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The potential risk assessment for different arsenic species in the aquatic environment

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ABSTRACT

The different toxicity characteristics of arsenic species result in discrepant ecological risk. The predicted no-effect concentrations (PNECs) 43.65, 250.18, and 2.00×10^3 μg/L were calculated for As(III), As(V), and dimethylarsinic acid in aqueous phase, respectively. With these PNECs, the ecological risk from arsenic species in Pearl River Delta in China and Kwabrafo stream in Ghana was evaluated. It was found that the risk from As(III) and As(V) in the samples from Pearl River Delta was low, while much high in Kwabrafo stream. This study implies that ecological risk of arsenic should be evaluated basing on its species.

Introduction

Arsenic is a toxic element, which occurs naturally in water, soil, and sediment throughout the world (Mandal and Suzuki, 2002; Cullen and Reimer, 1989). Both natural and anthropogenic sources are currently elevating pollution level of arsenic in the environmental matrices (Kim et al., 2009). Because of its toxicity and increasingly widespread occurrence, arsenic pollution has become a serious problem (National Research Council, 1999; Matschullat, 2000; Nordstrom, 2002; Terlecka, 2005). It has been reported that groundwater is contaminated with arsenic in 21 countries, including Argentina, Bangladesh, Chile, China, Hungary, India, Mexico, and the United States (Pearson et al., 2011; Nikolaidis et al., 2004). Bangladesh has the largest population suffering from the heavy arsenic pollution in groundwater supplies. Arsenic concentrations in groundwater of Bangladesh exceed the World Health Organization drinking water guidelines (0.01 mg/L) by more than 10 times (Rahman et al., 2002; Sarkar et al., 2008). Extremely high arsenic concentrations, 3.00 mg/L, have been found in water from the Bravona River, Corsica, France and one of its tributaries (Migon and Mori, 1999). Arsenic concentrations of 1.39–5.65 μg/L and 3.08–10.48 μg/L have been found in water from Taihu Lake and Dianchi Lake, respectively (Zhang et al., 2013). In addition, the pollution of arsenic in sediments should not be ignored because sediment is an important "sink" of pollutants and arsenic in sediment could be released into water and cause "secondary pollution". An average total arsenic concentration of 47.30 mg/kg has been found in surface sediment from Little Lake Jackson, FL, USA (Whitmore et al., 2008). Arsenic concentrations of 17.20–27.90 mg/kg have been found in surface sediment from Taihu Lake, China (Zhang et al., 2013).

The physical consequences of long-term exposure to elevated arsenic concentrations are severe. In addition, arsenic can accumulate in the aquatic environment, which may lead to ecological damage. The potential adverse effects of arsenic on ecological receptors (*e.g.*, mammals, birds, plants, and/or fish) should be evaluated. Up to now, lots of studies on the ecological

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risk assessment of arsenic pollution have been conducted (Zhang et al., 2013; Wang and Mulligan, 2006; Barringer et al., 2011; Peng et al., 2004; Wei et al., 2011; Keimowitz et al., 2005; Jackson et al., 1991; Mazej and Germ, 2009). However, most of the previous studies on arsenic concentrations and ecological risk assessment in sediment and water focused on the total arsenic concentrations, and limited information was available on arsenic speciation. In fact, arsenic can be present as different chemical species, including arsenite (As(III)), arsenate (As(V)), monomethylarsonic acid (MMA), and dimethylarsinic acid (DMA) (Cullen and Reimer, 1989; Francesconi and Edmonds, 1994), depending on the chemical and geological conditions (Arain et al., 2008). The biological availability and toxicological effects of arsenic depend on its chemical forms (Cullen and Reimer, 1989). For example, inorganic arsenic has a high toxicity level and increases risk of cancer, whereas methylated forms of arsenic, such as MMA and DMA, are significantly less toxicity (Nordstrom, 2002). Toxicity of As(III) is about 60 times higher than that of As(V). The total arsenic concentration in water or sediment does not represent the exact biological availability or potential hazards (Jain et al., 2007). Therefore, the different species and toxicity effects of arsenic should be involved in the ecological risk assessment.

The aim of the present study was: (1) to compute the ecological risk thresholds for those predominant arsenic species in the aquatic environment by collecting and analyzing their toxicity data, respectively; (2) to perform ecological risk assessment for different species of arsenic in the studied areas based on the computed risk thresholds of arsenic species. It is expected that the present study would provide useful information for exactly evaluating the potential risk of arsenic in the environment.

1. Materials and methods

1.1. *Toxicity data collection and screening*

The toxicity data of arsenic were taken from the US Environmental Protection Agency 'ECOTOX' database (http://cfpub.epa.gov/ecotox/) and a number of publications (*e.g.*, research papers and government reports). Data were collected for at least 10 species at three trophic levels (*e.g.*, algae, crustaceans, and fish). The inherent quality (reliability, relevance, and adequacy) of the toxicity data (acute and chronic lethal toxicity data and chronic reproductive toxicity data) were evaluated using standard methods (European Chemical Bureau, 2003; Klimisch et al., 1997). The means of several toxicity data for the species of interest, from the same location and time, were calculated, and a number of indices that express certain toxic characteristics, including mortality, growth parameters, biochemical parameters, and reproductive success, were selected as endpoints. The chronic toxicity data were screened by selecting the observed effect concentration (NOEC) measured using the longest exposure time if several eligible chronic toxicity data were available for the same species. If NOEC data was unavailable for a species, the half of lowest observed effect concentration was used as the NOEC (Balk et al., 1995).

1.2. *Calculating PNEC values for arsenic in water phase (PNECwater)*

The predicted no-effect concentration (PNEC) is an important index in evaluating potential risk of toxic chemical. The species sensitivity distribution (SSD) and assessment factor (AF) methods, proposed by the European Union, are often used to calculate PNECs (Wu et al., 2011a, 2011b, 2011c). The calculation of PNEC is usually based on the no observed effect concentration (NOEC). However, there are less NOEC data for many compounds, the PNECs for ERA are extrapolated from acute toxicity data, such as the median lethal/effective concentration (LC50/EC50).

1.2.1. *Species sensitivity distribution method*

The species sensitivity distribution method is usually used when at least 10 toxicity data are available (Jin et al., 2009; Balk et al., 1995). The method was first proposed by Kooijman (1987) and it was improved in subsequent studies (Aldenberg and Slob, 1993; Newman et al., 2000; Wagner and Lokke, 1991). The SSD method involves constructing a curve using the toxicity data that is available for as many species as possible for a specific pollutant. The criterion level is then determined by finding the pollutant concentration on the curve at a predetermined noticeable effect percentage. 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 reliability of the assessment increases as more data are available. The SSD method uses toxicological data for almost all species and takes into account the uncertainty caused by heterogeneity between species, and it is a direct and reasonable method for assessing the effects of pollutants. The toxicological data used in the SSD method needed to be assessed carefully, and log-transformed when necessary. The data were then sorted and the cumulative probability was calculated by Eq. (1):

$$\text{Cumulative probability} = i/(n+1) \tag{1}$$

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 from the curve.

1.2.2. *Assessment factor method*

The assessment factor method can be applied to compounds for which fewer toxicological data are available, generally no more than 10 datasets, and it was used to supplement the SSD method. There was strong variability in the data when less than 10 toxicity data were available, so the evaluation of the effect endpoint (HC5) may have been unreliable and the AF method was used. However, the AF method has shortcomings because the selection of an appropriate AF is relatively arbitrary, although it is very important to select suitable AF. The principles used to select the most appropriate AF are shown in Table 1. The PNEC is calculated with the ratio of the minimum LC50 (EC50, or NOEC) value to the corresponding AF value.

$$\text{PNEC} = \text{the minimum LC50(EC50, or NOEC)/AF} \tag{2}$$