



Environmental hazard assessment of metals in marine sediments of Sabah and Sarawak, Malaysia

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Received: 26 May 2021 / Revised: 22 October 2021 / Accepted: 26 August 2022
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Abstract

The fractionation of 10 metals (As, Co, Cr, Cu, Mn, Ni, Pb, Se, V, and Zn) within labile fractions in shallow marine sediments collected from the coasts of Sabah and Sarawak, Malaysia, was evaluated. Spatial distribution revealed that coastal sediments from Sabah were approximately 10% higher in metal content than sediments from Sarawak. Risk assessment code, enrichment factor, and pollution accumulation index calculations were used to investigate the environmental hazards of elements. For the risk assessment code, the modified Tessier sequential extraction procedure was applied. The risk assessment code values showed that metal V recorded the lowest environment risk (~ 10%) while As, Co, Cr, Cu, Mn, and Zn exhibited medium risk (Risk assessment code range of 11%–30%). The element Ni displayed no risk (0.67%) to the environment, whereas Se and Pb recorded the highest risk with values of 47% and 52%, respectively. For the enrichment factor calculation, the continental crust data presented by Taylor (Taylor, *Geochim Cosmochim Acta* 28:1273–1285, 1964) were used as background, with metal Al used as a reference element. Results illustrated that most of the metals show enrichment (enrichment factor > 1). However, Se was considered extremely severe to the environment (enrichment factor > 50). While the pollution accumulation index calculation demonstrated that all metals under study can be considered as non-contaminant elements except for Ni, V, and Co. These findings indicated that marine sediments in Sabah are more polluted with metal contaminants than the sediments in Sarawak, despite both states having numerous active oil- and gas-related production facilities.

Keywords Pollution · Sediments · Sequential chemical extraction · Risk assessment code · Enrichment factor · Metals

Introduction

Metal pollution in coastal areas is a common environmental problem that has been discussed by many researchers (Bubb and Lester 1991; Idris et al. 2007). There are numerous

sources of metal contaminations at shorelines, such as shipping traffic close to the coast, different activities (industrial and agricultural), and vehicle emissions (Basheer 2018). Metal pollution of the aquatic environment and the subsequent uptake by organisms and humans are health risks that can lead to the genetic alteration of cells or morphological abnormalities. Therefore, it is crucial to consider the level of metals in water and sediments as sediments act as a sink for contaminants.

The content of a particular metal discharged from polluted sediment depends on the metal speciation (Szefer et al. 1995; Soto-Jiménez and Páez-Osuna 2001). Generally, metals may either be bound within particles and can thus include metal complexes into organic matter, or be positioned in the facade coating deposited on the particles (Raj, Kumar, et al. 2019). The existing form of the metals controls the mobility and ecotoxicity of metals, knowledge of which is required to investigate the toxic effect and biogeochemical pathways of the metal species (Ali I 2005, Al-Mur 2020). Therefore, chemical extractions (single or sequential) are

Editorial responsibility: S. R. Sabbagh-Yazdi.

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applied to illustrate the environmental effect of metals. To assess the availability of heavy metals in soils, various routine single extraction methods, either acid or complexing solutions, have been long used (Lindsay & Norvell, 1978; Ure et al., 1993). These single-pass extractions are not likely to recover all the available metals because they are onetime point measurements and are not able to mimic the reactions taking place in the soil particles (Shirvani et al., 2007). On the other hand, in sequential extraction, the obtained fractions depend on the chemicals used to extract a chemically defined phase. For instance, five fractions are obtained with the Tessier method (Tessier et al. 1979): metals associated with exchangeable fraction, metals bound to carbonate, metals that connect to hydrous oxides of Fe, and Mn, metals associated with organic and sulfide compounds and residual fraction.

The association of the metals with the chemical fractions, followed by the required strength, shows their bioavailability and the risk coupled with their occurrence in the aquatic system (Tytła 2019). Several indexes have been developed to evaluate the environmental risk of metals in surface sediments, one of which was the risk assessment code (RAC) (2011). As proposed by (Perinetetal.1985), RAC mainly applies the sum of exchangeable and carbonate-associated fractions to assess the availability of metals in sediments. The RAC evaluates the accessibility of metals in solution by applying a scale to measure the percentage of these metals in sediments that can be extracted in the exchangeable fraction and bound to carbonate fractions. Metals in these fractions have weak bonds, which may lead them to be more labile and thus reflect the pollution history of the sediments (Mohan et al. 2012).

Recently, methodologies and models for evaluating hazards, setting priorities, establishing criteria for environmental quality, and evaluating risks have been developed (Dadar et al. 2017; Shahsavani et al. 2017; Ghasemidehkordi et al. 2018; Shen et al. 2019). Several metal risk assessment indicators of sediment and environmental quality have been established on different bases, such as geo-accumulation index (I_{geo}), which depends on the total constituents (Loska et al. 2004, Lu, Li et al. 2009), which modified by (Karbassi et al. 2007) to pollution accumulation index (I_{POLL}).

Risk assessment code (RAC) depends on availability (Jain 2004; Passos, Alves, et al. 2010; Thanh-Nho et al. 2019); sediment quality guidelines based on biological toxicity (Desrosiers et al. 2010), (Leung et al. 2006); and multiple variants approach (Viguri et al. 2007). Another type of model for evaluating hazards in sediment is normalization to the reference element. Normalization to the reference element method is based on the postulation that a linear association exists between the conventional element and the metals in natural conditions. If the concentration of the conventional metal changes, then because of the change in natural

phenomena, the concentration of other metals will change with the same factor as the conventional metal. (Rahn 1976; Veerle 1993) reported that the reference element should have several characteristics: (i) high concentration in rock or soil, (ii) minimal pollution sources, (iii) ease of determination by many analytical techniques, and (iv) free from contamination during sampling.

Understanding the behavior of metals at the shallower sediment of Sabah and Sarawak requires studying the content and geochemical distribution of heavy metals. This study aimed to explore the pollution status at Sabah and Sarawak bays as active oil and gas exploration and production areas and use RAC, enrichment factor (EF), and I_{poll} for evaluating the environmental hazard of some metals in the shallow marine sediment at both sites.

This study was carried out in the Malaysian Nuclear Agency, Malaysia, and King Faisal University, Saudi Arabia, 2020.

Materials and methods

A total of 26 sediment sites were chosen at various distances (0.7–113 m) from the coasts of Sabah and Sarawak, Malaysia, within $1^{\circ}45.93' - 7^{\circ}24.68'N$ latitude and $109^{\circ}49.20' - 119^{\circ}03.78'E$ longitude (Fig. 1). Three samples were collected from a total depth range of 3.5–109 m and designated as surface, middle, and bottom for each site. The samples were collected using a sediment grab sampler.

Samples were stored in polyethylene containers at $-4^{\circ}C$. They were then dried in a thermal oven at $50^{\circ}C$ and homogenized by powdering in an agate grinder. The homogenized samples were sieved through a 0.2 mm nylon grid sieve and heated at $50^{\circ}C$ until a constant weight was established. The moisture content of the prepared samples was measured using an AND MX-50 moisture analyzer and found to be $\leq 5\%$. The pH for the samples was also detected by immersing the sediment samples in deionized water with a sediment-to-water ratio of 1:5. The pH was measured after 10 min and found to range from 6.5 to 7.5 (ROSSA et al. 2015).

All the reagents were of analytical grade. The glassware and plastic materials used were earlier treated for a week in 10% (v/v) HNO_3 and then rinsed with deionized water.

Sequential extraction procedures

For the extraction, 1.00 g of each dried sample was accurately weighed in a 100-ml pre-cleaned centrifuge tube, and then, the modified Tessier scheme was applied (Table 1). At the end of each step, the tube was centrifuged for 10 min at 4000 rpm and the solution was decanted into a 50-ml polyethylene container. Next, 10 ml of deionized

Fig. 1 Locations of sampling area in Sabah and Sarawak States, Malaysia

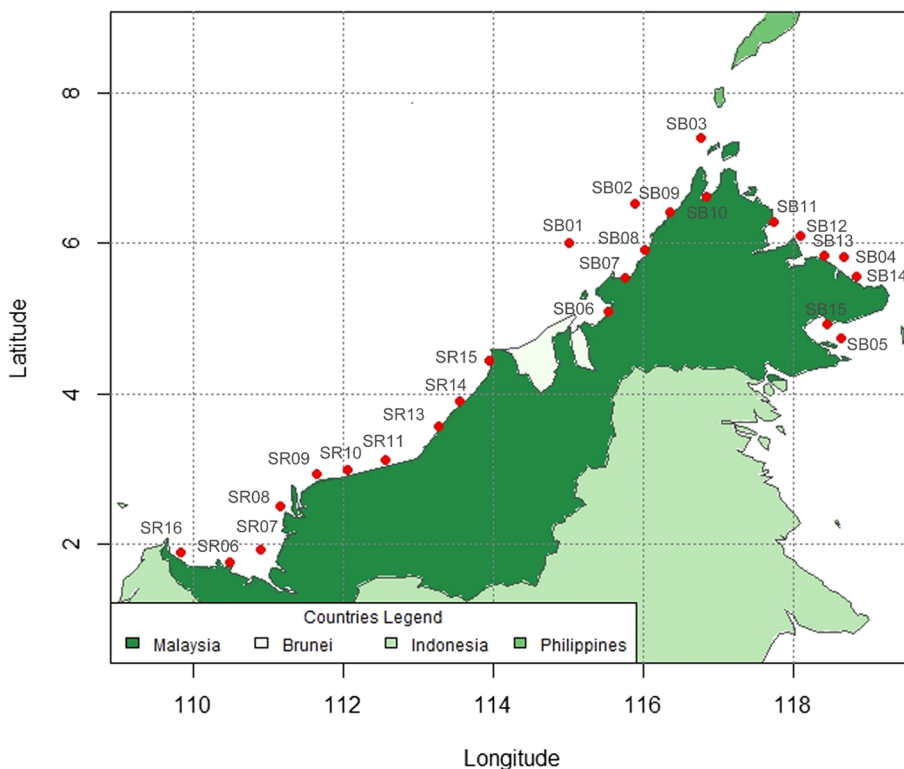


Table 1 Operation conditions of the modified Tessier sequential extraction procedure

Fraction	Extracting agent	Extraction conditions	
		Shaking time ^a	Temperature
F1. Exchangeable	10 mL NH ₄ CH ₃ COO (1 M, pH=7)	1 h	20 °C
F2. Carbonates	10 mL CH ₃ COOH (1 M, pH=5.5)	1 h	20 °C
F3. Fe and Mn oxides	20 mL NH ₂ OH-HCl (0.1 M, pH=2)	5 h	20 °C
F4. Organic matter and sulfides	5 mL H ₂ O ₂ (30%, pH=2) and then 10 mL CH ₃ COONH ₄ (1 M)	3 h, 16 h	85 °C, 20 °C
F5. Residual	8 ml HNO ₃ + 4 ml HF (Conc.) and then 10 ml H ₂ O ₂	16 h, 8 h	20 °C, 250 °C

^a Shaking was applied at 150 rpm

water was added to the residue and centrifuged for 5 min, after which the solution was decanted to 50 ml and then stored at 4 °C (Rosado et al. 2016) until analysis. The residue was used to proceed to the next step. A blank sample was prepared for each set following the above procedure without the addition of a sample.

In the original Tessier scheme, the use of MgCl₂ in the exchangeable fraction caused a matrix effect during the analysis of the extracted samples. Thus, a modification was carried out as shown in Table 1 (Filgueiras et al. 2002), where NH₄CH₃COO was used instead. In the Fe–Mn oxide fraction, the concentration of NH₂OH·HCl was increased from 0.04 M to 0.1 M to increase the extractability.

Digestion method

The digestion method was applied to achieve the total concentration of the metals under study. Currently, the most common method used to digest environmental samples is microwave-assisted total digestion (Sandroni and Smith 2002). For this method, 0.5 g of each dried sample was accurately weighed and mixed with 6 ml of 17 M HNO₃, 2 ml of 8.8 M H₂O₂, and 2 ml of 0.02 M HF (Marin et al. 2008). The samples were digested in a microwave oven (MARS 5 from CEM) within the program shown in Table 2. A standard reference material, namely marine sediment (PACS-2) from the National

Table 2 Microwave program used for the digestion of sediment samples

Max Power	Percent-age power	Ramp time	Pressure	Temperature	Hold time
1200 W	100%	20 min	600 PSI	200 °C	15 min

Research Council of Canada, was treated as above. Blank samples were also prepared for each set by adding the digestion acid mixture used above without any sample. All the processes were repeated in triplicate.

The prepared sediment samples were analyzed using an ELAN 6000 PerkinElmer SCIEX ICP-MS Spectrometer. ICP multi-element calibration standard solution from ScharlauChemie was used to calibrate the system. The concentration of metals in the dry sample was calculated using Eq. (2):

$$\text{Concentration – dryweight} \left(\frac{\mu\text{g}}{\text{g}} \right) = \frac{CV}{WS} \quad (1)$$

where

- C = digest concentration ($\mu\text{g}/\text{ml}$),
- V = final volume in ml after sample preparation,
- W = weight in g of wet sample and.
- S = % solids/100.

One of the most effective methods for normalization to a reference element is the enrichment factor (EF) calculation (Kusin et al. 2017).

The EF can be calculated from Eq. (2):

$$EF = \frac{\left(\frac{C_x}{C_n} \right)_{\text{ambient}}}{\left(\frac{C_x}{C_n} \right)_{\text{background}}} \quad (2)$$

where C_x enrichment is to be determined, C_n is the concentration of the n normalizing element assumed to be a unique characteristic of the background.

Another method that can give an effective way for measuring pollution was I_{geo} (Loska et al. 2004), which was modified by (Karbassi et al. 2007) to pollution accumulation index (I_{POLL}) as follows:

$$I_{\text{geo}} = \text{Log}_2 \left(\frac{C_n}{(1.5XB_n)} \right) \quad (3)$$

(where C_n is the sediment metal concentration and B_n is the metal concentration in the shale) to:

$$I_{\text{POLL}} = \text{Log}_2 (B_c | L_p) \quad (4)$$

where I_{POLL} , B_c , and L_p are indicative of pollution intensity, bulk concentration, and lithogenous portion, respectively.

Reliability of the results

Reliability of the obtained data was achieved by calculating the recovery of the fraction results of the sequential extraction procedures by the sum of the amounts of metals removed M_s in each step of the procedures with the results of the pseudo-total digestion M_t (Sect. 2.2), as shown in Eq. (5) (Hullebusch, Utomo, et al. 2005):

$$\text{Recovery (\%)} = \frac{\sum M_s}{M} \times 100 \quad (5)$$

Results and discussion

Spatial distribution of the elements

The sample sites in Sabah and Sarawak are shown in Figs. 2 and 3, respectively. However, as shown in Fig. 2, the spatial distribution of the metals throughout Sabah's coastal area shows a similar distribution of element As at all locations, except at sites SB05, SB13 and SB15, which display about twice the As concentration of other locations. All other metals show similar distributions throughout Sabah sites, which likely indicate no different sources for metal emissions in the sample sites.

In Fig. 3, the spatial distribution of metals throughout Sarawak shows a similar pattern for elements with some exceptions. For instance, the distribution of element As is similar at all sites, except at site SR14 (~25%). However, all other metals display low concentrations. Similarly, about 25% of the metal content at one site, location SR13, was identified as metals Ni and Cr. This finding can be an indication of a limited variety of metal emission sources.

The comparison between the spatial distribution of the metals in Sabah and Sarawak coastal sediments indicates that, despite both states having numerous active oil- and gas-related production facilities, the metal concentrations are higher in Sabah than in Sarawak. This result indicates that marine sediments in Sabah might be exposed to external pollution sources, or the higher metal content could be linked to the geological features of the Sabah coast.

Table 3 shows the reliability of the modified Tessier procedure. When applying the modified Tessier procedure, good recovery (between 90 and 110%) for metals As, Co, Cr, Cu, Ni, Pb, V, and Zn is obtained. The recovery for Mn and Se (119% and 88%, respectively) can be accepted, though it is slightly distant from the accepted limit (Bashar Qasim 2014).



Fig. 2 Special distributions of the metals (concentration ppm) through samples sites in Sabah

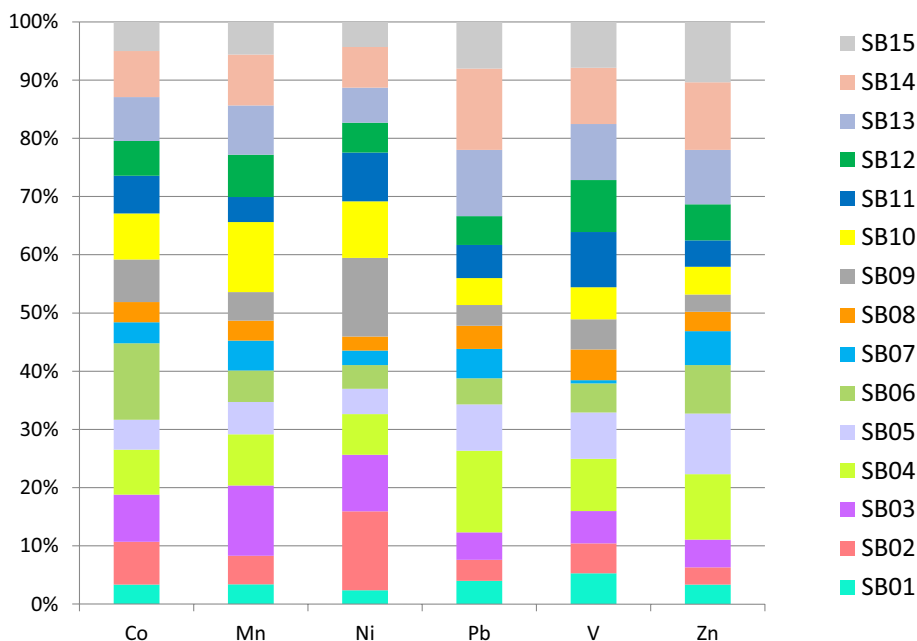
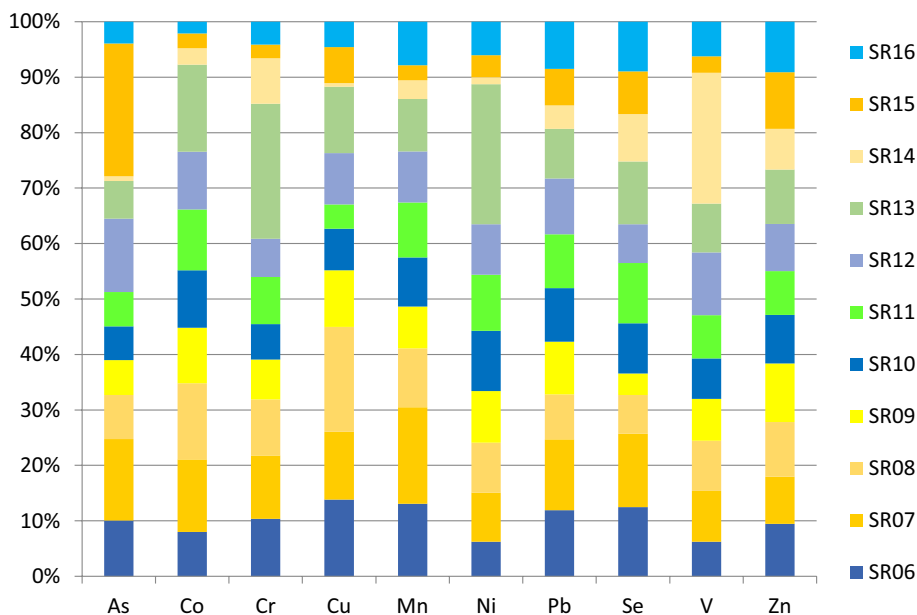


Fig. 3 Special distributions of the metals (concentration ppm) through samples sites in Sarawak



Summary of statistics of the mobile fractions

Tables 4 and 5 summarize the distribution of metals at the exchangeable and carbonate fractions using the modified Tessier sequential extraction procedure (mean, standard deviation, minimum value, maximum value, and median). The achieved minimum concentrations of the metals in the first two fractions were below the detection limit of the ICP-MS. This result agreed with the fact that Fe metal tends to associate with the Fe–Mn oxide fraction in sediments. As can be noted, the fractionation profile of elements varied between the first two labile fractions. The average

concentration of metals showed that only Pb preferred to bound into the exchangeable fraction while higher concentrations of As, Cr, Co, Cu, Mn, V, and Zn were found at the carbonate fraction. It has been reported that the geochemical behavior of the Cu, Mn, and Zn ions enables be adsorbed onto the surfaces of carbonate minerals and further incorporated into the crystal lattice (Billon et al. 2002).

Quality control of the data

Quality control of the achieved results was conducted using marine sediment from the National Research Council of

Table 3 Reliability for the modified Tessier procedure

Metals	$\sum M_s$	M_t	Recovery (%)
As	18.10	18.80	96.28
Co	14.76	13.40	110.15
Cr	67.80	68.90	98.40
Cu	41.20	37.20	110.75
Mn	578.80	483.20	119.78
Ni	56.48	51.80	109.03
Pb	41.13	40.90	100.56
Se	3.19	3.60	88.56
V	136.30	125.20	108.87
Zn	335.80	320.40	104.81

Canada, namely PACS-2 certified reference material (CRM). Table 6 shows the analytical and certified values, the error, and the recovery for the studied metals concerning the CRM. The table reveals that all metals under study show good recovery (where we compare the measured concentration to actual spike concentration added) and low error (recovery = $100\% \pm 20\%$) (El Zokm et al. 2015).

Summary of statistics for total element content

Table 7 shows the summary of statistics applied to obtain the average, standard deviation, minimum value, maximum value, and median for the total concentration of samples using ICP-MS.

RAC calculations

The released metals from the fractions are classified as weakly bonded metals. If the RAC percentage is less than 1%, then the sediment is of no risk to the aquatic

Table 6 Input comparison of the ICP-MS results (ppm) obtained in this work with the certified values for the CRM of PACS-2

Metals	Value found	Certified value	Recovery %	Error
Al	5920.00	6620.00	89.46	0.11
As	30.60	26.20	116.80	0.17
Co	11.47	11.50	99.70	0.003
Cr	87.59	90.70	96.57	0.03
Cu	346.39	310.00	111.74	0.12
Mn	446.64	440.00	101.51	0.02
Ni	42.42	39.50	107.39	0.07
Pb	218.17	183.00	119.22	0.19
Se	1.09	0.92	118.91	0.19
V	140.05	133.00	105.30	0.05
Zn	417.17	364.00	114.61	0.15

environment. When the percentage is in the range of 1%–10%, then it is associated with low risk. When the value of the RAC is in the range of 11%–30% and 31%–50%, then the sediment is linked with medium risk and high risk, respectively. The sediment considered to cause very high risk has a RAC value above 50% (Ghrefat and Yusuf 2006). Table 8 shows the calculated RAC percentages and the outcome from these values are discussed accordingly.

From Table 8 and the calculated RAC, metals As, Co, Cr, Cu, Mn, and Zn are considered as a medium risk to the environment as their RAC values are between 11 and 30%. The results are in agreement with the reported data for Cd, Cr, Cu, Co, Ni, Mn, Pb, and Zn on the river estuarine sediments from Mahanadi Basin, India (Sundaray et al. 2011). Moreover, metal V recorded the lowest environment risk (10%) while Ni displayed no risk (0.67%). By contrast, Se showed a high risk to the environment (47%) and Pb was considered the highest environment risk (52%). These results

Table 4 Summary statistics of the metal concentration (ppm) in exchangeable fraction using the modified Tessier scheme

Summary Statistics	As	Co	Cr	Cu	Mn	Ni	Pb	Se	V	Zn
Mean	1.29	0.51	5.35	0.25	24.48	0.21	15.62	0.93	1.31	4.33
SD	81.06	0.74	28.80	0.27	61.11	0.19	18.43	1.47	1.96	6.13
Min	–	–	–	–	–	–	–	–	–	–
Max	295.64	3.34	81.27	0.85	289.04	0.77	83.70	4.18	7.80	36.33
Median	6.93	0.20	-0.02	0.17	0.84	0.17	8.63	0.85	0.67	1.48

Table 5 Summary statistics of the metal concentration (ppm) in carbonate fraction using the modified Tessier scheme

Summary statistics	As	Co	Cr	Cu	Mn	Ni	Pb	Se	V	Zn
Mean	1.74	1.73	7.22	4.85	117.3	0.17	5.89	0.56	11.81	34.83
SD	3.07	3.92	16.84	150.32	51.16	0.26	10.03	1.56	19.09	96.90
Min	–	–	–	–	–	–	–	–	–	–
Max	7.80	20.00	54.40	839.30	468.20	1.00	16.00	3.30	69.90	418.40
Median	0.00	0.46	-0.13	-0.14	450.76	0.17	9.40	0.47	1.05	122.90



Table 7 Summary of the statistics for total metal concentration (ppm) for marine sediment samples using ICP-MS

Summary Statistics	Al	As	Co	Cr	Cu	Mn	Ni	Pb	Se	V	Zn
Mean	44,600.0	18.8	13.4	68.9	37.2	483.2	51.8	40.9	3.6	125.2	320.4
SD	38,700.0	7.8	6.9	64.2	28.7	250.5	47.0	10.4	1.7	43.2	137.3
Min	4000.0	0.3	2.1	4.8	1.0	61.0	13.4	22.5	2.8	45.7	119.2
Max	115,600.0	37.7	36.5	271.9	180.1	1325.3	189.0	66.8	6.6	252.9	881.3
Median	23,300.0	15.5	11.0	52.4	29.6	444.9	32.2	40.4	4.1	120.1	304.4

Table 8 Determination of RAC using modified Tessier scheme results

Metals	(F1) Exchangeable fraction (%)	(F2) Carbonate fraction (%)	F1 + F2
As	7.00	10.00	17.00
Co	3.00	12.00	15.00
Cr	8.00	11.00	19.00
Cu	1.00	12.00	13.00
Mn	4.00	20.00	24.00
Ni	0.37	0.30	0.67
Pb	38.00	14.00	52.00
Se	29.00	18.00	47.00
V	1.00	9.00	10.00
Zn	1.00	10.00	11.00

can be compared with those obtained by (Yu et al. 2011), who evaluated the environmental risk of heavy metals (i.e., Cu, Pb, Zn, Cd, and Cr) in surface sediments by using RAC. They found that the order of the elements according to their risk levels was $Zn > Cu$ and $Cd > Pb$ and Cr. (Ghrefat et al. 2011) used RAC in soil samples collected along Zerqa River, Jordan, and found that Cd came under the very high-risk category; Mn showed high risk; Cu, Ni, Pb and Zn showed the medium risk to the environment; and Cr posed a low risk to the environment.

We can conclude that the sediments of Sabah and Sarawak are at medium risk for most of the metals under investigation. However, regular environmental monitoring programs may offer data about to what extent the risk will affect the surrounding environment over a long period.

Enrichment factor

This method assumes a linear relationship between the conservative element and the heavy metals in natural conditions. If the concentration of the conservative metal changes, then due to the change in natural phenomena, the concentration of other metals will change with the same factor as the conservative element (Veerle 1993).

The EF was calculated using Eq. (2), and the results are summarized in Table 9.

The data of the continental crust were used as background data (Taylor 1964), with Al as the reference element

Table 9 Determination of enrichment factor in sediment samples

Metals	Average in sample (ppm)	Average in crust (ppm)	Enrichment factor
Al	45,480.0	82,300.0	
As	18.80	1.80	18.90
Co	13.40	25.00	0.97
Cr	68.90	100.00	1.25
Cu	37.20	55.00	1.22
Mn	483.20	950.00	0.92
Ni	51.80	75.00	1.25
Pb	40.90	12.50	5.92
Se	3.60	0.05	130.29
V	125.20	135.00	1.68
Zn	320.40	70.00	8.28

(Pourkhabbaz 2014, Tahir 2017); the results of Al concentration are listed in Table 7. As in the literature, EF values < 1 point to no enrichment, 1–3 are slightly enriched, 3–5 are moderate, 5–10 are moderately severe, 10–25 are severe, 25–50 are very severe, and > 50 are extremely severe.

From Table 9, all metals show enrichment ($EF > 1$), except Co and Mn, which show no enrichment ($EF < 1$). Metals Cr, Cu, Ni, and V have minor enrichment (1–3), Pb and Zn are moderately severe (5–10) and As is severe (18.9). However, Se is extremely severe to the environment ($EF > 50$). In a reported study, Al was used as the normalizing element to study the EF of trace elements in the sediments of Italian harbors (Renzi et al. 2011). They found that only Pb and Cu were enriched in the harbors while the values of the other elements were lower than expected compared to the natural levels. In addition, Al was used earlier (Léopold et al. 2008), in which EF calculations displayed a significant enrichment of toxic metals in the area, except for Ni with 0.72–1.39. In particular, the area was strongly polluted and moderately polluted with Cd and Pb, respectively.

Pollution accumulation index

Another measurement for pollution level in sediment was taken using Eq. 4 in which I_{POLL} was calculated for elements under study, and the results are tabulated in Table 10. As proposed by (Karbassi et al. 2007), the lithogenous portion

Table 10 Determination of pollution index (I_{POLL}) in sediment samples

Chemical Fraction	Metals									
	As	Co	Cr	Cu	Mn	Ni	Pb	Se	V	Zn
Exchangable	1.29	0.51	5.35	0.25	24.48	0.21	15.62	0.93	1.31	4.33
Carbonate	1.74	1.73	7.22	4.85	117.32	0.17	5.89	0.56	11.81	34.83
Fe–Mn Oxide	1.81	9.12	14.78	3.1	145.66	0.85	5.84	0.46	19.77	41.72
Organic	2.76	1.98	27.41	8.6	86.16	7.6	7.88	0.62	6.5	46.17
lithogenous portion	7.6	13.34	54.76	16.8	373.62	8.83	35.23	2.57	39.39	127.05
I_{POLL}	0.74	3.01	0.38	0.66	0.39	1.76	0.35	0.42	0.953	0.76

of metals can be calculated by summation of metal concentration in exchangeable, carbonate, bound to Fe–Mn, and organic fractions using a modified Tessier sequential extraction scheme. According to (Li et al. 2014), if the result of $I_{\text{POLL}} \leq \text{mean}$, sediments or soils are uncontaminated to moderately contaminated, while it will be moderately contaminated if the value $1 \leq I_{\text{POLL}} \leq 2$. On the other hand, the soil or sediment will be considered as heavily contaminated when $2 \leq I_{\text{POLL}} \leq 3$ and it will be heavily to extremely contaminated when $3 \leq I_{\text{POLL}} \leq 4$. Table 10 shows that sediment of Sabah and Sarawak is uncontaminated with all metals under study except for Ni, V (moderately contaminated), and Co (heavily to extremely contaminated).

Conclusion

The present study indicated that the metal content of shallow marine sediments is higher at Sabah coast than at Sarawak coast, despite the numerous active oil- and gas-related production facilities at both states. The spatial distribution of metals in Sabah and Sarawak coastal sediments also illustrates that marine sediments in Sabah received more metal pollution than those in Sarawak. According to the calculated RAC, which deals with the metals' concentrations in mobile fractions, most of the investigated elements in Sabah and Sarawak were at medium risk to the local environment. In terms of the EF, Co and Mn displayed no enrichment while Cr, Cu, Ni, and V showed minor enrichment. Pb and Zn were moderately severe while As was severe. However, only Se enrichment was considered extremely severe to the environment. For I_{POLL} , all metals under study can be considered as non-contaminant elements except for Ni, V, and Co.

Acknowledgements The authors acknowledge the Deanship of Scientific Research at King Faisal University, for the financial support under Ambitious Researcher [GRANT 496].

The authors also acknowledge the Malaysian nuclear Agency for their support in samples collection and sample preparation.

Authors contributions AYA was involved in conceptualization, investigation, visualization, methodology, and writing the original draft

preparation. MPA carried out supervision. SMS was responsible for statistical analysis, and writing, reviewing, and editing.

Funding Funding for this study was received from the Deanship of Scientific Research at King Faisal University, Ambitious Researcher [GRANT 496].

A data availability statement Data are available on request from the authors.

Code availability Not Applicable.

Declarations

Conflict of interests The authors declare no competing interests.

Ethics approval Not Applicable.

Consent to participate Not Applicable.

Consent for publication Not Applicable.

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