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Assessment of metal contamination in water and sediments from major rivers in South Korea from 2008 to 2015

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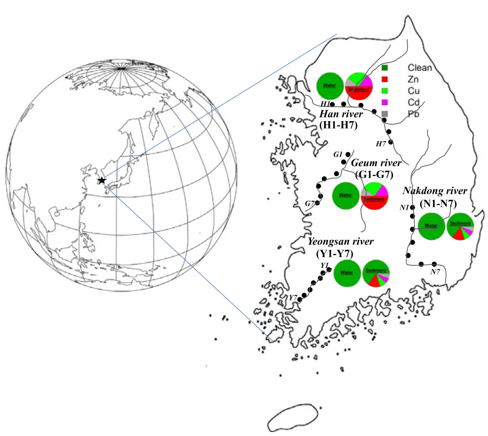
HIGHLIGHTS

- Korean rivers showed contamination of metals in the water and sediment fractions.
- Sediments were heavily contaminated with Cu and Zn.
- Pollution indices showed that the Geum and Han river sediments are polluted.
- Unsafe levels of Cd, Pb and Zn were reported in the sediment of the Han River.

GRAPHICAL ABSTRACT



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ABSTRACT

This study is the first report to evaluate (8 years data) the contamination degree and distribution characteristics of metals in the surface water and sediments of four Korean rivers (Nakdong, Yeongsan, Geum, and Han). Eight years of data were evaluated, and metal concentrations in the river water were found to be below permissible limits but high enough to cause detrimental effects (under chronic exposure) to aquatic organisms. The analysis of metals in the river sediments showed the following trend: Zn > Cu > Cd > Pb > Ni > As > Cr > Hg. The concentrations of metals in sediments (especially in the Geum and Han rivers) were above the permissible limits reported by international agencies. Concentrations of Cu, Ni, and Zn were high enough to pose risks to aquatic communities. In sediments, metals pollution was also evaluated using different indices, such as enrichment factor (EF), geoaccumulation index (I_{geo}), contamination factor (CF), degree of contamination (C_d), modified degree of contamination (mC_d), and pollution load index (PLI). The CF, EF, and I_{geo} indices demonstrated that most of the river sediment samples were moderately to heavily contaminated by Cd, Cu, Pb, and Zn. The PLI values were above one in the Geum and Han river sediments, which indicated polluted conditions. Similarly, C_d indicated

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a considerable to very high degree of contamination, while mC_d indicated a low to moderate degree of contamination in all four river sediments. Finally, it was found that the extent of metals pollution in the Korean rivers reached a critical condition, which could be detrimental to the biota of the rivers, as well as to humans in the long term.

1. Introduction

Fluvial ecosystem is liable to metal contamination due to disproportionate discharges of industrial and domestic wastes in their water (Moore and Langner, 2012). Metals are non-biodegradeable, bioaccumulative and thus damaging the residing biota of the waterbodies (Pandey et al., 2014). Globally, alarming levels of metals were reported in the water and sediment part of fluvial ecosystem (Nriagu and Pacyna, 1988; Liu et al., 2018). For example, in India metals concentration in the river Ganges ranges from 0.013 to 0.122 mg/L in water and 1.40 to 20.40 mg/kg in sediment for Cu, Cr, Cd, Pb and Zn (Gupta et al., 2009). In China, metals concentration in the river Jinjiang ranges from 0.00 to 0.002 mg/L in water and 0.44 to 104 mg/kg in sediment for As, Cd, Cr, Ni, Zn, Cu, and Pb (Liu et al., 2018). In France, metals concentration in the Lot-Garonne fluvial system ranges from 0.00 to 1.30 mg/L in water and 145 to 8180 mg/kg in sediment for Cd, Zn, Cu and Pb (Audry et al., 2004). In Japan, metals concentration in the Yoshino river (impacted with discharges from abandoned mines) ranges from 0.0012 to 3.77 mg/L in water and 0.45 to 808 mg/kg in sediment for Cd, Cu and Zn (Anazawa et al., 2004).

South Korea is a developed and industrialised country. However, large scale urbanisation, industrialisation, and land transformation pose serious threats to the pristine environments of this peninsula. In Korea, the use of chemical products has increased rapidly and continuously with industrial development and improvement in living standards. Currently, approximately 260,000 chemicals are produced worldwide, and about 40,000 chemicals are used in South Korea (Lee et al., 2011a). In Korea, for several decades, water quality degradation due to anthropogenic activities (urbanisation, intense land use, etc.) has been a focal area in river management research (Lee et al., 2011b). Efforts to improve the quality of water bodies (including rivers, streams, lakes, estuaries, coastal waters, and groundwater) in South Korea have been underway for a number of years (i.e., from 2003), which is mainly affected by sectors like, health, energy, environment, agriculture and food. Many studies have reported that the land use types and patterns within a watershed determine the characteristics of human activities, which in turn determine the anthropogenic substances carried into river systems (Lai et al., 2013; Song and Choi, 2017). Moreover, land uses within a watershed can impact various intrinsic attributes of river systems, including hydrological, geomorphological, chemical, and biological aspects (Hong et al., 2010; Lee et al., 2014). Contamination of water bodies by metals ranks among the major environmental problems, with many issues accompanying rapid economic development in both developed and developing countries (Nriagu and Pacyna, 1988; Liu et al., 2018). Korean fluvial ecosystem is continuously contaminated with metals directly or indirectly (Pandey et al., 2018). In particular, there are four major river basins (Han, Geum, Nakdong and Yeongsan) under regular monitoring for contamination with metal discharges from various industries (agrochemical, petro-chemical, electro-plating, textiles, etc.), urban (car washing, construction activities and street washing) and domestic wastes (Kang et al., 2009; Lai et al., 2013; Cho et al., 2014; Chung et al., 2016). In the past, several attempts were made to study the metals load in the water and sediment fractions of the Korean fluvial ecosystem, but these studies reported only metal concentrations either in the water or in the sediment part of a particular river. For example, Lai et al. (2013) examined influence of grain size and land use on the distribution of metals in the sediments of Han river basin. Kang et al. (2009, 2010) examined the metals load in the water fraction of Yeongsan river basin and suggested the need for detailed analyses of the metals load in the sediments as an appropriate management practice for the fluvial ecosystem. Similarly, Chung et al. (2016) and Kim et al. (2010) reported heavy metal load in the sediments of Nakdong river basin but not metals load in the water fraction. Lee et al. (2003) and Shim et al. (2015) reported metal loads in the sediment fraction of Guem river basin with information on the metal load in water fraction lacking.

Investigation of metals in the water and sediments could be used to assess the anthropogenic impacts and risks posed by waste discharge to riverine ecosystems (Pandey and Bergey, 2016; Liu et al., 2018). Therefore, it is important to assess the concentrations of metals in water and sediments of contaminated riverine ecosystems. Different methods have been used to assess the contamination of metals in sediments, such as pollution load index (PLI), enrichment factor (EF), contamination factor (CF), and geo-accumulation index (I_{geo}), among others (Liu et al., 2018; Islam et al., 2015). To evaluate the combined risk of numerous heavy metals in sediment, the PLI and potential ecological risk index (PER) have also been developed (Abrahim and Parker, 2008; Islam et al., 2015). The PER introduces a toxic-response factor for a given substance that provides a simple and quantitative value for ecological risk assessment (Håkanson, 1980).

Organic micropollutants (organochlorine pesticides, organophosphate pesticides, and volatile organic compounds) contamination has been comprehensively studied in the four major rivers of South Korea (Cho et al., 2014). However, to the best of our knowledge, no scientific research regarding the status of metals (in water and sediments) in major South Korean rivers has been conducted. Thus, in the present study, we investigated the status of metals distribution in the water and sediments of four South Korean rivers (Nakdong, Yeongsan, Geum, and Han) during the period 2008–2014 as the past and during 2015 as the present. Finally, we believe that our results will provide necessary baseline information regarding metals accumulation in Korean rivers, which will be helpful in setting standards for water and sediments in order to maintain ecological health of fluvial ecosystems.

2. Materials and methods

2.1. Study area and site selection

The Korean Ministry of the Environment (MOE) regularly monitors metals contamination (in sediment and water) at 141 sites in major Korean streams and rivers (Table S1). All samples were collected in the summer season (July to August). Collected data have been regularly released by the Korean government detailing the concentration of metals at numerous sites in Korean streams and rivers. Data from seven sites each in four major rivers (Nakdong, Yeongsan, Geum, and Han), which were regularly examined for metals contamination between 2008 and 2015, were analysed in the present study (Figs. 1 and S1; Tables S1 & S2). The seven examined sites in each of the four rivers were as follows: Ayang (N1), Ayang (N2), Keumho-1 (N3), Keumho-2 (N4), Dalseo-1 (N5), Dalseo-2 (N6), and Dalseo-3 (N7) in the Nakdong River; PD-1 (Y1), PD-2 (Y2), Gwangju-1 (Y3), Gwgongdan-1 (Y4), Gwangjucheon (Y5), GJ-2 (Y6), and GJ-3 (Y7) in the Yeongsan River; Masan (G1), Ohryang (G2), Sucheol (G3), Bangchuk (G4), Miho-5 (G5), Miho-8 (G6), and Miho-7 (G7) in the Geum