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Accumulation of Heavy Metals in the Vannamei Shrimp (*Litopenaeus vannamei*) and Pond Environment

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ABSTRACT

This study investigated the accumulation of heavy metals cadmium (Cd), copper (Cu), chromium (Cr), and lead (Pb) in the environment and body parts of *Litopenaeus vannamei* cultured in traditional shrimp ponds in Sidoarjo, Indonesia. Water, sediment, and shrimp samples (cephalothorax and abdomen) were collected from three representative ponds and were analyzed using Inductively Coupled Plasma–Atomic Emission Spectroscopy (ICP-AES). The highest concentrations of Pb (10.975ppm) and Cd (1.463ppm) were found in sediment and water, respectively. Heavy metal content was notably higher in the cephalothorax than in the abdomen, indicating a greater accumulation in organs responsible for filtration and metabolism. Contamination Factor (CF) analysis classified Cd as moderate and other metals as low in contamination. The Heavy Metal Evaluation Index (HEI) indicated a low pollution level across all ponds. Lifetime Cancer Risk (LCR) values for Cd in one pond exceeded the 10^{-6} threshold, suggesting an acceptable but non-negligible carcinogenic risk. Overall, the findings highlight the potential health risks of heavy metal bioaccumulation in traditionally farmed shrimp and emphasize the need for continued environmental monitoring in aquaculture systems.

INTRODUCTION

Litopenaeus vannamei, or the Pacific white shrimp, is recognized as one of the most commercially significant species in global aquaculture **(Kilawati *et al.*, 2024)**. Diverse systems, including the conventional method, can be employed in vaname prawn aquaculture. Conventional vaname shrimp farming relies on soil for pond building and significantly depends on rivers for aquaculture water supply. Conventional vaname cultivation of shrimp relies heavily on natural circumstances, as it does not employ artificial feed or specialised treatments during production. Consequently, reliance on the environment is exceedingly significant.

The sample site for this study was located in the Jabon sub-district of the Sidoarjo district. The Jabon sub-district is one of the three sub-districts affected by the Lapindo Sidoarjo mudflow. The conventional vaname shrimp farm examined in this study is encircled by several aquaculture and industrial operations. The Porong Sidoarjo River also encircles this site. The origins of these toxins are diverse, encompassing agricultural runoff, industrial emissions, and household garbage **(Li *et al.*, 2024)**. Heavy metals in these wastes are poisonous and detrimental to living organisms **(Jacob *et al.*, 2018)**. Heavy metals that serve as contaminants in vaname shrimp aquaculture include Cu, Cr, Cd, and Pb **(Wang *et al.*, 2023)**. Heavy metals such as cadmium, copper, chromium, and lead pose significant risks due to their poisonous characteristics, which can accumulate in the tissues of aquatic creatures. These metals have environmental persistence and may induce prolonged harmful effects upon entering the food chain. Cadmium (Cd) and lead (Pb) are recognised for interfering with organ function and the nervous system. In contrast, elevated quantities of copper (Cu) and chromium (Cr) can cause tissue damage and disturb metabolic processes **(Balali-Mood *et al.*, 2021)**.

The habitat of aquatic species, including cultured water and sediments, significantly influences the bioaccumulation of heavy metals **(Wang *et al.*, 2023)**. Vaname shrimp traverse and forage over the aquatic substrate, a region characterized by the accumulation of diverse waste materials, including heavy metals **(Bautista-Covarrubias *et al.*, 2022)**. Consequently, vaname shrimp can accumulate heavy metals in their cultivation environment. Heavy metal contamination impacts water quality, influencing the growth and development of vaname shrimp **(Li *et al.*, 2014)**. The buildup of heavy metals might ultimately risk human health through the use of contaminated fishing products.

Investigating the environmental quality of traditional vaname shrimp aquaculture (*Litopenaeus vannamei*) is essential because of the risk of heavy metal contamination from anthropogenic activities in the surrounding pond area, including agricultural, livestock, and residential waste. Vaname shrimp collect higher concentrations of heavy metals in the cephalothorax, particularly within the gill organs, antennae, and hepatopancreas **(Albuquerque *et al.*, 2020)**. The cephalothorax houses vital organs, including gills, hepatopancreas, and digestive systems, crucial to the filtration and absorption of environmental chemicals **(Ramos-Miras *et al.*, 2023)**. Heavy metals such as cadmium (Cd), copper (Cu), chromium (Cr), and lead (Pb) are known to accumulate in pond waters, negatively affect the health of cultured organisms, and reduce productivity. Vaname shrimp is used as an indicator organism because of its direct contact with the culture medium and its ability to absorb heavy metals from the surrounding environment. This study analyzed the heavy metal content of the culture environment and the distribution of heavy metal content in the body parts of vaname shrimp from the traditional culture system.

MATERIALS AND METHODS

Samples collection

Water, vaname shrimp, and sediment samples were obtained from traditional vaname shrimp ponds in Sidoarjo District. All samples were taken from 3 representative ponds. These ponds are located at geographical coordinates 7^{o}31'14.400' LS 112^{o}50'38.400' E to 7^{o}33'21.600' N.E. 112^{o}50'49.200' E. Observations were repeated three times with DOC 40-60. Water samples were taken using a water sampler, sediment using a grab tool, and vaname shrimp using a net tool. Vaname shrimp samples, after arriving at the laboratory, were frozen at -20°C for preservation and further analysis. The sampling location map can be seen in Fig. (1).

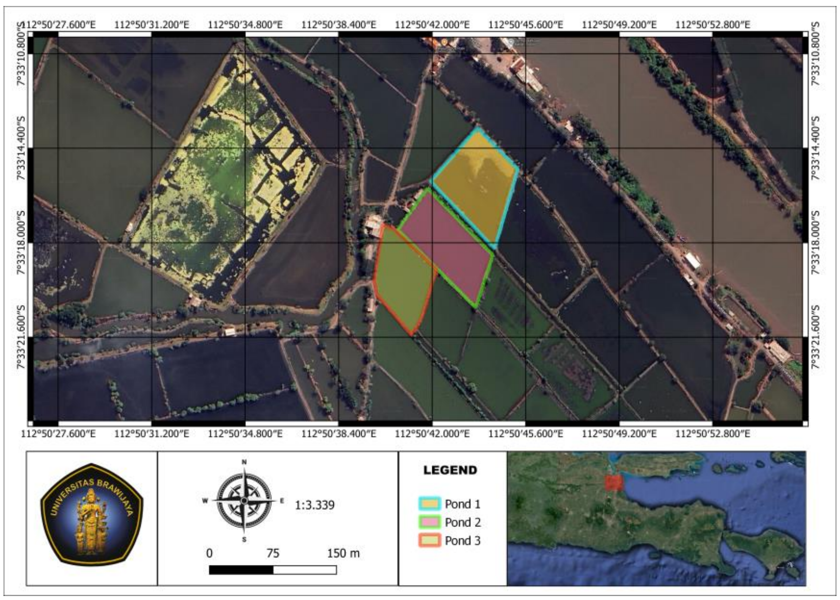

Fig 1. Map of sampling points

Analysis of heavy metals

Heavy metal studies were performed on water, sediment, and vaname shrimp (cephalothorax and abdomen) samples for cadmium, copper, chromium, and lead, which were initially exposed to acid digestion. The cephalothorax and abdomen samples, weighing 250±5mg, were pulverised with a mortar, and 100±5mg of oven-dried sediment was transferred into a microwave vessel (Multiwave Go Plus, Anton Paar, LRT UB). The samples were subsequently combined with 5ml of 65% HNO_3 (Merck, Sigma-Aldrich) and 2ml of 30% H_2O_2 (Merck, Sigma-Aldrich), adhering to a gradient temperature protocol that escalated from ambient to 160°C over 10 minutes; for sediment samples, the temperature was elevated to 180°C for the same duration. One hundred millilitres of pond water was placed in a glass jar and filtered using Whatman No. 41 filter paper to eliminate particulate matter. From the resulting filtrate, 9ml was aliquoted and combined with 1ml of 65% HNO_3; subsequently, the digestion procedure was executed. The microwave digesting system was programmed to attain a temperature of 160°C for 20 minutes. The data were analyzed utilizing ICP AES wavelengths of 226.502nm (Cd), 267.716nm (Cr), 327.396nm (Cu), and 220.353nm (Pb).

The assessment of heavy metal concentrations in all samples was performed using ICP-AES (ICPE-9820; Shimadzu, LRT UB), with results analyzed according to six calibration curve points: 0, 0.1, 0.5, 1, 2, and 5ppm **(Arisekar *et al*., 2022)**. The limit of detection (LOD) and limit of quantification (LOQ) of the approach are defined by the standard deviation of the response and the slope, namely 3.3 and 10, respectively.

A recovery study was performed utilising certified reference material, namely a multi-elemental standard mix (CRM, periodic table mix 1 for ICP, Merck, Sigma-Aldrich), to assess the instrument's precision and the efficacy of the digesting process. This substance was introduced into pond water, sediment, and vaname shrimp as Quality Control samples. The concentration was assessed before and after the spiking, facilitating the calculation of the recovery ratio. The mean recovery ratio of the analyzed heavy metals ranged from 81.00% to 90.20%. According to EU rules (EC/SANTE/11813/2017, 2017), the recovery of the tested elements was within the permissible range of 80%–120%, with a standard deviation (SD) of less than 10%.

Contamination factor (CF)

Contamination Factor (CF) is an index used to indicate heavy metal contamination in sediments. The CF value is obtained from the ratio between the measured heavy metal concentration in the sediment and the heavy metal's natural concentration or background value **(Rahman *et al*., 2022)**. Contamination Factor using equation 1.

$$CF = \frac{C_m}{C_n} \quad \text{.......} \quad (1)$$

Cm is the sediment's metal concentration, and Cn is the BGV (Cr: 100, Cu: 55, Cd: 0.2, Pb: 12.5) **(Khan *et al*., 2020)**.

Heavy metal evaluation index (HEI)

The heavy metal evaluation index (HEI) is a quantitative methodology for evaluating the extent of heavy metal pollution in water. This indicator is crucial for assessing the degree of heavy metal pollution and determining whether concentrations are within acceptable limits or have reached harmful levels for the environment and human health **(Sobhanardakani, 2016)**. According to **Igbemi *et al*. (2019)**, the heavy metals assessment index was established using Equation 2.

$$HEI = \sum_{i=1}^{n} H_c/H_{mac}, \quad \text{.......} \quad (2)$$

Where Hc is the heavy metal concentration in water, and Hmac is the maximum admissible concentration of heavy metals (Cr: 0.05, Cu: 1.00, Cd: 3.00, Pb: 1.50) **(Edet & Offiong, 2002; Siegel, 2002)**.

Lifetime cancer risk (LCR)

Carcinogenic risk is calculated using the Lifetime Cancer Risk (LCR) parameter, specifically for metals classified as carcinogenic by the USEPA. LCR values < 10^{-6} are considered to pose no cancer risk, values between 10^{-6} and 10^{-4} manhood are within the acceptable risk range, while LCR values > 10^{-4} manhood are categorised as unacceptable risk **(EPA, 2011)**. LCR using equation 3.

$$LCR = \frac{Cs \times EFr \times ED \times CSF}{Bw \times AT} \times 10^{-3} \quad \text{.. (3)}$$

RESULTS AND DISCUSSION

Heavy metals in water and sediment

The results of the investigation of heavy metal concentrations in the water and sediment from the three vaname shrimp aquaculture ponds are illustrated in Figs. (2, 3). Chromium (Cr) was not detected (ND) in the water or sediment of any pond, signifying that Cr concentrations were within the detection threshold of the equipment. The concentration of Cu metal in the water varied from 0.098 to 0.112ppm, with the maximum value recorded in Pond 1 at 0.112ppm and the minimum in Pond 2 at 0.098ppm. The quantity of Cd metal in the water was most significant at 1.463ppm in Pond 3, while the lowest was recorded at 0.768ppm in Pond 2. Lead metal was identified in all water samples, with a concentration range of 0.188 to 0.521ppm.

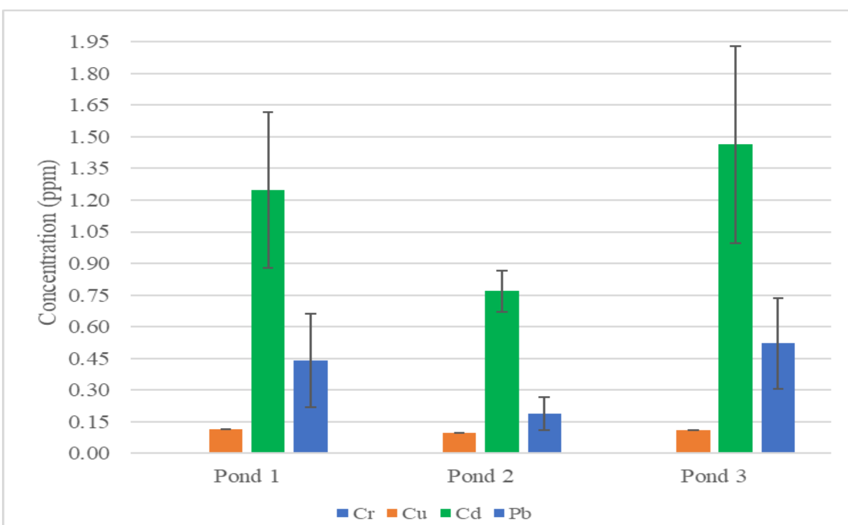

Fig. 2. Heavy metals in water

In sediment samples, Cu metal was undetected in the sediments of ponds 1 and 3 but was identified in pond 2 at a concentration of 0.093ppm. The maximum concentration of cadmium (Cd) was detected in Pond 2 at 0.902ppm, while the minimum was observed in Pond 1 at 0.052ppm. The maximum concentration of Pb in the sediment was recorded in Pond 2 at 10.975ppm, whereas the minimum concentration in Pond 1 was 7.203ppm. The concentration of Pb in the sediments significantly exceeded that in the water, suggesting the buildup of heavy metals at the pond's bottom. These findings demonstrate that heavy metals preferentially collect in sediment rather than water, particularly lead (Pb) and cadmium (Cd). Despite the accumulation of heavy metals in sediment through deposition, the quality criteria for heavy metals in sludge or sediment in Indonesia remain unidentified **(Han *et al*., 2024)**. Inlet water strongly influences aquaculture water quality in traditional systems. Mangroves filter the inlet water in this sampling location to reduce heavy metal content **(Islamy *et al*., 2020)**.

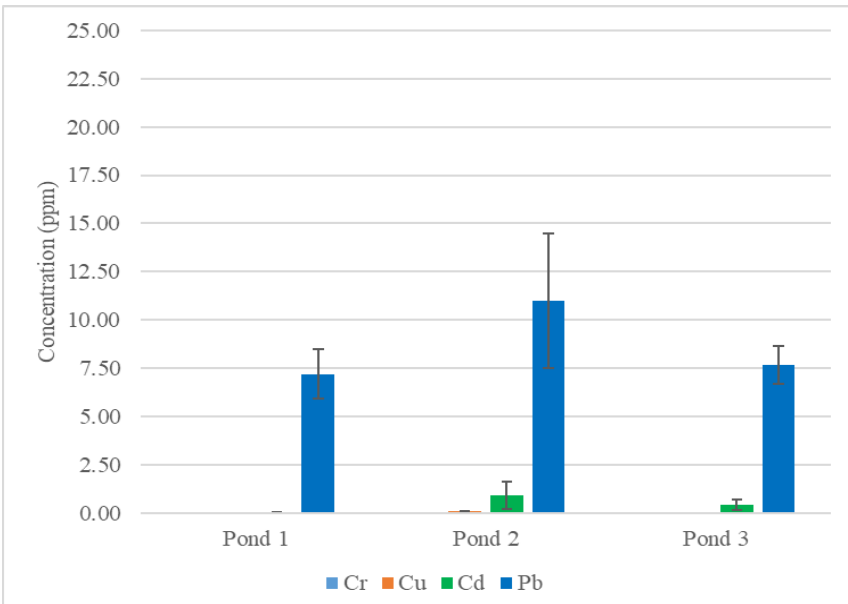

Fig. 3. Heavy metals in sediment

Heavy metal contaminants, including chromium (Cr), copper (Cu), cadmium (Cd), and lead (Pb), are known to have detrimental impacts on groundwater quality. The quantities of heavy metals will escalate if municipal, agricultural, and industrial wastes containing these pollutants discharge into the sea via rivers and accumulate on the seabed, ultimately harming marine creatures **(Herliwati *et al*., 2022)**. Indices of heavy metal contamination in the air significantly correlate with heavy metal contamination in irrigation water sources used in conventional agricultural systems **(Dippong & Resz, 2024)**. In addition, indirect sources of pollution include surface water infiltration that transports contaminants into groundwater or atmospheric deposition through rainfall **(Anilkumar *et al*., 2015)**. Moreover, biogeochemical processes and human activities can affect cadmium concentrations in coastal ecosystems **(Xing *et al.*, 2017)**. Heavy metals in aquaculture water will settle and accumulate on the pond bottom, resulting in sedimentation. This will expose vaname shrimp that forage on the pond bottom to heavy metals **(Apresia *et al.*, 2023)**. This study shows that variations in heavy metal concentrations can be caused by factors such as the type of land use, source of pollution, and aquaculture environmental management practices in each system.

This study identifies the sources of heavy metals Cd, Cu, and Pb as pollution from industrial, residential, and transportation activities surrounding the Porong River. This is derived from **Vig *et al.* (2023)**, indicating that environmental heavy metals may originate from geological, industrial, agricultural, pharmaceutical, domestic waste, and atmospheric sources. The concentration of heavy metals in aquaculture water is a crucial metric for evaluating environmental quality and its possible effects on aquatic life **(Liu *et al.*, 2024)**. Aquaculture water may get polluted with heavy metals from natural sources and human operations, necessitating constant monitoring. Monitoring can help identify the origin of pollution, whether it arises from natural processes, industrial effluents, or other human activity **(Dey *et al.*, 2024)**. Assessments of heavy metals, including Cd, Cr, Cu, and Pb, are performed to evaluate pollution levels and their correlation with the state of the aquatic ecosystem.

In addition to water, sediment significantly indicates pollution by accumulating heavy metals discharged into the environment. Heavy metals, originating from either natural sources or anthropogenic activity, can accumulate in sediments and indicate the historical contamination of an aquaculture habitat. Consequently, investigations of cadmium, chromium, copper, and lead concentrations in sediments were performed to elucidate the distribution patterns of heavy metals and their correlation with environmental conditions at the research location.

Heavy metal content in the body of vaname shrimp

The findings of the heavy metal content analysis in the cephalothorax and abdomen of vaname prawns from three aquaculture ponds are illustrated in Figs. (4, 5). In the cephalothorax, the heavy metal chromium was identified at a maximum concentration of 0.010ppm in Pond 1 and a minimum of 0.004ppm in Pond 3. The Cu level in this region varied from 0.146 to 0.235ppm, with the maximum value recorded in Pond 1. Cadmium (Cd) exhibited very low amounts, ranging from 0.012 to 0.015ppm, but lead (Pb) was discovered between 0.030 and 0.048ppm.

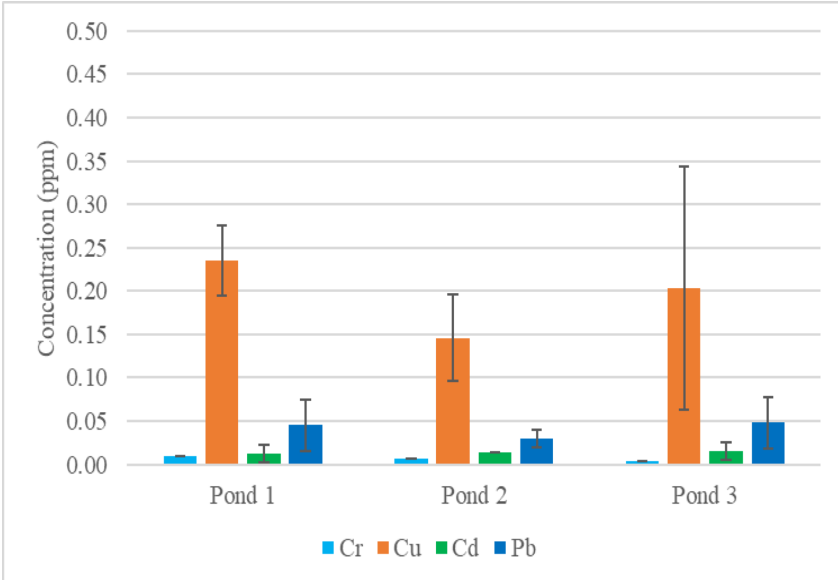

Fig. 4. Heavy metals in the cephalothorax

Meanwhile, chromium metal was not found (ND) in any of the ponds within the abdomen. Copper (Cu) was identified as the most significant quantity in Pond 3 at 0.037 ppm and the lowest in Pond 2 at 0.017ppm. Cadmium in the abdomen was discovered in ponds 1 and 3 at concentrations of 0.002ppm and 0.004ppm, respectively. Lead (Pb) was exclusively identified in pond 3 at a value of 0.007ppm, but it was absent in ponds 1 and 2. Heavy metal content was generally higher in the cephalothorax than in the abdomen. This is due to the cephalothorax's function as the center of physiological activity and the place of accumulation of metabolites including heavy metals.

Vaname shrimp collect higher levels of heavy metals than fish, particularly in the cephalothorax, which encompasses the gills, antennae, and hepatopancreas **(Albuquerque *et al.*, 2020)**. The concentration of heavy metal content in shrimp is often higher in the cephalothorax than in the abdomen. The cephalothorax houses vital organs, including gills, hepatopancreas, and digestive systems, essential for the filtration and absorption of environmental chemicals **(Ramos-Miras *et al.*, 2023)**. The assessment of heavy metals in shrimp species collected from sampling locations revealed the accumulation of heavy metals from water to sediments and ultimately within the biota of the sediment (shrimp) **(Herliwati *et al.*, 2022)**.

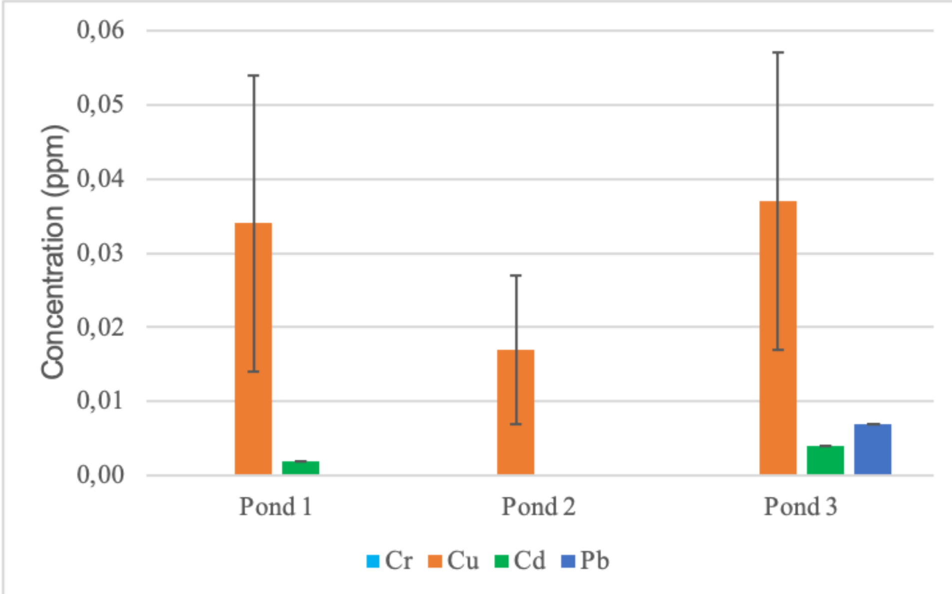

Fig. 5. Heavy metals in the abdomen

In the cephalothorax and abdomen, heavy metal Cu has the highest concentration. This is because Cu is an essential metal for vaname shrimp that has a role in helping blood regeneration and is beneficial to the health and vitality of shrimp **(Ortiz-Moriano *et al.*, 2024)**. Meanwhile, the second-highest heavy metal content was Pb. These heavy metals are mainly accumulated in the sediment because vaname shrimp tend to live on the bottom or near the sediment for half of the culture cycle length **(Wang *et al.*, 2023)**. Heavy metal content in the cephalothorax and abdomen of vaname shrimp is an important indicator in assessing the aquatic environment's pollution level and potential risks to human health **(Rainbow, 2018)**. Vaname shrimp can accumulate heavy metals from water and sediment through the bioaccumulation process, so the analysis of Cd, Cr, Cu, and Pb content in the cephalothorax and abdomen was carried out to understand the distribution pattern of heavy metals in the shrimp body.

Contamination factor (CF)

This parameter indicates the amount of heavy metals such as Cu, Cr, Cd, and Pb accumulated in the sediment compared to normal environmental concentrations. This study uses CF calculation to determine the Cu, Cr, Cd, and Pb contamination levels in sediments (Table 1).

Table 1. Contamination factor

***Contamination Factor* (CF)**				
Sample	**Cu**	**Cr**	**Cd**	**Pb**
Pond 1	0,00	0,00	0,26	0,58
Pond 2	0,01	0,00	4,51	0,08
Pond 3	0,00	0,00	2,13	0,61

Based on **Hakanson (1980)**, approach, CF values are classified based on the level of low contamination (CF < 1), moderate contamination (1≤ CF < 3), considerable contamination (3≤ CF < 6), and very high contamination (CF > 6). By this classification, the heavy metals Cu, Cr, and Pb are included in low contamination, while the heavy metal Cd is included in moderate contamination.

Heavy metal evaluation index (HEI)

The heavy metal evaluation index (HEI) is used to evaluate the overall level of heavy metal pollution in a water sample. This index provides a quantitative picture of the accumulation of various heavy metals such as Cu, Cr, Cd, and Pb that can harm the aquatic environment. HEI is calculated based on the sum of heavy metal concentrations compared to a predetermined threshold limit (Table 2).

Table 2. Heavy metal evaluation index

Sampel	Heavy Metal Evaluation Index
Kolam 1	0,21
Kolam 2	0,12
Kolam 3	0,24

According to **Ameh (2013)**, HEI is classified into three categories, which include HEI <10 (low pollution), 10< HEI <20 (moderate pollution), and HEI >20 (high pollution). By this classification, the HEI value falls into the low pollution category. Thus, there is no significant impact on aquatic organisms cultivated and grown in vaname shrimp farming ponds with traditional systems.

Lifetime cancer risk (LCR)

Table (3) presents the Lifetime Cancer Risk (LCR) values for Cr, Cd and Pb heavy metals identified in samples of vaname shrimp farmed under the traditional system. Copper (Cu) was not found in any of the samples. The evaluation of cancer risk based on LCR values covers three ponds.

Table 3. Lifetime cancer risk (LCR)

Sample	Cu	Cr	Cd	Pb
Pond 1	Nd	7.10×10^{-8}	6.84×10^{-7}	5.40×10^{-9}
Pond 2	Nd	5.00×10^{-8}	1.20×10^{-6}	3.68×10^{-9}
Pond 3	Nd	3.21×10^{-8}	9.18×10^{-7}	4.10×10^{-9}

The LCR values of heavy metals Cr and Pb in all three ponds were $<10^{-6}$ (no cancer risk). Heavy metal Cd in pond 2 showed an LCR value of 1.20×10^{-6} (acceptable risk), while ponds 1 and 3 had values $<10^{-6}$ (no cancer risk). This indicates that heavy metal Cd in traditional systems needs to be considered, although the overall risk is still relatively low.

Future studies should consider the use of biomarkers by integrating both native and non-native aquatic species such as the red devil cichlid **(Jatayu *et al.*, 2023)**, *Nemacheilus* spp. **(Valen *et al.*, 2024)**, *Xiphophorus helleri* and Midas cichlid **(Islamy *et al.*, 2025a)**, as well as *Gambusia affinis* (mosquitofish) **(Syarif *et al.*, 2025)** to allow for comparative evaluations of species-specific physiological responses. Investigations into immune response are also essential, particularly in evaluating how organisms exposed to heavy metals react when further challenged with pathogens such as *Aeromonas* spp. **(Islamy, 2019)** or viral agents **(Kilawati *et al.*, 2024; Kilawati *et al.*, 2025)**, in order to assess resilience and stability of health under combined stressors. Moreover, physiological indicators such as histopathological examination of reproductive organs, molecular diagnostics, and profiling of hemocyanin gene (HMC) expression **(Kilawati *et al.*, 2024; Kilawati *et al.*, 2025; Islamy *et al.*, 2025b)** should be applied to better understand the internal physiological conditions and reproductive capacity of aquatic organisms under heavy metal stress. From a nutritional standpoint, it is recommended to explore alternative natural feed ingredients with high nutritional value, including various seaweeds **(Islamy *et al.*, 2024a; Islamy *et al.*, 2024b; Islamy *et al.*, 2025a)**, neem leaves **(Islamy *et al.*, 2024c)**, *Ipomoea pes-caprae* **(Islamy *et al.*, 2024d)**, and alligator weed **(Serdiati *et al.*, 2024)**, to examine their role in promoting recovery from heavy metal exposure. Further studies should determine the optimal inclusion levels of these ingredients and assess their long-term efficacy in minimizing reliance on conventional feeds while enhancing the recovery and resilience of aquaculture species.

CONCLUSION

Based on the results of this study, the concentrations of heavy metals Pb, Cd, Cu, and Cr showed the highest concentrations in each sample. In sediment samples, the highest concentration of heavy metal Pb was in Pond 2, with a concentration of 10,975ppm. In the culture water samples, the highest concentration of heavy metal Cd was 1,463ppm in Pond 3. Meanwhile, in vaname shrimp body part samples, the cephalothorax showed higher heavy metal concentrations than the abdomen. The LCR assessment shows that vaname shrimp from the traditional system is still in the low category. In addition, contamination assessment based on the Contamination Factor (CF) and Heavy Metal Evaluation Index (HEI) indicated low contamination levels in the study area.

REFERENCES

Albuquerque, F.E.A.; Minervino, A.H.H.; Miranda, M.; Herrero-Latorre, C.; Júnior, R.A.B.; Oliveira, F.L.C.; Sucupira, M.C.A.; Ortolani, E.L. and López-Alonso, M. (2020). Toxic and essential trace element concentrations in fish species in the Lower Amazon, Brazil. Science of the Total Environment., 732: 138983.

Ameh, E.G. (2013). Geo-statistics and heavy metal indexing of surface water around Okaba coal mines, Kogi State, Nigeria.

Anilkumar, A.; Sukumaran, D. and Vincent, S.G.T. (2015). Effect of municipal solid waste leachate on ground water quality of Thiruvananthapuram District, Kerala, India. Applied Ecology and Environmental Sciences., 3(5): 151–157.

Apresia, F.; Ambariyanto, A.; Yulianto, B. and Payus, C.M. (2023). Heavy Metal Contamination on Vannamei Shrimp Aquaculture in North Coast of Central Java. ILMU KELAUTAN: Indonesian Journal of Marine Sciences., 28(3).

Arisekar, U.; Shakila, R.J.; Shalini, R.; Jeyasekaran, G.; Padmavathy, P.; Hari, M. S. and Sudhan, C. (2022). Accumulation potential of heavy metals at different growth stages of Pacific white leg shrimp, Penaeus vannamei farmed along the Southeast coast of Peninsular India: A report on ecotoxicology and human health risk assessment. Environmental Research, 212: 113105.

Balali-Mood, M.; Naseri, K., Tahergorabi, Z.; Khazdair, M.R. and Sadeghi, M. (2021). Toxic mechanisms of five heavy metals: mercury, lead, chromium, cadmium, and arsenic. Frontiers in pharmacology., 12: 643972.

Bautista-Covarrubias, J.C.; Valdez-Soto, I.E.; Aguilar-Juárez, M.; Arreola-Hernández, J.O., Soto-Jiménez, M.F.; Soto-Rodríguez, S. A.; López-Sánchez, J.A.; Osuna-Martínez, C.C. and Frías-Espericueta, M. G. (2022). Cadmium and copper mixture effects on immunological response and susceptibility to Vibrio harveyi in white shrimp Litopenaeus vannamei. Fish & Shellfish Immunology., 129: 145–151.

Dey, S.; Rajak, P. and Sen, K. (2024). Bioaccumulation of metals and metalloids in seafood: A comprehensive overview of mobilization, interactive effects in eutrophic environments, and implications for public health risks. Journal of Trace Elements and Minerals., 100141.

Dippong, T. and Resz, M.A. (2024). Heavy metal contamination assessment and potential human health risk of water quality of lakes situated in the protected area of Tisa, Romania. Heliyon, 10(7).

Ditia, S. (2024). The effect of industrial waste on air pollution and water pollution causes climate change. Journal of Waste and Sustainable Consumption., 1(1): 18-26.

Edet, A.E. and Offiong, O.E. (2002) Evaluation of water quality pollution indices for heavy metal contamination monitoring. A study case from Akpabuyo-Odukpani area, Lower Cross River Basin (southeastern Nigeria). GeoJournal., 57: 295–304.

Hakanson, L. (1980). An ecological risk index for aquatic pollution control. A sedimentological approach. Water Research., 14(8): 975–1001.

Han, X.; Wu, H.; Li, Q.; Cai, W. and Hu, S. (2024). Assessment of heavy metal accumulation and potential risks in surface sediment of estuary area: A case study of Dagu river. Marine environmental research., 196: 106416.

Herliwati, H., Rahman, M., Hidayat, A.S., Amri, U. and Sumantri, I. (2022). The Occurrences of Heavy Metals in Water, Sediment and Wild Shrimps Caught from Barito Estuary, South Kalimantan, Indonesia. HAYATI Journal of Biosciences., 29(5): 643-647.

Igbemi, I.A.; Nwaogazie, I.L.; Akaranta, O. and Abu, G.O. (2019). Water quality assessment by pollution indices in Eastern Obolo coastline communities of Nigeria. American Journal of Water Resources., 7(3): 111-120.

Islamy, R.A. and Hasan, V. (2020). Checklist of mangrove snails (Mollusca: Gastropoda) in south coast of pamekasan, Madura Island, East Java, Indonesia. Biodiversitas Journal of Biological Diversity., 21(7).

Islamy, R.A. (2019). Antibacterial activity of cuttlefish Sepia sp. (Cephalopoda) ink extract against Aeromonas hydrophila. Maj. Obat Tradit., 24(3): 184. https://doi.org/10.22146/mot.45315

Islamy, R.A.; Alfian, R.A.; Valen, F.S.; Alfian, R.A. and Hasan, V. (2025). First record of Xiphophorus helleri (Heckel, 1848) (Cyprinodontiformes: Poeciliidae) from the Bangka Island, Indonesia. Egypt. J. Aquat. Biol. Fish., 29(2): 1055–1065. https://doi.org/10.21608/ejabf.2025.418393

Islamy, R.A.; Hasan, V. and Mamat, N.B. (2024). Checklist of non-native aquatic plants in up, middle and downstream of Brantas River, East Java, Indonesia. Egypt. J. Aquat. Biol. Fish., 28(4): 415–435. https://doi.org/10.21608/ejabf.2024.368384

Islamy, R.A.; Hasan, V.; Kilawati, Y.; Maimunah, Y.; Mamat, N.B. and Kamarudin, A.S. (2024). Water hyacinth (Pontederia crassipes) bloom in Bengawan Solo River, Indonesia: An aquatic physicochemical and biology perspective. Int. J. Conserv. Sci., 15(4): 1885–1898.

Islamy, R.A.; Hasan, V.; Mamat, N.B.; Kilawati, Y. and Maimunah, Y. (2024a). Immunostimulant evaluation of neem leaves against non-specific immune of tilapia infected by A. hydrophila. Iraq. J. Agric. Sci., 55(3): 1194–1208. https://doi.org/10.36103/dywdqs57

Islamy, R.A.; Hasan, V.; Mamat, N.B.; Kilawati, Y. and Maimunah, Y. (2024b). Various solvent extracts of Ipomoea pes-caprae: A promising source of natural bioactive compounds compared with vitamin C. Iraq. J. Agric. Sci., 55(5): 1602–1611. https://doi.org/10.36103/5vd4j587

Islamy, R.A.; Hasan, V.; Poong, S.-W.; Kilawati, Y.; Basir, A.P. and Kamarudin, A.S. (2024c). Antigenotoxic activity of Gracilaria sp. on erythrocytes of Nile tilapia exposed by methomyl-based pesticide. Iraq. J. Agric. Sci., 55(6): 1936–1946. https://jcoagri.uobaghdad.edu.iq/index.php/intro/article/view/2087

Islamy, R.A.; Hasan, V.; Poong, S.-W.; Kilawati, Y.; Basir, A.P. and Kamarudin, A.S. (2025d). Nutritional value and biological activity of Kappaphycus alvarezii grown in integrated multi-trophic aquaculture. Iraq. J. Agric. Sci., 56(1): 617–626. https://doi.org/10.36103/6kp06e71

Islamy, R.A.; Mutmainnah, N.; Putri, R.T.; Valen, F.S.; Kamarudin, A.S. and Hasan, V. (2025b). Cochineal Powder as an Eco-Friendly Carotenoid Supplement to Enhance Coloration in Betta splendens. Journal of Ecological Engineering.

Islamy, R.A.; Senas, P.; Isroni, W.; Mamat, N.B. and Kilawati, Y. (2024e). Sea moss flour (Eucheuma cottonii) as an ingredient of pasta: The analysis of organoleptic, Effects of Water Quality on Ectoparasite Prevalence and Intensity in the Nile Tilapia (Oreochromis niloticus) Aquaculture with Different Feeding Strategies 1935 proximate and antioxidant. Iraq. J. Agric. Sci., 55(4): 1521–1533. https://doi.org/10.36103/kzmmxc09

Islamy, R.A.; Valen, F.S.; Ramahdanu, D. and Hasan, V. (2025). Presence of Midas cichlid (Amphilophus citrinellus Günther, 1864) (Actinopterygii: Cichlidae) on Bangka Island, Indonesia: An invasive non-native species. Egypt. J. Aquat. Biol. Fish., 29(2): 1045–1054. https://doi.org/10.21608/ejabf.2025.418392

Jacob, J.M.; Karthik, C., Saratale, R.G.; Kumar, S.S.; Prabakar, D.; Kadirvelu, K. and Pugazhendhi, A. (2018). Biological approaches to tackle heavy metal pollution: a survey of literature. Journal of Environmental Management, 217: 56–70.

Jatayu, D.; Insani, L.; Valen, F.S.; Ramadhanu, D.; Hafidz, A.M.; Susilo, N.B.; Swarlanda, N.; Sabri, A.; Islamy, R.A.; Tamam, M.B. and Hasan, V. (2023). Range expansion of Red devil cichlid Amphilophus labiatus (Günther, 1864) (Actinopterygii: Cichlidae) in Bangka Island, Indonesia. IOP Conf. Ser. Earth Environ. Sci., 1267(1): 12100. https://doi.org/10.1088/1755-1315/1267/1/012100

Khallaf, M.; El-Bahrawy, A.; Awad, A. and ElKhatam, A. (2020). Prevalence and histopathological studies of Trichodina spp. infecting Oreochromis niloticus in Behera Governorate, Egypt. JCVR, 2: 1–7. https://doi.org/10.21608/jcvr.2020.90213

Khan, R.; Islam, M.S.; Tareq, A.R.M.; Naher, K.; Islam, A.R.M.T.; Habib, M.A.; Siddique, M.A.B.; Islam, M.A.; Das, S and Rashid, M.B. (2020) Distribution, sources and ecological risk of trace elements and polycyclic aromatic hydrocarbons in sediments from a polluted urban river in central Bangladesh. Environmental Nanotechnology, Monitoring & Management., 14: 100318.

Kilawati, Y. and Islamy, R.A. (2019). The antigenotoxic activity of brown seaweed (Sargassum sp.) extract against total erythrocyte and micronuclei of tilapia Oreochromis niloticus exposed by methomyl-based pesticide. J. Exp. Life Sci. https://doi.org/10.21776/ub.jels.2019.009.03.11

Kilawati, Y., Maimunah, Y., Islamy, R.A., Amrillah, A.M. and Sugiarto, K.P. (2024). Histopathological Analysis of Acute Hepatopancreatic Necrosis Disease

(AHPND) Impact on the Hepatopancreas of Litopenaeus vannamei, using Scanning Electron Microscopy. Egyptian Journal of Aquatic Biology & Fisheries: 28(6)

Kilawati, Y.; Fadjar, M.; Maimunah, Y.; Lestariadi, R.A.; Yufidasari, H.S.; Ma`Rifat, T.N.; Syaifullah; Salamah, L.N.; Amrillah, A.M.; Perdana, A.W.; Rangkuti, R.F.A. and Islamy, R.A. (2024). Innovations in shrimp aquaculture: Optimizing seaweed biostimulants as an integrated approach to disease prevention. Egypt. J. Aquat. Biol. Fish., 29(2): 1221–1234. https://doi.org/10.21608/ejabf.2025.419362

Kilawati, Y.; Maimunah, Y.; Islamy, R.A.; Amrillah, A.M. and Sugiarto, K.P. (2024). Histopathological analysis of acute hepatopancreatic necrosis disease (AHPND) impact on the hepatopancreas of Litopenaeus vannamei, using scanning electron microscopy. Egypt. J. Aquat. Biol. Fish., 28(6): 867–876. https://doi.org/10.21608/ejabf.2024.393913

Kilawati, Y.; Maimunah, Y.; Widyarti, S.; Amrillah, A.M.; Islamy, R.A.; Amanda, T.; Atriskya, F. and Subagio, F.R. (2024). Molecular identification and hemocyanin gene (HMC) characterization of the shrimp Litopenaeus vannamei infected by acute hepatopancreatic necrosis disease (AHPND). Egypt. J. Aquat. Biol. Fish., 28(5): 1807–1820. https://doi.org/10.21608/ejabf.2024.387024 1936

Kilawati, Y.; Maimunah, Y.; Widyarti, S.; Amrillah, A.M.; Islamy, R.A.; Amanda, T.; Atriskya, F. and Subagio, F.R. (2025). Histopathological alterations of hepatopancreas and intestines in the vaname shrimp (Litopenaeus vannamei) infected by white feces disease (WFD). Egypt. J. Aquat. Biol. Fish., 29(2): 1235–1248. https://doi.org/10.21608/ejabf.2025.419575

Li, X.; Shen, X.; Jiang, W.; Xi, Y. and Li, S. (2024). Comprehensive review of emerging contaminants: Detection technologies, environmental impact, and management strategies. Ecotoxicology and Environmental Safety., 278: 116420.

Li, Y.; Zhou, W.; Liu, L.; Dong, Q. and Shu, Y. (2014). Water quality evaluation of Yanhe River based on the improved variable fuzzy sets. Yellow River, 36(04): 59–61.

Liu, S.; Wu, K.; Yao, L.; Li, Y.; Chen, R.; Zhang, L. and Zhou, Q. (2024). Characteristics and correlation analysis of heavy metal distribution in China's freshwater aquaculture pond sediments. Science of The Total Environment., 931: 172909.

Ortiz-Moriano, M. P.; Machado-Schiaffino, G.; Garcia-Vazquez, E. and Ardura, A. (2024). Traceability challenges and heavy metal risks in commercial shrimp and prawn. Food Control., 157: 110193.

Pratiwi, R.; Hariyadi, D.R.; Zahwa, M.A.D.I. and Ramadhani, D.E. (2024) The effect of water quality dynamics on the growth performance of vannamei shrimp

Litopenaeus vannamei in intensive ponds At CV. Daun Prima, East Java. Sains Akuakultur Tropis: Indonesian Journal of Tropical Aquaculture., 8(2): 151-157.

Rahman, M.S.; Ahmed, Z.; Seefat, S.M.; Alam, R., Islam, A.R.M.T.; Choudhury, T.R.; Begum, B.A. and Idris, A.M. (2022). Assessment of heavy metal contamination in sediment at the newly established tannery industrial Estate in Bangladesh: A case study. Environmental Chemistry and Ecotoxicology., 4: 1–12.

Rainbow, P.S. (2018). Heavy metal levels in marine invertebrates. Heavy Metals in the Marine Environment., 67–79.

Ramos-Miras, J.J.; Sanchez-Muros, M.J.; Renteria, P.; de Carrasco, C.G.; Roca-Perez, L.; Boluda-Navarro, M.; Pro, J. and Martín, J.A.R. (2023). Potentially toxic element bioaccumulation in consumed indoor shrimp farming associated with diet, water and sediment levels. Environmental Science and Pollution Research., 30(58): 121794–121806.

Sobhanardakani, S. (2016). Evaluation of the water quality pollution indices for groundwater resources of Ghahavand plain, Hamadan province, western Iran. Iranian Journal of Toxicology., 10(3): 35–40.

Vig, N.; Ravindra, K. and Mor, S. (2023). Heavy metal pollution assessment of groundwater and associated health risks around coal thermal power plant, Punjab, India. International Journal of Environmental Science and Technology., 20(6): 6259–6274.

Wang, Q.; Tian, Y.; Wang, J.; Li, J., He, W. and Craig, N.J. (2023). Assessing pathways of heavy metal accumulation in aquaculture shrimp and their introductions into the pond environment based on a dynamic model and mass balance principle. Science of The Total Environment., 881: 163164.

Xing, J.; Song, J.; Yuan, H.; Wang, Q.; Li, X.; Li, N.; Duan, L. and Qu, B. (2017). Atmospheric wet deposition of dissolved trace elements to Jiaozhou Bay, North China: Fluxes, sources and potential effects on aquatic environments. Chemosphere., 174: 428–436.