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Microplastic risk assessment in surface waters: A case study in the Changjiang Estuary, China

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ABSTRACT

The rapid development of plastic industry has resulted in a series of environmental problems caused by microplastics originating from larger plastics. Microplastic pollution risk in surface waters of the Changjiang Estuary was explored based on risk assessment models. The average microplastic concentration was 23.1 ± 18.2 n/100 L. Shape, size, color and composition types of microplastics were examined. The risk assessment models were developed using data on both the concentration and chemical hazard of microplastic polymers. Assessment results indicated that polyvinyl chloride exhibited a critical concern for microplastic risk. Areas around aquaculture farms were regarded as "hotspots" of microplastic pollution due to the accumulation of microplastics and the presence of hazardous microplastic. This risk assessment of microplastics bridged gaps in understanding between field research and policy-making for surface waters. This research provides baseline data for assessing the environmental risk of microplastics in this growing area of research.

1. Introduction

Plastics are synthetic polymers widely used in various industries, which largely originate from the polymerization of crude oil (Lithner et al., 2011). Given the wide range of use of plastic products, plastic waste contributes to a large amount of waste in the environment. A large amount of plastic waste is directly discarded into the ocean and it is estimated that will increase to 30 million tonnes by 2040 (Neufeld et al., 2016). Ocean dynamics and anthropogenic factors can result in the crushing of plastic debris and the formation of microplastics (MPs) (Thompson et al., 2004).

Most available information on the distribution of MPs in the environment comes from research in offshore areas, estuaries and the open ocean (Collignon et al., 2014; Doyle et al., 2011; Law et al., 2010; Moore et al., 2001). Ubiquitous MPs pose potential dangers to aquatic organisms, due to a number of characteristics. Various types of MPs, including fibers, pellets and fragments, are now commonly found in organisms (Lusher et al., 2013; Li et al., 2015; Jabeen et al., 2017). It has been reported that MP particles are more likely to be mistakenly ingested if they are similar in color to prey items (Laurier and Mason, 2007). MPs with a median particle size of 0.8 mm have been widely detected in the bodies of fish (Foekema et al., 2013). Hazardous MP polymers are known to induce detrimental biological effects on plankton, fish and birds (Mato et al., 2001; Ogata et al., 2009; Henry, 2013).

Current research in this area has included some risk assessments applying different methods and indicators. Wilcox et al. (2013) developed oceanic drift models to make predictions of the probability of a marine turtle being endangered by abandoned fishing gears. Based on chemical compositions of plastic polymers, Lithner et al. (2011) incorporated the chemical hazard of additives, monomers, polymers and polymerization, and developed a hazard ranking model of plastic polymers to assess the hazard effects on human health and organisms. Thermodynamic features of plastics have been selected as important factors in determining the adsorption capacity of MPs (Gouin et al., 2011). A MP risk assessment framework for a mega-city was constructed combining the distribution characteristics of MPs in an urban river (Peng et al., 2018). Severe ecological risk of MPs in mussels were correlated with high MP concentrations in the surrounding water, which suggested that mussels could be used as biological indicators to monitor MP pollution levels in coastal waters (Qu et al., 2018).

The MP risk assessment process remains difficult, although researchers have recently incorporated environmental influences. To date the actual risk posed by MPs has not been determined, as that laboratory exposure concentrations are not compared to environmentally relevant thresholds (Koelmans et al., 2017). Ambiguous statements like "potential", or "could" are often used to mislead policy making (Koelmans et al., 2017). Some studies may focus on a certain aspect of MP pollution, and thus cannot fully describe the risk of MPs (Bencze and Alsop, 2014). In terms of field research, there is no standardized

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method to monitor of MPs in the environment (Hidalgo-Ruz et al., 2012).

A previous study suggested that China may have the largest output of plastic waste from terrestrial sources entering the ocean globally (Jambeck et al., 2015). High levels of MPs have also been widely observed in surface waters of estuaries in China (Zhao et al., 2014, 2015). In addition, seafood collected from Shanghai, China had abundant MPs (Li et al., 2015; Jabeen et al., 2017). Therefore, the Changjiang Estuary might experience potential MP risks (Peng et al., 2017).

In the present study, an initial assessment in surface waters of the Changjiang Estuary and the adjacent East China Sea was performed adopting the hazard score of plastic polymers created by Lithner et al. (2011) and the pollution load index (PLI). The aim of the study was to provide a primary understanding of the risk of MP pollution in surface waters. It is hoped that this research will assist policy making for marine MP pollution by providing preliminary data on MP assessment.

2. Materials and methods

2.1. Data collection

The Changjiang Estuary is a funnel-shaped estuary. Chongming Island divides the estuary into the North Branch and the South Branch (Zhao et al., 2018). Runoff from Changjiang is mainly discarded via the South Branch (Gao et al., 2008). The Changjiang Estuary is the gateway where the Changjiang River flows into the East China Sea, which represents multiple characteristics affected by interactions between marine and terrestrial environments (Liu et al., 2001; Liu et al., 2018). Its ecological status plays an important role in the development of local industry, agriculture and trading in Shanghai (Liu et al., 2015). Therefore, the ecological protection of the Changjiang Estuary and the adjacent area has received worldwide attention.

Samples were collected at 29 sampling stations in the Changjiang Estuary (C stations) and the adjacent East China Sea (ECS) (E stations) in August 2017 on board the Runjiang No.1. (Fig. 1). At each sampling station, 100 L of water was pumped through a stainless steel sieve with a mesh size of 70 μm at a depth of 50 cm. Residues on the sieve were washed into clean 250 mL high – density polyethylene bottles with purified water. Three replicate samples were collected at each sampling station. All samples were persevered at 5 °C until further analysis. Due to diversity in the field, it was difficult to avoid aerial contamination during sampling. Measures were taken during field work to reduce aerial contamination as much as possible, including washing the sieve and sampling bottles in advance.

In the laboratory, samples were digested with a 30% H_2O_2 solution for at least 12 h to remove biological materials. Using an excessive amount of digestive solution over a sufficient time period ensures a complete reaction during this process. Samples were then heated in water bath at 50 °C to speed up the reaction before they were filtered onto a Sartorius filter (0.45 μm pore size). Residual material on the filters was carefully transferred to clean glass petri dishes and dried to a constant weight.

The particles on the filter were counted and photographed under a Leica M165 FC microscope. Suspected particles were then transferred onto another clean filter for chemical analysis of polymers. A small amount of pure water was dropped on to the filter beforehand to prevent particle loss during this process. The morphological descriptions (fiber, fragment, film and spherical pellet) of particles were selected based on criteria used in previous studies (Zhao et al., 2014, 2015). The particles were also classified into four size groups: < 0.07 mm, 0.07–1.0 mm, 1.0–5.0 mm, and > 5.0 mm. In addition, the particles were described according to their color (black, transparent or colored).

μ-FTIR (micro-Fourier transform infrared spectroscopy, Bruker LUMOS, Germany) was used to determine all suspected particles on the filters. Contaminants attached to the surface of the particles, such as sediments, were cleaned in an ultrasonic bath. The ATR (Attenuated Total Reflection) mode is generally adopted for surface analysis of particles. This mode measures changes in infrared beam, which exhibits total internal reflection when the ATR crystal comes into contact with a sample. Therefore, it is important to obtain accurate contact between the crystal and the sample. By determining the absorbance of the selected infrared beam, it is possible to differentiate between different types of polymers. A list of potential compounds with hit quality was contributed by FTIR library (based on Nature Fiber Library and Polymer Library). The components with the highest matching values were identified as the main types of suspected particles. In order to check the matching rate of spectra from samples and data libraries, plastic products of known materials, including food packaging (polyethylene), bottles (polypropylene), tableware (polystyrene) and fishing gear (polyamide), were tested. The polymer types of all plastic products tested were accurately detected under ATR mode. Materials with a spectra matching rate of over 60% were accepted as being the main components, but matches below 60% were not rejected. This is an effective and useful method to determinate the characteristics of resultant peaks with μ-FTIR observations.

Correct detection of MP polymer types in samples is important in the risk assessment, therefore airborne pollution must be strictly controlled during experimental procedures. Precautions to avoid aerial contamination following Zhao et al. (2017) were undertaken during the whole procedure. The stainless steel sieve used for sampling was cleaned repeatedly three times to ensure that no impurities remained. All solutions and purified water were pre-filtered using Sartorius filters (0.45 μm pore size). Glass ware was cleaned with purified water and placed in an autoclave at 450 °C for 2 h. Clothes and plastic containers made of unknown materials used in the lab were detected with μ-FTIR to exclude any suspected particles. In order to avoid potential air pollution during laboratory work, air was sucked through three 0.45 μm filter papers where any residues could be observed on the filter membrane.

2.2. MP risk assessment approach

Both the concentration and the chemical composition of MPs should be considered in order to evaluate the potential risks of MPs in surface waters of the Changjiang Estuary and the adjacent ECS. The risk of MPs in surface waters based on two indicators was assessed separately. Following Lithner et al. (2011), the chemical toxicity of MP polymers was used as an important index to evaluate its ecological harm. Our study utilized the hazard scores of plastic polymers from Lithner et al. (2011) and used the polymer types of MPs as indexes to assess the risk of MPs (see Table 1). The following formula was used:

$$H = \sum P_n \times S_n \tag{1}$$

where H is the calculated polymer risk index caused by MP, P_n is the percent of MP polymer types collected at each sampling station, and S_n is the score from Lithner et al. (2011) for the polymer compound that comprised MP particles.

In a larger area, it is not possible to complete the assessment solely on a single indicator. In such case, the pollution load index (PLI) which refers the MP concentration in Changjiang Estuary, was used. Tomlinson et al. (1980) proposed the pollution load index (PLI) to assess the level of pollution in estuaries. The PLI is regarded as a standardized rule for monitoring the degree of pollution between different areas (Angulo, 1996). The assessment model was as follows (Tomlinson et al., 1980):

$$\begin{aligned} CF_i &= C_i / C_{oi} \\ PLI &= \sqrt{CF_i} \\ PLI_{zone} &= \sqrt[n]{PLI_1 PLI_2 \cdots PLI_n} \end{aligned} \tag{2}$$

The pollution load index of MPs at each station (PLI) is related to MP concentration factors (CF_i). The CF_i of MPs is the quotient of the MP