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Accumulation of floating microplastics behind the Three Gorges Dam

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ABSTRACT

We investigated the occurrence and distribution of microplastics in surface water from the Three Gorges Reservoir. Nine samples were collected via trawl sampling with a 112 μm mesh net. The abundances of microplastics were from 3407.7×10^3 to $13,617.5 \times 10^3$ items per square kilometer in the main stream of the Yangtze River and from 192.5×10^3 to $11,889.7 \times 10^3$ items per square kilometer in the estuarine areas of four tributaries. The abundance of microplastics in the main stream of the Yangtze River generally increased as moving closer to the Three Gorges Dam. The microplastics are made exclusively of polyethylene (PE), polypropylene (PP), and polystyrene (PS). Together with microplastics, high abundance of coal/fly ash was also observed in the surface water samples. Comparing with previously reported data, microplastics in the TGR were approximately one to three orders of magnitudes greater, suggesting reservoirs as potential hot spot for microplastic pollution.

1. Introduction

Plastics are probably the most versatile synthetic materials invented by human. Due to the unique properties, such as light-weight, strength, durability, corrosion-resistance, and electrical insulation, plastics are widely used (Thompson et al., 2009). Nearly all products used in our daily life contain plastics. In the last 50 years, annual world production of plastics increased drastically. In 2012, 280 million tons of plastics were produced globally with less than a half got disposed in landfills or recycled while the rest may still be in use or otherwise be discarded into the environment (Rochman et al., 2013). In the environment, larger plastic items can slowly breakdown into small pieces via physical, chemical and biological processes (O'Brine and Thompson, 2010; Singh and Sharma, 2008). Plastic debris <5 mm is usually referred to “microplastics”, which can be ingested by aquatic organisms and cause potential harmful effects (Hidalgo-Ruz et al., 2012; Setälä et al., 2014; von Moos et al., 2012).

Since the first observation on the Sargasso Sea made by Carpenter and Smith (1972), detections of plastic debris in the environment are increasingly reported. Marine environment was found to be an important destination for plastic debris (Browne et al., 2011; Collignon et al., 2012; Eriksen et al., 2013b; Ivar do Sul and Costa, 2014; Thompson et al., 2004). In oceans, accumulation of plastic debris was observed in the large-scale subtropical convergence zones due to the circulation of ocean current (Law et al., 2010). Microplastics were recovered from the deep-sea sediments (Van Cauwenberghe et al., 2013; Woodall et al., 2014). Plastics were even found in the digestive tract of wild collected fish samples from the North Sea (Foekema et al., 2013).

Information on the plastic pollution from freshwater environment is limited comparing to those from marine environment (Wagner et al., 2014). In the Great Lakes, plastic pollution was observed both in the surface waters and along the shorelines (Eriksen et al., 2013a; Zbyszewski et al., 2014). In a remote lake in Mongolia, microplastics was found more abundant than the more developed Lakes, which was attributed to an impropriate waste management of the local government (Free et al., 2014). Recently, several studies were performed in estuarine areas, indicating rivers as a source for marine plastic debris (Rech et al., 2014; Yonkos et al., 2014; Zhao et al., 2014). Research along the Seine River showed that plastic debris was an important component of the floating debris (Gasperi et al., 2014). All these evidences support that plastic pollution can also be a serious environment issue in freshwater environment.

Reservoirs created by damming rivers could be a potential area

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for the accumulation of floating plastics. As a result of water impoundment, floating materials on the water surface cannot pass the dam. The Three Gorges Reservoir (TGR) is the largest reservoir in China, which was officially impounded in June 2003 and was in full operation in May 2012. The TGR has a total water storage capacity of 39.3 billion cubic meters and a surface area of 1084 km^2 at a water level of 175 m. Impoundment of the river has changed the hydrologic condition drastically. Floating materials from upstream and buoyant trash from sites submerged by rising water level are retained and accumulated in the water surface of the TGR, which causes water pollution and affects ship navigation. Research showed that plant residue, woody debris, and plastic debris are the major components of the floating materials in the TGR (Ning and Zhang, 2010). Removal of floating materials costs enormous amount of time and effort every year. Although large pieces of floating materials can be removed, small fragments such as microplastics might still be left in the water. Therefore, the purpose of this work is to quantitatively and qualitatively examine the occurrence and distribution of microplastics in surface water from the TGR.

2. Materials and methods

2.1. Sample collection

Floating debris was collected in September 23, 2014 using a trawl with a rectangular opening 50 cm high by 100 cm wide, and 1.5 m long 112 μm mesh size nylon net with a 500 mL polyethylene collecting bottle at the end. Nine samples, including four from the estuarine areas of the tributaries and five from the main stream of the Yangtze River within the TGR (Fig. 1), were collected by towing the net by the side of the boat at a speed of 5 km h^{-1} approximately. The sampling in the main stream was performed along the flow direction while the sampling in the estuarine areas was vertical to the flow direction. Unfortunately, the flow rate of the water was not measured during the sampling but according to other group from our institute the flow rate in the main stream during our sampling period was 1 km h^{-1} approximately. The towing distance was 400 m approximately, which was not correct with the flow rate (Table 1). A much short distance was used here than those typically used in previous research because of a much higher microplastic abundance found in the TGR (see below). The area of each sampling was calculated by multiplying the towing distance with the width of the trawl. Samples retained in the collecting bottle were transferred into a 1 L glass bottle. Debris remaining in the net was rinsed thoroughly with river water into a beaker and transferred into the same glass bottle. All samples were then preserved with 5% methyl aldehyde and stored at 4 °C before analysis.

2.2. Sample preparation and identification

Sample preparation was performed following a previous described method with slight modification (Eriksen et al., 2013a). Briefly, samples were passed through a 1.6 mm stainless steel sieve, liquid got through the sieve was collected and transferred into a 1 L separating funnel. Materials retained on the sieve were examined by naked eyes and suspected plastic debris were picked out using a stainless steel tweezers. Samples in the funnel were allowed to settle for a week. The floating debris on the surface were transferred to petri dishes, then oven-dried at 60 °C, and examined using a stereomicroscope to identify suspected microplastics. For identification, 50 to 100 suspected microplastics were randomly selected from each site and examined using a PerkinElmer (Waltham, MA, USA) Spotlight 400 Fourier Transform infrared (FT-IR) spectroscopy coupled to an Attenuated Total Reflectance (ATR) accessory. The FT-IR spectrum was recorded from 600 to 4000 cm^{-1} using the instrument. The FT-IR spectrum of the sample was compared with the spectrums of references in a database using the Thermo Scientific OMNIC Specta software. The types of references with the highest similarity (at least 90% similarity for confirmation) in the database were assigned to the samples.

3. Results and discussion

3.1. Abundance and types of microplastics

Microplastics were identified from all the sites with abundance ranging from 3407.7 × 10^3 to 13,617.5 × 10^3 items per square kilometer in the main stream of the Yangtze River and from 192.5 × 10^3 to 11,889.7 × 10^3 items per square kilometer in the estuarine areas of the tributaries (Table 1). In the mainstream, the abundance of microplastics generally increased as moving towards the dam except CJ02. Site CJ02 was next to the Guizhou port, which may reduce the water flow and cause the accumulation of microplastics near the port (Fig. 1). In addition, waste materials generated by human activities at the port may also contribute to the elevation of microplastics. Site CJ05, which is the nearest to the dam, had the highest abundance of microplastics. Microplastics from upstream transported by river water cannot pass the dam and therefore accumulate behind the dam as expected. The microplastics in the surface water can only be removed by sedimentation to the bottom of the reservoir (Van Cauwenberghe et al., 2013), or completely degraded, or accidentally ingested by aquatic organisms. The accumulation of microplastics can be determined by the amount of loadings from upstream, rate of generation and the rate of removal in the TGR. Microplastics will continue accumulating behind the dam if the rate of loading and generation surpasses the rate of removal, which might cause increasing risks to the aquatic organisms living within the TGR.

From the estuarine areas of the tributaries, microplastics from Qinggan River (QG), Yuanshui River (YS), and Tongzhuang River (TZ) were found relatively lower than those found from the mainstream sites. Whereas microplastics from Xiangxi River (XX) were comparable to those from CJ02 and CJ05. The ultimate sources of microplastics are the use and disposal of plastic products. Therefore, the abundance of microplastics can be directly related to the human activities within the river water basin. Previously, research showed that microplastics in four estuarine rivers in the Chesapeake Bay, USA was positively correlated with population density and proportion of urban/suburban development within watersheds (Yonkos et al., 2014). In the TGR, tributaries under intensive human impact can contribute significant amount of microplastics to the reservoir. Among the studied tributaries, Xiangxi River drain a much larger area (Table 1) and more people live within the Xiangxi River watershed (the exact population data within the watershed of the tributaries are unavailable).

The types of microplastics were identified to be polyethylene (PE), polypropylene (PP), and polystyrene (PS) (in the form of Styrofoam). PE and PP were the dominant, which accounts for 36.79%–57.12% and 42.14%–63.21% of the total microplastics, respectively (Table 1). The types of microplastics are less diverse comparing to those collected from marine environment (Browne et al., 2011, 2010; Dekiff et al., 2014). This may be attributed to a higher density of sea water, more types of plastic materials can float on the surface of water with higher density. Whereas at the Tamar Estuary, Southwest England, polyester, nylon, and polyvinyl chloride (all have a density > 1.0 g mL^{-1}) were also observed (Sadri and Thompson, 2014), likely due to a higher water velocity and a mix of fresh water with sea water. In the TGR, the water flow is