JURNAL PERIKANAN
UNIVERSITAS GADJAH MADA
Terakreditasi Ristekdikti No: 158/E/KPT/2021

ISSN: 2502-5066 (Online)
ISSN: 0853-6384 (Print)
Vol. 27 (1), 57-63
DOI 10.22146/jfs.106352

Accumulation of Cd, Cu, Cr, and Pb in Whiteleg Shrimp (*Penaeus vannamei*) and Pond Environment of Traditional Aquaculture Systems in Sidoarjo, Indonesia

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Submitted: 29 April 2025; Revised: 10 June 2025; Accepted: 13 June 2025; Published: 30 June 2025

ABSTRACT This study investigates the accumulation of heavy metals cadmium (Cd), copper (Cu), chromium (Cr), and lead (Pb) in the water, sediment, and body parts of whiteleg shrimp (*Penaeus vannamei*) cultured in traditional aquaculture ponds in Sidoarjo, Indonesia. The ICP-AES method showed that heavy metals were more concentrated in sediment than in water, particularly Pb and Cd. Cd levels in water and Pb levels in sediment exceeded national and international quality standards. In shrimp tissue, the highest accumulation occurred in the cephalothorax, especially for Cu, although all detected levels remained within the safety limits set by Indonesian standards. Monitoring heavy metals and shrimp in the aquaculture environment is essential, as these contaminants can bioaccumulate and pose health risks to aquatic organisms and humans throughout the food chain. Water quality parameters were generally suitable for shrimp farming, but low pH values may increase heavy metal solubility and bioaccumulation risks. These findings highlight the need for regular monitoring and better environmental management to ensure the sustainability and safety of traditional shrimp aquaculture systems.

Keywords: Brackish water; heavy metals; traditional system; whiteleg shrimp

INTRODUCTION

White shrimp (*Litopenaeus vannamei*) is a highly economically valuable brackish water fishery commodity. Various systems, including traditional systems, can be used in tiger shrimp farming. In conventional white leg shrimp farming, pond construction still uses clay soil and relies heavily on rivers as a source of aquaculture water (Pariakan & Rahim, 2021). Traditional white leg shrimp farming highly depends on natural conditions because it does not use artificial feed or special treatments in the cultivation process (Hermawan *et al.*, 2020).

Water contamination is a significant issue in conventional white shrimp aquaculture (Rukisah *et al.*, 2019). This study utilised a vaname shrimp farm in Sidoarjo Regency as the sample location. The site is in proximity to industrial operations and the Porong River. Numerous industrial, agricultural, and domestic wastes can contaminate the environment (Mustafa *et al.*, 2019). Heavy metals, which are poisonous and detrimental to living organisms, are among the hazardous components in these wastes (Jacob *et al.*, 2018). Copper, chromium, cadmium, and lead are heavy metal contaminants in traditional vaname shrimp aquaculture (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. The buildup of heavy metals might ultimately damage the health of those who ingest contaminated fish products. These metals have environmental persistence and may induce prolonged harmful effects upon entering the food chain. Cadmium and lead are recognised for impairing organ function and the neurological system, whereas elevated levels of copper and chromium can harm tissues and interfere with metabolic processes. These metals typically associate with proteins in the body, such as metallothionein, complicating their regular elimination (Muhajir, 2009).

Research on the environmental quality of traditional whiteleg shrimp farming (*Penaeus vannamei*) is necessary, given the potential for heavy metal pollution from anthropogenic activities around the pond area, such as agriculture, livestock, and domestic waste. 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. Whiteleg 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. The living environment of aquatic organisms, such as water and sediments, plays an essential role in bioaccumulating heavy metals (Wang *et al.*, 2023). Whiteleg shrimp have the habit of moving and foraging on the bottom of the water, where various types of waste, including heavy metals, are deposited (Bautista-Covarrubias *et al.*, 2022). Therefore, white leg shrimp can accumulate heavy metals in their culture environment. Heavy metal pollution affects water quality, which is crucial for the growth and development of white leg shrimp (Li *et al.*, 2014). However, studies on the distribution of heavy metal pollution in whiteleg shrimp body parts are rare.

The body part of the whiteleg shrimp consists of the head fused with the thorax (cephalothorax) and abdomen. Whiteleg shrimp accumulate more heavy metals in the cephalothorax, such as in the gill organs, antennae, and hepatopancreas (Albuquerque *et al.*, 2020). These organs filter and absorb substances from the environment (Ramos-Miras *et al.*, 2023). This study analysed the heavy metal content in the culture environment and body parts of white leg shrimp and the water quality of traditional culture systems.

MATERIALS AND METHODS

Water, whiteleg shrimp, and sediment samples were obtained from a traditional whiteleg shrimp farming pond in Sidoarjo District (Figure 1). All samples were taken from 3 representative ponds. The position of the aquaculture ponds used in sampling is in the Porong River, Sidoarjo. Observations were repeated three times every 20 days. Water samples were taken using a water sampler, sediment using a grab tool, and whiteleg shrimp using a net tool. Whiteleg shrimp samples, after arriving at the laboratory, were frozen at -20 °C for preservation and further analysis. The general condition of the sampling location map can be seen in Figure 2.

Figure 1. The general condition of the sampling location.

Heavy metal analyses were conducted on water, sediment, and whiteleg shrimp samples for Cd, Cu, Cr, and Pb. Analysis of heavy metal testing on all samples was carried out using ICP-AES (ICP-AES, ICPE-9820; Shimadzu, LRT UB) with the results of heavy metal concentrations interpreted with six calibration curve points, including 0, 0.1, 0.5, 1, 2, and five ppm (Arisekar *et al*., 2022). In addition to heavy metal analysis, water quality analysis was carried out using temperature with a thermometer, salinity with a refractometer, pH with a pH meter, and ammonia by spectrophotometric methods.

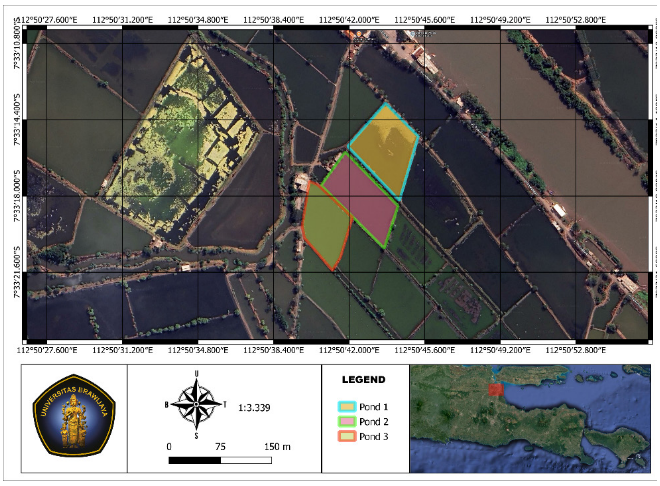

Figure 2. Location map of water, sediment, and whiteleg shrimp sampling ponds.

Analysis of heavy metals in water

100 ml of pond water was put into a glass jar and filtered using Whatman No.41 filter paper to remove dust particles. From the filtrate obtained, 9 ml was taken and added to 1 ml of 65% HNO_3; then, the digestion process was carried out. The microwave digestion system (Multiwave Go Plus, Anton Paar, LRT UB) was set with a temperature program that reached 160 °C for 20 minutes. Then, the results were analyzed using ICP AES wavelengths of 226.502 (Cd), 267.716 (Cr), 327.396 (Cu), and 220.353 (Pb).

Analysis of heavy metals in sediments

In the laboratory, sediment samples were oven-dried at 100 °C for 80 minutes before analysis. A total of 100±5 mg of sediment was placed into a microwave vessel. The samples were then added to 5 ml of 65% HNO_3 (Merck, Sigma-Aldrich) and 2 ml of 30% H_2O_2 (Merck, Sigma-Aldrich), with a gradual temperature program starting from room temperature to 160 °C for 10 minutes and then increased to 180 °C for 10 minutes. Then, the results were analyzed using ICP AES wavelengths of 226.502 (Cd), 267.716 (Cr), 327.396 (Cu), and 220.353 (Pb).

Analysis of heavy metals in the body of whiteleg shrimp

Before analysis, whiteleg shrimp were separated into two parts (cephalothorax and abdomen). A total of 250±5 mg of cephalothorax and abdomen homogenized using a mortar was put into a microwave vessel. The samples were then added to 5 ml of 65% HNO_3 and 2 ml of 30% H_2O_2, with a gradual temperature program, starting from room temperature to 160 °C for 10 minutes. Then, ICP AES was analyzed using wavelengths of 226,502 (Cd), 267,716 (Cr), 327,396 (Cu), and 220,353 (Pb).

RESULTS AND DISCUSSION

Heavy metals in water and sediment

The findings of examining heavy metal concentrations in the water and soil from the three whiteleg shrimp farming ponds are illustrated in Figures 3 and 4. Chromium (Cr) was undetected in both water and sediment samples across all ponds, signifying that its concentrations fell outside the detection threshold of the instrumentation. The concentration of Cu metal in the water varied from 0.01 to 0.11 ppm, with the maximum value recorded in Pond 1 at 0.11 ppm and the minimum in Pond 2 at 0.01 ppm. The quantity of Cd metal in the water was most significant at 1.46 ppm in Pond 3 and lowest at 0.77 ppm in Pond 2. Pb metal was identified in all water samples, with a concentration range of 0.19 to 0.52 ppm. According to Hutagalung (1991), some heavy metals can precipitate in sediments in the following sequence: Hg > Cu > Ni > Pb > Co > Cd. Consequently, cadmium concentrations exceed those of lead and copper. According to sediment quality guidelines established by Kepmen LH No. 51 Tahun 2004, the permissible limits for heavy metals are Pb at 0.008 ppm, Cd at 0.015 ppm, and Cu at 0.008 ppm. Consequently, Pb, Cd, and Cu metals surpass the established maximum thresholds of the quality requirements.

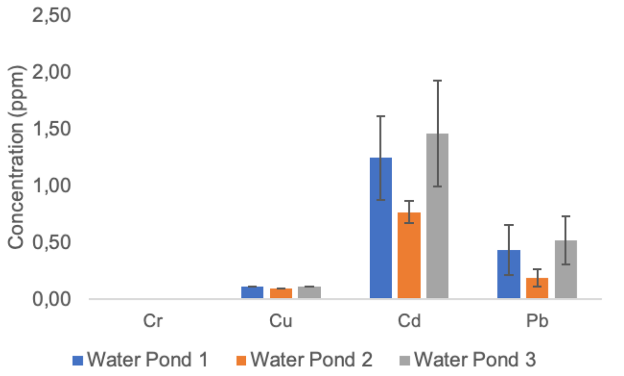

Figure 3. Heavy metals in water. Quality limit by KEPMEN LH No 51 (2004) is Cu<0,008 ppm; Pb<0,008 ppm; and Cd<0,015 ppm.

In sediment samples, Cu metal was undetected in Pond 1 and Pond 3 sediments but was identified in Pond 2 at a concentration of 0.09 ppm. The maximum concentration of cadmium (Cd) was detected in Pond 2 at 0.90 ppm, while the minimum was seen in Pond 1 at 0.05 ppm. The maximum concentration of Pb in the sediment was recorded in pond two at 10.98 ppm, whereas the minimum concentration in pond 1 was 7.20 ppm. The concentration of Pb in the silt significantly exceeded that in the water, signifying the buildup of heavy metals at the pond's bottom. The data 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 (Rochyatun et al., 2010). According to the sediment quality guidelines established by the Swedish Environmental Protection Agency (SEPA) in 2000, the permissible maximum concentrations of heavy metals are 25 ppm for Pb, 0.2 ppm for Cd, and 15 ppm for Cu. Consequently, heavy metal Pb and Cu concentrations remain within the established maximum threshold of the sediment quality guideline. Nonetheless, the concentration of heavy metal cadmium in ponds 2 and 3 is above the highest permissible limit of the quality standard.

Heavy metal contaminants, including chromium (Cr), copper (Cu), cadmium (Cd), and lead (Pb), are recognised for their detrimental effects on groundwater quality. This contamination may originate from direct sources, including industrial effluents, landfills, excessive fertiliser application, and household garbage. According to Megabuana *et al*. (2020), the heavy metal contamination index in the air is closely associated with heavy metal contamination in irrigation water sources utilised in traditional agriculture techniques. Furthermore, indirect sources of pollutants exist, including surface water infiltration that transports contaminants into groundwater, or atmospheric deposition from precipitation (Anilkumar *et al*., 2015). Furthermore, biogeochemical processes and human activities may affect Cd concentrations in coastal ecosystems (Xing *et al*., 2017). Heavy metals in aquaculture water precipitate and accumulate at the pond's bottom, resulting in sedimentation. This exposes white leg prawns that feed on the pond's bottom to heavy metals (Rahman, 2018). This study indicates that variations in heavy metal concentrations may result from factors like land use type, pollution sources, and aquaculture environmental management practices in each system. Heavy metal concentrations in white leg shrimp aquaculture pond sediments result from sediment accumulation at the pond's bottom.

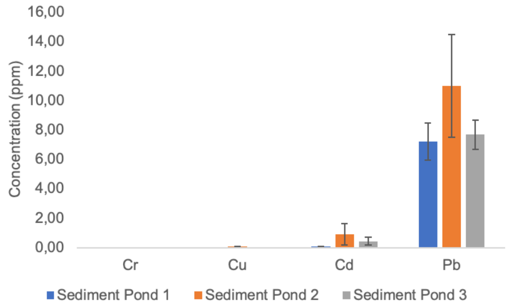

Figure 4. Heavy metals in water sediment. SEPA quality limit are Pb<25 ppm; Cd<0,2 ppm; and Cu<15 ppm.

This study identifies the sources of heavy metals Cd, Cu, and Pb as pollution from industrial, residential, and transportation activities surrounding the Porong River. According to Vig *et al*. (2023), heavy metals in the environment 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. Aquaculture water may get polluted with heavy metals from natural sources and anthropogenic activities; thus, consistent monitoring is essential. Assessments of heavy metals like Cadmium (Cd), Chromium (Cr), Copper (Cu), and Lead (Pb) are performed to evaluate pollution levels and their correlation with the state of the aquatic environment.

Besides water, sediment is a significant indicator of pollution since it accumulates 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 site.

Heavy metal content in the body of whiteleg shrimp

The results of the heavy metal analysis in the cephalothorax and abdomen of whiteleg shrimp from three culture ponds are illustrated in Figures 5 and 6. In the cephalothorax, the heavy metal chromium was identified at a maximum concentration of 0.01 ppm in pond one and a minimum of 0.004 ppm in pond 3. The Cu level in this region varied from 0.15 to 0.24 ppm, with the maximum amount recorded in Pond 1. Heavy metal cadmium exhibited very low amounts, ranging from 0.01 to 0.02 ppm, whereas lead was discovered at levels between 0.03 and 0.05 ppm.

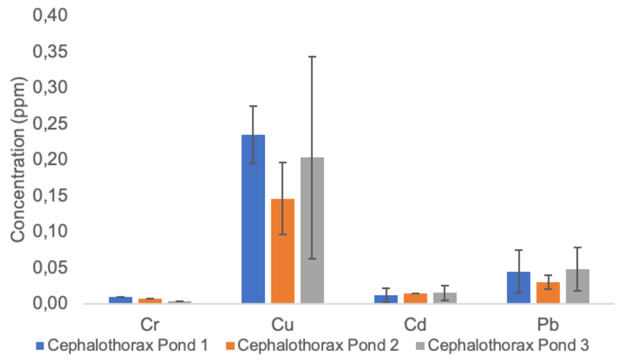

Figure 5. Heavy metal concentration in the cephalothorax. Quality limit by SNI 7387:2009 are Pb<0,3 ppm; Cd<0,1 ppm; and Cu<0,5 ppm.

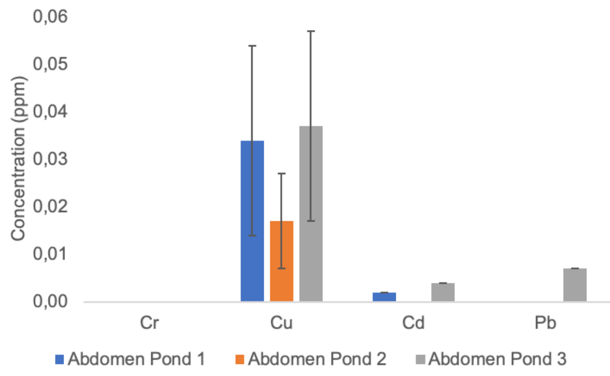

Figure 6. Heavy metal concentration in the abdomen. Quality limit by SNI 7387:2009 are Pb<0,3 ppm; Cd<0,1 ppm; and Cu<0,5 ppm.

Additionally, chromium metal was not found (ND) in any of the ponds within the abdomen. Copper (Cu) was identified at the maximum value of 0.04 ppm in Pond 3 and the lowest concentration of 0.02 ppm in Pond 2. Cadmium in the abdomen was discovered in ponds 1 and 3 at concentrations of 0.002 ppm and 0.004 ppm, respectively. Lead (Pb) was exclusively identified in pond three at a value of 0.007 ppm, whereas it was undetected in ponds 1 and 2.

Heavy metal concentrations were often greater in the cephalothorax than in the abdomen. This is attributable to the cephalothorax's role as the hub of physiological activity and the site of metabolite accumulation and heavy metals. According to the quality criteria for whiteleg prawns outlined in SNI 7387 of 2009, the maximum levels of heavy metals are Pb at 0.3 ppm, Cd at 0.1 ppm, and Cu at 0.5 ppm. Under the applicable rules, there is no established quality requirement for the heavy metal chromium in whiteleg shrimp. Consequently, the heavy metals Cd, Cu, and Pb remain beneath the established maximum thresholds of the quality requirements.

Whiteleg shrimp collect higher concentrations of heavy metals than fish, particularly in the cephalothorax, including the gills, antennae, and hepatopancreas (Albuquerque et al., 2020). The concentration of heavy metals in shrimp is often greater 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). Heavy metals may accumulate in the tissues of prawns, which typically occupy the terminal position in the aquatic food chain. While these elements may not consistently impact biota, the buildup of heavy metals might detrimentally influence human health (Rainbow, 2018).

The cephalothorax and abdomen have the highest heavy metal copper (Cu) concentration. Copper is critical for whiteleg prawns, facilitating blood regeneration and contributing to their health and vigour (Ortiz-Moriano *et al.*, 2024). Simultaneously, the second-highest concentration of heavy metal was lead (Pb). These heavy metals predominantly concentrate in the sediment since whiteleg prawns inhabit the bottom or vicinity of the sediment for approximately half of the culture cycle duration (Wang *et al.*, 2023). The concentration of heavy metals in the cephalothorax and abdomen of whiteleg shrimp serves as a critical indicator for evaluating the pollution levels of aquatic environments and associated dangers to human health. Whiteleg shrimp can absorb heavy metals from water and soil via bioaccumulation; hence, an examination of Cd, Cr, Cu, and Pb concentration in the cephalothorax and abdomen was conducted to elucidate the distribution pattern of heavy metals inside the shrimp's body.

Water quality of whiteleg shrimp farms

Water quality measurements were conducted on three whiteleg shrimp culture ponds in three sampling periods. Parameters analyzed included temperature, pH, salinity, dissolved oxygen (DO), ammonia, and Total Organic Matter (TOM). The measurement results are presented in Table 1. The water temperature in the three ponds was relatively stable, ranging from 30-32 °C. The highest temperature was recorded at 32 °C in ponds 2 and 3 in the first sampling, while the lowest temperature was 30 °C in ponds 1 and 3 in the second sampling. Temperatures within this range are still within the optimal range for whiteleg shrimp (*Litopenaeus vannamei*) growth, which is 27-32 °C (Tahe *et al.*, 2011).

The highest pH was recorded in Pond 1 in the first sample, 6.8, while the lowest pH of 6.5 was detected in Ponds 1 and 3 in the third sample. The higher the pH value, the lower the heavy metal content in the water. Conversely, the lower the pH value, the higher the solubility of heavy metals in the water (Masriadi *et al.*, 2019). This value indicates less favourable water conditions for the survival of whiteleg shrimp because the optimal range for whiteleg shrimp farming is 7.5-8.7 (Asni *et al.*, 2023).

The salinity range is 20-24 ppt. Pond 3 had the highest salinity of 24 ppt in the second sample, while

Pond 2 had the lowest salinity of 20 ppt in the third sample. This salinity range is still suitable for white leg shrimp, which are tolerant of a wide salinity range, but ideally ranges from 20-30 ppt (Asni *et al*., 2023). The bioaccumulation process of heavy metals at low salinity tends to increase, while the concentration of heavy metals at high salinity tends to decrease (Fernandes *et al*., 2023).

The DO concentration in the pond showed a relatively uniform value between 6.5 and 6.7 ppm and an optimal value range of 4 to 7 ppm (Asni *et al*., 2023). This condition reflects waters with good oxygen levels and supports shrimp metabolism and growth. Low DO values increase toxicity and bioaccumulation of heavy metal contaminants (Fernandes *et al*., 2023).

Ammonia (NH_3) concentration was very low, between 0.01 and 0.12 ppm. The highest value was recorded in pond 2 (0.12 ppm) in the first sample. This value is below the toxic threshold for whiteleg shrimp life, which is <0.25 ppm (Kurniawan *et al*., 2021).

Total Organic Matter (TOM) showed considerable variation between sampling and ponds, with the highest value of 31.2 ppm in Pond 3 (second sampling) and the lowest of 20 ppm in Pond 1 (second sampling). This value is still within the optimal range for whiteleg shrimp (*Litopenaeus vannamei*) growth, which is <40 ppm (Kurniawan *et al*., 2021). An increase in TOM may indicate the accumulation of organic matter from feed and metabolic waste, which, if not controlled, can reduce water quality and increase the risk of toxic compounds such as ammonia and H_2S.

Overall, the water quality parameters in the three ponds showed suitable conditions for white leg shrimp culture. However, special attention needs to be given to the pH parameter to maintain the culture's sustainability and prevent a decrease in water quality.

Table 1. Whiteleg shrimp farming water quality.

Parameters	Sampling	Results		
		Pond 1	Pond 2	Pond 3
Temperature (°C)	1	31	32	32
	2	30	32	31
	3	31	31	30
pH	1	6.8	6.7	6.7
	2	6.7	6.7	6.6
	3	6.5	6.6	6.8
Salinity (ppt)	1	22	22	23
	2	21	21	24
	3	21	20	22
DO (ppm)	1	6.7	6.7	6.6
	2	6.6	6.5	6.5
	3	6.7	6.7	6.6
Ammonia (ppm)	1	0.08	0.12	0.11
	2	0.01	0.06	0.05
	3	0.07	0.03	0.01
TOM (ppm)	1	22.7	23.2	30.5
	2	20	21	31.2
	3	21.5	21.3	31.1

CONCLUSION AND RECOMMENDATION

Conclusion

This study found that traditional whiteleg shrimp (*Penaeus vannamei*) aquaculture ponds in Sidoarjo, Indonesia, are contaminated with heavy metals, particularly cadmium (Cd), copper (Cu), and lead (Pb), due to surrounding industrial, agricultural, and domestic activities. Heavy metals were more concentrated in sediment than water, with Pb levels in sediment and Cd in water exceeding environmental quality standards. Heavy metal accumulation in shrimp was higher in the cephalothorax than in the abdomen, especially for Cu, though all levels remained within safe consumption limits. While overall water quality supported shrimp cultivation, low pH levels may increase heavy metal solubility, requiring closer monitoring and improved pond management.

Recommendation

Based on the research conducted, the suggestion for this study is to conduct regular monitoring of water and sediment quality to prevent heavy metal accumulation in traditional ponds. The application of simple technologies such as biofilters and education for farmers on sustainable environmental management should be improved. In addition, further research on the effects of heavy metals on the vital organs of shrimp and their potential risks to human health is essential to ensure safe consumption and sustainability of aquaculture.

AUTHORS' CONTRIBUTIONS

KPS conducted the research and wrote the manuscript, and YK and MH corrected it and applied for research funding.

ACKNOWLEDGEMENT

The authors thank the Integrated Research Laboratory of Universitas Brawijaya, Hydrobiology Laboratory—Div. Aquatic Environment, Faculty of Fisheries and Marine Science, and all those who have supported this research.

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How to cite this article Sugiarto, K.P., Y. Kilawati & M. Mahmudi. 2025. Accumulation of Cd, Cu, Cr, and Pb in whiteleg shrimp (*Penaeus vannamei*) and pond environment of traditional aquaculture systems in Sidoarjo, Indonesia. Jurnal Perikanan Universitas Gadjah Mada. 27 (1): 57-63. https://doi.org/10.22146/jfs.106352