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ASSESSMENT OF HEAVY METALS EXPOSURE AMONG SHRIMP FARM WORKERS

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Abstract

Human exposure to agrichemicals, including heavy metals, is a common occupational hazard in shrimp farming, with potential acute and chronic health effects. This study aims to assess the concentrations of selected heavy metals—copper (Cu), chromium (Cr), zinc (Zn), and lead (Pb)—in the personal air samples of shrimp farm workers and evaluate the associated health risks. The study involved a total of 10 shrimp farm workers. Personal air sampling pumps were positioned in the workers' breathing zones during their duties which included handling of chemicals and the samples were analyzed through Inductively Coupled Plasma Mass Spectrometry (ICP-MS). The hazard quotient (HQ) for each heavy metal suggesting the absence of significant carcinogenic risk. The total hazard index (HI) value for chromium (Cr) was 4.14×10^{-3}, which remained within the permissible safety limits while estimated cancer risk for chromium is 9.79×10^{-9}, which is within the tolerable risk limit. In conclusion, the non-carcinogenic and carcinogenic hazards associated with exposure to these heavy metals among shrimp farm workers were within tolerable thresholds. However, for the long-term exposure, there is a need for improvement especially on chemical handling and usage.

Keywords; heavy metals; shrimp farm workers; health risk assessment; occupational exposure

Introduction

Agriculture remains one of the most hazardous industries due to frequent exposure to chemicals and environmental stressors. Farmers typically spend long hours outdoors, often in extreme heat, while handling pesticides and fertilizers. Such working conditions increase their susceptibility to occupational health problems. Misuse of agricultural chemicals has been linked to respiratory illnesses, skin disorders, allergies, intoxication, and in some cases the spread of infectious diseases [1].

Excessive and uncontrolled chemical use also contributes to environmental degradation. Pesticide residues and other toxic compounds often accumulate in soil and water, leading to long-term ecological consequences. Studies have shown that organic chemical contamination

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is now a global issue, with pollutants found across nearly all ecosystems. At the end of their life cycles, these chemicals are either recycled back into use or improperly disposed of, creating persistent environmental risks [2].

Farmers themselves often lack awareness of the health impacts of prolonged chemical exposure. Those involved in pesticide preparation and application are especially vulnerable, with exposure occurring through inhalation of vapors and absorption through the skin. Daily tasks such as mixing, loading, and spraying pesticides present frequent opportunities for exposure [3], [4], [5]. Previous studies have even documented pesticide poisoning and deaths among paddy farmers in Tanjung Karang, demonstrating the seriousness of the hazard [6].
Beside agriculture, a range of chemicals including antibiotics were also being used in aquaculture sector particularly for shrimp farming. Common chemicals utilized for shrimp health management are lime, salt, potassium permanganate, magnesium, formalin, bleaching powder and malachite green as reported by Mostafa Shamsuzzaman & Kumar Biswas, (2012) and Villarreal, (2023)in their studies. However, the use of these chemicals is often poorly regulated. Many workers lack proper training on dosage, methods of application, and safe handling, leading to overuse and potential harm.

The health effects of chemical exposure can manifest in both acute and chronic forms. Acute effects appear shortly after contact and may include symptoms such as skin irritation, throat discomfort, dizziness, or even loss of consciousness due to toxic vapors [9]. hronic effects, by contrast, develop gradually after years of repeated exposure and are often irreversible. Farmers engaged in daily routines such as liming, fertilizing, and feeding are at constant risk of cumulative health impacts, especially in the absence of safety protocols. Preventive measures are therefore critical. The consistent use of personal protective equipment (PPE) can significantly reduce chemical exposure, while proper workplace chemical management helps protect workers and improve productivity. Effective safety practices not only minimize occupational health risks but also contribute to higher job satisfaction among farmers. Nonetheless, implementing such measures requires an accurate understanding of the types and levels of hazardous substances present in farming activities.

In aquaculture, particularly shrimp farming, there is still limited data on chemical hazards, especially regarding heavy metal exposure. Identifying the concentration of hazardous elements in routine farming practices is an essential step toward developing appropriate safety strategies. Addressing this knowledge gap is crucial for safeguarding workers' health and ensuring sustainable farming practices. Based on this context, the present study was designed to evaluate the level of heavy metal exposure among shrimp farm workers during their daily activities. By identifying the risks and potential health implications, this research seeks to provide evidence-based recommendations for safer chemical management in aquaculture.

Methodology

Sampling Strategy

In this study, the respondents were selected from only exposed workers group. A total sample size of 10 respondents is randomly selected regardless of their gender, race and age. The instrument used for personal monitoring is personal air sampling pump. Personal air sampling pump were used to assess the level of chemical exposure among farm workers. The sampling pump were attached to the worker (within the breathing zone) during while they performed their job or handled the chemical. The average sampling hours were 2 h/day^{-1}, ranging from 0.5 to 3 h/day^{-1} for each worker [10].

Sample Extraction and Analysis

This study adopted the hot acid digestion method as proposed by the NIOSH Manual of Analytical Methods (NMAM) for measuring heavy metals in ambient air. The Mixed Cellulose Esters (MCE) membrane filter used in sampling which had been contaminated with pollutants had been cut into fragments and placed into a 250 mL beaker containing10 mL of 10% of nitric acid. The process was continue using hot plate at certain temperature and time. Extracted sample were then transferred into vials and analyze by using ICP-MS.

In order to evaluate the non-cancer and cancer risks of heavy metals towards the worker's health, models that were developed by the United States Environmental Protection Agency were adopted. Even though heavy metals can enter human body through three pathways (ingestion, dermal contact, and inhalation), inhalation is the most essential route of exposure to

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particulate matter and heavy metals. The doses taken up by the human body were calculated each element as daily doses by using the following equations.

Ingestion Dose:

$$D_{ingestion}\ (mgkg^{-1}day^{-1}) = C\ x\ \frac{IngR\ x\ EF\ x\ ED}{BW\ x\ AT}\ x10^{-6} \quad (1)$$

Inhalation Dose:

$$D_{inhal}\ (mgkg^{-1}day^{-1}) = C\ x\ \frac{InhR\ x\ EF\ x\ ED}{PEF\ x\ BW\ x\ AT} \quad (2)$$

Dermal Dose:

$$D_{derm}\ (mgkg^{-1}day^{-1}) = C\ x\ \frac{SA\ x\ SL\ x\ ABS\ x\ EF\ x\ ED}{BW\ x\ AT}\ x\ 10^{-6} \quad (3)$$

Where C is the concentration of ($mgkg^{-1}$) of the heavy element in a sample, IngR is the ingestion rate, InhR is the inhalation rate, EF is the exposure frequency, ED is exposure duration, SA the exposed skin area, SL is skin adherence factor, ABS the dermal absorption factor (unit less), PEF is particle emission factor, BW is body weight average and AT the average time (days). For non-carcinogens, AT = ED × 365 days while for carcinogens AT = 70 × 365.

The assessment of cancer risk is made by calculating the lifetime average daily dose (LADD) as a weighted average for each exposure pathway and is given in the following equation;

Lifetime Average Daily Dose:

$$LADD\ \ (mgkg^{-1}day^{-1}) = \frac{EF\ x\ C}{AT}\ x\ \frac{CR\ x\ ED}{BW}\ x\ 10^{-6} \quad (4)$$

Where CR is the contact rate that is for ingestion (CR = IngR), for inhalation (CR = InhR) and for dermal absorption (CR = SA × SL × ABS). The non-carcinogenic health risk to any

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exposed human being which expresses the systematic toxicity for a single metal in soils is a dimensionless quantity called the hazard quotient (HQ). Toxicological risk of exposure to metals is assessed by comparing the estimated daily intake of each metal to its corresponding reference dose (RfD) in each exposure pathway. It is expressed as:

Hazard Quotient:

$$HQ = \frac{DI}{RfD} \quad (5)$$

$$HI = \sum HQ \quad (6)$$

Hazard index refers to the "sum of more than one hazard quotient (HQ) for multiple substances and/or multiple exposure pathways" (US Environmental Protection Agency, 1989). Hence, a combination of non-carcinogenic risk for humans from different exposure pathways can be estimated by adding the HI of each exposure pathway (ingestion, dermal contact and inhalation) together [11]. If the value of HQ or HI is ≤ 1, it is believed that there is no significant risk of non-carcinogenic effects. If the value of HQ or HI is > 1, it means that there is a great chance of non-carcinogenic effects, with a probability increasing with the increasing value of HQ or HI (US Environmental Protection Agency (EPA), 2015).

The estimated value for the carcinogenic risk (CR) is the probability that if an individual will develop any type of cancer from lifetime exposure to carcinogenic hazards. In general, the US EPA recommends that and CR lower than 1×10^{-6} can be regarded as negligible and a CR above 1×10^{-4} are likely to be harmful to human beings. A CR within a range from 1×10^{-6} ~ 1×10^{-4} indicates an acceptable or tolerable risk for regulatory purposes and desirable remediation, social stability and to human health [11]. The SF ($mgkg^{-1}$ day^{-1}) is the slope factor for carcinogenic exposure. Human health risk due to carcinogenic elements is calculated as "the incremental probability of an individual developing cancer over a lifetime as a result of exposure to the potential carcinogen"[12]. It is a dimensionless level of probability expressed as:

Cancer Risk:

$$CR = LADD \times SF \quad (7)$$

Table 1. Notation and Constant value for Hazard Quotient Equation

Notation	Rate
C	Concentration from sample
Ing_R	100 mg day $^{-1}$
Inh_R	20 m ^{3} day $^{-1}$
EF	180
ED	24 year
SA	5700 cm^2
SL	0.07 mg cm^{-2} h^{-1}
BW	70 kg
AT	Non-cancer: ED × 365 day Cancer: 70 × 365 day
ABS	0.001
PEF	1.36×10^9

Results and Discussion

Concentration of heavy metal

Determination of heavy metal from chemicals used in the shrimp farming activities was assessed by using ICP-MS. The heavy metals examined in this study are limited to Cr, Zn, Cu and Pb. The heavy metal chose for this study was based on the most commonly used products that contained chemicals from the ingredient used for shrimp farming activities or process. Some of the heavy metals also chosen based on the review of other journals and study. Samples of air were analyzed by using ICP-MS to determine the level of concentration of heavy metal exposed by the workers.

Table 2. Average Metal Concentration

Metal Detected	Minimum (ppm)	Maximum (ppm)	Mean (ppm)
Magnesium (Mg)	23.46	500.64	333.98
Potassium (K)	224.13	494.35	368.46
Calcium (Ca)	134.19	701.46	506.29
***Chromium (Cr)**	10.45	30.47	16.98
***Copper (Cu)**	1.34	14.11	9.41
***Zinc (Zn)**	238.82	378.93	293.79
***Lead (Pb)**	7.17	31.21	14.74

*Heavy metals

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Table 2 shows the minimum, maximum and mean of the concentration of metals/heavy metal exposed to the shrimp farm workers. The result demonstrate that the highest concentration of metal exposed to the workers is Calcium (Ca) which ranges from 134.19 to 701.46 ppm, with an average value of 506.29 ppm. The lowest concentration of heavy metal detected during this study is Copper (Cu), with an average 9.41 ppm with varies from 1.34 to 14.11 ppm. The carcinogenic element Chromium (Cr) and Lead (Pb) are within the acceptable limit.

During the data collection, the workers were using calcium carbonate for liming purpose at the shrimp pond. Calcium (Ca) comes from calcium carbonate which is used in the liming process in the shrimp farming. Liming is the application of calcium and magnesium compounds to the soil for the purpose of reducing soil acidity. It is usually applied during or after the pond drying stage. There are three methods of liming which are by broadcast over dried pond which includes the dike walls or by mixing with water and spraying over the pond, or by liming the water flowing into the pond.

Calcium carbonate was poured onto the ponds and the workers using bare hand without any hands gloves and face mask while handling the chemicals products. Thus, without proper personal protective equipment (PPE) will increase the amount of exposure among the workers through dermal contact, inhalation or ingestion. Calcium (Ca) also is used to increase the pH of water pond and to strengthen the shell of the shrimp. In ponds, calcium functions to minimize the rise in pH that can occur when photosynthesis rates are high. Most of farms (82.6%) apply lime to adjust pH when are low ($pH < 6$) and as preventing disinfectant. Calcium (Ca) and Magnesium (Mg) are considered to be very important for molting and new shell formation for shrimp.

Based on the result obtained, Cu has the lowest concentration level which is 9.41 ppm with minimum value of 1.34 ppm. Then, concentration of Magnesium (Mg) varies from 23.46 to 500.64 ppm with an average value of 333.976 ppm. The concentration of Potassium (K) were found to be in the range of 7.17 to 31.21ppm with a mean value of 14.74 ppm. Concentration of Chromium (Cr) varied between 10.45 to 30.47 ppm with an average value of 16.98 ppm. The concentration of Zn varies from 238.82 to 378.93 ppm and the average value of 293.79 ppm. Lastly, concentration of Pb is from the range of 7.17 to 16.34 ppm and the average value of

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14.74 ppm. Therefore, the overall heavy metal concentration exposed to the worker shows that Zn > Cr > Pb > Cu.

Non-cancerous element

Non-carcinogenic risk were calculated based on RfD value. These result for the inhalation, ingestion and dermal are all presented in terms of HQ. In this study the hazard quotient for non-cancerous effect are presented in Table 3.

Table 3. Average dose ($mgkg^{-1}$) due to non-cancerous elements

Metals/Heavy Metal Element	Dingestion	Dinhalation	Ddermal
Mg	2.35E-04	3.46E-08	9.39E-08
K	2.60E-04	3.82E-08	1.04E-07
Ca	3.57E-04	5.25E-08	1.42E-07
Cr	4.14E-03	6.15E-05	7.95E-05
Cu	1.66E-04	8.12E-08	2.22E-07
Zn	6.90E-04	3.04E-08	8.26E-08
Pb	2.97E-05	1.53E-09	4.14E-09

Table 3 shows the average dose ($mgkg^{-1}$) due to non-cancerous elements. Non-cancerous and cancerous element in this study were classified according to their group classified by US EPA. In this study, average dose due to non-cancerous element shows that dose from ingestion pathways record the highest exposure follow by dermal and inhalation. The highest taken dose are from ingestion pathway which is $4.14x10^{-3}$ for Cr followed by Pb ($2.97x10^{-3}$), Zn ($6.90x10^{-4}$) and Cu ($1.66x10^{-4}$). Ingestion was the highest exposure pathway among the other because of ingestion can be exposed directly by consumption of contaminated food or water that exposed to the environment.

According to Rauf et al., (2021) and Zulhilmi & Nurud, (2017) the results of risk analysis suggest that ingestion of food crops especially wheat is the main pathway for entering the metals to human body and threaten their health. In addition, Douglas et al., (2017) suggest that ingestion pathway delivers the toxicant more directly via the circulation through the target tissue. Next, exposure through dermal pathways for Chromium (Cr) was the highest which is $7.95x10^{-5}$ and the lowest exposure through dermal pathways is Copper (Cu) which is $2.22x10^{-7}$. Then, Chromium (Cr) was the highest dose taken through inhalation pathways which is $6.15x10^{-5}$ while the lowest dose taken through inhalation pathways is Copper (Cu) which is

$8.12x10^{-8}$. Excessive intake of Zn and Cu may cause non-carcinogenic effects on human health, even though they are essential to human life [16], [17].

From the result obtained, this shows that Chromium (Cr) were the highest dose taken for all ingestion, dermal and inhalation pathway. The overall hazard quotient is lower (HI < 1), somehow the highest value but still below the safe limit for Chromium (Cr) which is $4.14x10^{-3}$. The value indicates that the hazard index for all pathways is within the safe limit therefore it does not poses any hazard. None of the target compounds reported a hazard quotient (HQ) of >1, indicating that there were no significant health risks due to inhalation of pesticides during spraying activity. As conclusion, all elements are below the safe limit (HI < 1).

Table 4. Average hazard quotient for non-cancerous elements for each exposure pathway

Heavy Metal Element	Ingestion	Inhalation	Dermal	HI =∑ HQ
Magnesium	NA	NA	NA	NA
Potassium	NA	NA	NA	NA
Calcium	NA	NA	NA	NA
Chromium	4.00E-03	6.15E-05	7.95E-05	4.14E-03
Copper	1.66E-04	8.12E-08	2.22E-07	1.66E-04
Zinc	6.90E-04	1.01E-07	1.38E-06	6.91E-04
Lead	2.97E-03	4.35E-07	7.89E-05	3.05E-03

Cancerous Element

Carcinogenic risk for adults and children were calculated based on lifetime average daily dose for carcinogens with given slope factor of each element. The slope factor for Chromium (Cr) and Lead (Pb) were adopted from previous study (Matthew Tikpangi Kolo et al., 2018). The result for ingestion, inhalation and dermal pathways are all presented in terms of ∑HQ in Table 4. Chromium (Cr) and Lead (Pb) elements were selected as carcinogenic health risk assessment. The calculated result was based on LADD, then the value was calculated further for cancer risk. The US Environmental Protection Agency considers acceptable for regulatory purposes a cancer risk in the range of (1×10^{-6} to 1×10^{-4}). The calculated result for all type of element was lie within the acceptable range.

Table 5 Lifetime average of daily dose LADD ($mgkg^{-1}$ day^{-1}) of cancerous element

Heavy Metal Element	Dingestion	Dinhalation	Ddermal
Chromium (Cr)	7.03E-15	1.03E-18	2.33E-10
Lead (Pb)	3.70E-13	5.45E-17	1.47E-16

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Table 6. Average hazard indices and Risk calculated for the cancerous element

Heavy Metal Element	HQingestion	HQinhalation	HQdermal	Risk = ∑ HQ
Chromium (Cr)	2.95E-13	4.33E-17	9.79E-09	9.79E-09
Lead (Pb)	1.55E-13	2.29E-17	6.17E-17	1.55E-13

The highest value for cancerous element is Chromium (Cr) with cancer risk of 9.79×10^{-9}. The value somehow lies within the acceptable range. Then the lowest value for cancerous element is Lead (Pb) with cancer risk of 1.55×10^{-13}. According to Shahab Ahmadi Doabi et al. (2018) if HI < 1, the risk of non-carcinogenic health effects is negligible and if HI > 1 indicates the likelihood of occurrence of non-carcinogenic effects, the probability which increases with increasing HI.

Conclusion

According to this study, the concentration of metal were analyzed and showed that Calcium (Ca) was the highest value which is 506.29 ppm. This is due to the liming activities at the shrimp pond by the workers. Liming process involved the use of calcium carbonate in order to increase the pH of water pond and calcium also used to strengthen the shell of shrimp. Most farmers (82.6%) apply lime to adjust pH when are low (pH < 6) and as preventing disinfectant. Then the lowest concentration of heavy metal Copper (Cu) with average value of 9.41 ppm from the range 1.34 to 14.11 ppm. Therefore the overall heavy metal concentration exposed to the worker shows that Zn > Cr > Pb > Cu.

All heavy metal element was analysed by cancerous and non-cancerous risk by using US EPA (2015) method to calculate the hazard quotient and hazard index. Based on the result obtained, the highest value for cancerous element is Chromium (Cr) with cancer risk of 9.79×10^{-9}. The value somehow lies within the acceptable range. Then the lowest value for cancerous element is Lead (Pb) with cancer risk of 1.5×10^{-13}. Both total for hazard quotient and hazard index for all studied metals are far lower than the safe level thus indicating there is no non-carcinogenic risk from these metals.

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