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Assessment of heavy metal pollution risk in sediments of coastal ecosystems in Vietnam

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ABSTRACT

The grain sizes and heavy metal contents of surface sediments in coastal ecosystems of Vietnam, including estuaries, seagrasses, coastal lagoons, embayments, and coral reefs, were analysed from 43 samples. Heavy metal pollution indices such as geoaccumulation (Igeo), the contamination factor (CF), the enrichment factor (EF), the ecological risk potential (ER), the degree of contamination (CD), and the ecological risk (RI) were used to evaluate sediment quality. The surface sediments were distributed into 9 types: very fine gravel, very coarse sand, coarse sand, medium sand, fine sand, very fine sand, very coarse silt, coarse silt, and medium silt. The average concentrations of Fe, Mn, Zn, Pb, Cu, Cr, V, As, Co, Cd, and Mo were 1,0015.45, 252.83, 67.91, 14.17, 12.27, 13.98, 17.28, 4.00, 5.63, 0.09, and 0.17 mg/kg, respectively, heavy. The Igeo was unpolluted. The CF had low contamination, except for Zn, which had moderate contamination. The EF were moderate (Pb and As) and moderate (Cd and Zn). The ER, CD, and RI indices were low. Although the average pollution indices were low, some areas in estuaries and coastal lagoon ecosystems presented high values. The negative correlation between Md and heavy metals revealed that grain size impacts heavy metal accumulation. The positive correlation between heavy metals revealed that they had a source origin. Factor analysis also revealed that natural sources of heavy metals accounted for 67.99% of the total heavy metals. In addition, heavy metals were also supplied from anthropogenic sources, with Cd and Zn accounting for 13.31% of the total heavy metals. Some areas in estuaries and coastal lagoon ecosystems where Cu, Pb, As, and Zn in sediment exceed the ISQG need to be monitored to monitor the impact and risk to coastal ecosystems.

Keywords: Sediment, heavy metals, Vietnam, grain sizes.

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INTRODUCTION

Heavy metals in sediments impact organisms, causing stress, toxicity, and potential health risks in coastal areas, particularly through transmission through the food chain [1]. Fine sediments, especially clay minerals such as kaolinite, illite, and chlorite, can absorb metal ions from water [2], which are transported over long distances by currents and tides [3]. Although heavy metals are ubiquitous in the Earth's crust, their concentrations can be too high because of natural mechanisms and human activities. These mechanisms include weathering of rocks and soils, followed by transport and deposition in water bodies [4]. However, human activities are the main cause, which leads to the accumulation of metals in the environment and impacts organisms and humans [5].

Heavy metals in sediments in coastal areas affected by anthropogenic activities, which cause corals to lose their cover, reduce live corals and increase their cover of dead corals, are associated with increased heavy metal pollution over time in the northern Red Sea [6]. Industrial impacts release high concentrations of heavy metals that accumulate in coral reef sediments and affect marine ecosystems at Karaichalli Island (India) [7]. Dead coral skeletons contain higher metal values than their living counterparts do, which can be explained by the contamination of the skeleton surface over many years at the Gulf of Aqaba (Jordan) [8]. In the Bay of Almirante (Panama) and around the nearby archipelago affected by heavy metal pollution, nearshore reefs are at greater risk than offshore reefs for Cu, Zn and Hg. Anti-caking agents and port-related activities caused Cu and Zn contamination of nearby coral reefs, which increased in sediments over two decades, with four out of five survey sites exceeding the ERL of Cu in sediments and lower hard coral cover and species diversity near the port, suggesting that the reef has been degraded [9].

In the estuaries of the Red River system, which are affected by the increasing industrialization of Hai Phong, Thai Binh, Nam Dinh, Ninh Binh, and Thanh Hoa Provinces, heavy metals travel through estuaries, affecting coastal ecosystems. The concentrations of Cu, As, Pb, and Cd in the tidal sediments of the Cam and Van Uc Rivers [10, 11] exceed the ISQG levels [12]. In the Ba Lat estuary, heavy metals in the sediment cores (Cu, Pb, Zn, and Cr) exceed the ISQG levels [13]; surface sediments have contents of Cu, Pb, Zn, and Cr that exceed the ISQG level [14]; and the origin of heavy metals originates from the weathering process of many types of rocks in the basin, reflecting their natural origin. Moreover, agricultural activities and the use of agricultural chemicals have contributed significantly to the abundance of heavy metals in sediments, reflecting human impacts [15]. In coastal agricultural soils in Nam Dinh Province, As and Cd had enrichment factors (EF) ranging from 2.03-19.77 for As and from 0.05-10.77 for Cd, whereas the EFs of Cr, Cu, Pb, Zn, and Mn were < 5 [16]. High concentrations of Cu, Pb, and Zn have been recorded in sediments along the Red River, near industrial zones, bronze casting villages, and lead recycling areas [17]. In the Thanh Hoa coastal area, where the heavy metal concentrations of Cr, Pb, Cu, As, and Zn are higher than the ISQG levels, the source is the Red River, and the heavy metals are also derived from other human activities, such as mineral exploitation inside the mainland [18].

The concentrations of heavy metals in the sediments of Tam Giang - Cau Hai Lagoon were higher than the ISQG levels for Pb, Cr, and As, and the Igeo and ER indices of As and Bi were contaminated [19]. In 9 coastal lagoons in Central Vietnam, distributed from Thua Thien Hue to Ninh Thuan provinces, some lagoons had Cr, As, Pb, and Cu levels higher than the ISQG levels [20]. In the Cai River estuary (Nha Trang), the levels of the heavy metals As, Cu, and Cr exceed the ISQG levels [21]; in the Thi Vai River estuary and Can Gio mangrove forest, the concentrations of Cu and Cr are higher than the ISQG levels [22].

The heavy metal contents (Zn, Cu, Pb, Cr, As, Cd, and Hg) of water in aquaculture areas in Red River estuaries are within permissible standards, and those metals originate from both natural and anthropogenic sources [23]. Some metal casting villages near coastal areas that use metals in wastewater from the Red River Delta contain high levels of Fe, Mn, Cu, Pb, and Zn, which are typically 2–7 times higher than those in the QCVN 09:2023/BTNMT [24].

In general, sediments in coastal ecosystems of Vietnam have been studied for heavy metals in estuaries, embayments, coastal lagoons, and seagrasses. The concentrations of some heavy metals, such as Cu, Cr, Pb, Zn, and As, were higher than the ISQG levels in estuaries and coastal lagoons, indicating the occurrence of human activities inland that transport heavy metals into the environment. This study was carried out in both coastal and offshore areas to assess the environmental risks to ecosystems.

MATERIALS AND METHODS

Materials

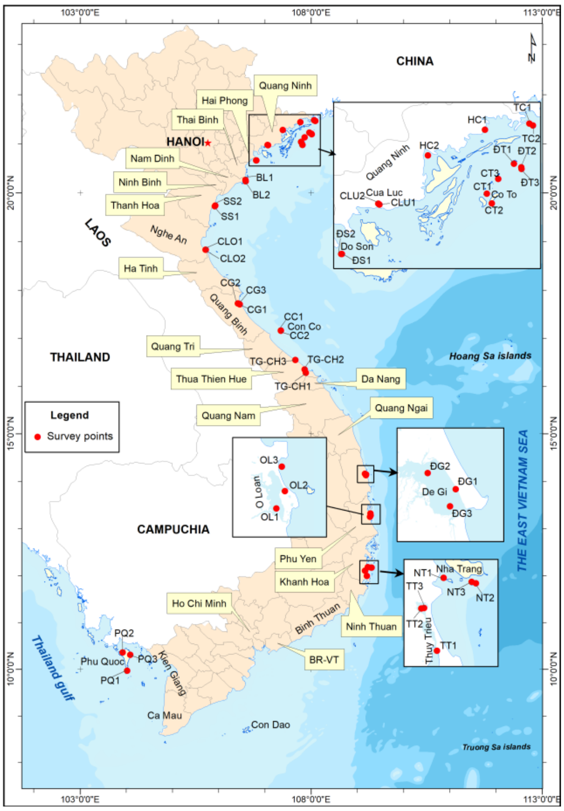

Figure 1. Sample collection positions

In 2017, sampling surveys were carried out in coastal areas such as the Ka Long estuary (TC1, TC2), Ha Dong - Ha Coi coastal areas (HC1, HC2), Tran Islands (ĐT1, ĐT2, ĐT3), Co To Islands (CT1, CT2, CT3), Cua Luc embayment (CLU1, CLU2), Cam and Van Uc estuaries (ĐS1, ĐS2), Ba Lat estuary (BL1, BL2), Hoi estuary (SS1, SS2), Cua Lo estuary (CLO1, CLO2), Cua Gianh estuary (CG1, CG2, CG3), Con Co Island (CC1, CC2), Tam Giang-Cau Hai Lagoon (TG1, TG2, TG3), De Gi Lagoon (ĐG1, ĐG2, ĐG3), O Loan Lagoon (OL1, OL2, OL3), Nha Trang embayment (NT1, NT2, NT3), Thuy Trieu Lagoon (TT1, TT2, TT3), and Phu Quoc Island (PQ1, PQ2, PQ3), including 43 surface sediment samples (Fig. 1). Surface sediments were collected using a Peterson grab; 0–10 cm of surface sediments were collected. All samples were stored in PP tubes and kept at 4°C in ice boxes until they were transferred to the laboratory.

In the laboratory, the sediments were dried in a controlled environment at 16°C under air conditioning. After the sediment was dried, a portion was analysed for particle size, and the heavy metal analysis portion was ground with an agate mortar and pestle and then sieved through a 2 mm sieve to remove particles of unusual size.

Methods

Grain size analysis was carried out at the Institute of Marine Environment and Resources. The organic matter and salts in the sediment were removed with H_2O_2 (10%) and distilled water, after which the sediment was wet sieved through a 63 µm sieve. The > 63 µm fraction remaining after evaporation of water in a water bath was dried overnight at 105°C, and the sediments were sieved through sieves with mesh sizes between 2,000 µm and 50 µm. After all the particles had settled, the < 63 µm fraction was decanted and filtered through filter paper under vacuum and dried overnight at 105°C. The < 63 µm fraction (5 g) was added to 1 ml of 10% NaOH, placed in an ultrasonic bath for 10 min to separate the particles, diluted with distilled water to 1,000 mL and analysed by pipette [25]. The mean diameter (Md) was calculated according to Folk [26], and the sediment types were classified according to Wentworth (Table 1) [27]. GRADISTAT software [28] was used to calculate Md.

For heavy metal analysis, 0.5 g of sediment was weighed into a flask, 10 ml of 8 N HNO_3 and 3 ml of H_2O_2 were added, the Virgeur reflux column was installed, boiled on a hot plate at

120°C for 2 h, cooled, filtered through a 0.45 µm filter, brought to 100 ml with deionized water and analysed via ICP–MS [29]. The PACS2 sediment reference materials were analysed to assess the recoveries of the Cu, Pb, Zn, Cd, As, Ni, Co, Mn and Fe metals at 91, 96, 84, 99, 85, 72, 69, 71 and 68%, respectively.

Table 1. Classification of sediments according to Wentworth 1922

No.	Mean diameter (Md) (µm)	Name of sediment
1	2,000	Very fine gravel
2	1,000	Very coarse sand
3	500	Coarse sand
4	250	Medium sand
5	125	Fine sand
6	63	Very fine sand
7	31	Very coarse silt
8	16	Coarse silt
9	8	Medium silt
10	4	Fine silt
11	2	Very fine silt
12	< 2	Clay

Sediment quality was assessed via comparisons with the Interim Guidelines for Marine Sediment Quality (ISQG) and the Potential Impact Level (PEL) [12]. In addition, heavy metal pollution indices such as geoaccumulation (Igeo) [30, 31], the contamination factor (CF) [32], the enrichment factor (EF) [33], the degree of contamination (CD), the ecological risk potential (ER) [32] and the ecological risk (RI) [32] were calculated (Table 2).

Statistical analysis and data processing: Pearson correlation analysis, factor analysis, and cluster analysis. Correlation analysis was performed between heavy metals and grain size to determine the relationship between heavy metals and grain size; the relationship between heavy metals together revealed sources of origin. Factor analysis identified the sources and factors influencing the accumulation of heavy metals in sediments. Cluster analysis was used to group stations and parameters in areas with similar environmental conditions. Origin Pro 2024 software was used for these analyses.

RESULTS

Distribution of grain sizes

Very fine gravel was distributed mainly in the coral reefs on Con Co Island (CC1), with an Md of 2.174 mm (Table 3).

Very coarse sand was distributed in the coral reefs in the Tran (ĐT2), Co To (CT2), and Con Co (CC2) Islands; the Md ranged from 1.082 to 1.544 mm, with an average of 1.278 mm (Table 3).

Coarse sand was distributed in coral reefs in the Tran (ĐT1) and Co To (CT1, CT3) Islands and the Nha Trang embayment (NT2, NT3), with Md values ranging from 0.512 to 0.956 mm and averaging 0.775 mm (Table 3).

Medium sand was distributed in coral reefs, coastal lagoons at Tran (ĐT3) Island, Nha Trang embayment (NT1), Phu Quoc Island (PQ2, PQ3), and O Loan Lagoon (OL3), with an Md ranging from 0.292 to 0.461 mm and an average of 0.355 mm (Table 2).

Fine sand was distributed in seagrasses, estuaries, coral reefs, and lagoons at Ha Coi-Ha Dong (HC1), Cua Gianh estuary (CG2), Tam Giang - Cau Hai Lagoon (TG1, TG3), Thuy Trieu Lagoon (TT1, TT3), De Gi (ĐG2, ĐG3), and Phu Quoc Island (PQ1), with Md values ranging from 0.156 to 0.245 mm and an average of 0.209 mm (Table 3).

Very fine sand was distributed in estuaries, lagoons at the Ka Long (TC1, TC2), Van Uc - Cam (ĐS1), Ba Lat (BL2), Cua Hoi (SS2), Cua Lo (CLO1), Cua Gianh estuaries (CG2, CG3), Tam Giang - Cau Hai (TG2) and O Loan (OL2) lagoons, with Md values ranging from 0.065 to 0.104 mm and an average of 0.086 mm (Table 3).

Very coarse silt was distributed in seagrasses, embayments, estuaries, coastal lagoons in the Ha Coi - Ha Dong (HC2) coastal area, the Cua Luc embayment (CLU2), the Van Uc-Cam estuaries (ĐS2), the Cua Hoi estuary (SS1) and the De Gi Lagoon (ĐG 1), with Md values ranging from 0.033 to 0.055 mm, with an average of 0.042 mm (Table 3).

Coarse silt was distributed in coastal lagoons and estuaries at Ba Lat estuary (BL2), Cua Lo estuary (CLO2), and O Loan lagoon (OL1), with Md values ranging from 0.017 to 0.028 mm, with an average of 0.022 mm (Table 3).

Medium silt was distributed in the embayment at Cua Luc (CLU1), with Md = 0.012 mm (Table 3).

Distribution of heavy metals

The Fe concentration ranged from 139.63 to 35,728.05 mg/kg, averaging 10,015.45 mg/kg, with a high concentration of Fe distributed nearshore areas with > 10,000 mg/kg in estuaries (ĐS1, ĐS2, BL1, BL2, SS1, SS2, CL1, CL2), coastal lagoons (TG2, ĐG1, ĐG2, OL1, OL2), and embayments (CL1, CL2); the sediment types were medium sand to medium silt. Concentrations < 10,000 mg/kg were distributed mainly in coral reefs (ĐT1–ĐT3, CT1–CT3, NT1–NT3, PQ1–PQ3), estuaries (TC1–TC2, CG1–CG3, TT1–TT3), and coastal lagoons (TG1, TG3, OL2) related to sediments ranging from coarse silt to very fine gravel (Table 3).

The Mn concentration ranged from 2.23 to 1,500.37 mg/kg, with an average value of 252.83 mg/kg. The concentrations of Mn from 700 to 1,500.37 mg/kg were distributed in estuaries (ĐS 2, BL2, SS1, CLO1–CLO2), those from 300 to 700 mg/kg were distributed in estuaries (ĐS1, BL1, SS2) and lagoons (TG2, ĐG2, ĐG3, OL1), and those < 300 mg/kg were distributed in estuaries (TC1–TC2, CG1-CG3), coral reefs (ĐT1–ĐT3, CT1–CT3, NT1–NT3, PQ1–PQ3), embayments (CL1–CL2), and lagoons (TG1, TG3, ĐG 1, OL2, OL3, TT1–TT3) (Table 3).

The Zn concentration ranged from 3.78 to 699.78 mg/kg, with an average value of 67.91 mg/kg. Concentrations from 124 to 699.78 mg/kg were distributed in coral reefs (CT2, CC2) and estuaries (BL1, SS1, CG1, CG3), and concentrations from 50 to 124 mg/kg were distributed in estuaries (TC1, ĐS1, ĐS2, BL2, SS2, CLO1, CLO2, CG2), coral reefs (ĐT2, CT1), and lagoons (TG2, ĐG2, ĐG3, OL1). Concentrations of 3.78 to 50 mg/kg were distributed in estuaries (TC2), coral reefs (ĐT1, ĐT3, CT3, CC1, NT1–NT3, PQ1–PQ3), and coastal lagoons (TG1, TG3, ĐG1, OL2, OL3, TT1–TT3) (Table 3).

The Pb concentration ranged from 0.57 to 88.30 mg/kg, with an average of 14.17 mg/kg. Pb concentrations > 30.2 mg/kg were mainly distributed in estuaries (ĐS2, BL1, BL2, SS1, CLO2). Pb concentrations ranging from 10 to 30.2 mg/kg were distributed mainly in estuaries (TC1, ĐS1, CLO1, CG1-CG3), seagrass (HC1), embayments (CLU1, CLU2), coastal lagoons (TG2, ĐG1–ĐG2, OL1), and concentrations ranging from 0.5 to 10.0 mg/kg were distributed in estuaries (TC2, SS2), coral reefs (ĐT1–ĐT3, CT3 CC1, CC3, NT1–NT3, PQ1–PQ3), seagrass (HC2), and coastal lagoons (TG1, TG3, OL2, OL3, TT1–TC3) (Table 3).

The Cu concentration ranged from 1.27 to 53.08 mg/kg, with an average value of 12.27 mg/kg. The concentrations of Cu > 18.7 mg/kg were distributed in estuaries (ĐS1, ĐS21, BL2, SS1, CLO1, CLO2) and coastal lagoons (ĐG2, ĐG3, OL1). Concentrations of 10–18.7 mg/kg were distributed in embayments (CLU1, CLU2), estuaries (SS2, CG3), and coastal lagoons (TG2, ĐG1). Concentrations < 10 mg/kg were commonly distributed in coral reefs (ĐT1–ĐT3, CT1–CT3, CC1–CC2, NT1–NT3, PQ1–PQ3), coastal lagoons (TG1, TG3, OL2, OL3, TT1–TT3), estuaries (TC1, TC2, CG1, CG2), and seagrasses (HC1, HC2) (Table 3).

The Cr concentration ranged from 0.47 to 48.53 mg/kg, with an average of 13.98 mg/kg. Concentrations ranging from 20 to 48.53 mg/kg were distributed in estuaries (ĐS1, ĐS2, BL1, BL2, SS1, SS2, CLO1, and CLO2), coastal lagoons (TG2, ĐG2, ĐG3, and OL1) and embayments (CLU1). Concentrations from 10 to 20 mg/kg were distributed mainly in seagrass (HC1, HC2), embayments (CLU2), estuaries (CG1, CG3) and coastal lagoons (TG1, ĐG1, OL3). The concentrations from 0.47 to 10 mg/kg were distributed in estuaries (TC1, TC2, CG2), coral reefs (ĐT1–ĐT3, CT1–CT3, CC1–CC2, NT1–NT3, PQ1–PQ3) and lagoons (TG3, OL2, TT1–TT3) (Table 3).

The V concentration ranged from 0.04 to 58.16 mg/kg, with an average of 17.28 mg/kg. Concentrations ranging from 17 to 58.16 mg/kg were distributed in seagrass (HC1, HC2), embayments (CLU1, CLU2), estuaries (ĐS1, ĐS2, BL1, BL2, SS1, SS2, CLO1, CLO2) and coastal lagoons (TG2, ĐG1-ĐG3, OL1). The concentrations < 17 mg/kg were in estuaries (TC1, TC2, CG1–CG3), coral reefs (ĐT1–ĐT3, CT1–CT3, CC1–CC2, NT1–NT3, PQ1–PQ3), and coastal lagoons (TG1, TG3, OL2, OL3, TT1–TT3) (Table 3).

Table 2. Thresholds and indices of heavy metal pollution for assessing sediment quality

Level/Indices	Formula	Levels	Meaning
ISQG (CCME 1999)	Cu = 18.7; Pb = 30.2; Zn = 124; Cd = 0.7; As = 7.24 mg/kg	(1) ≤ ISQG	(1) they are unlikely to impact animal life;
PEL (CCME 1999)	Cu = 108; Pb = 112; Zn = 271; Cd = 4.2; As = 41.6 mg/kg	(1) ISQG - PELs (2) ≥ PELs	(1) there is a low probable impact on animal life (2) animal life will likely be impacted
Geo-accumulation (*Igeo*) [30]	$Igeo = \log_2\left(\frac{Cn}{1.5Bn}\right)$ *where: Igeo* is the geoaccumulation index; $\log_2$ is log base 2; *Cn* is the metal concentration; and *Bn* is the average concentration of metal in Earth's crust [31]	(1) $Igeo \le 0$ (2) $0 < Igeo \le 1$ (3) $1 < Igeo \le 2$ (4) $2 < Igeo \le 3$ (5) $3 < Igeo \le 4$ (6) $4 < Igeo \le 5$ (7) $5 < Igeo$	(1) unpolluted (UP) (2) unpolluted to moderately polluted (UMP) (3) moderately polluted (MP); (4) moderately to strongly polluted (MSP) (5) strongly polluted (SP) (6) strongly to extremely polluted (SEP) (7) extremely polluted (EP)
Contamination factor (*CF*) [32]	$CF = C0/Cn$ *C*0: is concentration of metal in samples content of the substance; *Cn*: is concentration of metal in the Earth's crust [31]	(1) $0 < CF \le 1$ (2) $1 < CF \le 3$ (3) $3 < CF \le 6$ (4) $6 < CF$	(1) low contamination (LC) (2) moderate contamination (MC) (3) considerable contamination (CC) (4) very high contamination (VHD)
Enrichment Factor (*EF*) [33]	$EF = \frac{E_{sample}/Fe_{sample}}{E_{background}/Fe_{background}}$ *where:* E_{sample}/Fe_{sample} is the ratio of the heavy metal concentration in the sample to the iron concentration in the sample; and $E_{background}/Fe_{background}$ is the ratio of the average heavy metal concentration to the average iron concentration in Earth's crust [31]	(1) $0 < FF \le 1$ (2) $1 < EF \le 3$ (3) $3 < EF \le 5$ (4) $5 < EF \le 10$ (5) $10 < EF \le 25$ (6) $25 < EF \le 50$ (7) $50 < EF$	(1) no enrichment (NE) (2) minor enrichment (ME) (3) moderate enrichment (MOE) (4) moderately severe enrichment (MSE) (5) severe enrichment (SE) (6) very severe enrichment (VSE) (7) extremely severe enrichment (ESE)
Risk factor (ER) [32]	$ER = Tr^{i}.CF$ Tr^{i}: the toxic-response factor which are Cu = Pb = 5, As = 10, Cd = 30; Zn = 1; Cr =2; *CF*: contamination factor	(1) $40 < ER$ (2) $40 < ER \le 80$ (3) $80 < ER \le 160$ (4) $160 < ER \le 320$ (5) $320 < ER$	(1) low potential ecological risk (LER) (2) moderate potential ecological risk (MER) (3) considerable potential ecological risk (CER) (4) high potential ecological risk (HER) (5) very high ecological risk (VER)

Level/Indices	Formula	Levels	Meaning
Degree of contamination [32]	$$C_D = \sum_{i=1}^{n} C_f^i = \sum_{i=1}^{n} \frac{\overline{C}_{0-1}^i}{C_n^i}$$ *where:* C_D is the degree of contamination; C_f^i is the contaminant factor; $\overline{C}_{0-1}^i$ is the concentration of contaminant; C_n^i is the background concentration of heavy metals in the Earth's crust in parts per million	(1) $CD \leq 6$ (2) $6 < CD \leq 12$ (3) $12 < CD \leq 24$ (4) $24 < CD$	(1) low degree of contamination (LCD) (2) moderate degree of contamination (MCD) (3) considerable degree of contamination (CCD) (4) high degree of contamination ((HCD)
Ecological risk (*RI*) [32]	$$RI = \sum_{i=1}^{n} Er^i = \sum_{i=1}^{n} Tr^i.C_f^i$$ *where:* *RI* is the potential ecological risk; Er^i is the potential ecological risk factor; and Tr^i is the "toxic-response" factor for the given substance: Cd = 30; As = 10, Cu = Pb = 5; Zn = 1; Cr = 2	(1) $150 < RI$ (2) $150 < RI \leq 300$ (3) $300 < RI \leq 600$ (4) $600 < RI$	(1) low ecological risk (LR) (2) moderate ecological risk (MR) (3) high ecological risk (HR) (4) very high ecological risk (VR)

Table 3. Concentration of heavy metals and grain size in surface sediment in coastal areas of Vietnam

No.	Samples	Md (mm)	Fe	Mn	Zn	Pb	Cu	Cr	V	As	Co	Cd	Mo	Sediment types
1	TC1	0.082	8322.13	166.55	61.38	12.48	6.66	9.29	11.09	1.69	3.50	0.04	0.08	Very fine sand
2	TC2	0.104	4057.05	129.90	14.35	2.32	2.35	3.85	2.08	0.17	1.84	0.01	BLD	Very fine sand
3	ĐT1	0.956	483.78	18.05	13.35	0.64	2.63	0.47	0.15	0.35	0.33	BLD	0.01	Coarse sand
4	ĐT2	1.207	4758.12	56.77	62.71	4.79	5.20	5.25	4.23	**15.05**	1.48	0.04	0.03	Very coarse sand
5	ĐT3	0.339	2577.42	33.33	6.84	2.33	3.46	1.30	0.32	0.21	1.27	0.03	BLD	Medium sand
6	HC1	0.173	10517.11	120.96	36.26	10.91	7.77	13.51	18.13	2.40	4.31	0.05	0.41	Fine sand
7	HC2	0.033	8409.09	37.47	27.90	9.07	8.80	10.59	18.80	2.76	4.54	0.11	0.51	Very coarse silt
8	CT1	0.794	3038.73	36.55	85.27	10.43	3.13	2.22	2.28	1.75	1.16	0.06	0.14	Coarse sand
9	CT2	1.082	3529.18	135.71	**133.11**	13.69	4.76	3.27	3.85	1.63	1.40	0.10	0.18	Very coarse sand
10	CT3	0.774	3644.31	76.70	7.22	4.49	3.36	2.49	2.95	1.17	1.34	0.06	0.02	Coarse sand
11	CLU1	0.012	15232.94	205.05	51.55	21.83	18.65	22.19	30.05	**10.88**	8.78	0.12	0.30	Medium silt
12	CLU2	0.055	11517.54	256.38	76.19	11.49	13.82	15.42	17.07	4.83	7.58	0.04	0.12	Very coarse silt
13	ĐS1	0.087	15054.83	568.89	63.12	24.36	**24.13**	24.32	25.59	**8.64**	8.97	0.07	0.08	Very fine sand
14	ĐS2	0.033	25922.49	881.44	86.41	**60.96**	**43.20**	43.73	50.29	**17.41**	15.53	0.14	0.22	Very coarse silt

No.	Samples	Md (mm)	Fe	Mn	Zn	Pb	Cu	Cr	V	As	Co	Cd	Mo	Sediment types
15	BL1	0.017	19965.27	621.17	**699.78**	**88.30**	**45.94**	34.29	39.34	**16.74**	12.83	0.39	0.90	Coarse silt
16	BL2	0.074	22333.19	804.40	102.55	**44.12**	**53.08**	35.31	38.36	**16.24**	12.24	0.23	0.22	Very fine sand
17	SS1	0.044	26715.30	877.18	**152.77**	**38.06**	**33.99**	44.57	53.66	**11.88**	15.05	0.12	0.23	Very coarse silt
18	SS2	0.065	13306.94	397.15	67.31	8.67	13.61	21.48	22.69	3.14	8.06	0.03	0.02	Very fine sand
19	CLO1	0.074	19640.85	734.07	60.13	18.65	**19.40**	29.45	32.64	7.11	10.86	0.08	0.13	Very fine sand
20	CLO2	0.021	27505.03	1500.37	102.02	**42.15**	**32.12**	43.34	52.45	**13.07**	16.71	0.14	0.33	Medium silt
21	CG1	0.085	7674.13	113.04	**134.61**	15.03	9.84	14.44	15.18	1.04	4.97	0.24	0.13	Very fine sand
22	CG3	0.098	8241.21	130.60	**137.94**	14.22	10.06	13.06	13.34	2.14	5.54	0.22	0.32	Very fine sand
23	CG2	0.255	6162.34	87.99	99.47	10.67	8.88	7.62	8.58	1.40	5.00	0.09	0.12	Fine sand
24	CC1	2.174	2752.32	59.66	4.37	3.19	1.61	1.25	1.01	1.28	1.82	0.08	0.02	Very fine gravel
25	CC2	1.544	3312.43	84.53	**151.10**	4.12	3.01	1.73	0.52	0.53	2.08	0.09	0.05	Very coarse sand
26	TG1	0.156	5617.46	88.23	20.89	4.40	7.39	13.95	13.77	0.72	3.02	0.06	0.38	Fine sand
27	TG2	0.087	19964.73	382.61	54.80	16.49	10.77	23.33	21.81	5.43	11.34	0.15	0.16	Very fine sand
28	TG3	0.216	2814.94	80.71	15.54	3.33	5.20	4.24	4.54	0.71	1.86	0.05	0.01	Fine sand
29	ĐG1	0.045	10784.24	163.89	35.78	11.68	14.26	15.46	25.59	2.77	5.34	0.05	0.07	Very coarse silt
30	ĐG2	0.170	20015.20	362.76	54.31	18.69	**22.50**	24.95	54.65	1.07	12.94	0.12	0.23	Fine sand
31	ĐG3	0.235	22644.44	344.91	61.62	24.56	**19.96**	28.34	52.36	6.01	10.58	0.07	0.40	Fine sand
32	OL1	0.028	35728.05	565.29	71.97	11.05	**26.17**	48.53	58.16	1.24	22.88	0.19	0.31	Coarse silt
33	OL2	0.101	2734.97	25.91	12.46	2.82	5.98	3.27	4.57	0.39	1.28	0.04	0.13	Very fine sand
34	OL3	0.381	10337.62	183.17	26.30	7.15	8.68	11.93	14.99	1.18	5.22	0.06	0.10	Medium sand
35	NT1	0.461	2662.87	98.00	4.10	2.65	1.27	1.16	0.93	1.30	0.91	0.05	0.03	Medium sand
36	NT2	0.838	3822.14	66.85	7.15	4.64	1.46	3.73	4.32	2.67	1.15	0.05	0.03	Coarse sand
37	NT3	0.512	3760.66	74.68	15.75	3.83	2.55	2.35	1.83	0.76	1.40	0.07	0.06	Coarse sand
38	TT1	0.245	3595.28	59.55	46.63	6.89	6.43	4.51	6.51	0.33	1.17	0.04	0.14	Fine sand
39	TT2	0.292	5087.61	76.52	21.71	6.42	4.62	3.73	8.22	2.92	1.89	0.03	0.20	Medium sand
40	TT3	0.233	2172.29	106.09	12.37	3.31	3.92	1.88	3.74	0.18	0.81	0.03	0.05	Fine sand
41	PQ1	0.244	1350.16	15.97	6.86	1.74	2.55	2.79	1.86	0.16	0.44	0.02	0.07	Fine sand
42	PQ2	0.345	139.63	2.23	3.78	0.57	2.26	0.67	0.04	0.16	0.06	0.01	0.02	Medium sand

No.	Samples	Md (mm)	Fe	Mn	Zn	Pb	Cu	Cr	V	As	Co	Cd	Mo	Sediment types
43	PQ3	0.310	2758.23	40.46	10.42	2.11	2.10	1.79	0.60	0.34	2.44	0.06	0.02	Medium sand
Minimum		0.012	139.63	2.23	3.78	0.57	1.27	0.47	0.04	0.16	0.06	BLD	BLD	
Maximum		2.174	35728.05	1500.37	699.78	88.30	53.08	48.53	58.16	17.41	22.88	0.39	0.90	
Average		0.351	10015.45	252.83	67.91	14.17	12.27	13.98	17.28	4.00	5.63	0.09	0.17	
Standard deviation		0.459	8921.28	315.59	108.00	17.37	12.88	14.09	18.23	5.13	5.49	0.08	0.17	
ISQG		-	-	-	124	30.2	18.7	52.3	-	7.2	-	0.7	-	
Background [31]		-	39200	774.6	67	17	28	92	97	4.8	17.3	0.09	1.1	

Table 4. Comparison of the concentrations of heavy metals with those in other coastal areas

No.	Coasta areas	Fe	Mn	Zn	Pb	Cu	Cr	V	As	Co	Cd	Mo	Reference
1	Coastal of Viet Nam	10,015.45	252.83	67.91	14.17	12.27	13.98	17.28	4.00	5.63	0.09	0.17	This study
2	Mong Cai coastal area	28,966.66	176.17	38.86	17.72	12.15	20.78	27.21	12.26	6.15	0.07	0.58	[34]
3	Tien Yen bay	-	215.40	99.20	25.00	24.70	28.6	25.5	17.10	6.30	0.08	3.0	[35]
4	Ha Coi bay	-	-	165.30	21.80	55.30	133.8	-	98.0	21.70	3.90	-	[36]
5	Cua Ong coastal area	13,000.00	108.00	40.00	16.00	20.00	27.0	-	26.00	6.00	0.09	-	[37]
6	Ha Long Bay	-	-	50.87	30.39	14.53	-	-	6.06	-	0.08	-	[38]
7	Cam estuary	36,200.00	827.00	178.00	92.00	82.00	90	-	42.00	38.00	-	-	[10]
8	Bach Dang estuary	29,079.68	548.99	82.90	48.09	33.92	67.41	-	17.21	-	0.56	-	[39]
9	Hai Phong coastal area	34,427.58	741.50	82.34	43.85	37.39	34.51	-	17.62	13.16	0.12	0.34	[40]
10	Ba Lat estuary	32,986.64	766.45	98.64	56.19	40.42	75.71	87.14	21.41	-	0.39	0.62	[15]
11	Thai Binh to Ba Lat estuaries	37,600.00	806.00	127.00	66.00	83.00	85.71	97.00	-	-	0.35	-	[14]
12	Tidal flats of Red River	-	-	101.59	67.31	56.63	-	-	23.20	-	0.35	-	[11]
14	Thanh Hoa coastal area	49,777.65	1.167.34	142.37	66.76	56.51	52.29	58.18	24.70	20.04	0.21	0.41	[18]
15	Cai estuary (Nha Trang)	31,000.00	400.00	85.60	55.20	36.80	61.50	73.5	15.20	7.70	0.10	2.6	[21]
16	Dong Nai estuary	44,720.00	300.00	92.00	21.00	27.00	99.00	-	-	19.60	0.10	-	[22]
17	Leizhou coastal area, China	21,900.00	387.30	40.78	19.33	8.07	28.39	-	14.50	7.13	-	0.40	[41]
18	East Gulf of Thailand, Thailand	23,000.00	-	43.60	18.80	39.40	-	-	-	21.00	0.04	-	[42]
19	Coast eastern of Malaysia	-	-	41.80	4.20	27.60	14.57	-	7.10	-	0.10	-	[43]

The As concentration ranged from 0.16 to 17.41 mg/kg, with an average of 4.00 mg/kg. The concentrations > 7.2 mg/kg were distributed in estuaries (ĐS1, ĐS2, BL1, BL2, SS1, and CLO2) and were found only in coral reefs (ĐT2) at Tran Island and embayments (CLU1) at Cua Luc. The concentrations from 4 to 7.2 mg/kg were distributed in embayments (CLU2), estuaries (CLO1) and coastal lagoons (TG2, ĐG3). The concentrations < 4 mg/kg were distributed in estuaries (TC1, TC2, SS2, CG1, CG3, CG2), coral reefs (ĐT1, ĐT3, CT1–CT3, CC1–CC2, NT1–NT3, PQ1–PQ3), seagrasses (HC1, HC2), and coastal lagoons (TG1, TG3, ĐG1, ĐG2, OL1–OL3, TT1–TT3) (Table 3).

The Co concentration ranged from 0.06 to 22.88 mg/kg, with an average value of 5.63 mg/kg. The concentrations ranging from 10 to 22.88 mg/kg were distributed in estuaries (ĐS2, BL1, BL2, SS1, CLO1, and CLO2) and coastal lagoons (TG2, ĐG2, ĐG3, and OL1). Concentrations ranging from 5 to 10 mg/kg were distributed in embayments (CLU1, CLU2), estuaries (ĐS1, SS2, CG3, CG2) and coastal lagoons (ĐG1, OL3). Concentrations < 5 mg/kg were mostly distributed in estuaries (TC1, TC2, CG1), coral reefs (ĐT1-ĐT3, CT1–CT3, CC1, CC2, PQ1-PQ3, NT1-NT3), seagrass (HC1, HC2), and coastal lagoons (TG1, TG3, OL2, TT1–TT3) (Table 3).

The Cd concentration ranged from below the detection limit (BLD) to 0.39 mg/kg, with an average of 0.09 mg/kg. The concentrations ranging from 0.2 to 0.39 mg/kg were mainly distributed in estuaries (BL1, BL2, CG1, CG3). The concentrations from 0.1 to 0.2 were distributed in seagrass (HC2), coral reefs (CT2), embayments (CLU1), estuaries (ĐS2, SS1, CLO2), and coastal lagoons (TG2, ĐG2, OL1). The concentrations < 0.1 mg/kg are distributed in estuaries (TC1, TC2, ĐS1, SS2, CLO1, CG2), coral reefs (ĐT2, ĐT3, CT1, CT3, CC1, CC2, NT1–NT3, PQ1–PQ3), seagrass (HC1), embayments (CLU2) and coastal lagoons (TG1, TG3, ĐG1, ĐG3, OL2, OL3, TT1–TT3) (Table 3).

The Mo concentration ranged from BLD to 0.90 mg/kg and averaged 0.17 mg/kg. The concentrations from 0.2 to 0.9 mg/kg were distributed in seagrass (HC1, HC2), embayments (CLU1), estuaries (ĐS2, BL1, BL2, SS1, CLO2, CG3) and coastal lagoons (TG1, ĐG2, ĐG3, OL1, TT2). Concentrations from 0.1 to 0.2 mg/kg were distributed in coral reefs (CT1, CT2), embayments (CLU2), estuaries (CLO1, CG1, CG2) and coastal lagoons (TG2, OL2, OL3, TT1). The concentrations < 0.1 mg/kg were distributed in estuaries (TC1, ĐS1, and SS2), coral reefs (ĐT1, ĐT2, CT3, CC1, CC2, NT1–NT3, and PQ1–PQ3) and coastal lagoons (TG3, ĐG1, and TT3) (Table 3).

Correlations between heavy metals and grain size

The Pearson correlation matrix between heavy metals was positively correlated with each other, and a negative correlation was shown between heavy metals and grain size.

The negative correlation ranged from weak to moderate. Weak correlations exist between Md and Fe, Mn, Pb, Cu, V, Co, and Mo. A moderate correlation exists only between Md and Cr. The other heavy metals, Zn, As, and Cd, were not significantly correlated with Md (Fig. 2).

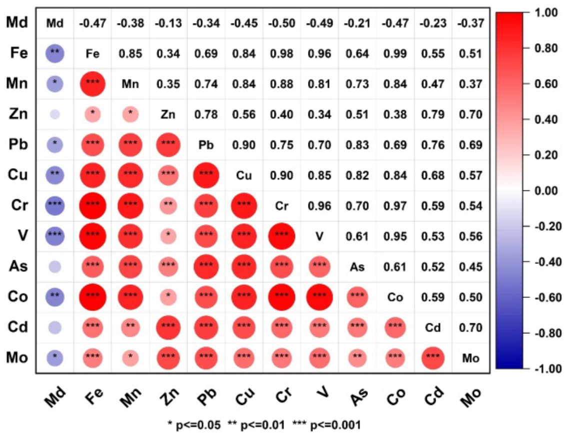

Figure 2. Pearson correlation matrix between heavy metals and grain size

A positive correlation was detected for almost all the heavy metals. Weak correlations between Fe and Zn; between Mn and Zn, Cd, Mo; between Zn and Cr, V, Co. Moderate correlations between Fe and Pb, As, Cd, Mo; between Mn and Pb, As; between Zn and Pb, Cu, As, Cd, Mo; between Pb and Cr, V, Co, Mo; between Cu and Cd, Mo; between Cr and As, Co, Mo; between V and As, Cd, Mo; between As and Co, Cd, Mo; between Co and Cd and Mo; and between Cd and Mo. Strong correlations exist between Fe and Mn, Cu, Cr, V, Co; between Mn and Cu, Cr, V, Cr; between Zn and Pb, Cd; between Pb and Cu, Cr, As, Cd; between Cu and Cr, V, As, Co; between Cr and V, Co; and between V and Co (Fig. 2).

DISCUSSION

Comparison of heavy metals with other regions

Compared with those in the Mong Cai coastal area [34], the concentrations of several heavy metals (Mn, Zn, Cu, and Cd) in the Mong Cai coastal area were greater, whereas those of several heavy metals (Fe, Pb, Cr, V, As, Co, and Mo) were lower (Table 4).

Compared with Tien Yen Bay [35], Ha Coi Bay (Van Don-Tra Co) [36] presented higher values (Table 3) in both bays near the shore affected by industrial activities, whereas the coastal areas of this study included offshore areas that were less affected by human activities.

Compared with those in the Cua Ong coastal area [37] and Ha Long Bay [38], the heavy metals in the two bays had higher Fe, Pb, Cu, Cr, As, and Co concentrations (Table 4). In Cua Ong and Ha Long Bay, industrial activities occurred around the bays, which may have been more affected than other areas in this study.

Compared with the Bach Dang estuary [39], Cua Cam estuary [10], Hai Phong coastal area [40], Ba Lat estuary [15], Thai Binh to Ba Lat estuaries [14], and tidal flats of the Red River Delta [11]. This study also revealed several lower values (Table 4) because the Bach Dang, Cua Cam, Ba Lat, and Thai Binh estuaries are close to large urban areas and large industrial zones and receive many supplies from the Red River system.

Compared with the southern seas from the Thanh Hoa coast [18], the Cai River estuary (Nha Trang) [21], and the Dong Nai estuary [22], which were higher than those in this study (Table 4), these estuaries received from the mainland, such as mineral exploitation inside Thanh Hoa Province, industries in the Dong Nai estuary, and urban areas in Nha Trang.

Compared with other seas, such as the Leizhou coast (China) [41], the Zn and Cu contents in this study were greater than those in the Leizhou coast; the remaining metals, Fe, Mn, Pb, Cu, Cr, As, and Mo, in the Leizhou coast were greater than those in this study (Table 4).

Compared with those in the Gulf of Thailand [42], the concentrations of Fe, Pb, Cu, and Co in the Gulf of Thailand were higher than those in this study, whereas the concentrations of Zn and Cd were lower (Table 4).

Compared with those on the east coast of Malaysia [43], the concentrations of Zn and Pb were lower than those reported in this study, whereas the concentrations of Cu, As, and Cd were higher (Table 4).

Comparison with standards and heavy metal pollution indices

Comparison with standards

Some heavy metals, such as Zn, Pb, Cu, and As, have higher levels than ISQGs. The concentrations of other remaining metals, such as Cr and Cd, are lower than those in the ISQGs (Table 2). No heavy metals exceed the PELs. The remaining heavy metals, including Fe, Mn, V, Mo, and Co, did not meet standard thresholds.

Geoaccumulation (Igeo)

Most heavy metals had average Igeo values for unpolluted (Igeo < 0), and some high values of Zn, As, and Cd were unpolluted to moderately polluted (Igeo > 1) (Fig. 3a). The Igeo values of Cu ranged from -5.05 to 0.34 and averaged -2.48, for Pb from -5.48 to 1.79 and averaged -1.68, those of Zn ranged from -4.73 to 2.80 and averaged -1.51, those of Cd ranged from -5.90 to 1.55 and averaged -1.14, those of As ranged from -5.54 to 1.27 and averaged -2.07, those of Mn ranged from -9.02 to 0.37 and averaged -3.20, those of Fe ranged from -8.72 to -0.72 and averaged -3.23, those of Co ranged from -8.83 to -0.18 and averaged -3.04, those of Mo ranged from -8.19 to -0.88 and averaged -4.18, those of Cr ranged from -8.18 to -1.51 and average -4.24, and those of V ranged from -11.80 to -1.32 and averaged -4.38 (Fig. 3a).

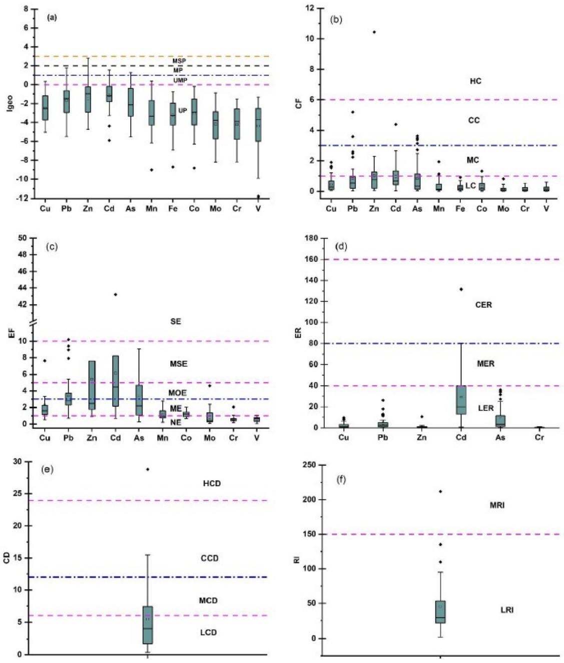

Figure 3. Box plots of heavy metal pollution indices

Contamination factor (CF)

The average contamination factor of heavy metals indicated low contamination (CF < 1), while some heavy metals exhibited moderate contamination (1 < CF < 3), considerable contamination (3 < CF < 6), and high contamination (CF > 6) (Fig. 3b). The concentrations of heavy metals were ranked in the following order: Cu ranged from 0.05 to 1.90, with an average of 0.44; Pb ranged from 0.03 to 5.19, averaging 0.83; Zn ranged from 0.06 to 10.44, with an average of 1.01; Cd ranged from 0.03 to 4.39, averaging 0.97; As ranged from 0.03 to 3.63, with an average of 0.83; Mn ranged from 0.00 to 1.94, averaging 0.33; Fe ranged from 0.00 to 0.91, with an average of 0.26; Co ranged from 0.00 to 1.32, averaging 0.33; Mo ranged from 0.01 to 0.81, with an average of 0.15; Cr ranged from 0.01 to 0.53, averaging 0.15. The final V ranged from 0 to 0.60, with an average of 0.18 (Fig. 3b).

Enrichment factor (EF)

The heavy metal enrichment factors were no enrichment, minor enrichment, moderate enrichment and moderately severe enrichment. No enrichment (Cr and V), minor enrichment (Cu, Mn, Co), moderate enrichment (Pb and As), and moderately severe enrichment (Zn, Cd) were detected (Fig. 3c). The EFs were ordered as follows: Cu ranged from 0.53 to 22.62 and averaged 2.29, Pb from 0.71 to 10.20 and averaged 3.39, Zn from 0.90 to 26.69 and averaged 5.41, Cd from 0.70 to 43.20 and averaged 6.11, As from 0.28 to 25.84 and averaged 3.39, Mn from 0.23 to 2.76 and averaged 1.15, Co from 0.68 to 2.00 and averaged 1.19, Mo from 0.06 to 4.62 and averaged 0.81, Cr from 0.19 to 2.05 and averaged 0.56, and V from 0.05 to 0.05. 1.10 and an average of 0.56 (Fig. 3c).

Ecological risk potential (ER)

The ER of the 6 heavy metals had a low potential ecological risk, and the highest ER had a moderate potential ecological risk (Cd) (Fig. 3d). For each heavy metal, the ER of Cu ranged from 0.23 to 9.48, with an average of 2.19; that of Pb ranged from 0.17-25.97, with an average of 4.17; that of Zn ranged from 0.06-10.44, with an average of 1.01; that of Cd ranged from 0.75-131.58, with an average of 28.96; that of As ranged from 0.32-36.28, with an average of 8.33; and that of Cr ranged from 0.01–1.05, with an average of 0.30 (Fig. 3d).

Degree of contamination (CD) and ecological risk (RI)

The CD had a low to moderate degree of contamination, and the highest was a considerable degree of contamination (Fig. 3e). The CD values ranged from 0.39–28.80, with an average value of 5.47.

The RI was low ecological risk, and the highest was moderate ecological risk. The RI ranged from 2.35 to 211.83, with an average of 44.97 (Fig. 3f).

Factors controlling heavy metals in sediments, sediment groups and the origins of heavy metals

Factor analysis revealed that 3 factors influence the accumulation of heavy metals in sediments. Factor 1 (FA1) accounted for 67.99%, including 11 heavy metals, namely, Fe, Mn, Zn, Pb, Cu, Cr, V, As, Co, Cd, and Mo. Factor 2 (FA2) accounted for 13.31%, including Zn and Cd. Factor 3 (FA3) was 7.42% by Md (Table 5).

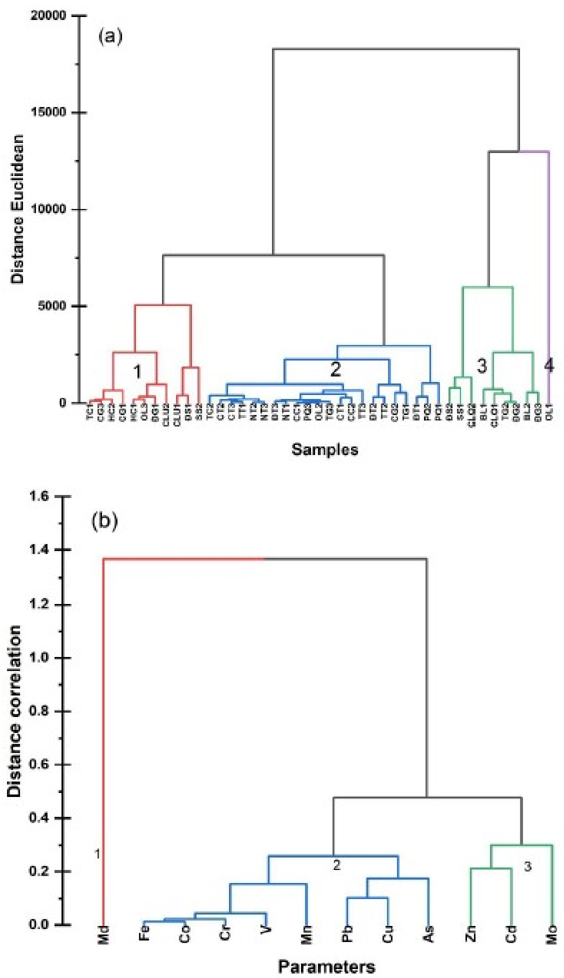

Figure 4. Groups of sediment samples and parameters

The samples were divided into 4 groups (Fig. 4a, Table 6). Group 1 had 11 samples distributed in estuary and lagoon ecosystems, with grain sizes that were greater than those of groups 3 and 4, and had lower heavy metal concentrations than those of groups 3 and 4, except for As. Group 2 included 22 samples distributed in coral reefs, lagoons, and estuaries; the grain sizes were the highest, and the heavy metal concentrations were the lowest, except for As, which was greater than that in Group 4. In Group 3, 9 samples were distributed in estuaries and lagoons, and the grain sizes were lower than those in Groups 2 and 1 but higher than those in Group 4. The concentrations of Mn, Zn, Pb, Cu, and As were the highest, except those of Fe, Cr, V, Co, Cd, and Mo. In Group 4, 1 sample was distributed in the embayment; the grain size was the smallest; the concentrations of Fe, Cr, V, Co and Cd were the highest; and the concentrations of Mn, Zn, and Cu were lower than those in Group 3 (Table 6).

The parameters were divided into 3 groups: Group 1 included the grain size (Md); Group 2 included the heavy metals Fe, Co, Cr, V, Mn, Pb, Cu, and As; and Group 3 included Zn, Cd and Mo. The parameter groups included group 1, which is characteristic of environmental dynamics; group 2, which includes heavy metals from the same source; and group 3, which includes Zn, Cd and Mo from another source (Fig. 4b). The Pearson correlation and factor analyses of heavy metals revealed that for 11 heavy metals (Fe, Mn, Zn, Pb, Cu, Cr, V, As, Co, Cd, and Mo) received 67.99% natural source. In addition, Zn and Cd were also other sources accounting for 13.31%. The natural source of heavy metals constitute a large proportion of the sources indicated in coastal areas such as Hai Phong [39], the Ba Lat estuary [14, 15], coastal lagoons [20], and the Cai estuary (Nha Trang) [21]. Anthropogenic sources account for a relatively small proportion of all sources due to industrial, agricultural, and urban activities around large estuaries [15, 22, 39].

Table 5. Results of factor analysis of heavy metals and grain size

No.	Parameters	FA1	FA2	FA3	FA4
1	Md	-0.49	0.30	**0.71**	0.40
2	Fe	**0.92**	-0.32	0.00	0.19
3	Mn	**0.86**	-0.28	0.24	-0.10
4	Zn	**0.62**	**0.72**	-0.03	-0.01
5	Pb	**0.90**	0.31	0.11	-0.20
6	Cu	**0.95**	-0.02	0.11	-0.14
7	Cr	**0.95**	-0.27	0.01	0.09
8	V	**0.91**	-0.30	-0.06	0.18
9	As	**0.79**	0.10	0.40	-0.36
10	Co	**0.92**	-0.29	-0.01	0.23
11	Cd	**0.74**	**0.50**	-0.09	0.20
12	Mo	**0.69**	0.45	-0.37	0.14
	Variance	8.16	1.60	0.89	0.54
	Percentage of Variance (%)	67.99	13.31	7.42	4.50

Table 6. Averages of heavy metals and grain size in sediment groups

Group	Number of sample	Md (mm)	Fe	Mn	Zn	Pb	Cu	Cr	V	As	Co	Cd	Mo
1	11	0.101	10,854.34	213.01	65.30	13.35	12.39	15.61	19.32	3.77	6.07	0.09	0.20
2	22	0.599	3,219.63	66.11	34.34	4.52	3.82	3.34	3.48	1.52	1.55	0.05	0.08
3	9	0.084	22,745.17	723.21	152.71	39.11	31.22	34.15	43.95	10.55	13.12	0.16	0.31
4	1	0.028	35,728.05	565.29	71.97	11.05	26.17	48.53	58.16	1.24	22.88	0.19	0.31

CONCLUSION

In coastal ecosystems in Vietnam, seagrasses, embayments, coral reefs, estuaries, and coastal lagoons have 9 sediment types: very fine gravel, very coarse sand, coarse sand, medium sand, fine sand, very fine sand, very coarse silt, coarse silt, and medium silt. Very fine gravel, very coarse sand, and coarse sand were distributed in the coral reefs. Coarse sand and medium sand are distributed in coral reefs, coastal lagoons, and estuaries. Fine sand is distributed in seagrasses, estuaries, coral reefs, and coastal lagoons. Very fine sand was distributed in estuaries and coastal lagoons. Very coarse silt is distributed in seagrass, embayments, estuaries, and coastal lagoons. The coarse silt was present in coastal lagoons and estuaries, and the medium silt was present.

The average concentrations of the heavy metals Fe, Mn, Zn, Pb, Cu, Cr, V, As, Co, Cd, and Mo were 10,015.45, 252.83, 67.91, 14.17, 12.27, 13.98, 17.28, 4.00, 5.63, 0.09, and 0.17 mg/kg, respectively. The heavy metal pollution indices were as follows: Igeo was unpolluted, the highest values of Zn, As, and Cd were from unpolluted to moderately strongly polluted; CF was characterized by low contamination (Fe, Co, Mo, Cr, V), the highest was moderate contamination (Cu, Pb, Zn, Cd, As, and Mn); EF was characterized by no enrichment (Cr and V), minor enrichment (Cu, Mn, Co), moderate enrichment (Pb and As), and moderately severe enrichment (Zn, Cd); the ER of the 6 heavy metals was characterized by low potential ecological risk (Cd); CD was characterized by a low degree of contamination; the highest was characterized by a moderate degree of contamination to a considerable degree of contamination; and RI was characterized by low ecological risk.

The heavy metals Fe, Mn, Zn, Pb, Cu, Cr, V, As, Co, Cd, and Mo had natural origins, whereas Zn and Cd also received other sources from human activities. Fine sediments affect heavy metal accumulation. Heavy metal concentrations were lower than those in the ISQG and PELs, but in some areas in estuaries and coastal lagoons, the concentrations of Cu, Pb, Zn, and As were higher than those in the ISQG. The indices with the highest values of CF, EF, CD, ER, and RI were moderate in estuaries and coastal lagoons, and embayment needs to be monitored to assess the risk to coastal ecosystems.To limit impacts on near-shore ecosystems, human-generated waste must be tightly managed and cleaned for pollution before being released into the environment.

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