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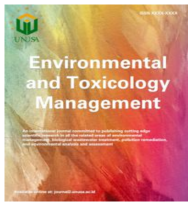

Health risk assessment for adult loei residents exposed to arsenic in water and food around an abandoned gold mine

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Abstract

This study assessed adult Loei residents' health hazards of arsenic (As) exposure around an abandoned gold mine. Forty-five environmental samples were collected from 1, 5 and 10 km from the gold mine based on a survey of 371 random adults. Inductively Coupled Plasma Optical Emission Spectrometry determined total As in environmental samples following Thai regulatory limits. With that, a deductive approach was made to assess the health risks using United States Environmental Protection Agency (USEPA) guidelines. As concentrations above the guidelines were found in river water (0.05- 0.09 mg/L), highest in 10 km, and below the guidelines were throughout in public water (0.001-0.006 mg/L), freshwater fish, shrimp and mussels (0.12-.017, 0.15-0.58 and 0.26-0.33 mg/kg, respectively), and rice in 1 km (0.02 mg/kg) but no As in vegetables and fruits. Hazard quotients (HQs) and cancer risks (CRs) of water for daily and agricultural use, and CRs of shrimp and mussels all over were below the guidelines (HQ: 1, CR: 10-6 - 10-4), where HQs and CRs of rice and freshwater fish, and HQs of shrimp and mussels in 5 km (18.0-34.9 year olds) were above the guidelines. The inhabitants are at risk of developing non-cancerous and cancerous diseases via food consumption but through water.

Keyword :
Arsenic, gold mine, risk assessment, hazard quotient, cancer risk

1 Introduction

Artisanal and small-scale mining (ASM) is common in Asia, Africa, Oceania, and Central and South America (Tiankao and Chotpantarat 2018). It outperforms agriculture, forestry, and fishing (Ali et al., 2019). ASM's most productive activity is gold mining. Although hazardous, ASGM generates 20-30% of the world's gold (Nawar et al., 2020). These mining activities use simple equipment and methods to extract gold from ore deposits, which raise environmental levels of arsenic (As), cadmium (Cd), mercury (Hg), lead (Pb), copper (Cu), and zinc (Zn) (Vareda et al., 2019). Due to their elemental impurities, carcinogenicity, and frequency, As, Cd, Hg, and Pb are the most harmful heavy metals to humans and animals (Rahman et al., 2011).

Specific organs and tissues can acquire heavy metals from the bloodstream (Ali et al., 2019). Fish, amphibians, and humans suffer from arsenic bioaccumulation in food (Nawar et al., 2020). Arsenic poisoning can cause stomach problems, tumors, anorexia, fever, fluid loss, goiter, hair loss, headache, herpes, slow healing, muscle spasms, a sore throat, weakness, and, most importantly, liver and kidney cancer (Rahman and Singh 2019). Short-term and long-term effects include a blood vessel damage, abdominal pain, nausea, vomiting, lung, and cardiovascular disease (Kiani et al., 2021).

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By complying with the above information around the globe, many investigations have found high quantities of heavy metals, including As, in Ghana (Ahmad and Carboo 2000), Iran (Rafiei et al., 2010), and Thailand (Tiankao and Chotpantarat 2018). Dermal exposure to heavy metals from tailings and soil was also recorded. Heavy metal exposure can induce kidney and liver malignancies, cutaneous keratosis, CNS damage, heart disease, joint discomfort, shyness, irritability, vomiting, poor attention span, and headache. Previous studies have assessed noncancer and cancer risks of dermal exposure to these heavy metals in gold mining sites in South Africa (Ngole-Jeme and Fantke 2017) and China (Liang et al., 2017).

Our research region, Loei Province, opened the Phu Thap Fah gold mine in 2006. Heavy metals, especially As, have contaminated local streams, rivers, and groundwater because of gold mining (Intamat et al., 2016). One hundred twenty gold mine locals had high blood cyanide levels, including dozens with Hg and As. Farmers surrounding the gold mine struggled with water and soil contamination. Since 2009, the government has encouraged communities to avoid drinking, bathing, cooking, and eating bivalves and crabs from local waterways. The study area is unprotected from water and ground collapse. The gold mine's environmental setting has boosted heavy metal levels, particularly arsenic (Intamat et al., 2016). Because of the above findings in the research area, a human health risk assessment of inhabitants near the gold mine is required.

Human health risk assessments predict how chemicals in polluted environmental media affect people's health. In Thailand, researchers looked into how much lead people were exposed to through the soil, food, and fish. The fact is that heavy metal contamination and acid mine drainage are severe environmental hazards where mining waste, especially metal-rich sulfides, has been stored or abandoned. Heating mercury-gold amalgams vaporizes mercury and extracts gold. Since 1887, poisonous sodium cyanide has extracted gold from low-grade ore. As sulfur minerals contain arsenic, mining companies often locate copper and gold sulfides in arsenic-rich soil and water to explore gold. Because arsenopyrite and arsenite (ASIII) are acidic, soluble, and can migrate into groundwater, surface water, and geological settings, tailings containing these minerals acidify water (Hou et al., 2019). Most rural and urban soils contain As from gold mining (Shen et al., 2019). Heavy metals, especially As, pollute sediment, dirt, and water and cause human carcinogenic and noncarcinogenic illnesses by inhalation, ingestion, and skin contact (Xiao et al., 2017). Abandoned spoils are more polluted than the active ones (Mensah et al., 2020). The IARC classifies arsenic, cadmium, chromium, and nickel as group 1 carcinogens. Inorganic arsenic in water, soil, and food is the most significant non-occupational health risk (Khosravi-Darani et al., 2022). Since the gold mine in Loei Province has been inactive for years, and most people in Loei depend on agriculture as their primary source of income—more than 80% grow rubber, rice, and soybeans—and use nearby forests and rivers a lot, this study aimed to determine the health risks of arsenic exposure for working adults (ages 20–59) who live near the abandoned gold mine in Loei, Thailand. The main objectives of this study were: (1) to determine the concentrations of As in water for daily and agricultural use in the study area; (2) assess the potential cancer and non-cancer health risks to adult residents associated with As exposure via skin contact with water and ingestion of food from common sources in the study area ; and (3) relate the health risk results of this study to the published standard health risk values to predict the potential cancerous and non-cancerous diseases in the study population.

2 Materials and method

2.1 The study area

The study area includes seven villages (dotted circles) around a dormant gold mine in Khao Luang sub-district of Wang Saphung district (Figure 1). It is a small rural district, over 12 miles from downtown Loei, where the locals depend profoundly on the surrounding natural resources, including forests and rivers, for their livelihoods. The study area has many small streams flow from the top of highland to lower areas. These streams eventually join the Loei River.

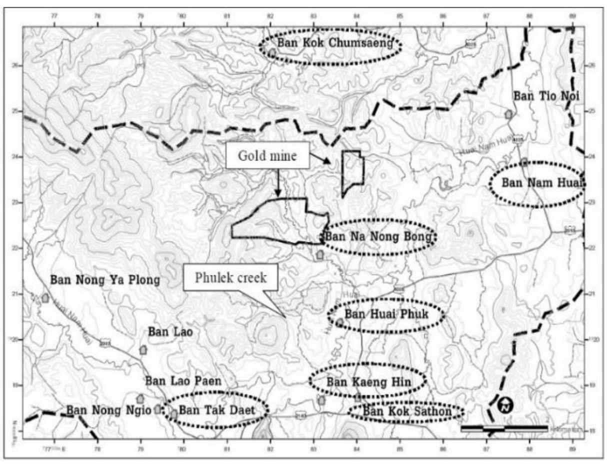

Figure 1 Sampling sites (dotted circled villages) around the gold mine

2.2 Collection of samples

2.2.1 Sample population recruitment

A survey of 371 randomly selected adult residents (aged: 20-59 years) out of 4,500 general population was conducted in the study area to research their daily water and food sources. The sample size was calculated using the WHO Sample Size Calculator with the relative precision (0.25), 95% CI (confidence interval) and power of the study as 80%. According to the survey, 68% of the residents drink bottled water followed by stored rainwater (40%). Most residents use tap water (68%) for daily activities, and everyone uses local river water for agriculture. Most residents consume locally grown white rice (83%), and fruits and vegetables (100%) throughout the week. Descriptive statistics were applied to analyze the above variables.

2.2.2 Collection of environmental samples

Purposive sampling method was applied to collect 45 environmental samples from 1, 5 and 10 km from the gold mine based on the survey findings. Among these, 9 water samples: 6 for tap water for daily use, 3 samples of river water for agricultural use; 3 samples of white rice from farmland and local markets; 12 aquatic food samples each containing 3 samples for freshwater fish, shrimp, and mussels from local waters and markets; 12 samples of plants grown locally and sold in local markets or corn, green cabbage, Chinese cabbage, and Thai Morning Glory, 3 samples for each category; and 12 samples of fruits grown locally and sold in local markets, namely papaya, mango, dragon fruit, and pineapple, 3 samples for each type. Drinking water was not on the list because the majority of respondents consume bottled water followed by stored rainwater.

2.3 Sample preparation and digestion

Water sample vials were washed with detergent and cleansed with 1:1 nitric acid and purified water. 1.5 L of water samples were taken in sampling containers at each sampling point. The water samples were acidified by adding 1 mL of investigational grade of 10% nitric acid, stored in the refrigerator at 4°C for As content analysis.

Almost 300 g of individual rice samples were taken in clean ziplock bags and refrigerated at 4°C until sample preparation. All rice samples were crushed and passed through a 0.42 mm sieve. The samples were dehydrated at 80°C in a hot air oven until a persistent weight was obtained. Subsequently, the samples were put in uncontaminated plastic tubes and kept in a desiccator until As analysis.

About 10 g of muscle (excluding the skin) was cut from each side of the fish and mussels. The edible parts of the shrimp were removed from the head and shell. The parts were washed once with deionized water, standardized, weighed, lyophilized, crushed and stored in glass bottles at 40°C until analysis. The water content was calculated with the weight of the samples before and after lyophilization at the laboratory for As analysis.

Only the edible parts of each herb were washed, cut into small pieces, crushed and packaged in plastic containers. The crushed samples (0.2 g) were added with 1 mL of concentrated nitric acid (65%) and digested at 95°C for 2 hours. The clear solution was then cooled and sieved through filter paper. The volume was adjusted to 10 mL of distilled water for As analysis.

2.4 Quality control

The LOD (Limit of Detection) of As was 0.020 mg/kg (or mg/L) and the % recovery of As was 101%.

2.5 Sample analysis

Inductively Coupled Plasma Optical Emission Spectrometry (ICP-OES) determined the level of As in each sample at the Center of Excellence for the Laboratory of Medical Biotechnology (CEMB), Faculty of Medical Sciences, Naresuan University, Phitsanulok 65000, Thailand. To compare the arsenic concentrations in samples, national permissible limits of arsenic concentration were taken as shown in Table 3 below. Descriptive statistical analysis was carried out to know the percentage (%) of arsenic in mg/kg.

2.6 Human health risk assessment

In this study, Human Health Risk Assessment (HHRA) was conducted applying the Integrated Risk Information System (IRIS) of the US Environmental Protection Agency. It consists of hazard identification, dose-response assessment, exposure assessment and risk characterization. Risk characterization in this study implicates evaluating the risk that As causes cancer or other diseases in 371 adult residents.

2.6.1 Exposure assessment

The exposure routes assessed for As contamination in the study area were: (1) dermal routes- water for daily and agricultural use, and (2) oral routes- collected food samples. Non-carcinogenic and carcinogenic health risks of the sample population by the exposure parameters are presented in Tables 1-2 below.

Table 1 Exposure parameters to assess the health risks of the study population caused by As

	Parameter	Unit
ADD	Average daily dose of As	mg/kg/day
C	Arsenic concentration	mg/L, mg/kg
P	Skin permeability coefficient	cm/h
SA	Exposed body surface area	cm^2
ET	Exposure time (h/day)	h/day
CF	Conversion factor	1 L/1000 cm^3
BW	Body weight	kg
IR	Ingestion rate of the food samples	-
EF	Exposure frequency	days/year
ED	Exposure duration	years
AT	Exposure duration [non-cancer health risk]	years (Table 2 below)
LT	Lifetime exposure [cancer health risk]	days/years (Table 2 below)
RfD	Dermal and oral reference dose	mg/kg/day
CSF	Dermal and oral cancer slope factor	1/mg/kg/day

Dermal contact with water for daily and agricultural use: Equation (1) was used in calculating the average daily dose from dermal contact with water (Table 1 below for calculation):

$$ADD\ dermal\ contact\ with\ water = \frac{CxPxSAxETxCF}{BW} \quad (1)$$

Exposure to arsenic via food ingestion: Equation (2) was used in calculating the average daily dose of As via ingestion of white rice, freshwater fish, shrimp and mussels by the study population (Table 1 below for calculation):

$$ADD\ oral = \frac{CxIRxEFxED}{BWxAT} \quad (2)$$

As is toxic to humans and produces various adverse health effects even at low concentrations through exposure by the food chain or mouth, skin and inhalation from contaminated water, sediment, ground or air. World Health Organization (WHO) has categorized this heavy metal as a class 1 human carcinogen based on adequate human epidemiological evidence that exposure to arsenic causes several forms of carcinogen. In addition, elevated mortality from many cancers of internal organs (liver, kidney, lung and bladder), and a higher incidence of skin cancer have been detected in populations consuming drinking water rich in inorganic arsenic. The heavy-duty exposure to As of the study population is now being recognized. Dose-response assessment in this study defines the degree and prospect of impairment related with As.

Table 2 Age group and gender specific non-carcinogenic and carcinogenic risk measurements of the sample population

Age	*Rice	*Fish	*Shrimp	*Mussels	BWM	BWF	**ED1	**ED2
18.0-34.9	12.33	0.88	0.05	0.21	65.5	66.9	30	70
35.0-64.9	11.94	1.04	0.03	0.11	66.32	65.73	30	70

Notes: (*) Ingestion rate (mg/kg-day; 97.5th percentile; nation wide). Ingestion rate of vegetables and fruits were not included because As was not found in vegetable and fruit samples (Table 3 below);
(**) ED1 and ED2 for age groups 18.0-34.9 and 35.0-64.9 were taken from USEPA (United States Environmental Protection Agency); BWM= Body weight of male organism, BWF=Body weight of female organism

2.6.2 Calculation of non-carcinogenic and carcinogenic health risks

$$HQ = \frac{ADD}{RfQ} \quad (3)$$

The non-carcinogenic risk or hazard quotient (HQ) for As exposure route was calculated by Equation (3) below (Table 1 below for calculation):

The reference dose (RfD) in this study is an estimate of the daily dermal or oral exposure of 371 residents unlikely to be affected during the lifetime.

$$CR = ADDxCSF \quad (4)$$

Cancer risk (CR) estimates of the sample population from oral and skin contacts of As in water and food samples were calculated using Equation (4) below (Table 1 above for calculation):

Cancer slope factor (CSF) in this study shows a high risk of cancer in 371 residents resulting from lifetime exposure to As by dermal or oral exposure.

3 Results and discussion

3.1 The Concentrations of Total As in the Environmental Samples

3.1.1 Water for Daily and Agricultural Use

Table 3 presents total concentration of As in environmental samples based on the sampling distance from the gold mine. According to Table 3, public water supply (tap water) were below the maximum contamination limit (MCL) in water all through (0.001-0.0056 mg/L). However, river water in all sites exceeded the MCL (0.051- 0.092 mg/L) with the highest level in 10 km. In our study area, As concentrations above the MCL were reported by Rahman et al. (2011) in river water (0.22±0.01 mg/L) and by Rahman and Singh (2019) in surface water of 0.85 mg/L in wetland inlet and 0.02 mg/L in wetland outlet. Due to gold mining, elevated As concentrations were also reported in the Moira River in Ontario, in the surface water, groundwater and leakage from gold mining activity in Johannesburg, South Africa and in streams by the Tarkwa gold mine area of Ghana.

3.1.2 White rice

Table 3 below shows that As below the MCL of 0.2 mg/kg was only found in farmland rice (0.02 mg/kg) in 1 km from the gold mine. It was lower than the mean As concentration found in a rice consumption study in Bangkok, Thailand by (Abdul-Wahab and Marikar, 2012) (0.205 mg/kg) and that of rice grain (n= 411) estimated as an overall normal range between 0.082 and 0.202 mg/kg.

Table 3 Total concentration of As in environmental samples based on the sampling distance from the gold mine

Environmental samples	Standard limit (mg/L, mg/kg)	Sampling site based concentrations of total As (mg/L, mg/kg)		
		1km	2km	3km
1 Water	0.01 mg/L			
1.1 Public water supply		0.001	0.0012	0.0056
1.2 River water		*0.051	*0.082	*0.092
2 White rice	0.2 mg / kg			
2.1 Farmland rice		0.02	NF	NF
2.2 Rice from other sources		NF	NF	NF
3 Aquatic Foods	2 mg/kg			
3.1 Freshwater fish		0.120	0.170	0.240
3.2 Freshwater shrimp		0.150	0.577	0.284
3.3 Freshwater mussel		0.258	0.287	0.326
4 Vegetables (corn, green cabbage, Chinese cabbage and Thai Morning Glory)	2 mg/kg	NF	NF	NF
5 Fruits (papaya, dragon fruit, mango and pineapple)	2 mg/kg	NF	NF	NF

3.1.3 Freshwater fish, shrimp and mussels

According to Table 3 above, the concentrations of As in freshwater fish, shrimp and mussels (0.12-0.24, 0.15-0.58, and 0.26-0.33 mg/kg, respectively) throughout were below the Thai regulatory limit of 2 mg kg -1. Weerasiri et al. (2013) in their study reported the mean As values lower than the MCL in muscle and visceral organs of Nile tilapia; striped snakehead fish; and walking catfish: 0.28, 1.05; 0.45, 1.64; and 0.38, 1.12 (μg/g wet wt), respectively. Thathong et al. (2019) found the As concentrations in river trout below the Canadian guidelines (3.5 mg / kg) from lakes associated with historic gold mining. Fish is a profound source of total arsenic exposure, especially nontoxic organic arsenobetaine (AsB). As accumulation in fish and other aquatic organisms around the gold mine area can have negative impacts on human health. As contents in freshwater shrimp in our study supported the findings of [20] on inorganic arsenic in river prawn (0.014 mg/kg). However, high levels of total As (1.84–6.42 mg/kg wet weight (ww)) were found in shellfish by Intamat et al. (2016) in Map Ta Phut, Thailand, where AsB was found to be the major As species (45 % of total As).

3.1.4 Vegetables and fruits

As was not found in our fruit and vegetable samples (Table 3 above). However, in the study area found As concentrations below the MCL in many vegetables and fruits within 1 km area from the gold mine. Chotpantarat et al. (2015) found As concentration also below the MCL in vegetables <0.020-0.650 mg/kg adjoining an abandoned tin mine in southern Thailand. It is evident that heavy metals are easily gathered in the edible parts of leafy vegetables, as compared to grain or fruits (Pamonpol et al., 2019). Hence, animals are highly exposed to heavy metals when they consume these metal-rich plants. Our study results suggested that the vegetables and fruits of the study area are safe for consumption.

3.2 Human health risk assessment (HHRA) results

3.2.1 HHRA in water for daily and agricultural use

In the study population, HQ values greater than 1.0 were generally interpreted as a level of non-cancer risk, and a range of 1.0×10^{-6} to 1.0×10^{-4} (1 case of cancer in every one million to 1 case of cancer in every 10 thousand) was considered a cancer risk (CR).

Table 4 The exposure of sample population to As through dermal contact with water for daily and agricultural use

	ADD (mg/kg/day)		HQ		CR	
Public water supply exposure to As: 1 km						
Age group	Male	Female	Male	Female	Male	Female
18.0-34.9	2.13×10^{-7}	2.08×10^{-4}	7.1×10^{-4}	6.95×10^{-1}	3.2×10^{-7}	3.13×10^{-4}
35.0-64.9	2.1×10^{-7}	2.12×10^{-4}	7.01×10^{-4}	7.08×10^{-1}	3.16×10^{-7}	3.18×10^{-4}
5 km						
18.0-34.9	2.56×10^{-7}	2.50×10^{-7}	8.52×10^{-4}	8.34×10^{-4}	3.83×10^{-7}	3.75×10^{-7}
35.0-64.9	2.52×10^{-7}	2.54×10^{-7}	8.42×10^{-4}	8.49×10^{-4}	3.79×10^{-7}	3.82×10^{-7}
10 km						
18.0-34.9	1.19×10^{-6}	1.17×10^{-6}	3.98×10^{-3}	3.89×10^{-3}	1.79×10^{-6}	1.75×10^{-6}
35.0-64.9	1.18×10^{-6}	1.19×10^{-6}	3.93×10^{-3}	3.96×10^{-3}	1.77×10^{-6}	1.78×10^{-6}
River water exposure to As: 1 km						
18.0-34.9	1.09×10^{-5}	1.06×10^{-5}	3.62×10^{-2}	3.55×10^{-2}	1.63×10^{-5}	1.6×10^{-5}
35.0-64.9	1.07×10^{-5}	1.08×10^{-5}	3.58×10^{-2}	3.61×10^{-2}	1.61×10^{-5}	1.62×10^{-5}
5 km						
18.0-34.9	1.75×10^{-5}	1.71×10^{-5}	5.82×10^{-2}	5.7×10^{-2}	2.62×10^{-5}	2.57×10^{-5}
35.0^{-6}4.9	1.73×10^{-5}	1.74×10^{-5}	5.75×10^{-2}	5.8×10^{-2}	2.59×10^{-5}	2.61×10^{-5}
10 km						
18.0-34.9	1.96×10^{-5}	1.92×10^{-5}	6.53×10^{-2}	6.4×10^{-2}	2.94×10^{-5}	2.88×10^{-5}
35.0-64.9	1.94×10^{-5}	1.95×10^{-5}	6.45×10^{-2}	6.51×10^{-2}	2.9×10^{-5}	2.93×10^{-5}

Table 4 represents that males and females (18.0-34.9 years old) were highly exposed to As via public water within 10 and 1 km from the gold mine, respectively. The lowest exposure in public water was reported males (35.0-64.9 years) in 1 km and females (18.0-34.9 years) in 5 km. For river water use, all (18.0-34.9 years) were found to be highly exposed in 10 km location. HQ and CR values lower than the USEPA guidelines indicated that dermal exposure to As via water has no cancer risk.

3.2.2 HHRA in white rice

According to Table 5, 18.0-34.9 years old were exposed more than 35.0-64.9 years old in 1 km. HQ (12-12.29) and CR (5.4×10^{-3}-5.65×10^{-3}) found were above the USEPA guidelines. It indicated that about 5 to 6 people in 1000 will develop cancer every year as a result of daily As exposure through eating white rice.

Table 5 The exposure of sample population to As via white rice consumption

	ADD (mg/kg/day)		**HQ**		**CR**	
			1 km			
Age group	Male	Female	Male	Female	Male	Female
18.0-34.9	3.76×10^{-3}	3.69×10^{-3}	12.55	12.29	5.65×10^{-3}	5.53×10^{-3}
35.0-64.9	3.60×10^{-3}	3.63×10^{-3}	12	12.11	5.4×10^{-3}	5.45×10^{-3}

3.2.3 HHRA in freshwater fish

Table 6 below denotes that residents (35.0-64.9 years) in 10 km were highly exposed to As. The lowest exposure by freshwater fish consumption was in 1 km for respondents (18.0-34.9 years). Generally, HQ (5.26 -12.65) and CR (2.37×10^{-3}- 5.7×10^{-3}) were greater than the USEPA guidelines. It suggested that about 2 to 6 in 1,000 people are likely to develop yearly cancer due to daily As exposure to the freshwater fish consumption.

Table 6 The exposure of sample population to As through freshwater fish consumption

	ADD (mg/kg/day)		**HQ**		**CR**	
			1 km			
Age group	Male	Female	Male	Female	Male	Female
18.0-34.9	1.61×10^{-3}	1.58×10^{-3}	5.37	5.26	2.42×10^{-3}	2.37×10^{-3}
35.0-64.9	1.88×10^{-3}	1.90×10^{-3}	6.27	6.33	2.82×10^{-3}	2.85×10^{-3}
			5 km			
18.0-34.9	2.23×10^{-3}	2.43×10^{-3}	7.61	7.45	3.43×10^{-3}	3.35×10^{-3}
35.0-64.9	2.67×10^{-3}	2.69×10^{-3}	8.89	8.97	4×10^{-3}	4.03×10^{-3}
			10 km			
18.0-34.9	3.22×10^{-3}	3.16×10^{-3}	10.75	10.52	4.84×10^{-3}	4.74×10^{-3}
35.0-64.9	3.76×10^{-3}	3.8×10^{-3}	12.55	12.66	5.65×10^{-3}	5.7×10^{-3}

3.2.4 HHRA in freshwater shrimp and mussels

Table 7 presents that residents (18.0-34.9 years) in 5 km and 10 km were the most exposed to As by freshwater shrimp and mussel consumption, respectively. The lowest exposure was reported among all (35.0-64.9 years) within 1 km. HQ > 1 (male: female=1.47:1.44 for shrimp and all: 1.43-3.48 for mussel consumption) in 5 and 10 km, respectively. It suggested that people (18.0-34.9 years) living in these areas are subject to a non-cancer health risk.

Table 7 The exposure of sample population to As through freshwater shrimp and mussel consumption

	ADD (mg/kg/day)		**HQ**		**CR**	
Freshwater shrimp						
			1 km			
Age group	Male	Female	Male	Female	Male	Female
18.0-34.9	1.15×10^{-4}	1.12×10^{-4}	0.38	0.37	1.72×10^{-4}	1.68×10^{-4}
35.0-64.9	6.79×10^{-5}	6.85×10^{-5}	0.23	0.23	1.02×10^{-4}	1.03×10^{-4}
			5 km			
18.0-34.9	4.40×10^{-4}	4.31×10^{-4}	1.47	1.44	6.61×10^{-4}	6.47×10^{-4}
35.0-64.9	2.61×10^{-4}	2.63×10^{-4}	0.87	0.88	3.92×10^{-4}	3.95×10^{-4}
			10 km			
18.0-34.9	2.17×10^{-4}	2.12×10^{-4}	0.72	0.71	3.25×10^{-4}	3.18×10^{-4}
35.0-64.9	1.28×10^{-4}	1.3×10^{-4}	0.43	0.43	1.93×10^{-4}	1.94×10^{-4}
Freshwater mussels						
			1 km			
18.0-34.9	8.27×10^{-4}	8.1×10^{-4}	2.76	2.7	1.24×10^{-3}	1.21×10^{-3}
35.0-64.9	4.28×10^{-4}	4.32×10^{-4}	1.43	1.44	6.42×10^{-4}	6.48×10^{-4}
			5 km			
18.0-34.9	9.20×10^{-4}	9.01×10^{-4}	3.07	3	1.38×10^{-3}	1.35×10^{-3}
35.0-64.9	4.76×10^{-4}	4.8×10^{-4}	1.59	1.6	7.14×10^{-4}	7.2×10^{-4}
			10 km			
18.0-34.9	1.05×10^{-3}	1.02×10^{-3}	3.48	3.41	1.57×10^{-3}	1.53×10^{-3}
35.0-64.9	5.41×10^{-4}	5.46×10^{-4}	1.8	1.82	8.11×10^{-4}	8.18×10^{-4}

HQ < 1 found in rest of the population can be ignored as a level of health concerns. CR values for shrimp (1.02×10^{-4}- 6.61×10^{-4}) by all and mussel consumption (6.42×10^{-4}- 8.18×10^{-4}) by 35.0-64.9 year olds below the US EPA guidelines suggested that the study population does not present a cancer risk through shrimp consumption, but mussel consumption is associated with cancer in the area mentioned above. However, CR values (1.21×10^{-3} - 1.57×10^{-3}) above the guidelines found in the study areas recommended that the individuals aged 18.0-34.9 years from the study area possess a cancer risk via shrimp and mussel consumption.

4 Conclusion

The aim of this study was to assess adult Loei residents' health hazards of arsenic (As) exposure around an abandoned gold mine. The results of the study revealed that residents around a dormant gold mine in Khao Luang sub-district of Wang Saphung district are at risk of developing non-cancerous diseases and cancer because of As intake which is possible through consumption of food but not through skin contact with water. Given that, the risk estimates predicted that the sample population would spend its lifetime (70 years) being consistently exposed to yearly concentrations of total As in water via dermal contact and in food via ingestion. The assumption could generate an overestimation of the prospective health risk if the As levels in the aforementioned sources decline. Despite, the findings could be a reference for the future studies on health risk assessment in the study area. Therefore, further research in the study area is recommended to investigate diseases associated with exposure to As, including inhalation routes of exposure in residents.

Declaration of competing interest

The authors declare no known competing interests that could have influenced the work reported in this paper.

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