



Assessment of the Influence of Wastewater from Diesel Power Plant Through the Accumulation Level and Distribution of Heavy Metals Cu, Fe and Zn in Marine Sediments in the Waters of Suppa, South Sulawesi

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ABSTRACT

Background: Diesel power plants (DPP) are crucial for energy production but can significantly impact the environment through the release of heavy metals such as copper (Cu), iron (Fe) and zinc (Zn). Pollutants originating from diesel combustion, lubricating oils and waste disposal often accumulate in sediments and aquatic ecosystems, posing risks to environmental health.

Methods: This study aims to evaluate the concentration and distribution of heavy metals, namely copper (Cu), iron (Fe) and zinc (Zn), in sediments around the suppa diesel power plant located in Pinrang Regency, South Sulawesi. The analytical methods used include the geoaccumulation index (Igeo), pollution load index (PLI), ecological risk index (ERI) and co-kriging spatial analysis.

Result: The results indicate that the measured concentrations of heavy metals, with Cu reaching 45 mg/kg, Fe 1,200 mg/kg and Zn 30 mg/kg, show significant variation among sampling locations. The findings reveal that the sediments in the area are generally uncontaminated; however, moderate contamination is observed at Station 1, indicating localized pollution, particularly near the shoreline and around the plant, highlighting the need for ongoing monitoring. The limitations of this study include a limited number of samples and a short sampling period, which may not fully reflect seasonal fluctuations in heavy metal concentrations. This research provides valuable insights for policymakers and stakeholders in formulating more effective and sustainable waste management strategies, as well as contributing to a deeper understanding of the environmental challenges posed by DPP operations, emphasizing the importance of continuous monitoring.

Key words: Co-kriging, Diesel power plant, Ecological risk index, Geoaccumulation index, Pollution load index, Sediment contamination.

INTRODUCTION

Electricity is a critical component of modern society, supporting various activities from households to industries. In Indonesia, PT. PLN (Persero) has expanded its power generation capacity to meet the growing demand (Susanto *et al.*, 2021). Diesel Power Plants (DPP) play a significant role in providing electricity, especially in areas with limited access to alternative energy sources. One such plant is the suppa diesel power plant, located in South Sulawesi, Indonesia, with a generation capacity of approximately 6×10.4 MW (Rahman *et al.*, 2022). However, the operation of DPPs generates waste that can potentially pollute the environment, including solid, liquid and gaseous waste. Hazardous waste such as used oil and heavy metals can contaminate the surrounding environment and harm local ecosystems if not managed properly (Alamsyah *et al.*, 2020). According to the results of research by Zubkova and Vinogradov (2022) the largest distribution of mobile forms of heavy metals in the impact zone of the ryazan state district power plant (RGRES) was observed in the southern and southeastern directions within a radius of 2.5 km to 30 km, in the southwestern direction within a radius of 500 m to 7 km and in the northern and northwestern directions within a radius of 500 m to 2.5 km from the station.

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Sedimentation is a process that involves the deposition of silt carried by water flow from soil erosion in upstream catchments (Kumar *et al.*, 2019). Soils, seawater and marine sediments harbor high levels of biodiversity and support biogeochemical processes related to life on earth (Mugip *et al.*, 2025). Heavy metal pollution in marine

sediments is a major concern. Heavy metals such as copper (Cu), iron (Fe) and zinc (Zn) can accumulate in sediments through chemical and physical adsorption processes. This accumulation is affected by sediment characteristics and the nature of the adsorbed compounds, which may pose long-term ecological risks (Zhou *et al.*, 2020). Despite concerns about environmental pollution from industrial activities, research specifically examining the impact of the Suppa Diesel Power Plant on local marine sediments is very limited. Previous studies have not provided adequate data on the spatial distribution and concentration of heavy metals in this area, indicating a significant gap in the literature.

This study aims to evaluate the level of heavy metal pollution in marine sediments around the suppa diesel power plant. The research will employ established pollution indices, including the geoaccumulation index (Igeo), pollution load index (PLI) and ecological risk index (ERI), to assess the extent of contamination and its potential impact on the ecosystem. By analyzing the distribution and concentration of heavy metals such as Cu, Fe and Zn, this study aims to provide information that can inform future waste management and pollution control strategies.

The originality and scientific innovation of this research lie in the use of sustainable methods to evaluate the environmental impact of DPPs. This study not only provides new data on heavy metal contamination in marine sediments around the suppa diesel power plant but also offers insights that can be used to develop better environmental management practices. By focusing on the specific body of water, namely the marine waters surrounding the suppa diesel power plant, this study is expected to make a significant contribution to the understanding and management of heavy metal pollution in Indonesia.

MATERIALS AND METHODS

This research was conducted in the waters around the suppa diesel power plant, South Sulawesi (Fig 1). Sample analysis was conducted at the Standardization and Services Center for Plantation Products, Metal Minerals and Maritime Industries of the Ministry of Industry of the Republic of Indonesia, as well as the Marine Geomorphology Laboratory, the Chemical Oceanography Laboratory of the Faculty of Marine and Fisheries Sciences and the Chemistry and Soil Fertility Laboratory of the Faculty of Agriculture, Hasanuddin University.

Sediment samples were collected from 12 locations using an Ekman dredge and then transported to the laboratory. Sampling was conducted on March 1st, 2024 with the collection location determined using a global positioning system (GPS). The Eh value of the sediment was measured using an Eh meter. The pH value of the sediment was measured using a pH meter. Parameters analyzed in the laboratory include metal concentrations of Cu, Fe and Zn using atomic absorption spectrometry (AAS).

Sediment composition was determined using the Wentworth scale and total organic matter concentration was determined using the loss of ignition (LOI) method.

Data analysis

Analysis of heavy metal distribution

The distribution of heavy metals was created using spatial interpolation techniques. The chosen interpolation method was Co-kriging. CoKriging is a multivariate variant based on the Kriging method. It estimates or predicts values with a minimal number of samples by utilizing a more informative variable (covariable). The variables must exhibit a high correlation (either positive or negative). CoKriging is effective for obtaining precise results. It uses a covariance semivariogram, considering weights $\sum \omega_i = 1$ and $\sum \eta_j = 0$, along with the Kriging method (ILWIS, 2014). The semivariogram values, such as γ_A , γ_B and the cross variogram model, are used for m observations of the predictand A_i and n observations of the covariate B_j , as outlined in the CoKriging equation below:

$$Z = \sum_{i=1}^m \omega_i A_i + \sum_{j=1}^n \eta_j B_j \quad \dots(1)$$

Analysis of sediment pollution levels

The obtained data was processed to determine the level of heavy metal contamination in the sediment using the Geoaccumulation Index (I-Geo) with the formula:

$$I_{geo} = \log_2 [C_n / (1.5 \times B_n)] \quad \dots(2)$$

Where,

C_n = Concentration of n metals in the sediment sample.

B_n = Concentration of n metals in the background or reference value.

Background values can be measured or taken from the literature for sediment background data. A factor of 1.5 is used due to possible variations in background values such as anthropogenic influences. The geoaccumulation index can be seen in Table 1.

Meanwhile, the pollution load is calculated using the pollution load index (PLI) by the following formula:

$$PLI = [CF_1 \times CF_2 \times CF_3 \dots \times CF_n]^{1/n} \quad \dots(3)$$

Description

CF = Contamination factor/Contamination factor of each metal/Contamination factor of each element.

n = Number of metals.

The ecological risks posed by the presence of heavy metals in sediments are determined using the ecological risk index (ERI) proposed by Hakanson (1980) is calculated using the following equation:

$$ERI = \sum_{i=1}^n E_r^i = \sum_{i=1}^n T_r^i \cdot C_r^i \quad \dots(4)$$

Description

C_r^i = Concentration value of metal i divided by the background value of the metal.

T_{ir} = The "toxic response factor" of metal i reflects the toxicity and sensitivity of bioorganisms to heavy metals. The ecological risk index can be seen in Table 2.

RESULTS AND DISCUSSION

Sediment characteristics

Sediment composition

The results of the sediment composition analysis found 3 types of sand, dust and clay (Fig 2). The diagram above shows that sand is the main component of the sediment at 40%, followed by clay at 38% and dust at 22%.

Sediment total organic matter concentration

The results of the analysis of total organic matter concentration in sediments at each observation point are presented in Fig 3.

Fig 3 shows that the concentration of total organic matter (TOM) varies, with TOM values ranging from 5.92 to 19.98 mg/L and an average value of 15.73 mg/L. Overall,

Table 1: Geoaccumulation index.

I-geo value	Contamination levels
I-geo ≤ 0	Not polluted
0 < I-geo < 1	Not polluted to moderately polluted
1 < I-geo < 2	Moderately polluted
2 < I-geo < 3	Moderately to heavily polluted
3 < I-geo < 4	Heavily polluted
4 < I-geo < 5	Severely to heavily polluted
I-geo > 5	Very heavily polluted

Source: Alahabadi and Hassan (2018).

Table 2: Ecological risk index (ERI).

ERI value	Ecological risks
RI < 150	Low risk
150 < RI < 300	Medium risk
300 < RI < 600	Considerable risk
600 > RI	High risk

Source: Wang *et al.* (2014).

the TOM concentration is distributed fairly evenly, although there are some low values. Organic matter is a very important geochemical component in controlling the binding of heavy metals from sediments (Maslukah, 2013).

Sediment Eh value

The results of the sediment Eh measurements at each observation point are shown in Fig 4. The sediment Eh values indicate a reduced condition of the sediments.

Redox potential (Eh) is an electrochemical property that can be used as an indication in measuring the degree of soil anaerobicity and the level of biogeochemical transformation that occurs. The redox potential value determines the oxidation-reduction reaction mechanism in the binding and release of heavy metals (Najamuddin *et al.*, 2020). The graph above shows the Eh value indicates anaerobic conditions in the sediment. A more negative value (point 4) indicates that the environment is more reductive, which can affect the biogeochemical processes in the sediment.

Sediment pH value

The result of sediment pH measurements at each observation point are shown in Fig 5. The result indicates that the water condition are relatively stable and not acidic.

The degree of acidity (pH) is used to express the level of acidity and basicity in a solution. Acidity degree makes it easy to express the hydrogen ion concentration of acidic, basic and neutral solutions (Basuki, 2021). The pH scale ranges from 1-14. The range of pH values 1-7 is included in acidic conditions, pH 7-14 is a base and pH 7 is a neutral condition (Ramadani *et al.*, 2021). A low pH level in a body of water can result in a corrosion process and then result in the dissolution of heavy metals in the water (Huzairah *et al.*, 2022). The graph above shows that point 4 has the highest pH value of 7.9 while point 1 has the lowest pH of around 7.4.

Accumulation of heavy metals Cu, Fe and Zn in sediments

The results of heavy metal concentration measurements (Cu, Fe and Zn) at each sampling point are presented in Fig 6.

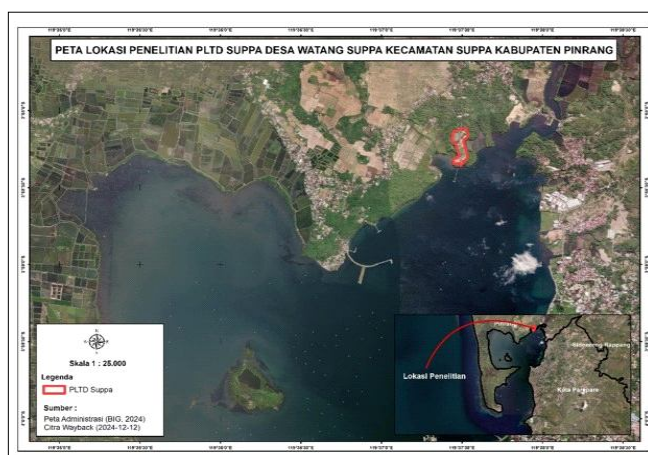


Fig 1: Research location and sampling points.

Fig 6 shows that the concentration of copper (Cu) in the sediment ranged from 2.21 to 12.72 mg/kg, with an average concentration of 6.37 mg/kg. The highest Cu concentration was found at station 1(12.72 mg/kg), while the lowest was at station 4(2.21 mg/kg). The concentration of iron (Fe) in the sediment ranged from 7,505.81 to 24,245.29 mg/kg, with an average concentration of 15,376.82 mg/kg. The highest Fe concentration was found at station 1(24,245.29 mg/kg), while the lowest was at station 4(7,505.81 mg/kg). The concentration of zinc (Zn) in the sediment ranged from 21.05 to 70.31 mg/kg, with an average concentration of 41.65 mg/kg. The highest Zn concentration was found at station 10(70.31 mg/kg), while the lowest was at station 4(21.05 mg/kg).

Distribution of heavy metals Cu, Fe and Zn in sediments

The distribution of copper (Cu), iron (Fe) and zinc (Zn) at the study site is presented in Fig 7. Spatially, the distribution of Cu, Fe and Zn metals showed a certain pattern. Higher concentrations of Fe were detected in sediments with greater depth, due to the accumulation of heavy metals trapped in the lower sediment layers. In contrast, the distribution of Cu and Zn was more even, although there was a slight increase in areas closer to the coast.

Cu, Fe and Zn metal pollution levels in sediments

The results of the pollution index calculation for metals in sediments around the Suppa coal-fired power plant waters are presented in Table 3.

Table 3 shows that the highest I-geo values for copper (Cu), iron (Fe) and zinc (Zn) were 0.413, 0.072 and 0.170, respectively. All of these values fall within the category of uncontaminated to moderately contaminated. This condition indicates that, in general, the sediments around the Suppa coal-fired power plant waters are relatively safe and do not show significant impacts from heavy metal pollution (Syafira *et al.*, 2023). Although the i-geo values of Cu, Fe and Zn metals show relatively safe conditions, they still need to be monitored to ensure that pollution does not increase in the future.

Table 4 further reveals that the sediment is classified as uncontaminated and poses a low ecological risk, as indicated by the pollution load and ecological risk indices.

The pollution load index provides an overall value of the toxicity status of sediments by heavy metals. PLI provides an overview of how much pollution load exists at a location based on several heavy metals measured (Handayani *et al.*, 2022). In this study, the level of pollution based on the PLI value of heavy metals in sediments ranged from 0.441-1.544. These results are in line with research conducted by Milasari *et al.* (2020) and Nugraha *et al.* (2022) that sediments in various locations can have varying levels of pollution depending on the source of pollution and surrounding human activities. This value indicates that PLI can provide a comprehensive picture of the level of pollution in an area (Vahyra and Solomon, 2020). In this case, although the PLI value at station 1 indicates

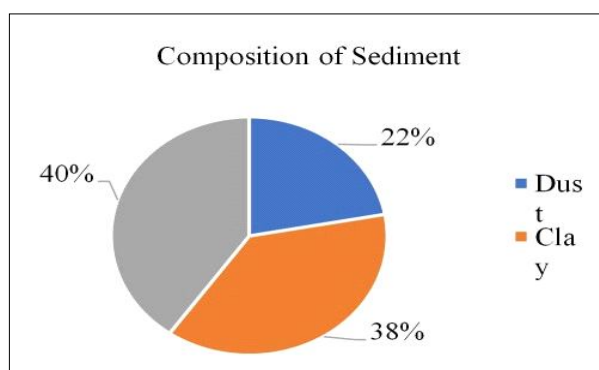


Fig 2: Composition of sediment in sampling location.

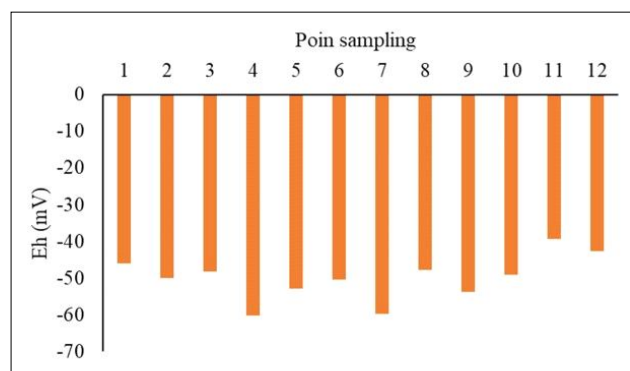


Fig 4: Sediment Eh value.

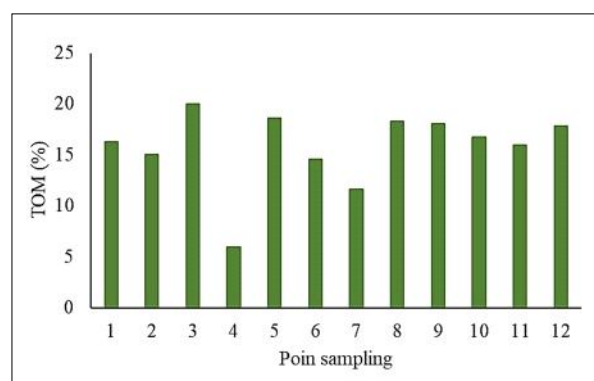


Fig 3: Sediment total organic matter concentration.

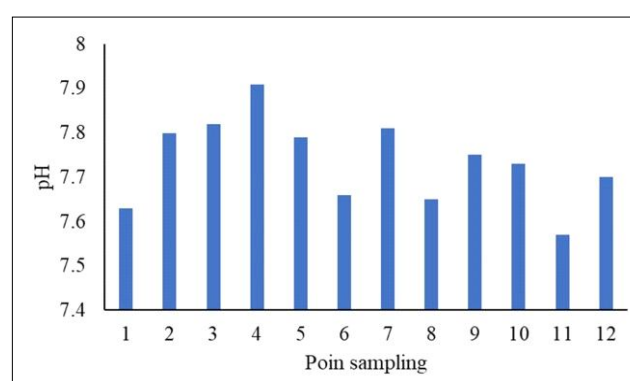


Fig 5: Sediment pH value.

the sediment has been contaminated, the value is still within manageable limits and needs monitoring and appropriate remediation measures to reduce the impact of pollution (Putra *et al.*, 2019).

In this study, the level of pollution based on the ERI value of heavy metals in sediments ranged from 23.08-12.73. Overall, the ERI values indicate that the level of heavy metal pollution in the waters around the Suppa Diesel Power Plant is still within relatively safe limits. The accumulation of heavy metals in sediments can be an important indicator to assess pollution in waters. As stated by Mariani *et al.* (2020) in their research that the concentration of heavy metals in sediments is higher than that of seawater so that sediments become a more sensitive indicator of pollution. Although the ERI value at each station shows a low risk, it is important to continue to monitor and prevent potentially more serious pollution in the future.

The correlation between sediment characteristics and heavy metal concentrations

The correlation between sediment characteristics and heavy metal concentrations is determined using the regression method. This statistical technique is essential for identifying cause-and-effect relationships between variables, allowing researchers to establish a linear

correlation. In this context, changes in sediment characteristics (independent variable, x) will influence the concentrations of heavy metals (dependent variable, y), resulting in a numerical output that quantifies this relationship.

The linear regression equation used to model this relationship is expressed as follows:

$$y = a + bx \quad \dots(5)$$

Where,

y = Dependent variable (effect), representing the concentration of heavy metals in the sediment.

x = Independent variable (cause), representing the specific sediment characteristic being analyzed (e.g., grain size, organic matter content, *etc.*).

a = Constant, which is the y -intercept of the regression line, indicating the value of y when x is zero.

b = Response magnitude induced by the predictor, representing the slope of the regression line, which indicates how much y changes for a one-unit change in x .

The concentrations of heavy metals Cu, Fe and Zn are related to sediment grain size, TOM, pH and Eh as shown in Table 5.

There is a negative correlation between sediment grain size and heavy metal concentration, indicating that the smaller the sediment grain size, the higher the concentration of accumulated heavy metals. Finer sediments tend to have a larger surface area, which can enhance their adsorption capacity and heavy metal accumulation (Nugraha *et al.*, 2022; Putra *et al.*, 2022; Darmansyah *et al.*, 2020).

The correlation between total organic matter (TOM) and heavy metals shows a positive correlation, indicating

Table 3: Metal geoaccumulation index.

Metals	I-Geo value	Status
Cu	-2.119-0.413	Not polluted to moderately polluted
Fe	-1.62-0.072	Not polluted to moderately polluted
Zn	-1.569-0.17	Not polluted to moderately polluted

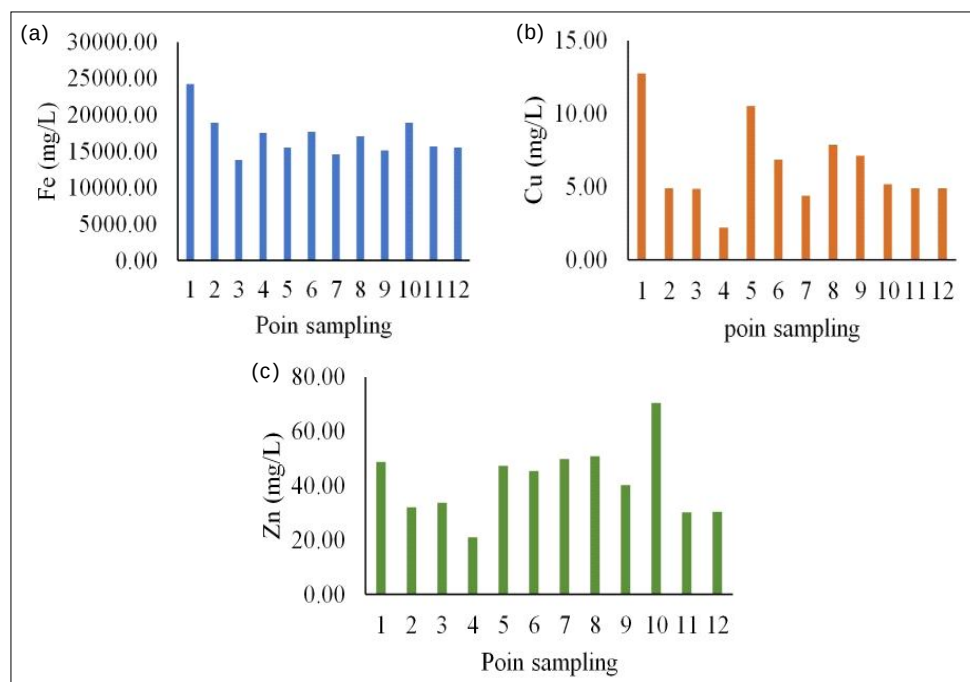


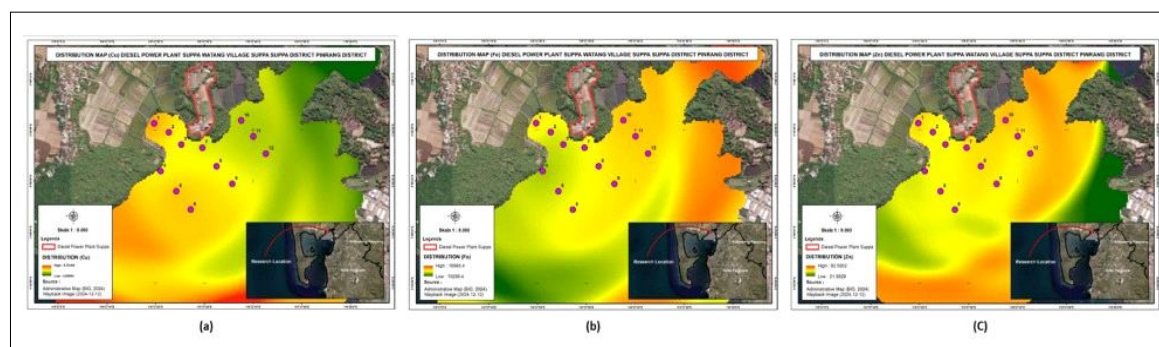
Fig 6: Accumulation of heavy metals (a) Fe, (b) Cu and (c) Zn in sediments

Table 4: Index value of heavy metal pollution load in sediment.

Sample code	PLI value	Description	ERI value	Description
S1	1.544	Contaminated	12.73	Low risk
S2	0.701	Not contaminated	5.20	Low risk
S3	0.822	Not contaminated	5.53	Low risk
S4	0.441	Not contaminated	2.73	Low risk
S5	1.236	Contaminated	10.39	Low risk
S6	1.104	Contaminated	7.62	Low risk
S7	0.922	Not contaminated	5.60	Low risk
S8	1.187	Contaminated	8.49	Low risk
S9	1.020	Contaminated	7.53	Low risk
S10	1.188	Contaminated	6.96	Low risk
S11	0.828	Not contaminated	5.59	Low risk
S12	0.827	Not contaminated	5.59	Low risk

Table 5: Correlation between heavy metal concentrations and sediment characteristics.

Element	Grain size	TOM	pH	Eh	Fe	Cu	Zn
Grain size	1						
TOM	-0.8262	1					
pH	0.5926	-0.4496	1				
Eh	-0.7477	0.6099	-0.7925	1			
Fe	-0.3216	0.3893	-0.6196	0.3336	1		
Cu	-0.4028	0.4788	-0.2620	0.2147	0.4498	1	
Zn	-0.5464	0.3493	-0.3702	0.4207	0.3939	0.2470	1

**Fig 7:** (a) Distribution Cu; (b) Distribution Fe, (c) Distribution Zn.

that as TOM increases, the concentration of accumulated heavy metals also increases. TOM in sediments can enhance the adsorption capacity and accumulation of heavy metals (Putra *et al.*, 2022; Darmansyah *et al.*, 2020).

Meanwhile, the correlation between pH and heavy metals shows a negative correlation, indicating that as pH decreases, the concentration of heavy metals increases. This occurs because at low pH, heavy metals tend to be more soluble and available, making their concentrations in the environment higher (Choudhury *et al.*, 2021; Świdwa-Urbańska and Zalewski, 2019; Zhao *et al.*, 2021).

The correlation between redox potential (Eh) and heavy metals shows a positive correlation, indicating that as Eh (oxidative conditions) increases, the concentration of heavy metals also increases. Under oxidative conditions, heavy metals tend to exist in dissolved and available forms. Redox

conditions (Eh) influence the solubility and availability of heavy metals in the environment (Zhao *et al.*, 2021).

CONCLUSION

This study successfully assessed the concentration and spatial distribution of copper (Cu), iron (Fe) and zinc (Zn) in sediments around the suppa diesel power plant, revealing that while sediments are generally safe, certain areas, particularly around Station 1, exhibit moderate contamination. The pollution load index (PLI) indicated manageable contamination levels but highlighted the need for further monitoring. Co-kriging analysis identified localized pollution hotspots, primarily near the shore and around the plant, suggesting uneven contamination distribution. The novelty of this research lies in its detailed spatial analysis of heavy metal contamination, an area

underexplored in prior studies. Unlike previous research, this study not only quantified metal concentrations but also examined their distribution patterns in relation to plant operations, offering new insights into the ecological risks associated with industrial power generation. The findings fill a critical gap in the literature by linking industrial activities to localized sediment contamination and demonstrating the spatial variability of heavy metal pollution. The study emphasizes the need for continuous monitoring and targeted pollution control, as even moderate contamination levels can escalate if left unchecked. This research provides a foundation for future studies on the long-term environmental impacts of power plants and supports the development of more effective environmental policies and sustainable waste management practices.

Conflict of interest

The authors certify that they have no affiliations with or involvement in any organization or entity with any financial or non-financial interest in the subject matter or materials discussed in this manuscript.

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