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Evaluation of heavy metals and environmental risk assessment in the Mangrove Forest of Kuala Selangor estuary, Malaysia

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ABSTRACT

This study was carried out to evaluate the distribution, enrichment and ecological risk of heavy metals (arsenic (As), zinc (Zn), manganese (Mn), copper (Cu) and lead (Pb)) concentration in Kuala Selangor estuary at the Kuala Selangor Nature Park. The results suggested that As and Pb in sediment were as high as the background value, suggesting the presence of anthropogenic contamination. The risk assessment of sediment I_{geo}, CD, and PERI, on the other hand, showed low risk of heavy metals in Kuala Selangor estuary. Meanwhile, risk assessment code (RAC) results showed that Mn, As and Zn presented medium to high level of environmental risk. The translocation factor and bioaccumulation factors of heavy metal concentration by mangrove vegetation showed a variety of trends, which indicates the different partitioning and uptake ability of heavy metal in the tissues of different mangrove species. Therefore, underscores the importance of preserving the high diversity of mangroves at securing the health and productivity of the coastal region. These results may play a critical role in facilitating decision makers in managing the sustainability of mangrove forests.

1. Introduction

Mangrove ecosystems are the most important intertidal zone in the protected estuarine shores in the tropical area (Tam and Wong, 2000). A mangrove forest consists of trees growing in zones such as estuaries or tidal swamps which are common features of the tropical and subtropical sheltered coasts (Hamdan et al., 2012; Peter, 1999). Besides its importance for the environment, these ecosystems also play an economic role, especially for the coastal dwellers, where various produces are obtained from mangrove forest. In addition, mangrove forests are very important to estuarine fisheries because of its function in supplying detritus and dissolved organic carbon within the food chain, and mangrove trees roots that provide shelter for fish and other faunal organisms (Holguin et al., 2001; Nagelkerken et al., 2008). Furthermore, the mangrove forests provide coastal buffer zone to safeguard coastal habitats from natural disaster (Tamin et al., 2011). The mangrove forests in Malaysia were estimated to cover 494,600 ha of areas in the year 2000 and subsequently reduced to 469,100 ha in 2014 (Hamilton and Casey, 2016). The destruction of mangrove forests has been partly due to climate change which resulted in the rise of sea level (Jusoff and Taha, 2008), as well as by anthropogenic activities such as changes of land use for coastal development, including aquaculture and agriculture activities (Jusoff and Taha, 2008).

Heavy metals pose a considerable level of danger to the aquatic environment due to its high toxicity and the possibility of accumulation in aquatic habitat and soil (Abuduwaili et al., 2015; Varol, 2011; Xu et al., 2016). Heavy metals have been generally used as environmental monitoring factors and their toxicity in humans, animals, and plants are well known (Xie et al., 2015). Likewise, heavy metal pollution has been determined to also be one of the major health causes, due to the indestructibility of metals and their impact on living organism in concentrations greater than the thresholds (Costa-Böddeker et al., 2016; Zhuang and Gao, 2015). Therefore, human and ecosystem health levels need to be assessed frequently by monitoring the concentration of heavy metals in the environment (Haris and Aris, 2015; Kennish, 2002). The total heavy metal concentration has always been used as a contamination indicator (Liu et al., 2016) while BCR (European Community Bureau of Reference, now known as the Standards Measurements and Testing Program) used to study mobility and bioavailability of heavy metals (Nemati et al., 2009, 2011; Rauret et al., 1999). In

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addition, sources of heavy metals were divided into natural sources, such as erosion and rock weathering process, and industrial sources, such as industrial and agricultural activities and wastewater (Alloway, 2013; Belkhiri et al., 2016; Li et al., 2016).

There are certain risk assessment criteria that could be used to assess the risk of heavy metals. Geoaccumulation index (I_{geo}) is a method that is used to estimate the contamination levels of heavy metals (Muller, 1969). Contamination factor (CF) is considered to be an effective tool for monitoring the pollution over a period of time while contamination degree (CD) is used to determine the degree of contamination of total heavy metal and is calculated by summing all values of CF (Hakanson, 1980). The potential ecological risk index (PERI) can evaluate environmental risks affected by heavy metals comprehensively (Soliman et al., 2015), while RAC is used to determine the heavy metal mobility in sediments (Perin et al., 1985).

The purpose of the present study is to identify potential sources of heavy metals pollution in the sediments and vegetation of mangrove forests in Kuala Selangor estuary, by using the appropriate sediment quality guidelines and risk assessment method. Information gathered in this study will assist to elucidate heavy metal pollution in sediments and vegetation in mangrove forests in Malaysia. This knowledge would be critical to support the decision-making process on sustainable development of mangrove forests in Malaysia. This would enable continuous active monitoring of environmental quality and complement any existing monitoring efforts presently available.

2. Material and methodology

2.1. Site description

This study was conducted in the Kuala Selangor Nature Park mangroves which is located at the mouth of the Selangor River in the Kuala Selangor District of the Selangor state, on the west coast of Peninsular Malaysia. The Selangor River begins at an elevation of 1500 m in a neutral zone and runs south west to the Straits of Melaka (Singh, 2010). It is located in the northern part of the Selangor state, the most developed state in Malaysia with an approximate of 3.9 million citizens. The Selangor River is the main source of public water supply producing 2500 (m^3/day) for 1.3 million residents in Selangor and the country's capital city, Kuala Lumpur (Leong et al., 2007). Selangor river contains different ecosystems and is also rich with natural resources (Zhila et al., 2014). The park is home to a number of large bird species such as milky storks and herons as well as primates, namely silver leaf monkeys and long-tailed macaques. Since 1987, the park has been managed by the Malaysian Nature Society (MNS) under a cooperative arrangement with the Selangor state government. It became the first park to be managed by an NGO in Malaysia. In 1997, Kuala Selangor Nature Park was recognized as a nature reserve for the purpose of conservation and ecotourism. The park is also recognized as an Important Bird Area (IBA) by Birdlife International (Fig. 1).

2.2. Sampling technique

Sediment and vegetation (leaf, stem and root) samples were collected from the Kuala Selangor forest in March 2017. A total of thirty plots of sediments (0–20 cm deep, triplicates for each plot) were collected using auger tools. The U.S. Geological Survey (USGS) bottom-material sampling manual (Radtke, 1997) was adopted as the sampling procedure. The sampling was designed based on the sedimentary properties as well as the accessibility and boat availability at the study area. The samples were transferred directly to the laboratory to be air dried, sieved with size of 0.63 μm for heavy metals analysis and size of 2 mm for physical properties analysis. Subsequently, the samples were kept in plastic bottles for further analysis (digestion and fractionation). Ninety vegetation samples (leaves, stems and roots) from *Rhizophora apiculata* were collected from the same site. The plant samples were kept in zipper bags and were later air dried, grinded, and kept in plastic bottles for further analysis.

2.3. Determination of sediment physicochemical properties

Sediment pH was analysed on a 1:5 suspension of soil deionized water using a glass electrode pH meter (EUTECH, 2700). EC meter was used for electrical conductivity (Hanna instruments HI, 2315). The loss on ignition (LOI) (organic matter content) was determined by ashing 1 g of dry sediment in a furnace (Phang et al., 2015). Sediment texture analysis was performed by using the particle soil analysis instrument (PSA, Coulter, model L 230).

2.4. Determination of heavy metal sediment

A 0.5 g sediment was used to analyse the total heavy metal concentration by Aqua regia mixture of 1 mL of nitric acid (HNO_3), and 3 mL of hydrochloric acid (HCl) (EPA-ROC, 1994). The heavy metals solution was filtered using the Whatman filter paper No. 42 into 100 mL volumetric flask and made up to the mark volume. An inductive coupled plasma (ICP-MS Agilent 7500) was used to measure As, Zn, Mn, Cu and Pb in the sediment samples. In order to verify accuracy of the heavy metal measurement, sediment total heavy metal digestion was applied with the standard reference material NIST SRM 2586. The actual and observed values together with the percentage recovery for sediment were reflected in Table 1. The analysis was repeated in order to minimize error in the sample analysis.

2.5. Sequential extraction for specifying heavy metal in sediment

In order to understand the mobility of heavy metal in sediment, the Rauret et al. (1999) method was applied in extracting the BCR sequential extraction of heavy metals. The BCR fractions were determined based on four steps as summarized in Table 2. Subsequent extracted sediments were measured using the ICP-MS, Agilent 7500.

2.6. Vegetation heavy metal determination

One gram of sample vegetation was placed in a crucible and placed in the furnace. The furnace's temperature was gradually increased from room temperature to 450 °C. The vegetation samples were ashed for 4 h, prior to being cooled and added with 5 mL of HNO_3. The samples were filtered with the Whatman filter paper No. 42 into 50 mL volumetric flask and made up to 25 mL. An inductive coupled plasma (ICP-MS Agilent 7500) was used to determine the heavy metals (As, Zn, Mn, Cu, Pb) in the vegetation samples following Tüzen (2003).

2.7. Quality control

Recovery is calculated by comparing the total metal content with a sequential extraction 4 steps as follows: where F is the number of sequential extraction steps for each metal. The recovery values obtained are shown in Table 3. There was an acceptable agreement in the analytical data based on the calculation of metals recovery, based on (Pan et al., 2013) applying the following formula:

$$\text{Recovery} = \frac{\mathbf{F1 + F2 + F3 + F4}}{\mathbf{Total\ element}} * 100\%.$$

2.8. Reagents

All reagents used were of analytical reagent grade. Deionized water was used for dilutions. The standard, reagent solutions and samples were kept in polyethylene bottles. Acetic acid (glacial, 100% grade AR) hydroxylammonium chloride, hydrogen peroxide (30% grade AR), and ammonium acetate and HNO_3 (65%, grade AR). The plastic and