Environmental Pollution 239 (2018) 223–232

Contents lists available at ScienceDirect

Environmental Pollution

journal homepage: www.elsevier.com/locate/envpol

Occurrence and ecological risk assessment of organic micropollutants in the lower reaches of the Yangtze River, China: A case study of water diversion☆

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ARTICLE INFO

Article history:
Received 12 January 2018
Received in revised form
8 March 2018
Accepted 5 April 2018

Keywords:
Micropollutant
Water diversion
Yangtze River
Water security

ABSTRACT

Water diversion has been increasingly applied to improve water quality in many water bodies. However, little is known regarding pollution by organic micropollutants (OMPs) in water diversion projects, especially at the supplier, and this pollution may threaten the quality of transferred water. In the present study, a total of 110 OMPs belonging to seven classes were investigated in water and sediment collected from a supplier of the Yangtze River within four water diversion projects. A total of 69 and 58 target OMPs were detected in water and sediment, respectively, at total concentrations reaching 1041.78 ng/L and 5942.24 ng/g dry weight (dw). Polycyclic aromatic hydrocarbons (PAHs) and pharmaceuticals were the predominant pollutants identified. When preliminarily compared with the pollution in the receiving water, the Yangtze River generally exhibited mild OMPs pollution and good water quality parameters, implying a clean water source in the water diversion project. However, in Zongyang and Fenghuangjing, PAHs pollution was more abundant than that in the corresponding receiving water in Chaohu Lake. Ammonia nitrogen pollution in the Wangyu River was comparable to that in Taihu Lake. These findings imply that water diversion may threaten receiving waters in some cases. In addition, the risks of all detected pollutants in both water and sediment were assessed. PAHs in water, especially phenanthrene and high-molecular-weight PAHs, posed high risks to invertebrates, followed by the risks to fish and algae. Pharmaceuticals, such as antibiotics and antidepressants, may also pose risks to algae and fish at a number of locations. To the best of our knowledge, this report is the first to describe OMPs pollution in water diversion projects, and the results provide a new perspective regarding the security of water diversion projects.

1. Introduction

Water diversion, a new remedy for water restoration, is being increasingly applied to alleviate water pollution and improve water quality in many water bodies, such as Barato Lake in Japan (Shinohara et al., 2008), Laguna Alalay Lake in Bolivia (Ayala et al., 2007), and Taihu Lake, Chaohu Lake, West Lake and Dianchi Lake in China (Ma, 1996; Li et al., 2013; Xie et al., 2009; Zhang et al., 2016). In these designed schemes, large volumes of water from a comparatively clean source are transferred to a heavily polluted water body in a short period of time to accelerate water exchange, dilute pollutants, and ultimately minimize water quality degradation in the water body. In the lower reaches of the Yangtze River in China, transportation of river water to Taihu Lake has been demonstrated to improve water quality and reduce the risk of algal blooms in the lake region (Zhai et al., 2010). A positive effect on nutrient pollution in Chaohu Lake was also observed after diverting water from the Yangtze River to Chaohu Lake (Xie et al., 2009). Ma et al. (2015) concluded that the transfer of freshwater from the

☆ This paper has been recommended for acceptance by Dr. Harmon Sarah Michele.

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https://doi.org/10.1016/j.envpol.2018.04.023
0269-7491/

Yangtze River could be used as an emergency measure to flush pollutants from the Lixia River watershed. Although the effectiveness of water diversion in relation to general water quality has been studied, most of these studies have concentrated on the changes in the receiving water, and scant attention has been paid to the supplier. Moreover, these investigations have only focused on the control of eutrophication and nutrient pollution (e.g., nitrogen, phosphorus) and have ignored the presence of organic micropollutants (OMPs), which may lead to more serious consequences to the environment.

In the aquatic environment, the occurrence and fate of OMPs, including both conventional priority pollutants and emerging contaminants, have increasingly attracted concern in recent years due to their undesired physiological effects on aquatic organisms, even when present at trace levels. For instance, the bioaccumulation of persistent organic pollutants (POPs) through food chains can result in serious side effects, including immunodeficiency, growth deformities, neurobehavioral deficiency, and even cancer and tumors, in organisms (Ashraf, 2017). The presence of antibiotics can notably accelerate the development of antimicrobial resistance among microorganisms, which causes humans and animals to be more susceptible to these microbes (Xu et al., 2016). The feminization of male fish in rivers, characterized by vitellogenesis, gonad atrophy and intersex, has been attributed to the release of estrogens, which further reduces the reproductive performance and population development of fish (Harris et al., 2011). Hence, it is necessary to monitor and assess the occurrence of these OMPs in waters to ensure water security. Previous studies have indicated the presence of OMPs in different waters and sediments; however, most of these studies have focused on a single class of OMP, ignoring the mixtures of OMPs in the environment.

The lower reaches of the Yangtze River, located in eastern China, is a highly fertile, populous and affluent region. This region includes the provinces of Jiangxi, Anhui, Jiangsu, Zhejiang and the city of Shanghai, and supports a population of more than 260 million people in 2015 (NBSC, 2016). Moreover, this region is known as “the land of fish and rice” by the Chinese and accounts for 25.7% of the national GDP, dotting with many well-known lakes and a network of rivers, such as Chaohu Lake, Taihu Lake, Qinhuai River, Huangpu River and the Grand Canal. Moreover, more than 17.8 billion tons of wastewater have been produced annually and continually released into the connecting water systems due to the rapid economic development and urbanization in this region (NBSC, 2016), resulting in a series of serious environmental and socioeconomic problems. For instance, in Taihu Lake, the excessive accumulation of nutrient-rich sewage and agricultural runoff from surrounding waters led to algal blooms in the lake in the summer of 2007, which forced the Wuxi government to shut down its water supply system and triggered approximately one million locals to resort to drinking bottled water (Guo, 2007). The continuous introduction of pollutants from industrial and domestic sewage in the city of Nanjing has transformed many urban rivers into black-odor rivers with peculiar odors smell, decreased surviving aquatic organisms, and collapsed structure of ecological system (He et al., 2015), seriously affecting the aquatic environment and human living conditions (Wan et al., 2014). The importance of protecting aquatic ecosystems has been strongly increasing in China with the Water Pollution Control Action Plan issued by the State Council in 2015. In subsequent years, many treatment technologies and management policies have been implemented to protect the aquatic environment from the potential threat of pollutants in this region, such as water diversion.

Therefore, in the current study, several water diversion projects in the lower reaches of the Yangtze River were selected as the study area. We investigated the concentrations of several classes of OMPs, such as pharmaceuticals, organic ultraviolet (UV) filters, perfluorinated compounds (PFCs), organochlorine pesticides (OCPs), polychlorinated biphenyls (PCBs), polycyclic aromatic hydrocarbons (PAHs), and hexabromocyclododecanes (HBCDs) in the surface water and sediment of the Yangtze River, as well as general water quality parameters and plankton diversity. And then, these measured concentrations of OMPs were compared with published values in the receiving water to preliminarily identify whether the Yangtze River has the potential to improve water quality in receiving water. Furthermore, the risks of OMPs to aquatic biota in the surface water and sediment were assessed based on measured environmental concentrations (MECs) and the available toxicity data to protect aquatic life.

2. Materials and methods

2.1. Chemicals and reagents

A total of 110 OMPs belonging to seven categories were selected as target chemicals in this study. The basic physical and chemical characteristics of these chemicals are presented in Table S1. The standards for all the chemicals were purchased from Dr. Ehrenstorfer (Augsburg, Germany) or Sigma-Aldrich (Flanders, USA). All solvents used in this study were of high-performance liquid chromatography (HPLC) grade and were purchased from Merck (Darmstadt, Germany).

2.2. Study area

Four representative water diversion projects in the lower reaches of the Yangtze River were selected as the study areas for the current study: Chaohu Lake Water Diversion (S1-S3), Qinhuai River Water Diversion (S4-S5), South-to-North Water Diversion (S6), and Taihu Lake Water Diversion (S7-S10). These projects have been approved by the government in recent years to solve different problems in the receiving region. Due to the severe eutrophication and pollution in Chaohu Lake, Qinhuai River, and Taihu Lake, the transfer of water from the Yangtze River into these large shallow lakes or urban rivers has been implemented to relieve these environmental problems. The east route of the South-to-North Water Diversion was designed to optimize the use of the limited water resources in northern China. A detailed description of these projects is listed in the Supplementary Material. The sampling map and detailed sampling site descriptions are provided in Fig. 1 and Table S2.

2.3. Sample collection, treatment and analyses

At each sampling site, both water and sediment samples were collected with three replicates from November 23, 2016 to December 5, 2016 with lowered water levels. Water diversion was also implemented in this dry season from November to March of next year in most cases. Since aquatic organisms (e.g. fish) were difficult to be captured during the sampling periods in the Yangtze River, the OMPs pollution in these organisms were not preformed. Water samples (5 L) collected from 50 cm below the surface were immediately transferred to the laboratory in iced containers for further treatment within 24 h. Surface sediment samples were simultaneously collected with a stainless-steel grab sampler and were subsequently lyophilized and stored in a freezer (−80 °C) in the laboratory for further treatment.

After filtration, the water samples were extracted using the solid phase extraction (SPE) method with different cartridges according to previous studies (Li et al., 2016a; Pintado-Herrera et al., 2017; Xie et al., 2017). The extracts were next evaporated to dryness under nitrogen and further reconstituted for instrumental analysis. All