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Evaluation the Situation of Heavy Metal Contamination on a Sandy Beach in the Eastern Provinces of Thailand

Patarapong Kroeksakul[1]*, Pakjirat Singhaboot[2], Sujit Pokanngen[1], Kitsakorn Suksamran[1] and Channaphat Klansawang[1]

[1]*Faculty of Environmental Culture and Ecotourism, Srinakharinwirot University, Bangkok, 10110 Thailand*
[2]*Agricultural Product Innovation and Technology, Srinakharinwirot University, Ongkharak, Nakhon Nayok, 26120 Thailand*

ABSTRACT

Thailand's eastern provinces are essential as a hub for industry and tourism, effect to the study has purposed for heavy metal contamination of a beach in the Thai Gulf area in the east of Thailand was monitored and focuses on the use of the enrichment factor (*EF*) and geoaccumulation index (*Igeo*) to indicate the environmental condition of beaches. The 30 sample sites were in Chonburi (CHR), Rayong (RY), Chanthaburi (CB), and Trad (TR) provinces, along a sandy beach of about 320 kilometers in length. An inductively coupled plasma technique (ICP-OES) was used to analyze the heavy metals present in the samples. The sand of the range with granulometries greater than 0.85 (18%), between 0.85–0.25 (77%), or less than 0.25 mm (5%). The most common heavy metal found in the samples was Fe at 1632±931 mg/kg dry weight, and the number of heavy metals found in the samples did not exceed the Pollution Control Department of Thailand standards. Principle Component Analysis (PCA) indicated that land use activities influence Hg content. The *Igeo* of Hg was 1–1.99 (moderately polluted) in sample location 4th of the Rayong province, which has an industrial zone and a port. The *EF* was mainly within the range of 2–5 in the four provinces studied (indicating deficiency to minimal enrichment), except for one location in Trad and Rayong province, which had an *EF* of over 5; a possible reason for this is that the area is close to agricultural and aquacultural zones, the government organizations can use the data to plan, monitor, and promote tourism in the future.

Keywords: Beach, Eastern provinces of Thailand, Enrichment Factor (*EF*), geoaccumulation index (*Igeo*), heavy metals, Thai Gulf

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E-mail addresses:
patarapong@g.swu.ac.th (Patarapong Kroeksakul)
pakjirat@g.swu.ac.th (Pakjirat Singhaboot)
sujit.pokanngen@g.swu.ac.th (Sujit Pokanngen)
kanokphon.ssr@g.swu.ac.th (Kitsakorn Suksamran)
channaphat.kla@g.swu.ac.th (Channaphat Klansawang)
*Corresponding author

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INTRODUCTION

There is a long history of studies of heavy metal contamination. Around 1959, mercury (Hg) was toxicology tested on a rat, which developed symptoms similar to Minamata disease in humans (Yorifuji & Harada, 2011). In the era of Hippocrates, lead (Pb) was found to give laborers in steel smelting factories stomach cramps. The present distribution of contamination by heavy metals such as cadmium (Cd), Pb, and Hg differs from previous eras. Exposure is often caused by smoke from combustion processes in industry and transportation (WHO, 2007). It is also possible for contamination to be caused by agriculture, as Cd, Pb, and Hg are components in chemical fertilizer (Zhao & Wang, 2010), and manganese (Mn), zinc (Zn), and copper (Cu) are components of pesticides (Chopra & Phathak, 2009; Alvers et al., 2016). Soils, sediments, air, and water can be contaminated by heavy metals present in rainwater (Maanan et al., 2004; Khayan et al., 2019). The ocean is at the end of the mineral and biogeochemical cycle and is the base of the pollution transfer cycle (Ilyina et al., 2006; Gioia et al., 2011; Foteinis et al., 2013), and this can result in the contamination of sand and organisms on beaches (Alshahri, 2017; Cabrini et al., 2017). Because many people travel to the beach to relax, this can lead to human health risks (Khaled et al., 2017; Benssa et al., 2021; Kim & Choi, 2016). However, the research focuses on the beach around the eastern provinces zone of Thailand because it is essential to the country's industrial zone and has the beach for tourism supported together. The beaches around the eastern region of Thailand are popular with tourists. About 13.7 million internal and foreign tourists visited the four eastern provinces of Thailand in 2009, and in 2015 this Figure increased by about 51% from 2009, with more than 26.9 million persons visiting the eastern region (National Statistic Office Thailand, 2021). This tourism is focused on the sea beaches in the Thai Gulf area. A geochemical survey of heavy metals provides a framework for assessing sources and mechanisms of element entry and enrichment distribution in beaches and sediments (Magesh et al., 2011). In 2021, it was reported that the Amazonian oceanic beaches were contaminated with Cd and Hg at moderate to very high levels (Vilhena et al., 2021), and Greek beaches were contaminated with Cu, Zn, and Pb (Foteinis et al., 2013). However, the amount of heavy metal is almost concentrated in the sediments, but the differences in studies focus on the beach to support people may rest and travel.

Environmental pollution monitoring involves using indicators to show the presence and amount of human pathogenic pollutants deposition on soil surfaces, and the purpose of this research is to examine the quality of sandy beaches by utilizing the enrichment factor (*EF*) and geoaccumulation index (*Igeo*) to measure the contamination of heavy metals on the beaches in Thailand's eastern regions. The enrichment ratio of heavy metals in the environment of eastern Thai beaches is ascribed to human activities, and the study focuses on Hg, Cd, Pb, Zn, Cu, Mn, nickel (Ni), and iron (Fe). The results of this environmental monitoring will support the unpolluted beaches and protection from heavy metal poisoning in beach around the eastern provinces of Thailand.

MATERIALS AND METHODS

Sample Collection Area

The sand samples were collected from beaches in the eastern provinces of Thailand, which include Chonburi (CHR), Rayong (RY), Chanthaburi (CR), and Trad (TR). These provinces have about 320 kilometers of beaches. The samples were collected at the 30 locations indicated in Figure 1 within the supratidal. Samples were collected by placing quadrats (1.5 x 1.5 m^2) on the sample area and collecting about 50g of soil at a depth of about 0–5 cm in the beach around 300–400 m. The total sample weight was about 1.3 kilograms from each of the 30 locations, and each of these 30 samples was homogenized by mixing in a polypropylene bag (Chen et al., 2019).

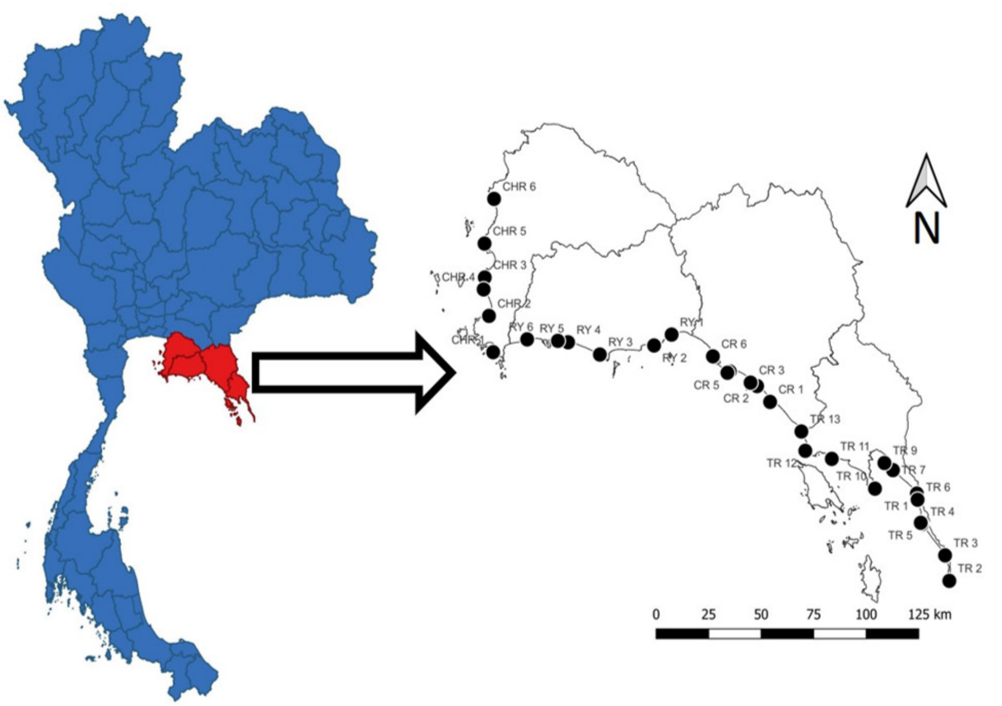


Figure 1. Sample collection areas in the beach of the eastern provinces of the Thai Gulf region

Sample Preparation and Heavy Metal Analysis

In the laboratory, the samples were air-dried on a plastic tray, and each sample was then sieved through a No. 20 sieve with a 0.85 mm mesh size and a No. 60 sieve with a 0.25 mm mesh size to separate the gravel fraction from grains below 1 mm in size, and to separate larger grains from smaller grains, for analysis. Samples of 5 g were then combined with a solution of 3% (v/v) hydrogen peroxide (H_2O_2) for 48 hours to remove most of the organic matter (Sanz-Prada et al., 2020). These samples were then dried in a hot air oven at 105°C for three days (until they were dry), and samples were taken for continuous extraction. These 2 g samples were mixed with 50 ml of acid (HF: HNO_3: $HClO_4$ ratio 1:1:1), heated to 180°C on a hot plate until the samples were dry, and re-dissolved with 50 ml 1% HNO_3. The samples were left for 24 hours before being filtered using a Whatman No. 5 filter and collected in PP tubes for analysis. The heavy element analysis used the inductively coupled plasma (ICP) technique in a PlasmaQuant 9100 series (Germany), and the sample references material with the AccuTrace™ standard (USA.). The concentration of heavy metals in the samples was calculated in Equation 1:

$$\text{Element concentration (mg/kg)} = Cx\ (v/w) \tag{1}$$

where Cx is the concentration value given by the instrument (µg/L), v represents the volume of the sample that is soluble (L), and w is the weight of the sample after extraction (g).

The Enrichment Factor (EF) and Geoaccumulation Index (Igeo)

The enrichment factor (*EF*) was derived from Equation 2:

$$EF=(C/RE)_{\text{sample}}/(C/RE)_{\text{background}} \tag{2}$$

where C/RE_{sample} is the value of element concentration (C) to a reference element (RE) in the samples, and $C/RE_{\text{background}}$ is the value of element concentration (C) to a reference element (RE) present in the background (Bern et al., 2019). Aluminum (Al) was used as the reference element because it is a major component of clay, and the background element concentration references for Pb, Cd, Cu, Zn, Fe, and Ni were taken from Looi et al. (2019). The geoaccumulation index (*Igeo*) was originally formulated by Muller (1980) and is a quantitative measure of pollution in aquatic sediment (Nobi et al., 2010) and was worked out on the basis of an understanding of the lithogenic effect. *Igeo* was derived using the formula in Equation 3:

$$Igeo = \log 2\ ([\text{sediment}]/\ 1.5^{*}\ [\text{reference sample}]). \tag{3}$$

where factor 1.5 is introduced to minimize the effect of possible variations in the background values, which might be attributed to lithologic variations in the sediments. Reference values for Cd, Pb, and Cu (0.3, 20, and 50 mg/kg, respectively) were taken from Brandl et al. (2013), reference values for Fe (43.4g/kg) and Zn (159 mg/kg) were taken from Potipat et al. (2015), and Hg (0.02 mg/kg) and Ni (25 mg/kg) reference values were taken from Guan et al. (2014). However, the meaning of indicates with *EF* and *Igeo* is present in Table 1.

Table 1
The meaning of EF and Igeo indicator

EF		*Igeo*	
<1	does not indicate enrichment	≤0	Unpolluted
<3	is slight enrichment	0–1	Unpolluted to moderately polluted
3–5	is moderate enrichment	1–2	Moderately polluted
5–10	is moderately severe enrichment	2–3	Moderately to highly polluted
12–25	is severe enrichment	3–4	Highly polluted
25–50	is very severe enrichment	4–5	Highly to extremely polluted
>50	is extremely severe enrichment	>5	Extremely polluted

Statistical Analysis

Data were analyzed using one-way ANOVA for variance. Differences in the data were compared using a Least Significant Difference (LSD) test at $p<0.05$ between data components. Principal Component Analysis (PCA) was used to evaluate the correlation matrix components, with factors of influence related to heavy metals on the beach and activity in the area, and the correlation analysis used Pearson correlation ($p<0.05$). All analyses were performed using the SPSS V.22 and Sigmaplot 12.0 programs (free trial versions).

RESULTS AND DISCUSSION

Sample Collection Locations and Grain Size of Samples

Human activities such as agriculture, fishing, and tourism affect the sample collection areas. As shown in Table 1S, these areas contain fishing and travel piers, agricultural regions, rest zones, industrial zones, and fish markets. There are differences in sand grain size between the different sample sites. Figure 2 presents the differences in grain size between the samples, which are categorized as over 0.85 mm, between 0.25 and 0.85 mm, or less than 0.25 mm (average proportions were 18, 77, and 5%, respectively). However, the analysis of heavy metals uses the size of the grain of sand between 0.25–0.85 mm, so its general grain size is in the range around the eastern provinces of Thailand.

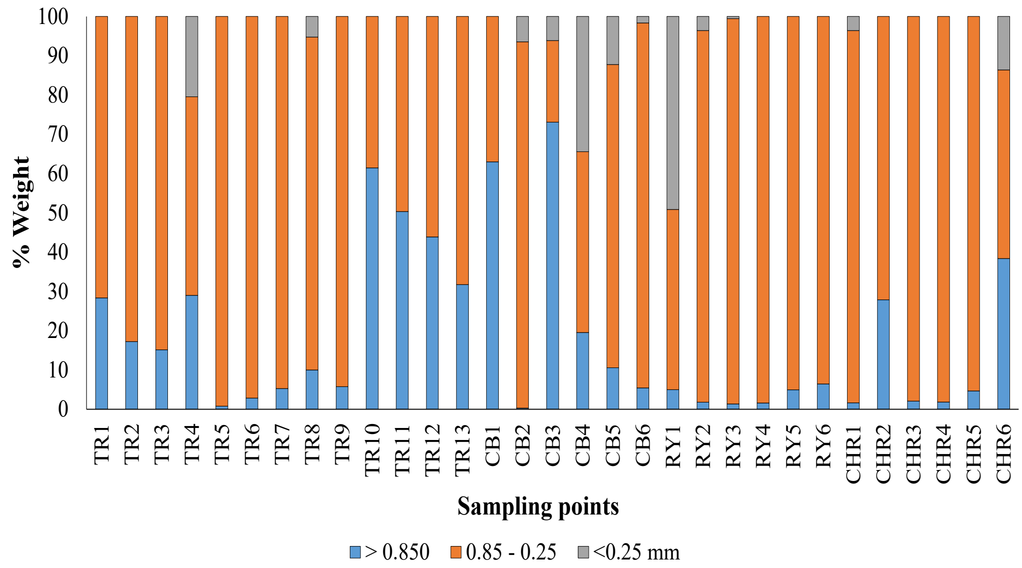


Figure 2. Grain sizes of sand samples along the eastern coastline of Thailand

Heavy Metal Content in Sandy Beach

Fe was the most common heavy metal in the samples, with an average content of 1632±931 mg/kg by dry weight, or 88% of the heavy metals in the sand samples. In descending order, the most common heavy metals on average in the samples were Fe, Mn, Zn, Cu, Pb, Cd, Ni, and Hg. The quantities of heavy metal contaminants found in the sand samples are presented in Table 2, and the spatial distribution of heavy metal contaminants is presented in Figure 3. Cd contamination was found to be significantly higher in the beaches of RY province than in the beaches of TR and CB provinces ($p<0.05$), and Fe contamination was significantly higher in the beaches of CB province than the beaches of TR, RY, and CHR provinces ($p<0.05$), and the Pb contamination in CB province was significantly higher ($p<0.05$) than in the TR, RY, and CHR provinces. However, no significant differences were found between the Cu, Hg, Ni, and Zn contamination levels between the four provinces. These data are presented in Table 3. Figure 4 shows the ratio of all heavy metal contaminants to Fe contamination and the distribution of heavy metal contamination in the four studied provinces.

Levels of heavy metal contamination in the beaches of the eastern region were not found to have reached emergency levels of contamination. The scale provided by the Pollution Control Department for agricultural and residential areas (Pollution Control Department, 2021) requires that heavy metal content must not exceed the following levels: Cd <67 mg/kg, Cu <2.9 g/kg, Mn<1.7 g/kg, Ni 140.4 mg/kg, Pb <400 mg/kg, and Hg <22 mg/kg. The average heavy metal content in the samples did not exceed this standard in any case, nor did it exceed World Health Organization (WHO) requirements the Hg <0.5 mg/kg, Cd<30 mg/kg, Pb<30mg/kg (WHO,2007).

Table2

Average heavy metal contamination in sampled beaches (mg/kg)

	Cd	Cu	Fe	Mn	Ni	Pb	Zn	Hg
Average	13.6	17.2	1632.6	140.6	12.2	15.3	20.5	0.005
SD	3.19	19.2	931.8	147.7	1.64	2.45	6.56	0.018
%	0.734	0.93	88.1	7.59	0.661	0.828	1.10	0.0002

Note. Pb=lead, Fe=iron, Cd=cadmium, Ni=nickel, Mn=manganese, Zn=zinc, Cu=copper, and Hg=mercury

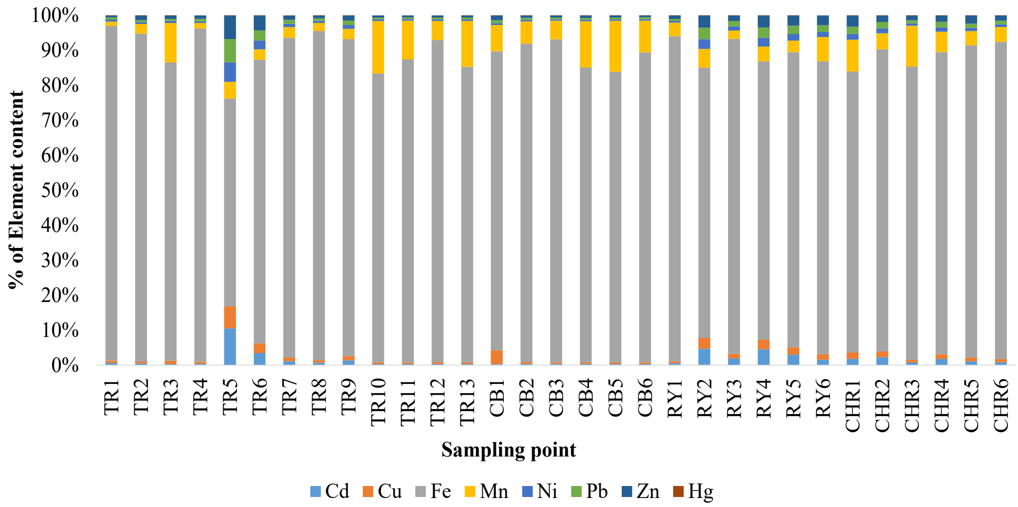


Figure 3. Heavy metal content classified by sampling point

Table 3

The volume of heavy metal contamination classified by province

Element (mg/kg)	Trad	Chanthaburi	Rayong	Chonburi
Cd	13.08±3.142[acd]	10.92±0.417[ac]	16.71±3.211[bd]	14.33±2.317[ad]
Cu	14.85±3.854	31.34±43.51	12.50±0.104	13.07±0.653
Fe	1864.7±908.1[a]	2607.5±6.32[b]	802.8±694.8[c]	985±371.8[c]
Hg	0.002±0.006	0.001	0.017±0.041	0.002±0.003
Mn	151.8±169.9[a]	281.9±0.417[a]	37.95±29.28[ab]	77.64±60.97[ac]
Ni	12.73±2.140	12.88±1.582	11.32±0.193	11.54±0.235
Pb	15.26±2.180[a]	17.75±3.654[b]	13.95±0.757[a]	14.45±0.566[a]
Zn	19.87±6.267	23.28±9.920	17.98±4.315	21.65±5.284

Note. Pb=lead, Fe=iron, Cd=cadmium, Ni=nickel, Mn=manganese, Zn=zinc, Cu=copper, and Hg=mercury

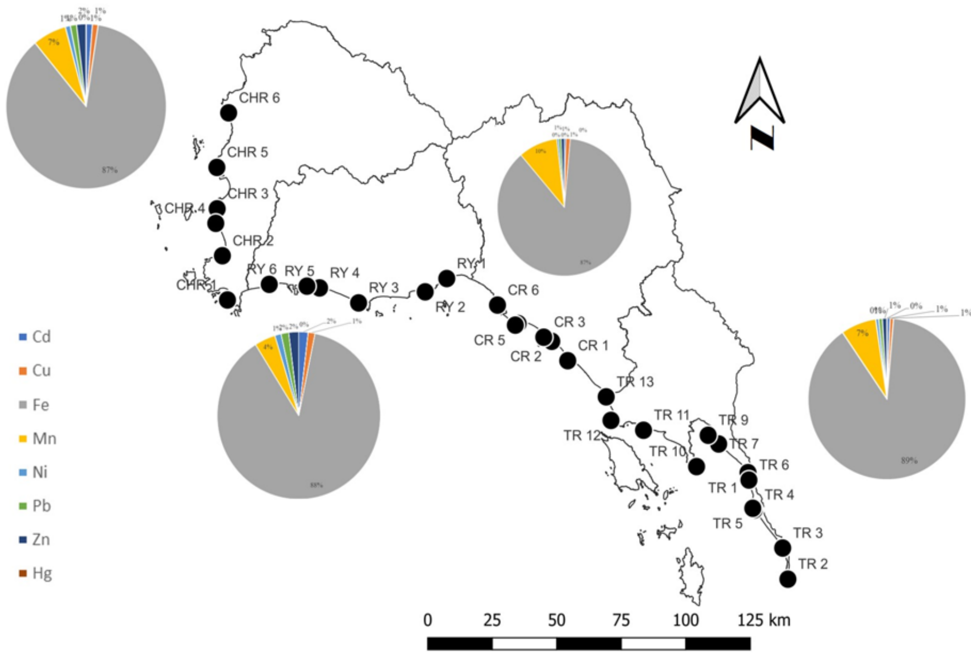


Figure 4. Spatial distribution of heavy metal contamination

Factor Analysis

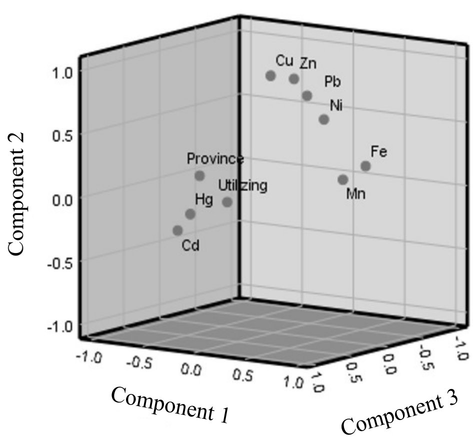
The factor analysis used 10 components as parameters in a PCA. Prior to this, heavy metal contamination components were tested using the Kaiser-Meyer-Olkin (KMO) and Bartlett tests. The KMO Measure of Sampling Adequacy was 0.698 (Table 4), and there was a significant difference between the eigenvalues ($p<0.001$). The three principal components (PCs) found had eigenvalues over 1 and explained 74.589% of the total variance in the dataset (Table 5). A variance of over 10% was found for PC1, PC2, and PC3. PC1 explained 44.153% of the variance (Table 4 & Figure 5). Pb was the most important contributor to PC1, with a factor loading of 0.853. For PC2, the factor loading of Cu was 0.637, so the two primary components of PC2 were Cu and the province. For PC3, local utilization was the most important factor, while Hg had a factor load of 0.883. It was interesting to note that despite the proximity of RY4 to an industrial zone and harbor, the Hg contamination level was only 0.1 mg/kg, which did not exceed the standard of the Pollution Control Department, which is 22 mg/kg (Pollution Control Department, 2021).

Table 4

Results of KMO and Bartlett tests of heavy metal contamination distribution

Kaiser-Meyer-Olkin Measure of Sampling Adequacy	0.698
Bartlett's Test of Sphericity Approx. Chi-Square	181.244
df	45
Sig.	.000

(a)



(b)

Figure 5. Results of the PCA for heavy metal contamination distribution: (a) the eigenvalue of components in the principal analysis; and (b) the loading of PC components: for PC1, various heavy metals, for PC2 is Cu and province, and for PC3 the local utilization and Hg

Table 5

Results of PCA of the statistical significance of heavy metal contamination distribution

PCs	Component		
	PC1	PC2	PC3
% of variance	44.153	15.839	14.589
Cumulative %	44.153	59.991	74.580
Eigenvalue	4.415	1.584	1.459
Pb	.843	-	-
Fe	.838	-	-
Cd	-.834	-	-
Ni	.790	-	-
Mn	.739	-	-
Zn	.698	-	-
Cu	.624	.637	-
Province	-	.504	-
Located utilization	-	-	.853
Hg	-	-	.640

Note. PC=Principal component; underlying factor loading is weighted higher when within 10% of the variation of the absolute value of the highest factor loading for each PC; Pb=Lead; Fe=Iron; Cd=Cadmium; Ni=Nickle; Mn=Manganese; Zn=Zinc; Cu=Copper; and Hg=Mercury

EF and *Igeo* Heavy Metal Contamination in A Sandy Beach of the Eastern Provinces, Thailand

The study sites almost all had *EF* values below 2 (deficiency to minimal enrichment), but the *EF* value for Mn was higher than 2 (mean deficiency to moderate enrichment) in locations TR6, RY2, RY4, and RY5, and the *EF* value for Mn in TR5 was 6 (significant enrichment). *EF* values classified by element and location are presented in Table 2S, *EF* values by element and location are shown in Table 6, and the spatial distribution of *EF* values is presented in Figure 6. However, the ratio with *EF* sediments in the Gulf of Thailand presents an average Cu of 0.80, average Cd of 0.91, average Pb of 1.32, and average Hg of 1.16 (Liu et al., 2016), so the *EF* value is almost below 2 is mean to deficiency to mineral enrichment.

Differences between the *EF* values of Cd between CB and RY provinces were found to be significant ($p<0.05$), differences between the *EF* values of Cu were not found to be significant, the *EF* values of Fe were not found to be significant ($p<0.05$) between RY and CHR provinces, and the *EF* values of Hg, Mn, Pb, and Zn were found to be significantly different ($p<0.05$) between CB and RY provinces. These data are presented in Figure 7, and Table 7 presents *EF* values by heavy metal and province. Mn *EF* values were found to be at levels of 2–5 and 6–20 in locations close to a community, restaurant, and a population of green mussels (*Perna viridus*) culture, so it is possible that Mn levels are related to community activity and transportation in the area (Pavilonis et al., 2015; Choi et al., 2020), and also to the soil parent material in the area (Sanz-Prada et al., 2020).

Table 6

EF by element and location

Element	*EF*<2	*EF* 2-5	*EF* 6-20
Cd	TR1-13/ CB1-6/RY1-6/CHR1-6		
Cu	TR1-13/ CB1-6/RY1-6/CHR1-6		
Fe	TR1-13/ CB1-6/RY1-6/CHR1-6		
Hg	TR1-13/ CB1-6/RY1-6/CHR1-6		
Pb	TR1-13/ CB1-6/RY1-6/CHR1-6		
Ni	TR1-13/ CB1-6/RY1-6/CHR1-6		
Mn	TR1,2,3,4,7,8,9,10,11,12,13/CB1-6/ RY1,3,6/CHR1-6	TR6, RY2, RY4, RY5	TR5
Zn	TR1-13/ CB1-6/RY1-6/CHR1-6		

Note. EF=Enrichment Factors, Pb=lead, Fe=iron, Cd=cadmium, Ni=nickel, Mn=manganese, Zn=zinc, Cu=copper, and Hg=mercury

Table 7

EF by heavy metal and province

		EF-Cd	EF-Cu	EF-Fe	EF-Hg	EF-Pb	EF-Ni	EF-Mn	EF-Zn
TR	Min	.030	.000	.002	.000	.007	.004	.115	.023
	Max	1.71	.094	.060	.000	.420	.253	6.42	1.30
	Average	.290	.010	.042	.000	.071	.042	1.087	.220
	SD	.451	.025	.020	.000	.110	.066	1.69	.344

Table 7 *(Continue)*

		EF-Cd	EF-Cu	EF-Fe	EF-Hg	EF-Pb	EF-Ni	EF-Mn	EF-Zn
CB	Min	.029	.000	.059	.000	.007	.004	.109	.022
	Max	.141	.003	.060	.000	.034	.020	.531	.107
	Average	.029	.001	.060	.000	.020	.012	.317	.064
	SD	.141	.000	.000	.000	.009	.005	.148	.030
RY	Min	.172	.001	.007	.000	.042	.025	.645	.131
	Max	.890	.009	.049	.000	.218	.131	3.33	.678
	Average	.172	.005	.018	.000	.129	.077	1.97	.400
	SD	.890	.003	.016	.000	.073	.044	1.12	.228
CBR	Min	.212	.002	.012	.000	.052	.031	.797	.161
	Max	.529	.005	.033	.000	.130	.078	1.985	.403
	Average	.212	.004	.022	.000	.095	.057	1.45	.296
	SD	.529	.001	.008	.000	.029	.017	.455	.092

Note. EF=Enrichment Factors, TR=Trad province, CB=Chanthaburi, RY=Rayong, CHR=Chonburi, *EF*=Enrichment Factor, Cd=cadmium, Cu=copper, Fe=iron, Hg=mercury, Pb=lead, Ni=nickel, Mn=manganese, Zn=zine

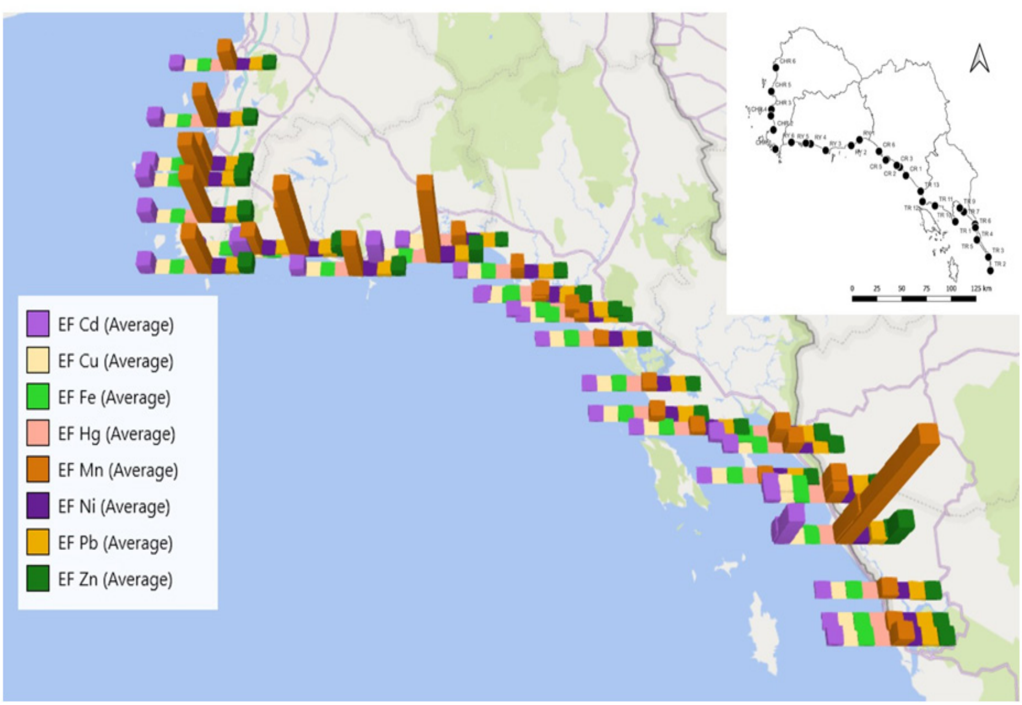


Figure 6. EF distribution in the sandy beach of eastern provinces groups, Thailand

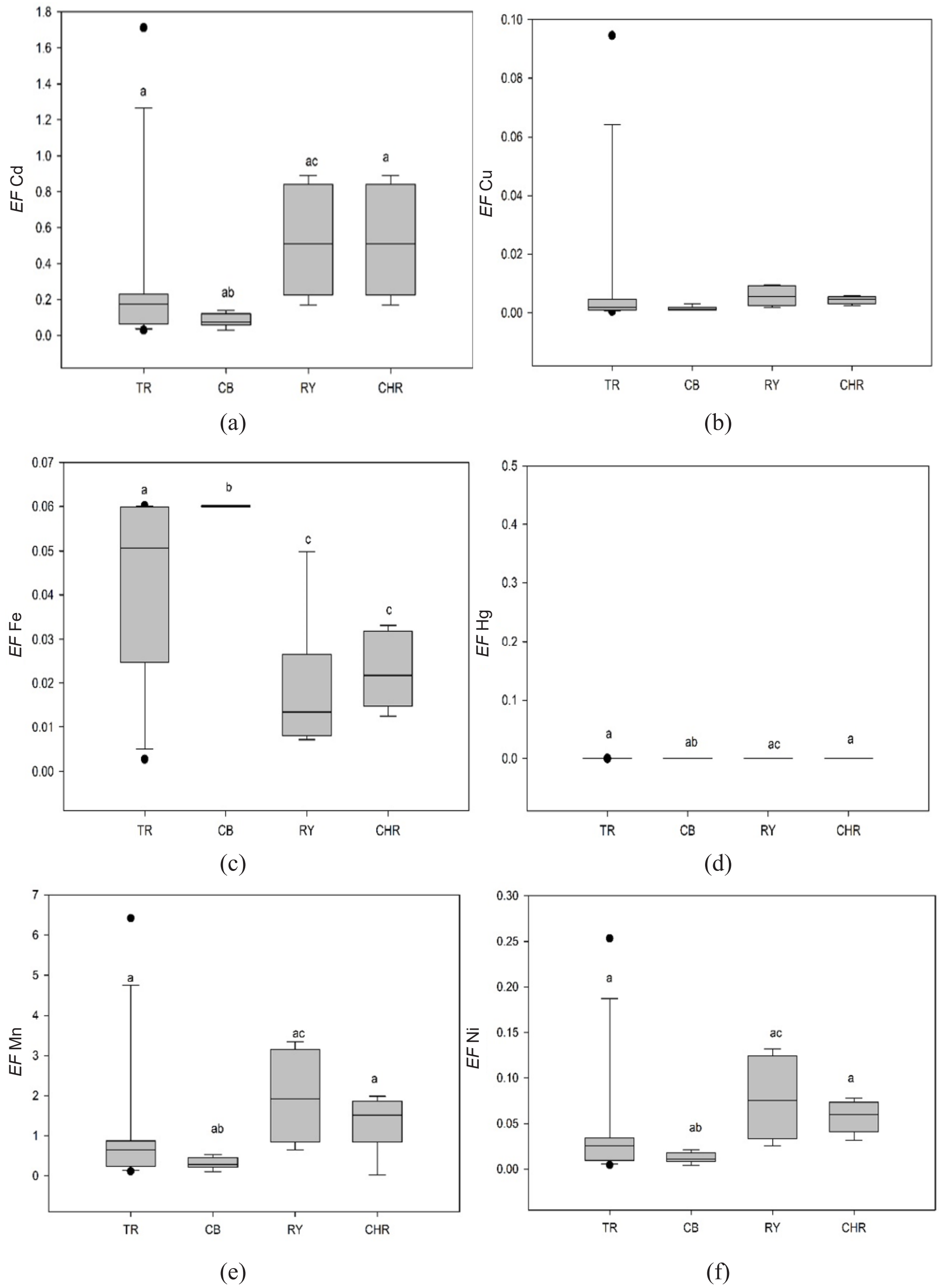
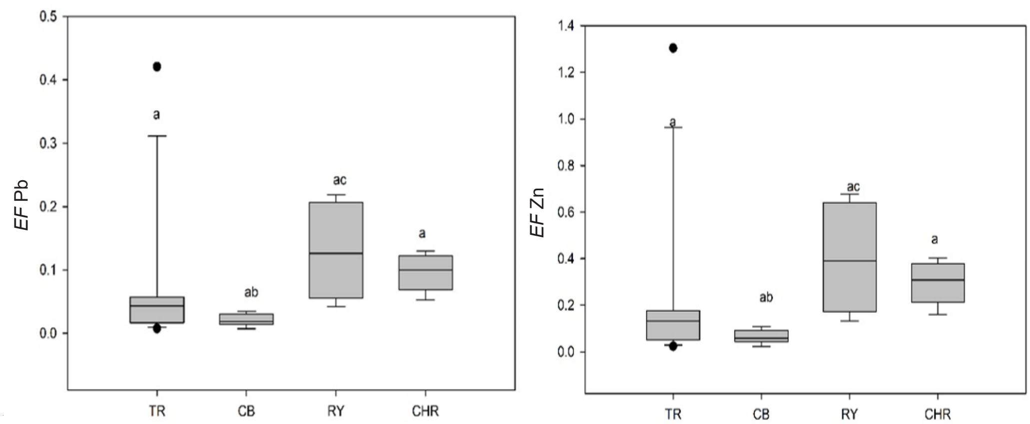


Figure 7. The *EF* results classified by provinces and heavy metals. (a) value *EF* of Cd, (b) value *EF* of Cu, (c) value *EF* of Fe, (d) value *EF* of Hg, (e) value *EF* of Mn, (f) value *EF* of Ni, (g) value *EF* of Pb, (h) value *EF* of Zn



(g) (h)

Figure 7. (Continue)
Note. [a, b, c,] and [d] indicate that the difference is significant at the 0.05 level (*LSD*)

As shown in Table 8, almost no *Igeo* values were over 0 (<0 = unpolluted). *Igeo* values for each heavy metal are presented by location in Figure 8 (Table 3S). The *Igeo* of Cd was over 0 in every location, and the *Igeo* values of Fe, Pb, Mn, and Zn did not exceed 0 at any location. However, the *Igeo* of Hg was found to be 1.00–1.99 at location RY4, meaning that the area is moderately polluted. Thongra-ar et al. (2008) have reported *Igeo* values of below 0 for Hg, Cd, and Ni, but our study found an *Igeo* of Hg of over 0 (1.76) in one location because the location was close to an industrial zone and a large pier. The *Igeo* of Cd was over 0 but not over 2, meaning the beaches were moderately polluted with Cd. However, the value with *Igeo* sediments in the Gulf of Thailand presents the average Cu -1.23, average Cd -1.08, average Pb -0.57, and average Hg -0.76 (Liu et al., 2016), so the *Igeo* value almost below 0 is not polluted.

The categorization of *Igeo* by province is shown in Table 9 shows that Cd and Fe levels were significantly different between TR and RY provinces (p<0.05) but not between RY and CHR provinces. Mn and Pb levels in the CB province significantly differed from those in TR, RY, and CHR provinces (p<0.05). No significant differences between provinces existed between Hg, Ni, and Zn levels. These relationships are presented in Figure 9.

Although our study demonstrates that the east coast beaches of Thailand have safe levels of heavy metal contamination, the *Igeo* of Cd, Ni, and Hg was found to be higher than 0 but not over 2. It means that concentrations of these heavy metals are between the 'non-polluted' and 'moderately polluted' categories, and it is very important that the monitoring and protection of the conserved environment of the beaches continues. The *Igeo* level and high *EF* values are associated with soil parent material, possible enrichment due to human activity (Barbieri, 2016), and the related character of the sea (Nowrouzi & Pourkhabbaz, 2014) the nearby seawater in the Gulf of Thailand will be high in some minerals as a result of the gravitational transfer of heavy metals from the land to the sea, especially in delta zones (Pellinen et al., 2021).

Table 8

Igeo by element and location

Element	*Igeo*	Location
Cd	<0	-
	0.01–0.99	TR1,2,3,4,10,11,12,13, CB1,2,3,4,5,6, RY1,6, CHR1,6
	1.00–1.99	TR5,6,7,8,9, RY2,3,4,5, CHR2,3,4,5
Cu	<0	TR1-13, CB2-6, RY1-6, CHR 1-6
	0.01–0.99	-
	1.00–1.99	CB1
Fe	<0	TR1-13, CB1-6, RY1-6, CHR 1-6
Hg	<0	TR1-13, CB 1-6, RY1,2,3,5,6, CHR1-6
	0.01–0.99	-
	1.00–1.99	RY4
Pb	<0	TR1-13, CB1-6, RY1-6, CHR 1-6
Ni	<0	TR1,2,3,5,6,7,8,9,10,11,13, CB1-6, RY1-6, CHR 1-6
	0.01–0.99	TR4,12
Mn	<0	TR1-13, CB1-6, RY1-6, CHR 1-6
Zn	<0	TR1-13, CB1-6, RY1-6, CHR 1-6

Note. Igeo= Geoaccumulation index, Pb=lead, Fe=iron, Cd=cadmium, Ni=nickel, Mn=manganese, Zn=zinc, Cu=copper, and Hg=mercury

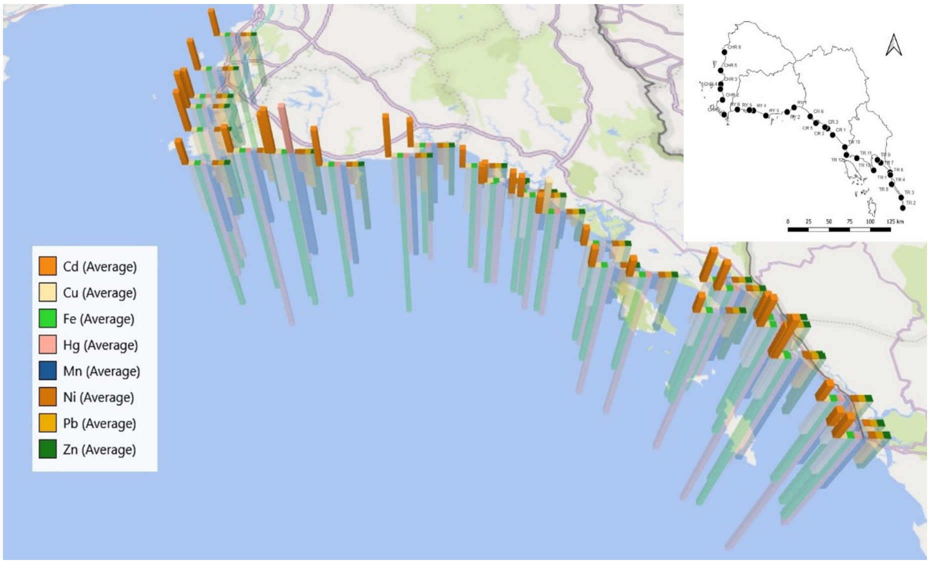


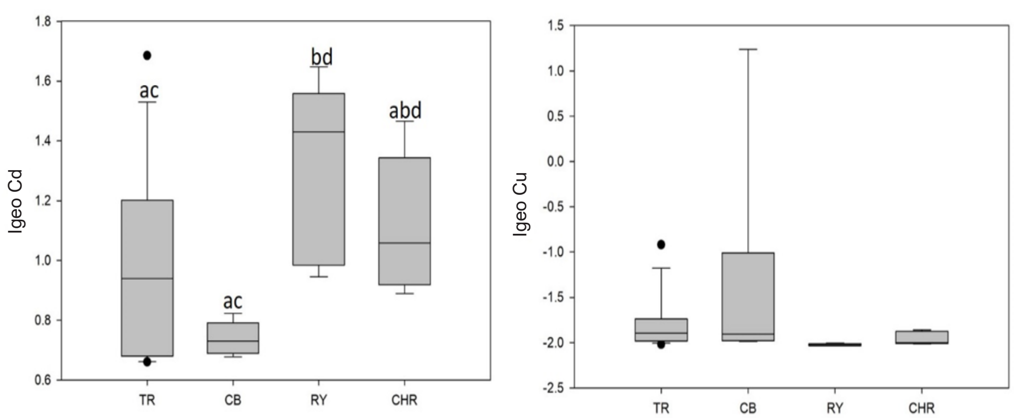
Figure 8. Igeo distribution in the sandy beach of eastern provinces groups, Thailand

Table 9

Igeo results from heavy metal and province

Province		*Igeo*							
		Cd	Cu	Fe	Hg	Pb	Ni	Mn	Zn
TR	Min	.66	-2.02	-9.10	-10.88	-1.47	-.77	-5.66	-3.05
	Max	1.69	-0.92	-4.64	-.28	-.82	.01	-.04	-1.64
	Average	.966	-1.80	-5.48	-5.92	-1.25	-.596	-2.72	-2.36
	SD	.316	.297	1.36	2.82	.193	.208	1.92	.428
CB	Min	.68	-1.99	-4.65	-5.40	-1.30	-.68	-1.69	-2.62
	Max	.82	1.24	-4.64	-4.65	-.53	-.25	-.08	-1.19
	Average	.739	-1.38	-4.64	-4.86	-1.04	-.572	-.893	-2.15
	SD	.054	1.28	.003	.28	.264	.163	.636	.509
RY	Min	.95	-2.04	-7.71	-8.88	-1.45	-.77	-4.66	-2.80
	Max	1.65	-2.00	-4.91	1.77	-1.23	-.72	-2.42	-2.05
	Average	1.11	-2.02	-6.68	-4.37	-1.37	-.750	-3.96	-2.48
	SD	.224	.012	1.01	3.44	.076	.020	.957	.335
CBR	Min	.66	-2.01	-6.90	-6.05	-1.38	-.75	-3.75	-2.74
	Max	1.69	-1.86	-5.50	-1.76	-1.22	-.68	-1.27	-1.74
	Average	1.02	-1.96	-6.13	-4.77	-1.32	-.72	-2.89	-2.21
	SD	.318	.070	.57	1.54	.055	.029	.848	.364

Note. Igeo=Geoaccumulation index, TR = Trad province, CB=Chanthaburi, RY=Rayong, CHR=Chonburi, *EF*=Enrichment Factor, Cd=cadmium, Cu=copper, Fe=iron, Hg=mercury, Pb=lead, Ni=nickel, Mn=manganese, Zn=zine



(a) (b)

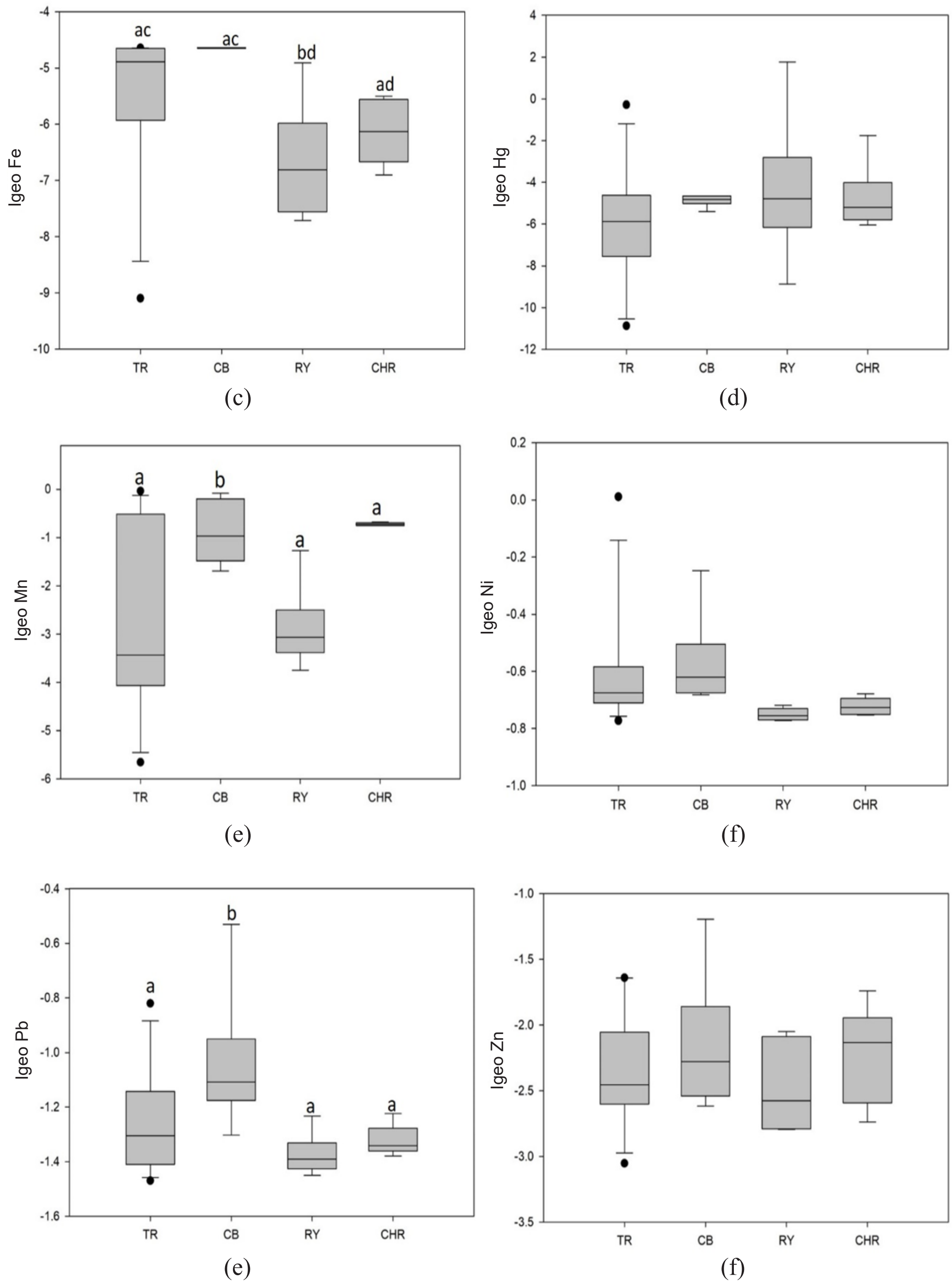


Figure 9. The *Igeo* results are classified by provinces and heavy metals. (a) value *Igeo* of Cd, (b) value *Igeo* of Cu, (c) value *Igeo* of Fe, (d) value *Igeo* of Hg, (e) value *Igeo* of Mn, (f) value *Igeo* of Ni, (g) value *Igeo* of Pb, (h) value *Igeo* of Zn

Note. The letters [a, b, c], and [d] indicate significant differences at the 0.05 level (*LSD*).

CONCLUSION

Overall, sand particles in the beaches of the east coast of Thailand were found to range in size between 0.25–0.85 mm, and the most common heavy metals on average in the samples in descending order were Fe, Mn, Zn, Cu, Pb, Cd, Ni, and Hg (the ratio was 88: 7.74: 0.9312: 0.8283: 0.7347: 0.6582: 0.0002). The volume of Cd contamination in the beaches of RY province was significantly higher than in TR and CB provinces ($p<0.05$), Fe contamination in the beaches of CB province was significantly different ($p<0.05$) to that in the beaches of TR, RY and CHR provinces, and Pb concentration in CB province was significantly different ($p<0.05$) to that in TR, RY, and CHR provinces. None of the contamination levels in the studied beaches exceeded national or international standards. Principle component analysis demonstrated that land use activities influence Hg. The *Igeo* of Hg (1–1.99, moderately polluted) in location RY4 results from the industrial zone and harbor. The *EF* of Mn was within the range of 2–5 in each of the four locations (indicating deficiency to minimal enrichment) and was over 5 (indicating significant enrichment) in one region in Trad and Rayong province. A possible reason for this high Mn *EF* is that the area is near farming and raises aquatic animals of a villager to live around the beach. This study indicates that human activity and land use around beaches can have an impact on the quality of the environment in terms of heavy metal contamination and that soil parent material has an influence on background heavy metal levels, so it is important to calculate background values to perform *EF* and *Igeo* analyses.

The results of this study show that heavy metal contamination in the beaches around the east coast of Thailand is at present within safety levels from the heavy metal, but the *Igeo* and *EF* values signal the possibility that pollution may occur in some areas to relate to human activity which may affect the environment. This information implies that the local and central governments should continue to monitor the environmental impact of human activity and land use around the east coast of Thailand.

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SUPPLIMENTARY DATA

Table 1S

The sampling location and coordinates, including the description of the sample spaces collected

ID	Limit point		Located near the beach to collect
	N	***E***	
TR1	12.0221134	102.76605800	Nearly estuary, and close local restaurant and resort.
TR2	11.6533522	102.90784420	Community
TR3	11.6879430	102.90128350	Community and local fishery pier.
TR4	11.7612855	102.88920890	Nearby the pier (Fish market) and community
TR5	11.8932093	102.78807520	Community and restaurant.
TR6	11.8988673	102.78306920	Community and restaurant.
TR7	11.9968267	102.76926490	Community
TR8	12.1217879	102.66205500	Restaurant
TR9	12.1520733	102.62421470	Community
TR10	12.0434036	102.58364800	Empty area
TR11	12.1691575	102.39527110	Community
TR12	12.2035554	102.27991430	Estuary and community
TR13	12.2851977	102.26292050	Aquaculture zone and community
CB1	12.4102581	102.12649630	Community and local fishery pier.
CB2	12.4777700	102.07000000	Estuary and community
CB3	12.4919145	102.04136630	Pier (Fish market)
CB4	12.5390000	101.95053000	Estuary and community
CB5	12.5336800	101.94046000	Estuary
CB6	12.6032149	101.87718030	Estuary and agriculture zone.
RY1	12.6950931	101.69717390	Estuary and community
RY2	12.6490500	101.62057000	Estuary
RY3	12.6108000	101.38428000	Community and resort
RY4	12.6676500	101.21545000	Neary by industrial zone.
RY5	12.6687729	101.20109160	Aquaculture zone
RY6	12.6750000	101.06728000	Community
CHR1	12.6209150	100.91894900	Tourism space and pier (travel)
CHR2	12.7742808	100.90095440	Estuary and community
CHR3	12.9368950	100.88236810	Tourism space and pier (travel)
CHR4	12.8864152	100.87751200	Restaurant and resort
CHR5	13.0803218	100.88141120	Tourism space and pier (travel)
CHR6	13.2694363	100.92309310	Tourism space and community (in city)

Table 2S

The EF classification by location and element

	EF							
	Cd	Cu	Fe	Hg	Pb	Ni	Mn	Zn
TR1	.239	.094	.045	.000	.058	.035	.898	.182
TR2	.174	.001	.050	.000	.042	.025	.653	.132
TR3	.049	.001	.059	.000	.012	.007	.185	.037
TR4	.101	.001	.060	.000	.024	.015	.381	.077
TR5	1.7	.018	.002	.000	.420	.253	6.42	1.30
TR6	.597	.006	.008	.000	.146	.088	2.23	.454
TR7	.218	.002	.026	.000	.053	.032	.818	.166
TR8	.186	.002	.042	.000	.045	.027	.698	.141
TR9	.224	.002	.022	.000	.055	.033	.842	.171
TR10	.030	.000	.059	.000	.007	.004	.115	.023
TR11	.067	.000	.059	.000	.016	.009	.251	.051
TR12	.105	.001	.060	.000	.026	.015	.397	.080
TR13	.063	.000	.059	.000	.015	.009	.239	.048
CB1	.029	.003	.059	.000	.007	.004	.109	.022
CB2	.067	.000	.060	.000	.016	.010	.254	.051
CB3	.116	.001	.060	.000	.028	.017	.436	.088
CB4	.082	.000	.060	.000	.020	.012	.309	.062
CB5	.070	.000	.059	.000	.017	.010	.264	.053
CB6	.141	.001	.060	.000	.034	.020	.531	.107
RY1	.172	.001	.049	.000	.042	.025	.645	.131
RY2	.890	.009	.007	.000	.218	.131	3.33	.678
RY3	.400	.004	.018	.000	.098	.059	1.50	.305
RY4	.823	.008	.008	.000	.202	.121	3.08	.627
RY5	.622	.006	.011	.000	.152	.091	2.33	.473
RY6	.245	.002	.015	.000	.060	.036	.919	.186
CHB1	.456	.005	.012	.000	.112	.067	1.71	.347
CHB2	.529	.005	.015	.000	.130	.078	1.98	.403
CHB3	.299	.003	.033	.000	.073	.044	1.12	.228
CHB4	.484	.005	.018	.000	.119	.071	1.81	.369
CHB5	.352	.004	.025	.000	.086	.052	1.32	.268
CHB6	.212	.002	.031	.000	.052	.031	.797	.161
Max	.029	.000	.002	.00001	.007	.004	.109	.022
Min	1.71	.094	.060	.00040	.420	.253	6.42	1.30
Average	.315	.006	.037	.00007	.077	.046	1.18	.239
SD	.346	.016	.021	.00008	.085	.051	1.30	.264

Table 3S

The Igeo value of location to collect sample

	Igeo							
Location	Cd	Cu	Fe	Hg	Pb	Ni	Mn	Zn
TR1	.981	-1.89	-5.03	-.282	-1.46	-.725	-4.20	-3.05
TR2	.938	-1.97	-4.88	-5.40	-1.35	-.697	-2.88	-1.63
TR3	.660	-.919	-4.65	-2.53	-1.16	.011	-0.495	-1.64
TR4	.734	-1.70	-4.64	-10.04	-.821	-.639	-3.47	-1.86
TR5	1.68	-2.01	-9.09	-5.00	-1.43	-.772	-5.65	-2.85
TR6	1.29	-1.99	-7.44	-6.04	-1.43	-.734	-5.14	-2.30
TR7	1.17	-1.96	-5.81	-10.8	-1.30	-.675	-3.66	-2.60
TR8	1.08	-1.98	-5.14	-4.33	-1.38	-.691	-3.44	-2.55
TR9	1.23	-1.97	-6.04	-5.87	-1.38	.684	-3.93	-2.59
TR10	.662	-1.56	-4.65	-7.70	-1.12	-.374	-0.037	-2.23
TR11	.697	-1.85	-4.64	-7.40	-1.21	-.596	-0.53	-2.51
TR12	.759	-1.76	-4.64	-6.64	-1.26	.599	-1.65	-2.45
TR13	.661	-1.88	-4.65	-4.90	-.980	-.570	-0.265	-2.40
CB1	.677	1.24	-4.64	-4.87	-.530	-.247	-1.08	-1.19
CB2	.779	-1.75	-4.63	-5.4	-1.09	-.590	-1.41	-2.27
CB3	.823	-1.98	-4.63	-4.64	-1.30	-.681	-1.68	-2.51
CB4	.736	-1.97	-4.64	-4.76	-1.13	-.602	-0.239	-2.07
CB5	.692	-1.87	-4.64	-4.64	-1.11	-.639	-0.082	-2.27
CB6	.724	-1.94	-4.63	-4.87	-1.10	-.672	-0.853	-2.61
RY1	.997	-2.01	-4.90	-5.26	-1.37	-.718	-2.42	-2.04
RY2	1.52	-2.03	-7.71	-4.43	-1.45	-.772	-4.48	-2.79
RY3	1.38	-2.03	-6.33	-4.33	-1.41	-.756	-4.51	-2.78
RY4	1.64	-2.02	-7.50	1.76	-1.41	-.769	-4.66	-2.67
RY5	1.47	-2.03	-7.01	-5.12	-1.36	-.753	-4.60	-2.47
RY6	.945	-2.00	-6.59	-8.87	-1.23	-.734	-3.11	-2.09
CHR1	.889	-2.00	-6.90	-5.26	-1.37	-.750	-2.96	-2.15
CHR2	1.46	-1.99	-6.58	-6.04	-1.35	-.753	-3.74	-2.73
CHR3	1.02	-2.01	-5.49	-4.76	-1.33	-.678	-1.26	-2.01
CHR4	1.30	-2.00	-6.37	-5.12	-1.34	-.734	-3.17	-2.54
CHR5	1.08	-1.86	-5.88	-5.70	-1.29	-.718	-3.26	-1.73
CHR6	.927	-1.87	-5.57	-1.75	-1.22	-.700	-2.91	-2.11
Max	1.68	1.24	-4.63	1.76	-.53	.011	-0.037	-1.19
Min	.66	-2.03	-9.09	-10.8	-1.46	-.772	-5.65	-3.05
Average	1.01	-1.79	-5.67	-5.19	-1.24	-.644	-2.63	-2.31
SD	.315	.601	1.19	2.44	.200	0.165	1.67	0.413