Distribution of heavy metals in sediment along the Southern coast of Vietnam

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Abstract. The heavy metals (HM), particularly As, Cd, Pb and Hg, are considered most toxic to biota and environment. In this study, spatial and seasonal distribution of HMs (Cd, Pb, Hg and As) were measured in two sediment fractions (< 63 µm and 63 – 500 µm) collected in the farming area of blood cockle. A total of 104 sediment sampled along the Southern coast of Vietnam between December 2012 and July 2015 were examined. The average concentrations (µg/g) of As, Cd, Pb and Hg in sediment fraction of 63 – 500 µm ranged from 4.16 to 16.8, < 0.004 to 0.219, 9.52 to 17.3 and 0.031 to 0.076, respectively. While, the mean levels (µg/g) of As, Cd, Pb and Hg in sediment fraction of < 63 µm ranged from 4.59 to 12.8, < 0.004 to 0.187, 9.94 to 14.6 and 0.042 to 0.080, respectively. Generally, no statistically significant differences were found for concentrations of HMs in both fractions between two seasons and among provinces. The concentrations of HMs analyzed in sediment were compared to quality guidelines for the protection of aquatic life recommended by the Canadian Council of Ministers of the Environment (CCME) and the Vietnamese organizations (QCVN 43 : 2012/BTNMT). HM levels in all samples were lower than the Vietnamese regulation and the probable effect level in the CCME guideline. However, As levels in 67/103 and 84/104 of two fractions of < 63 µm and 63 – 500 µm, respectively, exceeded the threshold effect level of 7.24 µg/g in the CCME standard. It suggested that As accumulated in sediment in these provinces could be harmful to the aquatic organism.

1. Introduction

Presently, about 50% of Vietnam’s population lives in the coastal provinces, and there are increasingly concentrating in large coastal cities (e.g., Ho Chi Minh, Da Nang, Hai Phong) in addition to coastal economic and centralized industrial zones. The increase of populations and economic activities in the coastal areas is causing a massive pollution, most likely in hotspots such as the major estuaries and the coastline. The government estimate that municipal, industrial and agricultural wastes and run-off account for over 60% of all marine pollution, specifically those resulting from nutrients, persistent organic pollutants and heavy metals in water and sediments [1].

The heavy metals (HM), particularly As, Cd, Pb and Hg, may affect the water chemistry and are potential hazards to biota because of their toxicity and bio-accumulative characteristics. HM contamination can result in adverse effects including growth changes, metabolic process, and disease
development [2]. When discharged into water column, HM may be adsorbed onto suspended particles and then deposited in sediments; but depending on the physicochemical factors, it can be released back into the water column when it is disturbed [3, 4]. Understanding the main factors that influence the distribution of HMs in water would allow better prediction of the changes in HM toxicity to aquatic organisms [4, 5].

The objectives of the present study are to evaluate the distribution pattern of four HMs (i.e. As, Cd, Pb and Hg) in two fractions (< 63 µm and 63 – 500 µm) of sediment collected in the farming area of blood cockle along the southern coast of Vietnam and the influence of overlying water and sediment parameters that control the distribution pattern of the studied HMs.

2. Materials and Methods

2.1. Sample collection and preparation

Sediment were collected in the farming area of blood cockle along the southern coast of Vietnam, including Ho Chi Minh City (HCM) and 6 provinces of Tien Giang, Ben Tre, Tra Vinh, Bac Lieu, Ca Mau, and Kien Giang between December 2012 and December 2015 (Figure 1).

Figure 1. A map showing sampling sites in Southern coast of Vietnam.

Surface sediment (0 – 5 cm) was taken manually using Ekman grabber. At each site, sediment was collected from 4 to 5 subsites and aliquots of the top 5 cm from each replicate subsite were composited to form the site sample. Samples were kept in an ice box, transported to laboratory of Faculty of Fisheries, Nong Lam University and stored in a deep freezer at –20°C before analysis.

2.2. Heavy metals and physicochemical analyses

Sediment from thawed samples was wet-sieved using a 2 mm aperture metal sieve to remove large objects, litter, plants and leaves. Then samples were wet-sieved using two Saulas stainless steel containers with mesh size 500 µm on top of the one with mesh size 63 µm to separate them into two sediment fractions (< 63 µm and 63 – 500 µm). Each of the sediment samples was dried at 60°C for 48 hrs and ground to a fine powder using a mortar and pestle in preparation for the analysis.

For Cd, Pb and Hg, approximately 1 g of the dried sample was digested with 10 ml acid mixture (HNO₃:H₂SO₄ = 7:3). Concentrations of Cd and Pb were determined by use of an inductively coupled plasma-mass spectrometer. Mercury was determined by use of a cold-vapour amalgam atomic absorption spectrometer (AAS). For As analysis, sample was digested with an acid mixture (HNO₃:H₂SO₄:HClO₄ = 10:1:1) and determined by use of hydride generation AAS.

pH value of sediment (63 – 500 µm) was determined after mixing samples with water at a sediment: water ratio of 1:5. The organic matter (OM) content was determined by igniting at 350°C for 8 hrs [6].

2.3. Quality assurance and quality control (QA/QC) procedure

Reagent grade chemicals were used in all analytical procedures. For each batch or 20 samples, at least one matrix spike, one matrix spike duplicate and two reagent blanks were used as the QA/QC procedure of the analysis. The accuracies of the methods were assessed by triplicate analysis of the
marine sediment reference material MESS-3 (National Research Council of Canada); recovery of the elements ranged from 95 to 111% of the certified values. Detection limits for As, Cd, Pb and Hg were 0.15, 0.0036, 0.085 and 0.0025 µg/g dry wt, respectively. All data were expressed on a dry weight basis (µg/g dry wt).

2.4. Statistical analyses
One-half of the value of the respective limit of detection was substituted for those values below the limit of detection and used in statistical analysis [7]. All data were tested for goodness of fit to a normal distribution and homogeneity of variances with a Kolmogorov–Smirnov’s one sample test and Levene test, respectively. Because most of the variables were not normally distributed, the data were logarithmically transformed and subjected to parametric statistics. Pearson correlation was used to measure the relationships among concentrations of HMs in two sediment fractions (< 63 µm and 63 – 500 µm) and physicochemical parameters. For testing provincial differences, log transformed data were analyzed using one-way analysis of variance (ANOVA) with Duncan multiple range test as pairwise comparisons. A p-value < 0.05 was considered to indicate statistical significance. These statistical analyses were executed by the program SPSS (version 19, SPSS, Chicago, IL, USA).

3. Result and Discussion

3.1. Physicochemical parameters of sediment samples
Physicochemical parameters of sediment samples were shown in Table 1. Average pH\textsubscript{H2O} ranged from 7.21 in the Ben Tre sediment to 7.74 in the Kien Giang sediment (Table 1), suggesting that sediment pH was neutral to slightly alkaline. pH values in sediment found in these regions were similar to those reported in the previous studies. pH values in sediment collected in Da Nang Bay ranged 6.5 to 8.2 [8]. In Nha Trang Bay, pH values in sediment were 7.2 – 7.6 [9]. While, pH in coastal sediments in Ngoc Hien District, Ca Mau ranged from 5.3 to 7.7 [10]. Similarly, pH values in sediment collected in Mekong River ranged from 6.25 to 8.08 [11].

Table 1. Physicochemical parameters of water samples collected from the coasts of Vietnam.

| Province       | N | pH\textsubscript{H2O}          | OM (%)     |
|----------------|---|-------------------------------|------------|
| Kien Giang     | 25| 7.74 ± 0.47\textsuperscript{a} | 12.4 ± 2.5 |
|                |   | (6.40 – 8.63)\textsuperscript{b} | (6.10 – 16.6) |
| Bac Lieu       | 22| 7.65 ± 1.05                  | 10.2 ± 4.9 |
|                |   | (3.83 – 8.59)                | (5.23 – 28.7) |
| Ca Mau         | 26| 7.22 ± 1.16                  | 14.1 ± 2.1 |
|                |   | (3.98 – 8.41)                | (10.2 – 18.1) |
| Tra Vinh       | 3 | 7.51 ± 0.29                  | 9.04 ± 1.47 |
|                |   | (7.17 – 7.7)                 | (8.10 – 10.7) |
| Ben Tre        | 15| 7.21 ± 0.70                  | 9.47 ± 1.55 |
|                |   | (5.20 – 7.85)                | (5.72 – 11.7) |
| Tien Giang     | 11| 7.47 ± 1.21                  | 9.20 ± 1.89 |
|                |   | (4.16 – 8.59)                | (6.24 – 13.1) |
| Ho Chi MinhCity| 3 | 7.33 ± 0.39                  | 12.4 ± 1.0 |
|                |   | (6.89 – 7.62)                | (11.3 – 13.2) |

\textsuperscript{a} Mean ± standard deviation.  
\textsuperscript{b} Range.

The lowest OM content (9.04 ± 1.47%) was found in sediment from Tra Vinh, and the highest value (14.1 ± 2.1) occurred in Ca Mau sediment. OM content in sediment from these regions were found to be similar to that reported in the Nguyen [10] work, OM content in sediment from the coast
of Ngoc Hien District, Ca Mau ranged from 1.6 to 6.2%. However, OM content in sediment in the present study was lower than that reported in Nha Trang Bay (1.71 – 27.06%) [9].

### 3.2. Provincial differences in heavy metal concentrations

Concentrations of HMs in two sediment fractions collected from the Southern coast of Vietnam were exhibited in Table 2.

**Table 2.** Heavy metal concentrations (µg/g dry wt.) in two sediment fractions (< 63 µm and 63 – 500 µm) collected from the Southern coast of Vietnam.

| Province       | n   | As        | Cd         | Pb          | Hg        |
|----------------|-----|-----------|------------|-------------|-----------|
| 63 – 500 µm    |     |           |            |             |           |
| Kien Giang     | 25  | 12.2 ± 7.4<sup>ab</sup> | 0.182 ± 0.188<sup>b</sup> | 13.9 ± 7.9<sup>abc</sup> | 0.046 ± 0.012<sup>ab</sup> |
|                | (0.624 – 26.2)<sup>c</sup> | (<0.0036 – 0.601) | (2.30 – 33.6) | (0.025 – 0.065) |           |
| Bac Lieu       | 22  | 14.7 ± 9.4<sup>b</sup> | 0.219 ± 0.284<sup>b</sup> | 17.2 ± 7.2<sup>b</sup> | 0.076 ± 0.037<sup>b</sup> |
|                | (1.16 – 32.7) | (0.009 – 1.28) | (3.96 – 33.2) | (0.033 – 0.175) |           |
| Ca Mau         | 26  | 16.8 ± 5.1<sup>b</sup> | 0.184 ± 0.122<sup>b</sup> | 17.3 ± 4.4<sup>c</sup> | 0.051 ± 0.011<sup>b</sup> |
|                | (8.14 – 27.9) | (0.022 – 0.468) | (6.72 – 26.6) | (0.031 – 0.068) |           |
| Tra Vinh       | 3   | 11.2 ± 4.9<sup>b</sup> | 0.051 ± 0.028<sup>ab</sup> | 16.1 ± 7.1<sup>b</sup> | 0.072 ± 0.041<sup>b</sup> |
|                | (6.23 – 16.0) | (0.019 – 0.068) | (11.7 – 24.3) | (0.043 – 0.119) |           |
| Ben Tre        | 15  | 12.9 ± 7.2<sup>b</sup> | 0.098 ± 0.111<sup>ab</sup> | 13.2 ± 4.7<sup>abc</sup> | 0.064 ± 0.014<sup>b</sup> |
|                | (1.20 – 24.0) | (0.007 – 0.426) | (5.59 – 20.9) | (0.035 – 0.100) |           |
| Tien Giang     | 10  | 12.0 ± 6.7<sup>b</sup> | 0.059 ± 0.050<sup>ab</sup> | 9.67 ± 3.29<sup>s</sup> | 0.069 ± 0.012<sup>c</sup> |
|                | (0.740 – 22.9) | (<0.0036 – 0.138) | (5.19 – 14.7) | (0.057 – 0.089) |           |
| Ho Chi Minh    | 3   | 4.16 ± 3.12<sup>a</sup> | <0.0036<sup>a</sup> | 9.52 ± 5.99<sup>ab</sup> | 0.031 ± 0.008<sup>a</sup> |
|                | (0.601 – 6.39) | (0.006-0.041) | (4.52 – 16.2) | (0.023 – 0.038) |           |
| < 63 µm        |     |           |            |             |           |
| Kien Giang     | 24  | 9.98 ± 8.50<sup>ab</sup> | 0.141 ± 0.179<sup>b</sup> | 14.6 ± 6.1<sup>a</sup> | 0.057 ± 0.030<sup>ab</sup> |
|                | (0.286 – 39.3) | (<0.0036 – 0.564) | (2.3 – 29.6) | (0.030 – 0.170) |           |
| Bac Lieu       | 22  | 12.8 ± 11.1<sup>ab</sup> | 0.187 ± 0.233<sup>b</sup> | 12.5 ± 7.6<sup>s</sup> | 0.069 ± 0.032<sup>ab</sup> |
|                | (0.836 – 44.0) | (0.007 – 0.954) | (3.56 – 28.5) | (0.041 – 0.196) |           |
| Ca Mau         | 26  | 14.9 ± 7.9<sup>b</sup> | 0.162 ± 0.113<sup>b</sup> | 9.94 ± 3.31<sup>a</sup> | 0.058 ± 0.011<sup>b</sup> |
|                | (5.00 – 36.1) | (0.022 – 0.490) | (4.14 – 14.9) | (0.039 – 0.08) |           |
| Tra Vinh       | 3   | 5.58 ± 4.04<sup>ab</sup> | 0.036 ± 0.021<sup>b</sup> | 16.1 ± 6.2<sup>s</sup> | 0.065 ± 0.005<sup>ab</sup> |
|                | (1.02 – 8.70) | (0.014 – 0.055) | (12.3 – 23.3) | (0.061 – 0.071) |           |
| Ben Tre        | 15  | 7.43 ± 8.47<sup>a</sup> | 0.071 ± 0.093<sup>b</sup> | 10.9 ± 5.4<sup>s</sup> | 0.080 ± 0.033<sup>b</sup> |
|                | (0.421 – 30.7) | (0.005 – 0.378) | (4.20 – 21.6) | (0.045 – 0.176) |           |
| Tien Giang     | 10  | 11.5 ± 5.5<sup>ab</sup> | 0.052 ± 0.048<sup>b</sup> | 10.8 ± 5.7<sup>s</sup> | 0.066 ± 0.018<sup>ab</sup> |
|                | (1.95 – 18.4) | (0.009 – 0.177) | (4.35 – 22.1) | (0.039 – 0.108) |           |
| Ho Chi Minh    | 3   | 4.59 ± 3.53<sup>a</sup> | <0.0036<sup>a</sup> | 13.5 ± 7.3<sup>s</sup> | 0.042 ± 0.008<sup>a</sup> |
|                | (0.525 – 6.82) | (<0.0036 – 0.017) | (5.32 – 19.3) | (0.033 – 0.049) |           |

<sup>1</sup> Mean ± standard deviation.

<sup>2</sup> Range.

In the same sediment fraction (< 63 µm or 63 – 500 µm), mean values in the same column with different superscript letters are significantly different (p < 0.05, one-way ANOVA with Duncan test).

#### 3.2.1. Arsenic

In this study, the general tendency in As concentrations in both fractions among different provinces were Ca Mau > Bac Lieu > Ben Tre, Kien Giang and Tien Giang > Tra Vinh > HCM. There were statistically significant differences in mean As concentration of 63 – 500 µm fraction among provinces (ANOVA, p < 0.05): As levels were lowest at HCM, but, no statistically significant differences was found in mean As concentration of sediment samples among remaining
provinces (p > 0.05). In 63 µm fraction, mean As levels were lowest at HCM and Ben Tre sediments (p < 0.05), whereas, As levels in other province sediments were not significantly different (p > 0.05). Concentrations of As in 63 – 500 µm sediment fraction collected in Southern coast fluctuated significantly from different sampling time. Concentrations of As accumulation in sediment collected at Kien Giang and Bac Lieu shows increasing trend over three year sampling period (Figure 2), while there were no clear trend in other provinces.

3.2.2. Cadmium. For 63 – 500 µm fraction, mean Cd concentrations ranged from < 0.0036 µg/g in sediment from HCM to 0.219 µg/g in sediment from Bac Lieu (Table 2). Similarly, for < 63 µm fraction, mean Cd concentrations ranged from < 0.0036 µg/g in sediment from HCM to 0.187 µg/g in sediment from Bac Lieu.

There were statistically significant differences in mean Cd levels of sediment samples (63 – 500 µm) among provinces (p < 0.05). Cadmium concentrations in HCM sediment were lower than those from Kien Giang, Bac Lieu and Ca Mau sediments (p < 0.05), but there were no significant differences between Cd values in sediment from these three provinces (p > 0.05). Moreover, Cd concentrations in

![Figure 2. Comparison of As, Cd and Pb levels in 63 – 500 µm fraction collected from the Southern coast of Vietnam among provinces and sampling time. Bar represent the mean and standard deviation of HM levels.](image-url)
sediments from Tra Vinh, Tien Giang and Ben Tre did not differ significantly from HCM and other three provinces Kien Giang, Bac Lieu and Ca Mau \((p > 0.05)\). For \(< 63 \, \mu m\) fraction, Cd concentration in the HCM sediment was lowest \((p < 0.05)\), but there were no significant differences in Cd concentration among other provinces \((p > 0.05)\). These results suggested that the concentration of Cd in sediments collected from the Southern coast of Vietnam is quite uniform among provinces. In general, fluctuation of Cd concentrations between sampling time seems to be less (Figure 2).

3.2.3. Lead. Lead levels in sediments from the Southern coastal zone narrowly varied among sampling sites (Table 2). Concentrations of Pb in sediment samples ranged from 9.52 ± 5.99 µg/g at HCM to 17.3 ± 4.4 µg/g at Ca Mau in fraction of \(63 \, \mu m – 500 \, \mu m\) and from 9.94 ± 3.31 µg/g at Ca Mau to 16.1 ± 6.2 µg/g at Tra Vinh in fraction of \(< 63 \, \mu m\). No statistically significant difference of Pb levels in fraction of \(< 63 \, \mu m\) was found among provinces \((p > 0.05)\), but there were statistically significant differences in mean Pb levels of sediment samples \((63 – 500 \, \mu m)\) among provinces \((p < 0.05)\). Lead concentrations in Tien Giang sediment were lowest, but did not differ significantly from HCM, Kien Giang and Ben Tre \((p > 0.05)\). While, there were no significant differences between Pb values in sediment from these three provinces and Tra Vinh and Bac Lieu \((p > 0.05)\). On the contrary, Pb concentrations in sediment collected from Ca Mau were highest, but did not differ significantly from Kien Giang, Ben Tre, Tra Vinh and Bac Lieu \((p > 0.05)\). Similar to Cd, fluctuation of Pb concentrations between sampling time seem to be less (Figure 2).

Similar results were reported by Tho [10], Pb levels in sediments ranged from 5.9 – 10.87 µg/g for the coastal regions of Ngoc Hien, Ca Mau.

3.2.4. Mercury. Generally, Hg was present in trace amounts in most of sediment samples and Hg levels in sediment shows a narrow fluctuation among provinces. Average levels of Hg in \(63 – 500 \, \mu m\) fraction of sediment collected from the southern coast were lowest in HCM \((0.031 ± 0.008 \, \mu g/g)\) and highest in Bac Lieu \((0.076 ± 0.037 \, \mu g/g)\). Similarly, mean levels of Hg in \(< 63 \, \mu m\) fraction of sediment were lowest in HCM \((0.042 ± 0.008 \, \mu g/g)\) and highest in Bac Lieu \((0.069 ± 0.032 \, \mu g/g)\).

The differences of Hg levels in \(63 – 500 \, \mu m\) fraction of sediment collected from the coastal zone were statistically significant among provinces (Table 2). Mercury concentrations in HCM sediment were lower than those from Bac Lieu, Tra Vinh, Tien Giang, Ben Tre and Ca Mau \((p < 0.05)\), but there was no significant difference between Hg value in sediment from HCM and Kien Giang \((p > 0.05)\). On the other hand, Hg concentrations in Tien Giang sediment were higher than those from Kien Giang and Ca Mau, but there was no significant difference between Hg value in sediment from Tien Giang and three provinces Ben Tre, Tra Vinh and Bac Lieu \((p > 0.05)\). While, the concentration of Hg in sediments did not differ significantly among Kien Giang, Ca Mau, Ben Tre, Tra Vinh and Bac Lieu \((p > 0.05)\).

3.3. Relationships between concentrations of total heavy metals in water and physicochemical properties

It is well-known that the HM bioavailability in sediment to aquatic organisms affect by sediment properties including grain size, OM, pH, redox potential, acid volatile sulphides. The main factors affecting the accumulation, mobility and availability of HMs are pH, OM content, major element chemistry and, to some extent, biological activity [12, 13]. In this study, relationships between physicochemical characteristics \((pH_{\text{H}_2O} \text{ and OM content})\) and HM concentrations in two sediment fractions were assessed using Pearson correlations (Table 3).

| Table 3. Correlation coefficients \((r)\) for relationships among log-transformed concentrations \((\mu g/g)\) of HMs in two sediment fractions \((< 63 \, \mu m \text{ and } 63 – 500 \, \mu m)\) and physicochemical parameters. |
|-----------------|------------------|------------------|------------------|
|                 | OM               | < 63 \(\mu m\)   | 63 – 500 \(\mu m\) |
|                 | \(pH_{\text{H}_2O}\) | As   | Cd   | Pb   | Hg   | As   | Cd   | Pb   | Hg   |
| pH_{\text{H}_2O} | -0.20*           | -0.13 | 0.00 | -0.15 | -0.02 | -0.05 | -0.02 | -0.16 | -0.01 |
The weak negative correlation found between pH$_{\text{H}_2\text{O}}$ and OM content ($r = -0.20$) (Table 3), implicating that increase in OM content in sediment lead to decrease in pH and vice versa. Similar results were reported by Tho [10], who found pH$_{\text{H}_2\text{O}}$ and OM content was weakly negatively associated ($r = -0.743$).

The significant positive correlations discovered between OM content and As levels in $< 63$ µm fraction ($r = 0.30$) and Pb levels in $63 – 500$ µm fraction ($r = 0.22$) (Table 3), suggesting that there is a close affinity between two elements and organic fraction in sediment. This result is comparable with the findings by Phuong et al. [14] and Ho et al. [15] in other coastal zones of Vietnam. Phuong et al. [14] reported that Cd (0.0%) and Hg (0.93%) rarely occurred in organic fraction, while 10.55% and 39.9% of As and Pb in sediment, respectively, were associated with organic fraction. This result also supported by Ho et al. [15] who reported that OM content has very strong correlations with As ($r = 0.56$) and Pb ($r = 0.77$) in sediment from the Ha Long Bay.

The weak positive correlations found between As levels and Cd levels in $< 63$ µm fraction ($r = 0.29$), and As levels in $< 63$ µm fraction and concentrations of As ($r = 0.38$), Cd ($r = 0.27$) and Pb ($r = 0.24$) in $63 – 500$ µm fraction (Table 3). Moreover, Cd levels in $< 63$ µm fraction was weakly negatively associated with Pb levels in $< 63$ µm fraction ($r = -0.38$) and positively associated with concentrations of As ($r = 0.38$) and Cd ($r = 0.76$) in $63 – 500$ µm fraction (Table 3). Furthermore, Pb levels in $< 63$ µm fraction were weakly negatively related to concentrations of Hg in $< 63$ µm fraction ($r = -0.30$) and Cd in $63 – 500$ µm fraction ($r = -0.23$) (Table 3). And, As levels in $63 – 500$ µm fraction were weakly positively correlated with concentrations of Cd ($r = 0.35$) and Pb ($r = 0.33$) in $63 – 500$ µm fraction (Table 3).

Metal relationships were evaluated using Pearson correlation coefficient ($r$) and showed that each paired element had an identical source, geochemistry, and/or common sink [16]. Moreover, weak correlations (negative or positive) between each paired HMs indicated that concentrations of HMs in sediment controlled by various factors. The levels of As and Cd between two fractions were strongly positively correlated, implying that fine grain-sized sediments influenced on concentrations of these two elements. In aquatic sediments, HMs are mostly enriched in and are associated with the fine-grained fractions [3, 16]. Studying geochemical factors affecting accumulation of HMs in sediment in the HCM canals, Thuy et al. [17] found positive relationships between Cd levels and clay fine fraction ($< 63$ µm). Ho et al. [15] also reported that strong to very strong correlations between As, Cd, Pb and the fine-grained fraction ($r = 0.63$, $r = 0.76$ and $r = 0.88$, respectively) for sediments from the Ha Long Bay.

### 3.4. Comparison with published data and guidelines

Concentrations of HMs in sediment in the present study were compared to those from other sites (Table 4). Compared to other published works, average concentrations of As in sediments collected from the Vietnam southern coast were comparable with or higher. Levels of As in the coast sediment of Can Gio, HCM were 12.8 µg/g [14]. According to Tho [10], accumulation levels of As in the coastal sediment of Ngoc Hien, Ca Mau ranged 3.23 – 14.97 µg/g. While, Duong and Tram [11] reported levels of As accumulated in sediment of Mekong River ranged 3.9 – 8.2 µg/g. However, concentrations of As in sediment in this study were higher than those collected from Da Nang coastal.

|          | OM  | As  | Cd  | Pb  | Hg  |
|----------|-----|-----|-----|-----|-----|
| < 63 µm  | 0.30| -0.04| 0.12| -0.09| 0.17|
|          | -0.04| 0.09| -0.15| 0.38| 0.27|
|          | 0.24| 0.17| -0.38| 0.38| 0.76|
|          | -0.11| -0.17| 0.03| -0.23| 0.13|
|          | 0.06| 0.14| -0.05| 0.06| 0.14|
| 63 – 500 µm | 0.35| -0.01| 0.05| -0.18| |

*Bold numbers in columns indicate significance at $p < 0.05$. 
zone (1.8 – 6.3 μg/g) [8]. On the contrary, concentrations of As in sediment in this study were lower than those collected from the Ha Long Bay, Quang Ninh (13 – 62 μg/g) [15, 18] (Table 4). The concentrations of As analyzed in sediments remained below sediment quality guidelines (SQGs) for the protection of aquatic life recommended by the Canadian Council of Ministers of the Environment (CCME) and the Vietnamese regulation (QCVN 43:2012/BTNMT) (41.6 μg/g) [24, 23] (Table 4). However, As levels in 67/103 (accounting for 65%) of < 63 μm sediment fraction and 84/104 (81%) of 63 – 500 μm sediment fraction exceeded the TEL of CCME; particularly, sediments collected from Ca Mau, Kien Giang, Bac Lieu, Ben Tre and Tien Giang. These results were similar to the findings by Nguyen et al. [18] and Ho et al. [15] in other coastal zones of Vietnam. Nguyen et al. [18] described on As values which exceed the TEL of CCME by 2-7 times in the Ha Long Bay. Similarly, Ho et al. [15] reported As has a mean concentration above TEL with 100% of samples exceeding TEL, in which 97% of samples fall in the range between TEL and PEL, and 3% of samples exceed PEL. These results implied that As are possible to have adverse effects on aquatic organisms that live in the sediment.

Table 4. Comparison of the concentrations of HMs in sediment in the present study with those from other studies

| Country          | Region                | As        | Cd         | Pb          | Hg         | Reference       |
|------------------|-----------------------|-----------|------------|-------------|------------|-----------------|
| Vietnam          | Southern coast        | 13.7 ± 7.4 | 0.158 ± 0.184 | 14.9 ± 6.5 | 0.059 ± 0.024 | This study      |
|                  |                       | (0.601 – 32.7) | (<0.004 – 1.28) | (2.3 – 33.6) | (0.023 – 0.175) |                 |
| Can Gio, Ho Chi Minh City |               | 12.8      | 0.140      | 14.31      | 10.82     | [14]            |
| Ho Chi Minh City canal |              | 0.06 – 4.31 | 10.4 – 52.3 | –          | –         | [17]            |
| Sai Gon – Dong Nai river |            | 13.15 – 49.89 | –          | –         | –         | [19]            |
| Mekong River     |                       | 5.9 ± 0.4  | 1.1 ± 0.1  | 3.8 ± 0.4  | 0.10 ± 0.01 | [11]            |
|                  |                       | (3.9 – 8.2) | (0.1 – 2.4) | (0.9 – 6.6) | (0.04 – 0.14) |                 |
| Mekong River     |                       | 3.23 – 14.97 | 0.023 – 0.093 | 2.07 – 11.3 | NDb         | [10]            |
| Ngoc Hien, Ca Mau |                       | 0.85 – 8.39 | 4.85 – 57.3 | 0.31 – 0.50 | [21]       |
| Central river    |                       | 1.8 – 6.3 | 0.023 – 0.994 | 3.00 – 40 | 0.03 – 1.2 | [8]             |
| Da Nang coastal zone |                  | 13 – 62   | 0.02 – 0.20 | 4 – 41      | –         | [15]            |
| Ha Long Bay, Quang Ninh |             | 14 – 46   | 0.081 – 0.408 | 21.1 – 38.9 | –         | [12]            |
| Thailand         | Gulf of Thailand      | –         | 1.24 – 2.32 | –         | –         | [22]            |
| Malaysia         | Strait of Malacca     | 41.6      | 4.2        | 112        | 0.7       | [23]            |
| QCVN 43:2012/BTNMT |                  | 7.24      | 0.7        | 30.2       | 0.13      | [24]            |
| CCME (threshold effect level, TEL) |        | 41.6      | 4.2        | 112        | 0.7       | [24]            |
| CCME (probable effect level, PEL) |          | 41.6      | 4.2        | 112        | 0.7       | [24]            |

*a Mean ± standard deviation.

b Range.

c ND: not detected.

d CCME: Canadian Council of Ministers of the Environment.

In this work, accumulation levels of Cd in sediments were compared to those in other researches (Table 4). Range of Cd levels in sediments collected from the cockle farming areas were comparable to those from clam farming area in Can Gio, HCM [14], Mekong River [20, 11], Ngoc Hien district, Ca Mau [10], the Da Nang coastal zone [8] and the Ha Long Bay, Quang Ninh [15]. However, Cd concentrations in sediments in the present study were lower than those collected from HCM canals and the Central river systems. In general, the results obtained in the present study were in the range found in other Southeast Asia countries, or even lower in some cases [12, 22] (Table 4).
Comparing results of the present study with other works, range of Pb levels were lower than those from the HCM canals [17], the Sai Gon – Dong Nai river system [19], the Central river systems [21], the Da Nang coastal zone, the Ha Long Bay [15, 18] and the Gulf of Thailand [12]. On the other hand, the values of Pb obtained at the cockle farming areas were very close to or higher than those obtained in Can Gio, Ho Chi Minh City [16], Mekong River [11, 20] and Ngoc Hien, Ca Mau [10] (Table 4).

Accumulation of Hg in sediments obtained in this study was similar to or lower than those reported from the other works (Table 4). Generally, Hg is present in trace amounts in most of sediment samples and the Vietnam inland or coastal waters have not been polluted with Hg.

Comparing results of the present study with the SQGs recommended by the CCME and the Vietnamese regulation, it was observed that concentrations of Cd in one sample (both fractions), Pb in two samples (63 – 500 µm fraction) and Hg in three samples (both fractions) are higher the TEL (0.7, 30.2 and 0.13 µg/g, respectively), respectively (Table 4), suggesting that these HMs are not probable to have adverse effects on aquatic organisms that inhabit the surface of the sediment.

4. Conclusions
Based on the results of this study, it may be concluded that the concentration of HMs in sediments collected from the Southern coast of Vietnam is quite uniform among provinces. The comparison of HM concentrations in these regions with other sites does not show any significant difference, indicating that the regions are in the range of ‘unpolluted’ water. However, As showed values exceeding the TEL SQGs that are probable to have adverse effects on biota. Further research on understanding the biological and ecological effects of potential toxic As in different aquatic animals from these regions is clearly warranted. These results could be useful for future relative studies of HM contamination and monitoring programs to assess marine pollution originates from land-based sources.

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