

An assessment of selected trace elements in intertidal surface sediments collected from the Peninsular Malaysia

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Abstract Concentrations of 11 trace elements (V, Cr, Co, Ni, Cu, Zn, As, Ag, Cd, Pb, and U) were determined in the intertidal surface sediments of Peninsular Malaysia. The average trace element concentrations are ranked as follows: Zn>V>As>Cr>Pb>Cu>Ni>Co>U>g>Cd. Interim Sediment Quality Guidelines (ISQGs) employed in present study are the Australia and New Zealand joint guideline (ANZECC/ARMCANZ), and the Hong Kong authorities. From the pooled data, none of these trace elements have the average concentration above the ISQG-high values. However, As and Ag average concentrations

were over the ISQG-low values. Some elements were found to have the average concentration above the ISQG-high and/or ISQG-low in certain locations, including Kampung Pasir Putih (JPP), Lumut Port (ALP), Kuala Perai (PKP), Port Dickson (NPD), and others. The lowest and highest concentrations in a specific sampling location and maritime area varied among the elements, variations that were greatly affected by natural and anthropogenic activities in a given area. For each trace element, there were various levels of concentration among the sampling locations and maritime areas. These patterns indicated pollutant sources of an element for each area perhaps derived from nearby areas and did not widely distributed to other locations. It is necessary for Malaysia to develop an ISQG for effective quick screening and evaluation of the coastal environment of Peninsular Malaysia.

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Introduction

Sediments are the ultimate sink for the numerous anthropogenic chemical contaminants that may be contained in effluents originating from agricultural, industrial, urban, and recreational

activities (Apitz et al. 2005; Hatji et al. 2002; Loganathan et al. 2006). Trace elements occur naturally and are ubiquitous contaminants in the aquatic sediments. These elements become toxic if they occur above certain threshold bio-available levels (Blackmore 1998). Concentrations of certain trace elements such as Cd, Cu, Ni, Pb, Zn, and other metals are often elevated above background levels in sediments that have been affected by human activities such as industrial, agricultural, mining, transportation, construction, and habitation (DOE 2007; Glasby et al. 2004; Ismail et al. 1993; Shazili et al. 2006). Earlier studies have correlated elevated concentrations of certain inorganic elements in sediments of rivers, estuaries, and coastal regions with increased industrial growth, agricultural operations, land use, etc. (Loganathan et al. 2006; Macauley et al. 1995). Contaminated sediments in rivers, lakes, and coastal regions have the potential to pose ecological and human health risks. Depending on the hydrodynamics, biogeochemical processes, and environmental conditions (redox, pH, salinity, and temperature) of the aquatic environment, sediments are recognized as an important sink for many pollutants in aquatic systems, as well as potential non-point sources of pollutants that might directly affect the overlying water (Calmano et al. 1993). This process commonly occurs in intertidal sediment flats in estuaries. Moreover, trophic transfer of pollutants is identified as an important pathway for pollutants in sediments to accumulate in marine invertebrates and fishes (Fisher and Reinfelder 1995; Wang and Fisher 1999).

In recent decades, much development has occurred around Peninsular Malaysia. Industrialization, urbanization, the advancement of agriculture, and other activities related to the modern era are occurring at a rapid pace. The Department of Environment, Ministry of Natural Resources and Environment Malaysia, stated in every annual report the activities that can be the sources of anthropogenic pollutants, and potentially contaminate the coastal environment. Until recently, there were a limited number of reports on the status of trace elements in the aquatic environment in Malaysia, particularly in relation to intertidal sediments. The studies conducted commonly focused on heavy metals such as Cu, Zn, Cd, and

Pb (Chester and Stoner 1974; Ismail et al. 1993, 1995; Ismail and Idris 1996; Law and Singh 1991; Yap et al. 2002, 2003). However, extensive study of trace elements is necessary in order to gain a deeper understanding of the possible threats of pollution to the Malaysian aquatic environment. Hence, present study was conducted to assess the concentrations of trace elements (V, Cr, Co, Ni, Cu, Zn, As, Ag, Cd, Pb, and U) in samples of surface intertidal sediments collected along the Peninsular Malaysia coastline.

Materials and methods

Description of sampling sites

Peninsular Malaysia is surrounded by busy and important waterways, including the Malacca Strait, the Johor Strait, and the South China Sea. The Malacca Strait is approximately 600 nm with the widest section (220 nm) near the north-west entrance, narrowing gradually to around 8 nm at the south-east entrance near the Riau Archipelago (Chua et al. 2000). It is listed as one of the busiest maritime routes in the world with 44,000 vessels in 1999, more than 70,000 vessels in 2007, and probably 120,000 vessels in the future (Anonymous 2008a; Sgouridis 2003). It is the shortest maritime route between the East and the West for trading goods (estimated worth more than US\$1 trillion), as well as being a fishing ground (used by approximately 30,000 fishermen and yielding more than 57% of the total landed fish in Peninsular Malaysia (Omar 2004)) and a source of natural resources. According to Chua et al. (2000), more than 23 million people live along the strait (west Peninsular Malaysia and east Sumatera).

Johor Strait is a relatively narrow and shallow maritime area that is for the most part less than 6 km in width and 25 m in depth (Wood et al. 1997). In 1924, the strait was divided into two parts by the construction of the Johor Causeway (linking Peninsular Malaysia and Singapore). The eastern part is connected to the South China Sea, and the western part to the Malacca Strait. The eastern and western ends of the strait remain important as fish and shellfish resources

for the people of Johor State (Malaysia) and Singapore. Wild bioresources as well as those in marine and estuary aquaculture projects are abundant. This area is known for its abundance of green mussel (*Perna viridis*), thus making it the source of young mussels for the transplanting programs since 1986 by Department of Fisheries Malaysia (Lovatelli 1991). Furthermore, the production of green mussel, mud crab (*Scylla serrata*), seabass (*Lates calcarifer*), mangrove snapper (*Lutjanus johnei*), and red snapper (*Lutjanus argentimaculatus*) from major aquaculture farms was 21,000 tonnes in 2001 and expected to reach 150,000 tonnes in 2005 (Omar 2004). With the introduction of new technologies and the expansion of aquaculture area, production from this area continues to rise enhancing its importance as a rich area for food resources. Recent developments along both sides of the strait might have contributed to physical and chemical changes in the aquatic environment. Besides, along the strait are Johor Port (ranked 82nd among global container terminals in 2007) and the new ports of Tanjung Pelepas and Tanjung Langsat (Sgouridis 2003). Each port is designed to handle specific trading and container activities. The population along the strait is roughly estimated at around three million people. Furthermore, a new economic zone known as Iskandar Malaysia has been launched to enhance and accelerate “high-impact” development in this area (Anonymous 2008b).

In contrast to the earlier two straits, the South China Sea is a large semi-enclosed sea, with an area roughly estimated to be 3,500,000 km² (Shazili et al. 1997; Valencia 1979). It is regarded as one of the major seas after the five oceans and is bordered by China, Taiwan, Hong Kong, Macau, Vietnam, Cambodia, Thailand, Malaysia, Singapore, Indonesia, Brunei, and Philippines. This sea is important as a fishing ground, for aquaculture, as a shipping route, and as a source of natural resources (Shazili et al. 1997; Valencia 1979). Along the east coast of Peninsular Malaysia it is known as a petroleum and natural gas exploration area. The population in this part of Peninsular Malaysia is less dense. Higher population can be found in the capitals of states along the shoreline. In addition, major ports (i.e. Kuantan Port and

Kemaman Port) act as gateways for transferring products from major petrochemical plants and handle large volumes of petrochemical and liquid bulk products (Sgouridis 2003).

Sample collection

Sediment sampling was conducted in 2007 and covered 30 sampling locations along the coast of Peninsular Malaysia (Fig. 1). Table 1 lists the locations with general site descriptions of the respective sampling areas. Sediment samples were collected in triplicate from the top 3–5 cm of the surface at each sampling site. Each sediment sample was stored in an acid-washed polyethylene bag and kept frozen (−20°C) prior to further analytical analysis.

Reagents and calibration

The reagents used were all of analytical reagent grade certified for high purity. Ultrapure water (water resistivity > 18.2 MΩ cm at 25°C; water TOC less than 5) was produced with a Mili-Q Integral 3 system (Millipore, MA, USA). High-purity concentrated HNO₃ and HCl (Kanto Chemicals Co., Inc., Tokyo, Japan) were used in aqua-regia digestion. Calibration was done using external and internal standards. The external standard was prepared by diluting the ICP Multi Element Standard Solution VI CertiPUR[®] (Merck[®], Darmstadt, Germany) with the same acid mixture used for sample dissolution. A mixture of scandium (Sc), indium (In), and bismuth (Bi) was used as an internal standard. All glass and plastic wares were cleaned by soaking overnight in a 4.0 M HNO₃ solution and were then rinsed with Mili-Q water.

Analytical procedures

Samples were dried in an oven at 60°C for at least 1 day until a constant dry weight was obtained. Later, the samples were agitated with a ceramic mortar and pestle and the fine fraction obtained after sieving through a 63-μm mesh sieve. All sieved samples were stored in sealed acid-washed polyethylene containers prior to chemical analysis. To determine pseudototal trace elements content in the sediments, the aqua regia digestion

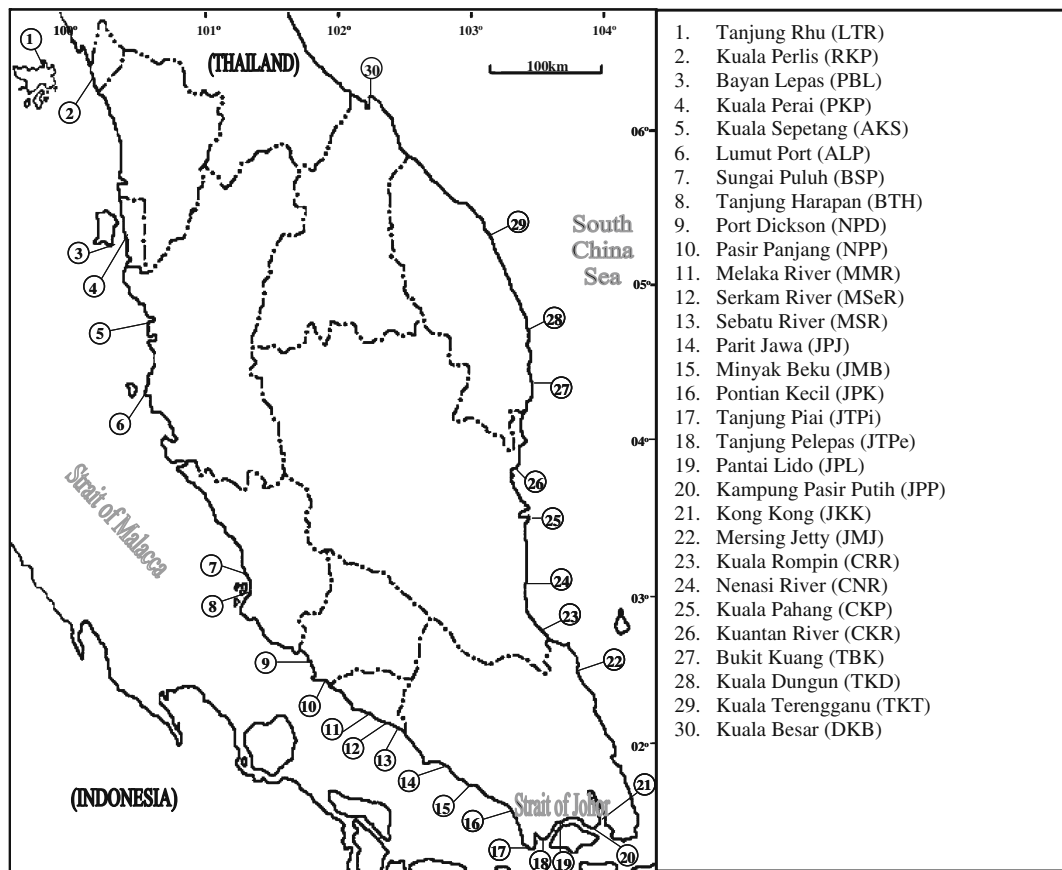


Fig. 1 Sampling locations for intertidal surface sediment along the Peninsular Malaysia coastline

method was employed according to ISO Standard 11466 (ISO 1995). Briefly, 1.0 g of fine fraction sample was weighed and placed into a 250-ml Erlenmeyer flask. About 0.5 to 1.0 ml Mili-Q water was then added to form a slurry. Approximately 7.0 ml of 12 M HCl was added followed by 2.3 ml of 15.8 M HNO₃ (3:1 ratio); these were added drop-by-drop to reduce foaming. The sample was allowed to pre-digest for 16 h (overnight). The suspension was then digested on a hot plate at 130°C for 2 h, in an open system. The suspension so obtained was then filtered through a 0.45 μm GD/X™ syringe filter (Whatman®, NJ, USA) into a polyethylene bottle. Finally, the filtered suspension was diluted to 50 ml with 0.5 M HNO₃ and stored at 4°C prior to metal content determination. In order to assure the accuracy and precision of the method, Standard Reference Material®

1646a Estuarine Sediment (National Institute of Standards and Technology, USA) was used and analyzed in the same way as the other samples. Recoveries of trace elements ranged from 93.21–108.40% (Table 2).

Measurements

All samples treated with the aqua regia method were analyzed using an inductively coupled plasma mass spectrometry, ICP-MS (Agilent 7500cs, Agilent, CA, USA) for determining element contents (⁵¹V, ⁵²Cr, ⁵⁹Co, ⁶⁰Ni, ⁶⁵Cu, ⁶⁶Zn, ⁷⁵As, ¹⁰⁷Ag, ¹¹¹Cd, ²⁰⁸Pb, and ²³⁸U). The operating conditions of ICP-MS are given in Table 3. All data are expressed on a dry weight basis (μg g⁻¹ dry weight).

Table 1 Locations and site descriptions of sampling areas along the coastal areas of Peninsular Malaysia

No.	Location	Code	Coordinate	Site descriptions
1	Tanjung Rhu	LTR	6°27.639' N; 99°49.915' E	<i>PR, vi, j, ve, R, aq, ag</i>
2	Kuala Perlis	RKP	6°23.931' N; 100°07.719' E	<i>d, tc, J, VE, r, aq, AG</i>
3	Bayan Lepas	PBL	5°18.663' N; 100°18.017' E	<i>D, TC, J, VE, r, aq, I</i>
4	Kuala Perai	PKP	5°23.025' N; 100°22.314' E	<i>D, TC, PO, VE, I</i>
5	Kuala Sepetang	AKS	4°50.618' N; 100°38.002' E	<i>PR, vi, j, ve, r, aq</i>
6	Lumut Port	ALP	4°13.986' N; 100°37.632' E	<i>D, TC, PO, VE, r, AQ, ag, I</i>
7	Sungai Puloh	BSP	3°04.304' N; 101°23.445' E	<i>d, tc, j, ve, ag, I</i>
8	Tanjung Harapan	BTH	3°00.617' N; 101°21.568' E	<i>D, TC, PO, VE, r, I</i>
9	Port Dickson	NPD	2°31.284' N; 101°47.743' E	<i>D, TC, po, VE, R, I</i>
10	Pasir Panjang	NPP	2°25.359' N; 101°55.638' E	<i>pr, vi, j, ve, r, aq, ag</i>
11	Malacca River	MMR	2°11.271' N; 102°14.641' E	<i>D, TC, J, VE, R, I</i>
12	Serkam River	MSeR	2°08.684' N; 102°21.241' E	<i>pr, vi, j, ve, r, aq, ag</i>
13	Sebatu River	MSR	2°06.621' N; 102°27.816' E	<i>pr, vi, j, ve, AQ, ag</i>
14	Parit Jawa	JPJ	1°56.995' N; 102°37.954' E	<i>d, VI, J, VE, r, aq, ag</i>
15	Minyak Beku	JMB	1°47.778' N; 102°53.331' E	<i>pr, vi, j, VE, aq, ag, I</i>
16	Pontian Kecil	JPK	1°28.851' N; 103°23.061' E	<i>d, tc, J, VE, AQ, ag</i>
17	Tanjung Piai	JTPi	1°15.853' N; 103°30.550' E	<i>PR, vi, j, ve, r, aq, ag</i>
18	Tanjung Pelepas	JTPe	1°20.882' N; 103°34.198' E	<i>d, tc, PO, VE, r, ag</i>
19	Pantai Lido	JPL	1°27.997' N; 103°43.634' E	<i>D, TC, j, ve, r, aq, I</i>
20	Kampung Pasir Putih	JPP	1°26.034' N; 103°55.805' E	<i>D, TC, PO, VE, r, AQ, I</i>
21	Kong Kong Laut	JKK	1°31.112' N; 103°59.877' E	<i>pr, vi, j, ve, r, ag</i>
22	Mersing Jetty	JMJ	2°26.071' N; 103°50.293' E	<i>d, tc, J, VE, R, ag</i>
23	Rompin River	CRR	2°48.559' N; 103°28.722' E	<i>d, vi, J, VE, R, aq, ag</i>
24	Nenasi River	CNR	3°08.041' N; 103°26.662' E	<i>pr, vi, j, ve, AQ, ag</i>
25	Kuala Pahang	CKP	3°31.741' N; 103°27.699' E	<i>pr, vi, j, ve, AQ, ag</i>
26	Kuantan River	CKR	3°48.598' N; 103°20.217' E	<i>D, TC, J, VE, R, I</i>
27	Bukit Kuang	TBK	4°14.537' N; 103°26.495' E	<i>D, tc, J, VE, r, aq, ag</i>
28	Kuala Dungun	TKD	4° 46.759' N; 103° 25.613' E	<i>d, tc, J, VE, r, aq, ag</i>
29	Kuala Terengganu	TKT	5°20.435' N; 103°09.662' E	<i>D, TC, J, VE, R, aq, ag, i</i>
30	Kuala Besar	DKB	6°13.329' N; 102°14.289' E	<i>d, VI, J, VE, r, ag, i</i>

Symbols with capital letter/s indicate that a particular area has high level of this description, whereas small letter/s indicate a particular area lower level of this description

PR/pr pristine area, *D/d* developed area, *VI/vi* village, *TC/tc* town/city, *PO/po* port, *J/j* jetty, *VE/ve* sea vessels, *R/r* recreation, *AQ/aq* aquaculture, *AG/ag* agriculture, *I/i* industrial area

Table 2 Recovery of trace elements in standard reference material[®] 1646a estuarine sediment

Element	Certified and estimated value (µg/g)	Measured concentration (µg/g)	Recovery (%)
V	44.84 ± 1.6 ^a	43.55 ± 0.52	97.13
Cr	40.9 ± 1.9 ^a	41.48 ± 1.87	101.41
Co	5.00 ^b	4.89 ± 0.25	97.75
Ni	23.00 ^b	23.86 ± 1.40	103.72
Cu	10.01 ± 0.34 ^a	9.59 ± 0.51	95.76
Zn	48.9 ± 1.6 ^a	49.82 ± 1.49	101.89
As	6.23 ± 0.23 ^a	6.13 ± 1.03	98.44
Ag	0.30 ^b	0.31 ± 0.03	104.88
Cd	0.15 ± 0.007 ^a	0.16 ± 0.02	108.40
Pb	11.70 ± 1.2 ^a	12.21 ± 0.59	104.40
U	2.00 ^b	1.86 ± 0.12	93.21

^aCertified value

^bEstimated value

Table 3 ICP-MS operating conditions

	Condition used
Instrument	Agilent 7500cs (with Octapole Reaction System (ORS))
RF Power	1,500 W
Gas	Ar
Carrier gas flow rate	0.80 L min ⁻¹
Auxiliary gas flow rate	0.44 L min ⁻¹
Instrument tuning	Performed using a 10 µg L ⁻¹ of Li, Y, Ce, and Tl solution
Measurement parameters	
Detector mode	Dual (electron multiplier operating in both pulse counting and analog modes)
Dwell time	0.010–0.20 per point (depending on the signal intensity)
Number of replicates	5
Points across peak	3
Sample reading time	63.0400 s
Sample wash delay	20 s
Autosampler	I-AS
Autosampler wash delay	10 s
Isotopes monitored	⁵¹ V, ⁵² Cr, ⁵⁹ Co, ⁶⁰ Ni, ⁶⁵ Cu, ⁶⁶ Zn, ⁷⁵ As, ¹⁰⁷ Ag, ¹¹¹ Cd, ²⁰⁸ Pb, ²³⁸ U

Data screening and statistical analysis

The Interim Sediment Quality Guideline (ISQG) is usually used to quickly screen and compare the guideline values in a particular country. The ISQGs employed in Australia and New Zealand (ANZECC and ARMCANZ 2000), and Hong Kong (Chapman et al. 1999) were adopted in this study for quick screening purposes (Table 4).

Statistical analysis was performed using SPSS (version 13.0, SPSS Inc., Chicago, IL, USA). Tukey's post-hoc method along with one-way ANOVA was applied to obtain the area-to-area differences in terms of trace element concentrations. The significance level was evaluated in two stages, $p < 0.05$ and $p < 0.01$.

Results and discussion

In this study, pooled concentrations data of 11 trace elements (V, Cr, Co, Ni, Cu, Zn, As, Ag, Cd, Pb, and U) present in surface intertidal sediments along the Peninsular Malaysia coastline were determined. Zn (130.06 ± 103.01 µg/g) was found to have the highest concentration and was followed by V (82.33 ± 47.85 µg/g), As (69.56 ± 58.71 µg/g), Cr (69.52 ± 33.79 µg/g), Pb (53.16 ± 17.46 µg/g), Cu (36.98 ± 42.60 µg/g), Ni (19.29 ± 7.10 µg/g), Co (7.71 ± 3.30 µg/g), U (6.21 ± 3.50 µg/g), Ag (2.88 ± 6.17 µg/g), and Cd (0.16 ± 0.19 µg/g). By comparing these elemental averages with the employed ISQGs, none of these elements had an average concentration above the ISQG-high

Table 4 Interim sediment quality guideline values compared

Guideline	V	Cr	Co	Ni	Cu	Zn	As	Ag	Cd	Pb	U
ISQG-high ^a	–	370	–	52	270	410	70	3.7	10	220	–
ISQG-high ^b	–	370	–	ns	270	410	70	3.7	9.6	218	–
ISQG-low ^a	–	80	–	21	65	200	20	1	1.5	50	–
ISQG-low ^b	–	80	–	40	65	200	8.2	1	1.5	75	–

ns not seen

^aANZECC and ARMCANZ (2000)

^bChapman et al. (1999)

value. However, As and Ag average concentrations were found over the ISQG-low value for both guidelines. Further analysis on data across the sampling locations showed some elements do have the average concentration above the ISQG-high and/or ISQG-low, as illustrated in Figs. 2 and 3. In comparison with the worldwide studies (Table 5), the present results indicated that almost all data of trace elements (V, Cr, Co, Ni, Cu, Zn, Cd, and Pb) were within the concentration range reported worldwide. However, there were some data of As, Ag, and U in present study showed higher concentrations than the worldwide concentration range.

Elements with concentrations above the ISQG-high values in some locations

Zn, As, and Ag were found as the three elements to have an elemental concentrations above the ISQG-high values in several locations. The respective critical guideline values for Zn, As, and Ag are noted in Table 4.

For Zn, the data ranged between 23.70 and 609.20 $\mu\text{g/g}$ (Fig. 2). Among the sampling locations, the highest average concentration of Zn was found in JPP ($605.97 \pm 2.91 \mu\text{g/g}$) and the lowest in NPD ($24.62 \pm 1.42 \mu\text{g/g}$). JPP was the only location having a Zn concentration above the ISQG-high value. Furthermore, this location was found to have the highest concentration for a few other elements (Ni, Cu, Cd, and Pb). Correlations were significant at the 0.01 level between Zn and these four elements (Table 6). There were three locations (PKP, JMB, and JPL) with Zn concentration above the ISQG-low value but below the ISQG-high value. These locations are presumed to receive anthropogenic Zn input from industrial activities (e.g., electrical and electronic factories), ports, coal-generated power plants, and transportation. Agriculture-related activities may also contribute anthropogenic Zn in several ways. A comparison of the maritime areas (Malacca Strait (MS), Johor Strait West (JSW), Johor Strait East (JSE), and South China Sea (SCS)) showed that JSE had the highest concentration ($361.38 \pm 267.97 \mu\text{g/g}$) of Zn in intertidal sediments and SCS the lowest ($102.74 \pm 25.19 \mu\text{g/g}$). Zn concentration in JSE was significantly different from

that in other maritime areas ($p < 0.001$), but no significant difference could be found among MS, JSW, and SCS. These data also did not differ from those obtained in previous local studies (Ismail and Idris 1996; Ismail et al. 1993; Yap et al. 2003).

As concentration ranged between 0.11 and 311.84 $\mu\text{g/g}$ (Fig. 2). Among the sampling locations, the highest average concentration of As was observed in NPD ($297.40 \pm 13.54 \mu\text{g/g}$) and the lowest in JTPe ($0.15 \pm 0.05 \mu\text{g/g}$). The concentration of As in NPD differed significantly from those found in other locations ($p < 0.001$). This high concentration is attributed to the presence of petroleum refinery complexes and the coal-based power station in the vicinity. The refinery complexes process crude oil mainly from the Middle East. According to Speight (2007) and Merian (1991), crude oil from this area (Dubai crude) has high content of V, Ni, Fe, As, and other elements. The coal-based power plant is also expected to discharge some amount of As into the environment since most of the coal mined around the world has an average As content of 21 $\mu\text{g/g}$. About 40% of the sampling locations, mainly along the east coast of Peninsular Malaysia, were found to have an As concentration above the ISQG-high value. Wooden structures and buildings—new and old—are common in this area. As could possibly be derived from leachates of chromated copper arsenate (CCA), which is used to treat and preserve woods. Some studies report having found that CCA is able to degrade or disintegrate to form other substances. The Cu derivative in CCA could have broken down to form other chemical structures that were transported through the food chain, since it is an essential trace element. However, the Cr (less essential) and As (non-essential) components of CCA might not be transported freely, which could explain their presence in the sediments. Reports state that the proportion of As in the treated wood reduced by 20–25% after 2–4 years (Henningsson and Carlsson 1984), and As concentration in the soil in the vicinity of the CCA-treated structures increased by 22–57% after 7 years (Fahlstrom et al. 1967; Smith and Williams 1973). In present study, correlation between As and Cr was found to be high ($r^2 = 0.760$; $p = 0.01$) in all sampling locations, as stated in Table 6. Thus, this high As concentration suggests

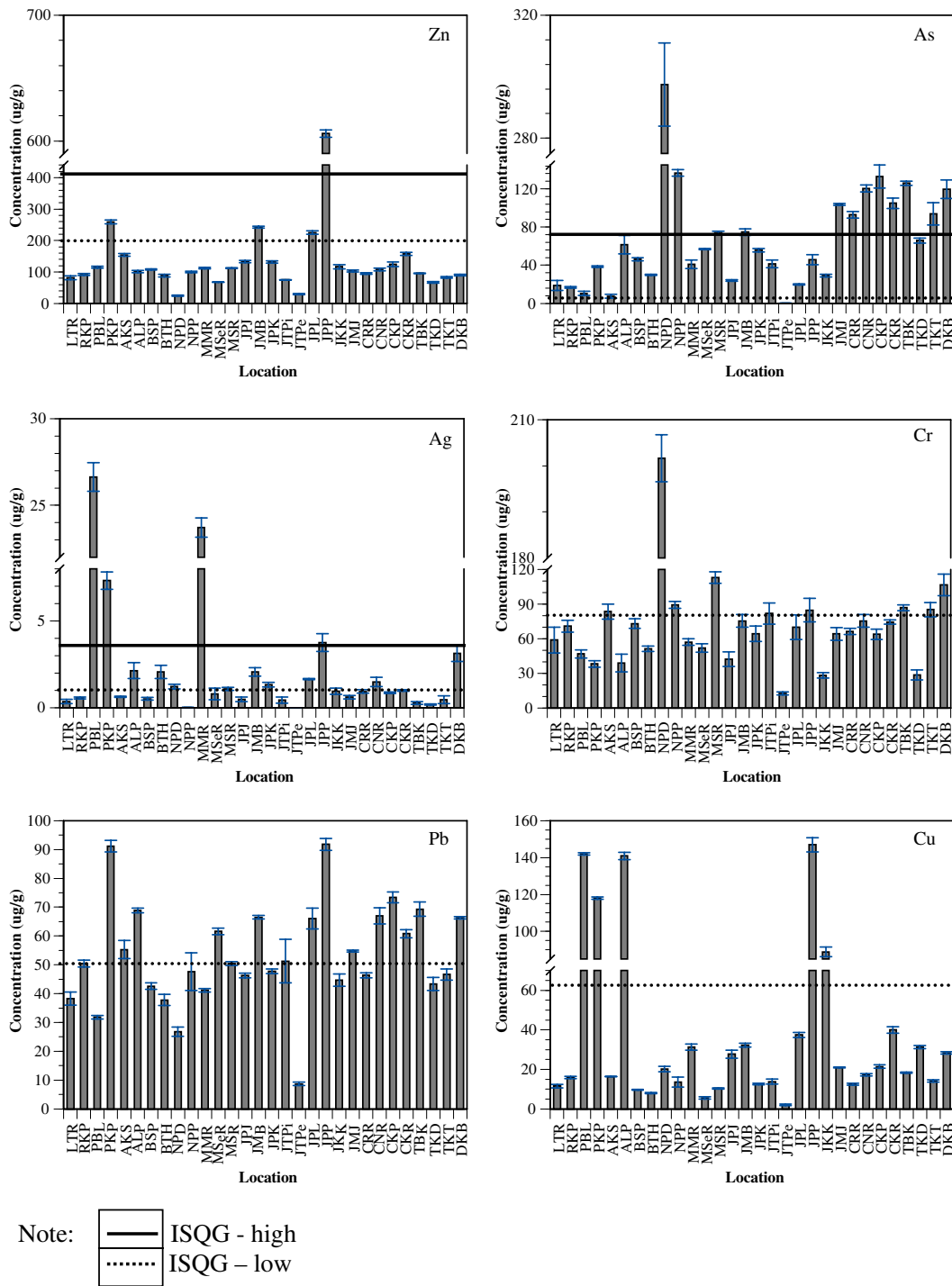
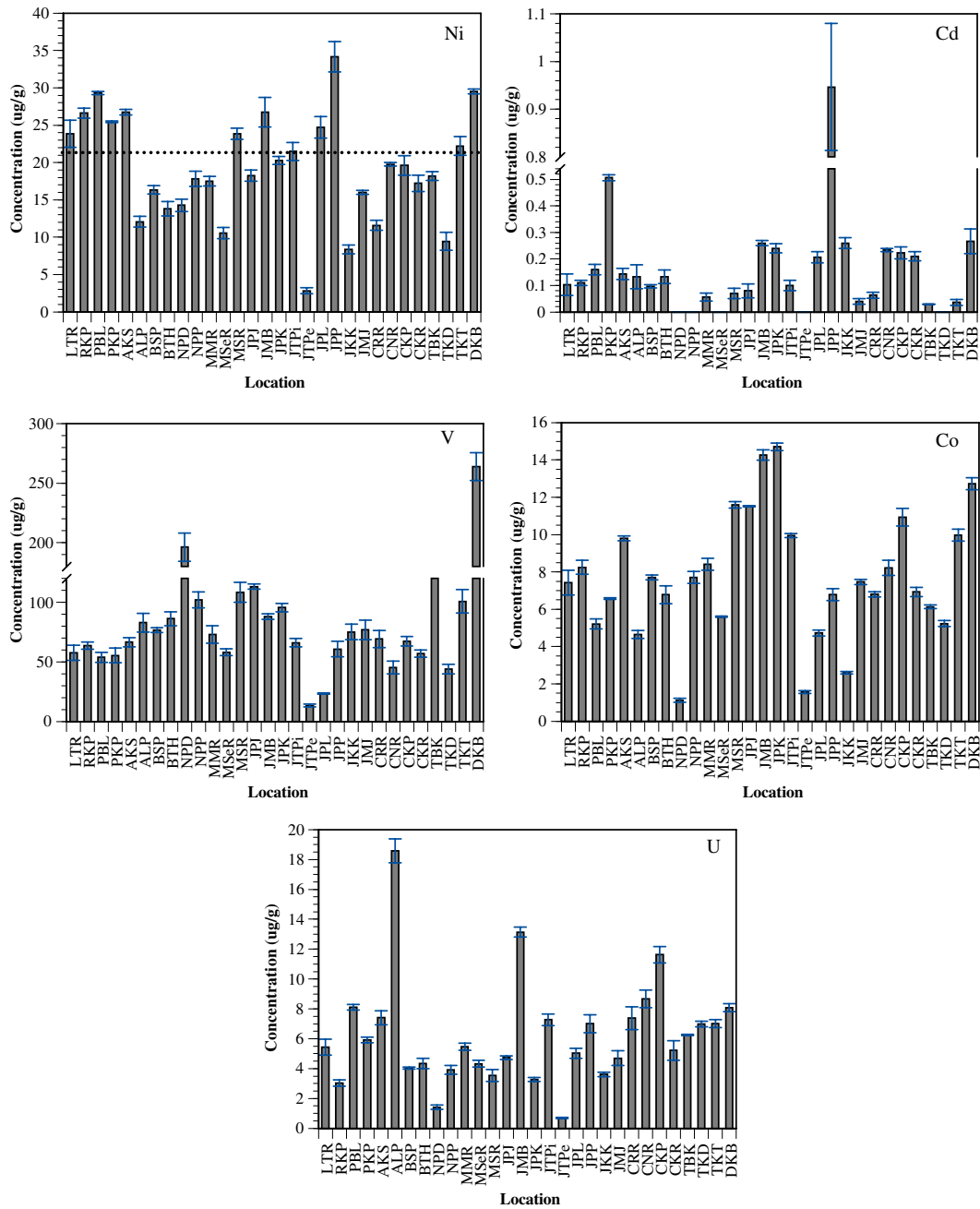


Fig. 2 Concentrations of Zn, As, Ag, Cr, Pb, and Cu in sampling locations along the Peninsular Malaysia coastline

that CCA is still be used illegally to treat the wood produced in the area. There is also a small possibility that As is derived from agricultural ac-

tivities, as it is sometimes used in insecticides and poisons used for control of pests and such threats. This study also found that 53% of sampling loca-



Note: ISQG – low

Fig. 3 Concentrations of Ni, Cd, V, Co, and U in sampling locations along the Peninsular Malaysia coastline

tions have an As concentration above the ISQG-low value but below the ISQG-high value, while another 8% were classified as As-clean areas. A comparison of As concentrations among the mar-

itime areas revealed the highest concentration was in SCS ($106.69 \pm 20.78 \mu\text{g/g}$) and the lowest in JSW ($10.06 \pm 10.86 \mu\text{g/g}$). Concentration of As in the SCS was significantly different from other

Table 5 Comparison of V, Cr, Co, Ni, Cu, Zn, As, Ag, Cd, Pb, and U concentrations ($\mu\text{g/g}$ dry weight) with other studies worldwide

Element	Peninsular Malaysia, Malaysia (this study, 2008)	San Francisco Bay, USA (Hwang et al. 2008)	North Sulawesi, Indonesia (Edinger et al. 2008)	Mangrove area, Singapore (Cuong et al. 2005)	Szczecin Lagoon, Poland (Glasby et al. 2004)	Florida Bay, USA (Caccia et al. 2003)	Straits of Johor, Malaysia (Wood et al. 1997)
V	12.10–276.46	90.1–122	25.8–182.4	–	34–59	34–411	23–119
Cr	11.16–207.04	135–241	8.3–51.9	9.38–39.74	–	60–347	13–66
Co	1.02–14.93	17.3–25.4	2.6–20.8	–	7.1–17	0.6–9.6	1.8–8.1
Ni	2.41–36.29	110–145	4.3–39.72	3.98–16.14	18–56	5–54	21–34
Cu	1.63–150.81	101–541	10.0–62.9	1.03–46.32	20–103	7–32	11–93
Zn	23.70–609.20	280–1,430	34.0–932.2	11.27–134.13	256–1,310	10–48	54–334
As	0.11–311.84	21.1–164	5.0–275.4	–	–	–	6.5–39.2
Ag	n.d.–27.27	0.70–1.73	–	–	–	–	–
Cd	n.d.–1.06	0.69–7.75	–	n.d.–0.44	1.2–6.3	–	0.08–0.34
Pb	7.97–93.11	218–750	2.5–12.0	7.10–37.14	42–167	3–15.7	19–160
U	0.65–19.50	–	–	–	1.6–3.7	–	2.8–7.0

n.d. not detectable

maritime areas ($p < 0.05$). However, there was no significant difference observed among the MS, JSW, and JSE locations.

Ag concentration varied between not detected (n.d.) and $27.27 \mu\text{g/g}$ (Fig. 2). Among the sampling locations, the highest average concentration of Ag was in PBL ($26.64 \pm 0.83 \mu\text{g/g}$), and Ag was not detected in JTPE. About 13% of the sampling locations were identified as having Ag concentrations above the ISQG-high value. The Ag concentrations in these locations differed significantly from those in other locations ($p < 0.001$). Generally, the Ag concentrations in these locations (PBL, MMR, PKP, and JPP) were derived from the active- and large-scale industrial activities (mainly electronics and semiconductors, manufacturing, chemicals production, etc.) in these areas. According to Wenger and Furrow (2000), pure silver has the highest electrical and thermal conductivities and the lowest contact resistance when compared with other metals. Therefore, many electrical and electronic products use Ag for its excellent properties related to power efficiency and data transmission, especially in printed circuits, soldering etc. Ag is also used in production of silverwares, photography, and as a catalyst in the manufacture of chemicals, production of battery, insecticides, and other products. Another 30% of the sampling locations were found to have Ag concentrations above the ISQG-low value but below the ISQG-high value. These areas are presumed to receive anthropogenic Ag from small to moderate scale industrial activities. The remaining 57% of the sampling locations could be classified as Ag-clean areas. Ag concentration did not differ significantly among the maritime areas ($p > 0.05$). This could be because only a few locations have a significantly high level of Ag concentration along the coastline of each maritime area.

Elements with concentrations lower than the ISQG-high values in some locations

In this study, Cr, Pb, Cu, and Ni were found to have concentrations above their ISQG-low values but lower than their ISQG-high values in some locations. The ISQG values for these elements are reproduced in Table 4.

Cr concentration ranged between 11.16 and 207.04 µg/g (Fig. 2). Among the sampling locations, the highest average concentration of Cr was in NPD (201.65 ± 5.07 µg/g) and the lowest in JTPe (12.55 ± 1.39 µg/g). About 13% of the sampling locations were found to have Cr concentration above the ISQG-low value but lower than the ISQG-high value. NPD was expected to have a high Cr concentration since it is one of the additive catalyst options in the production of gasoline (Speight 2007). Table 6 showed a strong correlation between Cr and V ($r^2 = 0.639$; $p = 0.01$) since V is one of the metals that have high concentration in crude oil (Merian 1991; Speight 2007). Cr also could be derived from the toxic CCA wood preservative since many old and new wooden structures (jetties, boats, houses, etc.) exist along the coastal areas of Peninsular Malaysia. A strong correlation emerged between Cr and As. These results suggest that the possible anthropogenic sources of Cr could be the petroleum refinery and CCA leachates from the wooden structures. In other areas of high Cr concentration, an increase in sea vessel traffic could have caused significant input of Cr into the aquatic environment due to oil spills, ballast cleaning, and other such activities. Moreover, several of these areas are located near the coal-based power plant. Hard and brown coals are reported to contain an average of 22 µg/g Cr. Combustion and improper disposal of coal ashes could contribute to the increase of Cr in surface sediments in the surround-

ing areas. Excessive usage of dyes and coloration without a proper disposal system might also have contributed a significant amount of Cr in one area (i.e., DKB). The remaining 70% of the sampling locations can be classified as Cr-clean areas. No significant differences in Cr concentration were observed among the maritime areas.

Pb concentration was found to range between 7.97 and 93.11 µg/g (Fig. 2). Among the sampling locations, the highest average concentration of Pb was in PKP (91.12 ± 2.00 µg/g) and the lowest in JTPe (8.65 ± 0.59 µg/g). The Pb concentration in about 53% of the sampling locations was above the ISQG-low but lower than the ISQG-high values. The concentration of Pb in the remaining 47% of sampling locations was below the ISQG-low value, and thus they could be classified as Pb-clean areas. The possible anthropogenic sources of Pb include the manufacture and use of batteries, cables, alloys, and chemicals; leaded fuel products; and the semiconductor industry and related industrial activities. Table 6 showed there was a positive correlation between Pb and a few elements used in industries (Ni, Cu, Zn, and Cd) suggests that industrial activities were the source of Pb. Moreover, land-based sources, particularly municipal wastes, were also expected to contribute significant amounts of Pb to the environment (DOE 2007). Meanwhile, JSW was significantly different from the other maritime areas ($p < 0.05$). This area is isolated from the main shipping route of MS and Singapore Strait. As for

Table 6 Correlation coefficients calculated for concentrations of selected trace elements in surface sediment along Peninsular Malaysia

	V	Cr	Co	Ni	Cu	Zn	As	Ag	Cd	Pb	U
V	1.000										
Cr	0.639 ^a	1.000									
Co	0.268 ^b	0.098	1.000								
Ni	0.187	0.317 ^a	0.520 ^a	1.000							
Cu	-0.131	-0.232 ^b	-0.275 ^a	0.290 ^a	1.000						
Zn	-0.182	-0.015	0.130	0.573 ^a	0.573 ^a	1.000					
As	0.592 ^a	0.760 ^a	-0.081	-0.107	-0.201	-0.201	1.000				
Ag	-0.082	-0.142	-0.065	0.262 ^b	0.461 ^a	0.090	-0.209 ^b	1.000			
Cd	-0.075	0.033	0.122	0.562 ^a	0.635 ^a	0.907 ^a	-0.165	0.099	1.000		
Pb	0.020	0.028	0.299 ^a	0.504 ^a	0.407 ^a	0.654 ^a	0.048	-0.108	0.660 ^a	1.000	
U	-0.003	-0.149	0.250 ^b	0.208 ^b	0.430 ^a	0.182	0.004	0.101	0.206	0.494 ^b	1.000

^aCorrelation is significant at the 0.01 level (two-tailed)

^bCorrelation is significant at the 0.05 level (two-tailed)

other maritime areas, no significant difference in Pb was found among them ($p > 0.05$). There was also no difference between findings of the present study and previous local studies (Ismail and Idris 1996; Ismail et al. 1993; Yap et al. 2003).

Concentration of Cu ranged between 1.63 and 150.81 $\mu\text{g/g}$ (Fig. 2). Among the sampling locations, the highest average concentration of Cu was in JPP ($146.99 \pm 3.86 \mu\text{g/g}$) and the lowest in JTPe ($2.03 \pm 0.43 \mu\text{g/g}$). In about 17% of the sampling locations, Cu concentrations were above the ISQG-low value. These areas (JPP, PBL, ALP, PKP, and JKK) differed significantly from the other locations ($p < 0.001$), with anthropogenic Cu being derived from an active coal-based power plant, industrial activities (particularly electronics), municipal wastes, agents in paints, shipyards, ports, and other sources (Ismail et al. 1993; Yap et al. 2002). In agriculture, Cu is used in fungicides, pesticides, algacides, nutritional supplements in animal feeds, and fertilizers (Ismail et al. 1995; Grant et al. 1990). Generally, there was no significant difference in Cu concentration in sediments among the other locations ($p > 0.05$). A comparison of the Cu average among maritime areas revealed that in JSE it was higher than and significantly different ($p < 0.001$) from that in others. No significant difference was observed among other maritime areas ($p > 0.05$). Findings of the present study did not differ from those of previous local studies (Ismail and Idris 1996; Ismail et al. 1993; Wood et al. 1997; Yap et al. 2002).

Meanwhile, Ni ranged between 2.41 and 36.29 $\mu\text{g/g}$ (Fig. 3). Among the sampling locations, the highest average concentration of Ni was found in JPP ($34.17 \pm 2.04 \mu\text{g/g}$) and the lowest in JTPe ($8.35 \pm 0.59 \mu\text{g/g}$). About 40% of sampling locations had Ni concentrations above the ISQG-low value. Ni concentrations in sediments at the remaining sampling locations (>60%) were found to be below the ISQG-low value. Most areas with high Ni content in sediments are situated in or near developed and industrial areas since Ni is used in many industrial and consumer products (e.g., stainless steel, coinage, magnets, and more than 3,000 alloys). Less significant but common events are coastal reclamations and sedimentation by laterite soils, which account for the high Ni

content of sediments in some areas. Based on geophysical evidence, Ni is probably derived from natural deposits in laterite soils with high principal nickeliferous limonite ore mineral (Aleva 1994; Schellmann 1983). A comparison of Ni concentrations among the maritime areas showed that there was no significant difference among them ($p > 0.05$).

Elements with no concentrations above the ISQG-low value or no ISQG values in any location

The concentrations of the remaining four elements (Cd, V, Co, and U) were found to be below the ISQG-low value or to have no ISQG values. Generally, Cd was found to range between n.d. and 1.06 $\mu\text{g/g}$ (Fig. 3). The highest average concentration of Cd among the sampling locations was in JPP ($0.95 \pm 0.13 \mu\text{g/g}$), and was not detectable in several locations. All locations could be classified as Cd-clean areas, since the Cd concentrations were below the ISQG-low value. On the whole, Cd concentration in JPP and PKP differed significantly from that of other locations ($p < 0.01$). This was probably because Cd is used as a stabilizer in petrochemical products (i.e., plastics and PVC), battery manufacture, solders, as coloring agent, and other applications. Presence of Cd was strongly correlated with that of Zn ($r^2 = 0.907$; $p = 0.01$) and thus showed a pattern similar to that of Zn in sediments. Among maritime areas, JSE was significantly different from other coastal areas ($p < 0.05$). No variation was found between findings of the present study and previous local studies (Ismail and Idris 1996; Ismail et al. 1993; Wood et al. 1997; Yap et al. 2002).

Concentration values for V were found to range between 12.10 and 276.46 $\mu\text{g/g}$ (Fig. 3). Among the sampling locations, the highest average concentration of V was in DKB ($263.94 \pm 11.78 \mu\text{g/g}$) and the lowest in JTPe ($13.34 \pm 1.18 \mu\text{g/g}$). Significantly, high V concentrations were also found in sediments of NPD. The main possible sources of V are petroleum and petroleum-related activities. Petroleum from Venezuela, Angola, California, and the Middle East contains more than 0.1‰V (up to 1‰; Speight 2007; Tissot and Welte 1984). Recent reports have shown more than 66 million

barrels of crude oil (mainly Dubai crudes) are being processed annually in these refinery complexes (Esso 2007; Shell 2007). A positive correlation was found between V and Cr ($r^2 = 0.639$; $p = 0.01$). It is likely that Cr is used as a catalyst and additive for gasoline production in the refinery. Areas with high boating and shipping activities also showed significant concentrations of V in sediments due to oil spills and water ballast discharges that had occurred in those areas. Comparison of V among the maritime areas revealed that in JSW was significantly different from the other maritime areas ($p < 0.05$), since its situation is remote and fewer sea vessels pass through it. In the other areas, no significant difference in V concentration was found among them ($p > 0.05$).

Co concentration in sediments ranged between 1.02 and 14.93 $\mu\text{g/g}$ (Fig. 3). Among the sampling locations, the highest average concentration of Co was in JPK ($14.70 \pm 0.20 \mu\text{g/g}$) and the lowest in NPD ($1.13 \pm 0.11 \mu\text{g/g}$). Co is usually lithogenic (Hansen et al. 1992). However, anthropogenic inputs of Co possibly derive from industrial and agricultural activities. Co was also reported to enhance the health of grazing and aquaculture animals since it functions directly and indirectly to develop and trigger some proteins (Kobayashi and Shimizu 1999). JPK is believed to have high concentrations of some essential trace elements including Co since large-scale aquaculture activities take place nearby. Co is also known for its pigmentation and coloring functions (Merian 1991). DKB and JMB are located in close proximity to textile industrial areas, and this accounts for the significant concentrations of Co in surface sediments. In the maritime areas, Co concentration in MS and SCS was found to differ significantly from that in JSW and JSE ($p < 0.05$). However, there were no differences within the respective pairs.

For U, concentrations were found to be between 0.65 and 19.50 $\mu\text{g/g}$ (Fig. 3). Among the sampling locations, the highest average concentration of U was found in ALP ($18.58 \pm 0.80 \mu\text{g/g}$) and the lowest in JTPe ($0.69 \pm 0.04 \mu\text{g/g}$). Significant amounts of U were also found in JMB and CKR. In this study, the measurement of U concentration was done as part of a national plan for establishing a civilian nuclear power plant and for the advancement of clinical technologies, biotech-

nology and nanotechnology. U measurement in the sediments of the coastal environment along Peninsular Malaysia was part of a preliminary study, although a general survey was conducted by Chu and Chand (1986). The east coast of Peninsular Malaysia is believed to have a significant unexploited U reserve. Some geologists are of the opinion that Malaysia may also have significant uranium reserves due to its geological similarities to other areas with reserves (Anonymous 2008c; Ramli et al. 2005). Technologies also exist for extracting U from sea water (JAERI 1999). The meeting point between land and sea could prove to be a potential U resource. Present data could provide useful information for future radiology studies of the coastal environment.

Developing a Malaysia interim sediment quality guideline

To date, no guideline for assessing sediment quality has been developed specifically for Malaysia. In this study, two sediment quality guidelines were used to determine the environmental status of particular areas as shown in Table 4. Recent studies have provided an improved understanding of the science underpinning sediment quality guidelines. However, there are still some limitations and uncertainties associated with the current approaches (Batley et al. 2003, 2005; Simpson and Batley 2003). The guidelines for the use of trace elements worldwide vary over several orders of magnitude and are not based on clear cause–effect relationships (Borgmann 2003; Chapman et al. 1999; Long et al. 1995; Simpson and King 2005).

Local legislative and government bodies in Malaysia usually refer to the Malaysia Interim Marine Water Quality Standard (DOE 2007), which includes only six in-situ parameters (temperature, pH, conductivity, salinity, dissolve oxygen, and turbidity). The other parameters such as total suspended solids, *Escherichia coli*, nitrate, total organic carbon, oil and grease, and selected heavy metals like Hg, Cd, Cr, Cu, Pb, and As in water samples collected from coastal and estuary areas were conducted in laboratories. Extensive studies of other parameters and wider range of trace elements should be conducted in the future to augment this guideline. In order to enhance the

monitoring program of the coastal environment, a specific ISQG for Malaysia should also be developed because a number marine and estuary biota are dependent on sediment substrates for survival. More importantly, any disturbance by sea current or through human activities will cause resuspension of sediment-bound trace elements into the water columns in the form of suspended solids or the likes and readily absorb by aquatic organisms. Study by Nayar et al. (2004) indicated intensive dredging, reclamation, construction, and shipping activities in Ponggol Estuary of Singapore (east of Johor Strait) may have led resuspension and bioavailability of particulate elements. This event could make the coastal environment unsuitable for survival of some biota. Praveena et al. (2008) claimed that among the ISQG available around the world, the Hong Kong ISQG is more suitable for use in the Malaysian environment since it meets prioritization criteria that are consistent with international initiatives and regulations. However, since a tropical area like Malaysia support a wide range of biota that react differently to pollution, a local ISQG should be established instead of using foreign guideline. Therefore, in order to establish a effective ISQG of Malaysia, further comprehensive and detail studies involving multiple components (biological data, toxicity, physico-chemistry) should be conducted using integrated approaches of various scientific fields.

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References

- Aleva, G. J. J. (1994). *Laterites: Concepts, geology, morphology and chemistry*. Wageningen: ISRIC.
- Anonymous (2008a). *Kapal di Selat Melaka perlu dihadkan*. Berita Harian (22 Oktober 2008). Page 1, Column 4.
- Anonymous (2008b). <http://www.iskandarmalaysia.com.my/>.
- Anonymous (2008c). <http://dkosopedia.com/wiki/Uranium>.
- ANZECC & ARMICANZ (2000). *Australian and New Zealand guidelines for fresh and marine water quality*. Canberra: Australian and New Zealand Environment and Conservation Council and the Agriculture and Resource Management Council of Australia and New Zealand (ANZECC & ARMICANZ).
- Apitz, S. E., Davis, J. W., & Finkelstein, K. (2005). Assessing and managing contaminated sediments: Part I. Developing an effective investigation and risk evaluation strategy. *Integrated Environmental Assessment and Management*, 1, 2–8.
- Batley, G. E., Humphrey, C. L., Apte, S. C., & Stauber, J. L. (2003). *A guide to application of the ANZECC/ARMICANZ water quality guidelines in the minerals industry*. Brisbane: Australian Centre for Mining Environmental Research (ACMER).
- Batley, G. E., Stahl, R. G., Babut, M. P., Bott, T. L., Clark, J. R., Field, L. J., et al. (2005). The scientific underpinnings the sediment guidelines. In R. Wenning, G. E. Batley, C. Ingersoll, & D. Moore (Eds.), *Use of sediment quality guidelines and related tools for the assessment of contaminated sediments*. Florida: SETAC.
- Blackmore, G. (1998). An overview of trace metal pollution in the coastal waters of Hong Kong. *Science of the Total Environment*, 214, 21–48.
- Borgmann, U. (2003). Derivation of cause-effect based sediment quality guidelines. *Canadian Journal of Fisheries and Aquatic Sciences*, 60, 352–360.
- Caccia, V. G., Millero, F. J., & Palanques, A. (2003). The distribution of trace metals in Florida Bay sediments. *Marine Pollution Bulletin*, 46(11), 1420–1433.
- Calmano, W., Hong, J., & Forstner, U. (1993). Binding and mobilization of heavy metals in contaminated sediments affected by pH and redox potential. *Water Science and Technology*, 28, 223–235.
- Chapman, P. M., Wang, F., Adams, W. J., & Green, A. (1999). Appropriate application of sediment quality values for metals and metalloids. *Environmental Science and Technology*, 33, 3937–3941.
- Chester, R., & Stoner, J. H. (1974). The distribution of zinc, nickel, manganese, cadmium, copper, and iron in some surface waters from the world ocean. *Marine Chemistry*, 2, 17–32.
- Chu, L. H., & Chand, F. (1986). *Status of uranium exploration in Peninsular Malaysia*. Kuala Lumpur: Geological Society of Malaysia, Bulletin 20.
- Chua, T. E., Gorre, I., Ross, A., Bernad, S. R., Gervacio, B., & Ebarvia, M. C. (2000). The Malacca Straits. *Marine Pollution Bulletin*, 41(1–6), 160–178.
- Cuong, D. T., Bayen, S., Wurl, O., Subramanian, K., Wong, K. K. S., Sivasothi, N., et al. (2005). Heavy metal contamination in mangrove habitats of Singapore. *Marine Pollution Bulletin*, 50, 1713–1744.
- DOE (2007). *Malaysia environmental quality report 2006*. Kuala Lumpur: Department Of Environment.
- Edinger, E. N., Azmy, K., Diegor, W., & Siregar, P. R. (2008). Heavy metal contamination from gold mining recorded in Porites lobata skeletons, Buyat-Ratototok district, North Sulawesi, Indonesia. *Marine Pollution Bulletin*, 56(9), 1553–1569.
- Esso (2007). *Annual report & accounts 2007*. Kuala Lumpur: Esso Malaysia Berhad.
- Fahlstrom, G. B., Gunning, P. E., & Carlson, J. A. (1967). Copper-chrome-arsenate wood preservatives: A study

- of the influence of composition on leachability. *Forest Products Journal*, 17(7), 17–22.
- Fisher, N. S., & Reinfelder, J. R. (1995). The trophic transfer of metals in marine systems. In: A. Tessier, & D. R. Turner (Eds.), *Metal speciation and bioavailability in aquatic ecosystems*. Cheshchester: Wiley.
- Glasby, G. P., Szefer, P., Geldon, J., & Warzocha, J. (2004). Heavy-metal pollution of sediments from Szczecin Lagoon and the Gdansk Basin, Poland. *Science of the Total Environment*, 330(1–3), 249–269.
- Grant, L. D., Elias, R., Nicholson, W., Goyer, R., & Olem, H. (1990). Indirect health effects associated with acidic deposition. In *State of science and technology (Report no. 23)*. Silver Spring: National Acid Precipitation Assessment Program (NAPAP).
- Hansen, A. M., Leckie, J. O., & Mee, L. D. (1992). Cobalt (II) interactions with near-coastal marine sediment. *Environmental Geology*, 19(2), 97–111.
- Hatji, V., Birch, G. F., & Hill, D. M. (2002). Spatial and temporal variability of particulate trace metals in Port Jackson Estuary, Australia. *Estuaries Coast Shelf Science*, 53, 63–77.
- Henningsson, B., & Carlsson, B. (1984). *Leaching of arsenic, copper and chrome from preservative-treated timber in playground equipment* (Document No. IRG/WP/3149). Stockholm: The International Research Group of Wood Preservation.
- Hwang, H.-M., Green, P. G., Higashi, R. M., & Young, T. M. (2008). Tidal salt marsh sediment in California, USA. Part 2: Occurrence and anthropogenic input of trace metals. *Chemosphere*, 64(11), 1899–1909.
- Ismail, A., & Idris, B. A. G. (1996). Lead, zinc and copper content in coastal sediments from the west coast of Peninsular Malaysia. *Malaysian Applied Biology*, 25, 37–39.
- Ismail, A., Badri, M. A., & Ramlan, M. N. (1993). The background levels of heavy metal concentration in sediments of the west coast of Peninsular Malaysia. *The Science of the Total Environment*, 134 (Supplement), 315–323.
- Ismail, A., Jusoh, N. R., & Idris, A. G. (1995). Trace metal concentrations in marine prawns off the Malaysian coast. *Marine Pollution Bulletin*, 31(1–3), 108–110.
- ISO (1995). *ISO 11466: Soil quality, extraction of trace elements soluble in aqua regia*. Geneva: International Organization for Standardization.
- JAERI (1999). *JAERI News FF no. 43 1999/4*. Chiba: Japan Atomic Energy Research Institute.
- Kobayashi, M., & Shimizu, S. (1999). Cobalt proteins. *European Journal of Biochemistry*, 261(1), 1–9.
- Law, A. T., & Singh, A. (1991). Relationships between heavy metal content and body weight of fish from the Kelang estuary, Malaysia. *Marine Pollution Bulletin*, 22(2), 86–89.
- Loganathan, B. G., Alexander, C., Chien, I. - L., & Sajwan, K. S. (2006). Temporal trends of inorganic elements in Kentucky Lake sediments. In: M. N. V. Prasad, K. S. Sajwan, & R. Naidu (Eds.), *Trace elements in the environment: Biogeochemistry, biotechnology and bioremediation*. Boca Raton: CRC.
- Long, E. R., MacDonald, D. D., Smith, S. L., & Calder, F. D. (1995). Incidence of adverse biological effects within ranges of chemical concentrations in marine and estuarine sediments. *Environmental Management*, 19(1), 81–97.
- Lovatelli, A. (1991). *Regional seafarming resources atlas* (Vol. II). Bangkok: FAO/UNDP Regional Seafarming Development and Demonstration Project (RAS/90/002).
- Macaulay, J. M., Summers, J. K., Engle, V. D., Heitmuller, P. T., & Adams, A. M. (1995). *Statistical summary: EMAP-Estuaries Louisianian Province—1993. EPA/620/R-96/003*. Florida: U.S. Environmental Protection Agency.
- Merian, E. (1991). *Metals and their compounds in the environment: Occurrence, analysis and biological relevance*. Weinheim: VCH.
- Nayar, S., Goh, B., & Chou, L. (2004). Environmental impact of heavy metals from dredged and resuspended sediments on phytoplankton and bacteria assessed in in-situ mesocosms. *Ecotoxicology and Environmental Safety*, 59, 349–369.
- Omar, I. (2004). *National report of Malaysia on the trans-boundary diagnostic analysis and preliminary framework of a strategic action programme for the Bengal (West coast of Peninsular Malaysia: Water-related concerns and environmental issues)*. Selangor: UPM Serdang.
- Praveena, S. M., Radojevic, M., Abdullah, M. H., & Aris, A. Z. (2008). Application of sediment quality guidelines in the assessment of mangrove surface sediment in Mengkabong Lagoon, Sabah, Malaysia. *Iranian Journal of Environmental Health Science and Engineering*, 5(1), 35–42.
- Ramli, A. T., Wahab, A., Hussein, M. A., & Wood, A. K. (2005). Environmental 238U and 232Th concentration measurements in an area of high level natural background radiation at Palong, Johor, Malaysia. *Journal of Environmental Radioactivity*, 80(3), 287–304.
- Schellmann, W. (1983). Geochemical principles of lateritic nickel ore formation. In *Proceedings of the international seminar on lateritisation processes*, São Paulo, pp. 119–135.
- Sgouridis, P. S. (2003). *The Malaysian transportation enterprise: Port report*. Massachusetts: Massachusetts Institute of Technology.
- Shazili, N. A. M., Hussein, M. L., & Rashid, M. K. A. (1997). Trace metal distribution in surface sediment from the Gulf of Thailand and the South China Sea. In *Proceeding of the 4th international conference on trace metals in the aquatic environment*, Kuala Lumpur, Malaysia.
- Shazili, N. A. M., Yunus, K., Ahmad, A. S., Abdullah, N., & Rashid, M. K. A. (2006). Heavy metal pollution status in the Malaysian aquatic environment. *Aquatic Ecosystem Health & Management*, 9(2), 137–145.
- Shell (2007). *Annual report 07*. Kuala Lumpur: Shell Refining Company.
- Simpson, S. L., & Batley, G. E. (2003). Disturbances to metal partitioning during toxicity test Fe(II)-rich estu-

- arine porewaters and whole-sediments. *Environmental Toxicology and Chemistry*, 22, 424–432.
- Simpson, S. L., & King, C. K. (2005). Exposure-pathway models explain casualty in whole-sediment toxicity tests. *Environmental Science and Technology*, 39, 837–843.
- Smith, D. N. R., & Williams, A. I. (1973). The effect of composition on the effectiveness and fixation of CCA and copper–chrome preservatives. Part II. Selective absorption and fixation. *Wood Science and Technology*, 7, 142–150.
- Speight, J. G. (2007). *The chemistry and technology of petroleum*. London: CRC.
- Tissot, B. P., & Welte, D. H. (1984). *Petroleum formation and occurrence* (2nd. ed.). Berlin: Springer.
- Valencia, M. J. (1979). South China Sea: Present and potential coastal area resource use and conflicts. *Ocean Management*, 5, 1–38.
- Wang, W. - X., & Fisher, N. S. (1999). Assimilation efficiencies of chemical contaminants in aquatic invertebrates: A synthesis. *Environmental Toxicology and Chemistry*, 18(9), 2034–2045.
- Wenger, G., & Furrow, R. (2000). Immersion Silver Surface Finishing: Usage requirement test results and production experience. In *Proceedings of the AESF SUR/FIN 2000*, Chicago, USA.
- Wood, A. K., Ahmad, Z., Shazili, N. A., Yaakob, R., & Carpenter, R. (1997). Geochemistry of sediments in Johor Strait between Malaysia and Singapore. *Continental Shelf Research*, 17(10), 1207–1228.
- Yap, C. K., Ismail, A., & Tan, S. G. (2003). Cd and Zn concentrations in the straits of Malacca and intertidal sediment of the west coast of Peninsular Malaysia. *Marine Pollution Bulletin*, 46, 1341–1358.
- Yap, C. K., Ismail, A., Tan, S. G., & Omar, H. (2002). Concentrations of Cu and Pb in the offshore and intertidal sediments of the west coast of Peninsular Malaysia. *Environmental International*, 28, 467–479.