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A critical review of microplastic pollution in urban freshwater environments and legislative progress in China: recommendations and insights

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Freshwater systems are vitally important, supporting diversity and providing a range of ecosystem services. In China, rapid urbanization (over 800 million urban population) has led to multiple anthropogenic pressures that threaten urban freshwater environments. Microplastics (<5 mm) result from intensive production and use of plastic materials, but their effects in urban freshwater environments remain poorly understood. Rising concerns over the ecological effects of microplastics have resulted in increased attention being given to this contaminant in Chinese freshwater systems. Some studies provide quantitative data on contamination loads, but in general relevant knowledge in freshwater environment remains narrow in China, and lacking adequate understanding of threshold levels for detrimental effects. Notably, non-standardized sample collection and processing techniques for point and non-point sources have hindered comparisons of contamination loads and associated risk. Meanwhile, legislative frameworks for managing microplastics in China remain in their infancy. This manuscript critically reviews what is known of the nature and magnitude of microplastic pollution in Chinese freshwater environments, and summarises relevant Chinese legislation. It provides recommendations for improving the legislative framework in China and identifies research gaps that need to be addressed to improve management and regulatory strategies for dealing with microplastic pollution in Chinese urban freshwater environments.

Keywords: microplastics, urban freshwater environment, abundance, China, legislation, policy

Content

1. Introduction

Annual global plastic resin and fibre production accelerated from 2 million metric tonnes in 1950 to 3.81 billion tonnes in 2015, contributing to the 6.3 billion tonnes of global plastic waste produced by 2015 (Geyer *et al.*, 2017). The ubiquity of plastics results in serious environmental problems worldwide, with over 99 million metric tonnes mismanaged yearly and approximately 79% of total plastic waste accumulating in landfills or in the natural environment (Geyer *et al.*, 2017; Lebreton and Andrady, 2019). Plastic pollution can be conveyed between different ecosystems, with for example around ten million metric tonnes of terrestrial-based plastic litter estimated to enter the oceans every year (Jambeck *et al.*, 2015). Freshwater systems are a major pathway for delivering plastic pollution to the marine environment (Crawford and Quinn, 2017b).

China is the largest plastic producer in the world, with monthly plastic production reaching at 5-12 million metric tonnes by 2019 (Garside, 2019). Since the early 1950s, the utilisation of plastic mulch in agriculture has become widespread across China, while plastic tableware and bags became prevalent in industrial and domestic sectors after the economic reforms in the late 1970s (Zhou *et al.*, 2016). The growth of E-Commerce further increased China's plastic consumption, especially the fast food delivery services which are part responsible for the approximately 60 million items of plastic tableware daily used in China, most of which is single-used (Industry, 2019). Thus, China plays an important role in global plastic production and consumption (Wang *et al.,* 2018). The Chinese plastic material market has resulted producing more than 8.82 million metric tonnes of mismanaged plastic waste annually, which ranked as the global highest (Jambeck *et al.*, 2015). Based on current trends, global mismanaged plastic waste is estimated to reach 155-265 million metric tonnes annually by 2060s, with China remaining as one of the major sources (Everaert *et al.*, 2018; Lebreton and Andrady, 2019; van Wijnen *et al.*, 2019).

"*Microplastics*", defined as plastic debris smaller than 5 mm in diameter, can be ingested by organisms, and abrade and clog breathing and feeding apparatus (Eerkes-Medrano *et al.*, 2015; Li *et al.*, 2018). Given the size of microplastics, they can be transported for long distances (i.e. more than thousands of km) and have been found in geographically remote regions (i.e. polar areas and waterbodies on undeveloped plateaus) (Lusher *et al.*, 2015; Horton *et al.*, 2017a; Baptista Neto *et al.*, 2019; C. Jiang *et al.*, 2019). Microplastics also have the potential to adsorb other contaminants (including hydrophobic persistent organic pollutants, pathogenic microorganisms and antibiotics) and transport these pollutants over a large spatial area (Lambert and Wagner, 2018; Arias-Andres *et al.*, 2019).

Microplastics encompass a highly diverse group of materials (e.g. Polyethylene Terephthalate (PET), Polystyrene (PS) and Polypropylene (PP)), morphologies (e.g. fragments, fibres and beads), colours and sizes (usually 1 μm to 5 mm). Microplastics are classified as being primary (manufactured at micro-size) or secondary (smaller fragments that have been eroded or weathered from the larger plastics) (Eerkes-Medrano *et al.*, 2015; Horton *et al.*, 2017b; Sharma and Chatterjee, 2017). Despite the potential significance of microplastic pollution, much remains unknown about its sources, pathways, fate and impacts on receptors. Major sources of plastic wastes and the burning and breakdown of those mismanaged larger plastic litter (e.g. via microbeads, fibres, etc.) is estimated to be the largest contributor of microplastics (Horton *et al.*, 2017b; Conley *et al.*, 2019), and is likely to be greater in urban areas. Urban freshwater environments may therefore be of great significance as a source of microplastics, rapidly conveyed from urban discharge into fluvial systems and eventually to marine systems via estuaries and deltas (Zhao *et al.*, 2014).

Zhao *et al.* (2014) were the first study to quantify microplastic pollution in freshwater environments in China, but there has been limited subsequent research. Some studies of Chinese freshwater bodies have reported higher microplastic concentrations than many other countries (Su *et al.*, 2016; Zhang *et al.*, 2018; X. Jiang *et al.*, 2019). Rivers in East Asia are predicted to carry the highest annual microplastic loads by 2050, approximately four times higher than the microplastic emission from other OECD (Organization for Economic Cooperation and Development) countries (van Wijnen *et al.*, 2019). Because of its size and population, China plays the most important role in the East Asia region. Chinese cities have large populations and substantial plastic use, but often with poor disposal management and limited knowledge of microplastic concentrations in urban freshwater environment. China's current legal framework still does not specifically cover the management of microplastic (Zhang *et al.*, 2019). Legislation aimed at reducing microplastic pollution can have multiple positive effects in China's, but an essential prerequisite for this is awareness of contamination sources, pathways and levels.

Microplastic pollution has been reported worldwide and, according to the reviews of Eerkes-Medrano *et al.* (2015) and Horton *et al.* (2017b), is constantly increasing in freshwater environments. Zhang *et al.* (2018) were the first to review what is known of microplastic pollution in Chinese inland water systems; they also considered the State-of-the-Art approaches for sampling microplastics. Fu and Wang (2019) reviewed research approaches, characteristics, sources and fate of microplastics in the Chinese freshwater environments and provided recommendations for the Chinese Government and public to reduce freshwater microplastic pollution. Fok *et al.* (2020) studied the investigating approaches used in microplastic studies in China, while Fu *et al.* (2020) synthesised knowledge of microplastic pollution in various ecosystems and provided an overview of policies related to plastic and microplastic management in China. These reviews established a thoughtful basis for future development of microplastic controls in the Chinese freshwater environment, but understanding of microplastics in Chinese urban catchments still remains limited. However, available literatures are still general on the discussion of microplastic management and current legislation do not provide specific guidance on developing appropriate policies.

Given the circumstances above, this manuscript reviews microplastic pollution in urban freshwater catchments in China, with a particular focus on legal frameworks for managing the problem. The aim of the review is to identify major knowledge and policy gaps that need to be filled to improve understandings of the environmental risks of microplastics. Specific objectives are:

1) To review what is known of microplastic abundance and characteristics in China's freshwater environment and identify current knowledge gaps, especially related to urban catchments.

2) To review key existing legislation and policies related to microplastics worldwide and in China.

3) To provide recommendations for managing microplastic pollution in China's freshwater environments, and specifically for dealing with pollution of urban catchments.

2. Current knowledge of urban freshwater microplastics in China

2.1. The foci of China's microplastics research

Following the first use of the term '*Microplastics*' (Thompson *et al.*, 2004), 1563 papers about microplastic pollution have been published (up an and including 2019; Web of Science). The trajectory during the last 16 years reflects a rapidly growing concern about microplastics worldwide (Fig. 1). The first data of microplastic loads in China were not published until 2014, when Zhao *et al.* (2014) reported on loads in both freshwater and seawater zones of the Yangtze River Estuary System. By the end of 2019, 255 papers concerning microplastics in China had been published, with these using a wide variety of sampling and sample processing approaches (Zhang *et al.*, 2018). Since then, China has become a significant contributor to the literatures, producing more than 16% (according to Web of Science) of the global microplastics research (China is ranked first, followed by USA, UK and Germany). This indicates that China is starting to play an important role in the understanding of microplastics, and consequently may influence future research directions. This section reviews Chinas 255 contributions to the global literature.

Figure 1 is about here

Figure 1. Number of academic publications about microplastics from 2004 to 2019 (data source: Web of Science). Blue bar represents global annual publication numbers and orange bars means yearly publication numbers from China.

The VOSviewer software (Leiden University, Netherlands) was used to provide an overview of current microplastics research in China (Figure 2). The academic terms repeatedly occurring in each paper were collected from the 255 publications and analysed in this software. The frequency of occurrence of each keyword and the co-occurrence of pairs of keywords were used to indicate the foci of published work; in the resulting schematic (Fig. 2), the foci of proximity between terms indicates the frequency of co-occurrence, the size of each term illustrating the occurrence frequency, and the colours indicate temporal patterns. This analysis demonstrates that the '*Marine Environment*' was a very common focus and was closest to '*Microplastics*' and '*Pollution*', indicating that a large proportion of microplastics research in China (and globally) has been conducted in marine environments. The red colour of '*Freshwater*' indicates that this topic is relatively new in China. The direct links from '*Freshwater*' to topics such as '*Sediments*', '*Coastal*', '*Soil*', '*Marine-environment*' and '*Transport*' demonstrated that microplastic pollution in China's freshwater environments correlates with microplastics in other compartments of the environment. Nonetheless, the relatively great distance between '*Freshwater*' and '*Microplastics*' suggests that relevant work is still limited in China. Notably, the missing connections between several focal terms (such as '*Exposure*', '*Toxicity*', and '*Wastewater*') to '*Freshwater*' indicates that gaps remain in understanding links between these things. The terms '*Urban*' and '*City*' do not appear in the figure highlighting the lack urban freshwater microplastics research in China. This supports the contention that more studies are required in urban freshwaters to assess the potential significance of microplastics (Zhang *et al.*, 2018).

Figure 2 is about here

Figure 2. A visualization of the keywords co-occurrence in 255 publications of China's microplastics researches (database: Web of Science) from 2014 to 2019, where colours represent the average publication time of each keyword (blue to red: early to current). Database: Web of Science from 2004 to 2019.

2.2. Microplastics in freshwaters in China

To further understand current progress in microplastics research in China's freshwater environments, twenty-one papers reporting microplastic loads in various types of Chinese freshwater environments were analysed in detail (Table 1).

Microplastic pollution has been investigated in freshwater systems including the Poyang Lake (the largest freshwater lake in China), Dongting Lake (the second largest freshwater lake in China), Qinghai lake (the largest inland lake in China), Yangtze River (the largest river catchment in China), Pearl River (the largest river catchment in Southern China), and other large waterbodies in the country (Zhao *et al.*, 2014; Lin *et al.*, 2018; Wang *et al.*, 2018; Xiong *et al.*, 2018; Zhou *et al.*, 2018; Yuan *et al.*, 2019). These studies provided quantitative evidence of microplastic pollution but so far none has investigated loads in any environments in an integrated way, so as to characterise contamination in waterbodies, sediments and biota; moreover, small- to medium-sized freshwater systems remain under-represented.

Table 1 is about here

Table 1. Twenty-one publications involving investigations of microplastic abundances in freshwater environments in China

The properties of microplastics are important indicators of sources. Microplastics detected in Chinese freshwaters consists of diverse materials including Polypropylene (PP), Polystyrene (PS), Polyethylene Terephthalate (PET (also abbreviated PETE)), Polyethylene (PE) and Polyvinyl Chloride (PVC). PP and PE were dominant in most investigated freshwater environments (PP in 12 waterbodies and PE in 11 waterbodies; Table 1). This condition fits with the current state of the Chinese plastics market, with the annual yields of PP and PE accounting for 27.21 and 30.04 million tonnes and representing more than 40% and 30% of global totals respectively by 2018 (Yin and Zhang, 2019; Zhang, 2019). Although published research used different sorting strategies, plastic fibres were dominant in 14 cases (Table 1). Size ranges of microplastics were also variable, with some suggesting smaller microplastics (e.g. < 1 mm) are disproportionately abundant (Su *et al.*, 2016; Yuan *et al.*, 2019).

Microplastic abundance also varied substantially between different geographic areas. For example, concentrations in surface water of rivers on the Tibet Plateau were 483 - 967 particles/m^3 compared to 4,137.3 particles/m^3 in the Yangtze Estuary (Table 1). Such cases also imply that densely populated areas (e.g. urban areas) have higher microplastic concentrations compared to remote areas. Concentrations are also variable over smaller geographic areas. For instance, within the same catchment, Lin *et al*. (2018) found that concentrations along the urban section (Guangzhou) of the Pearl River varied from 379 to 7,924 particles/m^3 in surface water (Table 1); a concentration of 0.167 particles/m^3 was recorded offshore from the Yangtze River in comparison to 4,137.3 particles/m^3 in the Yangtze estuary (Zhao *et al.*, 2014). The spatial variation in the Yangtze is likely due to dilution (Mendoza and Balcer, 2018; Wang *et al.*, 2018). No consistent relative patterns have been found in microplastic concentrations in water versus sediment in fluvial or limnetic environments (Zhou *et al.*, 2018; Ding *et al.*, 2019; Zhao *et al.*, 2019), which suggests complex sources and pathways and patterns of accumulation.

The properties of microplastics, hydrological conditions, surroundings and meteorological conditions have been investigated as the four major factors influencing microplastics' distribution patterns in waterbodies in China (W. Wang *et al.*, 2017). Unfortunately, no clear patterns or consensus has yet been reached. For example, recent studies indicated that the lower microplastic concentrations during the wet season (summer) in the Pearl River, China could be attributed to dilution by higher precipitation and river flows (Fan *et al.*, 2019). Conversely Zhao *et al*. (2019) found an increased concentration during wet periods, presumably due to more runoff washing plastic particles into waterbodies. As with suspended sediment, microplastic concentrations in recorded river water may be dictated by preceding conditions (e.g. whether a preceding flood has caused washout), such discharge-concentration relationships are not ways clear.

Sources differ greatly from place to place. For instance Peng *et al.* (2018) explained that polyester, rayon and other fibres detected in their samples were from clothes washing (based on the materials and shapes of microplastics), while Xiong *et al.* (2018) believed that the PE and PP microplastics detected in the Qinghai Lake, China originated from tourists, due to these types plastics being commonly used in packaging. Nevertheless, a problem that may contribute to different interpretations of sources and loads is the lack of consistent collection, identification and analytical approaches (Luo *et al.*, 2019). Zhao et al. (2015) used a 333 μm pore-size sieve to filter water samples from the Minjiang, Jiaojiang and Oujiang estuaries, while Wang *et al*. (2018) selected a 50 μm mesh-size steel sieve for the investigation in the Dongting Lake and the Hong Lake, China. In most microplastics studies in Chinese freshwater environments, smaller-sized microplastics (< 2 mm) are usually most abundant (see Table 1). Such differences cause large variation in reported concentrations.

2.3. Microplastic dynamics in Chinese freshwater environments

Rivers are often conceptualised as conveyor belts, transporting water, sediments and contaminants to the oceans. However, transport is not continuous, with material stored periodically (e.g. sediment deposited and stored for a period of time on the riverbed, before the next competent event leads to its onward conveyance). This and the different course areas – some of the, point sources and some of them diffuse - may underpin spatial variation reported to date. Wang et al. (2018) reported with high concentrations at the confluence between the Dongting Lake and Yangtze River. Based on work in the Pearl River, Lin et al. (2018) argued that tributaries transport microplastics to the mainstream and result in high concentration in confluence zones. Peng et al. (2018) observed that the microplastics transported by the Yangtze River and Huangpu River stagnated and accumulated at the plume front area formed between freshwater and seawater of the East China Sea. These findings not only indicate the significance of Chinese fluvial systems as a pathway, delivering microplastics towards trunk streams and marine environments, but also illustrate that confluence areas may be contamination 'hotspots'.

The transportation of microplastics may be critical to assessing and understanding health risks. Because of their lipophilic features and high surface area to volume ratio, which enable them to absorb chemical pollutants, including persistent organic pollutants (e.g. pesticides and antibiotics), as well as pathogenic bacteria, fungi and viruses (Zou *et al*., 2017), microplastics pose risks to ecosystems and human health. Additionally, toxic plastic additives, such as flame retardants, pigment and ultraviolet stabilizer can be release once plastics are in the freshwater environment (Gabriella, 2019). Risk partly depends storage dynamics. For instance, exposure of benthic organisms to microplastics depends how much material may be stored within the bed matrix, and the duration of residence here before being remobilised during high flows (van Cauwenberghe *et al*., 2015). Residence times are likely to be longer in stable sediments that are infrequently disturbed, so lentic environments can act as a longer term store for microplastics than fluvial environments (Eerkes-Medrano *et al*., 2015). Movement of microplastics can also be altered by absorption of other materials or colonisation by microbial communities, changing particle density and causing microplastics to settle more easily (Lin *et al.*, 2018; Wang *et al.*, 2018; Fan *et al.*, 2019). Research foci are now changing from simple assessment of loads to efforts understand pathways, including those in the subsurface (i.e. via hyporheic zone and groundwater), although such work still remains limited in China (Zhao *et al.*, 2015; Su *et al.*, 2016).

River Basin Management for navigation purposes, alongside with other factors such as, water supply, flood control and hydropower production alter flow regimes and flow hydraulics, and hence, may modify transport and storage dynamics of microplastics. Dams and reservoirs trap sediments, and therefore are likely to also trap microplastics (Crawford and Quinn, 2017b). Microplastics accumulated in stable freshwaters will not stop degrading, potentially generating and releasing smaller-sized, secondary microplastics that that may be more easily ingested by organisms.

Another issue relates to the temporal dimension. Most studies lack long-term, repeat sampling and measurement. This is important because, when studied, significant temporal differences in microplastic concentrations have been found to exist; this raises concerns over the representativeness of single date or spot sampling (Stanton *et al*. 2019). Such temporal differences may arise due to seasonal and/or weather-related factors, or dues to activities of organisms (Crawford and Quinn, 2017b). For example, in China cyclonic effects (i.e. typhoons) have been reported to increase microplastic loads in freshwaters and conveyance to the marine environment (e.g. especially along the Southern and Eastern coastline of China; Wang *et al.*, 2019). Studies are needed in China to elucidate the causes of temporal variation in microplastics and the implications of this for accurate assessment of loads and risk.

2.4. Sources of microplastics in urban freshwaters

Urban areas play a key role as sources of microplastics in China (Zhang *et al*., 2018; Fu and Wang, 2019). These sources are summarised in Figure 3. Primary microplastics are usually discharged from industrial areas associated with plastic production or residential areas through wastewater treatment plants (WWTPs) (Figure 3). Microplastics could be removed from sewage during the primary treatment and adsorbed by activated sludge during secondary treatment in WWTPs, but even if removal reached 95-99%, as recorded in some developed countries, the remaining material released to the environment could still be problematic (Talvitie *et al.*, 2015). Many WWTPs do not attain 99% removal efficiency of microplastics in China (Lin *et al.*, 2018); for example, a municipal WWTP equipped with activated sludge techniques in Wuhan only removed about 64.4% of microplastics (Liu *et al*. 2019). Another issue is that 60% of polluted sludge from WWTPs in China is disposed of in landfill sites (Sun *et al.*, 2019). Microplastics can leach from landfills and find routes through soils to contaminate freshwaters (He *et al.*, 2019). Thus, due to the relatively underdeveloped techniques and poor management of waste treatment, WWTPs play significant roles in Chinese urban microplastic pollution, as documented by W. Wang *et al.* (2017) and Lin *et al.* (2018), respectively.

Secondary microplastics usually reach freshwater environments through non-point sources. In Chinese urban areas, mismanaged plastics are the major terrestrial non-point source, which includes dumping and littering of solid wastes (W. Wang et al., 2017; Zhou et al., 2018; Fan et al., 2019). Fragmentation of large plastic waste generates secondary microplastics on land (Zhang *et al.*, 2015), while road dusts containing car tyre fragments contribute to loads entering freshwater systems as a result of runoff (Zhang *et al.*, 2018). Atmospheric dispersal of microplastic may also be important in urban areas (Dris *et al.*, 2016). For example, Zhou *et al.* (2017) found microplastic fibres in atmospheric deposition in Yantai, China. Shipping and fishing in urban catchments can also release microplastics directly to aquatic environments, where fragments and fibres from fishing nets or gear have been observed in urban waterbodies in Changsha City (Yin *et al.*, 2019).

Figure 3 is about here

Figure 3. Potential microplastic sources towards urban catchment (source by Yuyao Xu)

Previous literature has assessed factors influencing microplastic pollution in Chinese urban catchments. Fan *et al*. (2019) found a direct linear relationship ($R^2 = 0.772$) between microplastic abundance in water samples and population density in the Pearl River catchment, where large population centres generated and released more microplastics. Similarly, Wang *et al*. (2017) found an inverse linear relationship ($p < 0.001$) between the distance from an urban centre and microplastic concentration in surface waters of the Yangtze River. Other investigations have, however, failed to find such relationships (e.g. Shanghai) (Peng *et al.*, 2018).

Zhao *et al*. (2015) suggested that different economic structures might lead to different microplastic sources and abundances; interestingly this hypothesis was supported by the Gross Domestic Product (GDP) and microplastic data presented by Fan *et al*. (2019). Li (2020) reported microplastic concentrations in urban runoff from residential roads were significantly higher than from parking lots and cement pavements, which also indicates that local land-use conditions will affect microplastic pollution levels in urban areas.

Rapid urbanisation in China may increases pressures on urban freshwaters, including contamination by microplastics (Zhang *et al.*, 2018). Therefore, understanding the roles of land-use, population density and local economic structure in influencing microplastic distribution patterns in urban waterbodies is an important first step to developing policy measures designed to minimise risk. Taking a precautionary approach via implementation of legislative enactments and guidelines to control microplastics is a growing area of interest in China. This is the focus of the section that follows.

3. Management and Legislations on microplastics

3.1. General legislation

Plastic microbeads (10 – 500 µm in diameter), used in personal care products (PCPs) (Sharma and Chatterjee, 2017), are a type of primary microplastics. To help reduce risks posed by microbeads to wildlife, Five European countries (i.e. Netherlands, Austria, Luxembourg, Belgium and Sweden) issued a joint statement calling for banning the use of microbeads in PCPs (see Table 2). In 2014, the State Government of Illinois (USA) enacted the first prohibition of production and sales of PCPs that contain microbeads (see Table 2), which subsequently led to the US '*Microbead-Free Water Act of 2015*' (see Table 2). In 2015

Canada also limited the addition of microbeads in PCPs, by adding microbeads as a new toxic substance to the 1999 '*Environmental Protection Act*' (Table 2). European nations also expressed the concerns about Microbead pollution in cosmetics through the proposal '*Cosmetics Europe Recommendation on Solid Plastic Particles (Plastics Micro Particles)*' (Table 2). This recommendation has implications for future legislation worldwide (i.e. Microbeads in Toiletries Regulations by Canada in 2017). Following these first pieces of legislation, more countries (including the UK, France, South Korea, Italy, New Zealand, India and South Africa) joined in this '*Microbead-free*' action (see Table 2), which will make efforts to reduce the global release of microbeads. Nonetheless, microbeads are only a small part of the total microplastic load, approximately accounting for 0.1~ 4.1% (McDevitt *et al.*, 2017) of total global microplastic pollution in aquatic environments, so broader action is also needed.

In October 2019, the Chinese government officially issued the "Economic Structure Adjustment Guidance Catalogue", which included the prohibition of light plastic bags (< 0.025mm thickness), disposable-foamed plastic tableware, disposable plastic swabs, daily chemical products containing microbeads and polyethylene agricultural films (< 0.01 mm thickness) (Table 2). This catalogue not only highlights microbeads problem in both PCPs and cosmetics, but also looks at other commonly used in China but potentially polluting plastic products (NDRC, 2019).

Table 2 is about here

Table 2. Brief history of 'microbeads-free' activities worldwide (The word 'Microbead-free' was from the 'Microbead-free Act' in USA and used to represent the popularization of banning plastic microbeads in relevant products in different countries in this paper)

As yet, ‘*Microplastics*’ have not been adopted as a formal legislative object in any national or international laws (Zhang *et al.*, 2019). Nevertheless, because of the concern about marine microplastic pollution, several international conventions take microplastics into account (Crawford and Quinn, 2017a). The ‘*Oslo-Paris Convention for protecting and conserving the North-East Atlantic and its resources (OSPAR)*’ uses microplastic abundance in seabird stomachs as one indicator of marine ecological quality (see Table 3). In 2014, the United Nations Environment Assembly (UNEA) also identified microplastics as an emerging marine pollutant, which has placed marine microplastic management on the agenda of many countries worldwide (see Table 3). China has enacted a national marine environmental legislative framework that addressed the issues of shared maritime rights and obligations in the East and South China Seas, and extends to the management of waste dumping, shipping waste, construction waste and landfills in territorial waters (see Table 3).

Even though microplastics are not mentioned explicitly in these regulations and laws, their legislative power to reduce solid waste pollution in marine systems covers should help reduce plastic pollution (Li, 2018; Zhang *et al*., 2019). Lessons learned from their enactment, combined with lessons learnt from international conventions, are important for developing policies related explicitly to microplastics in China.

Table 3 is about here

Table 3. The international and Chinese legislation related to plastic and microplastics (mainly for marine environments)

3.2. Legislation directly relevant to freshwaters in China

There are multiple legislative efforts to protect and manage freshwater environments in China (see Table 4). Four basic laws established a legislative framework for Chinese freshwater management ("*The Water Pollution Law*", "*The Water Law*", "*The Soil and Water Conservation Law*", and "*The Flood Prevention Law*"). Some pieces of legislation relate more specific watersheds or to detailed management plans than to the issue of plastics, while others dealt more with wider hydrological issues connected to economic development (such as flood control, soil erosion, water and soil conservation, and land use demands), rather than tackling the water quality. For example, of 51 rules that make up the "*River Courses Regulations*" only two are concerned with freshwater pollution and wastewater management.

Several laws and regulations, including "*the National Water Law",* have been amended several times in the past 20 years to meet the needs of China's current development (see Table 4). The "*Environmental Quality Standards for Surface Water (GB3838-2002)*", which was updated from the older version (*GB3838-1998)*, was issued in 2002. This provides an appraisal system to classify the quality of Chinese surface water, and has been applied to fluvial systems, groundwater, lakes, and irrigation water quality (Table 4). Other more recent frameworks that aim to improve water quality include the "*Water Pollution Action of 2015*", the "*Sponge City Program*" (Chan *et al*., 2018), and the "*River Chief System*', these latest developed blue-green infrastructure and urban water management systems are the initiative to further integrate with microplastics and plastics control, in prior to improving the urban freshwater quality (Table 4). Nevertheless, Artificial Polymers (including microplastics) are not considered to be contaminants in the national water quality standards. Recently, an official letter was issued by the Ministry of Ecology and Environment to suggest setting up a list of toxic and harmful water pollutants, which includes heavy metal compounds. This letter reflects an official desire to update existing freshwater quality standards in China; it may be a timely opportunity to include artificial polymers as indicators or parameters of water quality in standards.

Table 4 is about here

Table 4. Legislation and progress for catchment management in China

4. Mitigation of microplastic pollutions in Chinese urban freshwater environment

The growing findings on microplastic pollution, especially in urban catchment (Figure 4), are likely to motivate legislative action in China (Yuan *et al*., 2019). However, there are major challenges to reducing plastic pollution in China, stemming from the many benefits of and society's reliance on plastics, and a lack of suitable alternatives for some applications. These challenges are summarised in Figure 5. Reflecting both current knowledge gaps and these challenges, we put forward a number of recommendations, as detailed in the remainder of this section.

Figure 4&5 is about here

Figure 4. Key research progresses on microplastic pollution in Chinese urban catchments (Source: Yuyao Xu)

Figure 5. Reasons of legislative difficulties on microplastic pollution (Source: Yuyao Xu)

4.1. Toxicology.

China needs to build a toxicological (dose-based) or environmental (impact-based) microplastic pollution risk assessment system, and formulate reasonable treatment plans based on this quantitative basis. Although microplastics are categorised as toxic pollutants and banned in Canada (Canada, 2015; Canada.ca, 2017), there are some uncertainties remaining over direct toxicity to humans and wildlife. A common problem is that many toxicity tests have been based on doses much higher than found in the environment, so assessing the risks to human and ecological health from current levels of contamination remains problematic (X. Jiang *et al.*, 2019). Advanced toxicological studies may either provide the impetus for the Chinese government to list microplastics as toxic pollutants or allay concerns about current levels. Risk assessment systems should also consider the interactions between microplastics and other relevant pollutants (persistent organic matters, microorganisms and heavy metal).

4.2.Recognising different types of microplastics

China should apply specific management measures for different types of microplastics. Microplastic is actually a general term, encompassing plastic debris with a wide variety of characteristics. These characteristics (e.g. sizes, shapes, chemical composition) affect their distribution patterns and environmental impacts, and require different solutions to manage each type of them. '*Microbead-free*' action is a successful case for the management of a single group of microplastics, but micro-fibres are far more abundant in many freshwaters, especially in urban catchments (see Table 1). Domestic household discharge (e.g. via washing clothes on urban rivers) is one of the main sources of fibres in freshwater environments (see Figure 3). Yang *et al.* (2019) found that polyester fabric releases fewer fibres during laundry compared to polyamide fabric and acetate fabric and so developing textiles that do not as readily shed fibres would be beneficial. Also, improving laundry and fabric filter techniques of washing machines may reduce the amount of fibres from washing machines into sewage pipes in residential areas, is a way to cut the transportation of microplastics. Compared to platen laundry machines, fibres are easier to peel off in pulsator laundry machine (Yang *et al.*, 2019). Another way to cut the transportation of synthetic fibres is to improve the microplastic removal rate of WWTPs in China. Legislation aiming at those three points can effectively control the amount of synthetic fibre emitted in densely populated areas. This approach to controlling fibre pollution could also be extended to other types of microplastics.

4.3.Consumption rates

We recommend reducing the consumption of plastic products, such as plastic bags and single-use food containers. This will be a considerable challenge as the amount of plastic consumed from these sources is increasing every year in China. By 2017, over 20 million fast-food deliveries were produced per day, where daily plastic bag consumption was enough to cover 168 football fields in China (Xue, 2017). In early 2011, the Chinese Government had to spend about 18.5 million yuan per year to control macro-plastic pollution (Zhu, 2011). Promoting the use of recyclable packaging throughout China's e-commerce industry, or supplying recycling services for non-disposable food containers in food delivery businesses, are therefore measures with great potential within China (Hao, 2019). This alone will not be enough and such reductions should be coupled with investment and development of adequate recycling infrastructure. Developing alternative materials for plastics or controllable plastics degradation technology is also an approach to reducing the society's dependence on plastic products.

4.4. Management strategy

The fourth recommendation is the devolution of management responsibility for microplastic pollution to local governments after central government sets general targets and overarching legislation. As evident in Table 1, microplastic loads vary markedly across different waterbodies and, therefore, local governments are better placed to specify management strategies given their detailed local knowledge and prioritisation of local environmental threats and constraints. This may then inform national action, as was employed in the USA for the "*Microbeads-free Waters Act*" (McDevitt *et al.*, 2017), and a similar approach has been used to develop the "*Sponge City Program*" in China (Chan *et al.*, 2018). As part of a better management strategy, it is useful to consider microplastics and water quality more broadly, in longer-term land-use improvement projects in China. By combining the microplastic risk assessment system and the approach that manages different types of microplastics separately, the abundance of some groups of microplastics (such as PP or PE in particular size range) could be listed as a water quality index of the national freshwater quality standard (e.g. based on the *GB3838-2002 that published by the National Environmental Bureau from the Chinese Government).* The updated water quality standards will have a long-term impact on China's future hydrologic and environmental management, accomplished with current freshwater management strategies such as the "*River/Lake Chief System*" and "*Sponge City Project*".

Complex land-use patterns and a multitude of industrial and urban activities create substantial challenge for employing a unified approach to freshwater management in China. As microplastic pollution is related closely to land-use function and local economic structure in Chinese cities, the country's urban planning system is well placed as to help integrate considerations of land-use demand and microplastic pollution, as part of strategies to promote more sustainable development.

5. Conclusion

In this paper, we have reviewed microplastics in Chinese urban freshwater environments and relevant legislation that aims at managing microplastic pollution. Microplastic properties, hydrological, meteorological and geographical conditions, population size and local land-use functions are critical factors determining microplastic concentrations in urban waterbodies in China. With the growing loads of microplastics entering lakes, streams and rivers, improving management strategies and developing legislation is a significant challenge in Chin but one that needs to be addressed. Unfortunately, fundamental knowledge of loads, transport pathways and mechanisms, and of the toxicological effects of microplastic, remains limited in China, so there remains a need for more empirical research to help underpin evidence-based legislation.

The Chinese government has paid more attention to urban water quality over the last three years, but as yet there is no legislation that deals explicitly with microplastics. This is an important issue, given that China is known to release large quantities of microplastic particles into its freshwaters. The potential ecological and human health risks posed by microplastics, speak to the need for improving legislation and policy frameworks, to better manage current and deal with future threats of plastic waste.

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Appendix: Abbreviation of organization names

AQSIQ: Administration of Quality Supervision Inspection and Quarantine (中华人民共和国国家质量监督检验检疫总局)

GOSC: General Office of the State Council of the People’s Republic of China (中华人民共和国国务院办公厅)

IMO: International Maritime Organization

MEE: Ministry of Ecology and Environment of the People’s Republic of China (中华人民共和国生态环境部)

MLR: Ministry of Land and Resources of the People’s Republic of China (中华人民共和国国土资源部)

MOF: Ministry of Finance of the People’s Republic of China (中华人民共和国财政部)

MOH: Ministry of Health of the People’s Republic of China (中华人民共和国卫生部)

MOHURD: Ministry of Housing and Urban-Rural Development of the People’s Republic of China (中华人民共和国住房和城乡建设部)

MWR: Ministry of Water Resources of the People’s Republic of China (中华人民共和国水利部)

NDRC: National Development and Reform Commission of the People’s Republic of China (中华人民共和国国家发展和改革委员会)

NPC: The National People’s Congress of the People’s Republic of China (中华人民共和国全国人民代表大会)

UNEA: United Nations Environment Assembly

WHO: World Health Organization

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