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Research Article

Ecological risk assessment of some heavy metals in sediments in the Dong Nai River section flowing through Binh Duong Province, Vietnam

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Abstract

This study assessed heavy metal contamination and ecological risk in the sediments of the Dong Nai River section flowing through Binh Duong Province, Vietnam. Four monitoring stations (DN1, DN2, DN3, DN4) were established to analyze the concentrations of heavy metals, including arsenic (As), copper (Cu), zinc (Zn), lead (Pb), cadmium (Cd), and chromium (Cr). The results indicated that the concentrations of heavy metals were generally low and within acceptable limits established by Vietnam national standards (QCVN 43:2012/BTNMT). Notably, chromium and arsenic exhibited the highest concentrations among the metals analyzed. The Degree of Contamination (*Cd*) across the sampling sites ranged from 1.48 to 1.64, indicating a low level of overall sediment contamination. Correspondingly, the Potential Ecological Risk Index (PERI) values ranged from 5.23 to 6.73, reflecting low ecological risk levels across all monitoring stations. These findings suggest that while the current sediment quality in this section of the Dong Nai River is stable, ongoing monitoring is essential to prevent potential risks associated with heavy metal accumulation, particularly for chromium and arsenic. The study underscores the importance of proactive environmental management to safeguard the aquatic ecosystem against future contamination threats.

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Introduction

The Dong Nai River is one of the largest and most important river systems in Vietnam, flowing through several provinces, including Dong Nai, Binh Duong, and Ho Chi Minh City (Pham et al., 2020). Serving as a vital source of water for agricultural, industrial, and domestic activities for millions of people, the Dong Nai River plays an irreplaceable role in the economic and social development of the region (Dao, 2006). However, due to rapid industrial development, urbanization, and inadequate waste management, the Dong Nai River faces significant pollution, particularly heavy metal contamination in sediments (Nguyen, 2017). Binh Duong, located along the downstream section of the Dong Nai River, is one of the provinces with the fastest industrial growth in the country (Huynh and Tran, 2012). These activities lead to direct and indirect discharges of heavy metals into the aquatic environment, adversely affecting sediment quality in the river (Nguyen et al., 2021; Nguyen et al., 2022). According to the Southern Center for Environmental Monitoring and Analysis (2018), concentrations of heavy metals such as cadmium (Cd), lead (Pb), copper (Cu), and zinc (Zn) have appeared at several monitoring points along the Dong Nai River (SCEMA, 2018).

Heavy metals in sediments not only affect water quality but also pose serious ecological risks to aquatic ecosystems (Liu et al., 2009; Gheorghe et al., 2017;

Xu et al., 2017). When accumulated in sediments, they can re-enter the water column under changing environmental conditions (e.g., pH changes or sediment disturbance), subsequently entering the food chain (Walker, 2017; Nguyen et al., 2020). Fu et al. (2013) found that heavy metal levels in sediments from the Yangtze River were significantly higher compared to those in sediments from Taihu Lake (Fu et al., 2013). Similarly, Mao's 2020 research on heavy metal risk assessment in sediments of the Lhasa River in China revealed that the downstream region, along with the Meldromarchu and Tölungchu tributaries, represented the main areas with elevated aquatic ecological risks (Mao et al., 2020).

Numerous studies have demonstrated that the accumulation of heavy metals in sediments can result in significant ecological consequences (Zhang et al., 2014). Hakanson (1980) developed the Potential Ecological Risk Index (PERI), a useful tool for assessing the ecological risk of heavy metals based on their concentrations and toxicity levels (Hakanson, 1980). This index has been applied in various studies worldwide. For example, Yozukmaz and Yabanlı (2023) had a potential ecological risk assessment in the sediments of Lake Bafa (Turkey) The findings indicate the following accumulation order of heavy metals in the sediment: Fe > Al > Mn > Ni > Cr > Zn > Pb > Co > Cd, with concentrations of Al, Mn, and Ni being high in the surface sediment samples. The PERI analysis indicates a moderate risk of heavy metal pollution at some stations. As one of the most comprehensive studies applying such indices to Lake Bafa, the results are very significant in evaluating the lake's ecological sustainability (Yozukmaz and Yabanlı, 2023).

In Vietnam, some studies have also been conducted on heavy metal pollution in sediments, though most focus on areas such as Sai Gon and Dong Nai. In a study by Nguyen et al. (2023), the sediment of the Saigon River was analyzed for heavy metal content, showing that Ag, Ba, Mn, and Zn carried the highest pollution risks, particularly during the rainy season. The total concentrations of heavy metals in the sediments ranged from 109.92 to 4591.01 mg/kg in the rainy season (Mn > Zn > Li > Ba > Ag > Cr > Cu > Pb) and from 0 to 3117.8 mg/kg in the dry season (Mn > Ag > Zn > Li > Ba > Cr > Cu > Pb). Despite the industrial development pressures in the section of the Dong Nai River flowing through Binh Duong, research in this area remains limited (Nguyen et al., 2023).

This study aimed to evaluate the ecological risk posed by selected heavy metals in sediments of the Dong Nai River section flowing through Binh Duong Province. By analyzing the concentrations of heavy metals such as Cd, Pb, Cu, and Zn at various monitoring points along the river and applying the Potential Ecological Risk Index (PERI) methodology, the research will provide a comprehensive overview of the risk levels these metals pose to the aquatic ecosystems in the area. The results of this study will not only raise awareness about the current pollution situation but also offer recommendations for managing and restoring sediment ecosystems, contributing to the protection of the Dong Nai River's water resources and public health.

Additionally, this research will contribute to the growing body of data on heavy metal pollution in Binh Duong, providing important information for regulatory agencies to develop and implement measures for pollution reduction, environmental protection, and sustainable development.

Materials and Methods

Research area

The Dong Nai River runs through several provinces, including Lam Dong, Dak Nong, Binh Phuoc, Dong Nai, Binh Duong, and Ho Chi Minh City (Nguyen et al., 2010). It stretches over 437 km in length, with a basin covering an area of 38,600 km². When measured from the Da Dang River's source, its total length extends to 586 km, or 487 km, from the confluence with the Da Nhim River below Pongour Waterfall. The river eventually empties into the East Sea in Can Gio District. Its upper section is referred to as the Da Dang River, originating from the Lam Vien Plateau and flowing in a northeast-southwest direction, crossing mountains and reaching the plains at Ta Lai in Tan Phu District, Dong Nai Province. It acts as a natural boundary between several regions, including Dak R'Lap (Dak Nong) and Bao Lam - Cat Tien (Lam Dong), Cat Tien and Bu Dang (Binh Phuoc) - Tan Phu, and between Tan Phu and Da The. After joining the Song Be River, the Dong Nai River becomes a natural divide between Dong Nai (Vinh Cuu) on the left bank and Binh Duong Province (Tan Uyen) on the right bank. Flowing in a north-south direction near Uyen Hung Ward, Tan Uyen City in Binh Duong, the river encircles the islands of Tan Uyen and Cu Lao Pho (Scienceinfo, 2024).

The research area selected for this study is the section of the Dong Nai River that flows through Binh Duong Province, a region experiencing rapid industrial and urban development. This section, located downstream in the Dong Nai River system, is significantly impacted by domestic waste discharge from upstream areas. The study focused on four monitoring stations (DN1, DN2, DN3, DN4) within this river section to evaluate heavy metal pollution levels in the sediments and assess potential ecological risks. The details of the four monitoring stations are provided in Figure 1 and Table 1.

A total of 12 sediment samples were collected at 4 monitoring stations (DN1, DN2, DN3, DN4) as shown in Figure 1. Each sampling point was collected at a depth of 15 cm using a WILCO bottom mud sampler (Model 196-F62) to ensure surface sediment samples, where heavy metal accumulation is highest (Based on TCVN 6663-13:2000 on water quality, sampling part 13 guidance on the sampling of water

sludge, wastewater sludge, and related sludge). After collection, samples were stored in locked plastic bags, labeled, transferred to the laboratory, and preserved according to TCVN 6663:15-2004.

Table 1. Description of the sampling locations along the Dong Nai River as it flows through Binh Duong Province.

Monitoring station	Sampling location symbol	Description of monitoring point	Sampling location	
			Latitude	Longitude
About 1km from the junction of Dong Nai River - Song Be River	DN1	Assessment of bottom sediment quality at the confluence of Dong Nai River and Song Be River.	$11^0$63’30.84’’	$106^0$55’30.3’’
Tan Hiep water plant water intake	DN2	Evaluation of the quality of input bottom sludge sediment for Tan Hiep water supply plant and the downstream area of Dong Nai River in Binh Duong Province.	$11^0$3’9”	$106^0$43’2’’
New bridge across Bach Dang Island	DN3	Assessment of the quality of bottom sediment impacted by fish farming activities and production activities of some factories.	$11^0$03’4.38’’	$106^0$47’8.94’’
Tan Ba water plant water intake	DN4	Evaluation of the quality of input bottom sludge sediment for Tan Ba water supply plant and the downstream area of Dong Nai River in Binh Duong Province.	$10^0$57’55’’	$106^0$42’55’’

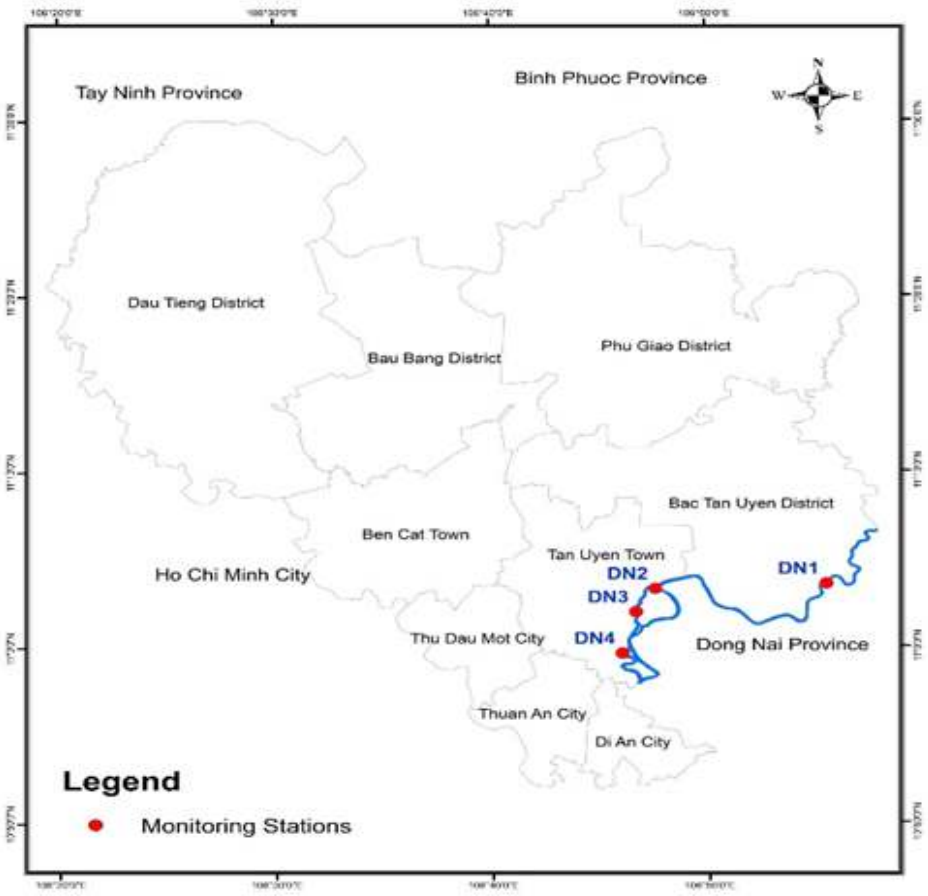

Figure 1. Sampling location.

Sample analysis

All sediment samples after collection were analyzed for heavy metal content based on Vietnamese standards for each type of heavy metal: arsenic (As), copper (Cu), zinc (Zn), lead (Pb), cadmium (Cd), chromium (Cr) using a flame atomic absorption spectrometer AAS - Model: AA400. Details are presented in Table 2.

Table 2. Sample analysis methods.

No	Heavy metals	Unit	Analytical method/ measuring device
1	As	mg/kg	TCVN 8467-2008
2	Cu	mg/kg	TCVN 6496-2009
3	Zn	mg/kg	TCVN 6496-2009
4	Pb	mg/kg	TCVN 6496-2009
5	Cd	mg/kg	TCVN 6496-2009
6	Cr	mg/kg	TCVN 6496-2009

Potential ecological risk index

Potential Ecological Risk Index (PERI) is a method used to assess the ecological risk of heavy metals in the environment, especially in sediments. The PERI index is not only based on heavy metal concentrations but also considers their toxicity factors to the ecosystem (Hakanson, 1980).

The potential ecological risk index for each heavy metal is calculated using Equation 1.

$$E_T^i = T_r^i \; x \; C_f^i \qquad (1)$$

in which:

E_T^i : Potential ecological risk index of heavy metals i

T_r^i : Ecotoxicity coefficient of heavy metal i (characterizing the toxicity level of each heavy metal). According to Hakanson, T_r^i of As = 10, Cu = 5, Zn = 1, Pb = 5, Cd = 30, Cr = 2

C_f^i : Pollution coefficient of heavy metal i, calculated as follows (Equation 2)

$$C_f^i = \frac{C_s^i}{C_n^i} \qquad (2)$$

in which:

C_s^i : Concentration of heavy metal i in sediment sample.

C_n^i : Background concentration of heavy metal i, i.e. natural concentration of that heavy metal in unpolluted environment.

The Degree of Contamination (C_d) (Table 3) was calculated by the sum of the pollution coefficient of heavy metal i(Equation 3).

$$C_d = \sum_{i=1}^{n} C_f^i \qquad (3)$$

Table 3. The degree of contamination.

C_d	Contamination level
$C_d < 8$	Low contamination
$8 \leq C_d < 16$	Medium contamination
$16 \leq C_d < 32$	High contamination
$C_d \geq 32$	Extremely high contamination

The Value (E_T^i) index is classified as follows (Table 4):

Table 4. Ecological risk level according to E_T^i.

Value E_T^i	Level of ecological risk
$E_T^i < 40$	Low risk
$40 \leq E_T^i < 80$	Medium risk
$80 \leq E_T^i < 160$	High risk
$160 \leq E_T^i < 320$	Very high risk
$E_T^i \geq 320$	Extremely high risk

Potential Ecological Risk Index (PERI): The potential ecological risk index (Table 5) is calculated by summing the E_T^i-indexes of all heavy metals surveyed (Equation 4)

$$\text{PERI} = \sum_{i}^{n} E_T^i \qquad (4)$$

Table 5. Potential ecological risk level according to PERI.

Value PERI	Level of ecological risk
PERI < 110	Low risk
110 ≤ PERI < 220	Medium risk
220 ≤ PERI < 440	High risk
PERI ≥ 440	Extremely high risk

Data analysis

The data collected were evaluated in comparison with the Vietnamese standards outlined in QCVN 43:2012/BTNMT (QCVN, 2012). Excel and Statgraphics software were used for data processing.

Results and Discussion

Evaluation of heavy metal content in sediment

Heavy metals content in Dong Nai River sediments flowing through Binh Duong province is shown in Table 6. Based on the analysis of heavy metal concentrations in sediment at four monitoring stations along the Dong Nai River section flowing through Binh Duong Province (DN1, DN2, DN3, DN4) and comparing with the QCVN 43:2012/BTNMT standards for sediment quality, the findings indicate the following:

Arsenic (As): The concentrations of As range from 3.18 mg/kg (DN4) to 6.04 mg/kg (DN1), which are significantly below the allowable limit of 17 mg/kg. These findings align with previous studies indicating that arsenic levels in sediments in this region are

generally within safe limits (Nguyen et al., 2018). This implies that the sediment does not currently present a risk of arsenic contamination. However, regular monitoring remains crucial given the potential for As leaching from upstream industrial activities.

Copper (Cu): Cu concentrations vary from 21.7 mg/kg (DN4) to 24.5 mg/kg (DN2), all well below the threshold of 197 mg/kg. This suggests that Cu contamination in the study area is negligible. In comparison to findings from the Song Hong River, where Cu concentrations ranged from 7.97-104.0 mg/kg (Trinh et al., 2022), the current levels in the Dong Nai River are notably lower, further confirming its relatively unpolluted status.

Zinc (Zn): Zn levels range from 29.8 mg/kg (DN3) to 62.2 mg/kg (DN2), considerably below the allowable limit of 315 mg/kg. Although the concentrations fluctuate across stations, they remain within safe limits, posing no significant risk of contamination. These results are consistent with studies on the Vam Thuat River, where Zn concentrations are within the allowable limits of Vietnam national standards (Le et al., 2018), suggesting that Zn pollution is not a concern in either region.

Lead (Pb): Pb concentrations range from 7.5 mg/kg (DN1) to 8 mg/kg (DN2 and DN3), significantly lower than the permissible limit of 91.3 mg/kg. Compared to sediment samples from the Ma River in Thanh Hoa Province, which reported Pb levels of up to 102.0 mg/kg (Bui and Cao, 2021), the Pb concentrations in the Dong Nai River are comparatively moderate, indicating lesser industrial or urban contributions.

Cadmium (Cd): Cd concentrations are extremely low, between 0.03 mg/kg and 0.04 mg/kg, compared to the standard limit of 3.5 mg/kg. This minimal level of Cd aligns with findings in the Red River sediments (Bui and Cao, 2021), where Cd concentrations range from 0.06-071 mg/kg. Cd is not a concern in the study area.

Chromium (Cr): Cr concentrations range from 74.3 mg/kg (DN3) to 87.5 mg/kg (DN4), nearing the standard limit of 90 mg/kg. While still within acceptable limits, Cr levels, particularly at DN4, suggest that localized sources may be contributing to the higher values. Compared to previous research on the Day River, where Cr concentrations reached up to 97.3 mg/kg (Le et al., 2018), the Dong Nai River exhibits slightly lower but comparable levels, emphasizing the need for continued monitoring.

All measured heavy metal concentrations are below the QCVN 43:2012/BTNMT standards. Although Cr levels are nearing the limit, the overall status of heavy metal pollution in the sediment at the study area is not alarming. This suggests that the environmental condition of the Dong Nai River section flowing through Binh Duong Province is relatively safe for the ecosystem, but continuous monitoring is required to detect potential emerging pollution risks, particularly for chromium (Cr).

Table 6. Heavy metals content in sediments.

Sample location	Heavy metals content (mg/kg)					
	As	Cu	Zn	Pb	Cd	Cr
DN1	6.04 ± 0.01	23.10 ± 0.01	56.70 ± 0.03	7.50 ± 0.01	0.03 ± 0.01	78.60 ± 0.01
DN2	5.55 ± 0.01	24.50 ± 0.01	62.20 ± 0.02	8.00 ± 0.03	0.03 ± 0.02	80.80 ± 0.02
DN3	5.77 ± 0.01	24.00 ± 0.01	29.80 ± 0.01	8.00 ± 0.01	0.04 ± 0.01	74.30 ± 0.02
DN4	3.18 ± 0.02	21.70 ± 0.01	55.90 ± 0.01	7.90 ± 0.02	0.03 ± 0.02	87.50 ± 0.01
QCVN 43:2012/BTNMT	**17**	**197**	**315**	**91.3**	**3.5**	**90**

Assessment of sediment contamination levels

The contamination levels by the total pollution coefficient of heavy metals in the Dong Nai River section flowing through Binh Duong Province are presented in detail in Table 7. The results presented in Table 7 show that the Degree of Contamination (C_d) index for the sampling sites ranges from 1.48 to 1.64, indicating a low level of contamination overall. This suggests that, while there is a presence of heavy metals in the sediments, the contamination levels remain within reasonable limits and do not pose a significant risk to the environment at this time.

Contamination levels by heavy metals: Chromium (Cr) has the highest contamination factor at all sites, especially at DN4, with C_f^i = 0.97. Arsenic (As) also ranked second highest, with pollution coefficient ranging from 0.19 (DN4) to 0.36 (DN1). Other heavy metals, such as copper (Cu), zinc (Zn), lead (Pb), and cadmium (Cd), exhibit very low contamination levels at all sites, particularly Cd, which is only 0.01, indicating it does not pose a significant risk of contamination. Comparison between sampling sites: DN1 has the highest overall contamination level (C_d = 1.62), mainly due to the contributions from Cr and As. DN4 has the highest Cr contamination level (C_f^i = 0.97), yet its total contamination level (C_d = 1.54) remains lower than that of DN1 and DN2. In which DN3 shows the lowest overall contamination level (C_d = 1.48), with all metals at low contamination levels and no significant variation.

The Degree of Contamination (C_d) values observed in this study range from 1.48 to 1.64, indicating a low overall level of sediment

contamination. These findings align with Trinh et al. (2022), who documented a comparable range of contamination in the sediments of the Red River (Trinh et al., 2022). In contrast, studies conducted in more heavily industrialized regions reveal significantly higher contamination levels. For example, Ye (2013) assessed the ecological risks of heavy metals in the Zhalong Wetland's surface sediments and identified cadmium (Cd) as the primary contaminant, with C_d values ranging from 11.02 to 19. This stark difference can be attributed to the influence of wastewater from intensive agricultural and aquaculture activities in the Zhalong Wetland, which introduces elevated levels of Cd into the environment (Ye, 2013). These findings underscore the variability of contamination sources and highlight the relatively lower impact of industrial and agricultural activities on the sediment quality in the current study area.

Table 7. Results of heavy metal contamination levels in sediments.

Sample location	C_f^i						C_d
	As	Cu	Zn	Pb	Cd	Cr	
DN1	0.36	0.12	0.18	0.08	0.01	0.87	1.62
DN2	0.33	0.12	0.20	0.09	0.01	0.90	1.64
DN3	0.34	0.12	0.09	0.09	0.01	0.83	1.48
DN4	0.19	0.11	0.18	0.09	0.01	0.97	1.54

Ecological risk assessment using PERI index

After assessing the heavy metals content and C_d contamination level. The study assessed the ecological risk level of heavy metals in the sediments of the Dong Nai River flowing through Binh Duong Province. The results are shown in Table 8. All monitoring stations (DN1, DN2, DN3, DN4) show Potential Ecological Risk Index (PERI) values ranging from 5.23 to 6.73, falling within the low-risk category according to PERI evaluation standards. This indicates that the heavy metal contamination levels in the Dong Nai River section flowing through Binh Duong Province currently do not pose a significant threat to the ecosystem. Detailed analysis by heavy metals:

Arsenic (As): The ecological risk index for arsenic (E_T^i) is the highest among the four stations, ranging from 1.87 (DN4) to 3.55 (DN1). Although As contributes the most to the total PERI, it remains within safe limits and does not present a serious risk.

Copper (Cu), zinc (Zn), lead (Pb), and chromium (Cr): The ecological risk indices for Cu, Zn, Pb, and Cr are relatively low and show minimal variation between stations. Cu and Zn exhibit the lowest indices, while Cr has slightly higher values, especially at DN4, with a value of 1.94.

Cadmium (Cd): Although Cd has the lowest risk indices among the surveyed heavy metals, ranging from 0.26 to 0.34, continuous monitoring is necessary as Cd is highly toxic even at low concentrations.

DN1 has the highest PERI value (6.73), while DN4 has the lowest (5.23). However, the differences between stations are not significant, and all fall within the low-risk category. In general, the heavy metals in the study area do not pose a considerable risk to the aquatic ecosystem at present. Nevertheless, ongoing monitoring programs should be maintained to detect any abnormal increases in heavy metal concentrations, particularly Cr and Cd, to ensure environmental safety.

In the research conducted by Zhao et al. (2009) on the ecological risks of heavy metals in surface sediments at Xijiu Lake, China, the sequence of ecological risk factors E_T^i was ranked as Cd > Cu > Zn > Pb > Cr. The authors attributed this pattern to the region's transition from agricultural to industrial activities, particularly industries releasing significant amounts of Cd in wastewater (Zhao et al., 2009). Similarly, Zhang et al. (2010) evaluated heavy metal risks in the sediments of Yangzonghai Lake, Yunnan, China, and observed results closely aligned with this study's findings on the Cu De River. The ecological risk factor E_T^i for Cu in Zhang's study ranged from 41.6 to 54.1, identifying Cu as the most critical contributor to ecological risk (Zhang et al., 2010).

When comparing the findings of this study with those of Tokatli et al. (2021), a notable similarity emerges in the ecological risk assessment of toxic metal contamination. In their study of a major mining basin in Turkey, Ni and Cr were identified as the most hazardous elements based on PERI results (Tokatli et al., 2021). Similarly, the Dong Nai River shows elevated levels of Cr, highlighting its potential as a significant contaminant. While the current Cr levels remain below the critical threshold, the findings underscore the necessity for ongoing monitoring to address any emerging risks and to prevent potential ecological harm.

Table 8. Risk assessment results according to PERI index.

Sample location	Value E_T^i						PERI index	Level of ecological risk
	As	Cu	Zn	Pb	Cd	Cr		
DN1	3.55	0.59	0.18	0.41	0.26	1.75	6.73	Low risk
DN2	3.26	0.62	0.20	0.44	0.26	1.80	6.57	Low risk
DN3	3.39	0.61	0.09	0.44	0.34	1.65	6.53	Low risk
DN4	1.87	0.55	0.18	0.43	0.26	1.94	5.23	Low risk

In conclusion, the research results indicate that the heavy metal contamination in the sediment of the Dong Nai River section through Binh Duong remains within safe levels for the ecosystem. However, continuous monitoring is essential to control potential risk factors that could emerge in the future.

Conclusions

The study conducted on heavy metal concentrations, contamination levels, and ecological risk indices in the sediments of the Dong Nai River section flowing through Binh Duong Province yielded several significant findings: The concentrations of heavy metals (As, Cu, Zn, Pb, Cd, and Cr) at all monitoring stations (DN1, DN2, DN3, DN4) were found to be relatively low, with all values falling within acceptable limits established by Vietnam national standards (QCVN 43:2012/BTNMT).

Besides, the degree of contamination (C_d) for the study sites ranged from 1.48 to 1.64, indicating a low level of contamination overall. The Potential Ecological Risk Index (PERI) for all stations indicated low ecological risk levels, ranging from 5.23 to 6.73. This low-risk classification implies that the current levels of heavy metal contamination in sediments are unlikely to have detrimental effects on the aquatic organisms inhabiting the river. While, the overall assessment of heavy metal concentrations, contamination levels, and ecological risk suggests that the conditions in the Dong Nai River section through Binh Duong Province are currently acceptable, proactive measures and regular monitoring should be implemented to ensure continued environmental safety and to address any potential increases in contamination levels in the future.

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