

LEAD AND ARSENIC EXPOSURE FROM THE ENVIRONMENT AMONG YOUNG CHILDREN AND HEALTH RISK ASSESSMENT AT AN ABANDONED MINE IN SOUTHERN THAILAND

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ABSTRACT:

Background: Abandoned tin mining in Tamtalu sub-district, Bannangsta district, Yala province in southern Thailand has left the area contaminated with lead and arsenic. The objectives of the study were to assess the risk among the children of exposure to lead and arsenic from the environment and to determine the quantities of the toxic substances accumulated in the body by analyses of blood and hair samples.

Methods: This study focused on children from newborn to six years old. A total of 119 households were randomly sampled from 157 households having children. The parents were interviewed. Environmental and biological samples from Tamtalu sub-district were collected and analysed for lead and arsenic levels by inductively coupled plasma-optical emission spectrometry (ICP-OES) and graphite furnace atomic absorption spectrometry (AAS). Risk assessment was calculated using conventional equations of US Environmental Protection Agency (EPA).

Results: Environmental lead levels were found ranged from 0.223-721.200 mg/kg, <0.010-5.215 mg/kg, 0.150-1.155 mg/L and <0.010-0.011 mg/L in soil, vegetable, breast milk and drinking water samples, respectively. Environmental arsenic levels ranged from 0.532-475.000 mg/kg, <0.020-0.650 mg/kg, <0.020-0.540 mg/L and <0.020-0.098 mg/L in soil, vegetable, breast milk, and drinking water samples, respectively. The hazard indices of lead and arsenic exposure via oral route were 0.2 and 2.1, respectively. It's mean that hazard from non- carcinogen from arsenic was unacceptable (>1). The risk of arsenic as a carcinogen was 3 in 1000 people, suggesting that the risk was unacceptable. The data suggested that the risk was highest from exposure to soil than vegetables, drinking water and breast milk, respectively. Lead levels ranged from 0.093-43.882 µg/dL and 0.045-7.670 mg/kg in the blood and hair samples, respectively. Arsenic levels in the hair samples ranged from <0.020-1.670 mg/kg.

Conclusions: The health of some of the young children appeared to be at risk from lead and arsenic exposure. Risk management through reduction of the exposure is needed.

Keywords: Risk assessment, Lead, Arsenic, Exposure, Abandoned mine, Thailand

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INTRODUCTION

Countries around the world have experienced problems of toxic waste contamination in the environment from ore minings. The impacts on the environment has caused deaths of more than 400

young people in central Nigeria [1]. In China, the residues of lead, cadmium and mercury from mining have contaminated surface water and soil. Affected people there had a daily intake of lead up to 7.7 µg/kg/day [2]. In Mexico, mined out areas were contaminated with arsenic. A maximum value of 0.4 mg/L in drinking water was recorded, much higher than the 0.01 mg/L World Health Organization (WHO)

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standard [3]. Studies in England found arsenic and other toxic metal contamination in mining waste and sediment 1-5 times higher than the standard level [4]. In Thailand there are many abandoned tin mines. One of them is in Tamtalu sub-district, Bannangsta district, Yala province in southern Thailand. Although the mine has been out of business since 1988 due to lower ore prices [5] but the vicinity is still contaminated with lead and arsenic from mining wastes [6]. In 1993, lead was found contaminated in the river sediment up to 3,333 mg/kg [7]. The blood lead levels among school students in the area were in a range from 3.0 - 10.2 µg/dL [8]. The major pathway of their exposure to lead and arsenic was the oral route [9]. Lead affects the nervous system and the development of young children. Young children are the most vulnerable to lead poisoning [10]. Arsenic is a carcinogen which also affects intelligence level and memory in a long term exposure. Risk assessment is the method which is conducted to know the risk of community [11]. Health risk assessment is thus, a method to determine risk on people's health in a community. In Thailand, a health risk assessment was conducted in cases of lead exposure among people who lived in Klity village near an abandoned lead mine in Kanchanaburi province. The sources of exposure there were soil, vegetables and fishes [12]. Health risk assessment of arsenic exposure studied in Ronpiboon district, Nakhon Si Thammarat province found that the sources of arsenic exposure were shallow well water and soil [13].

The objectives of this study were to assess the risk of young children from exposure to lead and arsenic in the environment and to determine the amount of lead and arsenic accumulated in the body through analyses of blood and hair samples. Young children, especially newborn to six year old, were the group of interest because they are more likely to get affected from lead and arsenic over other age groups [14]. This study was approved by the Ethics Committee on Human Research, Faculty of Medicine, Prince of Songkla University, project code 56-246-19-6-2.

MATERIAL AND METHODS

Study design:

Cross-sectional study (during July 2013- March 2014)

Children since newborn to six years old were high risk group from heavy metal, especially lead [15]. A total of 119 children were randomly sampled from a population of 157 young children with age between newborn to six years old [16]. The sample size was calculated from Krejcie and Morgan's

equation [17] significant level = 0.05. The simple random sampling was conducted by random number drawings [18]. The children's parents were interviewed. Environmental samples, including drinking water, vegetables, breast milk and surface soil, were collected from the environment which children were frequently exposed to. Children's blood and hair samples were collected for analysis of lead and arsenic levels. The 188 environmental samples and collected 116 biological samples, total 304 samples for analysis lead and arsenic for health risk assessment.

Environmental sample preparation

Environmental samples in this study focus on environment in the area for confirm the risk include drinking water, vegetables, breast milk, and soil with children play (risk from pica). Water consumption not include in this paper because the same source as drinking water. For food, the raw material such as meat not from the area. The environment samples that children expose total 188 samples included;

Drinking water 40 samples: bottle water, rain water, mountain water, shallow water, and stream water. Vegetables 64 samples: morning glory, gourd, spinach, lentil, kale, star gooseberry, Chinese cabbage, vegetable fern, acacia, fuffa, eggplant, sweet basil, and cucumber. Breast milk from mother total 13 samples, Soil 71 samples: from house, school, and playground soil.

1) Drinking water

Various types of the children's drinking water, including bottled water, rain water, shallow well water and stream water, were collected in 50 ml high density polyethylene (HDPE) bottles. Concentrated nitric acid (65%) was added until pH <2 to prevent precipitation or adsorption of the contained metals to bottle inner surface [19].

2) Vegetables

Various types of vegetables consumed by the children, including morning glory, gourd, spinach, lentil, kale, star gooseberry, Chinese cabbage, vegetable fern, acacia, fuffa, eggplant, sweet basil and cucumber were collected and packed in plastic containers, then washed, cut into small pieces and grounded. The grounded samples (0.2 g) were added with 1 ml of concentrated nitric acid (65%) and were digested at 95°C for 2 hrs. The clear solution was cooled down and filtered through filter paper. The volume was adjusted to 10 ml with distilled water [20].

3) Breast milk

Breast milk samples were collected from some mothers of the children and were kept in plastic

bottles. An aliquot of 0.2 g of each sample was added with 1 ml 65% concentrated nitric acid and was digested at 95°C for 2 hrs. The clear solution was cooled down and filtered through a filter paper. The volume was adjusted to 10 ml with distilled water [20].

4) Soil

Surface soil samples were collected from playgrounds at the children's home and in their school. A v-shaped hole was digged with a plastic drilling tool and the digged soil was thrown away. Then soil samples were taken from the side of the hole at 2 cm depth. Ten samples were taken from each hole. The soil samples were kept in plastic bags [21]. Dirt was separated and the soil samples were dried at 80°C. The dried soil was filtered through an 80 mesh sieve and was mixed thoroughly using coning and quartering technique [22]. An amount of 0.1 g of each sample was added with 1 ml of 65% concentrated nitric acid. The mixture was digested at 95°C for 2 hrs. The clear solution was cooled down and was filtered through a filter paper. The volume was adjusted to 10 ml with distilled water [20].

All of the environmental samples were stored at 4°C until analyses for lead and arsenic levels by inductively coupled plasma-optical emission spectrometry (ICP-OES) [23].

Biological samples

In this study focused at blood and hair as bio indicator for expose lead, and arsenic [24]. Urine lead and arsenic not suitable to be indicator in this study because in urine lead and arsenic can be detected within 0-12 hours after exposure. It very short time can not test in laboratory [25].

1) Blood

Blood samples of 5 ml each were taken from the children by nurses from the pediatric ward of the provincial hospital with permission from their parent. Ethylene diamine tetraacetic acid (EDTA) was added to prevent blood clotting. The samples were stored in blood collection tubes at 4°C until analyses for lead by graphite furnace atomic absorption spectrophotometry (AAS) [26].

2) Hair

Hair samples were collected from the children by cutting 20-30 hairs (5cm-long) close to the root and were kept in a plastic bag. Samples were cut into pieces (less than 1 cm long) and washed with acetone [27]. They were then washed with distilled water three times by soaking in distilled water and stirring for 10 minutes each time. The samples were then washed with acetone by soaking in acetone and stirring for 10 minutes

and were dried at 60°C to 0.1 g of each sample, 1 ml concentrated nitric acid was added and digested at 95°C for 2 hrs. The clear solution was cooled down and filtered with a filter paper. The volume was adjusted to 10 ml with distilled water [20].

Quality assurance and quality control

The LOD of arsenic was 0.020 mg/kg (or mg/L). The LOD of lead was 0.010 mg/kg (or mg/L). The % recovery of lead was 99 %. The % recovery of arsenic was 101 %. The % RSD of lead was 1.19%. The % RSD of arsenic was 1.10 %.

Risk assessment

Formula for risk assessment

1) The Hazard index of non-carcinogenic effects is derived from the following formula. For single substance use HQ, for multiple substance or multiple routes, use hazard index (HI) to calculate the non-carcinogenic risk [11] from drinking water, vegetables, breast milk and soil

$$\text{Hazard Quotient (HQ)} = \frac{\text{ADD}}{\text{RfD}}$$

$$\text{Hazard Index (HI)} = \sum \text{HQ}$$

Where

ADD is the average daily dose (mg/kg/day),

RfD is the reference dose

RfD = 0.007 mg/kg/day for lead [28]; RfD = 0.0008 mg/kg/day for arsenic [29].

A hazard index less than 1 indicates no risk, but if the hazard index is greater than 1 this indicates that a risk occurs [11].

2) The risk of carcinogenic effect assessed from arsenic only because arsenic was group A: human carcinogen [30]. The following formulas were used for exposures from drinking water, vegetables, breast milk and soil [31].

$$\text{Risk} = \text{LADD} \times \text{SF}$$

Where

SF is the slope factor or cancer potency factor (mg/kg/day).

SF of arsenic by the oral route was 1.5 mg/kg/day [32].

$$\text{LADD} = \frac{C \times IR \times EF \times ED}{AT \times BW}$$

Where

LADD is the lifetime average daily dose (mg/kg/day)

Table 1 The exposure of young children (newborn to six years of age) to lead and arsenic

Source	Mean concentration (C)	Intake rate (IR)	Exposure frequency (EF)	Exposure duration (ED)	Body weight (BW)
Drinking water	lead 0.001 ml/L arsenic 0.015 mg/L	0.293 l/day [35] 0.713 l/day [36]	350 days 350 days	6 years [35] 72.9 years [36]	13.30 kg [37] 63.12 kg [38]
Vegetables	lead 0.359 mg/kg arsenic 0.098 mg/kg	5.95 g/kg/day 0.060 kg/day 2.68 g/kg/day 0.179 kg/day	350 days 350 days	6 years 72.9 years	13.30 kg 63.12 kg
Breast milk*	lead 0.418 mg/L arsenic 0.104 mg/L	0.648 l/day	365 days	1 year	6.23 kg [37]
Soil**	lead 66.427 mg/kg arsenic 23.231 mg/kg	40 mg/day (.00004 kg/day)	350 days	6 years	13.30 kg

* From newborn - 1 year

** accidentally ingestion of soil (pica)

Table 2 Lead and arsenic contamination in the environment

Sources	Substances	$\bar{X} \pm S.D.$ (mg/kg, mg/L*)	Min.	Max.	Number exceeds std. level (percentage)	Standards (mg/kg, mg/L)
Drinking water*	lead	0.010 $\pm$ 0.003	<0.010	0.011	1 (2.50)	0.01 mg/L [40]
Vegetables	lead	0.359 $\pm$ 0.887	0.005	5.215	2 (3.13)	1 mg/kg [41]
Breast milk*	lead	0.418 $\pm$ 0.287	0.150	1.155	13 (100.00)	0.01 mg/L [40]
Soil	lead	66.427 $\pm$ 146.282	0.532	724.200	3 (4.22)	400 mg/kg [42]
Drinking water*	arsenic	0.020 $\pm$ 0.023	<0.020	0.098	15 (35.5)	0.01 mg/L
Vegetables	arsenic	0.098 $\pm$ 0.134	<0.020	0.650	0	2 mg/kg [42]
Breast milk*	arsenic	0.140 $\pm$ 0.141	<0.020	0.540	11 (84.62)	0.01 mg/L [40]
Soil	arsenic	23.231 $\pm$ 60.584	0.233	475.00	60 (84.51)	3.9 mg/kg [42]

LOD of arsenic = 0.020 mg/kg, mg/L, LOD of lead = 0.010 mg/kg, mg/L

C is the concentration of arsenic from sample analyses (ml/L, mg/kg)

IR is the intake rate from the oral route per day (L/day, kg/day)

EF is the exposure frequency (days/year)

ED is the exposure duration (years)

AT is the average life expectancy time (days)

BW is the body weight (kg)

The information for calculation of the exposure to lead and arsenic from drinking water, vegetables, breast milk and soil [33] is summarized in Table 1.

Total cancer risk from multiple sources (drinking water, vegetables, breast milk and soil) was derived from the following formula [31];

$$\text{Total cancer risk} = \sum (\text{LADD} \times \text{DF})$$

Where

LADD is the lifetime average daily dose (mg/kg/day)

SF is the slope factor or cancer potency factor (mg/kg/day)

If the risk is less than 10^{-6} means the risk is not significant. If the risk is between 10^{-6} - 10^{-4} means the risk is acceptable. If the risk is greater than 10^{-4}

means the risk is unacceptable [34].

RESULTS

Children and parent data

This study focused at young children, from newborn to six years old, who had been living in the area since birth. It was found that 58.8 % of 119 children were female and 69.7 % of the parents working in agriculture.

Lead and arsenic in environmental samples

A total of 188 environmental samples were collected from households of the exposed children. The highest value of lead in the soil was 724.20 mg/kg, followed by arsenic at 475.00 mg/kg. The lowest mean was lead in drinking water at 0.011 mg/L in Table 2. The study in China vegetables that plant in contaminated soil may absorb high lead into their stems especially, leaves such as kale, cabbage, and Chinese cabbage [39].

Health risk assessment

Hazard index of lead and arsenic exposure

The hazard indices of lead and arsenic exposure from the environment via the oral route were greater than 1 (2.3). If separate hazard index of lead and

Table 3 Hazard Index of lead and arsenic exposure

Sources	Substances	$\bar{X} \pm S.D.$ (mg/kg, mg/L*)	ADD (mg/kg/day)	HQ
Drinking water*	lead	0.010 ± 0.003	1.218×10^{-5}	0.002
Vegetables	lead	0.359 ± 0.887	106.730×10^{-5}	0.152
Breast milk*	lead	0.418 ± 0.287	0.059×10^{-5}	0.084
Soil	lead	66.427 ± 146.282	1.644×10^{-5}	0.002
Hazard index (HI) of lead				0.2
Drinking water*	arsenic	0.020 ± 0.023	18.269×10^{-5}	0.228
Vegetables	arsenic	0.098 ± 0.134	29.143×10^{-5}	0.364
Breast milk*	arsenic	0.140 ± 0.141	1.485×10^{-5}	0.186
Soil	arsenic	23.231 ± 60.584	101.719×10^{-5}	1.271
Hazard index (HI) of arsenic				2.1

Table 4 Cancer risk from arsenic

Sources	Substance	$\bar{X} \pm S.D.$ (mg/kg, mg/L*)	LADD (mg/kg/d)	Cancer risk
Drinking water*	arsenic	0.020 ± 0.023	18.269×10^{-5}	2.740×10^{-4}
Vegetables	arsenic	0.098 ± 0.134	29.143×10^{-5}	4.372×10^{-4}
Breast milk*	arsenic	0.140 ± 0.141	1.485×10^{-5}	2.226×10^{-4}
Soil	arsenic	23.231 ± 60.584	101.719×10^{-5}	15.258×10^{-4}
Total cancer risk (via oral route)				2.460×10^{-3}

Table 5 Lead and arsenic in the biological samples

Biological samples	n	Substances	$\bar{X} \pm S.D.$ (mg/kg, µg/dL*)	Min.	Max.	Number exceeds	Standard limit
						std. level (%)	
Hair	67	lead	1.209 ± 0.422	0.045	7.670	1 (1.49)	5 mg/kg
		arsenic	0.103 ± 0.217	<0.020	1.67	1 (1.49)	0.5 mg/kg
Blood*	49	lead	6.742 ± 6.564	0.093	43.882	6 (12.24)	10 µg/dL

arsenic found that hazard index of lead was 0.2, acceptable risk but for hazard index of arsenic was 2.1, unacceptable risk. Therefore, there is a risk for children in this community, especially from arsenic in environment. There is a high risk from arsenic in the soil in Table 3. Therefore, only exposure to arsenic in soil, the risk will occur (1.271) and arsenic has a higher risk than lead in every environment because when calculate risk R_{ED} of arsenic was lower than lead 0.0062 (R_{ED} lead 0.007, arsenic 0.0008). And found that the risk of lead and arsenic from soil > vegetables > drinking water > breast milk. In soil, children were exposed via oral route by pica and immature immunology as adults will cause health effect [14].

Risk of carcinogen

The risk of arsenic as a carcinogen through oral route from all environmental samples was 2.460×10^{-3} , which was greater than 10^{-4} and therefore the risks were unacceptable [34], Table 4.

Lead and arsenic in biological samples from children

The lead in the blood were 49 samples and lead and arsenic in the hair of the children were 67 samples total 116 samples. In term of ethic aspect, some of parent not allow to collect blood or hair of children that why the samples of blood and hair not equal.

In blood, highest quantities of lead was 43.882 µg/dL which is higher than the recommended 10 µg/dL [43]. Although blood lead levels <10 µg/dL, it can also affect a child's intelligence of children. Therefore, need to monitored children in the community.

The highest value of lead in the hair was 7.670 mg/kg, which was higher than the recommendation of 5 mg/kg [44]. Arsenic in the hair was 1.67 mg/kg, which is higher than the recommended 0.5 mg/kg [45] in Table 5.

Blood lead level which indicates that body has

been lead accumulation and as a indicator to assess the epidemiological of the population. The measurement of lead in the hair can be used as a bioindicator for obtaining the lead as chronic exposure [46]. Arsenic levels in hair suitable bioindicators of arsenic in the body because the hair keratin high can bind to arsenic. The arsenic in the hair can indicate a chronic arsenic [47]. Blood arsenic not suitable for bioindicator in this study because need large quantities in a short time and arsenic was eliminated from the bloodstream in a short time [48].

DISCUSSION

Previously, there were many tin mines in southern Thailand. These mines were located in so called "The Asian Tin Belt". At present, most of the mines have been abandoned because of low tin ore prices. Oxidation of ore minerals in acidic conditions released toxic elements to the environment. These elements varied in concentrations depending on which locations they were found. Lead and arsenic were found abundantly released to the environment in Tamtalu sub-district, Bannangsta district, Yala province during tin ore mining and tin ore dressing with concentrated acid solution. They were found contaminated in soil, stream water and sediment. It was speculated that local people in the vicinity of the mines were exposed to lead and arsenic from the environment. The results of this study confirm this speculation.

Drinking water

There were 35.5 % of the drinking water samples had arsenic higher than the standard allowance. The maximum level of arsenic was 0.098 mg/L. Sources of arsenic were from mining wastes (mine tailings) left contaminated in the environment. The study at Ronpiboon district, Nakhon Si Thammarat province found that arsenic from the drinking water range 0.001-0.047 mg/kg [13]. However, none of the drinking water samples had lead content higher than the standard limit.

Vegetables

There were only 3.1 % of the samples had lead content higher than the standard allowance. The maximum level of lead was 5.215 mg/kg in lentil and star gooseberry. A study in China reported that vegetables that were planted in lead contaminated soil might absorb some lead into the plants especially leaves such as kale, cabbage and Chinese cabbage [39]. Anyway, none of the vegetable samples had arsenic higher than the standard allowance.

Breast milk

All of the breast milk samples had lead levels higher than the standard limit. Furthermore, 84.62 % of the samples also had arsenic higher than the standard allowance for drinking water. The maximum value of lead found was 1.155 mg/L which was much higher than the value previously reported in China (0.041 mg/L) [49].

Soil

There were 60 samples out of 71 samples (84.5 percent) had arsenic in soil higher than the standard limit. The maximum value of arsenic found was 475 mg/kg. The maximum value of lead was 724.2 mg/kg. Lead contamination from lead mining in soil at Klity village maximum was 124,500 mg/kg [50] higher than this study 172 times. Higher arsenic content in soil (935 mg/kg) was reported in China [51], and the study at Ronpiboon district, Nakhon Si Thammarat province found that arsenic from the soil range 7.510-510.93 mg/kg [13].

The total cancer risk from arsenic via oral route from soil, vegetables, drinking water, and breast milk was $>10^{-4}$ which was unacceptable. Thailand at Klity village, Kanchanaburi province also study abandoned mine by sampling environment samples for risk assessment from lead and study the related from blood lead level and teeth of people with IQ. The result showed high concentration than standard in soil, vegetable, and fish. The hazard index was unacceptable risk same as this study. The IQ related to blood and teeth at Pearson's Correlation Coefficient was 0.397 and 0.290, respectively [12]. From this part, abandoned mine was area contaminated with heavy metal that still got health although no activities for long time.

Blood

There were 6 samples out of 49 samples (12.2%) had blood lead level higher than the standard limit. The maximum value of 43.882 µg/dL was found. In Island, blood lead level of kindergarten was 14.2 µg/dL [52] lower than this study.

Hair

There were 1 sample out of 67 samples (1.5%) had hair lead higher than the standard value and another sample had arsenic higher than the standard value. The maximum value of lead found was 7.670 mg/kg while that of arsenic was 1.670 mg/kg. In Italy [46], the maximum hair lead was 10.0 mg/kg higher than this study.

From the study, found high concentrations of lead and arsenic in blood and hair of children that can confirm the health risk assessment that

showed hazard index > 1 , got risk from oral route from environment. Lead from environment, the highest risk from vegetables because vegetable growth in the area might absorb some lead into the plants [39]. Arsenic from environment, the highest risk from soil. Children were exposed via oral route by pica [14].

The total cancer risk was > 1 in 10,000 people unacceptable risk. Children were at risk from lead and arsenic as non-carcinogen and lead as a carcinogen. According to the study of at Klity village [12] that also found the accumulation of heavy metal (lead) in the body of children, caused from abandoned mine.

Blood and hair as bioindicator for exposure to lead and arsenic [45]. The measurement of lead in the hair can be used as a bioindicator for obtaining the lead as chronic exposure [46]. The arsenic in the hair can indicate a chronic arsenic [47]. Blood arsenic is not suitable for bioindicator because arsenic was eliminated from the bloodstream in a short time [48]. Therefore, in this area should manage an environment that gets risk, such as avoided crops and may lead to treatment soil by phytoremediation because of cost and benefit [53] and take care children from pica [14]. Lead and arsenic in breast milk for all samples was higher than the WHO standard. Therefore, mothers should not breast feed their babies because, if children has high lead in the first two years and forecast that it will affect the nervous system of children in the future. This affects learning and IQ [54]. The people need a safe source of drinking water. To protect the health of the children and villagers water quality must be improved, or an alternative safe source selected.

CONCLUSIONS

Tamtalu was areas with high concentrations of lead and arsenic in environment and exposure to children body. The health risk assessment found that hazard index of the non-carcinogenic effects and risk of carcinogen both to get risk. Therefore, this area need to manage to protect health of children and people in the community to reduce the risks. It is important to think about participatory of community in management process.

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CONFLICT OF INTEREST

The authors declared no conflict of interest.

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