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Vertical profile, contamination assessment, and source apportionment of heavy metals in sediment cores of Kaohsiung Harbor, Taiwan

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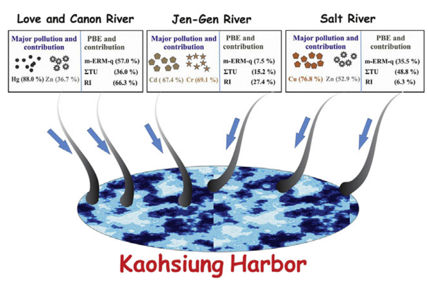
HIGHLIGHTS

- The heavy metals pollution in core sediments from Kaohsiung Harbor was evaluated.
- The contributions of heavy metal contents from the four rivers were quantified.
- The effects of Canon and Love Rivers to water ecosystem in Kaohsiung Harbor was highest.

GRAPHICAL ABSTRACT



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ABSTRACT

Six sediment cores collected at the Kaohsiung Harbor of Taiwan were analyzed to evaluate their vertical profiles, enrichments, accumulations, and source apportionments of heavy metals. This was performed to investigate any potential ecological risks posed by heavy metals. Results indicated that the mean heavy metal content (mg kg^{-1}) in the six sediment cores was as follows: Hg (0.4–6.4), Cd (<0.05–2.4), Cr (18–820), Cu (16–760), Pb (31–140), and Zn (76–1900). The patterns of heavy metal content in the sediment cores differed substantially among the four river mouths. However, the vertical profiles of metals were relatively stable, indicating that wastewater has the constant characteristics and has been discharged into the rivers for a long period of time. Results of pollution assessment of enrichment factor, geo-accumulation index, and pollution load index revealed that river mouths experience severe enrichment, strong accumulation, and high contamination from the primary heavy metals. It was not consistent in the assessment results of mean effect range median quotient, potential ecological risk index, and total toxic unit method. Potential ecological risks caused by Hg in the sediments at Canon River and Love River mouths on aquatic organisms were extremely high. The estimates derived from the receptor modeling of multiple linear regression of the absolute principal component scores indicated that the contributions of the composite heavy metals derived from the Canon River and the Love River on the potential toxicity and risks to the water environment of Kaohsiung Harbor were highest, followed by those derived from Salt River and Jen-Gen River.

1. Introduction

Particular attention is allotted to the heavy metal contaminants in the environment. Because heavy metals are not

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biodegradable, certain concentrations of them can adversely influence organisms and natural environments and can threaten human health by entering the food chain (Uluturhan and Kucuksezgin, 2007; Yi et al., 2011; Wang et al., 2013). The substantial amount of heavy metals produced by various types of human activities (e.g., urban, industrial, and agricultural activities) can enter water systems directly through wastewater discharge or indirectly through rainfall–runoff and atmospheric deposition (Zheng et al., 2008; Zhang et al., 2013). After heavy metals enter water systems, they tend to be absorbed into suspended particles and accumulate in sediments (Cundy et al., 2003). Sediments in water are naturally occurring large sinks and reservoirs for heavy metals, especially the sediments at estuary and harbor areas. However, a certain extent of accumulation of heavy metals in sediments can generate adverse effects on the benthos and water environments (Long et al., 2000).

Kaohsiung Harbor is the largest harbor in Taiwan, in which is located in the southwest coast of Taiwan. This region (Kaohsiung City) has a tropical monsoon climate with the average annual rainfall of 1885 mm and the clear dry season and wet season. Wet season includes from May to September and its rainfall accounted for about 88% of annual rainfall; whereas the remaining months are classified as the dry season, the average monthly number of rainy days and rainfall are 4 days and 32 mm, respectively. Kaohsiung frequently occurs with thunderstorm and typhoon in the duration of June and September. According to statistics, about 1–4 typhoons with the huge rainfalls hit this region every year (CWB, 2016), leading to the pollutants that accumulated in the harbor may be diluted by the instant heavy rainfall. But the huge rainfalls may also make the point source pollution and non-point source pollution into the harbor. Kaohsiung Harbor is adjacent to Kaohsiung City, which is the largest industrial city in Taiwan. A total of four contaminated rivers flowing through the Kaohsiung City district feed into the harbor, causing large amounts of sedimentary particles and pollutants to accumulate in harbor basins, especially in the river–port junction areas (Chen et al., 2012a). Four polluted rivers from north to south are respectively from Love River, Canon River, Jen-Gen River, and Salt River, the drainage areas of those are covered by the Holocene alluvium and the thickness is up to a maximum of 80 m, in which are constituted by mud, sand, and gravel. Therefore, the sediment that is transported from those four rivers is belonged the detrital minerals of modern sediments. Love River has the length of about 20 km and its area holds the dense populations (accounting for about 60% of Kaohsiung City) and many industries, which contain a number of metal plating factory, car wash factory and medical institutions. Love River is originated from the plains without the constant abundant water supply, inputting generally by the farmland over water, wastewater of industry, and domestic sewage. There are many factories such as metal factory, petrochemical factory, agriculture factory and machinery factory located at the banks of Canon River which has the length of about 3 km. In addition, groundwater and soil in the nearby area of Canon River have been examined and found to be contaminated with high concentrations of Hg (Chen et al., 2013). The downstream of Canon River flows through the densely populated district of Kaohsiung City, receiving the untreated urban sewage for a long time. Jen-Gen River, with the total length of 18.6 km, has a lot of plating factories and leather factories located on the river banks, resulting in the main source of water pollution is industrial wastewater, followed by a sequence of domestic wastewater, leachate, livestock wastewater, etc. (Chen et al., 2013). Salt River is about 6.5 km length, there are a lot of steel, chemicals and plastic industries along the banks of river, causing industrial wastewater and domestic sewage were the main sources of pollutants.

Sediment in the harbor berth and channel maintains a favorable quality, because the sediment is dredged annually that it can remove the contaminated materials from aquatic environment and subsequently process by ocean dumping and land reclamation (Chen et al., 2013; Wang and Feng, 2007). Sediment at the river–port junction areas contains high heavy metal enrichment and high organic pollution loads because of the rapid accumulation of pollutants from upstream sources (Chen et al., 2010; 2012a; Dong et al., 2014, 2015a,b), potentially generating adverse effects on the aquatic organisms. The sediments in these areas are unsuitable for direct ocean dumping or land reclamation before they are appropriately treated because they can pollute the marine environments in the sediment disposal areas and the reclaimed lands. Temporal and spatial changes are evident in the heavy metals in sediments accumulated in harbors. Therefore, before sediment executed appropriate treatments, a detailed understanding of heavy metal contamination is imperative, including the temporal and spatial distributions of heavy metal concentration, species of contamination, degree of contamination, source apportionment, and potential ecological influences of heavy metal contamination.

The following indices are widely applied for assessing the degree of contamination of heavy metals in sediments derived from human-made or natural sources and the potential biological effects: the enrichment factor (EF), geo-accumulation index (I_{geo}), pollution load index (PLI), toxic unit (TU), and mean effect range median quotient (m-ERM-q) values (Chen et al., 2007; Zhang et al., 2009; Dong et al., 2013a,b; Fu et al., 2014; Gao et al., 2016). In addition, multivariate analysis techniques have been used by numerous studies for judging the source and source contribution of heavy metals (Zhou et al., 2007a,b,c; Mostert et al., 2010; Gao et al., 2016), such as the methods of factor analysis (FA), principal component analysis (PCA), positive matrix factorization (PMF), UNMIX, principal component analysis/absolute principal component scores (PCA/APCS), and multiple linear regression of the absolute principal component scores (MLR-APCS). Among these methods, MLR-APCS receptor modeling is widely applied for estimating the source and contribution of pollutants (e.g., heavy metal and polycyclic aromatic hydrocarbons) (Zhou et al., 2007a,b,c; Mostert et al., 2010; Gao et al., 2016; Chen et al., 2012b, 2016).

This study primarily executed on-site sampling and monitoring of the physicochemical properties of the sediment cores collected from the inlets of the four rivers (i.e., the Love River, Canon River, Jen-Gen River, and Salt River) flowing into the Kaohsiung Harbor area and the two harbor entrance (Entrance I and II), in which the sediment samples were analyzed for metal content (e.g., Hg, Pb, Cd, Cr, Cu, Zn, and Al), water content (WC), organic matter (OM), total grease (TG), and grain size. Through the analysis results, the present study assessed the vertical profile of the heavy metal concentrations, degree of contamination, and species of contamination in the sediment cores collected from the four river inlets as well as their potential influences on human health and the ecosystem. The innovation of this study is using the MLR-APCS receptor model to define the main sources of pollution, and to estimate the contribution of the multiple heavy metals to potential toxicity and risks in contaminated river input Kaohsiung Harbor. Moreover, integrative assessment method of heavy metal pollution in aquatic environments is constructed, including heavy metal content measurement, pollution indices estimation, and statistical analysis. Therefore, the results can provide useful information to the governments for harbor managing, especially the target metal in four main contamination river mouths. This study can be the pioneer survey for deciding the arrangement of treatment for the future management.