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Baseline

Assessment of heavy metal pollution in surficial sediments from a tropical river-estuary-shelf system: A case study of Kelantan River, Malaysia

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ABSTRACT

To understand the source-to-sink of pollutants in the Kelantan River estuary and the adjacent shelf area in Malaysia, a total of 42 surface sediment samples were collected in the Kelantan River-estuary-shelf system to analyze for grain size, total organic carbon (TOC) content, Al and heavy metals (Cr, Ni, Cu, Zn, Cd and Pb). The surficial sediments were mainly composed of clayey silt and the TOC content in sediments decreased from the river to the shelf. The surficial sediments experienced Pb pollution; Cr only showed a certain level of pollution in the coastal area of the estuary but not in other areas, and Ni, Cu, Zn, and Cd showed no pollution. The heavy metals mainly originated from natural weathering and erosion of rocks and soils in the catchment and enriched near the river mouth. Total organic carbon can promote the enrichment of heavy metals in sediments.

A critical issue of current global concern is environmental pollution resulting from increasing human activities, particularly in areas such as rivers, estuaries, and coastal waters that are closely linked to human survival. As the intensity of human activities continues to increase, the global sediment flux from rivers into the sea has decreased significantly worldwide, leading to changes in the material transport pattern of estuaries and adjacent sea areas (Syvitski et al., 2005). However, in the tropics, increasing human activities in river basins have aggravated the destruction of tropical rainforests in recent years. In the background of heavy rainfall, the sediment flux from rivers into the sea has increased, making the biogeochemical cycling processes more complex in tropical estuaries and adjacent shelf areas (Syvitski et al., 2005).

Malaysia is a country in Southeast Asia with relatively high socio-economic development. Since the 1980s, the water environment in most areas of Malaysia has suffered a certain level of pollution (Abdullah, 1995; Muyibi et al., 2008; Yap et al., 2011; Looi et al., 2013), seriously affecting local socio-economic development and the safety of people's lives and property. In recent years, there has been gradually increasing investigation and research into marine heavy metal pollution in Malaysian coastal area, especially estuaries and seaport areas closely related to human activities (Din, 1995; Yap et al., 2002; Sany et al., 2013; Yusoff et al., 2015; Shaari et al., 2015).

The Kelantan River basin is located in the northwestern part of Malaysia. The range of this river basin covers the entire Kelantan state, and it flows into the South China Sea through the vicinity of Kota Bharu, the state capital of Kelantan. The entire river basin covers an area of 13,100 km^2, and its highest altitude is 2135 m; approximately 95% of the river basin area is steep mountains, and only 5% of the basin area is lowland plains (Koopmans, 1972; Ayane, 1998; Milliman and Farnsworth, 2011). The upstream mountains are mainly covered by primary tropical rainforests, while paddy, rubber and oil palm are planted midstream and downstream. Along with the consistent local socio-economic development, the water environment of the Kelantan River basin has shown a certain level of heavy metal pollution in recent years (Ahmad et al., 2009; Yen and Rohasliney, 2013; Ab Razak et al., 2016); and, heavy metals are enriched in vegetables and fish (Aweng et al., 2011; Hashim et al., 2014; Khairiah et al., 2014), affecting the livelihood and production activities of local residents. There has been little research on heavy metal contamination in sediments from estuarine wetlands and adjacent shelf areas (Abdulla et al., 2012). Additionally, previous studies have not investigated the river, the estuary, and the adjacent shelf area as an integrated system. Various materials in the river basin are discharged through the river into the estuary and then into coastal waters. Various processes of materials in this system contribute to system behaviors, and a change in each link will alter the system behavior. Moreover, the main human activities are dominated by agricultural development in the range of the Kelantan River basin. However, with continuous socio-economic development, a certain level

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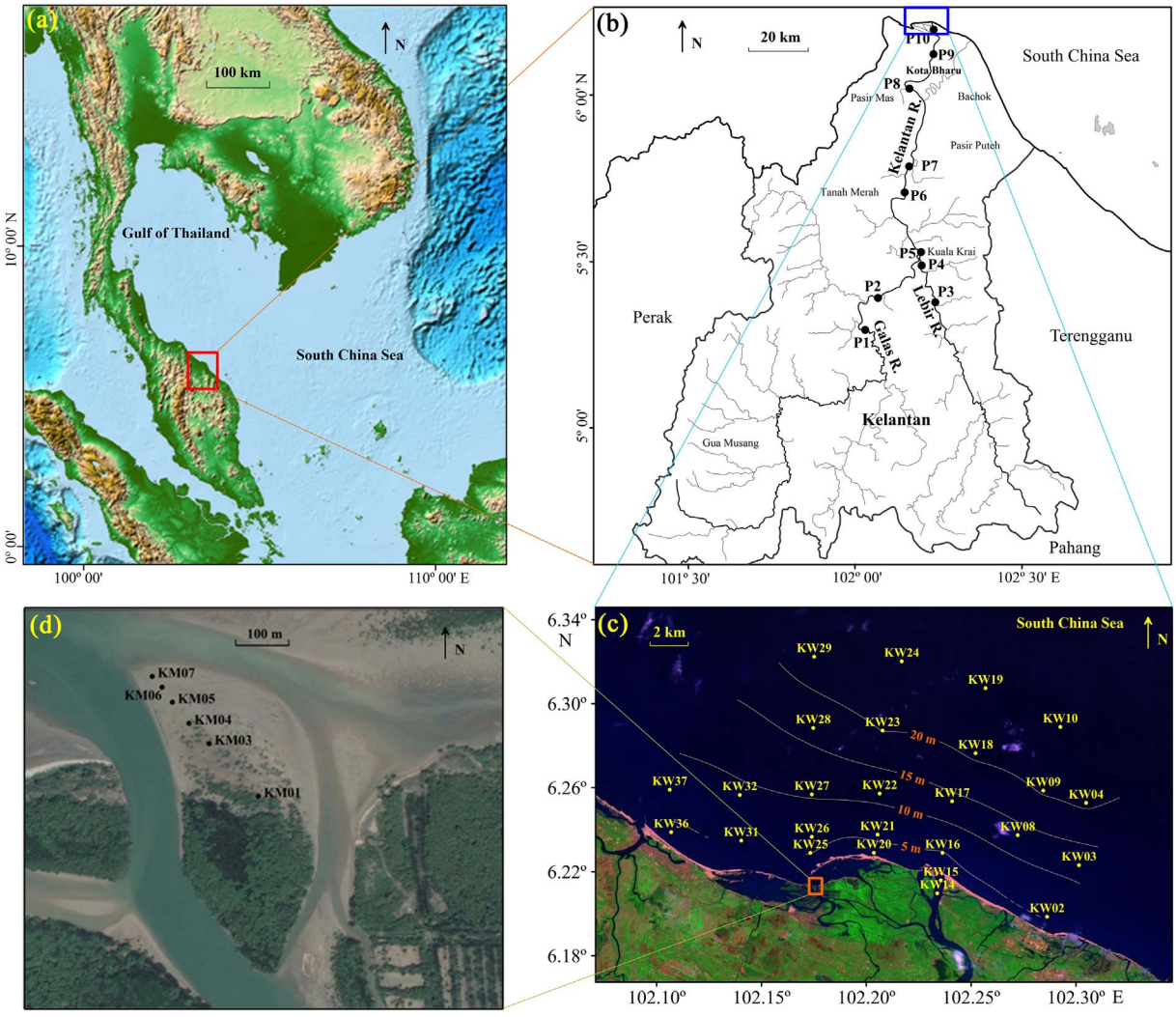

Fig. 1. Location of the study area and schematics of the sampling stations.
(Note: a: Location of the study area, b: Range of the river basin and map of the sampling stations, c: Sampling stations in the estuary and adjacent shelf area, and d: Sampling stations in the estuarine inter-tidal flat).

of industrialization may also be the future choice of the Kelantan region. Therefore, it is necessary to carry out systematic research on heavy metal content and pollution risk assessment in sediments from the Kelantan River channel-estuary-shelf system and understand the status of heavy metal pollution and the origin and fate of heavy metal pollutants.

In the present study, we examined the Kelantan River channel, estuarine wetland, and adjacent shelf area as an integrated system. The objectives of the study were to investigate the heavy metal content in surficial sediments from the Kelantan River channel-estuary-adjacent shelf system, analyze the origin of heavy metals, assess the risk of heavy metal pollution in this region, and reveal the origin and fate of heavy metals in sediments in order to provide a scientific reference for protecting local marine environments and managing river basin development.

The Kelantan River is located in the northwestern part of Malaysia (Fig. 1a). There are two tributaries, the Galas and Lebir Rivers, which converge at Kuala Krai ~100 km upstream of the estuary and the Kelantan River flows from south to north for a total river length of 248 km (Fig. 1b). The whole range of the river basin is under the control of monsoons. From October to January, the basin area is controlled by the northeast monsoon and receives more rainfall (also known as the wet season), with large wind waves in the estuary and adjacent shelf area (Adnan and Atkinson, 2011). In other periods, the basin area is controlled by the southerly or southwesterly winds, and the weather is relatively dry (also known as the dry season), with a smooth sea condition in the estuary and adjacent shelf area.

The Kelantan River estuary directly faces the South China Sea. Divided by a sand bar, the estuary forms multi-level braided channels (Fig. 1c). The length of the sand bar ranges from 400 to 800 m (Zakaria, 1975). Mangrove wetlands and inter-tidal flats are commonly developed within the braided estuary, with mangroves covering an area of ~3.4 km^2 (Satyanarayana et al., 2011). A sand beach is formed on the shore adjacent to the main river mouth, ranging from 20 to 150 m in width (Tilmans, 1991). The water depth generally ranges between 5 and 25 m (Radzir et al., 2016), and the sea floor slope is gentle in the shelf area adjacent to the estuary (Fig. 1c). The estuary area has irregular tides, with a 1.5:1 ratio of diurnal to semidiurnal tides; the maximum tidal range is 1.2 m, and the mean spring range is 0.6 m (Raj et al., 2007). The Kelantan River basin has a mean annual runoff into the sea of1.8×10^{10} m^3 and a mean sediment load of 2.5×10^6 t (Milliman and Farnsworth, 2011).

The samples used in this study were collected in the Kelantan region from November 28 to December 3, 2014. River channel surficial sediments were mainly taken near the waterline of the river channel point bar, and 10 sediment samples were obtained (station distribution as shown in Fig. 1b). Estuary and adjacent shelf seabed surficial sediments were mainly collected using a clamshell bucket. The samples used for