

A Study of Heavy Metal Accumulation in Sediments at Phuket Bay, Saphan Hin, Phuket Province

Kaimook Jaileak and Pensiri Akkajit

Abstract—The concentrations of heavy metals (Sn, Pb, and Zn) were investigated in two sediment cores at Phuket bay, Phuket, Thailand. The analysis of heavy metal content was carried out by using *aqua regia* digestion and measured by using inductively coupled plasma optical emission spectrometer (ICP-OES). The concentrations of Sn, Pb, and Zn were ranged from 49.9 to 167 mg kg⁻¹, 9.6 to 58.7 mg kg⁻¹ and 45.4 to 144 mg kg⁻¹, respectively. The degree of pollution in sediments assessed by Geo-accumulation index (I_{geo}) indicated that the sediment samples in this study were either not contaminated or moderately contaminated with Zn and Pb (-1.40 to 0.26 and -1.24 to 0.97, respectively). In addition, the accumulation of heavy metals was evaluated using Enrichment Factor (EF) and the results showed that sediment samples are minimal to significant enrichment from anthropogenic activity (Pb and Zn: 1.6 to 6.2 and 2.1 to 6.9, respectively).

Index Terms—Accumulation, enrichment factor, geo-accumulation, heavy metal, sediment.

I. INTRODUCTION

Currently, the aquatic environment problem has become a worldwide concern due to anthropogenic activities such as mining, industrial and urban has discharged wastewater directly into water resources that cause the impact on water quality [1], [2] such as the increased heavy metal level in aquatic environment [3]. The heavy metal contamination can affect human and living organisms due to their toxicity, persistence, non-degradability and accumulative behaviors [4]. Metal distribution in the aquatic environment can cause the adverse effects to human health because of food chain transfer. The main sources of the heavy metals in the aquatic environment are difficult to identify. Phuket is one of the provinces in the South of Thailand with the tin (Sn) mining

industry is very popular in the past for the economic development [5]. Tin mining activities have released various metals and toxins to the nature basin without a pre-treatment, and therefore cause metal contamination in the water and sediment [6]. Bang-Yai canal is the main canal of Phuket that used mostly in the past for transportation. Bang-Yai canal is approximately 8,000 meters in length started from Kathu waterfall and ended at the seacoast of the Phuket bay in Saphan Hin at Muang Phuket district. It can be considered as the drainage area receiving many effluents from various community sources from Phuket Town such as old Sn mining ponds, domestic wastewater discharge, and boat parking areas [7]. Therefore, heavy metal accumulation of Lead (Pb), Tin and Zinc (Zn) in the coastal environment is of the interest in this research. The main objective of this study is to study the accumulation and contamination levels of heavy metals at Saphan Hin, Phuket province. The levels of heavy metal contamination in the area were evaluated by using enrichment factor (EF) and geo-accumulation index (I_{geo}) to assess the impact and contamination levels of heavy metals. The results of this research can be used in environmental impact assessment in the area in order to prevent the environmental impact caused by heavy metal pollution.

II. METHODOLOGY

A. Sediment Core Sampling

The study area is located at Saphan Hin, Phuket bay, Muang Phuket District, Phuket province. Sediment samples were collected in May 2017 during the lowest tide of 0.7 to 0.8 meters above the water level [8]. Two sediment cores were sampled namely point A (longitudes 7°52'7.10"N; latitudes 98°24'5.38"E) and point B (longitudes 7°52'3.88"N; latitudes 98°24'4.50"E), respectively by Russian corer (100 cm in length and 12 cm in diameter) (Fig. 1). Each core was sub-sectioned at 5 cm intervals. There are totally 20 sediment layers for each sediment core (totally 40 sediment samples for Core A and B). All of the samples were stored in polythene bags, kept in the icebox at 4°C and brought to the laboratory immediately.

B. Physicochemical Parameters

Physicochemical parameters of the sediment samples in the two cores were determined on-site included sediment pH, oxidation-reduction potential (ORP), and electrical conductivity (EC) (1:5 sediment/water ratio) by pH meter (Eutech version: Cyber scan Diamond Series pH 450) and EC meter (HM version: EC-3M), respectively. Sediment samples were digested following the EPA 3052 guideline [9]. The 0.5 g of dried sediment were digested with *aqua regia* (HNO₃

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and HCl) and analyzed by Inductively Coupled Plasma Optical Emission Spectrometry (ICP-OES) (Perkin Elmer Optima, 4300 DV/Perkin Elmer Optima 800). All glassware was cleaned using HNO₃ (10%) followed by repeated rinsing with deionized water and dried in an electric oven prior to use. The accuracy of the analytical procedures for the analysis of heavy metals in sediment samples was checked using the certified reference material MESS-4 [10]. The results of recovery were Zn 104 ± 6.7% and Pb 114 ± 21.5 %, respectively.

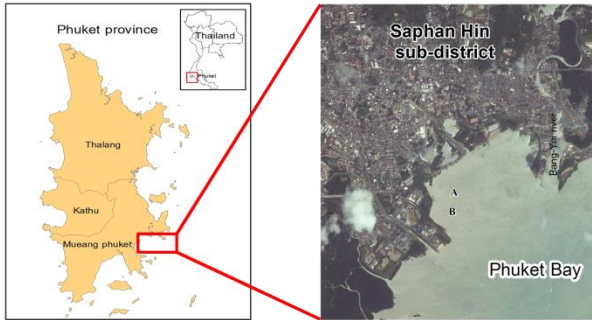


Fig. 1. Sampling sites of sediments at the Phuket Bay.

C. Metal Pollution Level

In order to evaluate the extent of the historical heavy metal pollution, an enrichment factor (EF) was used in this study [11] and calculated as follows;

$$EF = (C_{\text{metal}}/Al)_{\text{sample}} / (C_{\text{metal}}/Al)_{\text{background}} \quad (1)$$

where $(C_{\text{metal}}/Al)_{\text{sample}}$ is the concentration ratio of metal to Al in sediment cores and $(C_{\text{metal}}/Al)_{\text{background}}$ is the average ratio of the same metal to Al in the background sample. The background concentrations of Al, Pb, Zn and Sn in Phuket Province used in this study are: 115,360 mg kg⁻¹, 20 mg kg⁻¹, 80 mg kg⁻¹, and 420 mg kg⁻¹, respectively [12]. The EF values were interpreted as suggested by Department of pollution control (2012) [13] as if EF < 2 means deficiency to minimal enrichment, EF is between 2 to 5 means moderate enrichment, EF is between 5.01 to 20 means significant enrichment, EF is between 20.01 to 40 means very high enrichment, and EF > 40 means extremely high enrichment.

In addition, the Geo-accumulation Index (I_{geo}) was also calculated as criteria to evaluate the intensity of heavy metal contamination in the study area. The calculation is followed [14] as below:

$$I_{\text{geo}} = \text{Log}_2[C_{\text{metal}}(\text{sample}) / 1.5C_{\text{metal}}(\text{background})] \quad (2)$$

where $C_{\text{metal}}(\text{sample})$ is the concentration of a given element and $C_{\text{metal}}(\text{background})$ is the concentration of background value for the metal in sediments. The I_{geo} values were interpreted as: $I_{\text{geo}} < 0$ unpolluted, $0 < I_{\text{geo}} < 0.99$ unpolluted to moderately polluted, $1 < I_{\text{geo}} < 1.99$ moderately polluted, $2 < I_{\text{geo}} < 2.99$ moderately to strongly polluted, $3 < I_{\text{geo}} < 3.99$ strongly polluted, $4 < I_{\text{geo}} < 4.99$ strongly to very strongly polluted, and $I_{\text{geo}} > 5.00$ very strongly polluted [13].

D. Statistical Analysis

Data analysis was done by using one-way analysis of

variance (ANOVA) to indicate the significant differences among different sediment layer depths. All statistical analyses were computed by using SPSS version 16.

III. RESULT AND DISCUSSION

A. Physico-Chemical Properties

The physicochemical properties of the sediment core samples are presented in Table I. It was found that sediment samples are neutral to very strongly alkaline in core A (pH 7.2 to 9.1) and slightly alkaline in core B (pH 8.1 to 8.7). These results are consistent with the research in Bandon Bay, Surat Thani Province as the pH value of the sediments was ranged from 6.15 to 8.37 [15]. The pH value is an important parameter due to most of the chemical reactions in aquatic environment is controlled by any change in its pH value. Anything either highly acidic or alkaline would kill marine life [16]. It was known that high pH values enhance the precipitation of heavy metals through the formation of insoluble carbonates [17]. In addition, redox potential is an important parameter in environmental quality research. The mobility of heavy metals can also be limited due to the reducing conditions of the sediment [18] as it indicates the tendency of an environment to receive or give electrons. Redox potential, together with pH, can be considered as one of a driving variable for speciation of heavy metals [19]. Soil oxidation and reduction depend on soil respiration, diffusion of oxygen, and carbon dioxide in soil and on changes in biochemistry of the system [20]. In this study, the redox potential values in core A and B are ranged from -131 to 59.9 mV and -117 to 122 mV, respectively. These values implied that the sediments in both of cores were oxidized and reduced form. The mobility of metals increases in low oxidation stage ($E_h < 100$ mV) [21]. Heavy metals in the oxidation stage can be more mobile in the environment, however heavy metals in the reduction condition is immobile [22]. The results of this study consistent with another study in the U-Taphao canal, Songkla province found higher ORP ranged values of -221 to 406 mV [23]. Electrical conductivity (EC) is another factor which affects the bioavailability of metals to plant [24]. It is controlled by the extent of soluble salts such as calcium, magnesium and sodium. In this study, the EC values in core A and B are ranged from 789 to 2626 $\mu\text{S cm}^{-1}$ and 752 to 2495 $\mu\text{S cm}^{-1}$, respectively. The sediments with high EC value are without of metals such as iron and zinc [25], and also sediment EC values more than 1000 $\mu\text{S cm}^{-1}$ consist of highly conductive clays [26]. The results of this study consistent with the research in Chanthaburi Estuary found that EC values to be 3500 to 4000 $\mu\text{S cm}^{-1}$ [27].

B. Heavy Metal Concentrations in Sediment

The heavy metal concentrations of Sn, Pb, and Zn in both sediment cores are presented in Table II. Metal contents in core a are as following; Sn: 49.9 to 167 mg kg⁻¹, Pb: 12.7 to 44.5 mg kg⁻¹, and Zn: 45.4 to 88.0 mg kg⁻¹. In sediment core B, metal contents are as following; Sn: 77.5 to 153 mg kg⁻¹, Pb: 9.6 to 58.7 mg kg⁻¹, and Zn: 59.9 to 144 mg kg⁻¹. Suteerasak and Bhongsuwan (2008) [6] studied metal contamination of Al, As, Cu, Cr, Mn, Ni, Pb, Sn, Zn and Fe in

sediment from Bang-Yai River in Phuket Province. They found high concentrations of Zn, Pb, Sn and Al (41-242 mg kg⁻¹, 17-113 mg kg⁻¹, 471 to 15,174 mg kg⁻¹ and 28,945 to 99,961 mg kg⁻¹, respectively). Heavy metal concentrations in this study were compared with other sediment quality standards (Table III.). It was found that metal concentration was less than the Soil Quality Guidelines for the Protection of Environmental and Human Health (Pb 58.7 mg kg⁻¹ and Zn

144 mg kg⁻¹) but Sn concentration was higher than standard. In addition, the measured concentrations of these metals were compared with Sediment Quality Guidelines (SQGs) of Threshold Effects Concentration level (TEC) and Sediment quality in coastal and found that the metal concentration of this study was relatively higher than SQGs and TEC standards.

TABLE I: PHYSIO-CHEMICAL PROPERTIES OF SEDIMENT CORE SAMPLES

Depth (cm)	Core A			Core B		
	Parameters			Parameters		
	pH	ORP (mV)	EC (µS/cm)	pH	ORP (mV)	EC (µS/cm)
1 – 5	7.2 ± 0.32 ^a	17.6 ± 5.7 ^d	1117 ± 13 ⁱ	8.5 ± 0.01 ^e	47.9 ± 16.9 ^h	752. ± 46.1 ^c
6 – 10	7.7 ± 0.09 ^b	-35.1 ± 6.1 ^d	967 ± 69.5 ^h	8.6 ± 0.06 ^e	-37.6 ± 0.62 ^{g,h}	1092 ± 230 ^c
11 – 15	8.0 ± 0.11 ^c	-51.3 ± 1.0 ^d	1017 ± 82 ^h	8.7 ± 0.06 ^e	41.9 ± 0.29 ^{g,h}	979 ± 109 ^b
16 – 20	8.1 ± 0.04 ^d	-115 ± 5.4 ^{c,d}	789 ± 46.8 ^h	8.6 ± 0.01 ^{d,e}	70.9 ± 3.2 ^{f,g,h}	843 ± 92.2 ^b
21 – 25	8.2 ± 0.02 ^{d,e}	32 ± 4.4 ^{c,d}	1045 ± 39.9 ^{g,h}	8.5 ± 0.07 ^{c,d,e}	106 ± 2.6 ^{f,g}	1040 ± 24.8 ^b
26 – 30	8.4 ± 0.02 ^{d,e,f}	43.2 ± 3.7 ^c	1598 ± 24.6 ^{g,h}	8.5 ± 0.08 ^{c,d,e}	89.5 ± 5.6 ^{f,g}	1338 ± 243 ^{a,b}
31 – 35	8.3 ± 0.07 ^{e,f}	-116 ± 4.8 ^b	1415 ± 95.4 ^{f,g,h}	8.4 ± 0.34 ^{b,c,d,e}	91.7 ± 2.6 ^{e,f}	1666 ± 69.5 ^{a,b}
36 – 40	8.3 ± 0.03 ^f	-116 ± 2.5 ^b	1626 ± 253.2 ^{f,g,h}	8.6 ± 0.02 ^{b,c,d,e}	79.1 ± 4.9 ^{d,e,f}	1609 ± 155 ^{a,b}
41 – 45	8.4 ± 0.03 ^f	-128 ± 6.4 ^b	1848 ± 14.9 ^{e,f,g}	8.7 ± 0.03 ^{b,c,d,e}	76.2 ± 6.0 ^{d,e,f}	1251 ± 249 ^{a,b}
46 – 50	8.7 ± 0.05 ^g	-123 ± 3.6 ^b	1380 ± 130 ^{e,f}	8.5 ± 0.04 ^{b,c,d,e}	77.8 ± 7.1 ^{d,e,f}	1598 ± 154 ^{a,b}
51 – 55	8.7 ± 0.04 ^{g,h}	-113 ± 4.2 ^b	1926 ± 19.8 ^{e,f}	8.5 ± 0.13 ^{b,c,d,e}	89.1 ± 6.9 ^{d,e,f}	1356 ± 229 ^{a,b}
56 – 60	8.7 ± 0.09 ^{g,h,i}	-131 ± 2.8 ^b	1131 ± 218 ^{d,e}	8.5 ± 0.09 ^{b,c,d,e}	100 ± 5.8 ^{d,e}	1389 ± 94.4 ^{a,b}
61 – 65	8.8 ± 0.05 ^{g,h,i}	-124 ± 6.9 ^a	2148 ± 34.8 ^{c,d,e}	8.1 ± 0.18 ^{b,c,d,e}	122 ± 11.1 ^{d,e}	1190 ± 156 ^{a,b}
66 – 70	8.8 ± 0.08 ^{g,h,i}	-68.2 ± 2 ^a	2066 ± 53 ^{b,c,d,e}	8.4 ± 0.06 ^{b,c,d,e}	119 ± 5.1 ^{d,e}	2495 ± 119 ^{a,b}
71 – 75	8.8 ± 0.01 ^{g,h,i}	-35.9 ± 12 ^a	2167 ± 248 ^{a,b,c,d}	8.6 ± 0.08 ^{b,c,d,e}	116 ± 1.1 ^d	2481 ± 188 ^{a,b}
76 – 80	8.9 ± 0.03 ^{h,i}	-49.1 ± 5.2 ^a	2041 ± 159 ^{a,b,c,d}	8.7 ± 0.04 ^{b,c,d}	102 ± 2.1 ^d	1070 ± 24.8 ^{a,b}
81 – 85	8.8 ± 0.03 ⁱ	-59.9 ± 16 ^a	2134 ± 69.5 ^{a,b,c}	8.6 ± 0.08 ^{b,c}	95.5 ± 5.1 ^c	977 ± 24.8 ^{a,b}
86 – 90	9.1 ± 0.03 ^j	55.3 ± 1.7 ^a	2626 ± 102 ^{a,b}	8.5 ± 0.09 ^b	71 ± 7.4 ^c	1256 ± 38.7 ^{a,b}
91 – 95	8.9 ± 0.07 ^j	59.9 ± 2.3 ^a	1731 ± 243 ^a	8.4 ± 0.10 ^a	86 ± 0.88 ^b	993 ± 114 ^a
96 – 100	8.9 ± 0.06 ^j	59.7 ± 2.8 ^a	1457 ± 174 ^a	8.2 ± 0.19 ^a	-117. ± 1.9 ^a	1054 ± 54.6 ^a
Max	9.1	59.9	2626	8.7	122	2495
Min	7.2	-131	789	8.1	-117	752
Mean	8.5	-50	1612	8.5	73.9	1321

TABLE II: CONCENTRATIONS OF ZINC (ZN), LEAD (PB) AND TIN (SN) IN THE STUDIED CORES

Depth (cm)	Core A				Core B			
	Concentrations (mg kg ⁻¹)				Concentrations (mg kg ⁻¹)			
	Zn	Pb	Sn	Al	Zn	Pb	Sn	Al
1 – 5	65.4 ± 2.1	12.7 ± 1.6	99.1 ± 0.05	15429 ± 127	144 ± 6.5	11.1 ± 0.51	89.9 ± 0.06	21233 ± 215
6 – 10	50.9 ± 3.8	17.5 ± 6.1	107. ± 0.06	17664 ± 147	95.7 ± 3.5	52.5 ± 2.5	105 ± 0.10	21986 ± 795
11 – 15	60.7 ± 1.1	18.1 ± 0.2	98.1 ± 0.06	20684 ± 213	59.5 ± 1.6	30.5 ± 2.1	113 ± 0.07	24873 ± 192
16 – 20	46.5 ± 6.1	20.2 ± 2.1	111 ± 0.07	23321 ± 111	64.2 ± 7.1	38.2 ± 2.3	118 ± 0.01	18387 ± 444
21 – 25	46.5 ± 3.4	22.4 ± 3.7	126 ± 0.01	29293 ± 322	68.6 ± 5.3	42.5 ± 7.3	113 ± 0.08	19429 ± 408
26 – 30	88.0 ± 3.3	25.3 ± 1.3	111 ± 0.02	22874 ± 544	69.9 ± 9.3	45.9 ± 3.4	128 ± 0.08	35683 ± 932
31 – 35	54.4 ± 4.5	23.9 ± 2.6	129 ± 0.04	26191 ± 179	89.9 ± 1.1	39.1 ± 1.9	123 ± 0.04	43681 ± 794
36 – 40	62.9 ± 1.1	27.1 ± 8.7	162 ± 0.13	24981 ± 133	95.1 ± 5.5	58.7 ± 2.8	77.5 ± 0.03	46225 ± 753
41 – 45	66.9 ± 5.1	35.9 ± 5.3	150 ± 0.04	37466 ± 614	112 ± 10.1	54.5 ± 2.1	92.1 ± 0.11	41144 ± 149
46 – 50	69.1 ± 5.8	33.0 ± 4.6	167 ± 0.06	36681 ± 347	98.6 ± 5.2	36.0 ± 7.4	106 ± 0.04	56974 ± 307
51 – 55	71.1 ± 9.1	35.7 ± 3.1	49.9 ± 1.85	34735 ± 502	111 ± 6.5	49.1 ± 1.3	110 ± 0.05	30058 ± 302
56 – 60	76.1 ± 4.2	37.0 ± 7.0	156 ± 0.03	35782 ± 459	75.2 ± 3.4	36.2 ± 1.3	118 ± 0.05	66034 ± 324
61 – 65	59.7 ± 1.1	27.2 ± 1.5	152 ± 0.15	29400 ± 638	82.9 ± 7.3	45.3 ± 3.2	111 ± 0.03	72306 ± 382
66 – 70	50.9 ± 2.7	44.5 ± 1.5	139 ± 0.17	29260 ± 576	86.4 ± 1.2	37.2 ± 4.9	127 ± 0.04	50962 ± 481
71 – 75	45.4 ± 1.4	31.0 ± 4.7	129 ± 0.08	34867 ± 151	83.7 ± 4.1	30.8 ± 8.5	124 ± 1.28	60584 ± 759

76 – 80	62.3 ± 8.3	32.4 ± 3.9	145 ± 0.06	32916 ± 490	61.6 ± 0.7	16.4 ± 3.6	153 ± 0.05	56501 ± 908
81 – 85	79.9 ± 2.4	26.7 ± 3.5	136 ± 0.12	29568 ± 395	69.7 ± 1.2	9.6 ± 3.1	109 ± 0.3	51683 ± 106
86 – 90	70.9 ± 5.3	16.8 ± 1.6	146 ± 0.06	25600 ± 197	79.5 ± 1.2	14.5 ± 1.1	133 ± 0.07	45673 ± 284
91 – 95	85.3 ± 2.1	14.6 ± 1.9	148 ± 0.16	22083 ± 538	74.2 ± 6.1	13.8 ± 2.4	121 ± 0.11	69066 ± 338
96 – 100	58.8 ± 1.9	13.4 ± 0.7	153 ± 0.11	18287 ± 224	78.1 ± 5.4	17.9 ± 2.5	105 ± 0.08	33630 ± 873
Max	88.0	44.5	167	37466	144	58.7	153	72306
Min	45.4	12.7	49.9	15429	59.9	9.6	77.5	18387

TABLE III: SEDIMENT QUALITY FROM THE NATIONAL AND INTERNATIONAL STANDARDS

Standards	Concentrations (mg kg ⁻¹)			References/years
	Zn	Pb	Sn	
1. Soil Quality Guidelines for the Protection of Environmental and Human Health	200	140	50	Canadian Council of Ministers of the Environment, 1999 [28]
2. Sediment Quality Guidelines: SQGs Threshold Effects Concentration level (TEC)	121	35.8	-	Department of pollution control, 2012 [29]
3. Sediment quality in coastal (to prevent marine benthic)	102	52	-	Department of pollution control, 2015 [30]
4. This study	144	58.7	167	This study, 2017

C. Geo-Accumulation Index (I_{geo}) Evaluation of Heavy Metals

The calculated I_{geo} values for Zn in core A showed the values of less than zero (-1.40 to -0.45) which indicated unpolluted condition of the sediments. In addition, the I_{geo} values for Zn in core B are ranged from -1.01 to 0.26 indicated unpolluted to moderately polluted level of the sediments. In contrast, the I_{geo} values for Pb were observed to be from -1.24 to 0.57 and -1.64 to 0.97 in core A and core B, respectively indicated that the sediment was unpolluted to moderately polluted level. Therefore, it is suggested that almost all of the sediment samples in this study were not contaminated or moderately contaminated with Zn and Pb. The low I_{geo} values were found in other studies. For example, Pb was found to be unpolluted/moderately polluted in Bangpakong estuary, Chachoengsao province [31] and the sediments at the inner Gulf of Thailand were found to be moderately polluted with Pb [32].

D. Enrichment Factor (EF) Evaluation of Heavy Metals

The enrichment factor (EF) is a useful tool for differentiating the man-made and natural sources of metal contamination [33]. This evaluating technique is carried out by normalizing the metal concentration based on geological characteristics of [34]. Al has been widely used for normalizing the metal concentration in sediments because it is a major metal element in the earth crust and not affected by man-made factors [35]. In this study, the EF profiles for Zn in core A and B are ranged from 2.1 to 6.9 and 1.6 to 6.2, respectively. These results indicated that sediment samples are minimal to significant enrichment. The EF values of Pb in Core A and B ranged from 3.4 to 9.8 and 1.9 to 6.9, respectively. It also indicates that sediment samples are minimal to significant enrichment from human activity in the studied area. The human activities from local contribution can be influenced the pollution level in this study area. In addition, it was observed that Zn is enriched in the upper layers as compared to the lower layers of core sediments. However, Pb was observed to be enriched in the lower layers

(40 to 75 cm) as compared to the upper layers of sediment cores. These results are consistent with the research in the inner Gulf of Thailand as they found the significant Pb enrichment of sediments by anthropogenic activities [32].

IV. CONCLUSIONS

In conclusion, this study shows that the concentrations of the heavy metals in Phuket bay were ranged over following intervals: Sn 49.9 to 167 mg kg⁻¹, Pb 9.6 to 58.7 mg kg⁻¹ and Zn 45.4 to 144 mg kg⁻¹ that are found to be below the Soil Quality Guidelines for the Protection of Environmental and Human Health except for tin (Sn) metal (Sn, Pb and Zn: 50, 140 and 200 mg kg⁻¹, respectively). While the measured concentrations of these metals were higher than Sediment Quality Guidelines: SQGs Threshold Effects Concentration level (TEC) (Pb and Zn: 35.8, 121 mg kg⁻¹, respectively) and Sediment quality in coastal (Pb and Zn: 52, 102 mg kg⁻¹, respectively). The contamination levels of the heavy metals by calculated I_{geo} values suggested that almost all of the sediment samples in this study were either not contaminated or moderately contaminated with Zn and Pb metals (-1.40 to 0.26 and -1.24 to 0.97, respectively), and the sediment samples are minimal to significant enrichment from anthropogenic activity (the EF values for Pb and Zn: 1.6 to 6.2 and 2.1 to 6.9, respectively). It was suggested that the anthropogenic activities may be from local contribution and influence of urbanization recently. However, since sediments can accumulate for heavy metals in the aquatic system, their potential risks to the environment must be considered.

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REFERENCES

- [1] E. Callender, "Heavy metals in environment-historical trends," *Elsevier-Pergamon*, pp. 67-106, 2005.
- [2] L. Bruggemann, A. Paschke, B. Daus, and H. Weiss, "Characterization of sediments in an 405 abandoned mining area; a case study of Mansfield region," *Ger. Environ. Geol.*, vol. 45, pp. 818-833, 2004.
- [3] J. O. Nriagu, "Global metal pollution: poisoning the biosphere," *Environ Sci Policy Sustain Dev*, vol. 32, pp. 7-33, 1990.
- [4] R. Yu, X. Yuan, Y. Zhao, G. Hu, and X. Tu, "Heavy metal pollution in intertidal sediment from Quanzhou Bay, China" *Journal of Environment Science*, vol. 3, pp. 125-142, 2008.
- [5] N. Khongkwan, *Mining in Thailand*, PR Content Center, Bangkok, 2015.
- [6] T. Suteerasak and T. Bhongsuwan, "Contamination of heavy metals Al, As, Cu, Cr, Mn, Ni, Pb, Sn, Zn and Fe in sediment from Bang-Yai River in Phuket Province," *Research and Development KMUTT J.*, vol. 31, pp. 765-779, October-December, 2008.
- [7] The Department of mineral resources, *Classification of Geology and Mineral Resources Management Phuket Province*, Bangkok, 2013.
- [8] Navy Hydrographic Department, *Tidal Sea Level of Phuket Province*, Phuket, Thailand, 2017.
- [9] US EPA, *Method 3052 Microwave Assisted Acid Digestion of Siliceous and Organically Based Matrices*, 1996.
- [10] National Research Council Canada MESS-4: *Marine Sediment Reference Material for Trace Metals and other Constituents*, Canada, 2014.
- [11] P. Woitke, J. Wellmitz, D. Helm, P. Kube, P. Lepom, and P. Litheraty, "Analysis and assessment of heavy metal pollution in suspended solids and sediments of the river Danube," *Chemosphere*, vol. 51, pp. 633-642, 2003.
- [12] M. S. Garson, B. Young, A. H. G. Mitchell, and B. A. R. Tait, *The Geology of the Tin Belt in Peninsular Thailand around Phuket, Phangnga, and Takua Pa*, Natural Environment Research Council, Institute of Geological Sciences, London, 1975.
- [13] The Department of pollution control, *Report Set the Benchmark in Quality, Sediment, and Surface Water Sources*, Office waste management and hazardous substances, Bangkok, 2012.
- [14] G. Müller, "Index of geoaccumulation in sediments of the Rhine River," *Geo J.*, vol. 2 pp. 109-118, 1969.
- [15] C. Sukudom, M. Kaewner, I. Wudtisn, T. Yoshikawa, Y. Okamoto, K. Watanabe, S. Ishikawa, and J. Salaenoi, "Organic contents and pH profiles of sediments in cockle farm at Bandon Bay, Surat Thani Province," *KHON KAEN AGR J.*, vol.43, pp. 265-276, 2015.
- [16] U. Pravin *et al.*, "Assessing the physico-chemical parameters of sediment ecosystem of vasai creek at Mumbai, India," *Marine Science*, vol. 1, pp. 22-29, 2011.
- [17] G. Sposito, *The Chemistry of Soils*, Oxford University Press, New York, 1989.
- [18] P. Kelderman and A. A. Osman, "Effect of redox potential on heavy metal binding forms in polluted canal sediments in delft (The Netherlands)," *Water Res.*, vol. 41, pp. 4251-4261, 2007.
- [19] W. Salomons, "Environmental impact of metals derived from mining activities: processes, predictions, prevention," *J. Geochem. Explor.*, vol. 52, pp. 5-23, 1995.
- [20] J. Nemecek, L. Smolikova, and M. Kutilek, *Pedologie a Paleopedologie Academia*, p. 552, 1990.
- [21] A. Kabata and H. Pendias, *Trace Elements in Soils and Plants*, 3rd edition, CRC Press, Florida, 2001.
- [22] W. Wisawapipat, "Remediation technologies of heavy metal contaminated soils using phosphate materials," *KHON KAEN AGR. J.*, vol. 40, pp. 373-378, 2012.
- [23] N. Aunjangwang, "Contamination of arsenic and lead in sediment of U-Taphao canal," M.S. thesis science in marine and coastal resources management, Prince of Songkla University, Songkla, Thailand, 2013.
- [24] J. Nouri, B. J. Alloway and P. J. Peterson, "Forms of heavy metals in sewage sludge and soil amended with sludge," *Pak J Biol Sci*, vol. 4, pp. 1460-1465, 2001.
- [25] P. Kathuli, "Soil salinization in selected irrigation schemes in Taveta Sub County, Kenya," *East Africa Agriculture and Forestry Journal*, 2014.
- [26] W. T. Ward, G. McTainsh, D. McGarry, and K. J. Smith, "The soils of the agricultural research station at 'Myall Vale', near Narrabri, NSW, with data analysis by fuzzy k-means," *CSIRO Technical Report 21/99*, 1999.
- [27] W. Seatang, W. Laongmanee, B. Paibulkichakul, and C. Paibulkichakul, "Soil electrical conductivity at Chanthaburi Estuary during winter and rainy seasons," *KHON KAEN AGR. J.*, vol. 42 suppl. 1, 2014.
- [28] Canadian Council of Ministers of the Environment, *Canadian Sediment Quality Guidelines for the Protection of Aquatic Life: Summary Tables Updated. In: Canadian Environmental Quality Guidelines 1999*, Canadian Council of Ministers of the Environment, Winnipeg, Canada, 2002.
- [29] The Department of pollution controls, *Sediment Quality Guidelines (SQGs) of Threshold Effects Concentration level (TEC)*, Bangkok, 2012.
- [30] Department of pollution controls, *Sediment quality in coastal*, Bangkok, Thailand, 2015
- [31] W. Thongra-ar, C. Musika, W. Wongsudawan, and A. Munhapon, "Distribution and accumulation of some heavy metals in mangrove sediments of Ban Laemchabang Community, Chon Buri Province," *Burapha University International Conference 2015, Proceedings of the Burapha University International Conference 2015*, July, pp. 780-788, 2015.
- [32] P. Mingkwan, M. Suksomjit, and S. Jiewjareun, *The Quality of Sediment in the Gulf of Thailand after the Floods in 2012*, Department of Pollution Control, Bangkok, 2012.
- [33] J. Morillo, J. Usero, and I. Gracia, "Heavy metal distribution in marine sediments from the southwest coast of Spain," *Chemosphere*, vol. 55, pp. 431-442, 2004.
- [34] W. C. Chiu, F. C. Chih, and D. D. Cheng, "Distribution and enrichment evaluation of cadmium in the sediments of Canon River Mouth, Taiwan," *Energy Procedia*, vol. 16, pp. 895 - 900, 2012.
- [35] C. W. Chen, C. M. Kao, C. F. Chen, and C. D. Dong, "Distribution and accumulation of heavy metals in the sediments of Kaohsiung Harbor, Taiwan," *Chemosphere*, vol. 66, pp. 1431-1440, 2007.



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