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Predicted no-effect concentrations for mercury species and ecological risk assessment for mercury pollution in aquatic environment

Meng Du[1,2], *Dongbin Wei*[1,*], *Zhuowei Tan*[1], *Aiwu Lin*[2], *Yuguo Du*[1]

1. *State Key Laboratory of Environmental Chemistry and Ecotoxicology, Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences, Beijing 100085, China. E-mail: meng820701@163.com*

2. *Water Quality Monitoring Center of Beijing Waterworks Group Company Limited, Beijing 100192, China*

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ABSTRACT

Mercury (Hg) exists in different chemical forms presenting varied toxic potentials. It is necessary to explore an ecological risk assessment method for different mercury species in aquatic environment. The predicted no-effect concentrations (PNECs) for Hg(II) and methyl mercury (MeHg) in the aqueous phase, calculated using the species sensitivity distribution method and the assessment factor method, were 0.39 and 6.5×10^{-3} μg/L, respectively. The partition theory of Hg between sediment and aqueous phases was considered, along with PNECs for the aqueous phase to conduct an ecological risk assessment for Hg in the sediment phase. Two case studies, one in China and one in the Western Black Sea, were conducted using these PNECs. The toxicity of mercury is heavily dependent on their forms, and their potential ecological risk should be respectively evaluated on the basis of mercury species.

Introduction

Mercury (Hg) is a toxic element that exists in the environment and impacts human and ecosystem health even at extremely low concentrations. Both natural and anthropogenic sources are responsible for increasing the levels of Hg in aquatic environment. In the 1970s, Hg pollution appeared for the first time in the state of Michigan, USA (Taylor, 2000). The total Hg concentration in sea water in Vlora Bay of Albania was about 0.121 mg/L (Lodenius et al., 2004). In an 8-ha residential area in Southern Germany, there was a groundwater plume with a maximum Hg concentration of 230 μg/L (Bollen et al., 2008). A great deal of research on Hg pollution has also been conducted in China. For example, Hg concentration of 3.89 μg/L have been found in the Weisha River reach of the Songhua River, and average Hg concentrations of 1.61 μg/L have been found in water from the Gedian area (Hu, 2008). In addition, studies of Hg pollution in sediments should not be ignored due to the frequent transfer and transform. Bollen et al. (2008) found that a residential area was contaminated with up to 11,000 mg/kg of Hg in Southern Germany. Total Hg concentrations of 11.19–78.22 mg/kg have been found in sediments in the province of Liaoning (Hu, 2008). Some developing countries, such as Brazil, Indonesia, Laos, Sudan, Tanzania, and Zimbabwe, which are engaged in artisanal gold mining are also contaminated with Hg; this is particularly true in northwest Tanzania, where the concentration of Hg in urban soils was 0.05–9.2 mg/kg (Taylor et al., 2005).

Hg pollution has attracted much attention because of the high toxicity of Hg and its increasingly widespread presence. It has been reported that low doses of Hg can damage different organ systems, like the nervous system, the motor system, the cardiovascular system, and the kidney system (Zahir et al.,

* *Corresponding author*. E-mail: weidb@rcees.ac.cn (Dongbin Wei).

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2005). A recent study showed that mercurial compounds would readily cross the placental barrier and the blood–brain barrier, damaging the developing brain (Christinal and Sumathi, 2013). In fact, Hg occurs as different chemical species, including inorganic (*e.g.*, Hg(I) or Hg(II)) and organic (*e.g.*, methyl mercury (MeHg), ethyl mercury (EtHg), and phenyl mercury (PhHg)). It has been proved that mercury with different forms exhibited quite different toxicities, but organic Hg compounds are more toxic than inorganic species (Leopold et al., 2010). Among them, MeHg is the most common but most toxic mercurial species in the environment (Mason and Fitzgerald, 1996). Because of the close relationship between toxicity and chemical form for Hg species, it is very hard to accurately represent the potential toxicity or biological availability using the total Hg concentration in water or sediment samples (Jain et al., 2007). Therefore, instead of total Hg, the concentrations of the different species of Hg in environmental samples should be respectively determined, which is important for accurately performing ecological risk assessment (ERA) on Hg pollution. The aim of this study was: (1) to obtain predicted no-effect concentrations (PNECs) for the predominant Hg species in aqueous environments by collecting and analyzing their toxicity data; and (2) to assess the ecological risk of different Hg species in case studies based on the computed risk thresholds of mercury species. The results of the present study may provide useful information for an accurate assessment of the potential risk of different species of Hg in the environment.

1. Materials and methods

1.1. Toxicological data collection

Hg toxicity data were collected from the US Environmental Protection Agency 'ECOTOX' database (http://cfpub.epa.gov/ecotox/) and a number of publications, including research papers and government reports. The reliability, relevance, and adequacy of all the data that included acute and chronic lethal toxicity data and chronic reproductive toxicity data were then evaluated by standard methods (European Commission, 2003; Klimisch et al., 1997). Data were collected for at least 10 species at three trophic levels (*e.g.*, algae, crustaceans, and fish). The means of several toxicity datasets were calculated for the species of interest collected from the same location at the same time, and a number of indices that express certain toxic characteristics, including mortality, growth parameters, biochemical parameters, and reproductive success, were selected as endpoints. For the screening of chronic toxicity data, the no observed effect concentration (NOEC) with the longest exposure time was selected when several eligible chronic toxicity data for the same species were available. When the NOEC of species was not available, NOEC was estimated to be equivalent to half of the lowest observed effect concentration (LOEC) value for the species (Balk et al., 1995).

1.2. Calculating PNEC values for mercury in water phase ($PNEC_{water}$)

The predicted no-effect concentration (PNEC) is an important index in evaluating potential risk of toxic chemical. To protect most organisms in the environment, the species sensitivity distribution (SSD) curve and assessment factor (AF) method proposed by the European Union, which are commonly used for determining water quality criteria to calculate the predicted no-effect concentration (Wu et al., 2011a,b,c). PNEC is obtained on the basis of the NOEC. However, owing to the lack of NOEC available for many compounds, the NOECs used for ERA are extrapolated from acute toxicity data, such as the median lethal concentration (LC50) or the 50% effective concentration (EC50).

1.2.1. Species sensitivity distribution method

The SSD method was first proposed by Kooijman (1987) and later improved by subsequent studies (Aldenberg and Slob, 1993; Newman et al., 2000; Posthuma et al., 2002; Wagner and Lokke, 1991). It is generally applied to circumstances in which there are at least 10 available toxicity data (Jin et al., 2009; Balk et al., 1995; Lei et al., 2009). In the SSD method, the curve for a pollutant is established based on available toxicological data for all species. The criterion level is then determined by finding the pollutant concentration on the curve that results in a predetermined noticeable effect in a certain percentage of the population. The criterion level, which is usually labeled HC5, is the pollutant concentration that is hazardous to 5% of the species for which data are available (Van Straalen and Van Rijn, 1998). In general, the more data there is available, the higher the reliability of the assessment. The SSD method uses toxicological data for almost all species and considers the uncertainty resulting from heterogeneity between species. In the SSD method, data processing is critical. Specifically, the collected toxicological data should be checked first, and log-transformed when necessary. Then the data are sorted and the cumulative probability (P_c) is calculated by Eq. (1):

$$P_c = i/(n+1) \quad (1)$$

where, i is the rank of a species in the data series and n is the total number of species examined (Hall et al., 1998; Schuler et al., 2008). The SSD curve was constructed using the mean toxicity (or the logarithmic value) as the x-axis and the cumulative probability as the y-axis. The HC5 was determined by extrapolating the curve.

1.2.2. Assessment factor method

The assessment factor (AF) method that is applied in situations in which there are fewer toxicological data, generally no more than 10 datasets; it is used as a Supplementary method of the SSD method. It is widely used because of the simplicity of the operations involved and the less restrictive condition requirements. There was high variability in the data when less than 10 toxicity datasets were available, so the calculated effect endpoint (HC5) may have been unreliable; therefore, in such instances the AF method was used. The most important component of the AF method is the selection of a suitable assessment factor. Table 1 provides the guidelines for the selection of appropriate AF values given the amount and type of data available. The PNEC is calculated as the ratio of the minimum LC50 (EC50, or NOEC) value to the corresponding AF value.

1.3. Calculating PNEC values for mercury in sediment phase ($PNEC_{sed}$)

The ERA of sediment contamination is similar to that of water contamination. The PNEC for each toxic pollutant in sediment