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Impacts of channel morphology on residues and ecological risks of polychlorinated biphenyls in water and sediment in Chahe River

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Abstract

The impacts of channel morphology on the residues and ecological risks of 14 polychlorinated biphenyl (PCB) congeners in water and sediment were investigated in summer (July) and autumn (September) in the Chahe River, in Nanjing, China. The residual concentrations of tri-chlorobiphenyls (tri-CBs, PCB 18) and tetra-CBs (PCB 52) in water were significantly higher than those of penta-CBs to deca-CBs, and the average residual concentration of ∑PCBs (sum of 14 PCB congeners) in summer was about six times higher than in autumn. However, the residues in sediment did not change significantly. Redundancy analysis (RDA) indicated that channel morphology and the corresponding environmental indices had significant impacts on PCB residues and their composition profiles in water and sediment. The overflow weir and lake-type watercourse may remarkably reduce the residual concentration and ecological risks of PCBs in water. The highest reduction percentages of the residual concentration and ecological risks of ∑PCBs induced by an overflow weir were 78% and 67%, respectively, and those induced by a lake-type watercourse were 36% and 70%, respectively. The watercourses with different channel morphologies were ranked by residual ∑PCBs concentrations in the following descending order: the natural ecological watercourse, vertical concrete watercourse, and vegetation-type riprap watercourse. However, they were ranked by residual ∑PCBs concentrations in sediment in the following descending order: the vertical concrete watercourse, vegetation-type riprap watercourse, and natural ecological watercourse.

Keywords: PCBs; Channel morphology; RDA; Ecological risk; Toxic equivalent concentration

1. Introduction

Polychlorinated biphenyls (PCBs) are one set of semi-volatile organic compounds, which have been used widely as electric insulators in transformers, hydraulic fluids, and paint additives since they began being produced commercially in 1929 (Wang et al., 2011). A great deal of concern has been expressed over the presence of PCBs in different environmental matrices, due to their high toxicity, persistence, bio-accumulation, biomagnification, and long-range transportation (Zhang et al., 2002; Wan et al., 2005). Once released into the aquatic environment, PCBs are usually bound to suspended

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particles or absorbed by aquatic organisms. They can be biomagnified to about 200−70000 times along the food chain and cause potential risks to organisms and humans (Ashley et al., 2000; Fontenot et al., 2000; Pruell et al., 2000; UNEP, 2004; Dodoo et al., 2012). It is now common knowledge that PCBs pose a major threat to humans and the environment even at very low concentrations (Baars et al., 2004; Dodoo et al., 2012). Exposure to PCBs can cause a series of health impacts, including reproductive disorders and immune suppression of various organisms, and even result in cancer, teratogenesis, and mutations (Van den Berg et al., 2006; Zhao et al., 2014).

China produced a total of approximately 10000 tons of PCBs from 1965 to 1974, including 9000 tons of tri-CBs and 1000 tons of penta-CBs (Wu et al., 2011, 2015). Although PCBs are not produced any more, some of them remain in the environment. Many studies have already analyzed and reported the distribution, level, and fate of PCBs in air, water, soil (Zhang et al., 2007; Wang et al., 2008, 2010), sediment, organisms, and the human body (Zhang et al., 2003; Nakata et al., 2005; Li et al., 2008; Weijs et al., 2009; Wu et al., 2009, 2011; Hu et al., 2010; Bao et al., 2012; Consonni et al., 2012; Dodoo et al., 2012). The levels of PCBs in the Haihe and Huaihe rivers are 311−3110 ng/L ($\sum PCB_{12}$, sum of 12 PCB congeners) and 46.8−194 ng/L ($\sum PCB_{57}$, sum of 57 PCB congeners), respectively, which are higher than those in the Yangtze River (with a $\sum PCB_{18}$ concentration ranging from 0.92 to 5.11 ng/L, sum of 18 PCB congeners) and the Pearl River (with a $\sum PCB_{20}$ concentration ranging from 0.12 to 1.47 ng/L, sum of 20 PCB congeners) (Bao et al., 2012).

In addition, some studies show that increased amounts of aquatic plants and phytoplankton productivity can reduce the concentrations of persistent organic pollutants (POPs) in aquatic ecosystems, and the species and biomass of aquatic plants and phytoplankton can affect the bioaccumulation and distribution of PCBs (Taylor et al., 1991; Cailleaud et al., 2007; Nizzetto et al., 2012; Frouin et al., 2013; Galbán-Malagón et al., 2013; Zhao et al., 2014). The physical and biogeochemical characteristics of the aquatic environment such as light, temperature, eutrophication, and nutrient stress can affect the bioaccumulation of PCBs in aquatic ecosystems (Magnusson and Tiselius, 2010; Berrojalbiz et al., 2011; Zhao et al., 2014). However, few researchers have investigated the impact of channel morphology on the residual characteristics of PCBs. Recently, China has embarked on a pilot national monitoring program to assess ecological integrities of major watersheds since 2010. The components used in this monitoring program included hydrology, channel morphology, physico-chemical parameters, residues of pollutants (e.g., heavy metals, nutrients, and POPs), ecotoxicological aspects, types and numbers of biota and age, and growth of fish (Wang et al., 2014). The change of channel morphology can affect the flow rate, physico-chemical indices, such as pH and dissolved oxygen (DO), and the deposition of suspended particles, leading to a change in residual characteristics of POPs in water and sediment (Ko and Baker, 2004; Wurl and Obbard, 2006; Yan et al., 2008; Sandy, 2010).

The objectives of this study were to describe the impact of channel morphology on the residues and ecological risks of PCBs based on the investigation and redundancy analysis (RDA) of residual PCBs and environmental indices at different sampling sites.

2. Materials and methods

2.1. Study area

The Chahe Watershed, a typical small agricultural watershed consisting mainly of small patches of uplands and paddy fields, is located in Baima Town (at a latitude of 31°34′N and a longitude of 119°10′E) in Nanjing, China (Fig. 1). The study area is located in a subtropical monsoon climate zone with an average annual temperature of 15.4°C and an annual rainfall of 1087.4 mm (Zhu et al., 2013). The total area is about 4.087 km^2 and most of the land is used for farming, of which paddy fields account for 50% and uplands account for 30%. The river mainly undertakes the functions of irrigation and drainage. In addition, most of the watercourses show a natural formation with small cross-sections and large curvature. For the purposes of irrigation and impoundment, a large number of sluices, dams, and other impounding buildings were built along the watercourses. Overflow weir 1 and Overflow weir 2 are located near Bridge 1 and Bridge 2, respectively. These structures affect the transportation of pollutants and sediment. There are mainly two kinds of pollution sources (mainly containing high concentrations of nitrogen, phosphorous, and trace POPs) along the river: (1) a large amount of field water, with agricultural non-point source pollutants, directly draining into the upper reaches of the Chahe River, especially at sampling site #1; and (2) a point source sewage outfall located between sampling sites #4 and #5. In addition, a paint factory and a waste plastics recovery plant located near the Chahe River are also possible pollution sources (Bao et al., 2012). The Chahe River has been heavily polluted by the agricultural non-point source pollutants and sewage. In order to improve its water quality, some ecological engineering measures, such as overflow weirs, aquatic plants, and ecological riverbanks and watercourses, have been applied to the river since 2009.

2.2. Sample collection

The samples of water and sediment were collected according to the channel morphology along the Chahe River in the summer (on July 7, 2013) and autumn (on September 30, 2013) (Fig. 1). In July, the rainy season of this region, there is a lot of surface runoff flowing into the river. Rice in July is at its tillering stage, and it needs plenty of pesticides and extensive irrigation. Therefore, field water easily drained into the river and increased the pollution load of the river. Meanwhile, in September, rice is at its milk stage, and the climatic characteristics are entirely different from those in July. The sampling sites were set according to the channel morphology of the Chahe River from north to south: the #1, #2, #3, #4, #5, and #6 sites (Fig. 1 and Table 1). Sites #1 and #2 were located