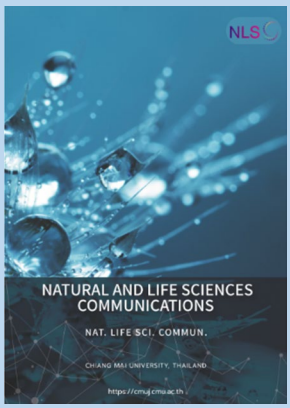
Research article



Editor:
Sirasit Srinuanpan
Chiang Mai University, Thailand

Article history:
Received: August 20, 2024;
Revised: November 14, 2024;
Accepted: November 26, 2024;
Online First: December 3, 2024
https://doi.org/10.12982/NLSC.2025.013

Corresponding author:
Patsiri Srivieng,
E-mail: patsiri.s@fph.tu.ac.th

Probabilistic Health Risk Assessment of Heavy Metals in People Living Near the Mine-Closure in Tak Province

Chaiwat Phadermrod and Patsiri Srivieng*

Faculty of Public Health, Thammasat University, Lampang 52190, Thailand.

ABSTRACT

Heavy metals including lead (Pb), zinc (Zn), and cadmium (Cd) can damage the kidney, liver, brain, lungs, blood composition, and other vital organs. As a result, their toxicity, especially when contaminated in food, water, and soil, can be harmful to human health. This study evaluated the risk of adverse health effects to residents near closed zinc mines in Tak Province, Thailand. Data was collected from three subdistrict sites and analyzed for probable health risk. Scenario pathways were oral and dermal contact of heavy metals; including Pb, Zn, and Cd, in four age groups with average daily dose and hazard quantification; hazard index (HI); and cancer risk (CR) considered. Results were that carcinogen risk quantification exceeded the recommended limit (CR $\leq 10^{-6}$) in all scenarios, and the hazard index for non-carcinogenic risk was below the acceptable level (HQ ≤ 1), in which Cd dominated for all categories. These findings suggest that all medias and food products should be appropriately monitored, especially with carcinogenic surveillance, to mitigate health effects on residents.

Keywords: Health risk assessment, Cancer risk, Hazard index, Heavy metals

Funding: The authors are grateful for the research funding provided by Faculty of Public Health, Thammasat University, Thailand.

Citation: Phadermrod, C. and Srivieng, P. 2025. Probabilistic health risk assessment of heavy metals in people living near the mine-closure in Tak province. Natural and Life Sciences Communications. 24(1): e2025013.

INTRODUCTION

The largest zinc (Zn)-containing area which was developed into a Zn mine is in the vicinity of Doi Pha Daeng, Mae Sot District, Tak Province (Tothirakul and Puangsawai, 2009). Heavy metals were dispersed and contaminated as a result of stripping in deposit-ore areas caused by various activities including mining and agriculture. The zinc in that area exhibited collocation with lead (Pb) and cadmium (Cd) minerals.

Since January 2004, news of Cd contamination in Pa de and Mae Tao mai village (Provincial Office of Natural Resources and Environment Tak, 2004) had been widely reported in the media. A significant deal of panic had been induced in society, which has been detrimental to Thailand's rice export levels. It has long been recognized that there was a Cd problem in this area. The Cd was absorbed into the soil, where it may have also affected the ground water (Thunyawatcharakul and Chotpantarat, 2018). As a means of supporting the recovery of people who were exposed to cadmium contamination, the Public Support Welfare Fund was established (Inthawan and Chunnual, 2017).

A certain group of elements commonly known as heavy metals are potentially very harmful to living matter. Both the soil and the water are potential entry points for heavy metals into the ecosystem. It builds up in food chains, as well. Contamination occurs as it enters the body by water or through aquatic creatures, and affects plants and animals normally used for human consumption. Heavy metals were absorbed through bodily pathways via consumption and exposure to other media, such as exposure to lead, according to this study. Lead was absorbed by the body and attached itself to the red blood cells in the circulatory system. It permeated the body's tissues and built up in the bone, with a half-life of around 20-30 years (Wannaprasat, 2011). The excretion of cadmium through the kidneys was less than the absorption (10%), leading to accumulations in the liver and kidneys (Siriwarasai and Kaocharoen, 2002). It has been reported that heavy metals such as cadmium, mercury (Hg) and especially lead were found in large quantities in breast milk (Abadin et al., 1997). Groundwater had increased concentrations of related metals such as Pb, arsenic (As), mercury (Hg), selenium (Se) and Cd, especially in locations near active mines, where the area is highly mineralized (Obasi and Akudinobi, 2018).

Health risk assessment is the study of possible adverse health effects that may occur from exposure to various contaminants and ways of mitigating the potential effects on local residents of extended exposure to such contaminants like the heavy metals from a mine. Probabilistic risk assessment is used to establish other variables and unknown parameters deterministically from all perspectives, while defining simulation parameters based on probability (Simpson et al., 2016). Health risk assessment was an essential instrument in determining the likelihood that individuals who have lived close to mining areas in earlier times were contaminated with heavy metals, despite the fact that the quantity of contamination from heavy metals such as Pb, Cd and Zn in the soil and surface water did not exceed the standards set by the Announcement of the National Environmental Board on the Water-Quality Index (2537) (PCD, 1994) or the Soil-Quality Index (2564) (PCD, 2021). There were questions on how potentially hazardous it was and whether it would have any effect on people's health. The health risk assessment included the following four major steps: 1. hazard identification, 2. dose response, 3. exposure assessment and 4. risk characterization (U.S. EPA, 2023).

Arsenic and lead exhibited unacceptable levels for both carcinogenic and non-carcinogenic contaminants in a study of abandoned mines in Yala Province (Pongkaset and Witthayawirasak, 2017). It was found that adolescents were exposed to hazardous levels of non-carcinogenic chemicals, mostly manganese (Mn). On the other hand, while it is among a group of chemicals known to cause cancer, its presence is still considered acceptable. Contaminants of interest consisted mostly of cadmium and chromium (Luo et al., 2020). It can be seen that in abandoned mines,

there are unacceptable risks when assessing health risks. In coal mining production, human health risk assessment via soil exposure of heavy metals was conducted in Pakistan. It was found that the contamination factors for zinc and cadmium were moderate in Gilgit-Baltistan and Baluchistan provinces. (Din et al., 2023). Hazard index of children who exposed to soil was exceeded the threshold limit in Hangu and Kurram district, Pakistan. Locals may be at chronic health risk due to higher hazard index values. Oral consumption was identified as the main exposure mechanism.(Din et al., 2024) The levels of potentially toxic element (PTE) in Turkey showed the results of Zn > Pb > Cd contamination with acceptable values in carcinogenic and non-carcinogenic risks. (Tokatlı et al., 2023; 2024). The sediment in the lake in Pakistan were found that PTE concentrations Cu and cadmium Cd exceed the guideline. (Muhammad et al., 2024). Also, it was found that water contaminated with Zn presented the lowest of < 0.01 for adults, However, children had a significantly greater risk since their HQ values were higher than those of adults. (Muhammad, 2023). As a result, this study provides assessment the public health concerns at the past mining sites in the Mae Tao and Mae Ku streams in the Mae Sot district. Whether mining operations have an effect on the health of those who live around it by exposing them through contact and ingestion.

MATERIAL AND METHODS

Study area

In the present study, Mae Sot District, Tak Province was the selected location, as shown in Figure 1. The Province of Tak is situated in the Western Region of Thailand. The area under study consists of communities situated along two streams (the Mae Tao Stream and Mae Ku Stream) located in the three sub-districts shown below. This area is expected to be affected by health threats:

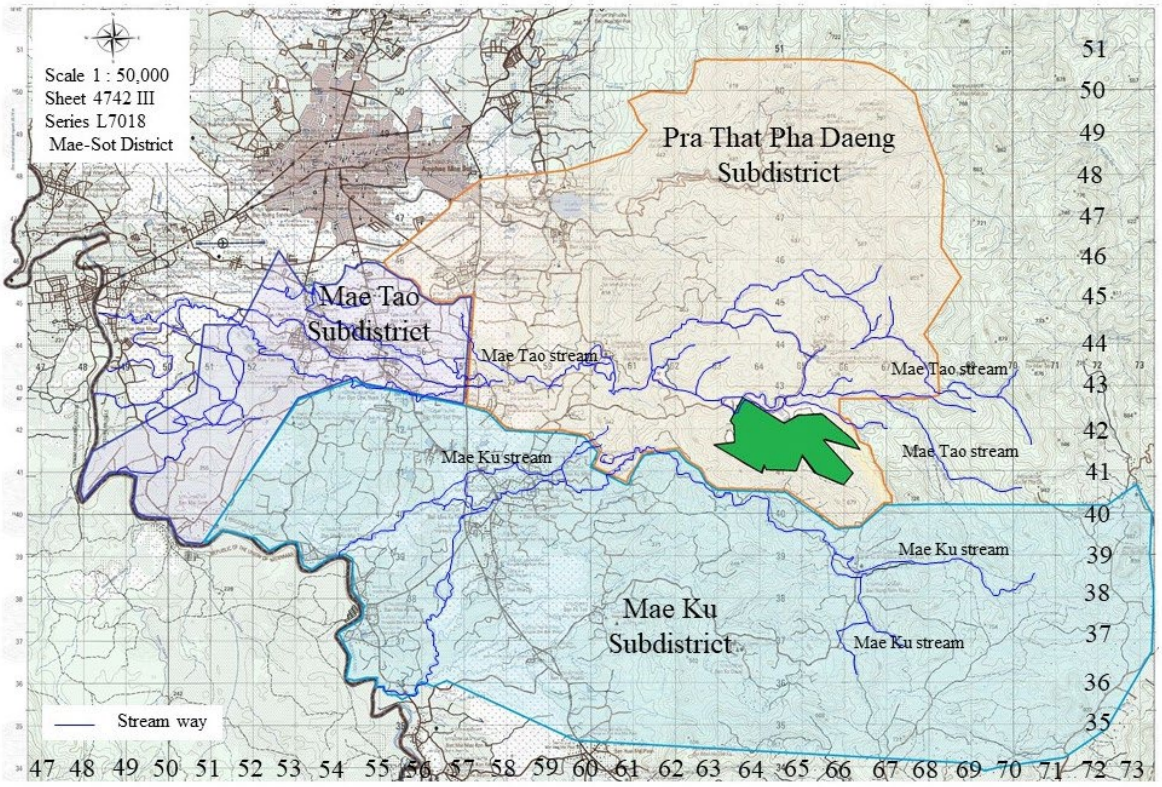


Figure 1. Three areas of interest areas in Mae-sot District, Tak Province, Thailand (The Royal Thai Survey Department, 2023).

1) The Phra That Pha Daeng Sub-district Administrative Organization, a total of 7 communities and total number of population is 5,113 people* (updated : 2024)

2) The Mae Tao Sub-district Municipality, a total of 6 communities and total number of population is 8,211 people* (updated : 2024)

3) The Mae Ku Sub-District, sub-divided into the following administrative areas and total number of population is 8,719 people* (updated: 2024):

3.1) The Mae Ku Sub-district Municipality, a total of 6 communities

3.2) The Mae Ku Sub-district Administrative Organization, a total of 6 communities

* Department of Health Service Support, Ministry of Public Health, Thailand (2024)

The majority of the people in the research area are wage workers and farmers. Cattle, buffalo, and sheep are the livestock raised in their daily farming activities, while their primary economic crops are corn, rice, soybeans and sugar cane. Both mines operate in two small watersheds: the Huai Mae Ku watershed, which spans 6,689 rai (10.66 km^2), and the Huai Mae Tao watershed, which covers 18,607 rai (29.74 km^2), as in Figure 2 (Natural Resources and Environmental Policy and Planning, 2013). Sampling area according to Post-Evaluation Report of the zinc mining project, 2013; surface water samples were collected using the grab sampling technique and were analyzed were analyzed of heavy metals by Flame Atomic Absorption Spectrophotometry. To collect soil, drilling technique was used in two different levels: topsoil level (0-30 cm.) and bottom soil level (50-100 cm.). The heavy metals were analyzed in the laboratory using the same analytical method is used as for surface water analysis. The surface water and soil sampling location were shown in Table 1

Figure 2. This current photo of the zinc mine project was taken in July, 2023.

Table 1. The location of water and soil sampling.

Surface Water Sampling*				Soil Sampling**			
Sub-district	No.	Location (UTM) Easting (m E)	Northing (m S)	Sub-district	No.	Location (UTM) Easting (m E)	Northing (m S)
Phra That Pha Daeng and Mae Tao[1]	1	467000	1842700	Phra That Pha Daeng	1	462700	1842800
	2	466400	1841000		2	463000	1841750
	3	465900	1842300		3	464100	1842450
	4	465600	1842350		4	465100	1842600
	5	464900	1841800		5	465300	1842500
	6	465400	1841400		6	468700	1842400
	7	464700	1842400		7	468900	1842100
	8	464400	1842200		8	462000	1841200
	9	464390	1842900		9	463000	1842100
	10	464375	1842800		10	462000	1841700
	11	463200	1842750		11	463200	1841800
	12	460450	1843200	Mae Tao	12	454000	1842400
	13	459050	1842800		13	452500	1844600
	14	458400	1842750	Mae Ku	14	464200	1840200
	15	457300	1843200		15	464100	1840100
Mae Ku	16	466400	1838900		16	466240	1841000
	17	463300	1840200		17	466200	1839900
	18	462609	1840700		18	466000	1839800
	19	459450	1840550				

Source: *Environmental Monitoring Report after the mining activities finishing in the 5th year. (as received from the Provincial Office of Natural Resources and Environment Tak., 2022)

**Post-Evaluation Report of the zinc mining project (as received from the Office of Natural Resources and Environmental Policy and Planning, 2013)

[1]Since Huai Mae Tao is a stream that flows continuously from Phra That Pha Daeng Subdistrict to Mae Tao Subdistrict. Therefore, the sampling points of surface water in Mae Tao Creek were used for both sub-districts.

Exposure assessment

This research study on health risk assessment took place after the end of mining activities. It took the form of a case study of a mine operating in the Mae Tao watershed, Mae Sot District, Tak Province. The researcher used the health risk assessment framework for application in the area where operations came to an end. The study can be summarized as illustrated in Figure 3.

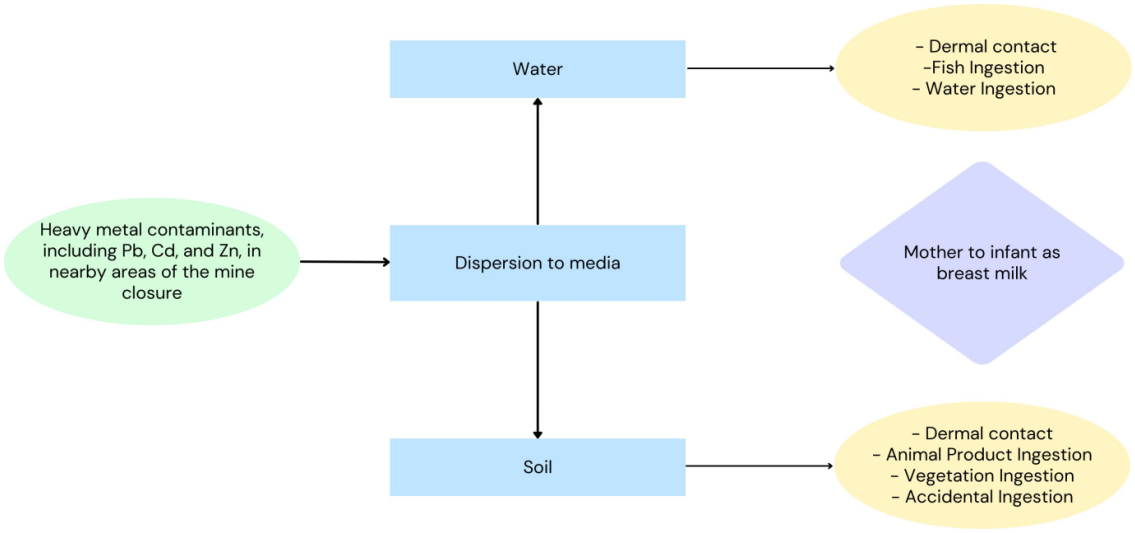


Figure 3. Conceptual framework of the research.

An assessment of the health risks for the residents of the two communities — the Mae Tao and Mae Ku streams — took place after the mining operations were completed in the three sub-districts. This study made use of secondary data regarding the concentration of heavy metals (Table 2), which included lead, cadmium and zinc (as adapted from the Provincial Office of Natural Resources and Environment, Tak). Table 2 shows demographic data of people living – infants (0-1 year), toddlers (>1-5 years), children (>5-15 years) and adults (>15 years), while data in Table 3 (as received from the Health-Promoting Hospital) were put into the model to estimate the risk from carcinogenic and non-carcinogenic chemicals that cause serious risk of adverse health effects, as indicated by the U.S. Environmental Protection Agency (EPA). Ingestion and contact were the two potential pathways of exposure to pollutants. The U.S. EPA advised using the total concentrations and dividing the total exposure by the average time (AT) to obtain a dosage exposure per unit time for determining exposure concentration (EC) values. Life expectancy was based on a Thai life expectancy of 77.77 years (the World Bank, 2019), while the AT for carcinogenic health effects, which varies by country, would be the 30-year period that the U.S. EPA recommended for non-carcinogenic effects.

Table 2. Average heavy metals in surface water and soil.

Sub-district	Average heavy metal concentrations as soluble in surface water (mg/kg)*			Average heavy metal concentrations in soil (mg/kg)**		
	Zn	Cd	Pb	Zn	Cd	Pb
Phra That Pha Daeng	0.01	0.0001	0.0005	1,540.18	27.67	128.18
Mae Tao	0.01	0.0001	0.0005	440.00	1.00	136.90
Mae Ku	0.01	0.0001	0.0005	31.50	1.00	7.50

Source: * Environmental Monitoring Report after mining activities were finished in the 5th year (as received from the Provincial Office of Natural Resources and Environment Tak, 2022)
** Post-Evaluation Report of the zinc mining project (as received from the Office of Natural Resources and Environmental Policy and Planning, 2013)

Table 3. Individuals' average height, weight, and body surface area in three subdistricts.

Sub-district		Phra That Pha Daeng*	Mae Tao**	Mae Ku***
Average weight (kg)	Infant	8.69	8.04	7.82
	Toddler	14.10	16.73	14.29
	Child	34.60	31.39	26.94
	Adult	54.71	59.56	56.68
Average height (cm)	Infant	65.29	74.24	73.89
	Toddler	93.05	97.60	96.26
	Child	136.11	131.84	155.00
	Adult	154.58	159.50	172.00
Average body surface area (cm^2)	Infant	3,726.25	3,957.04	3,896.45
	Toddler	5,916.80	6,586.50	6,098.71
	Child	11,416.38	10,704.34	11,278.88
	Adult	15,211.94	16,133.15	16,684.83

Source: * JHCIS of Phra That Pha Daeng Sub-District Health-Promoting Hospital, 2023
** JHCIS of Mae Tao Sub-district Health-Promoting Hospital, 2023
*** JHCIS of Mae Ku Sub-district Health-Promoting Hospital, 2023

Three of the heavy metals were dominant toxic pollutants, namely Cd, Pb and Zn. The average daily-intake values were calculated as 4 groups of population, infants (<1yr), toddler (1-5 yrs), child (6-15 yrs) and adult (>15 yrs). Ingestion and skin contact with soil and water were the primary routes of exposure, for which Table 4 illustrates the various exposure scenarios for each group. The intake equations 1 and 2 were supplied by the U.S. EPA (Office of Solid Waste, 2005). Although the majority of people are adults, heavy metal exposure can have adverse health effects more easily on vulnerable age groups like infants and toddlers. Only infants, in particular, could be exposed to the harmful substances through their mothers' milk. The population intake calculations are as follows below:

For ingestion,

$$I_{ing} = \frac{I*IR*EF*ED*CF}{BW*AT*365} \quad (1)$$

For dermal contact,

$$I_{dermal} = \frac{DAevent*EF*ED*SA}{BW*AT*365} \quad (2)$$

Where

I_{ing}= intake of ingestion dose (mg/kg of body weight per day as shown in Table 4)

I = total daily intake of chemicals through ingestion (mg/kg)

IR =Ingestion Rate (g/day/person) shown in Table 5

EF = Exposure Frequency (350 days/yr from (Office of Solid Waste, 2005))

ED = Exposure Duration (30 years (Office of Solid Waste, 2005))

BW = Body Weight (kg)

AT = Averaging Time (30 years for non-carcinogenic risk (Office of Solid Waste, 2005), 77.77 years for carcinogenic risk)

365 = conversion factor (days/yr)

I_{dermal} = Intake of contact dose (mg/kg of body weight per day)

DAevent = Dermally absorbed dose per event (mg/cm^2-event)

SA = Skin surface area subject to contact (cm^2)

Table 4. Exposure route for locals living close to the closing mining (as received from Srivieng et al., 2021).

Scenarios	Contaminant exposure						
	Soil	Water	Animal products	Vegetation products	Fish	Natural water	Mother's milk
Infant	dc, ai	dc	ii	ii	ii	ii	ii
Toddler	dc, ai	dc, ai	ii	ii	ii	ii	-
Child	dc, ai	dc, ai	ii	ii	ii	ii	-
Adult	dc, ai	dc, ai	ii	ii	ii	ii	-

Note: dc is dermal contact; ai is accidental ingestion; ii is intentional ingestion

Table 5 The consumption rate of all groups.

Parameter	Infant	Toddler	Child	Adult	Reference
soil (kg/day)	0.0002	0.0002	0.0002	0.0001	U.S.EPA[1]
fruit and vegetables (kg/day)	0.0138	0.0138	0.0342	0.0514	MOAC[2]
beef (kg/day)	0.0080	0.0080	0.0197	0.0247	MOAC[2]
pork (kg/day)	0.0080	0.0080	0.0197	0.0247	MOAC[2]
poultry (kg/day)	0.0080	0.0080	0.0197	0.0247	MOAC[2]
eggs (kg/day)	0.0189	0.0189	0.0478	0.0399	MOAC[2]
milk (kg/day)	0.0219	0.0219	0.0587	0.1310	MOAC[2]
fish (kg/day)	0.0125	0.0125	0.0444	0.0936	MOAC[2]

Note: [1]Office of Solid Waste, U.S. EPA, 2005
[2]Ministry of Agriculture and Cooperatives, 2011

To estimate a spatial health risk assessment, cancer-risk (CR) and hazard-quotient (HQ) models were conducted. The toxicity indices were employed to predict whether there would be any risk to the general population in the study area using data that was provided for this study. These predictions would quantify both carcinogenic and non-carcinogenic effects by using Equations 3-4. Slope factor (SF), a key hazardous indicator, was used to evaluate the potential for carcinogens, which, together with the reference dose (RfD), were used to determine the probability of non-carcinogenic effects, as shown in Table 6.

$$CR = I_{total} * SF \quad (3)$$

$$HQ = \frac{I_{total}}{RfD} \quad (4)$$

Where

CR = cancer risk (non-dimensional)

I_{total} = Total intake (sum of intake of digestion and contact dose) (mg/kg of body weight per day)

SF = slope factor (kg.day/mg)

HQ = hazard quotient (non-dimensional)

RfD = reference dose (mg/kg.day)

The total cancer risk (TCR) for all contaminants and exposure routes should be less than 10-6 to be considered acceptable. If CR value 10^{-6} indicates acceptable risk (U.S. EPA, 1991), it is important to highlight that the individual heavy metal concentration does not present a concern to the exposure group. In addition to HQ, the value should be less than 1 (U.S. EPA, 1991), for the individual heavy metal as well as the sum of HQ as hazard index (HI) for aggregate of all heavy metals. The formulation of TCR and HQ has presented in the Equations 5-6.

$$TCR = \Sigma CR \quad (5)$$

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

Where

TCR = total of cancer risk (non-dimensional)
HI = total of HQ (unitless)

Table 6. SFs and RfDs of the heavy metals.

Heavy metal	Cancer group (IARC, 2022)	Target	SF [(mg/kg/day)$^{-1}$]	RfD (mg/k/day)
Cd	Carcinogenic to humans	Urinary[a]	3.80E-01[a]	3.00E-04[a]
Pb	Probably carcinogenic to humans	Stomach[b]	8.50E-03[b]	n/a
Zn	N/A	Immune, Hematologic[c]	n/a	3.00E-01[c]

Note : [a]IRIS assessment : Cadmium, 1989 https://iris.epa.gov/ChemicalLanding/&substance_nmbr=141

[b] OEHHA : Lead and Lead compounds, 2009 https://oehha.ca.gov/chemicals/lead-and-lead-compounds

[c]IRIS assessment : Zinc and Compounds, 2005 https://iris.epa.gov/ChemicalLanding/&substance_nmbr=426

*Since dermal Slope Factors have not been determined, 100% of the oral SF was assumed for the dermal SF. (Srivieng et al.2021, U.S.EPA., 1992)

Ethical considerations

This study was approved by the Human Research Ethics Committee of Tak Provincial Public Health Office. The approval number is 010/2566, which was approved on 01/06/2023.

RESULTS

Quantification of population exposure

People who lived near the mine in the three sub-districts had been concerned about toxic substances since the mine closed in 2016. Cd and Pb, two potentially hazardous heavy metals, have half-lives of 15 to 1,100, and 700 years in soil, respectively (Laidlaw et al., 2005; FAO, 2022). The soil and water concentrations as shown in the Table 1 were above the Thai standard. The four population groups were exposed to pollutants through contact and ingestion. The ingestion pathways were calculated from the intake of pollutants through the soil, vegetation, beef and dairy, pork, chicken and eggs, fish and drinking water. The dermal contact was estimated using both incidental and intentional data exposed to water and soil.

Figure 4 provides the comparison of the calculation using Equations1-2, including the concentrations of indirect exposure in each sub-district. The outcomes varied according to the chemical concentration in each area. Phra That Pa Daeng experienced the greatest intakes as it is located along the initial waterway path through which many of the contaminants can be dispersed. Regardless of the location, the largest intakes occurred in Phra That Pa Daeng, because it was the site of the first stream where the pollutants could migrate at a considerable rate. Cd as non-carcinogenic intake in three subdistricts ranged from 4.29E-05 to 1.40E-01 mg/kg-day, were found to be the most exposed to residents, particularly in the adult, Phra That Pa Daeng sub-district with the route of ingestion as of at 1.40E-01 mg/kg-day. For Zn as non-carcinogenic intake ranged from 5.86E-04 to 1.83E-01 mg/kg-day. In Phra That Pa Daeng sub-district, zinc also found to be the most exposed to residents, especially in child at 7.35E-03 mg/kg-day. The highest carcinogenic Pb intake found that adult in Mae Ku sub-district by ingestion at 7.35E-03 mg/kg-day, with total intake in three subdistricts ranging from 5.28E-05 to 7.13E-03 mg/kg-day. Total carcinogenic Cd intake found ranging from 8.74E-06 to 1.60E-03 mg/kg-day in Phra That Pa Daeng subdistrict, was the highest exposure to residents, especially in adult as shown in Table S-1.

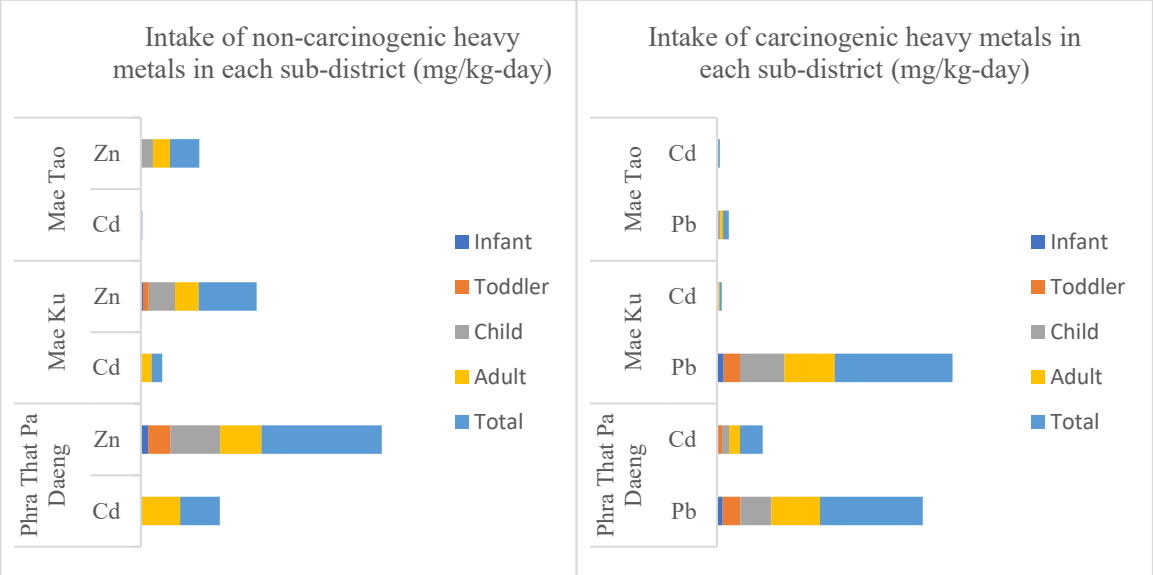


Figure 4. Comparison of contaminant intake levels for each scenario in the 3 sub-districts.

As consuming was a necessary daily activity, ingestion became the main source of exposure for the residents in every scenario. Since adults could be exposed to pollutants by both ingestion and contact, the results indicated that their intake values constituted the majority of the total intake. Comparing the consumption quantity to the other scenarios, it is also significant.

Health risk assessment

Contaminants could be ingested from contact with soil or water in scenarios involving infants, toddlers, children and adults. The metallic elements Pb, Cd and Zn were the pollutants of concern. According to the International Agency for Research on Cancer, both Pb and Cd have carcinogenic effects on human health (IARC, 2023). However, Cd also has non-carcinogenic effects. Zn, however, did not show any carcinogenic effects. The contaminants were most likely in the form of heavy metals.

According to the results of the TCR assessment (Table 7), the risk values exceeded the acceptable level (E-06). The highest value was 3.34E-03 for Phra That Pha Daeng, followed by 2.77E-04 and 8.21E-05 for Mae Ku and Mae Tao, respectively. None of the individual contaminants' CR was acceptable. Cadmium was the main pollutant since, it was a by-product of this zinc mine. Additionally, when assessing TCR by age group, the following is total heavy metals, ordered according to the group: toddler >adult >child>infant in all sub-district areas.

Nevertheless, the HI values were above the allowable threshold (<1). Phra That Pha Daeng had the greatest value at 1.35E-01, followed by Mae Ku and Mae Tao at 1.31E-01 and 1.05E-02, respectively (Table 7). Additionally, both of the individual pollutants' HQs were acceptable. Furthermore, when evaluating HI by age group, the total heavy metals are listed below, arranged by group: In the cases of Mae Ku and Mae Tao, adult > child> toddler> infant. On the other hand, Phra That Pa Daeng found that infant> toddler>child>adult, arranged by age group.

Table 7. Unit risk of carcinogenic and non-carcinogenic effects in three sub districts (dimensionless).

Non-carcinogenic risk	Phra That Pa Daeng			Mae Ku			Mae Tao		
	Cd	Zn	HI	Cd	Zn	HI	Cd	Zn	HI
Infant	6.60E-02	6.56E-05	6.61E-02	1.43E-04	2.81E-05	1.71E-04	7.70E-05	1.95E-06	7.89E-05
Toddler	4.06E-02	4.04E-05	4.06E-02	3.43E-04	6.74E-05	4.10E-04	1.85E-04	4.70E-06	1.90E-04
Chlid	1.72E-02	4.35E-04	1.76E-02	1.10E-03	3.23E-04	1.42E-03	5.56E-04	1.40E-04	6.95E-04
Adult	1.08E-02	2.20E-04	1.10E-02	1.44E-03	4.17E-04	1.85E-03	9.32E-03	2.10E-04	9.53E-03
Total	1.35E-01	7.62E-04	1.35E-01	3.02E-03	8.35E-04	3.86E-03	1.01E-02	3.57E-04	1.05E-02
Carcinogenic risk	**Phra That Pa Daeng**			**Mae Ku**			**Mae Tao**		
	Cd	Pb	TCR	Cd	Pb	TCR	Cd	Pb	TCR
Infant	3.75E-04*	2.11E-06*	3.77E-04*	6.17E-06*	8.42E-06*	1.46E-05*	3.32E-06*	4.49E-07	3.77E-06*
Toddler	1.15E-03*	6.49E-06*	1.16E-03*	1.48E-05*	2.02E-05*	3.50E-05*	7.98E-06*	1.08E-06*	9.06E-06*
Chlid	8.77E-04*	4.86E-06*	8.82E-04*	4.74E-05*	5.56E-05*	1.03E-04*	2.4E-05*	2.5E-06*	2.65E-05*
Adult	9.17E-04*	4.96E-06*	9.22E-04*	6.19E-05*	6.25E-05*	1.24E-04*	3.95E-05*	3.27E-06*	4.28E-05*
Total	3.32E-03*	1.84E-05*	3.34E-03*	1.30E-04*	1.47E-04*	2.77E-04*	7.48E-05*	7.30E-06*	8.21E-05*

Note: * unacceptable level for carcinogenic risk (<10-6)

DISCUSSION

The relationship between human exposure to heavy metals and health effects might be explored using an aggregate health risk assessment in the surrounding area of the mining site, which has been closed for the past 5 years. It has been reported that residents who live near the closure mine had been affected from the mine activities before the mine started. (Inthawan and Chunnual, 2017). In the study showed that, people who lived close to the mine closure may have incurred adverse health effects from their own food production, so that the main route was most likely ingestion (Qu et al., 2012). Adults seemed to make up the most exposed group, followed by children, because they frequently ate and contact in soil and water that took place within the contaminated area. This scenario poses significant hazards to the health of both children and adults (Bineshpour et al., 2021).

As based on the average daily intake by ingestion and skin contact, a CR assessment indicated that residents were exposed to Cd and Pb above the acceptable level (10^{-6}) in the three sub-districts, even though the concentrations of contaminants in these media did not exceed the standard. This indication was similar to the findings of the risk assessment conducted on workers at incinerators, which showed that while the concentration of air pollutants was below the limit, the CR of heavy metals were above the reference level (Srivieng et al., 2022).

CR by age group, it was discovered that toddlers were at the most risk because, while exposure can occur through many pathways, the body weight for the divisor in Eq. 1-2 was lower than that of the child and adult groups. In Table S-2 showed that ingestion pathways exceeded the acceptable level in all scenarios. In the present research, cadmium was shown to be the most significant contributor, at levels of mostly 90%. This finding contrasted with the results of a study conducted in China. In the Chinese study, soil samples were collected, from which it was found that As > Pb > Cd > Ni. It was concluded that these heavy metals had been absorbed mainly by ingestion (Huang et al., 2017). Additionally, it was discovered in a tin mine in southern Thailand that Pb and As significantly exceeded ($\sim 10^{-3}$) in ingestion pathway of cancer risk assessment in children, similar to what was found at Phra That Pa Daeng (Pongkaset and Witthayawirasak, 2017). In China, As and copper (Cu) exposure levels were found to be in excess of the recommended level for the assessment of CR in lead and zinc mines. Children formed the group that was most

vulnerable to these elements and accordingly were most likely to develop adverse health effects (Kan et al., 2021).

According to HQ's findings, three areas were considered acceptable (<1). The presence of Cd seemed to be approaching to the excessive levels, leading to a variety of adverse health effects. In a gold mine in Myanmar, it was found that a gold miner can be exposed to As, Cd, Hg and Pb via the dermal route from the soil. Although the HI were below the reference level, the CR was found to be greater than the acceptable level (Wongsasuluk et al., 2021). For the concentration of Zn, found that was high, it might be were mainly from the use of chemical fertilizers and pesticides (Zhang et al., 2020). By contrast, levels of As and Pb in tin mines were found to be in excess of non-CR assessment values (Pongkaset and Witthayawirasak, 2017). Similarly in China, the HQ of zinc and lead mine were above acceptable level in levels of As and Cu (Kan et al., 2021). The lead-zinc mine tailings study conducted in Iran also discovered that the HI for Pb, Zn, and Cd were above unity, indicating a non-carcinogenic risk exposure for adults and children similarly (Akhavan and Golchin, 2023), also found similar results as the abandoned gold mine in Ghana (Mensah et al., 2021). The research carried out by Rehman et al. (2018), in contrast to our study, which revealed that Pb presented an insignificant risk for cancer, the local population was not expected to be at risk for cancer from exposure to Pb concentrations in either soil or surface water. In general, HI and CR of all scenarios were consistent. However, most remediation methods prioritize on lowering the levels of heavy metals in soil and the food chain in order to minimize of adverse health effects. To prevent an excessive buildup of heavy metals in the body, it is advised that residents of this area should stay away from consuming large amounts of these products. (Orisakwe et al., 2012; Sultana et al., 2016; Rai et al., 2019).

CONCLUSION

Since the contaminants were harmful and had prolonged half-lives, monitoring was still necessary, despite the fact that the zinc mine had been closed for five years. The risk assessment demonstrated that, because the concentration levels of the three chemicals in the soil and surface water were below the Thai standards, the CR findings have been deemed unacceptable (10^{-6}) in all sites for the presence of toxic chemicals. This unacceptable result might be the result of basing the model on daily consumption, even though different individuals might not receive the same dose each day. In order to keep track of the pollutant concentration for each chemical, a monitoring measure had to be considered for soil and water. If the safety of foods containing heavy metals could be evaluated for plant and animal produce from these areas, such a situation would be ideal. The vulnerable population, which includes infants, toddlers and the elderly, should be under the observation of the health authorities. It could be noted from the model findings that, rather than suggesting that it is potentially harmful to carry out some activities in this area, the carcinogen excess risk levels should be taken into consideration to mitigate or to lower their multi-route exposure channels to contaminants for those who are in vulnerable groups.

This study used a U.S.EPA equation to determine the HRA which was calculated using the default values from the U.S. federal government, the U.S. EPA, or earlier research because some factors were unavailable in Thailand. Additionally, since the HRA results were used to represent the general population in the region of interest, there may be some factors that we employed as assumptions and are not inevitably accurate for all local residents.

ACKNOWLEDGEMENTS

The author gratefully acknowledges the financial support provided by the Faculty of Public Health, Thammasat University contact no. 2/2566

AUTHOR CONTRIBUTIONS

Chaiwat Phadermrod assisted in survey development, coordinated and conducted data collection, and wrote the manuscript. Patsiri Srivieng prepared the core idea of the research, conducted data collection and data analyses, and wrote the manuscript. All authors have read and approved of the final manuscript.

CONFLICT OF INTEREST

The authors declare that they hold no competing interests.

REFERENCES

Abadin, H. G., Hibbs, B. F., and Pohl, H. R. 1997. Breast-feeding exposure of infants to cadmium, lead, and mercury: A public health viewpoint. Toxicology and Industrial Health. 13(4): 495-517.

Akhavan, A., and Golchin, A. 2023. Health risk assessment of lead-zinc mine tailing in Angoran, Zanjan, Iran. Environmental Quality Management. 33(3): 141-155.

Bineshpour, M., Payandeh, K., Nazarpour, A., and Sabzalipour, S. (2021). Assessment of human health risk and surface soil contamination by some toxic elements in Arak city, Iran. Journal of Advances in Environmental Health Research. 9(4): 321-332.

California Office of Environmental Health Hazard Assessment (OEHHA). 2009. Lead and Lead compounds. Retrieved 15 January 2024 from https://oehha.ca.gov/chemicals/lead-and-lead-compounds.

Din, I.U., Muhammad, S., and Rehman, I. 2023. Heavy metal(loid)s contaminations in soils of Pakistan: A review for the evaluation of human and ecological risks assessment and spatial distribution. Environmental Geochemistry Health. 45:1991–2012.

Din, I.U., Muhammad, S., Faisal, S., Rehman, I., and Ali, W. 2024. Heavy metal(loid)s contamination and ecotoxicological hazards in coal, dust, and soil adjacent to coal mining operations, Northwest Pakistan. Journal of Geochemical Exploration 256. 107332

Department of Health Service Support, Ministry of Public Health, Thailand. 2024. Information of Mae Sot, Tak. Retrieved 14 November 2024 from https://3doctor.hss.moph.go.th/main/rp_tambon?region=2&prov=NjM=&provn=4LiV4Liy4LiB&ampid=6306&ampn=4LmB4Lih4LmI4Liq4Lit4LiU

Food and Agriculture Organization of the United Nations (FAO). 2022. Code of practice for the prevention and reduction of cadmium contamination in cocoa beans. Retrieved 19 March 2024 from https://www.fao.org/fao-who-codexalimentarius/shproxy/en/?lnk=1&url=https%253A%252F%252Fworkspace.fao.org%252Fsites%252Fcodex%252FStandards%252FCXC%2B81-2022%252FCXC_081e.pdf

Huang, S., Li, Q., Yang, Y., Yuan, C., Ouyang, K., and You, P. 2017. Risk assessment of heavy metals in soils of a lead-zinc mining area in Hunan province (China). Kemija u industriji: Časopis kemičara i kemijskih inženjera Hrvatske, 66(3-4): 173-178.

International Agency for Research on Cancer (IARC). 2023. List of classifications by cancer sites with sufficient or limited evidence in humans IARC Monographs Volumes 1-132. International Agency for Research on Cancer. Retrieved 19 March 2024 from https://monographs.iarc.who.int/wp-content/uploads/2019/07/Classifications by_cancer_site.pdf

Inthawan, L. and Chunnual, N. 2017. Effects of impact management of cadmium contamination in Mae Taw sub – district, Mae Sod district, Tak province. Payap University Journal. 27(2): 115-132.

Java Health Center Information System (JHCIS) of Phra That Pha Daeng Sub-District Health-Promoting Hospital. 2023. Nutrition status in children and adults in Phra That Pha Daeng Sub-District.

Java Health Center Information System (JHCIS) of Mae Tao Sub-district Health-Promoting Hospital. 2023. Nutrition status in children and adults in Mae Tao Sub-District.

Java Health Center Information System (JHCIS) of Mae Ku Sub-district Health-Promoting Hospital. 2023. Nutrition status in children and adults in Mae Ku Sub-District.

Kan, X., Dong, Y., Feng, L., Zhou, M., and Hou H., 2021. Contamination and health risk assessment of heavy metals in China's lead–zinc mine tailings: A meta–analysis. Chemosphere. 267(128909).

Laidlaw, M. A., Mielke, H. W., Filippelli, G. M., Johnson, D. L., and Gonzales, C. R. 2005. Seasonality and children's blood lead levels: Developing a predictive model using climatic variables and blood lead data from Indianapolis, Indiana, Syracuse, New York, and New Orleans, Louisiana (USA). Environmental Health Perspectives. 113(6): 793-800.

Luo X., Ren, B., Hursthouse, A.S, Thacker, J. R. M., and Wang, Z. 2020. Soil from an abandoned manganese mining area (Hunan, China): Significance of health risk from potentially toxic element pollution and its spatial context. International Journal of Environmental Research and Public Health. 17(18): 6554.

Mensah, A. K., Marschner, B., Antoniadis, V., Stemn, E., Shaheen, S. M., and Rinklebe, J. 2021. Human health risk via soil ingestion of potentially toxic elements and remediation potential of native plants near an abandoned mine spoil in Ghana. Science of The Total Environment. 798: 149272.

Ministry of Agriculture and Cooperatives. 2011. Food consumption data of Thailand: The Agricultural Co-operative Federation of Thailand Publisher.

Muhammad, S. 2023. Evaluation of heavy metals in water and sediments, pollution, and risk indices of Naltar Lakes, Pakistan. Environmental Science and Pollution Research. 30: 28217–28226.

Muhammad, S., Zeb, A., Shaik, M. R., and Assal, M. E. 2024. Spatial distribution of potentially toxic elements pollution and ecotoxicological risk of sediments in the high-altitude lakes ecosystem. Physics and Chemistry of the Earth 135: 103655.

Natural Resources and Environmental Policy and Planning. 2013. Chapter 5. Post Environmental Evaluation Report of the zinc ming project. pp. 10-70.

Obasi, P. and Akudinobi, B. 2020. Potential health risk and levels of heavy metals in water resources of lead–zinc mining communities of Abakaliki, southeast Nigeria. Applied Water Science. 10(7): 1-23.

Office of Solid Waste and Emergency Response. 2005. Chapter 6: quantifying exposure. p.1-21. In Human Health Risk Assessment Protocol for Hazardous Waste Combustion Facilities. Cincinnati, Ohio: United State Environmental Protection Agency.

Orisakwe, O. E., Nduka, J. K., Amadi, C. N., Dike, D. O., and Bede, O. 2012. Heavy metals health risk assessment for population via consumption of food crops and fruits in Owerri, South Eastern, Nigeria. Chemistry Central Journal. 6: 1-7.

Pollution Control Department (PCD). 2021. Announcement of the National Environmental Board about Soil Quality Index. Retrieved 9 January 2024 from https://www.pcd.go.th/laws/25162

Pollution Control Department (PCD). 1994. Announcement of the National Environmental Board about Water Quality Index. Retrieved 9 January 2024 from https://www.pcd.go.th/laws/4168

Pongkaset, A. and Witthayawirasak, B. 2017. Lead and arsenic exposure from the environment among young children and health risk assessment at an abandoned mine in southern Thailand. Journal of Health Research. 30(4): 257–265.

Provincial Office of Natural Resources and Environment Tak. 2004. Report of the study of Cadmium Contamination in the Area of Huai MaeTao, Mae Sot district, Tak Province. P.73-74. Ministry of Natural Resources and Environment.

Provincial Office of Natural Resources and Environment Tak. 2022. Chapter 3 the implementation of mitigation and monitoring measures. p.57-72 In Report of Environmental Monitoring after the mining activities finishing in the 5th year.

Qu, C. S., Ma, Z.W., Yang, J., Liu, Y., Bi, J., and Huang, L. 2012. Human exposure pathways of heavy metals in a lead-zinc mining area, Jiangsu Province, China. PLoS One. 7(11): e46793.

Rai, P. K., Lee, S. S., Zhang, M., Tsang, Y. F., and Kim, K. H. 2019. Heavy metals in food crops: Health risks, fate, mechanisms, and management. Environment International, 125, 365-385.

Rehman, I., Ishaq, M., Ali, L., Khan, S., Ahmad, I., Din, I. U., and Ullah, H. 2018. Enrichment, spatial distribution of potential ecological and human health risk assessment via toxic metals in soil and surface water ingestion in the vicinity of Sewakht mines, district Chitral, Northern Pakistan. Ecotoxicology and Environmental Safety. 154: 127-136.

Royal Thai Survey Department, Ministry of Defense. 2023. Topographic map of Mae Sot District, Tak Province, Sheet 4742 III, Series L7018. Thailand.

Simpson, S., Council, G., Ijaz, T., Covert, D., and Teaf, C. 2016. Soil cleanup goal for dioxin using probabilistic risk assessment techniques. Soil and Sediment Contamination: An International Journal. 25(7): 824-836.

Siriwarasai, J. and Kaocharoen, S. 2002. Heavy metal: Cadmium. Retrieved 20 April 2023 from https://www.rama.mahidol.ac.th/poisoncenter/sites/default/files/public/pdf/bulletin/bul2002/bul2002-n1.pdf Srivieng, P., Watchalayann, P., and Suadee, W. 2021. Cancer risk assessment around municipal solid waste incinerators. Environment Asia. 14: 102-16.

Srivieng, P., Watchalayann, P., and Suadee, W. 2022. Occupational health risk assessment of municipal solid waste incinerator workers. Science, Engineering and Health Studies. 16: 22050021.

Sultana, M. S., Rana, S., Yamazaki, S., Aono, T., and Yoshida, S. 2017. Health risk assessment for carcinogenic and non-carcinogenic heavy metal exposures from vegetables and fruits of Bangladesh. Cogent Environmental Science. 3(1): 1291107.

The World Bank. 2019. Life expectancy at birth, total (years) - Thailand. The World Bank. Retrieved 5 July 2023 from https://data.who.int/countries/764

Thunyawatcharakul, P. and Chotpantarat, S. 2018. Sorption characteristics of cadmium in a clay soil of Mae Ku creek, Tak Province, Thailand. IOP Conference Series: Earth and Environmental Science. 150: 012009.

Tokatlı, C., Ustaoğlu, F., Muhammad, S., and Yaksel, B. 2024. Spatiotemporal variations, source identification, and risk assessment of potentially toxic elements in the surface water of Felent stream impacted by the silver mine. Environmental Monitoring and Assessment. 196: 870.

Tokatlı C., Varol, M., Ustao, F., and Muhammad, S., 2023. Pollution characteristics, sources and health risks assessment of potentially hazardous elements in sediments of ten ponds in the Saros Bay region (Türkiye). Chemosphere. 340: 139977.

Tothirakul, W., and Puangsawai, T. 2009. Minerals in northern Thailand Office of Primary Industries and Mines Region 3, Department of Primary Industries and Mines, Ministry of Industry. Retrieved 15 April 2024 from https://www.dpim.go.th/ service/download? articleid=216&F=882

U.S. Environmental Protection Agency. 1989. Integrated risk information system (IRIS) assessments: Cadmium. Retrieved 15 January 2024 from https://iris.epa.gov/ChemicalLanding/&substance_nmbr=141

U.S. Environmental Protection Agency. 1991. Risk Assessment Guidance for Superfund. Volume I - Human Health Evaluation Manual (Part B, Development of Risk-based Preliminary Remediation Goals), Washington D.C.: Office of Emergency and Remedial Response, pp.1-6.

U.S. Environmental Protection Agency. 1992. Supplemental Guidance for Dermal Risk Assessment," Part E of Risk Assessment Guidance for Superfund, Human Health Evaluation Manual (Volume I). EPA/540/R/99/005.2004.: Chapter 4 toxicity management: Retrieved 15 January 2024 from https://www.epa.gov/sites/default/files/2015-09/documents/part_e_final_revision_10-03-07.pdf

U.S. Environmental Protection Agency. 2005. Integrated risk information system (IRIS) assessments: Zinc and Compounds Retrieved 15 January 2024 from https://iris.epa.gov/ChemicalLanding/&substance_nmbr=426

U.S. Environmental Protection Agency. 2023. Conducting a Human Health Risk Assessment. U.S. Environmental Protection Agency. Retrieved 15 January 2024 from https://www.epa.gov/risk/conducting-human-health-risk-assessment#tab-2

Wannaprasat, S. 2011. Antidote: lead poisoning. Retrieved 15 April 2024 from https://www.rama.mahidol.ac.th/poisoncenter/sites/default/files/public/ pdf/books/Antidote_book1-11_LEAD POISONING.pdf Wannaprasat S. 2011. Antidote: Lead poisoning. [accessed 15 April 2024] https://www.rama.mahidol.ac.th/poisoncenter/sites/default/files/public/pdf/books/Antidote_book1-11_LEAD POISONING.pdf

Wongsasuluk, P., Tun, A., Chotpantarat, S., and Siriwong, W. 2021. Related health risk assessment of exposure to arsenic and some heavy metals in gold mines in Banmauk Township, Myanmar. Scientific Reports. 11: 22843.

Zhang, Y., Long, H., Wang, M. Y., Li, Y., Ma, L., Chen, K., Zheng, Y., and Jiang, T., 2020. The hidden mechanism of chemical fertiliser overuse in rural China. Habitat International. 102: 102210.

OPEN access freely available online
Natural and Life Sciences Communications
Chiang Mai University, Thailand. https://cmuj.cmu.ac.th

Supplementary material

Equation for DA_{events}

Dermally Absorbed Dose per Event for water: The total absorbed dose that dissolves in the skin following exposure to contaminants during a swimming event is represented by the dermally absorbed dose per event. Equations S-1 are used to determine the dermally absorbed dosage per event for substances of *Risk Assessment Guidance for Superfund Volume 1: Human Health Evaluation Manual (Part E, Supplemental Guidance for Dermal Risk Assessment* (RAGS, Part E) (USEPA, 2004)

$$DA_{event} = 2FA.K_p.C_{dw}\sqrt{\frac{6\tau_{event}.t_{event}}{\pi}} \qquad \text{(S-1)}$$

where
DA_{event} = dermally absorbed dose per event (mg/cm^2-event)
FA = fraction absorbed water (dimensionless)
K_p = dermal permeability coefficient of chemical in water (cm/hr)
C_{dw} = chemical concentration in the dissolved water phase (mg/cm^3)
τ_{event} = lag time per event (hr/event)
t_{event} = duration of the swimming event (hr/event)

Dermally Absorbed Dose per Event for soil. The quantity of contaminants absorbed as a result of entering to contact with soils that contain COPC is represented by the dermally absorbed quantity per event. Equation S-2 taken from RAGS, Part E (USEPA, 2004) and below was used to determine the dermally absorbed dosage per event:

$$DA_{event} = Cs.10^{-6}.AF.ABS_d \qquad \text{(S-2)}$$

where
DA_{event} = dermally absorbed dose per event (mg/cm^2-event)
Cs = chemical concentration in soil (mg/kg)
10^{-6} = conversion factor (kg/mg)
AF = soil adherence factor (mg/cm^2-event)
ABS_d = dermal absorption fraction (dimensionless)

Table S-1. The intake of non-carcinogenic and carcinogenic heavy metals in each group (mg/kg).

Scenarios	Phra That Pa Daeng		Mae Ku		Mae Tao	
Non-carcinogens	Cd	Zn	Cd	Zn	Cd	Zn
Infant	4.80E-04	2.65E-02	4.29E-05	8.42E-03	2.31E-05	5.86E-04
Toddler	1.48E-03	8.17E-02	1.03E-04	2.02E-02	5.55E-05	1.41E-03
Child	2.67E-03	1.83E-01	3.30E-04	9.69E-02	1.67E-04	4.19E-02
Adult	1.40E-01	1.51E-01	3.85E-02	8.69E-02	2.80E-03	6.31E-02
Total	1.45E-01	4.42E-01	3.90E-02	2.12E-01	3.04E-03	1.07E-01
Scenarios	**Phra That Pa Daeng**		**Mae Ku**		**Mae Tao**	
Carcinogens	**Pb**	**Cd**	**Pb**	**Cd**	**Pb**	**Cd**
Infant	8.35E-04	1.82E-04	9.91E-04	1.62E-05	5.28E-05	8.74E-06
Toddler	2.57E-03	5.60E-04	2.38E-03	3.90E-05	1.27E-04	2.10E-05
Child	4.57E-03	1.01E-03	6.54E-03	1.25E-04	2.94E-04	6.31E-05
Adult	7.13E-03	1.60E-03	7.35E-03	1.63E-04	3.85E-04	1.04E-04
Total	1.51E-02	3.35E-03	1.73E-02	3.43E-04	8.59E-04	1.97E-04

Table S-2. The unit risk of carcinogenic effects in three sub districts via each pathway (dimensionless).

	Exposure group	Carcinogenic Risk						
		Ingestion			Dermal contact			TCR
		Pb	Cd	Total	Pb	Cd	Total	
Phra That Pa Daeng District	Infant	2.11E-06*	9.47E-05*	9.68E-05*	4.54E-09	2.03E-07	2.07E-07	9.70E-05*
	Toddler	6.49E-06*	2.92E-04*	2.98E-04*	7.40E-10	3.31E-08	3.38E-08	2.98E-04*
	Child	4.85E-06*	2.22E-04*	2.27E-04*	1.39E-08	4.35E-07	4.49E-07	2.27E-04*
	Adult	4.95E-06*	2.32E-04*	2.37E-04*	9.16E-09	2.56E-07	2.65E-07	2.37E-04*
	Total	1.84E-05*	8.40E-04*	8.59E-04*	2.83E-08	9.27E-07	9.56E-07	8.60E-04*
Mae Ku District	Infant	8.42E-06*	6.17E-06*	1.46E-05*	4.13E-10	2.70E-10	6.82E-10	1.46E-05*
	Toddler	2.02E-05*	1.48E-05*	3.50E-05*	1.57E-09	1.03E-09	2.60E-09	3.50E-05*
	Child	5.55E-05*	4.71E-05*	1.03E-04*	1.63E-08	3.09E-07	3.25E-07	1.03E-04*
	Adult	6.25E-05*	6.15E-05*	1.24E-04*	1.98E-08	4.65E-07	4.85E-07	1.24E-04*
	Total	1.47E-04*	1.30E-04*	2.76E-04*	3.80E-08	7.75E-07	8.13E-07	2.77E-04*
Mae Tao District	Infant	4.49E-07	3.32E-06*	3.77E-06*	2.41E-11	1.44E-10	1.68E-10	3.77E-06*
	Toddler	1.08E-06*	7.98E-06*	9.06E-06*	9.64E-11	5.75E-10	6.71E-10	9.06E-06*
	Child	2.49E-06*	2.37E-05*	2.62E-05*	1.09E-08	2.87E-07	2.98E-07	2.65E-05*
	Adult	3.26E-06*	3.91E-05*	4.23E-05*	1.70E-08	4.55E-07	4.72E-07	4.28E-05*
	Total	7.27E-06*	7.41E-05*	8.13E-05*	2.80E-08	7.43E-07	7.71E-07	8.21E-05*

* unacceptable level for carcinogenic risk ($<10^{-6}$)