



КООПЕРАЦИЯ НАУКИ И ОБЩЕСТВА КАК ИНСТРУМЕНТ МОДЕРНИЗАЦИИ И ИННОВАЦИОННОГО РАЗВИТИЯ

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КООПЕРАЦИЯ НАУКИ И ОБЩЕСТВА КАК ИНСТРУМЕНТ МОДЕРНИЗАЦИИ И ИННОВАЦИОННОГО РАЗВИТИЯ: сборник статей Международной научно-практической конференции (10 июля 2025 г., г. Таганрог). - Уфа: Аэтерна, 2025. – 196 с.

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Vietnam Academy of Science and Technology,
Hanoi, Vietnam**Nguyen Quoc Phi**Hanoi University of Mining and Geology,
Hanoi, Vietnam**Nguyen Thi Hong**Hanoi University of Mining and Geology,
Hanoi, Vietnam**GEOCHEMICAL ASSESSMENT AND SPATIAL DISTRIBUTION OF HEAVY
METALS IN COASTAL SEDIMENTS AROUND CAI BAU ISLAND,
BAI TU LONG BAY, NORTHERN VIETNAM****Annotation**

This study evaluates the geochemical distribution and ecological risk of heavy metals (As, Pb, Hg, Cd, Zn, Cu) in surface sediments from 11 coastal sites around Cái Bầu Island, northern Vietnam. Assessment using enrichment Factor (EF), geoaccumulation index (Igeo), and potential ecological risk index (PERI) revealed elevated levels of As and Hg at several sites, especially TT01, TT03, and TT04. Mercury posed the greatest ecological risk across all stations. Temporal trends showed decreasing As and Cd levels but increasing Cu and Zn at TT08–TT11 in 2021, likely due to aquaculture and land runoff. PCA identified two pollution sources: industrial / atmospheric (As, Pb, Hg) and local runoff (Cu, Zn, Cd). HCA classified stations into three clusters based on contamination profiles. Integrating geochemical and multivariate approaches provides a scientific basis for monitoring and managing coastal sediment quality in northern Vietnam.

Keywords

Heavy metals; Sediment; Ecological risk; Cai Bau Island.

1. Introduction

In recent decades, the accumulation of heavy metals (HMs) in coastal sediments has become a critical environmental issue worldwide due to increasing industrialization, urban expansion, and anthropogenic pressures on coastal ecosystems. Numerous international studies have identified marine sediments as both sinks and secondary sources of heavy metals, emphasizing the importance of geochemical assessments to evaluate ecological risks and inform management strategies. For instance, in coastal zones of Malaysia, fractionation studies revealed medium to high ecological risks from metals such as Cu, Zn, Se, and Pb using tools like Risk Assessment Code (RAC), Enrichment Factor (EF), and Pollution Load Index (PLI) (Ahmed *et al*, 2023). In the semi-arid Brazilian delta, metal accumulation correlated strongly with sediment composition and was assessed using CF, Igeo, EF, and PERI indices, showing generally low but spatially variable contamination levels (de Paula Filho *et al*, 2021). Similarly, ecological risk assessments along the Bay of Bengal emphasized moderate to high risks posed by Cd and As in dynamic coastal systems (Naik *et al*, 2023).

In Vietnam, coastal sediment studies have been conducted along multiple regions, with a growing body of research emerging over the past two decades. Studies from the Tien Yen estuary near Cai Bau Island found elevated concentrations of trace metals such as Zn, Pb, and Cu, highlighting anthropogenic inputs from upstream catchments and aquaculture zones (Quy *et al*, 2012). Research along the central coast from Nghe An to Quảng Tri revealed distinct spatial gradients in heavy metal distributions, with higher concentrations in sediments closer to industrial and urban centers, further supporting the influence of human activities (Ha *et al*, 2016). In Bai Tu Long Bay itself, mangrove sediment studies indicated localized accumulations of As, Pb, and Cr, often associated with fine - grained sediments and organic matter, underscoring the geochemical control of sedimentary processes on metal distribution (Trung *et al*, 2024).

More recently, assessments from other Vietnamese coastal areas, including Mong Cai (Loan *et al*, 2022) and the southern coastline from Dong Nai to Tho Chu Islands (Duong and Nhung, 2024), have confirmed significant spatial variation and ecological risk posed by heavy metals such as Cd, Pb, Cu, and Zn. These studies frequently utilized integrated approaches including atomic absorption spectroscopy (AAS), principal component analysis (PCA), and geochemical indices (*EF*, *CF*, *Igeo*, *PERI*) to quantify contamination sources and distribution patterns.

However, despite these advancements, there remains a critical spatial data gap around Cai Bau Island, a key geographic feature in northern Quang Ninh province that acts as a barrier island to Bai Tu Long Bay. This area is of increasing concern due to rising aquaculture development, port infrastructure, and tourism, potentially contributing to sediment contamination. No comprehensive study has yet focused on spatial geochemical profiling and ecological risk assessment of heavy metals specifically in the coastal sediments around Cai Bau Island. Such an assessment is vital to establish baseline conditions, track pollutant sources, and formulate scientifically informed coastal management policies.

Therefore, this study aims to fill that knowledge gap by conducting a detailed geochemical assessment and spatial distribution analysis of heavy metals in coastal sediments surrounding Cai Bau Island. The research leverages advanced analytical techniques and internationally validated pollution indices to determine contamination levels, ecological risks, and potential anthropogenic sources.

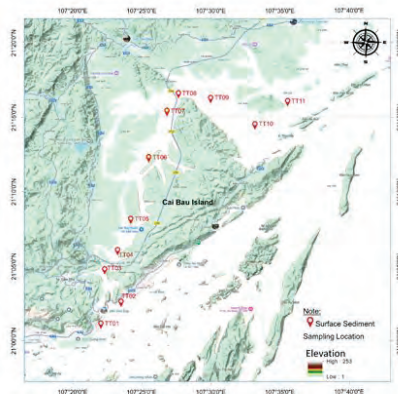


Fig 1. Location of sampling sites in the Cai Bau Island intertidal zone

2. Materials and methods

2.1. Study area

Cai Bau Island is located in Bai Tu Long Bay, northern Vietnam. It is a key coastal barrier island, facing increasing anthropogenic pressure due to aquaculture, maritime transport, and tourism development. The island lies adjacent to the mainland with a complex network of estuaries and semi - enclosed bays, creating favorable conditions for the deposition of fine - grained sediments that act as sinks for heavy metals.

Surface sediment samples ($n = 11$) were collected from the nearshore zone around Cai Bau Island, covering the spatial extent from TT01 (X: 2324621; Y: 460131) to TT11 (X: 2351942; Y: 483053) in VN2000 coordinate system, projection zone 3, 107°45' (Fig 1). The locations were selected to reflect gradients of industrial, aquacultural, and relatively undisturbed zones to assess spatial distribution trends of heavy metal contamination.

2.2. Sample collection and preparation

Surface sediment samples were collected using a Van Veen grab sampler to recover the upper 0–5 cm of unconsolidated material. Each sample was stored in acid - washed polyethylene containers, transported on ice, and subsequently air - dried at 40°C in a clean lab environment. Samples were then disaggregated, sieved through a 63 μ m stainless steel mesh, and homogenized to ensure uniform particle size for trace metal analysis.

2.3. Analytical techniques

For heavy metal quantification (As, Pb, Hg, Cd, Zn, Cu), samples were digested using HNO₃–HCl (aqua regia) in a closed - vessel microwave digestion system (USEPA Method 6020A) (Tessier and Bisson, 1979). Metal concentrations were determined using Inductively Coupled Plasma Mass Spectrometry (ICP - MS), with internal standards and procedural blanks used for quality assurance. Calibration curves were prepared using certified reference materials. Replicate measurements were carried out to ensure precision, with relative standard deviations maintained below 10 %.

2.4. Interim Sediment Quality Guidelines (ISQG)

To evaluate contamination levels, heavy metal concentrations were compared to the Interim Sediment Quality Guidelines (ISQG) established by the Canadian Council of Ministers of the Environment (CCME, 2001). The ISQG threshold represents the concentration below which adverse biological effects are expected to occur rarely. Values above this threshold suggest potential ecological concern.

2.5. Data processing

- The Enrichment Factor (*EF*) was applied to distinguish anthropogenic inputs from natural lithogenic contributions:

$$EF = \frac{C_n(\text{sample}) / C_{ref}(\text{sample})}{B_n(\text{background}) / B_{ref}(\text{background})} \quad (1)$$

where: $[C_n]$ sample / $[C_{ref}]$ sample is the sample concentration of metals in the analysed sediment samples and $[B_n]$ background / $[B_{ref}]$ background refers to the background value of the metal.

EF values were interpreted as: <1 (no enrichment), 1–3 (minor), 3–5 (moderate), 5–10 (significant), and >10 (very high) (Taylor and McLennan, 1985).

- The Geoaccumulation Index (*I_{geo}*) was used to assess metal contamination relative to geochemical background levels:

$$I_{geo} = \log_2 \frac{C_n}{1.5B_n} \quad (2)$$

Where C_n is the measured metal concentration and B_n is the background concentration. The constant 1.5 accounts for natural fluctuations and lithogenic variability. The Igeo scale classifies contamination into seven grades, from unpolluted ($I_{geo} \leq 0$) to extremely polluted ($I_{geo} > 5$) (Müller, 1969).

- To evaluate the ecological risk posed by heavy metals, Hakanson's Potential Ecological Risk Index method was employed. The risk coefficient for each element was calculated as:

$$E_r^i = C_f^i \cdot T_r^i \quad (3)$$

$$RI = \sum_{i=1}^n E_r^i \quad (4)$$

where: E_r^i is the ecological risk factor for element i and T_r^i is the toxic - response factor (e.g., Zn=1, Cu=5, Pb=5, As=10, Cd=30, and Hg=40)

RI values were categorized as low (<150), moderate (150–300), considerable (300–600), and very high (>600) ecological risk (Hakanson, 1980).

- Multivariate Statistical Analysis: To identify patterns and possible sources of heavy metals, Principal Components Analysis (PCA) and Hierarchical Clustering Analysis (HCA) were conducted using SPSS Statistics.

PCA was applied to log - transformed, standardized data to reduce dimensionality and identify dominant geochemical processes and source contributions.

HCA using Ward's method and Euclidean distance was used to cluster sampling sites based on their geochemical signatures. The resulting dendrogram helped classify locations by similarity in pollution characteristics.

3. Results and discussion

3.1. Comparison with ISQG thresholds

The summary statistics of six heavy metals (As, Pb, Hg, Cd, Zn, Cu) in surface sediments across 11 sampling sites (TT01–TT11) during 2020–2021 are presented in Fig 2. The Canadian ISQG guidelines indicate the following thresholds ($\text{mg} \cdot \text{kg}^{-1}$): As (7.24), Pb (30.2), Hg (0.13), Cd (0.7), Zn (124), and Cu (18.7). Key observations include:

Arsenic (As): Mean values at TT01, TT03, and TT04 exceed the ISQG threshold, suggesting potential ecological risk.

Lead (Pb): All values remain below the ISQG threshold (30.2 mg / kg), but TT01 and TT08 exhibit levels approaching concern.

Mercury (Hg): All sites significantly exceed the ISQG (0.13 mg / kg), indicating high ecological concern.

Cadmium (Cd): All sites fall below the ISQG (0.7 mg / kg), although close to the threshold in many samples.

Zinc (Zn): Generally below ISQG (124 mg / kg), except TT07 which exceeds the threshold.

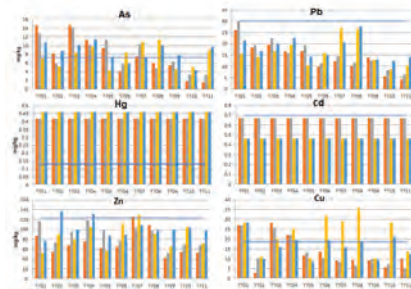


Fig 2. Descriptive statistics of heavy metal concentrations ($\text{mg} \cdot \text{kg}^{-1}$ dry weight) by location

Copper (Cu): Values at TT01, TT03, and TT04 exceed ISQG (18.7 mg / kg), pointing to anthropogenic sources.

In this study, the results of analyzing the content of heavy metals in sediment did not exceed the allowed limit, however, they were higher than the results of the previous study (Anh and Giang, 2006), except for Pb and Hg. It has been corroborated that the content of heavy metals in the sediments of the study area is increasing and is likely to impact benthic organisms due to sediment disturbance.

3.2. Enrichment Factor (EF) and Geoaccumulation Index (Igeo)

The Enrichment Factor (EF) calculated shows that each heavy metal has the following enrichment levels (Table 1):

Table 1. Mean enrichment factor and geoaccumulation index by metal and location

Metal Location	As		Pb		Hg		Cd		Zn		Cu	
	EF	Igeo	EF	Igeo	EF	Igeo	EF	Igeo	EF	Igeo	EF	Igeo
TT01	5.607	- 0.188	4.844	- 0.237	35.577	0.654	31.875	0.582	5.957	- 0.145	6.471	- 0.088
TT02	2.574	- 0.389	2.578	- 0.360	26.378	0.654	22.693	0.582	4.689	- 0.121	1.354	- 0.653
TT03	4.525	- 0.167	3.147	- 0.300	27.841	0.654	24.737	0.582	4.679	- 0.119	4.220	- 0.190
TT04	3.493	- 0.199	2.585	- 0.325	24.396	0.654	21.566	0.582	5.115	- 0.022	3.518	- 0.186
TT05	3.338	- 0.347	2.735	- 0.420	32.403	0.654	27.244	0.582	4.823	- 0.175	2.261	- 0.494
TT06	3.729	- 0.461	3.557	- 0.484	51.371	0.654	48.357	0.582	8.200	- 0.122	5.494	- 0.296
TT07	5.093	- 0.282	4.948	- 0.343	45.021	0.654	36.263	0.582	10.231	0.019	4.770	- 0.395
TT08	4.381	- 0.350	4.609	- 0.356	41.987	0.654	35.969	0.582	8.334	- 0.049	4.591	- 0.378
TT09	3.554	- 0.454	3.262	- 0.472	43.193	0.654	39.694	0.582	5.366	- 0.257	2.785	- 0.541
TT10	2.935	- 0.704	3.298	- 0.666	71.767	0.654	67.210	0.582	10.723	- 0.145	5.652	- 0.436
TT11	2.960	- 0.567	2.027	- 0.695	44.458	0.654	40.552	0.582	6.261	- 0.198	2.822	- 0.545

Mercury (Hg) showed great enrichment at TT06 to TT11 (EF = 41.99–71.77), and high enrichment at TT01 to TT05 (EF = 24.40–35.58).

Cadmium (Cd) was highly enriched at most sites (EF = 21.57–39.69) and had great enrichment at TT06, TT10, and TT11 (EF = 40.55–67.21).

Zinc (Zn) generally exhibited moderate to significant enrichment, with some localized enrichment (e.g., TT07 = 10.23 and TT10 = 10.72).

Arsenic (As) and Copper (Cu) exhibited consistently high EF values across all sites, approaching the boundary of significant enrichment (e.g., TT01 As = 5.61, TT07 As = 5.09, TT01 Cu = 6.47, TT06 Cu = 5.49 and TT10 Cu = 5.65).

Lead (Pb) had EF < 5 across all stations, with minor to moderate enrichment, indicating human input and a dominantly natural origin.

The Geoaccumulation Index (Igeo) calculated shows that each heavy metal has the following enrichment levels (Table 1):

Hg and Cd across all stations showed Igeo > 0, placing it in the unpolluted to moderately polluted category.

As, Pb, Zn, and Cu mostly fell below zero (Igeo < 0), suggesting unpolluted background levels.

These findings point to localized anthropogenic enrichment of Hg, Cd, Zn, As, and Cu, especially in the northern part of the study area (TT06–TT10), likely linked to runoff or industrial sources. In contrast, As, Cu, Zn, and Pb exhibit background levels at most sites, suggesting limited contamination from direct human inputs.

3.3. Ecological risk assessment

The contamination factor (C_f^i) for each heavy metal and the degree of contamination (C_d) are presented in Table 2. The integrated contamination level of sediments, as evaluated through C_d values ranging from 7.01 to 7.06, indicates a low overall contamination status for the study area’s coastal sediments.

Table 2. Results of contamination factor (Cd) of selected heavy metals at different sites

Metal	As	Pb	Hg	Cd	Zn	Cu	C_d	Sediment quality
C_f^i	1.04 - 1.17	0.46 - 0.60	3.23 - 3.54	0.66 - 0.96	0.58 - 0.83	0.71 - 1.89	7.01 - 7.67	Lowly contaminated

The results of the potential ecological risk coefficient (E_r^i) and the composite potential ecological risk index (PERI) are summarized in Table 3. The order of metal contributions to the total RI is as follows: Zn < Pb < Cu < As < Cd < Hg, with all individual E_r^i values falling within the moderate ecological risk range, by the classification thresholds proposed by Hakanson (1980).

When evaluating the individual ecological risks of each metal (Table 3), all six – Zn, Pb, Cu, As, Cd, and Hg – are categorized as posing moderate ecological risk based on their respective E_r^i values. However, it is noteworthy that Hg and Cd exhibited significantly higher toxic response coefficients and contributed disproportionately to the total RI. Mercury alone maintained a mean E_r^i of approximately 135, placing it within the considerable risk category, while cadmium showed a lower average E_r^i of 24.5, indicating low to moderate risk.

Table 3. Results of ecological risk factor (RI) of selected heavy metals at different sites

Metal	As	Pb	Hg	Cd	Zn	Cu	RI	Ecological risk
E_r^i	10.56 - 11.72	2.31 - 2.99	129.23 - 141.54	19.71 - 28.71	0.58 - 0.83	3.55 - 5.94	175 - 181	Mediumly ecological risk

In conclusion, there is no strong evidence of heavy metal contamination or ecological threat in the tidal flat sediments along the coastal zone of Cai Bau Island, based on current contamination and risk indices. Nonetheless, preventive actions should remain a priority, particularly about

controlling input sources of highly toxic elements such as Hg and Cd, due to their persistence, potential for bioaccumulation, and harmful ecological effects.

3.4. Cluster and principal components analysis

Cluster and principal component analyses (Fig 3) grouped the sampling sites as follows:

Group TT01, TT03: characterized by high concentrations of As and Cu, indicating areas influenced by anthropogenic activities such as aquaculture and domestic wastewater.

Group TT05, TT06, TT07: more isolated, with lower metal concentrations, primarily influenced by natural factors.

This pattern suggests that anthropogenic factors - such as aquaculture, waterway traffic, and runoff from the mainland - significantly affect the distribution of heavy metals in the intertidal zone.

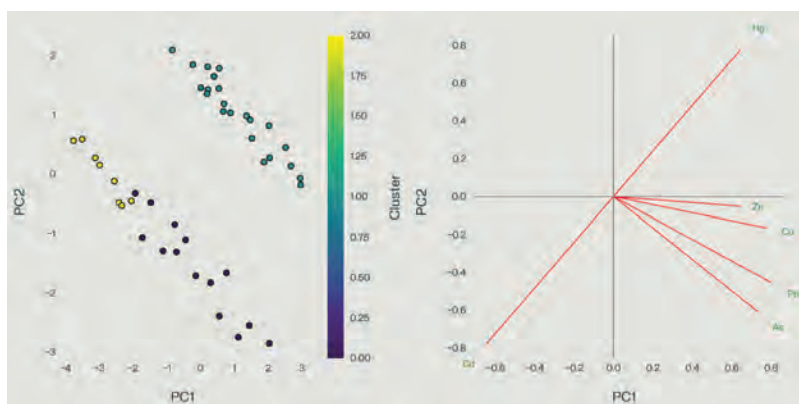


Fig 3. Cluster and principal component analysis of heavy metal loads

4. Conclusion

This study provides a comprehensive geochemical assessment of heavy metals (As, Pb, Hg, Cd, Zn, Cu) in surface sediments around Cái Bấu Island, Quảng Ninh Province, northern Vietnam. Analytical results revealed that:

Concentrations of As and Hg frequently exceeded ISQG thresholds, with TT01, TT03, and TT04 identified as ecological risk hotspots ($RI > 300$).

Mercury posed the greatest ecological concern across all sites due to its high toxicity and consistent enrichment.

Enrichment factor (EF) and geoaccumulation index (Igeo) analyses confirmed moderate to significant anthropogenic input of As, Hg, and Cd.

Temporal analysis indicated a decline in As and Cd from 2020 to 2021, but a sharp increase in Cu and Zn at sites TT08–TT11, suggesting emerging land - based sources.

PCA and HCA identified two distinct pollution sources: industrial / atmospheric (As, Pb, Hg) and local runoff / aquaculture (Cu, Zn, Cd), allowing spatial grouping of stations by contamination profiles.

These findings emphasize the spatial and temporal complexity of metal contamination in coastal sediments and demonstrate the effectiveness of combining geochemical indices with multivariate statistics for source apportionment and risk evaluation.

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**ASSESSING THE CURRENT ENVIRONMENTAL STATUS AND DETERMINING
THE CAUSES OF ENVIRONMENTAL POLLUTION IN MINERAL EXPLOITATION
ACTIVITIES IN COASTAL AREA
OF DUC THO, CAN LOC, HA TINH PROVINCE**

Annotation

The mining industry has been increasingly occupying an important position in our country's economy and is an important resource in the country's industrialization process. According to the results of the investigation and actual survey in Duc Tho - Can Loc area, there are currently 9 mineral mines including: 03 manganese mines, 02 construction stone mines and 04 landfill mines. Based on the field survey, analysis of samples and documents related to the research area, the article analyzes the current status and causes of environmental pollution. The results of the investigation and assessment of the current environmental status related to mineral exploitation activities have shown that the environment in the research area shows signs of pollution to serious pollution. Through the results of measuring and analyzing surface water samples, it shows that some indicators exceed the allowable standards many times, typically: DO is 2.7 - 1.07 times lower; pH is 1.01 times lower; COD is 2.4 - 31.2 times higher; BOD5 2.8 - 3.8 times; Mn: exceeds 3.9 times. Groundwater in people's domestic wells is particularly seriously polluted. The water is opaque white and soil sample analysis results show that Cu content exceeds 1.2 - 15.7 times; Mn exceeds 1.3 times; As exceeds 2.2 - 8.9 times. It is acknowledged that there are two main causes of environmental pollution in the study area as identified by the authors including: natural causes (including topographic factors, river network factors) are the prerequisite factors for environmental pollution and human causes are the most direct and important factors causing environmental pollution in mineral exploitation mines.

Keywords

Environmental pollution, mineral exploitation, Duc Tho, Can Loc

1. Introduction

The mining industry has been playing an increasingly important role in our country's economy and is an important resource in the country's industrialization process. However, besides the positive aspects, mining activities also cause many negative impacts on the ecological environment and human life and property. The exploitation and use of mineral resources in general have a strong impact on the natural environment; including the living environment. [4]. In addition, the work of assessing the current state of the environment has not been given due attention and has not been