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Mercury and methylmercury distribution in the intertidal surface sediment of a heavily anthrophogenically impacted saltwater-mangrove-sediment interplay zone

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HIGHLIGHTS

- There is a significant positive correlation between Hg and MeHg concentration.
- Mixing area and input from urbanized rivers influenced Hg distribution.
- Fine sediment particles have a positive correlation with MeHg concentration.
- Sediment particle size has no correlation with Hg concentration in the sediment.
- Hg in the study area originated from the catchments of the urbanized rivers.

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ABSTRACT

Total mercury (THg) and methylmercury (MeHg) concentrations were determined from sediment samples collected from thirty sampling stations in Port Klang, Malaysia. Three stations had THg concentrations exceeding the threshold effect level of the Florida Department of Environmental Protection and the Canadian interim sediment quality guidelines. THg and MeHg concentrations were found to be concentrated in the Lumut Strait where inputs from the two most urbanized rivers in the state converged (i.e. Klang River and Langat River). This suggests that Hg in the study area likely originated from the catchments of these rivers. MeHg made up 0.06–94.96% of the sediment's THg. There is significant positive correlation ($p < 0.01$) between THg and MeHg concentrations. Significant positive correlation ($p < 0.05$) was also observed between fine sediment particles (i.e. clay and silt) with MeHg concentrations. Sediment particle size, however, was not found to have any influence on THg concentrations in the sediment in the study area.

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1. Introduction

Mercury (Hg) and its most prevalent organic form, methylmercury (MeHg), are considered priority hazardous substances due to their adverse biological effect and toxicity to the environment. Consuming food with high MeHg levels can cause damage to the human brain and kidney (ATSDR, 1999; Sathe et al., 2013). Children exposed to foods with high MeHg levels tend to have lower IQ because MeHg interferes with brain development (ATSDR, 1999). Hg and MeHg are also known to alter the behavior and sexual orientation of birds (Frederick and Jayasena, 2010) by disrupting the gonadotropin-releasing hormone (GnRH) input to the pituitary gland (Tartu et al., 2013). The physiological activities of plants such as transpiration (Godbold and Hüttermann, 1988), mineral uptake (Cho and Park, 2000), and photosynthetic (Israr et al., 2006) and membrane integrity (Ma, 1998) have also been reported to be affected by Hg (Haris and Aris, 2014).

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Even though a lot is known about Hg and MeHg toxicity to organisms and plants, some of the factors that influence their concentration and distribution in sediment is still inconclusive. As opposed to most other metals, which concentration in sediment is strongly influenced by sediment particle size (Kralik, 1999; Adie and Osibanjo, 2009; Astera, 2010; Haris and Aris, 2015), the relationship of THg and MeHg with sediment particle size is still unclear as specific geochemical conditions (e.g. organic material content; the presence of other metals competing for sorption sites) may also influence its (i.e. THg and MeHg) concentration in the sediment.

Accumulation of Hg and MeHg in coastal and mangrove areas pose considerable danger to the local human population and to ecosystems. Coastal and mangrove areas act as feeding and breeding grounds for aquatic wildlife and birds (i.e. migrating birds) (Chong, 2006), and are economically important for activities such as aquaculture, fisheries, tourism and logging (Chong, 1998, 2006; MPP-EAS, 1999; Haris and Aris, 2013). Due to this, several studies have been conducted to monitor the concentrations of total Hg (THg) and MeHg in the sediment found in Malaysia (Table 1). Nevertheless, as can be seen in Table 1, not many studies were done to assess MeHg in Malaysia's sediment or in the sediment of ports around the world. Most of the studies in Asia and especially in South East Asia were more focused on general monitoring rather than a detail investigation on Hg speciation. In order to address this, Port Klang has been chosen as the site for the study on mercury speciation in sediment with special focus on the area near and within the Lumut Strait.

Few studies have been carried out in areas within the Lumut Strait (Haris and Aris, 2015). This is the case despite the fact that it is surrounded by commercial ports and receives input from two of the most urbanized rivers in the state of Selangor (i.e. the Klang River and the Langat River). The Lumut Strait is also an important area for coastal fisheries and tourism activities, evidenced by the multiple fish landing sites in the area and the presence of the Royal Selangor Yacht Club marina in the Klang River estuary nearby. The ferry terminal to Pulau Ketam, Tanjung Balai Asahan and Dumai in Indonesia is also located here. The hive of activity in the area, coupled with the role it plays in the community and the ecology of its surroundings, makes the Lumut Strait an important focus for more studies to ensure that the integrity of the area is preserved.

The objectives of this study were: i) to determine Hg speciation and its distribution in the intertidal surface sediment; and ii) to assess the degree of Hg pollution in the sediment and elucidate the relationship between THg and MeHg concentrations and sediment particle size.

2. Materials and methods

2.1. Site description

Port Klang (3°0′0″N, 101°24′0″E) is the busiest container port in Malaysia and the twelfth busiest in the world (Salisbury, 2013). Cargo entering Port Klang is handled by the three main ports, namely Northport, Westport and Southport. In addition to logistics-related services, the land use in Port Klang is dominated by industrial areas (i.e. Pulau Indah Industrial Park, Westport Industrial Estate, North Klang Strait Industrial Area, Telok Gong Industrial Park and Pandamaran Industrial Park) as well as commercial and residential areas. Some of the industries that operate within the area include ship repair and maintenance, steel mills, rubber and plastic manufacturing, and food processing.

The aquatic environment of Port Klang is also influenced by input from the two main rivers in the state of Selangor, namely the Klang River and the Langat River. The Langat River is a major source of water to 1.2 million people within its basin (Shafie et al., 2014). It also contributes substantially to the potable, industrial and agricultural water used in the area (Mokhtar et al., 2009; Shafie et al., 2012). The average annual discharge of the Langat River is 35 m^3/s (Zakaria et al., 2010) while that of the Klang River is 17.2 m^3/s (Balamurugan, 1991).

2.2. Sample collection

The top 0–5 cm surface sediment samples were collected with a polypropylene scoop from thirty sampling stations in the study area. Locations of the sampling stations are shown in Fig. 1. At each station, the samples were collected in triplicates and homogenized in a plastic tray before being transferred to a labelled double zip-lock bag. In order to avoid exposure of the collected sediment samples to direct sunlight, the samples were covered with black plastic as they were being homogenized. This was done to

Table 1
The concentration of Hg and MeHg in sediment around the world.

Location	THg (μg kg^{-1})	MeHg (μg kg^{-1})	Reference	Note
Off Kuala Terengganu, Malaysia	20–127	0.01–0.53	Kannan and Falandysz (1998)	Coastal
West coast of Peninsular Malaysia	3–201		Yap et al. (2003)	Coastal
Victoria Harbor, Hong Kong	47–855	<0.1–1.5	Shi et al. (2007)	Harbor
Taheri Port, Iran	28–40	0.2–0.3	Agah et al. (2009)	Port
Dayyer Port, Iran	19–33	0.1–0.3	Agah et al. (2009)	Port
Dongjiang Harbor, China	10–270		Guo et al. (2010)	Harbor
Persian Gulf, Iran	13–40	0.09–0.21	Agah et al. (2010)	Coastal
Klang River, Malaysia	20–450		Naji and Ismail (2011)	Urbanized river
Dora, near Beirut Harbor, Lebanon	100–650	0.07–0.5	Abi-Ghanem et al. (2011)	Coastal; near harbor
Sundarban mangrove, India	32–196	0.04–0.13	Chatterjee et al. (2012)	Mangrove wetland
12 South Korea Harbor	3–3000		Choi et al. (2012)	Harbor
Westport, Malaysia	0.25		Tavakoly Sany et al. (2012a)	Port
Northport, Malaysia	0.1–0.2		Tavakoly Sany et al. (2012b)	Port
Kaohsiung Harbor, Taiwan	ND - 19000		Lin et al. (2013)	Harbor
Rize Harbor, Turkey	10–70		Gedik and Boran (2013)	Harbor
Ambarlı Port, Turkey	6–589		Sari et al. (2014)	Port
Rijeka Harbor, Croatia	160–3400		Frančišković-Bilinski and Cukrov (2014)	Harbor
Batang Ai Dam, Malaysia	80–170		Sim et al. (2014)	Inland; dam
Strait of Malacca, Malaysia	17–114		Looi et al. (2015)	Coastal
Weihe River, China	156–282	0.80–3.11	Li et al. (2015)	Inland river; tributary
Bakun Dam, Malaysia	30–390		Sim et al. (2016)	Inland; dam

ND = non-detected.

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