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Spatial Distribution of Heavy Metals in Tropical Coastal Sediment of the Northern Malacca Strait, Malaysia

Hasrizal Shaari*(**)†, Nur Sakinah Abdul Razak*, Wan Mohd Afiq Wan Mohd Khalik*, Noor Azhar Mohamed Shazili and Joseph Bidai****

*School of Marine and Environmental Sciences, Universiti Malaysia Terengganu, 21030 Kuala Nerus, Malaysia
**Institute of Oceanography and Environment, Universiti Malaysia Terengganu, 21030 Kuala Nerus, Malaysia
†Corresponding author: Hasrizal Shaari

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ABSTRACT

Spatial distribution of eight heavy metals (Al, Fe, Mn, Zn, Pb, Cu, Co, Cd) in surface sediments of northern Malacca Strait were investigated. Samples were taken from 18 stations in June, 2013. The concentrations of metals ranged between 1.70-5.75% (Al), 1.13-3.19% (Fe), 117.53-323.19 µg/g (Mn), 30.14-79.42 µg/g (Zn), 8.88-29.28 µg/g (Pb), 3.51-16.58 µg/g (Cu), 2.16-5.93 µg/g (Co) and 0.00-0.50 µg/g (Cd). The mean concentrations of the studied metals were in decreasing order as follows: Al > Fe > Mn> Zn > Pb > Cu > Co > Cd. Higher concentrations were found in the nearshore area of Kuala Kedah, Kuala Perlis and Langkawi Island. Pearson correlation explicates that most metals are predominantly from the assortment sources. Based on the enrichment factor value, all metals, except Pb, fall in the category of deficiency to minimal enrichment. Geoaccumulation index and pollution load index revealed that this area was not polluted with the studied metals. This work is vital to disclose the status of heavy metal sink to surficial sediment, thus any changes in concentration are easily monitored and appropriately managed.

INTRODUCTION

Heavy metal contamination is one of the serious global issues that were highlighted in various ecosystems. Naturally, heavy metals exist at low concentrations (Turekian & Wedepohl 1961, Wedepohl 1995), but the anthropogenic sources lead their increment in our environment (Cobela-Garcia & Prego 2003, Shaari et al. 2015, Sunderland 2000, Zhang & Liu 2002). Over the past few decades, the spatial or temporal distribution of heavy metals in marine environment was ubiquitously reported (Denton et al. 2005, Loska et al. 2004, Marchand et al. 2006, Muller 1981, Wood et al. 1997). This situation indicates that the monitoring work in the marine environment, dealing in metal enrichment, remains relevant and the interest is ongoing. The enrichment of metals is well known in giving negative effects towards ecosystems and organisms, especially in the aquatic environments.

In case of the Malaysian coastal area, distribution and pollution status of heavy metals in surface sediment are well-documented (Kamaruzzaman et al. 2004, Kamaruzzaman et al. 2011, Shazili et al. 1999, Siaon et al. 2007, Yap et al. 2003, Yap & Pang 2011, Zahir et al. 2012). Major contribution is linked to heavy exercise of metal-based industries. In fact, metal is one of the pollutants listed in the Malaysian freshwater or marine water quality criteria. However, scientific reports on heavy metal enrichment in surface sediment of northern Malacca Strait are still limited, and previous literature is focused on specific location, either river, estuarine (Jamil et al. 2014, Lias et al. 2013, Yap & Pang 2011) or coastal area of Langkawi Island (Kamaruzzaman et al. 2011, Zahir et al. 2012). Besides, the limitations of previous reports also identified that only anthropogenic metal was used as the model target study. This situation has created a knowledge gap regarding the distribution of other metals in the coastal area of Langkawi Island-Kuala Perlis-Kuala Kedah.

Literature studies have successfully pointed out that the concentration levels of heavy metals in sediment were remarkably used as an indicator for environmental status monitoring (Corbelo-Garcia et al. 2003, Idris et al. 2009, Muohi et al. 2003, Usero et al. 2003, Tomlinson et al. 1980). Thus, the aim of this study is to evaluate the distribution, via spatial variation and pollution status, of eight heavy metals in surface sediment taken from the northern side of Malacca Strait.

MATERIALS AND METHODS

Sample collection and preservation: Surface sediments were collected from 18 sampling stations in June 2013. Samples were taken by using Ponar Grab sampler. Water depth level was measured between 1.9 metres and 21.7 metres. The coordinate and location for each station are provided in Table 1 and Fig. 1, respectively. Samples were kept in a cleaned acid-treated plastic container with temperature controlled at 4°C before being transferred to laboratory. In laboratory, samples were oven-dried at 50°C and homogenised, before further chemical analysis.

Heavy metal analysis: Sample digestion was followed from published methods reported by Noriki et al. (1980) and Kamaruzzaman (1999) with the modification of mixed acid ratio and digesting temperature. In general, an approximately 0.05 g of homogenised samples were digested in concentrated mixed acid of HF, HNO_3 and HCl (2: 3.5: 3.5) in a sealed Teflon vessel at 100°C for 7 hours. After cooling at room temperature, a clear digested solution was transferred into 15 mL polypropylene test tube, followed by dilution with deionised water. An inductively coupled plasma mass spectrometer (ICP-MS) was used for quantitative analysis of heavy metals. The accuracy of analytical procedure was examined by analysing a standard research material NBS 1646a in duplicate.

Environmental index assessment: Enrichment factor (EF), geoaccumulation index (Igeo) and pollution load index (PLI) were applied to distinguish the degree of contamination and source of pollution in surficial sediment (Muohi et al. 2003, Shaari et al. 2015). All indexes used in this study are well established and reported every where as strong tools to determine the status and sources of pollution in various environments. Enrichment factor is widely used as an indicator for the status of marine sediment pollution in Malaysia (Kamaruzzaman et al. 2004, Shaari et al. 2015). In this study, the average value of metals in shale proposed by Turekian & Wedepohl (1961) was used as the background metal contents. Aluminium was used as a reference element due to its conservative characteristic (Kamaruzzaman et al. 2010).

The EFs were calculated by using the equation proposed by Sutherland (2000). Geoaccumulation index was generally used to compare the status of heavy metal concentration with the background values. The index value can depict the relation between measured metal in the sediment fraction and geochemical value in fossil argillaceous sediment or shale content (ATSDR 2008). Igeo was computed by using the formula previously published by Müller (1969). Pollution load index is widely used as a simple comparative way to evaluate the degree of pollution by heavy metal in marine sediments (Loska et al. 2004, Shaari et al. 2015). The index is derived from the contamination factor (CF). The detailed formula is as described in literature (Muller 1981).

Identifying the source of pollution was recognised by using principal component analysis through Eigen decomposition method. Factor analysis was applied to extract the latent information. The interpretation and analysis were conducted by using a statistical software Minitab Version 17 (Minitab Inc., State College, USA).

Table 1: The coordinates of each sampling points.

Station	Depth (m)	Latitude (N)	Longitude (E)
LKW1	1.9	6°23.858'	100°7.136'
LKW2	2.1	6°23.347'	100°6.903'
LKW3	3.9	6°22.834'	100°6.023'
LKW4	4.9	6°21.917'	100°5.003'
LKW5	8.2	6°21.000'	100°3.504'
LKW6	16	6°20.016'	100°2.183'
LKW7	16.4	6°18.760'	100°0.042'
LKW8	15	6°17.252'	99°57.127'
LKW9	6.8	6°12.444'	99°54.925'
LKW10	11.5	6°4.238'	99°52.759'
LKW11	16.2	6°12.931'	99°57.839'
LKW12	19.4	6°12.231'	99°58.125'
LKW13	16.7	6°11.110'	100°1.179'
LKW14	20.6	6°9.729'	100°4.246'
LKW15	18.8	6°9.265'	100°6.716'
LKW16	21.7	6°8.628'	100°9.519'
LKW17	20	6°7.227'	100°12.363'
LKW18	7	6°6.176'	100°15.150'

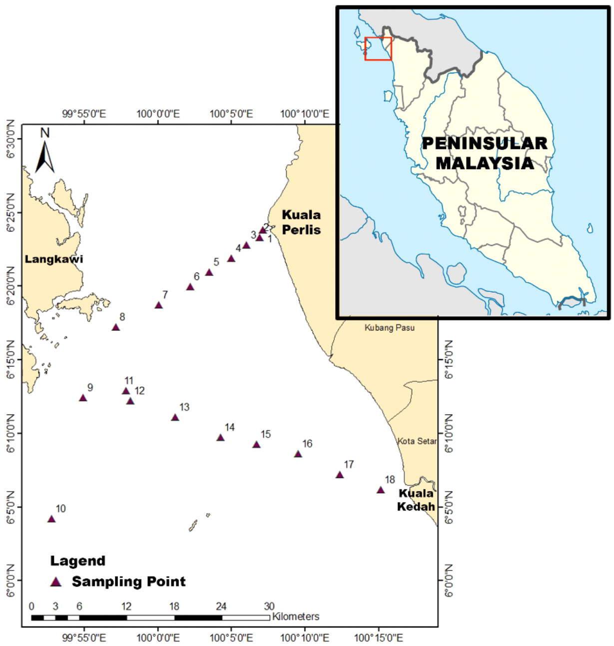

Fig. 1: Location of sampling points in the northern Malacca straits.

RESULTS AND DISCUSSION

Concentration levels of heavy metals: The recovery test in this study coincided with the certified values of NBS 1646a

Table 2: The value of accuracy analysis for standard reference.

Metals	NBS1646a (µg/g)	Measured Value (µg/g)	Accuracy Test (%)
Al	2.297	2.2	95.78
Fe	2.008	1.66	82.67
Mn	234.5	181.57	77.43
Zn	48.9	35.68	72.97
Pb	11.7	8.41	71.88
Cu	10.01	8.72	87.11
Co	5	5.08	101.60
Cd	0.148	0.13	87.84

(Table 2). The precision test for eight heavy metals was ranged from 71.88% to 101.60%. The concentration levels of the studied metals in the study area were ranged from 117.53 µg/g to 323.19 µg/g (Mn), 30.14 µg/g to 79.42 µg/g (Zn), 8.88 µg/g to 29.28 µg/g (Pb), 3.51 µg/g to 16.58 µg/g (Cu), 2.16 µg/g to 5.93 µg/g (Co), not detected to 0.50 µg/g (Cd), 1.13% to 3.19% (Fe) and 1.70% to 5.75% for aluminium. The mean concentrations of the studied metals were in decreasing order as follows: Al > Fe > Mn > Zn > Pb > Cu > Co > Cd.

Distribution pattern of heavy metals: Pearson correlation matrix was used to define the relation between the studied metals (Table 3). Five strong correlations were shown between the elements like Fe-Pb (r = 0.88), Fe-Co (r = 0.86), Fe-Mn (r= 0.81), Pb-Co (r = 0.88), Pb-Mn (r = 0.85), Mn-Co (r = 0.81). While, five moderate correlations were shown between Al-Pb (r = 0.72), Al-Cu (r = 0.61), Co-Cu (r = 0.61) and Cu-Cd (r = 0.65). Most studied metals showed a strong or moderate correlation, except for Cd. Hossain et al. (2015) suggested that metals in sediments originate from similar sources if they exhibit strong correlations. Thus, the finding gives an idea that most of the studied metals are considered to originate from similar sources.

Aluminium concentration was found slightly higher adjacent to Kuala Perlis and Kuala Kedah shore than the other sites. High concentration of Al in both areas is expected from natural or anthropogenic sources. Naturally, this metal is easily found in soil, minerals (e.g. sapphires, rubies, and turquoise), rocks (especially igneous rocks), and clays (ATSDR 2008). There is high possibility that aluminium-rich sediment was transported from terrestrial via Perlis River and Kedah River to the Kuala Perlis and Kuala Kedah. Distribution trend of another abundant metal, Fe in the study area, was different from Al. The correlation matrix between both the elements was down to the moderate category (r=0.45). Concentration level of Fe was found higher close to Kuala Perlis (LKW1 and LKW2) stations as compared to Kuala Kedah and other stations. Urbanisation and industrial activities in Kuala Perlis were believed to play a significant role, leading to the increase of this pollutant for past years. Denton et al. (2005) suggested that the waste discharges from industrial processes are remarkably induced by the increment of metal content in natural environment. Unfortunately, to date there are no available data of Fe content in the river sediment or water that can be linked with the urban activity to substantiate this possibility.

The distribution pattern of Mn was almost similar to Fe content. Higher concentration of Mn was observed close to Kuala Perlis station as compared to the other location. It was believed that the distribution pattern of Mn is closely related to the iron-rich deposits. The argument was based on strong correlation exhibited between both the metals (r = 0.81). According to Salomons & Forstner (1984), iron oxides are able to adsorb large quantities of metals through the cation exchange processes, thus indirectly play an important role in trapping metals in aquatic sediments (Horowitz & Elrick 1987). Another significant source of Mn might be resulted from agriculture and urbanisation activities. Adriano (2001) revealed that manganese fertilisers in the form of $MnSO_4$ and MnO were widely used to increase agricultural products. Indeed, the concentration levels of Mn in the present study were three times lower than the value of the average shale value (Turekian & Wedepohl 1961). Thus, it is noteworthy to highlight the anthropo-

Table 3: Pearson correlation matrix among the determined concentrations of selected heavy metals.

	Metals							
	Al	Fe	Mn	Zn	Pb	Cu	Co	Cd
Al	1							
Fe	0.45	1						
Mn	0.35	0.81	1					
Zn	0.52	0.52	0.28	1				
Pb	0.72	0.88	0.85	0.51	1			
Cu	0.61	0.31	0.24	0.5	0.44	1		
Co	0.56	0.86	0.81	0.51	0.88	0.61	1	
Cd	0.3	0.39	0.04	0.34	0.21	0.64	0.34	1

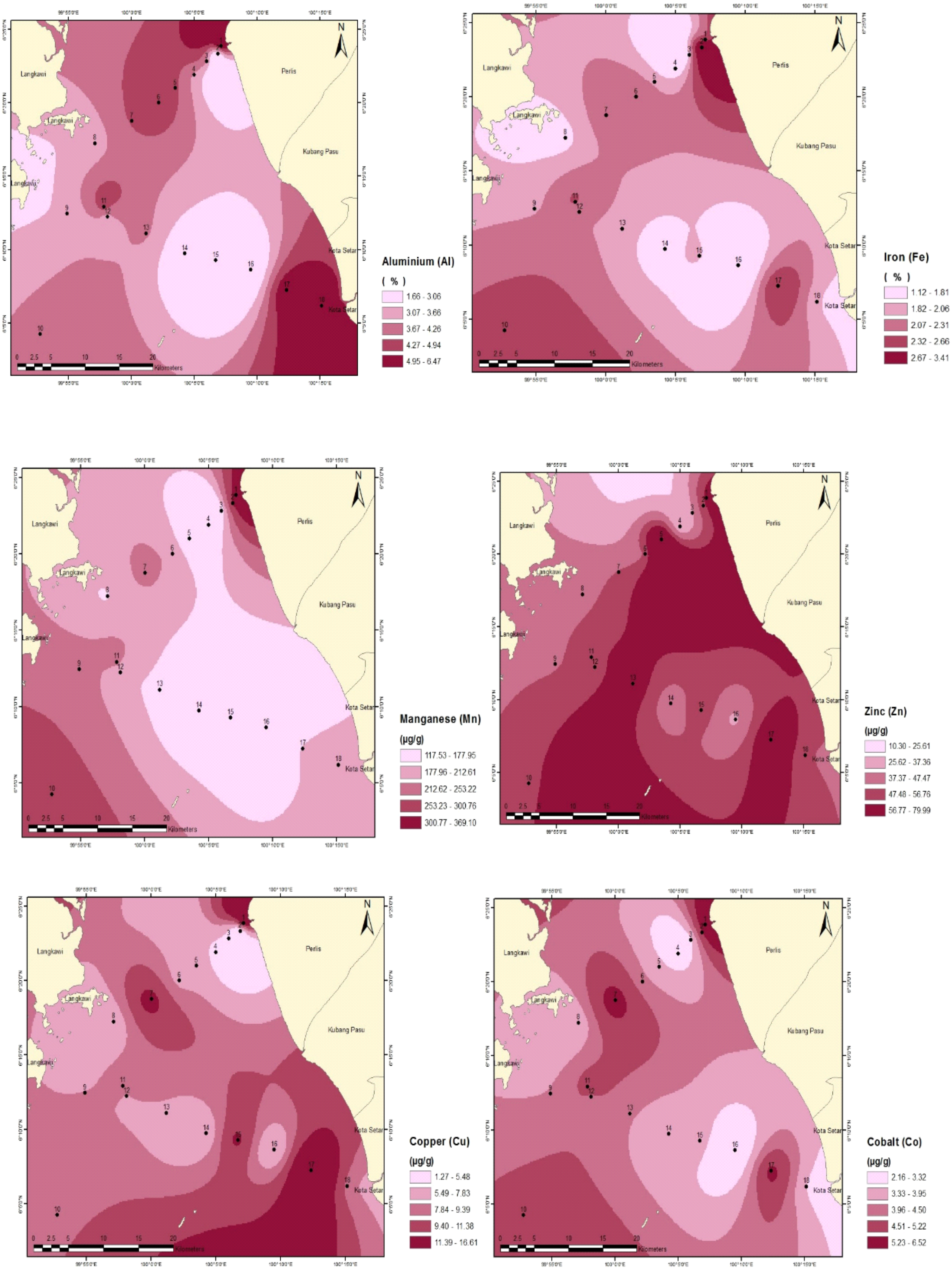
Langkawi
Perlis
Kubang Pasu
Kota Setar
Kilometers
Aluminium (Al)
(%)
1.66 - 3.06
3.07 - 3.66
3.67 - 4.26
4.27 - 4.94
4.95 - 6.47
Iron (Fe)
(%)
1.12 - 1.81
1.82 - 2.06
2.07 - 2.31
2.32 - 2.66
2.67 - 3.41
Manganese (Mn)
(µg/g)
117.53 - 177.95
177.96 - 212.61
212.62 - 253.22
253.23 - 300.76
300.77 - 369.10
Zinc (Zn)
(µg/g)
10.30 - 25.61
25.62 - 37.36
37.37 - 47.47
47.48 - 56.76
56.77 - 79.99
Copper (Cu)
(µg/g)
1.27 - 5.48
5.49 - 7.83
7.84 - 9.39
9.40 - 11.38
11.39 - 16.61
Cobalt (Co)
(µg/g)
2.16 - 3.32
3.33 - 3.95
3.96 - 4.50
4.51 - 5.22
5.23 - 6.52

Fig. 2 cont....

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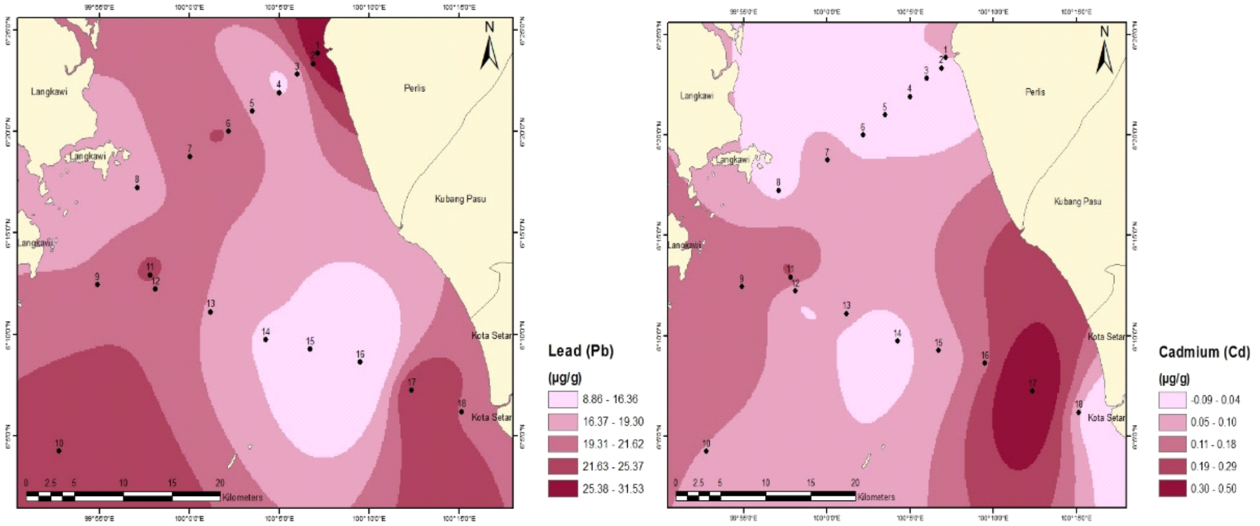

Fig. 2: The spatial distribution of metals in the northern Malacca straits.

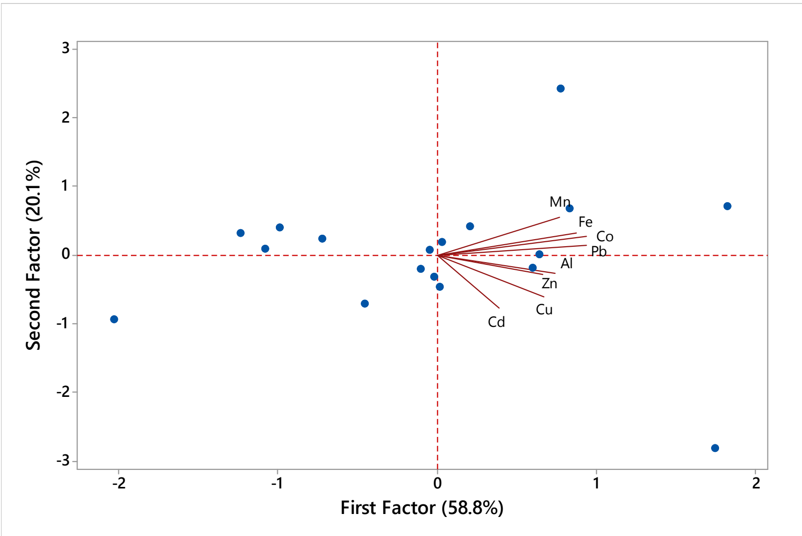

Fig. 3: Loading plot of principal component analysis.

genic sources of Mn was unlikely the significant contributing factor. Thus, the concentration level of Mn in surficial sediments may reflect the background value for studied area.

Zinc is an essential metal commonly present in agricultural food wastes, pesticides and antifouling paints. Other possible sources of Zn are generated from motor oil, grease, phosphate fertilisers, sewage sludge, transmission fluid and concrete (Monaci & Bargagli 1997). Under the natural condition, the weathering effects lead to conversion of usual zinc species into soluble form and be released into the aquatic environment (Horowitz & Elrick 1987). Concentration levels of Zn at most of the sampling stations is uniformly distributed and suggest that the potential anthropogenic sources are not the serious issue in the study area. Zinc metal may represent the background value of the study area during the study period. Distribution patterns are shown in Fig. 2.

High concentration of Cu was determined in Kuala Perlis and Kuala Kedah waters. The main possible source of Cu in both Kuala Perlis and Kuala Kedah waters originated from paddy straw burning. Local paddy farmers in Perlis and

Table 4: The EF and Igeo values of the studied metals in the studied area.

Station	Al		Fe		Mn		Zn		Pb		Cu		Co		Cd	
	EF	Igeo	EF	Igeo	EF	Igeo	EF	Igeo	EF	Igeo	EF	Igeo	EF	Igeo	EF	Igeo
LKW 1	-	-1.23	0.82	-1.52	0.59	-1.98	0.98	-1.26	2.29	-0.04	0.44	-2.40	0.49	-2.26	0.21	-3.47
LKW 2	-	-2.33	2.24	-1.17	1.18	-2.09	1.89	-1.42	4.27	-0.24	0.26	-4.26	0.91	-2.47	-	-
LKW 3	-	-1.82	0.87	-2.03	0.41	-3.11	0.88	-2.00	2.08	-0.77	0.22	-3.99	0.39	-3.19	0.05	-6.21
LKW 4	-	-1.87	0.82	-2.16	0.41	-3.15	0.78	-2.24	2.00	-0.87	0.25	-3.86	0.37	-3.31	-	-
LKW 5	-	-1.58	0.84	-1.83	0.37	-3.03	1.67	-0.84	1.89	-0.66	0.31	-3.26	0.37	-3.00	0.15	-4.30
LKW 6	-	-1.51	0.91	-1.65	0.45	-2.66	0.99	-1.52	2.04	-0.48	0.31	-3.19	0.42	-2.76	0.16	-4.17
LKW 7	-	-1.62	0.95	-1.69	0.53	-2.52	1.04	-1.57	2.15	-0.52	0.55	-2.47	0.60	-2.36	0.40	-2.94
LKW 8	-	-1.99	0.95	-2.06	0.55	-2.85	1.21	-1.71	2.33	-0.76	0.36	-3.46	0.48	-3.05	0.24	-4.06
LKW 9	-	-2.03	1.15	-1.82	0.73	-2.48	1.33	-1.61	2.71	-0.59	0.47	-3.10	0.57	-2.83	1.40	-1.54
LKW 10	-	-1.74	1.16	-1.52	0.74	-2.17	1.28	-1.38	2.64	-0.34	0.44	-2.92	0.57	-2.55	0.76	-2.13
LKW 11	-	-1.56	0.95	-1.63	0.51	-2.53	1.13	-1.38	2.17	-0.44	0.39	-2.94	0.49	-2.59	1.12	-1.39
LKW 12	-	-1.91	1.10	-1.77	0.56	-2.76	1.38	-1.44	2.59	-0.53	0.43	-3.11	0.59	-2.68	0.51	-2.89
LKW 13	-	-1.82	0.95	-1.89	0.47	-2.91	1.59	-1.14	2.23	-0.66	0.39	-3.17	0.50	-2.81	0.36	-3.28
LKW 14	-	-2.49	1.30	-2.11	0.63	-3.16	1.63	-1.78	2.96	-0.92	0.53	-3.40	0.68	-3.05	0.29	-4.26
LKW 15	-	-2.36	1.32	-1.96	0.67	-2.95	1.92	-1.42	2.71	-0.93	0.90	-2.52	0.67	-2.94	0.89	-2.54
LKW 16	-	-2.95	1.21	-2.68	0.71	-3.44	1.96	-1.98	2.29	-1.76	0.65	-3.58	0.59	-3.72	2.62	-1.56
LKW 17	-	-1.20	0.84	-1.45	0.32	-2.83	1.11	-1.04	1.86	-0.30	0.56	-2.03	0.43	-2.41	2.56	0.16
LKW 18	-	-1.37	0.67	-1.94	0.38	-2.78	0.91	-1.50	1.85	-0.49	0.35	-2.90	0.31	-3.08	0.29	-3.14
Average		-1.85	1.06	-1.83	0.57	-2.74	1.32	-1.51	2.39	-0.63	0.44	-3.14	0.52	-2.84	0.66	-2.65

Note: - refer to no available data

Table 5: The value of PLI of the studied metals in the sampling stations.

Station	CF value								PLI Value	Categories
	Al	Fe	Mn	Zn	Pb	Cu	Co	Cd		
LKW 1	0.64	0.52	0.38	0.63	1.46	0.28	0.31	0.14	0.44	No pollution
LKW 2	0.30	0.67	0.35	0.56	1.27	0.08	0.27	-	0.42	No pollution
LKW 3	0.42	0.37	0.17	0.37	0.88	0.09	0.16	0.02	0.20	No pollution
LKW 4	0.41	0.34	0.17	0.32	0.82	0.10	0.15	-	0.31	No pollution
LKW 5	0.50	0.42	0.18	0.84	0.95	0.16	0.19	0.08	0.30	No pollution
LKW 6	0.53	0.48	0.24	0.52	1.08	0.16	0.22	0.08	0.32	No pollution
LKW 7	0.49	0.47	0.26	0.51	1.05	0.27	0.29	0.20	0.39	No pollution
LKW 8	0.38	0.36	0.21	0.46	0.88	0.14	0.18	0.09	0.27	No pollution
LKW 9	0.37	0.42	0.27	0.49	1.00	0.17	0.21	0.51	0.38	No pollution
LKW 10	0.45	0.52	0.33	0.57	1.18	0.20	0.26	0.34	0.42	No pollution
LKW 11	0.51	0.48	0.26	0.58	1.10	0.20	0.25	0.57	0.43	No pollution
LKW 12	0.40	0.44	0.22	0.55	1.04	0.17	0.23	0.20	0.34	No pollution
LKW 13	0.43	0.40	0.20	0.68	0.95	0.17	0.21	0.15	0.32	No pollution
LKW 14	0.27	0.35	0.17	0.44	0.79	0.14	0.18	0.08	0.24	No pollution
LKW 15	0.29	0.39	0.19	0.56	0.79	0.26	0.20	0.26	0.33	No pollution
LKW 16	0.19	0.23	0.14	0.38	0.44	0.13	0.11	0.51	0.23	No pollution
LKW 17	0.65	0.55	0.21	0.73	1.22	0.37	0.28	1.67	0.57	No pollution
LKW 18	0.58	0.39	0.22	0.53	1.07	0.20	0.18	0.17	0.34	No pollution
Average	0.43	0.43	0.23	0.54	1.00	0.18	0.22	0.28	0.35	No pollution

Kedah burn the leftover paddy straw after the harvesting season in order to eliminate insect pests. In addition, Perlis River that flows via urban areas (e.g. Kangar and Kuala Perlis city town) may carry copper-based chemicals, municipal untreated sewage sludge, leachate and corrosion of copper materials. Leachate that contains the soluble form of Cu may permeate into the estuarine and coastal area (Farkas et al. 2007, Machado et al. 2002, Marchand et al. 2006, Guigue et al. 2013, Segura et al. 2006). Indeed, the concentration levels recorded are still very low in terms of enrichment on surface sediments.

The concentration of Co was slightly high in front of Kuala Perlis (LKW1 and LKW2) stations. Cobalt may enter

Table 6: Comparison of heavy metal concentration in the present study with other studies.

Area	Al*	Fe*	Mn	Zn	Pb	Cu	Co	Cd
Present study	3.81± 1.10	2.08± 0.47	197.34± 56.93	51.26± 12.13	19.97± 4.49	8.24± 3.32	4.11± 1.01	0.10± 0.12
Langkawi coastal water (a)	-	-	-	-	41.87 ± 7.3	11.19 ± 5.2	-	-
Kuala Kedah jetty (b)	-	-	-	53.21	26.81	-	-	-
Kuala Perlis (c)	-	-	-	94.45± 18.57	39.22± 8.18	23.63± 8.87	-	0.11± 0.06
Langkawi coastal water (d)	-	-	-	41.02- 137.1	14.4- 38.6	-	-	0.6- 2.4
Strait of Johor (e)	8.25± 2.49	3.04± 0.67	265± 152	132.5± 52.6	-	30.72± 2.5	5.8± 1.5	-
Strait of Malacca (f)	-	2.15± 0.59	421± 209	63.68± 21.93	-	17.46± 8.08	-	-
Average Shale (g)	8.8	4.8	850	95	20	45	19	0.3
SQG (Canada) (h)								
Lowest Effect Level	-	2	-	120	31	16	-	0.6
Severe Effect Level	-	4	-	1100	250	110	-	10

*The concentration of Al and Fe in percentage (%), other elements are in µg/g; a (Kamaruzzaman et al. 2011), b (Yap & Pang 2011), c (Jamil et al. 2014), d (Zahir et al. 2012), e (Wood et al. 1997), f (Saion et al. 2007), g (Turekian & Wedepohl, 1961), h (Persaud et al. 1993)

the aquatic environment from both natural sources and human activities (ATSDR 2004). It was believed that Co and Cu in the study area originated from the related sources due to the moderate correlation between both metals ($r = 0.61$). The main route of these metals presented in the study area is possibly via the discharge of Perlis River and Kedah River. Under natural conditions, Co is usually found in most rocks, soil and water. Cobalt may enter aquatic environment via run-off. On the other hand, Faroon et al. (2004) stated that the primary anthropogenic sources of Co are linked to phosphate fertilisers. Thus, in this case, it could be due to the agricultural activities adjacent to the riverbank area.

Meanwhile, high concentration of Pb at Kuala Perlis (LKW1) indicated that the area was contaminated with anthropogenic activities. Concentration level of Pb in this study was almost comparable to the average shale value (Turekian &Wedepohl 1961). Lastly, the Cd concentrations in all sampling stations were found lower than that of the average shale value. The highest concentration reported at LKW17 indicated that the main source of this metal enrichment came from anthropogenic deposited directly or indirectly by human activities such as urbanisation.

The distribution patterns of studied metals significantly varied, with most of the metals consistent with high concentration adjacent to Perlis and Kedah River, but low concentration in the area close to the Langkawi Island. It gave an idea that the river discharge becomes the major transporter of the heavy metals from terrestrial into the coastal area. High concentration of some metals in the coastal area of Kuala Perlis was linked to the weak flow of Perlis River than Kedah River. The river flow of Perlis River is not strong enough to flush out the metal-rich sediment far from coastal areas. The other factor that may influence the distribution pattern of metals in sediment is the coastal current dynamics. However, we are unable to discuss this factor in detail due to the absence of long-term current dynamic data specifically in this region.

Environmental index status: The EF was calculated for detailed assessment of anthropogenic input for each metal. The average EF for Pb (2.39) indicated that the surface sediments in the study area were moderately enriched (Birch 2003). The highest EF value for this metal was recorded at LKW1 (4.27). The EF value above 1.5 indicated an anthropogenic contribution (Zhang & Liu 2002). The average EF values of Co (0.52), Fe (1.06), Cu (0.44), Mn (0.57), Zn (1.32) and Cd (0.66) suggested that the sediments have no enrichment of anthropogenic sources at current status. According to Zhang & Liu (2002), most of the studied metals in northern coastal water of Malacca Strait were relatively considered as of natural origin due to the EF value that was less than 1.5. The Igeo values of the present study are given in Table 4. The Igeo values of Pb (-0.63), Zn (-1.51), Al (-1.85), Fe (-1.83), Cd (-2.65), Mn (-2.74), Co (-2.84) and Cu (-3.14) explicated that it remain in class 0, suggesting that the study area is in the background value with respect to the studied metals (ATSDR 2008).

The mean CF values for the studied metals in the present study in decreasing order are Pb (1.00) > Zn (0.54) > Fe (0.43) > Al (0.43) > Cd (0.28) > Mn (0.23) > Co (0.22) > Cu (0.18) (Table 5). Similar to EF index, the calculated Pb values at all stations were slightly higher than the other metals. However, in terms of the total metal contamination, PLI value < 0.5 implied that the northern Malacca Straits were not polluted with the studied metals. Literature reveals that the combination of low CF (C<2) and PLI (<1) is remarkably noted as not polluted (Zhang & Liu 2002, Muller 1969).

The heavy metal concentration in the present study was compared with the literature studies (Table 6). The concentration levels of studied metals seemed to be lower with respect to the regional studies (Kamaruzzaman et al. 2011, Saion et al. 2007, Yap & Pang 2011, Wood et al. 1997). The average concentrations of studied metals were also relatively lower than the average shale value. Based on the aquatic sediment quality, the surficial sediments during the period of study can be categorised as lowest effect level. Thus, it indicates that the presence of metals in the surficial sediments is still tolerated by most benthic organisms (Persaud et al. 1993).

Principal component analysis/factor analysis: Principle components showed pronounced change in the screen plot after two eigen values (4.70, 1.61). It explained about 78.90% of the total variance in data sets (Fig. 3). The first component had strong loading on Fe, Pb and Co that accounted for 58.8% from data sets. It is noteworthy to highlight here, that this group of metals is actively used in metal industries. Second component was contributed by negative loading of Cd and Cu with 20.1% of variance data sets. Contrarily, Pearson correlation between both the metals was only exhibited at moderate level. Furthermore, there was a negative loading for the both metals. Station LKW 12 was identified as the most affected station with metal enrichment during the study period. Communalities of variance were high (0.82-0.95), indicating that the extracted factor in each species fitted well with the factor solution.

CONCLUSIONS

There are two obvious conditions that might influence the metal distribution in the present study. First, higher concentration of metals in front of Kuala Perlis than Kuala Kedah which may be subjected to weak river flow of Perlis River. Second, high metal contents in the area close to the mainland are linked to the terrestrial origin. Based on the enrichment factor (EF) value, metal abundance in the study area falls in the category of deficiency to minimal enrichment, except for Pb, which is categorised as moderately enriched. The geoaccumulation index (Igeo) and pollution load index (PLI) indicate that this area is not polluted with the studied metals. The principal component analysis/factor analysis helps extract and identify the factors/sources responsible for variations in the studied area. Thus, this work is important to disclose the status of heavy metals in the study area so that any change in concentration of metal contents can be monitored and appropriately managed.

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