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Distribution of heavy metals in surface sediments from the South China Sea ecosystem, Malaysia

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Abstract The concentrations of arsenic, cadmium, chromium, copper, mercury, nickel, lead and zinc in surface sediments collected from the east coast of peninsular Malaysia, along the South China Sea, were measured by two methods instrumental neutron activation analysis and inductively coupled plasma mass spectroscopy. The obtained results were use to determine the areal distribution of the metals of in the east coast of peninsular Malaysia and potential sources of these metals to this environment. The geochemical data propose that most of the metals found in the east coast of peninsular Malaysia constitute a redistribution of territorial materials within the ecosystem. Then, the metal concentrations can be considered to be present at natural background levels in surface sediments.

Keywords Heavy metal · Marine ecosystem · Surface sediments · Malaysia

Introduction

Natural environment pollution by heavy metals is a worldwide problem because these metals are not destructible, and most of them have toxic effects on concentration (MacFarlane and Burchett 2000; Dalman et al. 2006; Chen et al. 2007). Heavy metals affect on ecological system since they are not removed from water as a result of self purification but accumulate in sediments and enter the food chain (Loska and Wiechułła 2003). The occurrence of heavy metals in the environment results primarily from anthropogenic activities. The natural process, such as weathering of rocks and volcanic activities, plays a noticeable role on heavy metal concentrations in sediments (Farkas et al. 2007; Reddy et al. 2004). Heavy metal contamination in a marine coastal environment is related to sources of pollution in the adjacent estuaries and rivers. Heavy metals are mainly transported to the marine environment by rivers through estuaries. In most circumstances, the major contribution of anthropogenic heavy metals in a

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marine coastal area is of terrestrial origin, i.e., from agriculture industries and urban development and other human practices near rivers and estuaries (Morton and Blackmore 2001; Ip et al. 2007). In fact, during the last few decades, industrial and urban activities have contributed to the increase of heavy metals contamination into marine environment and have directly influenced the coastal ecosystems (Ong and Kamaruzzaman 2009). The aim of this study is to describe the distribution of heavy metals, to provide preliminary data on the environmental conditions and to evaluate the risks from heavy metal contamination.

Material and methods

Study area

Many meandering and slow flowing rivers and streams (Ong and Kamaruzzaman 2009) dissect the coastal waters in South China Sea. The largest river is the Pahang River which slightly over 434 km length and has a catchments area of about 29,137 km^2. Moreover, Kelantan River in the state of Kelantan has a catchments area about 11,900 km in northeast Malaysia including part of Taman Negara National Park. The main economic yield of this coastal water includes fishery resources with an utilizable mangrove forest resources and swamp peat areas along the backshore of the coast. These waters, which are shared by three developing countries namely Thailand, Indonesia and Malaysia, were important as an international shipping route especially for the northern countries such as Thailand, Vietnam, China, Taiwan, Japan and Korea which particular on logistic purpose.

Sampling

The samples were collected from 10 transects (30 sampling stations) in South China Sea East Coast coastal water (Fig. 1) with a standard poner grab sampler, which has a capability of collecting 8.2 L of sediments to obtain surface sediment. The sampling area was 23×23 cm^2. The sampler has a pair of weighted-tapered jaw scoops to minimize sediment washout during descent. This type of ponar grab dredge is practical for most of the sediment types from soft, fine grained to firm sandy material except hard-packed clay. When the scoops strike the bottom, their tapered cutting edges penetrate with very little sample disturbance. An

Fig. 1 Location of the surface sampling stations

attached under lip wipes the scoop clean of pebbles and cobble that would interfere when closing. Removable top screens with neoprene 75 flaps allow water to flow through scoops during descent, decreasing the risk of surface disturbance. The sampler was released three times approximately 1 m apart at the bottom to collect three sediment samples for each station. The Samples transferred into pre-cleaned and pre-weighed polyethylene bottles and refrigerated at −5°C, thus preventing any movement of the elements in the samples when kept at ambient temperature.

Analytical method

Sample preparation for instrumental neutron activation analysis

The samples were weighted approximately 0.05 to 0.1 g for short irradiation and 0.15–0.20 g for long irradiation (USEPA 2001). The samples and the standard reference material IAEASoil-7 were then irradiated with thermal neutron flux of 4×10^{12} cm^{-2} s^{-1} 86 at the MINT TRIGA Mark II research reactor operated at 750 kW where a pneumatic transport facility was used. The irradiation, decay and counting times for short irradiation were 1, 20 and 5 min, respectively. For long irradiation, the samples irradiated for 6 h and counted for 1 h after a cooling time of 3 to 4 and 21 to 28 days.

Sample preparation for inductively coupled plasma atomic emission spectroscopy

The sediment sample were digested analyzed according to methodologies in literatures (Sen Gupta and Bertrand 1995; Yap et al. 2002; Defew et al. 2005) for total As, Cd, Cr, Cu, Hg, Ni, Pb and Zn. An inductively coupled plasma atomic emission spectroscopy (ICP-AES) was used, for the quick and precise determination of As, Cd, Cr, Cu, Hg, Ni, Pb and Zn in the digested sediment. The digestion method involved heating of 50 mg of a finely powdered sample in a sealed Teflon vessel in a mixture with a mixed acid solution (1.5 mL) of concentrated HF, HNO_3 and HCl. The Teflon vessels were kept at 150°C for 5 h. After cooling, a mixed solution of boric acid and EDTA (3 mL) was added and the vessel was again heated at 150°C for 5 h. After cooling at room temperature, the content of the vessel was transferred into a 10-mL polypropylene test tube and was dilute to 10 mL with deionized water. A clear solution without residue should be obtained at the last stage. The precision assessed by the replicate analyses was less than 3%.

Methods for estimating pollutant impact

Enrichment factor, geoaccumulation index and modified degree of contamination methods that are discussed in the following sections have been used to quantify the degree of metal enrichment in sediments, e.g. Ridgway and Shimmield (2002).

Enrichment Factor

A general estimating of the anthropogenic impact on sediments is calculation of a normalized enrichment factor (EF) for metal concentrations above uncontaminated background levels (Abrahim and Parker 2008; Dickinson et al. 1996; Hornung et al. 1989). The enrichment factor method normalizes the measured elemental concentrations with respect to a sample reference metal such as Fe, Sc or Al (Ravichandran et al. 1995). In this work, the *EF* is calculated according to the following equation:

$$\mathrm{EF} = \frac{\left(\frac{C_x}{C_{\mathrm{ref}}}\right)_{\mathrm{Sample}}}{\left(\frac{C_x}{C_{\mathrm{ref}}}\right)_{\mathrm{Average\ shale}}} \tag{1}$$

where $(C_x/C_{\mathrm{ref}})_{\mathrm{Sample}}$ is the sediment sample concentrations ratio of the heavy metal and Sc (or other normalizing element), while $(C_x/C_{\mathrm{ref}})_{\mathrm{Average\ shale}}$ is their concentrations in a suitable background or baseline reference material such as average shales (Salomons and Förstner 1984). If the enrichment factor for each element is equal or less than one means that the main source is natural and originally came from the crustal or marine while if the enrichment factor is much greater than one, it shows that the main source is anthropogenic contribution.

Geoaccumulation index

The geoaccumulation index (I_{geo}) is another estimating of the enrichment of metal concentrations above background or baseline concentrations (Müller 1969). This method assesses the degree of metal pollution in terms of seven enrichment classes based on the increasing numerical values of the index (Abrahim and Parker 2008). This index is calculated as follows:

$$I\text{geo} = \log_2[C_n/\,(1.5 \times B_n) \tag{2}$$

where C_n is the concentration of the element in the enriched samples, and B_n is the background or pristine value of the element. The factor 1.5 is introduced to minimize the effect of possible variations in the background values which may be attributed to lithologic variations in the sediments (Stoffers et al. 1986). Then, if the concentration of element in a sample is five times greater than the concentration of it in the background, the sample is extremely polluted. Müller proposed the following descriptive classes for increasing I_{geo} values in Table 1:

Table 1 Muller's classification for geoaccumulation index

I_{geo}value	Class	Qualification of sediment
≤ 0	0	Unpolluted
0–1	1	From unpolluted to moderately polluted
1–2	2	Moderately polluted
2–3	3	From moderately polluted to strongly polluted
3–4	4	Strongly polluted
4–5	5	From strongly polluted to extremely polluted
> 5	6	Extremely polluted

Modified degree of contamination

This method is based on the calculation contamination factor (Cf) values for each pollutant. However, the Cf needs that at least five surficial sediment samples be averaged for producing a mean pollutant concentration then is compared with a baseline pristine reference level, according to the following equation:

$$Cf = \frac{C_{\text{Sample}}}{C_{\text{Background}}} \tag{3}$$

where C_{Sample} and $C_{\text{Background}}$ respectively refer to the mean concentration of a pollutant in the contaminated sediments and the pre-industrial "baseline" sediments or average shales (Abrahim and Parker 2008). The numeric sum of the k specific contamination factors expressed the overall degree (Hakanson 1980) of sediment contamination (C_{d}) that comes in the following formula:

$$C_{\text{d}} = \sum_{i=1}^{k} Cf^i \tag{4}$$

The C_{d} is expressed a measure of the degree of overall contamination in surface layers in a particular core or sampling site. Moreover, all n species must be analyzed in order of calculating the correct C_{d} for the range of classes defined (Hakanson 1980). A modified and generalized form of the (4) equation to calculate of the overall degree of contamination are presented by Eq. 5 at a given sampling (Abrahim et al. 2005). The modified formula is generalized by defining mC_{d} as the sum of all the Cf for a given set of estuarine pollutants divided by the number of analyzed pollutants (Abrahim and Parker 2008). The modified equation for a generalized approach to calculate the degree of contamination is given below:

$$\text{m}C_{\text{d}} = \frac{\sum_{i=1}^{n} Cf^i}{n} \tag{5}$$

where n and i, and Cf are number of analyzed elements, ith element (or pollutant) and contamination factor, respectively. Using this generalized formula to calculate the mC_{d} allows the incorporation of as many metals as the study may analyze with no upper limit (Abrahim and Parker 2008).

Table 2 (Hakanson 1980) classification of the modified degree of contamination

mC_{d} values	Qualification of sediment
$\text{m}C_{\text{d}} < 1.5$	Nil to very low degree of contamination
$1.5 \leq \text{m}C_{\text{d}} < 2$	Low degree of contamination
$2 \leq \text{m}C_{\text{d}} < 4$	Moderate degree of contamination
$4 \leq \text{m}C_{\text{d}} < 8$	High degree of contamination
$8 \leq \text{m}C_{\text{d}} < 16$	Very high degree of contamination
$16 \leq \text{m}C_{\text{d}} < 32$	Extremely high degree of contamination
$\text{m}C_{\text{d}} \geq 32$	Ultra high degree of contamination

(Abrahim and Parker 2008)

Table 3 Comparison of determined concentrations of heavy metals in the IAEA-Soil-7 by two INAA and ICP-AES methods with the certified values

Elements	Certified values	Measured values by INAA	Recovery (%)	Measured values by ICP-AES	Recovery (%)
As	13.4	13.99	104.4	14.9	111.2
Cd	1.3	–[a]	–[a]	0.3	433.0
Cr	60	52.8	88	54.7	91.2
Cu	11	–[a]	–[a]	9.5	86.4
Fe%	2.57	2.6	101.2	3.5	136.1
Hg	0.04	–[a]	–[a]	0.05	125
Ni	26	–[a]	–[a]	31	119.2
Pb	60	–[a]	–[a]	82.3	137.5
Zn	104	114.9	110.5	–[a]	–[a]

[a] The elements did not calculated by the related method

Table 2 shows the mC_d to classify and descript of estuarine sediments.

Quality assurance and quality control

In this study, triplication of the analysis samples, the blank samples and the certified reference material such as IAEA-Soil-7 and IAEA-SL-1 have been used for quality control procedures. Also, a routinely daily checking such as checking the energy calibration of the gamma spectroscopy system had been applied. The mean of the results of the three analyses were calculated in the overall analytical results and the recovery in many elements is about 100% except for Cd (Table 3). Furthermore, the accuracy and precision of two methods INAA and ICP-AES were ensured by analyzing certified reference material such as IAEA-Soil-7, IAEA-SL-1 and two standard solutions along each batch of samples in each method.

Results and discussion

Table 4 shows the concentration of As, Cd, Cr, Cu, Hg, Ni, Pb and Zn in surface sediment of the east coast of peninsular Malaysia (Fig. 1). The results are expressed as mg of metal extracted per kg of dry sediment and the mean value of three replicates. IAEA-Soil-7 standard reference material was analyzed in parallel with metal determination to assess the accuracy of methodology, which the measured metal content was consistent with those certificate values, the recoveries for elements were between 86.4 to 137.2.

Table 4 Heavy metal concentrations, in mg/kg, measured in the surface sediments of the east coast of Peninsular Malaysia

Station	As	Cd	Cr	Cu	Hg	Ni	Pb	Zn
EC6	22.4 ± 1.7	0.4 ± 0.05	79.2 ± 27.7	16.8 ± 1.4	0.13 ± 0.06	23.7 ± 0.8	64.8 ± 4.5	79.5 ± 5.6
EC7	9.7 ± 2.2	0.2 ± 0.0	32.4 ± 1.9	5.9 ± 0.4	0.1 ± 0.0	21.6 ± 2.7	25.5 ± 7.4	52.2 ± 4.1
EC8	7.3 ± 4.1	0.1 ± 0.05	39.2 ± 5.0	4.6 ± 1.4	0.1 ± 0.0	19.3 ± 7.1	20.9 ± 7.9	40.6 ± 10.0
EC9	14.3 ± 4.4	0.2 ± 0.06	39.5 ± 5.1	7.6 ± 1.0	0.1 ± 0.0	17.3 ± 5.1	27.8 ± 9.3	52.7 ± 11.2
EC10	15.4 ± 2.9	0.2 ± 0.05	35.9 ± 3.8	6.9 ± 1.1	0.1 ± 0.0	16.2 ± 2.1	31.9 ± 9.7	55.5 ± 13.6
EC11	7.1 ± 5.2	0.2 ± 0.05	35.9 ± 4.0	6.2 ± 2.1	0.1 ± 0.0	15.7 ± 0.8	28.4 ± 4.0	52.8 ± 4
EC12	25.2 ± 2.6	0.3 ± 0.0	48.4 ± 1.9	15.1 ± 0.6	0.1 ± 0.0	22.2 ± 3.1	49.3 ± 12.2	4.4 ± 0.2
EC13	25.5 ± 0.3	0.33 ± 0.05	46.8 ± 1.2	15.2 ± 0.8	0.1 ± 10.0	22.5 ± 2.4	62.3 ± 5.1	74.5 ± 6.4
EC14	7.3 ± 1.1	0.2 ± 0.0	60.0 ± 6.5	6.3 ± 0.4	0.1 ± 0.0	22.0 ± 3.2	26.1 ± 4.1	8.4 ± 0.6
EC15	14.4 ± 4.6	0.3 ± 0.0	57.2 ± 6.6	8.7 ± 1.3	0.1 ± 0.1	19.5 ± 4.1	37.2 ± 6.9	11.5 ± 1.3
Average	14.9	0.25	46.4	9.3	0.1	20.1	37.4	44.3
CV	50.8	30.6	30.9	48.4	18.5	20.5	44.1	59.4

Variation of heavy metals in the surface sediments

Analysis of marine sediment from Kelantan, Pahang and Rompin areas had shown an elevated As level of order of 25 mg/kg in sediment sample from the rivers mouth areas, while in the samples slightly away from the rivers mouth areas the As concentrations varied of order of 7 mg/kg. The values ranged from 1.5 to 27.6 mg/kg for sediments estuaries with an average 14.3 mg/kg. Cd shows a homogeneous distribution in all surface sediments by an average concentration 0.25 mg/kg. The maximum concentration of Cd is observed in the near Kelantan river mouth with 0.4 mg/kg. The concentration of Cr is ranging from 30.2–98.9 mg/kg with an average 46.4. The highest concentration of Cr is found in the Kelantan river mouth. The concentration of copper varies from 3.0 to 18.0 mg/kg with an average of 9.3 mg/kg in the surface marine sediments. The areas close to the large rivers recorded the highest values of Cu. The behavior of Ni is similar in all the surface samples and the concentration of Ni is varying from 11.7–27.4 mg/kg with a 20.0 mg/kg average. The concentration of Pb in the surface sediments is varying from 14.7 to 69.0 mg/kg in the Kelantan mouth and a mean Pb content of 37.4 mg/kg. It shows a relative higher concentration in the areas of the east coast where are located the large rivers mouth such as Kelantan, Pahang and Rompin rivers. The concentration of Zn in the surface sediments in this study is ranging from 4.3–85.1 mg/kg and averaging 44.3 mg/kg. The maximum concentration of Zn is 85.1 mg/kg in the Kelantan river mouth. The Hg heavy metal also is investigated in the surface marine sediments and has homogenous behavior in the studied area with an average concentration 0.1 mg/kg.

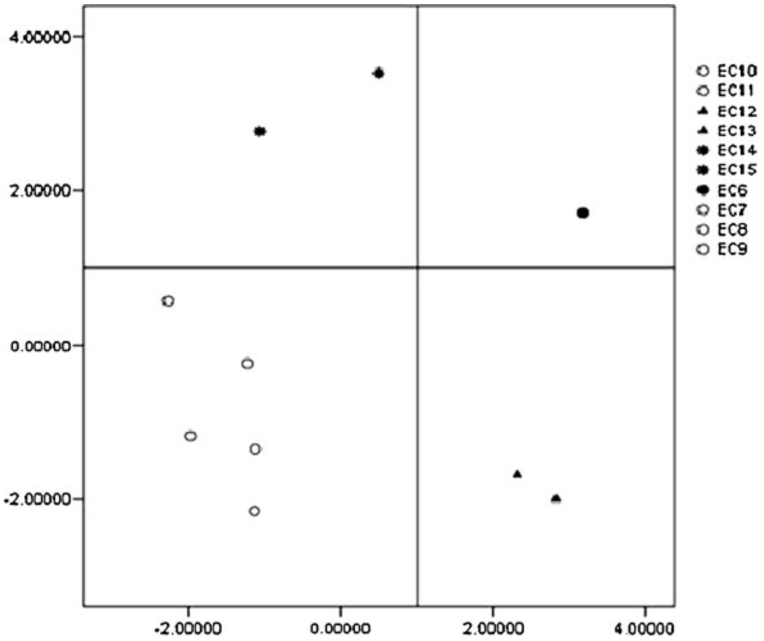
Principal component analysis

Principal component analysis has been carried out on the raw data of total heavy metals. This kind of analysis allows reducing the number of variables to be considered for a complete description of the data variability. This is accomplished through the diagonalization of the metal correlation matrix. The matrix eigenvectors are the new variables, while the ratio of the single eigenvalue to their sum represents the relative amount of the total variability it is able to describe. The first two (out of five) principal components are found to describe about 88.6% of the total variability (74.0% for the first one, and 14.6% for the second one). Moreover, seven of the original variables (the heavy metal concentrations) are found to have similar projection values on the first two principal components, while Cu (the first component) stand alone from this point of view. This suggests that Cu sources are different from those of the other elements. In Fig. 2, the position of the sampling sites in the plane is defined by the first two principal components. The meaning of the different symbols used in this plot will be explained below. It is worth noticing that sites EC6 are located close to the Kelantan mouth and show the highest values of Cu concentration ratios with respects to other elements. Sites located at negative values of both components are those showing the lowest values of Cu concentrations (Fig. 2). Figure 2 clearly shows that the east coast of Peninsular Malaysia can be divided into two groups, the first group is those near the large river mouth (Kelantan, Pahang and Rompin rivers) that are located in the second column and the other part is those near the small or the nil river mouth that are located in the first column.

Enrichment factor

The heavy metals can be divided into two groups, anthropogenic and non-anthropogenic heavy metals, and it is important to note that this division is based on the enrichment factor. The enrichment factor is a powerful tool to evaluate natural sediments from sediments that are released to the environment by anthropogenic activities. Al, Na, Fe and Sc are elements that generally are used to normalize element concentrations. The reasons for chosen these elements are that, Al is the second most abundant metal in earth's crust, is highly refractory moreover its concentration is not influenced by anthropogenic sources. Sc and Na are used to normalize element concentrations of marine origin and sea water respectively and Fe for heavy metals of this study is chosen for the correlation coefficient data in the studied sediments

Fig. 2 Surface sampling site distribution in the plane defined by the first two principal components 471 for heavy metals



indicates that Fe concentrations are generally not correlated to the other metals.

Normalized EF values were calculated using the continental shale abundance of Fe (4.8%) (Bowen 1979; Mason and Moore 1982; Turekian and Wedepohl 1961; IAEA-TCS-4 1992). In this study, the elements studied were proven to be deficient to minimal enrichment, with EF values were ranged from 0.4–1.5 for As and Cd; 0.1–0.4 for Cu; 0.2–0.9 for Cr; 0.2–1.0 for Hg; 0.1–0.5 for Ni; 0.5–2.6 for Pb and 0.3–1.4 for Zn (Fig. 3). This figure shows that the enrichment factor of lead in mouth Kelantan and Pahang Rivers is greater than two and is known as anthropogenic heavy metals in these stations; this is attributed to near these rivers to the main road of two big Kuantan and Pahang cities. The enrichment factor values of Cu, Cr, Hg and Ni for all stations are less than one; it shows that these heavy metals are non-anthropogenic.

Assessment results using geoaccumulation index and modified degree of contamination

Hakanson equation (Hakanson 1980) was used to calculate the mC_d for the nine analyzed elements

Fig. 3 EF of heavy metals in the surface sediments of the east coast of peninsular Malaysia, normalized with respected to the iron content in the continental shales

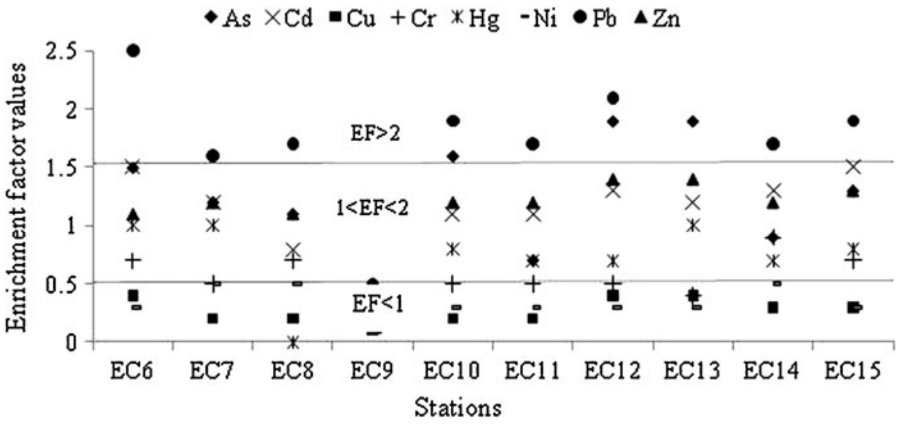


Table 5 Contamination factors, mC_d using average shale baseline values for heavy metals in the surface sediments of the east coast of Peninsular Malaysia

Station	Contamination			Factors					$\sum^{Cf}$	mC_d
	As	Cd	Cu	Cr	Hg	Ni	Pb	Zn		
EC6	1.7	1.8	0.4	0.8	0.0	0.3	2.8	2	9.8	1.1
EC7	0.8	0.9	0.1	0.3	0.0	0.3	1.1	1.3	4.8	0.5
EC8	0.6	0.4	0.1	0.4	–	0.3	0.9	0.9	3.6	0.4
EC9	1.1	0.9	0.2	0.4	0.0	0.3	1.2	1.4	5.5	0.6
EC10	1.2	0.9	0.2	0.4	0.0	0.2	1.4	1.4	5.7	0.6
EC11	0.5	0.9	0.1	0.4	0.0	0.2	1.2	1.3	4.6	0.5
EC12	1.9	1.4	0.4	0.5	0.0	0.3	2.1	2.1	8.7	1.0
EC13	2	1.4	0.4	0.5	0.0	0.3	2.7	2.2	9.5	1.0
EC14	0.6	0.9	0.2	0.6	0.0	0.3	1.1	1.2	4.9	0.5
EC15	1.1	1.4	0.2	0.6	0.0	0.3	1.6	1.7	6.9	0.8

(As, Cd, Cu, Cr, Hg, Ni, Pb and Zn). It is so abstruse to determine B_n values of marine sediments gathering along east coast of Peninsular Malaysia, because geochemical variability of various area and different anthropogenic activities. For determining B_n values in this study, the concentration of average shales is chosen (Turekian and Wedepohl 1961). The mC_d has been calculated for each element and the results are shown in Table 5. The mC_d for the individual stations generally lies in the range 0.4–1 as shown in Table 5. The mC_d data indicate nil to very low degree of contamination in all sampling station.

I_{geo} has been calculated and the results are shown in Table 6. This table shows for all heavy metals As, Cd, Cu, Cr, Hg, Ni, Pb, Se and Zn using average shales background value, 100% of samples fall in class 0 and class 1 then the east coast of Peninsular Malaysia is not a contamination area for these elements. In conclusion, geoaccumulation index allows us to deduce the east coast peninsular Malaysia is an uncontaminated or moderately contaminated area for heavy metals because the average I_{geo} class is 0–1 indicating uncontaminated to moderately contaminated levels. Details of the I_{geo} values for individual elements in the ten sampling stations are presented in Table 6. The negative I_{geo} values found in the table are the results of relatively low levels of contamination for some metals in some marine sediments and the background variability factor of 1.5 in the I_{geo} equation.

Table 7 shows comparison of means and ranges of the heavy metals in the surface sediments of the east coast of Peninsular Malaysia with those of the Straits of Malacca, Johor and the Penang Island (Wood et al. 1997, 2004; Al-Zahrany and Saion 2007). By comparison, between the average

Table 6 I_{geo} of heavy metals in the surface sediments compared to the average shale baseline values

Station	Index of I_{geo}								I_{geo} Class
	As	Cd	Cu	Cr	Hg	Ni	Pb	Zn	
EC6	0.2	0.3	−1.8	−0.9	−4.8	−2.1	0.9	−0.2	0–1
EC7	−0.8	−0.7	−3.3	−2.2	−5.6	−2.2	−0.4	−0.8	0
EC8	−1.4	−1.7	−3.4	−1.9	–	−2.4	−0.7	−1.3	0
EC9	−0.4	−0.7	−2.9	−1.9	−6.0	−2.5	−0.3	−0.8	0–1
EC10	−0.3	−0.7	−3.1	−2.1	−5.8	−2.6	−0.1	−0.7	0
EC11	−1.4	−0.7	−3.2	−2.1	−6.0	−2.7	−0.3	−0.9	0
EC12	0.4	−0.3	−1.9	−1.6	−5.3	−2.2	−0.5	−0.1	0–1
EC13	0.4	−0.1	−1.9	−1.6	−5.2	−2.2	0.9	−0.1	0–1
EC14	−1.3	−0.7	−3.2	−1.3	−6.3	−2.2	−0.4	−1	0
EC15	−0.4	−0.3	−2.7	−1.4	−5.6	−2.4	0.1	−0.4	0

Table 7 Mean and range of heavy metal concentrations (mg/kg dry weight) in the surface sediments of the east coast of Peninsular Malaysia with those in Straits of Malacca, Straits of Johor, Pinang Island, average shales and crustal material

Element	As	Cd	Cr	Cu	Hg	Ni	Pb	Zn
Our work	15.0	0.2	49.1	9.3	0.1	20.1	37.3	44.3
Range	7.1–25.5	0.1–0.4	35.9–79.2	4.6–16.8	0.5–5	15.9–24.0	20.9–64.8	4.4–79.5
Malacca[b]	8.15	0.14	52.6	13.6	nd	26.9	39.2	72.9
Range	2.1–21.9	0.0–0.5	23.3–86.5	7.8–21.4	nd	10.0–41.9	15.2–64.8	32.0–119.2
Johor[c]	19.7	0.2	45.2	30.7	nd	30.2	42.3	132.5
Range	6.4–64.0	0.1–0.4	21.9–62.8	10.8–92.9	–	21.2–46.8	26.4–69.9	68.5–230.7
Pinang[d]	6.2	0.1	46.6	17.2	nd	32.6	27.4	60.1
Range	3.2–8.1	0.0–0.2	11.5–59.6	9.3–43.0	nd	19.2–44.0	17.3–35.5	36.7–83.7
Mean crustal[e]	1.5–1.8	0.1–0.2	100	50–55	nd	75–80	13–14	70–75
Average shales[e]	13	0.22	90	39.0	0.12	68	23	120

nd not detectable

[b] Al-Zahrany and Saion (2007)

[c] Wood et al. (1997, 2004)

[d] Wood et al. (2004)

[e] Bowen (1979); Mason and Moore (1982); Turekian and Wedepohl (1961); IAEA-TCS-4 (1992)

concentrations of the total heavy metals among the obtained results of the different coasts, the east coast has the minimum average concentrations of total heavy metals. However, The concentrations of As is higher when compared with straits of Malacca and island of Pinang because the east coast of peninsular Malaysia covered by agriculture industry, fertilizer in agriculture include arsenic. The high concentration of Cd is attributed to the sewage that comes from cities along the east coast of Peninsular Malaysia. Moreover, the results are compared to the average shales and mean crustal material values published in different references (Bowen 1979; Mason and Moore 1982; Turekian and Wedepohl 1961; IAEA-TCS-4 1992). Among the heavy metals, Cd, Cr, Hg, Ni, Se and Zn have concentrations less than average shales.

The maximum concentration of each heavy metal is compared with Probable effect levels of Canadian Sediment Quality Guidelines for the Protection of Aquatic Life, sever effect level of Technical Guidance for Screening Contaminated Sediments (New York) and maximum permissible concentration of Australian and New Zealand Guidelines for Fresh and Marine Water Quality and clearly all heavy metal concentrations of the east coast of Peninsular Malaysia are less than probable effect level in this guideline as a result of this comparison it is concluded that the east coast of Peninsular Malaysia is a clean area.

Conclusion

The results obtained in this study provide an overview of selected heavy metal concentrations within surface sediments from the east coast of peninsular Malaysia, along the South China Sea. These are of great importance considering the limited data on metal concentrations within this area.

No the surface sediments exhibit detectable levels of cadmium, presumably because of the low background levels within the underlying rocks. This is important given that cadmium is extremely toxic, even at very low concentrations (Andrade et al. 2001). In contrast, high lead and arsenic concentrations have been recorded in the studied sediments of the mouth of Kelantan, Pahang and Rompin rivers; considering the input of the whole related freshwater system that come from automotive emission and agriculture industries.

Finally, it is important to recognize that the concentrations of arsenic, cadmium, chromium, copper, mercury, nickel, lead and zinc as recorded in the studied surface sediments of the east coast of peninsular Malaysia constitute the natural background levels of the system.

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