic abundance, and characteristics were extracted. A summary of sampling method of microplastic in fresh water lake sediments is given in Table 1.

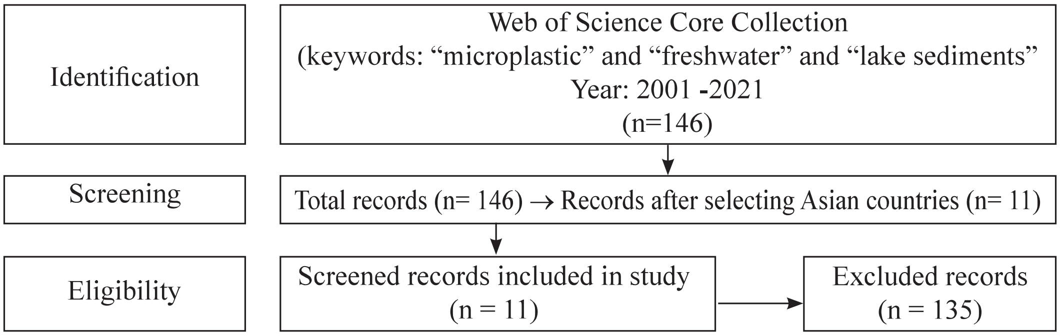

Fig. 1: Diagram presenting the information through the different phases of review

3. Sampling, extraction, and identification of microplastic from freshwater sediments

3.1 Sample collection

For quantifying microplastic, sampling is the first important step which may be selective, volume-reduced, and bulk sampling (Hidalgo-Ruz et al., 2012). In selective sampling, the sample is directly selected by the naked eye with means of sampling tools. In volume-reduced sampling, the sample volume is decreased during the sampling process. Whereas, in bulk sampling no sediment volume or weight is reduced (Hidalgo-Ruz et al., 2012). The bulk sampling technique was practiced in all 11 freshwater sediment studies. Different sample tools can be used for removing the sediments for microplastic study. In India, all 3 studies use Van Veen grab samples whereas, in China stainless-steel shovel, Peterson sample and Van Veen grab sample were used.

The sampling unit is precisely related to the sampling tool used (Hidalgo-Ruz et al., 2012). Around 63% of the studies use sampling unit as area, which varies from 25 cm^2, 225 cm^2, 400 cm^2, 1000 cm^2, 2500 cm^2 to 6000 cm^2. Other sampling units were weight (150 g, 1 kg, and 2 kg). One study did not mention a sampling unit.

In most of the studies, a uniform depth of 2 cm sediment sample was taken for the study of microplastic. Sampling site, depth, and distance from human habitat largely determines the concentration of microplastic (Qiu et al., 2016). Due to lack of standardized sampling technique, it hampers global inter-study comparison of the reported abundance of microplastic in sediments (Hanvey et al., 2017)

3.2 Sample separation

Processing of the sample is crucial to remove microplastic from complicated matrix (Li et al., 2018). Density separation is the most common method used for the extraction of plastic debris from the sediment sample which is based on the difference in density between the sediment sample and the plastic particles (Van Cauwenberghe et al., 2015). Saturated NaCl solution (density 1.2 g/cm^3) is a widely used separating solution because it is cost effective, non-toxic, and easily accessible (Hidalgo-Ruz et al., 2012). 6 out of 11 studies used saturated NaCl. Other solutions like potassium formate (density 1.58 g/cm^3) were also used by Zhang et al. (2016) and Xiong et al. (2018). Similarly, zinc chloride ($ZnCl_2$) solution (density 1.6 g/cm^3) was used by 3 studies as shown in Table 1. $ZnCl_2$ solution is more hazardous than potassium formate however, the cost is higher compared to $ZnCl_2$. Hence, care should be taken for reuse (Li et al., 2018). Elutriation, oil extraction method, and pressurized fluid extraction are some of the other extraction methods. However, these methods have not been used presently in Asian countries. For the better quantification of microplastic from sediment samples, the organic matter present in the sample should be removed. 82% (9/11) of the studies used 30% H_2O_2 to digest organic matter.

3.3 Sample identification

Visual inspection is a mandatory step in all reviewed studies (Hidalgo-Ruz et al., 2012). Stereomicroscope is mostly used for visual inspection but compound/ light microscopes are also used for microplastic identification (Irfan et al., 2020; Sruthy & Ramasamy, 2017). 1 out of 11 studies (Bharath et al., 2021) have not reported the type of microscope used. Fourier-transform infrared (FT-IR) spectroscopy or Raman spectroscopy are a more authentic technique for microplastic polymer confirmation. All the reviewed articles have either used FT-IR or Raman Spectroscopy for polymer identification. The distinction between plastic and natural particles is made possible by the use of spectroscopic techniques. The existence or absence of distinctive frequency bands resulting from excited vibrational states in the sample material is examined in the spectra from absorption or scattering processes. The spectral signal reflects the energy differential between an excited and ground state, which is specific to a certain molecule structure. In Fourier transform infrared (FTIR) microscopy a focal plane array (FPA) sensor is applied which allowed the detection of microplastic particles down to a size of 20 µm (Mintenig et al., 2019). Whereas, in Raman spectroscopy monochromatic light is used to excite the molecules which causes the scattering of the beam revealing the structural information of the sample. Raman spectroscopy can identify even smaller particle sizes ranges from 5 µm and 1 µm size. (Ossmann et al., 2018; Schymanski et al., 2018). Therefore, it is mainly suitable for identifying microplastics in drinking water samples where particle sizes are in the smaller range. Raman spectroscopy is complimentary to FTIR tests in that it offers a better response for symmetric, non-polar bonds while FTIR offers a more precise identification of polar groups. However, the choice of technique depends on research need and cost.

4. Abundance and characteristics of microplastic in lake sediments of Asia

4.1 Abundance of microplastic in Asian lake sediments

The overview of the abundance of microplastic in freshwater lake sediments in Asia is presented in Table 2. The average abundance of microplastic differs largely among various study regions.

In 2020, the highest abundance (92 to 604 items/kg) of microplastic was observed in lake bottom sediment of Veeranam Lake, India (Bharath et al., 2021). This was probably due to fishery activities where plastic debris leached from fishery-related tools thereby increasing the load of microplastic concentration in Veeranam Lake (Bharath et al., 2021). In Poyang Lake, China, the concentration of microplastic (54-506 items/kg) is a little lower than Veeranam Lake (Yuan et al., 2019). A similar concentration was found in Red Hill Lake, India (Gopinath et al., 2020) and Lake Ulansuhai, China (Qin et al., 2020) as 27 items /kg and 24±7 to 14±3 items/kg respectively. All the reported unit for lake bottom sediments were items per kg except Vembanad Lake which express the concentration of microplastic (96-496) as items /m^2 (Sruthy & Ramasamy, 2017).

Poyang Lake, China (Liu et al., 2019) recorded the highest abundance of microplastic as 11 to 3153 items/kg in lakeshore sediment. Similarly, the south Dongting Lake had a higher concentration of microplastic than the west side of Dongting Lake (200 to 1150 items/kg south and 320 to 480 items/kg west Dongting Lake) (Jiang et al., 2018).

In Rawal Lake, Pakistan the concentration of microplastic in lakeshore sediment was recorded as 104 items/kg (Irfan et al., 2020). Due to poor waste management plans, even the Remote Lake in Tibet Plateau was found to have a high concentration of microplastic (4-1219 items/m^2) (Zhang et al., 2016). In Qinghai Lake, China, a similar microplastic concentration (50- to 1292 items/m^2) was found and the important source of microplastic in Qinghai Lake was considered to be tourism activities (Xiong et al., 2019).

4.2. Characteristics of microplastic in lake sediments

Microplastic typically can be categorized into fibers, films, fragments, foam, and pellets (Fahrenfeld et al., 2019). Fibers are the most common component found in freshwater lake sediments. 8 out of 11 studies reported fibers as the dominant type found in lake sediment. However, fragments were the dominant type of microplastic detected in the sediment of Poyang Lake specifying the source as secondary that may have been generated by fragmentation of plastic waste (Liu et al., 2019). Likewise, Sruthy and Ramasamy (2017) also found secondary microplastic as the source of microplastic in the sediment of Vembanad Lake where the sediment was dominated by film and foam. Poor waste management practices, the dense human settlement around the water bodies, domestic waste input and fishing activities are some of the factors that attribute to the high concentration of fibers in those lake sediments of Asia.

Polymer identification of microplastic can be analyzed by Fourier-transform infrared spectroscopy (FT-IR) and Raman spectroscopy. In Asia, the main polymer type found in freshwater lake sediments is polyethylene (PE) followed by polypropylene (PP) as shown in Table 2. Other types of polymers like polystyrene (PS), and polyethylene terephthalate (PET) dominated in Dongting Lake (Jiang et al., 2018). In Taihu Lake, cellophane was found to be the most abundant type of microplastic (Su et al., 2016).

The sources of microplastics entering the lake include the direct mixing of wastewater, washing clothes along the lake's edge, improper waste management by hotels and restaurants, recreational boating in the eastern part, and beach littering by both locals and visitors (Malla-Pradhan et al., 2022b). Another potential source of microplastics is runoff from urban ditches (Malla-Pradhan et al., 2022a).

5. Conclusion.

Microplastic contamination is beginning to pollute our aquatic ecosystem. Studies of freshwater lake sediments are limited around the world. This review article provides research progress and the status of microplastic contamination in Asian countries which indicates that Asia lies far behind in microplastic studies except for China. Rapid population growth, weak implementation of pollution law, and haphazard disposal of plastic waste in Asian countries is the reason for microplastic pollution. More microplastic research needs to be conducted to aware people of the negative consequences it brings to our environment. Simple and cost-effective standardized methods for sampling and measurement of microplastic will synthesis researchers of Asian countries in this new field.

Table 1: Sampling techniques for microplastic extraction from freshwater lake sediment, Asia

S N	Location	Instrument Used	Sample depth and area/ mass	Density Separation	Detection	Purification	Reference
1	Red Hill Lake, India	Van Veen grab	150 g	NaCl	Stereomicroscope ATR-FTIR + SEM/EDX	30% H_2O_2 + Fe(II),	Gopinath et al. (2020)
2	Vembanad Lake, India	Van Veen grab	25cm^2	NaCl	Compound Microscope, micro Raman spectrometer	30% H_2O_2	Sruthy and Ramasamy (2017)
3	Veeranam Lake, India	Van Veen grab	1 kg	$ZnCl_2$	Visually, ATR-FTIR	30% H_2O_2	Bharath et al. (2021)
4	Rawal Lake, Pakistan	Stainless-steel trowel	2cm, 15cm 15cm	NaCl	Light microscope, FTIR	30% H_2O_2	Irfan et al. (2020)
5	Lakes in Tibet plateau, China	Shovel	2cm, 20cm × 20cm	Potassium formate	Stereomicroscope Raman Spectroscopy + SEM		Zhang et al. (2016)
6	Poyang Lake, China	Shovel	2cm, 50cm × 50cm	NaCl	Stereomicroscope, SEM		Liu et al. (2019)
7	Dongting Lake, China	Stainless-steel shovel	2cm, 0.3 m × 0.2 m	$ZnCl_2$	Stereomicroscope Micro-Raman Spectroscopy	30% H_2O_2 +Fe(II)	Jiang et al. (2018)
8	Taihu Lake China	Peterson sample	2 kg	NaCl	Stereomicroscope □-FTIR, SEM/EDS	30% H_2O_2	Su et al. (2016)
9	Qinghai Lake, China	Stainless-steel shovel	2cm, 20cm × 20cm	Potassium formate	Stereomicroscope Raman Spectroscopy	30% H_2O_2	Xiong et al. (2019)
10	Poyang Lake, China	Van Veen Grab	0.25 m^2, 500g (twice)		Stereomicroscope Micro-Raman Spectroscopy	30% H_2O_2	Yuan et al. (2019)
11	Lake Ulansuhai of Yellow river basin, China	Van Veen Grab	10cm	NaCl + $ZnCl_2$	Stereomicroscope FTIR, SEM/EDS	30% H_2O_2	Qin et al. (2020)

Table 2: Comparison of microplastic abundance and characteristics of freshwater lake sediment, in Asia

SN	Study Area	Microplastic abundance	Shape	Polymer Type	Reference
1	Red Hill Lake, India	27 items/kg	Fibers fragments films	PE, PP	Gopinath et al. (2020)
2	Veeranam Lake, India	92 to 604 items/kg mean 309 items/kg	Fibers, fragments, foam, pellets	Nylon, PE, PS, PP, PVC	Bharath et al. (2021)
3	Poyang Lake, China	54-506 items/kg dry weight	Fibers, films, fragments	PP, PE	Yuan et al. (2019)
4	Lake Ulansuhai of yellow river basin, China	247 to 143 items/kg	Fibers	PE, PET, PP, PVC	Qin et al. (2020)
5	Taihu Lake China	11-234.6 items/kg dry weight	Fibers	Cellophane	Su et al. (2016)
6	Vembanad Lake, India	96-496 items /m^2	Film, foam	LDPE	Sruthy and Ramasamy (2017)
7	Lakes in Tibet plateau	8±14 to 563±1219 items/m^2	Sheet, lines, fragments, foam	PE, PP	Zhang et al. (2016)
8	Qinghai Lake, China	50 to 1292 items / m^2	Fibers, sheets	PE, PP	Xiong et al. (2019)
9	Rawal Lake, Pakistan	1.04 item/0.01 kg (104 items/kg)	Fibers, fragments	PE, PP	Irfan et al. (2020)
10	Poyang Lake, China	Average 1134 items/kg dry weight range 11 to 3153 items/kg dry weight	Fragments		Liu et al. (2019)
11	Dongting Lake, China	320 to 480 items/kg and 200 to 1150 items/kg west & south	Fibers	PET	Jiang et al. (2018)

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