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Microplastics in freshwater river sediments in Shanghai, China: A case study of risk assessment in mega-cities[☆]

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ABSTRACT

Microplastics, which are plastic debris with a particle diameter of less than 5 mm, have attracted growing attention in recent years. Its widespread distributions in a variety of habitats have urged scientists to understand deeper regarding their potential impact on the marine living resources. Most studies on microplastics hitherto are focused on the marine environment, and research on risk assessment methodology is still limited. To understand the distribution of microplastics in urban rivers, this study investigated river sediments in Shanghai, the largest urban area in China. Seven sites were sampled to ensure maximum coverage of the city's central districts, and a tidal flat was also included to compare with river samples. Density separation, microscopic inspection and μ-FT-IR analysis were conducted to analyze the characteristics of microplastics and the type of polymers. The average abundance of microplastics in six river sediment samples was 802 items per kilogram of dry weight. The abundance in rivers was one to two orders of magnitude higher than in the tidal flat. White microplastic spheres were most commonly distributed in river sediments. Seven types of microplastics were identified, of which polypropylene was the most prevailing polymers presented. The study then conducted risk assessment of microplastics in sediments based on the observed results, and proposed a framework of environmental risk assessment. After reviewing waste disposal related legislation and regulations in China, this study conclude that *in situ* data and legitimate estimations should be incorporated as part of the practice when developing environmental policies aiming to tackle microplastic pollution.

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1. Introduction

The usage of plastics has alarmed human society with growing scientific evidence concerning the deleterious impacts of end-of-life plastic products on wildlife. The rapid increase of plastics production in the 21st century has witnessed growth from 200 million tons in 2002 to 311 million tons in 2014 (Plastics Europe, 2015), with China, the EU, and North America being the major contributors. China's upward trend in plastics production, along with its mismanagement of waste, has been much debated (Jambeck et al., 2015). Plastic marine debris accumulation in ocean gyres poses an even greater threat to the marine environment, with microplastics being one of the contributors (Thompson et al., 2004).

Public and academic interest in microplastics has grown exponentially over the past several years. Microplastics, commonly defined as plastic particles smaller than 5 mm (Arthur et al., 2009), are widely distributed in many types of habitats from land to the ocean. Microplastics are found in the most remote places, such as the deep sea (Van Cauwenberghe et al., 2013), the Tibet plateau (Zhang et al., 2016), and the Arctic (Obbard et al., 2014). The growth of microplastic research in recent years reflects the attention it has garnered in academia, yet most microplastic studies focused on marine microplastics (Rillig, 2012). Data collected from freshwater environments is scarce (Wagner et al., 2014). Thus far, microplastic data in freshwater ecosystems has concentrated on lakes, e.g., the Great Lakes (Eriksen et al., 2013) and the Taihu Lake (Su et al., 2016). The spatial distribution of microplastics in river shore sediments has been previously studied (Klein et al., 2015). Ecological effects of microplastics include ingestion by biota (Remy et al., 2015), bioaccumulation and transport of persistent organic pollutants (POPs) (Andrady, 2011), and transport of microbial community and pathogens attached to microplastics (Zettler et al., 2013). The effects mentioned above may also apply to freshwater ecosystems,

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therefore studies on freshwater and terrestrial microplastics require more scientific attention. A recent study in urban surface waters confirmed that anthropogenic factors affect the abundance of microplastics (Wang et al., 2016). In the terrestrial environment, Dris et al. (2016) found microplastic concentration was higher at an urban site than that at a suburban site, revealing a possible atmospheric source of microplastics. To assess the environmental risk associated with microplastics, it is imperative that more data be collected from different ecosystems.

Here, we show that urban freshwater river sediments are a possible reservoir for land-based microplastics, and a source of marine microplastics. The lack of studies of microplastics in freshwater ecosystems has now become a hindrance to the understanding of the source and fate of microplastics. The study of river sediments throughout Shanghai urban river systems may provide a representative example of urban river input of microplastics in coastal cities. Evidence of microplastic transport pathways from land sources to the seas and oceans is still lacking. Shanghai is currently the most populated city in China, with a population of 24.15 million within a land area of 6340 km^2 in 2015 (Shanghai Statistical Yearbook, 2016). Gross Domestic Product (GDP) of Shanghai in 2015 reached 2512.34 billion yuan (approximately 370 billion USD), ranking first among Chinese cities (including Hong Kong). Shanghai is located in the Changjiang River Estuary, in which Changjiang River Plume is a significant hydrological process that affects the distribution of microplastics. Under the pressure of population growth and economic development, natural environment protection should be taken into consideration to achieve green development. The study is a pioneering research to conduct risk assessment of microplastics using data collected from bed sediments from urban river systems in mega-cities. Microplastic concentration data, possible sources, and the environmental behavior of urban plastic (microplastic) input were investigated. This study attempted to establish risk assessment indicators specific to sediments. Recommendations for constructing risk assessment systems were proposed in the Chinese context. To evaluate sources of microplastics and make suggestions for policy-makers, current legislation and regulations related to waste disposal in China were also summarized.

2. Materials and methods

Seven sampling sites covered six rivers and one tidal flat (NH) in Shanghai urban districts (Fig. 1). Detailed information on each sampling site is given in Table 1. Samples were collected during July and August 2016. River sediments were sampled during July 15 and August 1, 2016. Sediments from a tidal flat were sampled on July 13, 2016. The six rivers covered different river scales – small, medium and large rivers. Riverside samples include one from a park in Caohejing in Xuhui District (XH), one from a residential area in Beishagang in Songjiang District (SJ), one from a rural area in Jiangjiagang in Minhang District (MH), one from a park in Yujiabang in Pudong New Area (PD), one from a park in Shajinggang in Hongkou District (HK), and one from Gongqing park on a branch of Huangpu River in Yangpu District (YP). Sediments from a tidal flat located in Nanhuizui foreland (NH) were chosen to compare the concentration of microplastics in different environments. In the tidal flat, three sampling sites from high tide line to low tide line were chosen, and these samples were collected using a 0.5*0.5 m quadrat, where a quarter of the sediments were taken from the upper 5 cm in the quadrat. For each sampling site, 3 replicates were randomly collected along the accessible banks (for rivers) due to limited width in the river banks, or using a quadrat (for the tidal flat). Samples were collected with a shovel and moved to clean tin cups (for rivers) or aluminum foil (for the tidal flat) to avoid direct

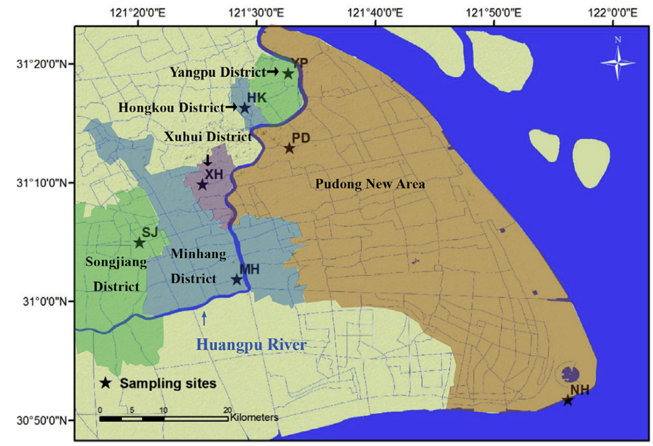

Fig. 1. Sampling sites of sediments from rivers and a tidal flat in Shanghai. Seven sites include YP, HK, XH, SJ, MH, PD and NH, with the land area of each municipal district shown in 4 colors. Black stars represent sampling sites. Blue lines on the map illustrate the urban river system, with the thick blue line being the Huangpu River. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

contact with bags during transfer. Then, sediments were placed in sealed bags, marked and transferred to the laboratory. Approximately 500 g sediments per replicate were collected from each sampling site.

The density separation process was carried out using the methods by Thompson et al. (2004), with modifications adjusted according to Masura et al. (2015). We excluded wet sieve and wet peroxide oxidation (WPO) during the process because no visible debris was found. To avoid airborne microfiber contamination, we took measures according to Zhao et al. (2017). Samples were first dried in an oven at 70 °C to constant weight. Then, a sample of 100 g dry sediment was weighed and placed in a glass beaker pre-rinsed with Milli Q water. Concentrated saline solution of NaCl (1.2 g mL^{-1}) was added to the beaker and stirred with a clean glass rod for 2 min. After it settled for 24 h, the supernatant containing microplastics was vacuum-filtered. We chose filter paper (Whatman GF/B, $\varphi = 1$ μm) that would collect the majority of microplastics. The last step of filtration was adding Milli Q water to remove chemicals. Filter paper containing microplastic particles was then dried to constant weight. The same process was repeated for all of the samples. Microscopic observations were carried out using Leica M165 FC. Photos of all suspected microplastic particles were taken and categorized according to shape, color and size. Then, microscopic Fourier transform infrared spectroscopy (μ-FT-IR) was applied to identify polymer types of suspected microplastics. μ-FT-IR analysis was carried out using Thermo Fisher Nicolet™ iN™10 in Shanghai Jiao Tong University and Bruker LUMOS in East China Normal University. Transmittance mode was chosen for Nicolet™ iN™10 and ATR (Attenuated Total Reflection) mode was chosen for LUMOS to acquire spectra. Library comparison results that match >70% confidence can be concluded to be plastic polymers. Summarized steps for two kinds of μ-FT-IR analysis are listed in Table S1. Statistical analyses were processed with IBM SPSS Statistics 22.

The ecological risk index method was proposed by Håkanson (1980), and is one of the most important ways to assess the potential ecological risks of sediments. Not only does this method take into account the environmental impact of various pollutants in particular environments, it also fully reflects the combined effects of multiple pollutants, thus rating the potential ecological risk. This method has been widely applied in the study of heavy metals (e.g.,

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