Marine Pollution Bulletin 102 (2016) 230–239

Contents lists available at ScienceDirect

Marine Pollution Bulletin

journal homepage: www.elsevier.com/locate/marpolbul

Baseline

Monitoring of trace metals in coastal sediments around Korean Peninsula

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ARTICLE INFO

Article history:
Received 21 April 2015
Received in revised form 23 September 2015
Accepted 28 September 2015
Available online 27 November 2015

Keywords:
Sediment
Trace metal
Sediment quality guidelines
Geoaccumulation index
Korea

ABSTRACT

Spatial distributions and temporal variations of trace metals in Korean coastal sediments were investigated by determining seven metals (As, Cd, Cr, Cu, Hg, Pb, and Zn) in sediment collected from 71 stations between 2004 and 2010 (n = 491). High metal concentrations were found in the southeastern coast, where there are many cities and industrial complexes, indicating that metal concentrations in Korean coastal sediment are significantly influenced by human activities associated with urbanization and industrialization. However, metal concentrations in sediment did not markedly vary temporally, which was because the coast is managed sustainably and because of the characteristics of the sediment environments. Based on the sediment quality guidelines and geoaccumulation index, Korean coastal sediments are practically unpolluted with Cd, Cr, Cu, Hg, Pb and Zn but moderately polluted with As. More intensive monitoring is required to determine the potential As sources and to understand the As geochemical cycles in Korean coastal sediments.

Trace metals in coastal environments originate from natural processes (such as the weathering and erosion of soils and rocks) and anthropogenic sources (including the combustion of fossil fuels and waste, mining and ore processing, and agriculture), and they are continually introduced to coastal environments in river discharges, through the atmosphere, and in submarine groundwater discharges (SGD) (Hwang and Yang, 2003; Çevik et al., 2009; Yuan et al., 2012). Trace metals released into coastal water rapidly bind to particulate matter, most of which settles and accumulates in coastal sediment before they reach the open ocean (Hedge et al., 2009; Lim et al., 2013; Ra et al., 2013). However, some trace metals can be remobilized by diagenesis in sediment or resupplied to the overlying seawater (Fichet et al., 1998; Cukrov et al., 2011; Ra et al., 2011).

Trace metals in coastal sediments have received a great deal of attention in the last several decades because of their important effects on marine ecology and other aspects of the marine environment. The presence of trace metals in sediment is considered to pose potential threats to marine ecosystems because trace metals are non-biodegradable, persistent, and toxic, meaning that sediments that are contaminated with trace metals can cause critical problems (Christophoridis et al., 2009; Bednarova et al., 2013; Lai et al., 2013; Lim et al., 2013). One of the main problems is the potential for persistent and toxic trace metals to bioaccumulate and biomagnify, and these processes can result in long-term impacts on human health and on marine ecosystems (Rainbow, 2007; Wang and Rainbow, 2008).

Human activities concentrated in urban and industrial areas influence the distributions of toxic metals in coastal environments (Frignani and Belluci, 2004; Lim et al., 2013). Abrahim and Parker (2008) and Horowitz and Stephens (2008) reported that trace metal concentrations in sediment in an area tend to increase as the degree of industrial development and urbanization in the catchments increases. Many large cities and heavy industry complexes have been constructed along the Korean Peninsula coastlines since the 1960s because the South Korean economy has grown rapidly. The aquacultural production of fish and shellfish has also developed rapidly around the coast of South Korea over the last few decades. These changes have resulted in a range of marine environmental problems, such as metal pollution, harmful red-tide outbreaks, entrophication, and hypoxia, are occurring frequently around Korean coast.

The South Korean government has established national laws and policies to effectively manage the marine environment since the 1990s, and discharges of contaminants such as nutrients, trace metals, and persistent organic pollutants (POPs) through stream and river have been restricted (Hong et al., 2006). Some coastal areas near heavily industrial complexes and large-scale cultivating area have been designated “special management areas” (the Ulsan and Onsan coasts, the Busan coast, Masan Bay, and Gwangyang Bay) and “marine environment conservation areas” (Gamak Bay, Deunkryang Bay, Wando-Doam Bay, and Hampyeong Bay) in the Marine Environment Management Act (Hong et al., 2006; Choi et al., 2011). Despite such efforts, many researchers have recently reported that coastal sediments around the Korean Peninsula are still affected by anthropogenic trace metal pollution (Hyun et al., 2007; Lee et al., 2008; Ra et al., 2011, 2013; Lim et al., 2012, 2013). However, no useful data are available to allow us to understand the overall trace metal contamination status of Korean coastal

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http://dx.doi.org/10.1016/j.marpolbul.2015.09.045

sediments because most of the studies that have been reported were conducted only near large industrial complexes and urban areas.

A comprehensive nationwide monitoring study of trace metals in coastal sediments is therefore needed to allow effective plans for managing the marine environment management and protecting coastal ecosystems to be developed. Trace metal concentrations vary less temporally and spatially in sediment than in seawater, so monitoring trace metal concentrations in sediments provides useful data for evaluating metal contamination in the coastal environment and predicting the influence trace metals may have on marine ecosystem (Lai et al., 2013; Ra et al., 2013). The objectives of this study were (1) to determine the spatial distributions and temporal trends of trace metal concentrations in Korean coastal sediments, and (2) to evaluate the metal pollution statuses in the sediments using geochemical assessment techniques (the geoaccumulation index, I_{geo}, and sediment quality guidelines, SQGs).

Korea is a peninsula in the northeastern Asia. It is surrounded by three seas, the East Sea to the east, the Yellow Sea to the west, and the Korean Strait and East China Sea to the south, and these seas are called as East Sea, West Sea and South Sea, respectively, by Koreans (Fig. 1). The West and South Seas are shallow (<100 m depth), with large tidal range (3–10 m), broad intertidal zones, ria coastalines, and archipelagos, whereas the East Sea is deep (>200 m depth) and has a small tidal range (<1 m), a narrow continental shelf, and a relatively uniform coastline without ria.

Approximately 70% of the land area in South Korea (approximately 99,000 km^2) is made up of mountains and uplands, thus more than 40% of the population and most of the industrial facilities are concentrated along the coast (MOE, 2008). Approximately 3.9×10^{10} m^3/year of freshwater is discharged into the ocean through small streams and large rivers, such as the Nakdong River and Soemjin River on the southern coast and the Han River, Guem River, and Youngsan River on the western coast. However, the flows of the river are limited because of the artificial dams that have been constructed in the downstream of the rivers. The river flows also have large seasonal variations because South Korea is strongly influenced by the East Asian monsoon, which brings typhoons (periods of strong wind and heavy rain). The annual precipitation in South Korea ranges from ~900 mm in land to ~1900 mm on Jeju Island (a volcanic island), and most falls in the summer(late June to early September) (KMA, 2001).

The Korean Peninsula has five major geological features, the Gyeonggi and Youngnam (Sobaegsan) Massifs, the Okcheon Fold Belts, the Cretaceous Gyeongsang Basin, and the Pohang Basin (Chough et al., 2000). The Gyeonggi and Youngnam massifs, in the middle of the peninsula, are Precambrian basement domains with different sources,

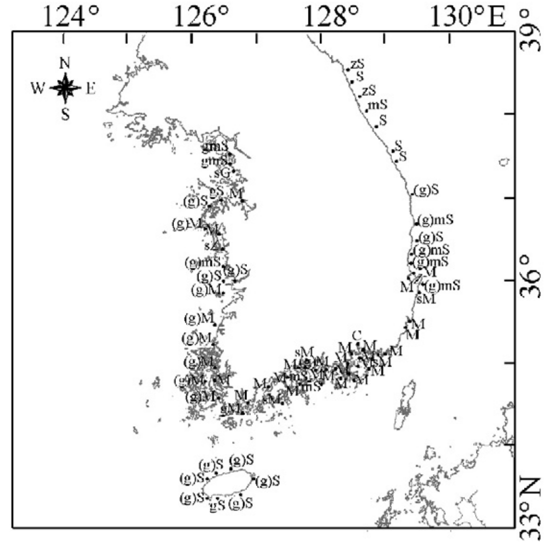

Fig. 2. Horizontal distribution of sediment types at each sampling site, classified using the ternary diagrams suggested by Fork (1968) (Abbreviations: sG — sandy gravel, S — Sand, mS — muddy sand, zS — silty sand, gS — gravelly sand, (g)S — slightly gravelly sand, gmS — gravelly muddy sand, (g)mS — slightly gravelly muddy sand, M — mud, gM — gravelly mud, (g)M — slightly gravelly mud, sM — sandy mud, Z — silt, sZ — sandy silt, and C — clay).

formation histories, petrography, and metamorphic histories (Na, 1987; Lee et al., 2001). These massifs are separated by the Okcheon Fold Belt. The Cretaceous Gyeongsang Basin and Pohang Basin are in the southeastern part of the peninsula and the boundary between them follows a northeast–southwest direction. The basement rocks are mainly composed of high grade gneisses and schists (late Archean to early Proterozoic) that are unconformably overlain by supracrustal sequences (schists, quartzites, marbles, calc silicates, and amphibolites) (Lee, 1987; Lee et al., 2001).

Sediment samples were collected from 68 to 71 stations in the Korean coastal zone (18 sites in the West Sea, 31–34 sites in the South Sea, and 19 sites in the East Sea) in February each year between 2004 and 2010 (Fig. 1). The samples were taken using a van Veen grab sampler. Each surface sediment sample (~300 g) was placed in a pre-acidified polyethylene bottle immediately after being collected, and then it was kept at below approximately 4 °C or frozen until analysis.

The particle size analysis of sediment samples that were collected in 2009 were performed by using standard sieve and pipette technique

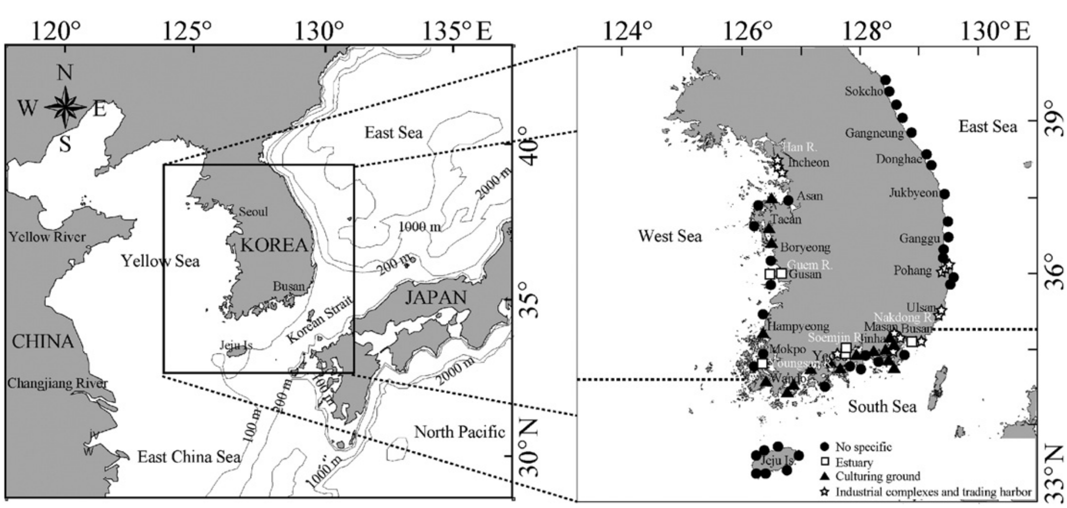

Fig. 1. Map showing the study area and the sites (n = 71) from which coastal sediment samples were taken between 2004 and 2010 for the analysis of trace metals. The dotted lines indicate the boundaries that were used to define the different coastal seas.