ECOLOGICAL RISK ASSESSMENTS OF METALS IN SEDIMENTS OF PENANG COASTAL AREA

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ABSTRACT

Rapid development and increasing human activities within Penang coastal area may increase the possibility of metals accumulation. This study was conducted to determine the potential ecological risk of metals in the sediment. Sediment samples were acid digested and extracted prior to metals (Fe, Hg, As, Pb, Cd, Cr) analyses using Inductively Coupled Plasma Optical Emission Spectrometry (ICPOES). The highest measured mean concentration of metals in sediment at Tanjung Tokong are Fe (0.357μg/g) and As (0.357μg/g). Fe has the highest measured mean concentration at Queensbay, South Bay and Teluk Bahang with 0.313 μg/g, 0.420 μg/g, and 0.219 μg/g respectively. Pb showed the highest mean concentration measured at Bayan Lepas and Balik Pulau with 0.684 μg/g and 0.575 μg/g. The potential ecological risk analysis of sediment metals concentration indicated low ecological risk of metals from Penang coastal ecosystem. Identifying the risk of metals pollution within the coastal ecosystem is the first step towards an effective environmental monitoring and management.

Keywords: Coastal, ecological risk assessment, metal, surface sediment.

INTRODUCTION

Sediments can be sensitive indicators for monitoring contaminants such as metals in aquatic environment [1]. Metals are ubiquitous in the environment [2] and may be classified into essential and non-essential metals [3]. Essential metals are required by organisms to carry out their biological metabolism while non-essential metals can cause harmful effect even at lower concentration. Magnesium (Mg), zinc (Zn), copper (Cu), cobalt (Co) and manganese (Mn) are essential metals which are needed in biological metabolism where fluctuation of the concentration can disturb biological function in all organisms [4]. Chromium (Cr), lead (Pb), cadmium (Cd), Arsenic (As), and mercury (Hg) are non-essential and toxic metals even at lower concentration [5]. The presence of metals in the environment originated from natural and anthropogenic sources [6-11]. Accumulation of metals in sediment may occur due to numerous urban and industrial activities [7].

Previous studies on metals in soil showed that researchers were focused on the concentration of the elements, sources identification and the status of the pollution [12, 15]. These studies emphasized on the total concentration of metals in the samples and compare these metals with sediment quality guidelines [13, 14]. Table 1 showed ecological risk assessment studies in Malaysia from early 2012 until 2016. To evaluate the potential ecological risk caused by pollutants in the environment such as metals, a methodology is developed by Hakanson [6] for Potential Ecological Risk Assessment or PERI. Toxic-response factor of pollutant is introduced and used to evaluate the combined pollution risk towards ecological system using PERI [16]. PERI method is vital for better understanding of the ecological risk of metals to the environment [17, 18].

The objective of this study is to determine the potential ecological risk of metals in the sediment. The outcome of this study will serve as a baseline data of potential ecological risk from surface sediment in Penang island.

Table 1. Previous studies on ecological risk assessment in Malaysia from 2012 to 2016.

Location	Topic	Authors
Malaysia	Heavy metals pollution and ecological risk assesment in surface sediments of west coast of Peninsular Malaysia	[19]
Malaysia	Potential human health risks and ecological risk assessment of heavy metals	[7]
Malaysia	Distribution characteristics and ecological risk assessment of heavy metals	[20]
Malaysia	Assessment of heavy metal in soil	[21]

MATERIALS AND METHODS

Sampling Area

Penang is a small island with 1031 km2 in size and has 1.663 million of human population. The small state is located at the northern part of Peninsular Malaysia with an average temperature of 26.8°C. Penang comprises of two part that is an island and mainland which is neighboured to Kedah state. Urbanization is more rampant at the island compared to the mainland. There are several constructions and reclamation projects which were carried out around the island due to the increase in population density and land scarcity.

This study was conducted at Penang island and six sampling sites were chosen to determine the metal concentrations in the sediments. Handheld global position system (GPS) was used to identify the latitude and longitude of sampling sites where sediment samples were collected from Dec 2016 to Feb 2017. A simple random sampling technique was used to select the sampling location based on the accessibility of the locations. The surface sediment samples collected were stored in the fridge at 4°C. Figure 1 showed the location of the sampling sites chosen around the island and Table 2 described the characteristics of the sampling sites selected.

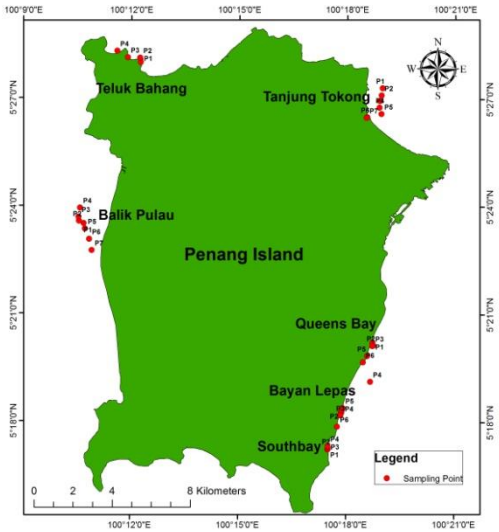

Figure 1. Sampling map for Penang island.

Table 2. The description of sampling sites of Penang island.

Bil	Station	Description
1	Tanjung Tokong	Land reclamation activity, coastal area, receiving domestic waste
2	Queensbay	Land reclamation activity, coastal area
3	Bayan Lepas	Industrial area, boating activity (fishery)
4	South Bay	Land reclamation area, jetty, boating activity (fishery)
5	Balik Pulau	Fishery activity, mangrove area
6	Teluk Bahang	Coastal area

Sample Preparation

The surface sediment samples were oven-dried at 80°C for about 3 days before crushed with mortar and pestle to acquire homogenized sediment size. Ball mill was used to further crush the sediment size.

Metal Analysis

The dried sediment samples were digested by using microwave digester and mixed acid of hydrofluoric acid (HF), sulphuric acid (H_2SO_4) and nitric acid (HNO_3). Total metals analysis of selected metals (Fe, Cd, Cr, Pb, Hg, As) was done using Inductively Coupled Plasma Optical Emission Spectroscopy (ICP-OES) PerkinElmer Optima.

RESULT AND DISCUSSION

The average concentration of the selected metals; cadmium (Cd), chromium (Cr), lead (Pb), mercury (Hg), arsenic (As) and iron (Fe) in the surface sediment of Penang coastal area were displayed in Table 3. The table showed the highest average metal concentration reported at Tanjung Tokong area are As and Fe with 0.357 µg/g for both metals followed by Cr (0.134 µg/g), Pb (0.180 µg/g), Cd (0.095 µg/g) and Hg (0.012 µg/g). The average metals concentration at Tanjung Tokong was ranked as Fe > As >Cr > Pb > Cd/Hg. Sediment Quality Guidelines used as reference baseline in this study were EPA Ecological Screening Values [23] and Canadian Interim Sediment Quality Guidelines, comprising of Threshold Effect Concentration (TEC) and Probable effect concentration (PEC) [24]. Reference values by Turekian and Wedepohl [22] were also used as a reference value for shales sedimentary rock. The average metals concentration at Tanjung Tokong for all selected metals except Fe recorded lower than values quoted in the EPA Ecological Screening Values [23] and in both TEC and PEC of the Canadian Interim SQG [24]. However, all average metals concnetration were reported lower than values recorded for the reference value of shales sedimentary rock [22]. Higher concentration of Fe and As metals at Tanjung Tokong could be caused by higher amount of sand from active land reclamation activity of Sri Tanjung Pinang Phase 1 project nearby the area and discharge from the outlet. Higher significant metals concentration in sediments was reported from an active urban area with potentially receiving domestic waste and vehicle runoff [25] The highest average metal concentration reported at Queensbay was Fe with 0.313 µg/g followed by Cr (0.145 µg/g), Pb (0.135 µg/g), Cd (0.101 µg/g), As (0.020 µg/g) and Hg (0.014 µg/g). The average concentration of metals were ranked as Fe > Cr > Pb > Cd > As > Hg. According to Turekian and Wedepohl [22], all selected metals at Queensbay coastal area did not exceed the reference value. Furthermore, the average metals concentration of the selected metals did not exceed values quoted for EPA Ecological Screening Value [23] and Canadian Interim SGQ [24] except for Fe. Highest concentration of Fe at Queensbay coastal area resulted from on-going project of land reclamation conducted at the area which brought higher amount of sand to the area. Lead (Pb) was detected as the highest average metal concentration at Bayan Lepas area with 0.684 µg/g and followed by As

(0.382 µg/g), Fe (0.382 µg/g), Cr (0.307 µg/g), Cd (0.231 µg/g) and Hg (0.009 µg/g). The order for average metals concentration was Pb > As/Fe > Cr > Cd > Hg. Average mean concentration in Table 3 showed that metals in surface sediments of Bayan Lepas area did not exceed the reference values as outlined by Turekian and Wedepohl [22]. Cd, Cr, Pb, Hg, and As average mean concentration also indicated lower value compared to EPA Ecological Screening Value [23] and Canadian Interim SGQ [24]. Our finding suggests that industrial areas surrounding Bayan Lepas did not elevate the metals concentration in the sediment.

South Bay coastal area reported highest average metal concentration of Fe (0.420 µg/g) followed by Pb (0.231 µg/g), Cr (0.123 µg/g), Cd (0.098 µg/g), As (0.023 µg/g) and Hg (0.012 µg/g). The average metals concentration was ranked as Fe > Pb > Cr > Cd > As > Hg and also did not exceed the reference value by Turekian and Wedepohl [22]. Besides, the selected metals value of average mean concentrations of all metals except Fe recorded lower than EPA Ecological Screening Value [23] and Canadian Interim SGQ [24]. At Balik Pulau coastal area, Pb was the highest average metal concentration detected with 0.575 µg/g. This is followed by Cr, Fe, Cd, As, and Hg with average concentration of 0.191 µg/g, 0.167 µg/g, 0.125 µg/g, 0.018 µg/g, 0.012 µg/g respectively. The order of the average concentration was Pb > Cr > Fe > Cd > As > Hg. Compared to EPA Ecological Screening Value [23] and Canadian Interim SGQ [24], the average mean concentration of Cd, Cr, Pb, Hg, and As were lower except for Fe. Result of all average metals concentrations at Balik Pulau coastal area did not exceed the reference value by Turekian and Wedepohl [22]. The last station was Teluk Bahang where Fe also was recorded as the highest average metal concentration with 0.219 µg/g. Next was Pb (0.170 µg/g), Cr (0.115 µg/g), Cd (0.094 µg/g) and lastly As and Hg both with same value of 0.012 µg/g. The average metals concentration was ranked as Fe > Pb > Cr > Cd > As/Hg and all metals detected did not exceed the reference value of Turekian and Wedepohl [22]. The results also showed lower value than EPA Ecological Screening Value [23] and Canadian Interim SGQ [24]. Teluk Bahang is gazetted as Penang National Park where the area is well protected by the local authorities from excessive human activities. Higher detection of Fe at the area might originates from natural source such as weathering of sediment from the sea. Metals deposition in marine sediments occurs due to natural process such as weathering of minerals, salt dissolutions and erosion [28].

Table 3. The average metals concentration of six stations at Penang island, in comparison with sediment quality guidelines

	Average metals concentration (µg/g)					
Stations	Cd	Cr	Pb	Hg	As	Fe
Tanjung Tokong	0.095	0.134	0.180	0.012	0.357	0.357
Queensbay	0.101	0.145	0.135	0.014	0.020	0.313
Bayan Lepas	0.231	0.307	0.684	0.009	0.382	0.382
South Bay	0.098	0.123	0.231	0.012	0.023	0.420
Balik Pulau	0.125	0.191	0.575	0.012	0.018	0.167
Teluk Bahang	0.094	0.115	0.170	0.012	0.012	0.219
Shale sedimentary rock[a]	0.3	90	20	0.4	13	47 200
EPA Ecological Screening value[b]	1	52.3	30.2	0.13	7.24	-
Canadian ISQG[c] (TEC)	0.596	37.3	35	0.17	5.9	-
Canadian ISQG[c] (PEL)	3.53	90	91.3	0.486	17	-

*Note: TEC = Threshold effect concentration: PEL = Probable effect level
[a](Turekian and Wadepohl, 1961)[22] [b]EPA (1995)[23] [c]Environment Canada (2002)[24]

Table 4. Results of potential ecological risk assessment.

	Er values					
Stations	Cd	Cr	Pb	Hg	As	RI
Tanjung Tokong	2.85	0.002	0.015	1.84	0.24	4.947
Queensbay	3.03	0.004	0.01	2.28	0.01	5.334
Bayan Lepas	6.93	0.006	0.05	1.44	0.25	8.676
South Bay	2.94	0.002	0.015	1.88	0.02	4.857
Balik Pulau	3.75	0.004	0.04	1.88	0.01	5.684
Teluk Bahang	2.82	0.002	0.01	1.84	0.01	4.682

To measure the degree of metal pollution in surface sediments at Penang coastal area, geoaccumulation (I-geo) index [26, 27] and pollution load index (PLI) [28] were calculated. Geoaccumulation (Igeo) index for average metals concentration at six stations of Penang coastal ecosystem was Grade 1 ($0 < \text{I-geo} \leq 1$) which was categorized as slightly polluted or little to moderate contamination occurred. Based on the calculation from average metals concentration of surface sediments for PLI value, Penang coastal ecosystem was indicated as no pollution (< 1). Contamination Factor (CF) ratio for selected metals (Fe, Cd, Cr, Pb, Hg, As) at six stations was graded as low level with CF value < 1. To determine the ecological risk assessment of metals contamination in surface sediments of Penang island, PERI [29] method was used and the result as showen in Table 4. Degree of contamination or (C^i_f) of metals in surface sediment was categorized under low contamination factor ($C^i_f < 1$) and classification of RI (potential ecological risk assessment) was low potential ecological risk with RI value < 150 and Eri < 40.

CONCLUSION

In conclusion, the study provided the baseline data of selected metals (Fe, Cd, Cr, Pb, Hg, As) for surface sediments of Penang coastal area. Based on the calculation of geoaccumulation (I-geo) and PLI indexes, surface sediments at Penang coastal area were categorized as Grade 1 as no pollution effect. Potential ecological risk assessment of the area also indicated low risk to the sediment. Continuous assessment of metals in the sediment is needed to monitor the rapid development and human activities within the coastal area which may increase the metals above the reference values and sediment quality guidelines.

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