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Weir building: A potential cost-effective method for reducing mercury leaching from abandoned mining tailings

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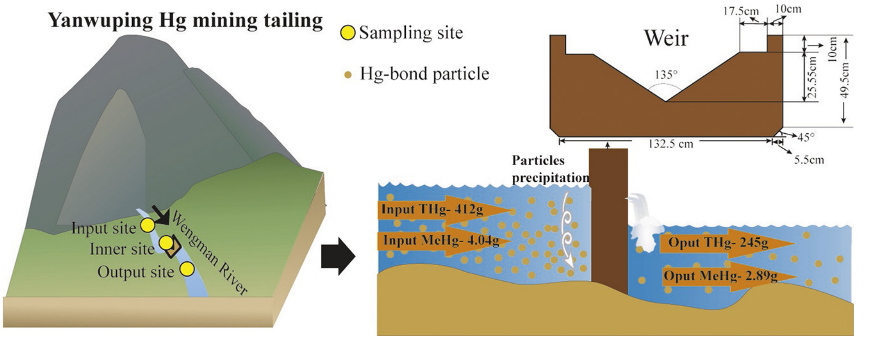
HIGHLIGHTS

- A weir is tested on contaminated stream to reduce Hg transport to downstream.
- A whole year monitoring of Hg species was done at the inlet and outlet of the weir.
- Approximately 40.4% THg and 38.4% TMeHg was retained by the weir on an annual basis.
- Intensive sampling at a rainstorm confirms the dominant role of particulate Hg.
- Weir construction is cost-effective to control particulate Hg transport.

GRAPHICAL ABSTRACT



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ABSTRACT

To mitigate mercury (Hg) pollution and reduce Hg downstream transportation, a weir was designed by a river system that had been inflicted by leachate from the slagheap of the Yanwuping Hg mine in Wanshan Hg mining area. A whole year monitoring of Hg species was conducted, and the efficiency of Hg reduction by the weir application was evaluated. The Hg concentrations in the river water were significantly higher in the wet season than in the dry season. Waterflow was confirmed to be the main driving factor for Hg mobilization and transportation, and an episode study revealed that most Hg was released in times of storms. Increased monitoring and preventive maintenance measures need to be taken on barriers in advance of storms. A large proportion of the total Hg (THg) and methylmercury (MeHg) is associated to particles. During the study period, approximately 412 g THg and 4.04 g total MeHg (TMeHg) were released from the YMM slagheap, of which 167 g THg and 1.15 g TMeHg were retained by the weir. Annually, 40.4% THg and 38.4% TMeHg was retained by the weir. Weir construction is considered as a potential cost-effective measure to mitigate Hg in river water and should be promoted and extended in the future after optimization.

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1. Introduction

Mercury (Hg) is a biologically non-essential and highly toxic metal. It, in particular methylmercury (MeHg), has caused great concern due to its neurotoxicity (Tchounwou et al., 2003) and biomagnification within the food chain (Clarkson, 1972; Kocman et al., 2011). The global cycling of Hg via atmospheric transport results in elevated Hg levels in fish of pristine aquatic ecosystems that are distant from major source regions (Driscoll et al., 2013).

An abandoned Hg mining district is a significant source of Hg pollution, and pose a continuous threat to local ecosystems (Wang et al., 2004; Li et al., 2009; Qiu et al., 2013; Kim et al., 2016a), and river systems is a major pathway for the downstream transport of Hg (Qiu et al., 2006; Xu et al., 2018). There are large amounts of Hg-containing secondary minerals in slagheap, such as elemental mercury, metacinnabar and mercury sulfate, chloride, and oxide compounds (Jasinski, 1995). Drainage from slagheaps serves as an important pathway introducing Hg to adjacent river systems via the discharge of Hg-bearing particles and dissolved Hg, where Hg methylation may occur under suitable conditions (Biester et al., 2000; Dary et al., 2010). Due to the bioaccumulation and biomagnification effect of MeHg, elevated Hg may cause high Hg levels in fish, crops, and vegetables (Mortazavi et al., 2016; Tanner et al., 2017), which could be a health threat to residents and wildlife (Bose-O'Reilly et al., 2016; Qiu et al., 2008). After being contaminated by Hg, it may take decades, even centuries, to remediate the river systems and bring Hg to safe levels (Wang et al., 2004). However, few studies about Hg remediation in river systems have been applied at Hg-contaminated sites (Vahedian et al., 2014).

As the third largest Hg mine in the world, Wanshan Hg mine has produced large amounts of Hg. With >125 million tons of waste remains in Wanshan Hg mining areas (Liu, 1998), THg and total MeHg (TMeHg) in the river water near slagheaps can be as high as 12,000 ng/L and 11 ng/L, respectively (Zhang et al., 2010a; Zhang et al., 2010b). Appropriate and cost-effective environmental remediation measures should be taken in Wanshan Hg mine. A variety of methods, such as isolation and containment, mechanical separation, pyro-metallurgical separation, chemical treatment, and permeable treatment walls, are usually applied as prevention and remediation technologies in engineering practices (Mulligan et al., 2001a). The selection of appropriate methods is based on the site characteristics. Source confinement by means of isolation and containment has been implemented to prevent solid waste from migrating in Wanshan Hg mining area. However, elevated Hg can still be found in the downstream area of the slagheap (Zhang et al., 2010a; Zhang et al., 2010b). It is necessary to take steps to limit its impact in specific areas by building infrastructure.

A weir is a small dam across the horizontal width of a river, which can alter the flow characteristics of the water (Kim et al., 2016b). Weirs are constructed for a wide variety of purposes, such as flow measurement (Bragato et al., 2009), invasive species control (Walker et al., 2015), flood control (Kim et al., 2016b). It was found to have the ability to deposit the particles and then the particle-bond Hg (Heaven et al., 2000). Based on mentioned reasons, weir building was selected to retain Hg in the river due to its low-cost and low environmental impact. Compared with other remediation technologies which might either be energy-intensive, high reagent consuming, or expensive in maintenance costs (Mohmood et al., 2016), a weir is supposed to be a cost-effective method to reduce fluvial particulate pollutants.

A weir was designed and constructed in Wanshan Hg mining area as a pilot study. Subsequently, hydrological parameters and Hg speciation in the river water up and downstream of the weir were measured biweekly over a full year period. The objectives of this study were to investigate the treatment efficiency of the weir after the cement coverage of slagheap and its influence factors of Hg retention by weir construction, to evaluate the cost and benefit of the weir construction.

2. Materials and methods

2.1. Study area

Wanshan Hg mining area is in Guizhou province, Southwest China, where locates the Yanwuping Hg mine (YMM), one of the largest Hg mines in Wanshan. The YMM covers about 1 km^2, with >3.1 $*$ 10^5 m^3 slag waste produced during the long-lasting mining activities. In 2011, the slagheap was covered with cement. The YMM is located in a typical mountainous and karstic terrain, with elevations ranging from 340 to 1010 m. The average annual rainfall is 1386 mm. The dominant ore mineral of the YMM is cinnabar (Zhang et al., 2012). More information about the YMM slagheap is present in SI.

Originated from the YMM slagheap is Wengman River (Fig. 1), which belongs to Yangtze River basin. The typical average water depth of this river is 1 m in summer. Most Hg mine wastes and retorts in this region are located in scattered hillsides at the upstream portion of Wengman River.

2.2. Weir design

According to technical information from previous studies (Qiu et al., 2013; Lin et al., 2011), a concrete weir was built across the upstream portion of the Wengman River in February 2012. A weir trough was designed to determine the flow rate of water, with a flow measurement instrument employed. The location of the weir is approximately 1000 m from the YMM slagheap. The width and height of the weir are 7 m and 1 m, respectively. A sketch of the weir design is supplied in SI.

2.3. Sampling

The flow measurement and sampling campaigns were conducted for a whole year. Water samples were collected biweekly from April 2012 to March 2013. The sampling sites are illustrated in Fig. 1.

Surface water samples were collected in duplicate at every sampling. One unfiltered sample was directly stored in a 200 mL borosilicate glass bottle for THg and TMeHg measurements, and the other sample was filtered in situ through a 0.45 μm polyvinylidene fluoride filter for dissolved Hg (DHg) and dissolved MeHg (DMeHg) analysis (Qiu et al., 2006). In addition, a 1.5 L sample was collected for the determination of total suspended solids (TSS) in water each time.

A few floods occurred in the summer 2012 and were unfortunately not captured by the discontinuous Hg sampling scheme. To elucidate the flooding effect, we performed an intensive sampling campaign during a rainstorm event in August 2013. The sampling frequency was every 5 min and lasted for a total of 1.7 h.

2.4. Hg and MeHg analysis

Mercury fractions were operationally defined as THg, DHg, particulate Hg (PHg), TMeHg, DMeHg, and particulate MeHg (PMeHg) in the water samples (Wang et al., 2013). Measurements of THg and DHg involved BrCl oxidation (0.5%, v/v), $NH_2OH\cdot HCl$ pre-reduction (0.25 mL, 30%, v/v), and $SnCl_2$ reduction; then elemental Hg was preconcentrated and quantified by the dual stage Au amalgamation coupled with a Cold Vapor Atomic Fluorescence Spectrophotometry (CVAFS, Model III, Brooks Rand, USA) following Method 1631 (USEPA, 2002). For TMeHg and DMeHg, the water sample was measured following distillation, $NaBEt_4$ ethylation, and Tenax trap, and GC-CVAFS according to Method 1630 (USEPA, 2001; Liang et al., 1994). PHg and PMeHg were obtained as the difference between THg and TMeHg in filtered and unfiltered water, respectively (Wang et al., 2013; Covelli et al., 2006).

The ratio of PHg or DHg in THg was expressed as PHg% and DHg%, respectively. The ratio of PMeHg or DMeHg in TMeHg was expressed as PMeHg% and DMeHg%, respectively.