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Synthesis of dominant plastic microfibre prevalence and pollution control feasibility in Chinese freshwater environments

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Abstract

Microplastic pollution of freshwaters is known to be a great concern in China and these pollutants can be discharged into the coastal environment through fluvial processes, posing threats to the global marine ecosystem. This paper reviewed the literature measuring microplastic pollution in the Chinese freshwater environment and found that microfibres dominate other plastic morphologies in more than 65% of samples collected in surface water, sediments and effluents of wastewater treatment plants and domestic sewers. Current potential sources of microfibre pollution are identified including fishery activities, laundry sewage, and waste textiles according to previous research. Recommendations are offered using the circular economy management framework, such as textile waste reuse and recycling systems in China, for improving current control measures for microplastics in freshwaters.

Keywords: Microplastic, microfibre, freshwater, textile, China

1. Introduction

Microplastics, defined as plastic debris with a size ranging from 1 µm to 5 mm, have been detected in various environments as emerging contaminants since 2004 (Eerkes-Medrano et al., 2015; Horton et al., 2017). Given their large surface area to volume ratio (SVR) and hydrophobicity, microplastics can easily absorb other pollutants present in environments, including *Persistent Organic Pollutants* (POPs) and pathogenic microorganisms, and deliver them elsewhere (Caruso, 2019). Microplastics can also release toxic substances (monomers and additives) during degradation processes (Zou et al., 2017). Ingestion of microplastics by small organisms can have detrimental impacts, with the potential for bioaccumulation into higher trophic rungs and negative effects on the human food chain (Caruso, 2019; Yuan et al., 2019; Zou et al., 2017). Microplastics in environments can also pose threats to respiratory and olfactory systems of organisms through inhalation (Shi et al., 2021; Verla et al., 2019). The Chinese fluvial system is one of the most important sources of microplastics in global marine environments, repeatedly demonstrated over the last decade from field measurements (Zhang et al., 2018) and simulations of microplastic transportation (van Wijnen et al., 2019).

Several patterns of microplastics abundance have been documented in major Chinese river basins since 2014, such as the Pearl River (Fan et al., 2019; Lam et al., 2020; Lin et al., 2018; Ma et al., 2020), Yangtze River (Hu et al., 2018; Li et al., 2019a; Li et al., 2020; Zhao et al., 2014), Yellow River (Han et al., 2020; Qin et al., 2020; Wang et al., 2019), Dongting Lake (Jiang et al., 2018; Wang et al., 2018; Yin et al., 2020), and Poyang Lake (Liu et al., 2019c; Yuan et al., 2019). Given the substantial and growing industrial system and the market demand for plastic materials in China, the establishment and improvement of relevant management of plastic production and disposal in China may have beneficial impacts on mitigating the global fluvial microplastic discharges (Xu et al., 2020). It is estimated that more than two million tonnes of plastic microfibres are released into global oceans annually (Sunanda et al., 2019). A number of studies on microplastic pollution in Chinese freshwaters document the dominance of microfibres in samples (Ding et al., 2019; Lin et al., 2018; Su et al., 2016; Wang et al., 2017; Zhang et al., 2020b; Zhao et al., 2015; Zhao et al., 2014). Understanding the sources and characteristics of this form of microplastic pollution, will inform the efforts of stakeholders and authorities to reduce emissions of microfibres from Chinese freshwaters into the global marine environment.

Definitions of '*microfibre*' in the literature are ambiguous. For example, microfibre can refer to natural fibres (e.g. cotton, wool, linen and silk), synthetic fibres (e.g. nylon, polyester and acrylic) and anthropogenic cellulosic fibres (e.g. viscose and rayon) at the same time (Jerg and Baumann, 1990; Liu et al., 2019a). Microfibre can also be classified into staple fibres (veranne) and filament (sillionne) according to their "*Length-Diameter Ratio*" (LDR) (Salvador Cesa et al., 2017). An explicit definition of '*microfibre pollution*' is required to avoid confusion associated with different particles. In the textile industry, microfibres are usually defined as fibres finer than 1 denier and less than 10 μm in width (Jerg and Baumann, 1990). Liu et al. (2019a) combined the fineness and LDR standards of fibres, as well as the size standard of microplastics, to define microfibre as '*any natural or artificial fibrous materials of threadlike structure with a diameter less than 50 μm, length ranging from 1 μm to 5mm, and LDR greater than 100*'. This definition aids particle characterisation but eliminates the finer fibres that pose the greatest risks to respiratory systems that are increasingly used in the textile industry, such as sports apparel (Wright and Kelly, 2017). Here, we do not assign a minimum fibre width to account for these common fibres of potentially great ecological detriment. The definition used herein is explicitly targeting material, and is also inclusive of particle size; '*Plastic microfibres*' are defined here as fibrous particles made from synthetic petrochemical-derived polymers of between 1 μm to 5 mm in length. Natural textile fibres have recently been found to dominate fibre populations in a multiple environments (Guen et al., 2019; Stanton et al., 2019; Suaria et al., 2020). Natural textile fibres and some regenerated textile fibres (e.g. viscose, rayon) that are synthesised from natural cellulosic material (Liu et al., 2019a), have similar potential environmental impacts to plastic fibres, including the release of chemical additives during degradation (Stanton et al., 2019). Here, this article will only focus on plastic microfibres, due to the limitations of current research progresses on natural fibre pollution.

It is well acknowledged that microplastic pollution encompasses a wide range of substances, and it is challenging to manage a large panoply of microplastics together (Rochman et al., 2019). Reclassification of microplastics by material types and morphologies can contribute towards more targeted regulations, such as establishing relevant legislative policy guidelines of plastic microbeads (Xu et al., 2020). Plastic microfibres may be disproportionately problematic because they are likely to be the most common microplastic morphology in the Chinese freshwaters, and have the potential to cause significant ecological harm through entwining and/or clogging organisms breathing and feeding apparatus (Ma et al., 2020; Yuan et al., 2019). The number of publications on plastic microfibres has rapidly increased over the last 5 years, and have focused on different environmental matrices and methodologies. The rapid increase in work means that it is timely to review and reflect on the key trends established, to identify limitations in this work and, to suggest areas where understanding remains limited, particularly in China. In the past few years, Sunanda et al. (2019) reviewed the microfibre pollution in global marine environments and stated that rivers delivered the most microfibre pollution from domestic drainage system to oceans; while Singh et al. (2020) reviewed global microfibre pollution conditions and reported that China has the largest microfibre discharge capacity, globally (approximately 9.17 Mt/year). This paper focuses more specifically on microfibre pollution with an emphasis on freshwater environments in China; the specific research objectives are as follow:

a. Review plastic microfibre abundances in Chinese freshwater environments including surface waters, sediments, and effluents of wastewater treatment plants;
b. Use the reviewed information to investigate the potential sources of plastic microfibres in Chinese freshwater environments, and;
c. To suggest potential management interventions to reduce plastic microfibre pollution.

2. Plastic microfibre abundance in the Chinese freshwater systems

Zhou et al. (2020) investigated plastic microfibre pollution in industrial sewage and effluents of wastewater treatment plants (WWTPs) in an industrial textile district of Zhejiang (China). Their results showed the highest recorded concentration of 54,100 microfibres per litre. Although local WWTPs have been recorded to remove 84.7% - 99.5% of plastic microfibres from sewage (Zhou et al., 2020), the high concentrations recorded mean many would still pass through these facilities. For example, 573.5 microfibres per litre were still be detected in the effluent of WWTPs in the study of Zhou et al. (2020). There are few studies that solely investigate microfibre pollution in Chinese freshwater environments, but many have quantified microfibre concentrations within broader investigations of microplastic pollution.

2.1. Data collection and screening methods

For the purpose of more comprehensively understanding the abundance of plastic microfibres in China's freshwater environment, this study searched the publications available on "*Web of Science*" (WOS) and "*China National Knowledge Internet*" (CNKI) from 2014 to 19th November 2020, focused on freshwater microplastic pollution (search string for WOS: *'microplastic* AND (water OR freshwater OR wastewater OR sediment* OR sewage OR river* OR lake* OR reservoir*) AND CU = China'*; and similar search string in Chinese for CNKI). All publications involving the investigation of microplastic abundances in three freshwater environmental matrices (surface water, sediment and effluents of wastewater treatment plant (WWTP)) were selected for further review. These publications usually qualified microplastics into one of four categories according to their physical properties, namely fibre/line, fragment/sheet, film and sphere/pellet (there are also articles separating foamed microplastics as a category). After excluding the articles that did not provide the proportion of fibrous microplastics, a total of 93 papers were included in this study.

For each paper, all samples in every individual investigated waterbody (e.g. different rivers, lakes, ponds, or different wastewater treatment plants) were classified into a single sample set. If a study conducted a multi-scale investigation on one waterbody (e.g. during multiple seasons, or before and after a typhoon event, etc), the samples from that waterbody were grouped again according to the research variables (e.g. dry season and wet season). Although some articles have investigated microplastic pollution in different waterbodies or at multiple scales, some of them only provide an average or an overall proportion of microplastic shapes, without a complete dataset for each sample that they took. In such cases, all samples corresponding to one microplastic shape proportion were classified as a sample set, even if these samples were collected from different waterbodies or seasons. When fibrous microplastics accounted for the largest proportion in one microplastic sample set compared to other microplastic shapes, we recorded that plastic microfibres were dominant in that sample set. Some publications only provided figures without the underlying data. In these cases, Image J was used to estimate the proportion of microplastic shapes from the figures. This approach may lead to small errors but, the impact on the overall result is expected to be negligible.

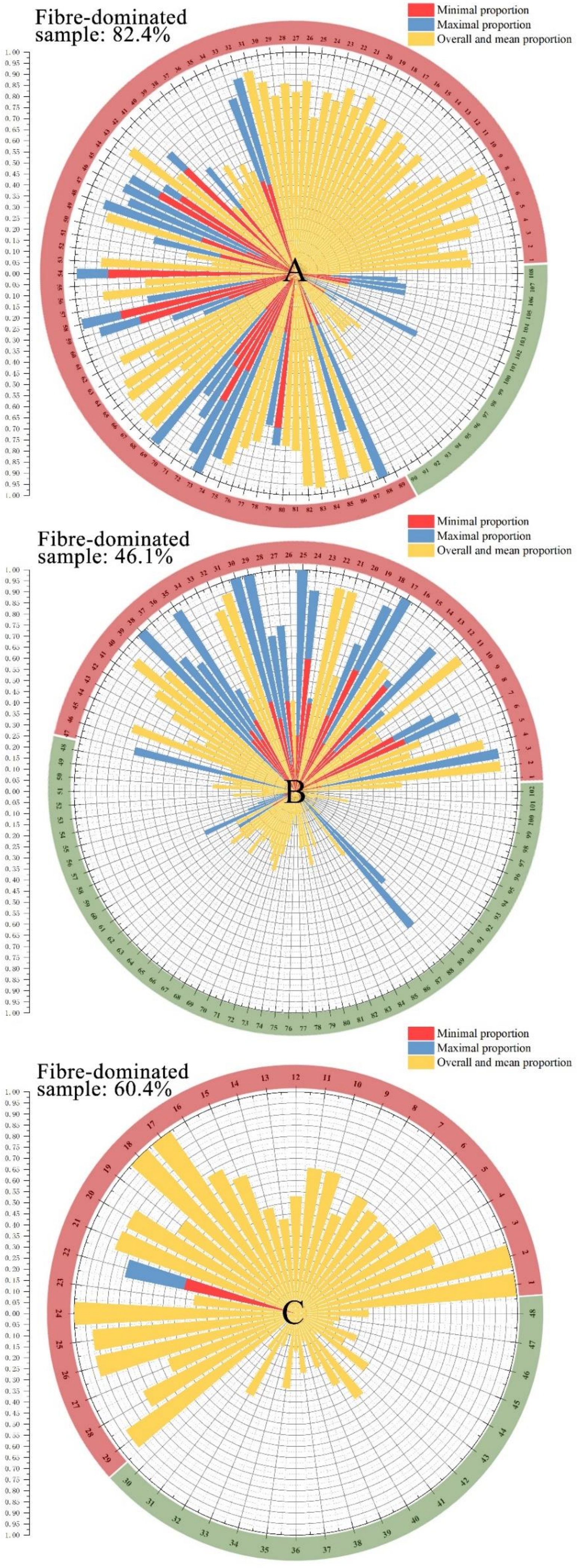

Figure 1. Bar-polar diagrams of the proportion of fibrous microplastics in each set of samples collected from Chinese freshwater environments (made in OriginLab 2018). (A) Surface water samples, (B) sediment samples, (C) WWTP effluent samples. Red bars and blue bars represent the minimal and maximal proportions of fibrous microplastics, respectively. Yellow bar are the overall or mean proportion in samples. The radius of the polar circle represents 100%. The light red outer ring indicates the fibre-dominated samples while the light green outer ring indicates other-shape dominated samples. Each number on the rings corresponds to a set of data. The sources of these data are shown in Table S1, S2 & S3.

2.2. Results and limitations

As a result of the above decision, 108, 102 and 48 sets of microplastic shape distribution data were extracted for surface water, sediment, and wastewater effluent samples, respectively. These are presented in Fig. 1, which shows the proportion of fibrous microplastics in each sample. Some papers provided a range of fibrous microplastic proportions while other papers provided an average or a total value of their samples. We distinguished these situations with coloured bars in Fig. 1. In 82.4% (n=108), 46.1% (n=102) and 60.4% (n=48) of the samples of surface water, sediments and sewage treatment plant effluent, respectively, fibrous microplastics accounted for the largest proportion.

The major limitation of the methods is the reliability of original data. As there are currently no unified microplastic investigation methods, the microplastic concentrations reported by different publications might be influenced by various sampling strategies, quality assurance/quality control methods, sample preparation treatments, and identification approaches that the scientists selected (Cowger et al., 2020). For example, Zhang et al. (2020a) used plankton nets with different pore-size and pump samplers to sample microplastics from the urban surface water of Qin River (in Beibu Gulf), and found that different sampling equipment had significant impacts on the recorded concentrations. Thus, it is a challenge for us to define the validity, comparability, and representativeness of those collected data and eliminate potential errors and bias. Whilst these limitations will affect the absolute concentrations recorded in studies, the fundamental finding that fibres dominated water samples, is unlikely to be altered. Future research on investigating microplastics should apply the '*Reporting guidelines for microplastic research*' (Cowger et al., 2020) to ensure the comparability and reproducibility. The visual identification approaches that have been certified by related industries (e.g. the Chinese textile industry standard microscopy identification methods *FZ/T 01057,3-2007*) or established for microplastic research communities (Lusher et al., 2020; Stanton et al., 2019) recommended to distinguish natural, cellulose regenerated, synthetic and other fibrous materials in future microfibre research.

3. Potential sources of plastic microfibres in China

Some articles have summarised the potential sources of plastic microfibres in China, such as the textile industry, plastic products, laundering and plastic bags (Singh et al., 2020). Our study finds that several potential sources are repeatedly mentioned by the literature including fishery, laundry effluents, textile industry sewage, wastewater treatment plants and other sources (e.g. atmospheric deposition) in China (e.g. Li et al., 2019b; Su et al., 2016; Wang et al., 2017; Zhou et al., 2020). In view of the limitations of current traceability studies, it is challenging to define the contribution ratio of different microfibre pollution sources. Thus, the order of following sections does not indicate the level of pollution severity associated with these sources.

3.1. Fishery

Frequent use of aging fishing gear (such as nets, lines and ropes) in fishery activities is one of the most discussed sources of microfibre pollution in Chinese freshwater environments (Ma et al., 2020; Yuan et al., 2019; Zhao et al., 2014). For example, the paint that protects the hull of fishing vessels can release microfibres (Mishra et al., 2020). Ma et al. (2020) reported microplastic concentrations that were positively correlated to the prosperity of local fishery activates, with microplastic concentrations higher in fishpond water than in pond influents (Pearl River Estuary), where 68.1-78.9% of total microplastics were fibres. Such conditions might be important because ponds have been the major waterbodies for inland aquaculture since 2013 in China (Kang et al., 2017).

The output value of fisheries in China has continuously increased over recent decades (Ma, 2019). By 2018, China had a fishing population of 18,786,800 and 863,900 fishing boats, with a total fishery output value was 2.59 trillion RMB (approximately 0.4 trillion US dollars) (Xu and Lv, 2018). Aquaculture and fishing made up 49.6% of the total fishery output value in 2018 (compared to fishery processing and service) (Cao and Sang, 2019). Primary fisheries (i.e. aquaculture and fishing) with relatively low added value of products, still occupies the main industrial share of the total fisheries output in China, indicating that China still notably has an extensive traditional fisheries production. Traditional fishery production is associated with severe resource inefficiencies and other ecological problems (i.e. one ton of water used for aquaculture yields 0.07 US dollars) (Fig. 2) (Ma, 2019). Aquaculture usually requires the long-term use of fishing gear and equipment, which is likely causing further microfibre pollution via gear degradation and gear-aging issues. By 2018, China's freshwater aquaculture area reached 51,464.6 km^2 while the equivalent marine aquaculture area reached only 20,430.7 km^2. This demonstrates the high plastic emission potential of freshwater fisheries in China.

Microfibre pollution from fishing activities can directly enter waterbodies and has been recorded in multiple fish species (Chagnon et al., 2018; Tien et al., 2020; Yuan et al., 2019). Microfibres can be similar in size, shape and colour to fish prey, leading to mistaken ingestion by fishes (Ma et al., 2020; Mishra et al., 2020; Tien et al., 2020; Yuan et al., 2019). Yuan et al. (2019) found that fibrous microplastics were the most common microplastic morphology found in adult female *Carassius auratus* (main fish consumed by local people) in the Poyang Lake. Small aquatic invertebrate organisms can also ingest microfibres, which pass up through the food chain to predatory fish. Hu et al. (2018) documented the dominated microfibre abundances in tadpoles from the Yangtze River Delta. Through consumption of farmed fish, microfibres could enter human bodies. From 1952 to 2017, the per capita consumption of aquatic products in China rose from 2.67 kg to 11.5 kg (3.3 times) (Cao and Sang, 2019), which indicates the potential risks of Chinese people ingesting microplastics and microfibres are also rising. Whilst the current understanding of the impact of microplastics (including microfibres) on human health is in the research stage, it is still essential to locate the fishery sources of microplastics and microfibres and to apply management measures to reduce potential environmental and health risks.

source: http://www.91esh.com/forum.php?mod=viewthread&tid=13091895

source: https://www.meipian.cn/2zdf4k5r

Figure 2 (A) Picture of Chinese traditional fishery activities; (B) picture of people washing clothes in the river in China (see source addresses in picture)

3.2. Laundry effluent

Domestic laundry effluent is also a source of microfibres, which is frequently mentioned in previous research (Li et al., 2019a; Mishra et al., 2020; Salvador Cesa et al., 2017; Wang et al., 2017). Chemical (e.g. detergent) and physical (e.g. washing machine) washing cycles during laundry can cause surface wear and tear of clothing, releasing microfibres that can pass through WWTP (Cotton et al., 2020; De Falco et al., 2018). Napper and Thompson (2016) observed that a 6 kg wash load of acrylic fabric could release about 700,000 microfibres on average during each laundry cycle and De Falco et al. (2018) found that 5 kg of polyester fabric could release over 6 million microfibres during each laundry cycle. In 2019, the Chinese annual gross production of acrylic and polyester fibres reached 0.58 and 47.51 million tonnes, respectively (Sun, 2020).

Not all laundry sewage is treated by WWTPs in China before entering waterbodies; some will directly enter the freshwater environment without treatment. Shen et al. (2020) reported that a residential area in Shanghai had only established a rainwater drainage system and was not equipped with a domestic sewage discharge pipe. As a result, rainwater and domestic sewage shared one drainage system, so that laundry wastewater entered waterbodies through the rainwater pipe directly, without essential treatment. Thus, in urban areas, microfibers can directly enter urban catchments through drainage systems that merge rainwater and sewage drains, particular during high flow rainfall events when a large volume of water containing microfibres can be released to river systems, bypassing treatment. In addition, in sub-urban and rural areas of China, the number of sewage treatment systems is limited, as well as some villagers retain their habit of washing textiles directly in ponds, streams or rivers (Fig. 2). The numbers of plastic microfibres derived from this hand washing is difficult to quantify, complicating efforts to estimate global plastic microfibre budgets.

3.3. Textile industry sewage

The textile industry is a major producer of synthetic fabric, representing a complex set of processing steps, from the grey cloth into garments or other textile products, including sizing, de-sizing, scouring, bleaching, mercerizing, dyeing, printing, and finishing with multiple discharges of liquid (Hou et al., 2019; Zhang, 2020). Industrial sewage discharged during the above mentioned processes is an important source of microfibre pollution due to limited sewage treatment, particularly in developing regions (Zhang, 2020). Zhou et al. (2020) found the microfibre concentration (537.5 microfibres per liter in average) in the sewage in a Chinese textile industry park (Shaoxing, Zhejiang) was 10-10,000 times higher than in most municipal sewage in China.

Meanwhile, industrial wastewater from dyeing and printing textiles had notably higher microfibre concentrations than other textile workshops (Zhou et al., 2020). Standard textile dyeing and printing workshops often own private treatment processes for discharged effluent. Hou et al. (2019) found that even if a Chinese WWTP for dyeing and printing textile workshops could reach 90 - 94% removal rate of microfibres, there would still be 2.7×10^7 to 7.5×10^7 of microfibres discharged into waterbodies from that single mill per day.

In 2019, there were about 34,734 textile industry enterprises (above Chinese designated size) registered on the National Government trade record, which implies a huge discharge of industrial plastic microfibres. Due to the heavy use of chemicals (e.g. acids, alkali and enzyme), some studies regard the textile industry wastewater as a more important source of plastic microfibre than domestic laundry wastewater in China (Napper and Thompson, 2016; Zhou et al., 2020).

3.4. Wastewater Treatment Plants (WWTPs)

WWTPs in the regions with advanced environmental technologies and developed economic structures, usually can efficiently remove microplastics (including microfibres) from wastewater using a range of treatment techniques, including air flotation, filtration and flocculation processes. For example, removal rates of microplastics over 95% have been documented in WWTPs in Canada (98.3%), Finland (99%) and USA (99.9%) (Li et al., 2019b; Mason et al., 2016; Talvitie et al., 2015). However, currently in China, WWTPs usually do not have such a high removal rate. In the reviewed literature on microplastic pollution in Chinese WWTPs, 29 sets of data provide microplastic removal rates of those WWTPs, of which 14 sets (48.28%) fail to reach 80% removal rates and 20 sets (69.00%) fail to achieve 90% remove rate (Tab. S3). The removal rates of microplastics in three riverside WWTPs along Guangzhou urban area of the Pearl River reached only 40.5%, 40% and 57.1% (Lin et al., 2018). Two tertiary-treatment WWTPs in Wuhan, which represent advanced treatment following two preceding treatments for high-quality water effluent, had microfibre removal rates as low as 66.1% and 62.7% (Tang et al., 2020) and 43.75% was reported for a tertiary WWTP in Nanjing (Chen et al., 2020). In 2017, 2209 WWTPs treated a total of 45.29 billion m^3 of sewage in Chinese urban areas (Liu and Xu, 2019). Those WWTPs undertake both domestic sewage and industrial wastewater and have great potential to discharge into the environment.

Plastic microfibres removed from WWTPs can still end up in the environment because the particulate matter removed during treatment is sometimes applied to agricultural land as sludge. The annual output of water-containing sludge (approximately 80% water content) from Chinese WWTPs is up to 40 million tonnes, and the amount of microplastics entering the soil environment from sludge is estimated to reach between 15 trillion to 51 trillion, annually (Li et al., 2019b). Tang et al. (2020) found that microfibres accounted for 60% to 75% of microplastic in samples of sludge from two WWTPs in Wuhan. The substantial quantities of microfibres in sludge can still find a way to re-enter the freshwater environment via overland flow after rainfall, especially if agricultural practices are not promoting soil conservation measures. Therefore, microfibres retained by WWTPs also need to be carefully managed to avoid secondary diffusion.

3.5. Other sources

Wear and tear of fabrics, tyre dust and mismanaged disposal of textiles have also been mentioned as potential sources of plastic microfibres in the environment (Henry et al., 2019; Zhou et al., 2020). About 60% of the fabric produced globally is made from synthetic fibres and China produces 70% of the world's synthetic fibres (Mishra et al., 2020). In addition, atmospheric deposition and precipitation are also important potential sources of microfibres in China, which can deposit microfibres directly into freshwater environments, or via rainwater generated runoff. Zhou et al. (2017) reported that the deposition flux of microplastics in the Chinese coastal urban area (at coastal city - Yantai, Shandong Province in E coast) was 1.46×10^5 particles per m^2 each year and that 95% of particles were fibrous microplastics. Cai et al. (2017) found that 90% of microplastics in atmospheric samples collected in Dongguan, South China were fibrous. Liu et al. (2019b) found fibres were the dominant shape (67%) in atmospheric microplastic samples in Shanghai. Microplastic concentrations in atmospheric deposition are likely to be highly variable through time and space, as documented by Stanton et al.

(2019) and research is required monitoring atmospheric deposition at higher resolution and longer timescales to truly assess its significance as a source.

4. Management of microfibres in China

Synthetic fibres are important materials for society and economic development and, unlike cosmetic microbeads, are not easy to remove from production. The implementation of strategies to reduce plastic microfibre pollution are challenging, and will involve waste disposal, wastewater treatment, public consumption and manufacturing processes.

The "*Circular Economy Promotion Law of the People's Republic of China"* (CEPL) legislated on 1st January 2009 was revised on 26th October 2018, defines the meaning of 'circular economy' in the context of Chinese legislation as "*a generic term for the reducing, reusing and recycling activities conducted in the process of production, circulation and consumption*" (Standing Committee of the National People's Congress, 2009). The concept of circular economy provides a regulatory framework for addressing Chinese microfibre pollution problems in the ways of reduction, re-use and resource recovery, discussed individually below.

4.1. Reducing

4.1.1. Improvement of Chinese fishery

CEPL defines reducing as '*reducing the consumption of resources and the production of wastes in the process of production, circulation and consumption*'. Reducing fishery waste production is a feasible way to decrease the emission of plastic microfibres and progress has been made in this area since the publication of the *Guiding Opinions on Speeding up the Development of Agricultural Circular Economy*, which proposes the establishment of a basic circular agricultural industrial system (National Development and Reform Commission, PRC et al., 2016).

China is the largest exporter of fish in the world and is in a critical period of transformation from traditional to modern and circular fisheries, with more efficient use of mechanized tools and equipment (Cao and Sang, 2019). The Chinese fishing population has been declining in recent years, dropping 7.7% from 20,350,400 in 2014 to 18,786,800 in 2018 and the freshwater aquacultural area has also dropped 15.4% from 60,808.88 km^2 in 2015 to 51,464.6 km^2 in 2018 (Xu and Lv, 2018). China's aquaculture is moving towards mechanised, digitised and automated equipment, which will improve efficiencies and reduce the quantities of wastewater discharge (Huang et al., 2019). Mechanisation can also reduce pollution caused by aging equipment. With technological upgrades and improvements, microfibre pollution discharged by Chinese fisheries is likely to decline. The magnitude of that reduction is not known and microfibre reduction is currently not the primary focus in this regulation.

4.1.2. Domestic and industrial textile effluent

Chemical and mechanical friction, water temperature and hardness, fabric features and laundry equipment are the major factors influencing the amount of plastic microfibres released from fabrics via the domestic (e.g. laundry) and industrial cleaning processes (Cotton et al., 2020; Liu et al., 2019a). De Falco et al. (2018) found that washing fabrics made of plain weave polyester materials released 162±52 microfibres per gram of fabric without detergent but, released 1273±177 microfibres with liquid detergent and 3538±664 microfibres with powder detergent. Using liquid detergent could help reduce microfibre release compared by powder detergents during the laundry process. That said, using less detergent could help further reduce microfibre pollution. Improving the efficiency of detergent in washing processes should be a future research direction in China (Dong et al., 2020).

Decreasing the mechanical friction during washing is another way of minimising plastic microfibre discharge. De Falco et al. (2018) reported using softener could reduce over 35% of microfibre discharge during laundry processes due to lesser mechanical friction. Yang et al. (2019) reported that using platen laundry machines could also reduce microfibre discharge compared with pulsator laundry machines. The discharge of microfibres also increases with rising water temperature and hardness during laundry

(Cotton et al., 2020; De Falco et al., 2018; Yang et al., 2019). Cotton et al. (2020) noticed a significant increase in microfibres discharged during washes with high water temperature (>40ºC) and long washing times (over 85 minutes). This indicates cooler and quicker washing in appropriate laundry equipment, combined with fabric softener, can effectively reduce the microfibre discharge. Governmental institutions and departments should collaborate with the washing machine and detergent production industry to establish an incentive mechanism and policies promoting appropriate washing regimes and encouraging investment in relevant technologies to reduce microfibres pollution.

Direct capture of released microfibres during washing is another approach to reducing microfibre loadings. Yang et al. (2019) report that filter bags assembled inside washing machines can effectively block fibres from entering laundry wastewater. These are already found in some separate washing machine accessories, such as the *Cora Ball* that can trap microfibres (31%) in the drum of the laundry machine during washing and the *Guppy Friend* washing bag that protect fabrics from mechanical friction and intercepts microfibre discharge (54%) during laundry processes (Fig. 3) (Herweyers et al., 2020; Napper et al., 2020).

External filters are also an effective option to stop laundry fibres entering sewage, such as *XFiltra* (Fig. 3), which can reduce microfibre discharge by 78% (Napper et al., 2020). Recently, laundry balls and washing bags (Fig. 3) have become popular but in China these products are not aimed at reducing microfibre discharge. External laundry filters are still rare in the Chinese market. Whilst these products are capable of intercepting fibres that might otherwise have polluted aquatic and terrestrial environments, it is important to note that they may still enter the environment after disposal as they are likely to end up in landfill (Napper et al., 2020).

https://yichang.1688.com/offer/606869392645.html

https://www.163.com/dy/article/EU5EIJA60514EELP.html

Figure 3 (A) Cora Ball (coraball.com); (B) Guppy Friend Washing Bag (us.guppyfriend.com); (C) XFiltra external laundry sewage filter(www.xerostech.com); (D) and (E) the in-drum laundry filter net and washing bag sold in China without special microfibre-block function (see source addresses in picture)

4.1.3. Sewage treatment system

Mason et al. (2016) found that the quantity of microplastics in the influent of WWTPs was in direct proportion to the number of people that it serves. This finding may have implications for the enormous pollution pressure facing Chinese WWTPs. Li et al. (2019b) concluded that fibres flocculate relatively easily and settle-out during wastewater treatment. The primary treatment process (i.e. screening - initial sedimentation tank screened by pollutant density) can effectively remove microfibres, whereas the removal ability of the secondary treatment process (i.e. biological treatment via microbial activities and sedimentation) is currently limited for microfibres (Li et al., 2019b). The ability of the tertiary treatment to remove microplastics (include plastic microfibres) is controversial as some tertiary techniques might result in conflicting removal efficiencies; for example, low microplastic removal rates via percolation filters while membrane bioreactors have high microplastic removal capacity (Mason et al., 2016;

Talvitie et al., 2015). As such, fibres were the only shape of microplastic particles detected from the water outlet of tertiary WWTPs in Beibu Gulf, Guangxi Province (Zhang et al., 2020a) and in Nanjing (Chen et al., 2020).

In order to effectively remove microfibres from wastewater, more studies are required on Chinese WWTPs and the physicochemical property of local sewage, and lessons to be learned from high-efficiency treatment technologies that are documented to effectively remove microfibres and microplastics elsewhere. The Municipal Governments should provide the latest information on wastewater purification standards for local WWTPs, including the technical memorandum (e.g. treatment guidelines) to tackle microplastics and microfibres, which will significantly reduce these pollutants discharge.

4.2. Reusing and recycling

Reusing was defined as '*the direct use of waste as using wastes as products directly, using wastes after repair, renewal or reproduction or using part or all wastes as components of other products'* in CEPL, and recycling defined as '*using wastes as raw materials directly or after regeneration*' (Standing Committee of the National People's Congress, 2009). Production of synthetic fibres does not only increase microplastic pollution, but also consumes a huge amount of petroleum resources and discharges CO_2 and other greenhouse gasses (Li and Yang, 2001; Liu et al., 2019a). There are benefits to the reuse and recycling of synthetic fibres rather than purely restricting pollution emissions.

4.2.1. Garbage Classification

The prerequisite of reuse is to collect discarded fabric. According to the China Textile Industry Federation, the country is estimated to generate over 20 million tonnes of waste fabrics annually, with a recycling utilization rate less than 0.1% (Guo, 2013). In developed countries (UK, Japan, USA and Germany), the recycling utilization rate of fabric wastes was higher than 15% (Guo, 2013). Huge quantities of waste textiles are being buried or burned in China, such as in Shanghai where clothing alone generated more than 130 thousand tonnes of waste, annually (Wang, 2019).

China established a national “*Municipal Solid Waste*” (MSW) classification system in 2019 (Wang, 2019). 46 major cities (including Beijing, Tianjin, Guangzhou, Chongqing, Shanghai etc.) are playing important roles in establishing the local domestic waste management regulations (Zhu et al., 2020). The regulations are affiliated with textile products (e.g. old clothes, bed sheets, pillows, quilts, leather shoes, plush toys, cotton-padded jackets, bags and silk products, etc.), with targets to encourage the recycling of these products by public and industrial sectors. The regulation imposes penalties on those who violate relevant regulations on garbage classification. For example, Ningbo links the behaviours that do not conduct garbage classification to personal credit files (Standing Committee of Ningbo Municipal People’s Congress, 2019). Shenzhen encourages setting separate waste-fabric collection containers in residential areas and promotes the recycling of collected fabrics (Standing Committee of Shenzhen Municipal People’s Congress, 2019).

4.2.2. Fabric Recycling

In reuse and recycling processes, fabrics are often stacked in domestic Chinese residences, which can be a challenge (Guo, 2017). In order to mobilise this fabric waste, China established a fabric recycling system. Major Chinese cities (e.g. Shanghai, Tianjin, Guangzhou, Shenzhen, and Qingdao) have established some notable progress in recycling systems for used clothing and materials from domestic (household) sources (Chen, 2017; Guo, 2017; Wang, 2019). Figure 4 summarises an overall process.

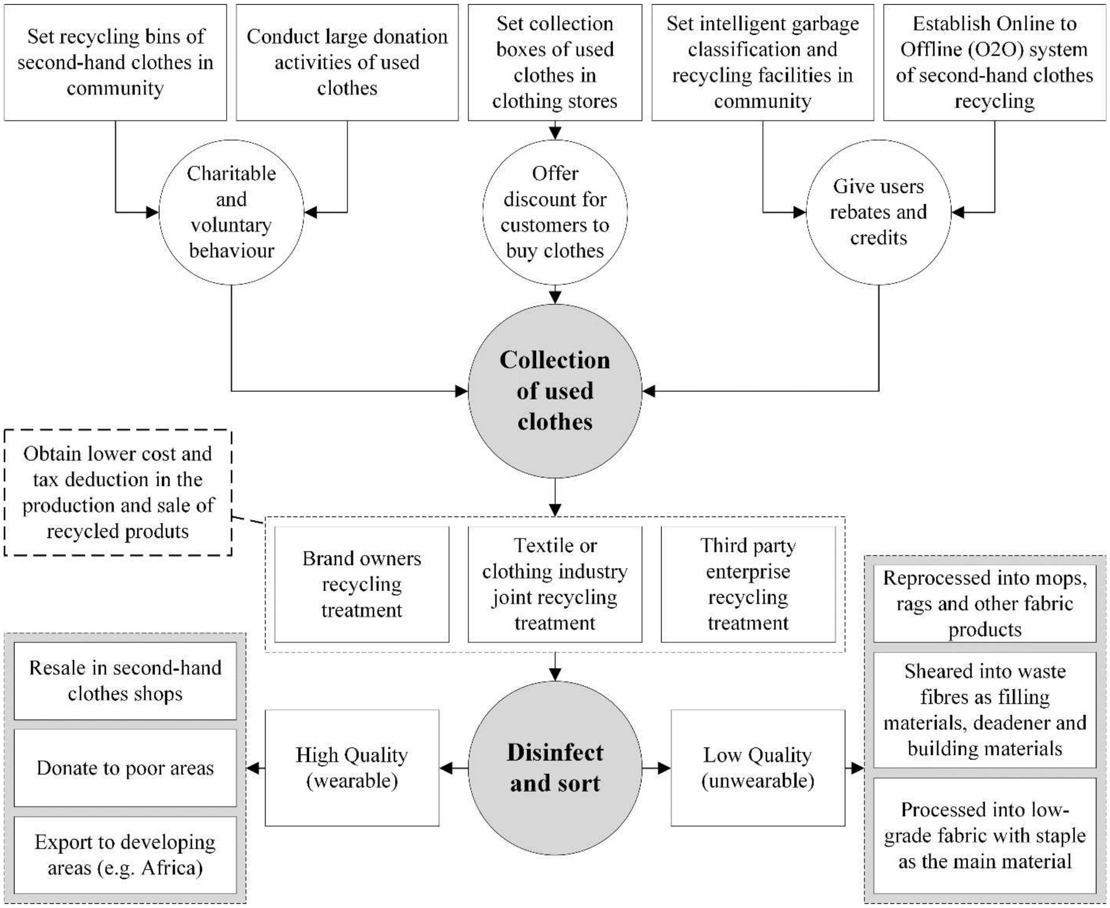

Figure 4 Old clothes recycling system in China (source: authors)

In China, commonwealth organizations, social and non-profit organizations, major clothing brands (e.g. *ZARA, H&M and Uniqlo*) and related enterprises cooperate with the municipal government. These are the major stakeholders that are responsible for recycling used clothing and materials (Chen, 2017; Wang, 2019). Used clothing products are usually collected from domestic recycling boxes (in community or clothing shops) or via used-clothes donation campaigns. For example, there are 40 recycling boxes that are located in 23 residential districts in Guangzhou and have collected approximately 58.33 tons of waste textiles between August and October in 2016 (Guo, 2017). More intelligent recycling systems are now developed using big data approaches in China (Fig. 5). For example, users can make an arrangement with a recycling company online via the internet or a mobile app to pick up their unwanted clothing and materials, termed an "*Online-to-Offline*" (O2O) approach

(Chen, 2017; Wang, 2019). Smart waste sorting systems (i.e. sorting devices) have now been placed in local communities, in order to improve the efficiency of recycling old fabrics (see Fig. 5). In 2015, the used clothing materials collected by smart household sorting machines have reached 7% of total collected recyclables in Tianjin (Chen, 2017).

Figure 5 A second-hand clothes donation box (green box in the left) and a smart waste sorting device in Chinese community (at University of Nottingham, Ningbo China; blue device in the right). The waste sorting device can encourage residents to dispose of recyclables scientifically by paying rebates electronically or by accumulating credits. (Source: author)

According to the *Catalogue of Products for Comprehensive Utilization of Resources and Preferential Labour Value-added Tax,* manufacturers of products that consist of 90% recycled fibres can have a 50% tax rebate in China (Wang, 2019). Such economic incentives encourage clothing brands, textile industry and third-party enterprises to invest in recycling of old fabrics.

Collected old clothing materials will be disinfected and sorted into two major categories, namely wearable and unwearable clothes. The wearable clothing is normally reused, refurbished and sold as second-hand clothing, or exported to developing regions (e.g. Africa). Charities also donate used clothes to poor areas (such as the northwest of China). A second-hand clothes-recycling project (namely '*Yiyibushe*') collected nearly 20 thousand tons of used clothes from more than 40 cities in China from July 2015 to the end of 2016, and donated more than 100 tons of wearable winter clothing to vulnerable communities (e.g. Tibet, Qinghai, Gansu, Yunnan and Guizhou) (Chen, 2017).

Unwearable clothing can be synthesised and reused as fabric products (e.g. mops and dusters). In addition, waste fabric materials can be physically disassembled into waste fibres and reused as filling materials for furniture, sound insulation materials and construction materials. For example, recycled fibres were used as vibration-adsorptive materials in roadbeds (Zhu et al., 2020). Unwearable waste fabrics can recover and transform into staple fibres by chemical and physical processes, and then woven into low-grade fabric products (Zhang and Zhao, 2012). Due to synthetic fibres usually have relatively high calorific value (i.e. polyethylene fibre can reach 46 MJ/kg), recycled fibres can also be burned in power stations or hot water plants with professional tail gas treatments (Li and Yang, 2001).

5. Conclusion

This manuscript reviewed plastic pollution in Chinese freshwater environments and found that microfibres dominate other plastics in more than 65% of samples. Microfibres contribute to the environmental impacts associated with microplastic pollution and are potentially disproportionately detrimental in environments because they can be easily ingested by aquatic organisms due to their flexible deformation and can tangle in breathing and feeding apparatus.

Domestic and industrial laundry wastewater, fisheries activity, residual microfibres in the effluent of WWTPs, atmospheric deposition and mismanaged waste fabrics are considered to be the major sources of microfibres in Chinese freshwater environments. Given the wide distribution of these microfibre sources in China, there is great potential to reduce microfibre discharges in China. Technological developments and behavioural changes encouraged through legislation can reduce the discharge of microfibres and promote the reusing and recycling of fabrics, reducing the potential for inappropriate disposal.

Our findings illustrate that China should establish legislative restrictions on wastewater discharges and upgrade the standards for WWTPs, including the separation of rainwater and wastewater drainage. Improving washing machines' wastewater purification performance, both through technological advances and behavioural change would also help to reduce microfibre discharge.

Lastly, we conclude that more research on investigating the trends of microfibre pollution and controlling microfibre pollution in China is urgently needed, given the high concentrations being recorded in the environment and the potential for significant reductions in pollution with behavioural change and technological improvements. Current developments, such as advancements in the fisheries industry, could dramatically lower microfibre concentrations but these do not have microfibre reduction as a core aim. Refocusing or adapting current strategies could better reduce and mitigate the impacts of microplastics in freshwaters, and their eventual discharge to the marine ecosystem that more importantly are urgently required further establishment of legislation and policy control to achieve reduction of microplastic (microfibre) pollution, in prior achieving relevant Sustainable Development Goals (SDGs) (i.e., 6, 14, etc.).

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Disclosure statement

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Appendix: microplastic concentration data from collected publications

Table S1 Supplemental materials for Figure 1 (A). A part of microplastic concentration and microfibre proportion data was estimated from the figures of literatures by Image J. For accurate raw data, please see original papers.

Index number in Figure 1 (A)	Citation	Location	Microplastic concentration (n/m^3)	Microfibre proportion	Dominant shape
1	(Zhao et al., 2014)	Yangtze Estuary System	500-10700	79.1%	Fibre
2	(Zhao et al., 2015)	Jiaojiang Estuary	Mean: 955.6	78%	Fibre
3	(Zhao et al., 2015)	Oujiang Estuary	Mean: 680	65%	Fibre
4	(Zhao et al., 2015)	Minjiang Estuary (Before typhoon)	Mean:1170	81%	Fibre
5	(Zhao et al., 2015)	Minjiang Estuary (After typhoon)	Mean: 1245.8	86%	Fibre
6	(Su et al., 2016)	Taihu Lake	3400-25800	70%	Fibre
7	(Wang et al., 2017)	Bei Lake, Wuhan City	Mean: 8925	86%	Fibre
8	(Wang et al., 2017)	Huanzi Lake, Wuhan City	Mean: 8550	96%	Fibre
9	(Wang et al., 2017)	Tazi Lake, Wuhan City	Mean: 6175	93%	Fibre
10	(Wang et al., 2017)	Sha Lake, Wuhan City	Mean: 6390	78%	Fibre
11	(Wang et al., 2017)	Nantaizi Lake, Wuhan City	Mean: 6162	68%	Fibre
12	(Wang et al., 2017)	Nan Lake, Wuhan City	Mean: 5745	53%	Fibre
13	(Wang et al., 2017)	Dong Lake, Wuhan City	Mean: 5914	77%	Fibre
14	(Wang et al., 2017)	Wu Lake, Wuhan City	Mean: 1660	68%	Fibre
15	(Wang et al., 2017)	Yangtze River Wuhan City section	Mean: 2516	76%	Fibre
16	(Wang et al., 2017)	Hanjiang River, Wuhan City	Mean: 2933	79%	Fibre
17	(Wang et al., 2017)	Houguan Lake, Wuhan City	Mean: 3795	62%	Fibre
18	(Wang et al., 2017)	Hou Lake	Mean: 2905	80%	Fibre
19	(Wang et al., 2017)	Huangjia Lake	Mean: 3421	74%	Fibre
20	(Wang et al., 2017)	Beitaizi Lake, Wuhan Lake	Mean: 3600	87%	Fibre
21	(Wang et al., 2017)	Jinyin Lake, Wuhan City	Mean: 4410	80%	Fibre
22	(Wang et al., 2017)	Longyang Lake, Wuhan City	Mean: 4854	87%	Fibre
23	(Wang et al., 2017)	Moshui Lake, Wuhan City	Mean: 5264	80%	Fibre
24	(Wang et al., 2017)	Sanjiao Lake, Wuhan City	Mean: 3641	83%	Fibre
25	(Wang et al., 2017)	Tangxu Lake, Wuhan City	Mean: 3230	71%	Fibre

26	(Wang et al., 2017)	Yandong Lake, Wuhan City	Mean: 2324	87%	Fibre
27	(Wang et al., 2017)	Yanxi Lake, Wuhan City	Mean: 2393	82%	Fibre
28	(Wang et al., 2017)	Zhushan Lake, Wuhan City	Mean: 2256	86%	Fibre
29	(Lin et al., 2018)	Guangzhou City section of the Pearl River	374-7924	80.9%	Fibre
30	(Hu et al., 2018)	Small waterbodies from Yangtze River Delta	480-21520	87.8%	Fibre
31	(Li et al., 2019)	18 lakes along Yangtze River	240-1800	93.81%	Fibre
32	(Wang et al., 2018a)	Dongting Lake	900-2800	41.9%-91.9%	Fibre
33	(Wang et al., 2018a)	Hong Lake	1250-4650	44.2%-83.9%	Fibre
34	(Yin et al., 2019)	Xianjia Lake, Changsha City	Mean: 3825	50%	Fibre
35	(Yin et al., 2019)	Yang Lake, Changsha City	Mean: 2425	55%	Fibre
36	(Yin et al., 2019)	Yue Lake, Changsha City	Mean: 3300	47%	Fibre
37	(Yin et al., 2019)	Yuejin Lake, Changsha City	Mean: 7050	58%	Fibre
38	(Yin et al., 2019)	Donggua Lake, Changsha City	Mean: 7050	42%	Fibre
39	(Ding et al., 2019)	Wei River	3670-10700	38.25%-61.95%	Fibre
40	(Yin et al., 2019)	Poyang Lake	5000-34000	41.2%	Fibre
41	(Wang et al., 2019b)	Ulansuhai Lake, Yellow River Basin	1760-10120	68.18%-78.64%	Fibre
42	(Jiang et al., 2019)	Baqu River, Tibet	Mean: 967	69%	Fibre
43	(Jiang et al., 2019)	Naqu River, Tibet	Mean: 817	93%	Fibre
44	(Jiang et al., 2019)	Lhasa River, Tibet	683-700	62%-71%	Fibre
45	(Jiang et al., 2019)	Nyang River, Tibet	483-517	71%-86%	Fibre
46	(Liu et al., 2020a)	Haihe River (pumping sampler), Tianjin	2640-18450	17.4%-86.7%	Fibre
47	(Wu et al., 2019)	Haihe Estuary	650-2700	24%-82%	Fibre
48	(Wu et al., 2019)	Yongdingxinhe Estuary	540-1550	45%-92%	Fibre
49	(Wu et al., 2019)	Dagu Estuary	Mean: 2400	89%	Fibre
50	(Zhou et al., 2020a)	Urban waters along Tuojiang River Basin	911.57-3395.27	35%-65.85%	Fibre
51	(Zhang et al., 2020a)	Qin River urban section (75 micron plankton nets) in Beibu Gulf	0.1-5.6	49.6%	Fibre
52	(Zhang et al., 2020a)	Qin River urban section (300 micron plankton nets) in Beibu Gulf	0.1-4.6	38.2%	Fibre
53	(Zhang et al., 2020a)	Qin River urban section (pumping sampler) in Beibu Gulf	16.67-611.1	88%	Fibre
54	(Han et al., 2020b)	the lower Yellow River near estuary	380000-1392000	84.56%-98.93%	Fibre
55	(Ma et al., 2020)	Fish ponds of Station 1, Pearl River Estuary	10300-60500	68.1%	Fibre

56	(Ma et al., 2020)	Fish ponds of Station 2, Pearl River Estuary	33000-87500	87.5%	Fibre
57	(Mao et al., 2020b)	Wuliangsuhai Lake, northern China	3120-11250	18.3%-67.9%	Fibre
58	(Tien et al., 2020)	Fengshan River system	334-1058	81%-99%	Fibre
59	(Zhang et al., 2020b)	Yongjiang River, Nanning City	500-7700	73.3%-92.2%	Fibre
60	(Jian et al., 2020)	Major tributries of Poyang Lake	289-1064	32%-59%	Fibre
61	(Jian et al., 2020)	Reserve sites of Poyang Lake	35-72	25%-45%	Fibre
62	(Wang et al., 2020c)	Manas River Basin, Xinjiang	21000-49000	88%	Fibre
63	(Chen et al., 2020a)	Jinze Reservoir in summer	24500-34900	73%	Fibre
64	(Chen et al., 2020a)	Suzhou Creek in summer	11600-21900	91.70%	Fibre
65	(Chen et al., 2020a)	Huangpu River in summer	19800-56800	93.50%	Fibre
66	(Chen et al., 2020a)	Jinze Reservoir in winter	23800-35800	67.10%	Fibre
67	(Chen et al., 2020a)	Suzhou Creek in winter	6700-15700	95.1%	Fibre
68	(Chen et al., 2020a)	Huangpu River in winter	11000-54300	93.8%	Fibre
69	(Di et al., 2019)	Danjiangkou Reservoir	467-15017	20.8%-99.2%	Fibre
70	(Jiang et al., 2018)	Lake shore surface water, West Dongting Lake	616.67-2216.67	45%-68%	Fibre
71	(Jiang et al., 2018)	Lake shore surface water, South Dongting Lake	716.67-2316.67	50%-77.42%	Fibre
72	(Jiang et al., 2018)	Lake centre surface water, West Dongting Lake	433.33-1500	66%-93%	Fibre
73	(Jiang et al., 2018)	Lake centre surface water, South Dongting Lake	366.67-1566.67	49%-100%	Fibre
74	(Di and Wang, 2018)	Mainstream, the Three Gorges Reservoir, China	1597-12611	28.6%-90.5%	Fibre
75	(Zhao et al., 2019)	Changjiang Estuary (Spring)	Mean:64	91.6%	Fibre
76	(Zhao et al., 2019)	Changjiang Estuary (Summer)	Mean: 166	82%	Fibre
77	(Zhao et al., 2019)	Changjiang Estuary (Winter)	Mean: 108	77.8%	Fibre
78	(Ye, 2020)	Urban surface water, Nanjing City	3475-21975	26.79%-69.38%	Fibre
79	(Xie et al., 2020)	Li River urban section, Guilin	44.4-85.3	70%-78%	Fibre
80	(Feng et al., 2019)	Inner channel of Xiaxin Dock, Dongting Lake	Mean: 600	78%	Fibre
81	(Feng et al., 2019)	Outer channel of Xiaxin Dock, Dongting Lake	Mean: 667	80%	Fibre
82	(Zhao et al., 2020b)	Surface water, semi-urban area, Shanghai	Mean: 6000	96%	Fibre
83	(Zhao et al., 2020b)	Surface water, centre urban area, Shanghai	Mean: 10000	97.2%	Fibre
84	(Liu et al., 2019b)	Lake centre, Poyang Lake	Mean: 16.24	37.8%	Fibre
85	(Deng et al., 2020a)	‘China Textile City’, Zhejiang Province	2100-71000	95%	Fibre

86	(Zhao et al., 2020a)	The Qiantang River and its tributaries, Hangzhou	54-3379	23%-74%	Fibre
87	(Xia et al., 2020)	Dong Lake, Wuhan City, Hubei Province	7400-29600	95.04%	Fibre
88	(Feng et al., 2020)	The Qilian mountains, Northeast part of Tibetan Plateau	66.67-773	25%-100%	Fibre
89	(Yan et al., 2019)	Guangzhou urban section of Pearl River	8725-53250	7%	Film
90	(Tan et al., 2019)	the Feilaixia Reservior, Beijiang River	0.28-1.1	15.73%	Film
91	(Yin et al., 2019)	Meixi Lake, Changsha City	Mean: 2563	46%	Fragment
92	(Yin et al., 2019)	Nianjia Lake, Changsha City	Mean: 5600	23%	Fragment
93	(Yin et al., 2019)	Dong Lake, Changsha City	Mean: 4113	34%	Fragment
94	(Li et al., 2020c)	Chongming Island, Yangtze River Estuary	0-259	33%	Fragment
95	(Wang et al., 2020a)	Qing River in Beijing in summer	Mean:170	33.75%	Fragment
96	(Wang et al., 2020a)	Qing River in Beijing in winter	Mean: 260	37.80%	Fragment
97	(Pan et al., 2020b)	Zhangjiang River of South eastern China	50-725	18.50%	Fragment
98	(Lam et al., 2020)	Inner Lingding Bay of the Pearl River Estuary	0.688-8.221	15-22%	Fragment
99	(Liu et al., 2019b)	Lake bank, Poyang Lake	Mean: 63.33	16%	Fragment
100	(Pan et al., 2020a)	Danjiangkou Reservoir	457-35466	0%-61%	Fragment
101	(Wu et al., 2020)	Inland waterway of Guangdong-Hong Kong-Macao Greater Bay Area	3500-25500	0.9%	Fragment
102	(Yan et al., 2019)	Pearl River Estuary	7850-10950	9%	Granule
103	(Zhang et al., 2019a)	Seven small-scale estuaries in Shanghai	13530-44930	3.87%	Granule
104	(Liu et al., 2019b)	Bird habitat, Poyang Lake	Mean: 710.26	24%	Pellet
105	(Mao et al., 2020a)	Mainstream of Yulin River	7-17	24-50%	Pellet/foam
106	(Mao et al., 2020a)	Tributaries of Yulin River	20-200	25%-50%	Pellet/foam
107	(Mao et al., 2020a)	Bays of Yulin River	200-600	16%-46%	Pellet/foam
108	(Fan et al., 2019)	Pearl River Basin	140-1960	20%	Sheet

Table S2 Supplemental materials for Figure 1 (B). A part of microplastic concentration and microfibre proportion data was estimated from the figures of literatures by Image J. For accurate raw data, please see original papers.

Index number in Figure 1 (B)	**Citation**	**Location**	**Microplastic concentration (n/kg dw)**	**Microfibre proportion**	**Dominant shape**
1	(Su et al., 2016)	the Taihu Lake	11-234.6	48%	Fibre
2	(Peng et al., 2017)	Changjiang Estuary	20-340	93%	Fibre
3	(Lin et al., 2018)	Guangzhou City Section of the Pearl River	80-9597	12%-93%	Fibre
4	(Peng et al., 2018)	Nanhuizui foreland tidal flat, Shanghai	Mean: 53	87.2%	Fibre
5	(Jiang et al., 2019)	Buqu River, Tibet	Mean: 130	54%	Fibre
6	(Jiang et al., 2019)	Naqu River, Tibet	Mean: 50	60%	Fibre
7	(Jiang et al., 2019)	Lhasa River, Tibet	180-195	54%-81%	Fibre
8	(Jiang et al., 2019)	Nyang River, Tibet	65-90	50%-70%	Fibre
9	(Hu et al., 2018)	Small waterbodies from Yangtze River Delta	35.76-3185.33	44.8%	Fibre
10	(Yuan et al., 2019)	Poyang Lake	54-506	44.1%	Fibre
11	(Li et al., 2019)	18 lakes along middle and lower reaches of Yangtze River	90-580	94.77%	Fibre
12	(Ding et al., 2019)	Wei River	360-1320	42.25%-53.20%	Fibre
13	(Wu et al., 2019)	Haihe Estuary	96.7-333.3	25%-89%	Fibre
14	(Wu et al., 2019)	Yongdingxinhe Estuary	56.7-113.3	62%-65%	Fibre
15	(Deng et al., 2020b)	Restored mangrove wetland at Jinjiang Estuary	980-2340	68.58%	Fibre
16	(Zuo et al., 2020)	Mangrove sediments of the Pearl River Estuary	100-7900	69.7%	Fibre
17	(Li et al., 2020c)	Chongming Island, the Yangtze River Estuary	10-60	25%-100%	Fibre
18	(Tien et al., 2020)	the Fengshan River System	508-3987	61%-93%	Fibre
19	(Jian et al., 2020)	Major tributries of Poyang Lake	821-1936	37%-72%	Fibre
20	(Fraser et al., 2020)	Hangzhou Bay Estuary	130-280	55%	Fibre
21	(Chen et al., 2020a)	Suzhou Creek (summer)	2200-7400	93.5%	Fibre
22	(Chen et al., 2020a)	Suzhou Creek (winter)	2900-9900	93.80%	Fibre
23	(Qin et al., 2020)	Lake Ulansuhai of Yellow river Basin, Inner Mongolia	14-24	40.1%-42.5%	Fibre
24	(Li et al., 2020a)	Huangjinxia Reservoir, Shannxi Province	233.33-870	60%-91%	Fibre
25	(Di et al., 2019)	Danjiangkou Reservoir	15-40	25%-100%	Fibre
26	(Wen et al., 2018)	Donggua Lake, Changsha City	Mean: 468.03	41%	Fibre
27	(Jiang et al., 2018)	Lake shore surface water, West Dongting Lake	320-480	41%-75%	Fibre

28	(Jiang et al., 2018)	Lake shore surface water, South Donting Lake	200-1150	12.17%-71%	Fibre
29	(Di and Wang, 2018)	Mainstream, the Three Gorges Reservoir, China	25-300	33.9%-100%	Fibre
30	(Yin et al., 2019)	East Dongting Lake	180-693	42%-100%	Fibre
31	(Zhao et al., 2020b)	semi-urban area, Shanghai	Mean: 1312.8	94%	Fibre
32	(Zhao et al., 2020b)	centre urban area, Shanghai	Mean: 2013.3	88.35%	Fibre
33	(Qi et al., 2019)	Moshui River, Shandong Province	0-170	46.91%	Fibre
34	(Wang et al., 2020d)	Nan Lake, Maanshan City, Anhui Province (spring)	93-2371	37%-53%	Fibre
35	(Wang et al., 2020d)	Nan Lake, Maanshan City, Anhui Province (summer)	48-505	28%-97%	Fibre
36	(Wang et al., 2020d)	Yushan Lake, Maanshan City, Anhui Province (spring)	173-1618	34%-72%	Fibre
37	(Wang et al., 2020d)	Yushan Lake, Maanshan City, Anhui Province (summer)	30-786	30%-79%	Fibre
38	(Liu and Fang, 2020)	Dishui Lake, Shanghai (around the lake site)	Mean: 46	0%-100%	Fibre
39	(Xu et al., 2019a)	North Port, Changjiang Estuary, Shanghai (March)	Mean: 195	79%	Fibre
40	(Xu et al., 2019a)	North Port, Changjiang Estuary, Shanghai (July)	Mean: 152.5	93%	Fibre
41	(Xu et al., 2019a)	South Port, Changjiang Estuary, Shanghai (March)	Mean: 58	77%	Fibre
42	(Xu et al., 2019a)	South Port, Changjiang Estuary, Shanghai (July)	Mean: 160	65%	Fibre
43	(Liu et al., 2020a)	North tributary, Gan River, Poyang Lake	2-9	46%	Fibre
44	(Liu et al., 2019b)	Bird habitat, Poyang Lake	Mean: 333.9	53.6%	Fibre
45	(Deng et al., 2020a)	‘China Textile City’, Zhejiang Province	16.7-1323.3	79%	Fibre
46	(Xu et al., 2020)	Liaohe Estuary, Liaoning Province	80-220	30.61%	Fibre
47	(Feng et al., 2020)	Qilian mountains, Northeast part of Tibetan Plateau	20-160	0%-75%	Fibre
48	(Rao et al., 2020)	Yongfeng River, Maanshan City, Anhui	5-72	33.7%	Film
49	(Han et al., 2020a)	Daliao River	20-193.33	28.75%	Film
50	(Liu et al., 2019b)	Lake Centre, Poyang Lake	Mean: 112.1	37.5%	Film
51	(Xu et al., 2020)	Daliao River, Liaoning Province	100-467	15.63%	Film
52	(Xu et al., 2020)	Shuangtaizi River, Liaoning Province	67-300	28.26%	Film
53	(Liu et al., 2020a)	Nanji Mount, Poyang Lake	14-102	18%	Foams
54	(Zhou et al., 2018)	Up stream of Le'an River	832-1334	4%-9.5%	Fragment
55	(Zhou et al., 2018)	Tributary of Le'an River	2619-3153	4%-7.5%	Fragment
56	(Zhou et al., 2018)	Downstream of Le'am River	929-1484	6%-18%	Fragment
57	(Wang et al., 2018b)	Wen-Rui Tang River, Wenzhou	18690-74800	4.9%-23%	Fragment

58	(Liu et al., 2019a)	Poyang Lake	11-3153	1%-45%	Fragment
59	(Wu et al., 2019)	Dagu Estuary	Mean:123.3	30%	Fragment
60	(Jian et al., 2020)	Reserve sites of Poyang Lake	41-182	12%-30%	Fragment
61	(Fraser et al., 2020)	Qiantang River, Tonglu	70-400	31%	Fragment
62	(Fraser et al., 2020)	Qiantang River, Fuyang	180-260	37%	Fragment
63	(Fraser et al., 2020)	Andong Salt Marsh	Mean:150	31%	Fragment
64	(Wen et al., 2018)	Xianjia Lake, Changsha City	Mean: 270.17	24%	Fragment
65	(Wen et al., 2018)	Yue Lake, Changsha City	Mean: 536.34	23%	Fragment
66	(Wen et al., 2018)	Nianjia Lake, Changsha City	Mean: 557.63	35%	Fragment
67	(Wen et al., 2018)	Yuejin Lake, Changsha City	Mean: 866.59	27%	Fragment
68	(Wen et al., 2018)	Meixi Lake, Changsha City	Mean: 779.12	24%	Fragment
69	(Wen et al., 2018)	Yang Lake, Changsha City	Mean: 375.55	26%	Fragment
70	(Wen et al., 2018)	Dong Lake, Changsha City	Mean: 635.18	28%	Fragment
71	(Wen et al., 2018)	Jinjiang River, Changsha City	Mean: 401.78	33%	Fragment
72	(Wen et al., 2018)	Longwanggang, Changsha City	Mean: 307.55	37%	Fragment
73	(Wen et al., 2018)	Laodao River, Changsha City	Mean: 580.79	29%	Fragment
74	(Wen et al., 2018)	Liuyang River, Changsha City	Mean: 364.9	22%	Fragment
75	(Zhang et al., 2020c)	Qiantan Park, Pudong new area, Shanghai	Mean: 35.46	13%	Fragment
76	(Zhang et al., 2020c)	Binjiang Forest Park, Pudong new area, Shanghai	Mean: 74.22	15%	Fragment
77	(Zhang et al., 2020c)	Dongtang Road Ferry, Pudong new area, Shanghai	Mean: 39.69	11%	Fragment
78	(Li et al., 2020b)	Doushan, Poyang Lake to Changjiang River Section	356-877	26%	Fragment
79	(Li et al., 2020b)	Dukou, Poyang Lake to Changjiang River Section	1090-1452	25%	Fragment
80	(Li et al., 2020b)	Tuoji, Poyang Lake to Changjiang River Section	858-1114	34%	Fragment
81	(Gong et al., 2020)	the Yellow River (from Gansu to Shandong)	15-615	10%	Fragment
82	(Zhou et al., 2020b)	Fuhe River, Hebei Province	212-1049	26.4%	Fragment
83	(Liu et al., 2020a)	Middle tributary, Gan River, Poyang Lake	1033-1936	4%	Fragment
84	(Liu et al., 2020a)	South tributary, Gan River, Poyang Lake	1173-1413	11%	Fragment
85	(Jian et al., 2018)	Raohe River of Poyang Lake	Mean: 938	7%	Fragment
86	(Wu et al., 2020)	inland waterway of Guangdong-Hong Kong-Macao Greater Bay Area	25-560	2.30%	Fragment

87	(Liu et al., 2019b)	Lake bank, Poyang Lake	Mean: 201.8	36.2%	Pellet
88	(Zhang et al., 2020a)	Qin River urban section in Beibu Gulf	0-97	3%-80%	Sheet
89	(Liu and Fang, 2020)	Dishui Lake, Nanhui New Town, Shanghai (the canal side)	Mean: 230	3%-57%	Sheet
90	(Zhang et al., 2019b)	Fuxi River, Sichuan Province	160-292	14.67%	Sheet
91	(Peng et al., 2018)	urban river in Yangpu District, Shanghai	Mean:723	6%	Sphere
92	(Peng et al., 2018)	urban river in Hongkou District, Shanghai	Mean: 765	3.30%	Sphere
93	(Peng et al., 2018)	Xuhui District	Mean: 1535	5.50%	Sphere
94	(Peng et al., 2018)	Songjiang District	Mean: 160	10.9%	Sphere
95	(Peng et al., 2018)	urban river in Minhang District, Shanghai	Mean: 1120	3%	Sphere
96	(Peng et al., 2018)	urban river in Pudong New Area, Shanghai	Mean: 410	8.8%	Sphere
97	(Yu et al., 2019)	Longkou wetland, Poyang Lake	Mean: 679	9%	Debris
98	(Yu et al., 2019)	Wucheng wetland, Poyang Lake	Mean: 1013	13%	Debris
99	(Yu et al., 2019)	Nanji Mount wetland, Poyang Lake	Mean: 54	24%	Debris
100	(Yu et al., 2019)	Middel section of Gan River, wetland, Poyang Lake	Mean: 1455	4%	Debris
101	(Yu et al., 2019)	Dutou Villege, wetland, Poyang Lake	Mean: 1000	10%	Debris
102	(Yu et al., 2019)	Ruihong Town, wetland, Poyang Lake	Mean: 633	3%	Debris

Table S3 Supplemental materials for Figure 1 (C). A part of microplastic concentration and microfibre proportion data was estimated from the figures of literatures by Image J. For accurate raw data, please see original papers.

Index number in Figure 1 (C)	Citation	Location	Microplastic concentration (n/m^3)	Microfibre proportion	Dominant shape	Microplastic removal rate
1	(Lin et al., 2018)	Guangzhou City section of Pearl River (WWTP1)	Mean: 2700	100%	Fibre	40.5%
2	(Lin et al., 2018)	Guangzhou City section of Pearl River (WWTP2)	Mean: 300	100%	Fibre	40%
3	(Lin et al., 2018)	Guangzhou City section of Pearl River (WWTP3)	Mean: 600	66.70%	Fibre	57.1%
4	(Bai et al., 2018)	a WWTP in Shanghai	Mean: 52000	74.4%	Fibre	55.6%
5	(Mak et al., 2020)	Sha Tin secondary treatment plant, Hongkong (March)	Mean: 3260	56%	Fibre	N/A
6	(Mak et al., 2020)	Sha Tin secondary treatment plant, Hongkong (June)	Mean: 1274	56%	Fibre	N/A
7	(Mak et al., 2020)	Sha Tin secondary treatment plant, Hongkong 5(September)	Mean: 423	57%	Fibre	N/A
8	(Mak et al., 2020)	Kuwn tong stormwater treatment work, Hongkong (December)	Mean: 1241	60%	Fibre	N/A
9	(Mak et al., 2020)	Kuwn tong stormwater treatment work, Hongkong (March)	Mean: 6480	48%	Fibre	N/A
10	(Mak et al., 2020)	Kuwn tong stormwater treatment work, Hongkong (June)	Mean: 3003	66%	Fibre	N/A
11	(Mak et al., 2020)	Kuwn tong stormwater treatment work, Hongkong (September)	Mean: 2570	66%	Fibre	N/A
12	(Mak et al., 2020)	Yau Ma Tei stormwater treatment plant, Hongkong (December)	Mean: 3994	53%	Fibre	N/A
13	(Mak et al., 2020)	Yau Ma Tei stormwater treatment plant, Hongkong (December)	Mean: 4800	43%	Fibre	N/A
14	(Mak et al., 2020)	Yau Ma Tei stormwater treatment plant, Hongkong (December)	Mean: 3113	49%	Fibre	N/A
15	(Tang et al., 2020)	Urban residential wastewater treatment plant, Wuhan	Mean: 7900	66.6%	Fibre	66.10%
16	(Tang et al., 2020)	Suburban wastewater treatment plant for industrial and residential sewage, Wuhan	Mean: 30300	73.2%	Fibre	62.7%
17	(Zhang et al., 2020a)	WWTP1 along Qin River, Beibu Gulf	Mean: 130	100%	Fibre	92.8%
18	(Chen et al., 2020b)	Tertiary wastewater treatment plant in Nanjing, China	Mean: 900	100%	Fibre	78.57%
19	(Wei et al., 2020)	A rural WWTP (A/A/O-CW), Fuyang District, Hangzhou	Mean: 300	65%	Fibre	82.6%
20	(Yang et al., 2019)	Gaobeidian sewage treatment plant, Beijing	400-731	85.92%	Fibre	95.16%
21	(Xu et al., 2019b)	Eleven WWTPs, Changzhou	3630-13630	86.66%	Fibre	89.17%-97.15%
22	(Wang et al., 2020e)	Advanced drinking water treatment plant, Yangtze River Delta	Mean: 930	51.6%-78.9%	Fibre	79.7%-95.4%
23	(Xu and Wang, 2020)	Drinking water treatment plant, Jiangsu Province	Mean: 1125000	46.4%	Fibre	80.10%
24	(Xie et al., 2020)	Beichong WWTP, Guilin	Mean: 70	100%	Fibre	90%

25	(Jia et al., 2019)	WWTP1, Shanghai	Mean: 226.27	92.06%	Fibre	63.25%
26	(Jia et al., 2019)	WWTP2, Shanghai	Mean: 171.89	92.46%	Fibre	59.84%
27	(Jiang et al., 2020)	WWTP, Harbin City	Mean: 30600	61.40%	Fibre	75.70%
28	(Ding et al., 2020)	Outlet of Sequencing batch reactor activated sludge WWTP, Beijing	Mean: 62000	77.4%	Fibre	43.10%
29	(Ren et al., 2020)	A WWTP in Zhengzhou, Henan Province	Mean: 2900	93.10%	Fibre	81.90%
30	(Wang et al., 2020b)	Nine residential WWTPs, Taihu Lake Basin, Jiangsu	6000-26000	4%	Film	35%-98%
31	(Wang et al., 2020b)	Nine residential WWTPs, Taihu Lake Basin, Jiangsu	7000-12000	20%	Film	N/A
32	(Mak et al., 2020)	Sha Tin secondary treatment plant, Hongkong (December)	Mean: 1483	42%	Fragment	N/A
33	(Mak et al., 2020)	Stonecutters Island chemical-enhanced primary treatment plant, Hongkong (December)	Mean: 3639	16%	Fragment	N/A
34	(Mak et al., 2020)	Stonecutters Island chemical-enhanced primary treatment plant, Hongkong (March)	Mean: 10729	10%	Fragment	N/A
35	(Mak et al., 2020)	Stonecutters Island chemical-enhanced primary treatment plant, Hongkong (June)	Mean: 3728	34%	Fragment	N/A
36	(Mak et al., 2020)	Stonecutters Island chemical-enhanced primary treatment plant, Hongkong (September)	Mean: 1147	17%	Fragment	N/A
37	(Mak et al., 2020)	Yau Ma Tei stormwater treatment plant, Hongkong (December)	Mean: 6666	27%	Fragment	N/A
38	(Wang et al., 2020a)	Four WWTPs along Qing River, Beijing (July)	Mean: 350	13%	Fragment	N/A
39	(Wang et al., 2020a)	Four WWTPs along Qing River, Beijing (November)	Mean: 320	26%	Fragment	N/A
40	(Wei et al., 2020)	A rural WWTP (A/A/O), Yuhang District, Hangzhou	Mean: 400	37%	Fragment	65.20%
41	(Wei et al., 2020)	A rural WWTP (A-CW), Fuyang District, Hangzhou	Mean: 750	47%	Fragment	65.2%
42	(Ruan et al., 2019)	Shek Wu Hui WWTP, Hongkong	Mean: 270	13%	Fragment	86.9%
43	(Ruan et al., 2019)	Stonecutters Island WWTP, Hongkong	Mean: 400	40%	Fragment	60.4%
44	(Yuan et al., 2020)	WWTP C, Nanjing City	Mean: 240	25%	Granular	97.67%
45	(Yuan et al., 2020)	WWTP P, Nanjing City	Mean: 340	29.41%	Granular	98.46%
46	(Long et al., 2019)	Seven WWTPs in Xiamen, Fujian	200-1730	17.7%	Granules	79.33%-97.84%
47	(Wang et al., 2019a)	Yundang WWTP, Xiamen City	Mean: 324	20%	Pellet	80.97%
48	(Zhang et al., 2020a)	WWTP2 along Qin River, Beibu Gulf	Mean: 40	33%	Sheet	73.3%

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