Water quality and Health Risk Assessment on Arsenic and Manganese Exposure of Community Located in the Border Adjoining Phichit, Phetchabun and Phitsanulok Provinces, Thailand

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Abstract

This cross-sectional study research aimed to determine water consumption sources and assess the risk of manganese and arsenic exposure due to consumption of well water and village water supply in a community located in the border adjoining Phichit, Phetchabun and Phitsanulok Provinces in Thailand. Interviews of 314 households on their water consumption behavior were conducted. Additionally, the water from 18 wells and 49 village water supplies were analyzed for a suite of water quality parameters.

The studied found that there were approximately 5% and 6% of households using well water for cooking and water supply for drinking purpose respectively. The concentration of heavy metals, namely Cr, Cd, As and Hg in well water were not found while As was found below the drinking water standard in village tap water samples. The concentrations of manganese in well water and village water supplies varied from 0.002 to 2.64 mg/l and from 0.002 to 1.12 mg/l respectively.

Health risk assessments of manganese and arsenic exposure were performed at an intake rate dictated by water sampling (i.e., at 97.5 percentile). Health risk associated with manganese exposure was determined to be at acceptable levels. In addition, the average skin cancer risk attributable to tap water consumption for drinking purpose in the age group 3 years did not exceed the acceptable level of 1 in 1,000,000. However the maintenance of village water supply system is recommended.

1. Introduction

Trace metals in a water supply, such as arsenic, cadmium, chromium, manganese, and mercury, may occur naturally (e.g., from weathering of rocks, soils) or may be the result of contamination attributable to human activities. Inorganic arsenic is known to be highly toxic to humans while organic compound are less toxic to human health (ATSDR, 2007). Long-term inorganic arsenic exposure via drinking water is known to cause skin cancer. In addition, longer oral exposure has also been associated with adverse reproductive outcomes and increased risk of cancer in the liver, bladder, and lungs (ATSDR, 2007; Kim Yoon-J; Smith et.al., 1992).

Manganese is a naturally occurring element and is known as an essential nutrient. Several enzyme catalytic system and cell functions depend on manganese availability (ATSDR, 2012), as does the formation cartilage and bone. In addition, manganese is required for the maintenance of mitochondria and the production of glucose. Epidemiological studies both in children and the elderly have found that extremely high levels of manganese exposure may lead to neurological and brain development effects (ATSDR, 2012; U.S.EPA, 2004).

According to the Department of Health drinking water surveillance report which the water supply and well water quality in 8 villages for an area of Tambon Tabklor, Phitjit province has been sampling and analyzed annually between 2011 and 2014 (Department of Health,2014), it was found that manganese levels in the village water supply and well water, exceeded the drinking water standard. In addition, at an adjoined area of Phichit,Phetchaboon and Phitsanuloke provinces, a 16-year gold mining located 0.6 kilometers from a village where manganese and arsenic levels in surface water monitoring wells exceeded the standards at some stations.The objective of this study are to determine water consumption sources and to determine health risk from arsenic and manganese exposure in well water and tap water in a community located on the border adjoining Phichit, Phetchabun and Phitsanulok Provinces,Thailand.

2. Material and methods

The present study focused on the potential area of gold mineralization, 24 villages, at the adjoined area of three provinces. It's approximately 5- 10 km from an open-pit mine where the ground and surface water move through. In addition, manganese and arsenic exposure were found in the villager were found.

2.1 Source of drinking water determination

An interview was conducted to identify community sources of drinking water among the villager. Ten percent of all households in the 24 villages were randomly selected (400 out of 3,981 households).The structure of the questionnaire included detailed questions on drinking and cooking water sources.

2.2 Sampling and analytical of heavy metals in drinking water

With respect to water quality sampling, all village water supplies and water wells used for drinking purpose across the 24 villages were assessed. Samples were collected on two occasions (summer and raining season) – once in March and September 2016. In total,water samples from 49 tap water stations and 67 wells were collected. Samples were analyzed for arsenic, , following the Standard Method for the examination of water and wastewater (APHA,AWWA,WEF, 2012).

2.3 Health risk assessment

In this step of the study, information was analyzed to determine whether heavy metal results may cause adverse effects following exposure to a risk source. Manganese and arsenic exposure assessment and risk characterization were assessed by following the United States Environmental Protection Agency guidance (U.S.EPA.1989a, 2001). The most common measureis are the chronic daily intake (CDI). Risk characterization of noncancer effects due to manganese and arsenic exposure were then evaluated by comparing an exposure level (CDI) with toxicity value (RfC) which were expressed in term of hazard quotient (HQ). If the calculated HQ is equal or less than 1, noncancer adverse effects due to drinking water pathway is assumed to be negligible. For the risk estimated of an individual developing cancer over a life time due to inorganic arsenic exposure is expressed as cancer risk (CR) which accepted in the range of $1x10^{-4}$ to $1x10^{-6}$.

Drinking water exposure and risk equations used in this study, were calculated as follows:

Exposure assessment: $$\mathrm{CDI} = \frac{\mathrm{C} \times \mathrm{IR} \times \mathrm{EF} \times \mathrm{ED}}{\mathrm{BW} \times \mathrm{AT}} \quad (1)$$

Cancer risk assessment: $$\mathrm{Risk} = \mathrm{CDI} \times \mathrm{CSF} \quad (2)$$

Noncancer risk assessment: $$\mathrm{HQ} = \frac{\mathrm{CDI}}{\mathrm{RfC}} \quad (3)$$

Where: CDI is the chronic daily intake of arsenic and manganese (mg/kg-day); C is the concentration of inorganic arsenic and manganese in tap water or well water (mg/L).; IR is the ingestion rate (L/day); EF is the exposure frequency (days/year); ED is the exposure duration (years); BW is the body weight (Kg); AT is the averaging time, (equal to ED x 365 days/year for noncarcinogen and 70 years x 365 day/years for carcinogen); CSF is the cancer slope factor for inorganic arsenic $(mg/kg\text{-}day)^{-1}$; RfC is the reference concentration for the manganese and inorganic arsenic for assessing noncancer health effects (mg/kg-day). Total arsenic concentration in water samples was assumed to be inorganic arsenic and 100% absorption. In the same manner, manganese concentration in water samples was assumed 100% absorption.

Arsenic and manganese exposure and risk characterization for eight different age groups were calculated in the study, and included0 to 3 year, 3 to 6 year, 6 to 9 year, 9 to16 year, 16 to 19 year, 19 to 35 year, 35 to 65 year and >65 year categories. Exposure parameters were obtained from a national study of food consumption data which was conducted by the National Bureau of Agricultural Commodity and Food Standards (ACFS, 2006), Thailand.

Health risk was determined under a worst case scenario of exposure where 97.5th percentile of drinking water consumption in different age groups and 97.5th percentile of manganese and arsenic concentration were used.

3. Results

3.1 The community source of drinking water

Of the households randomly targeted with surveys, 314 were successfully interviewed (7.8 percent of total household). Table 1 confirms that most of the households in the community used bottled water, rain water and tap water for drinking purpose at percentages of the total approximately 65%, 14% and 6 % respectively. These data also indicate that bottled water, tap water, rain water and well water are the dominant sources of cooking water with reported percentages of use roughly 39%, 29%, 11%,and 5.1% respectively.

Table 1 Source of drinking water in the community

Source of Drinking Water		Number (Percentage)							
		Bottled Water	Rain Water	Bottled and Rain Water	Tap water	Tap and Bottled Water	Well	Tap and Rain Water	Others
Drinking	n %	205 (65.3)	43 (13.7)	26 (8.3)	19 (6.1)	0	0	0	21 (6.7)
Cooking	n %	123 (39)	35 (11)	6 (1.9)	90 (29)	23 (7.3)	16 (5.1)	15 (4.8)	6 (1.9)

3.2 Heavy metal concentrations

Water samples from 49 tap water stations and 67 water wells were collected and analyzed for manganese, chromium, cadmium, arsenic, and mercury concentrations in March and September 2016. The concentrations of chromium, cadmium, and mercury were not found in both tap and well water. The mean, minimum, maximum, and 97.5th percentile of manganese and arsenic were evaluated and showed in table 2.

Table 2 Metals concentration in drinking water

Metals	Tap Water (n=49)			Well Water (n = 67)		
	Mean (mg/L)	Min-Max (mg/L)	97.5th percentile	Mean (mg/L)	Min-Max (mg/L)	97.5th percentile
Manganese	0.16	0.0015-1.124	0.973	0.43	0.002-2.64	2.30
Chromium	ND	ND	-	ND	ND	-
Cadmium	ND	ND	-	ND	ND	-
Arsenic	0.006	0.005-0.007	0.007	ND	ND	-
Mercury	ND	ND	-	ND	ND	-

ND= not detected

3.3 Exposure and Health Risk Evaluation

Exposure parameters used in this study are shown in Table 3.The 97.5th percentile manganese and arsenic concentration measured in tap water and well water were used to estimate risk. The study assumed total arsenic concentrations returned by water samples occurred as inorganic arsenic. Intake rates (IR) for the risk evaluation were 97.5th percentile values per national intake rate and ranged from 0.78 to 2.1 L/dayfor the eight age groups considered. In addition, exposure duration and body weight were range from 3 to 31 years and 10-60 kilograms respectively.

Table 3 Exposure parameter used in risk analysis

Variables	Values	Units	References
Concentration of Mn in tap water	0.973	mg/L	This study
Concentration of Mn in well water	2.3	mg/L	This study
Concentration of Inorganic As in tap water	0.007	mg/L	This study
IR	0 to 3 year =0.781 3to6year =1.1 6to9year =1.2 9to16year =1.6 16to19year =1.8 19to35year =2.05 35to65year =2.1 >65 year =1.9	L/day	ACFS,2006
EF	365	day/year	(U.S.EPA.1989a, 2001)
ED	0to3year = 3 3 to 6year =3 6to9year = 3 9 to16year =7 16to19year = 3 19 to35year =16 35to60year = 31 >65 year =5	year	Constance
BW	0to3year =10 3to6year =17.1 6to9year =22.8 9to16year =39.73 16to19 year =53.23 19to35year =58.28 35 to 65 year =60.37 >65 year =54.53	Kg	(ACFS, 2006)
AT	EDx365	Year	(U.S.EPA.1989a, 2001)
RfC (Mn)	0.14	mg/kg-day	(U.S.EPA.IRIS, 1988)
RfC (Inorganic As)	0.0003	mg/kg-day	(U.S.EPA.IRIS, 1988)
CSF (Inorganic As)	$5x10^{-8}$	unitless	(U.S.EPA.IRIS, 1988)

3.3.1) Noncancer risk effects - Manganese

The CDI and risk characterizations for manganese via drinking water are reported per age group in Table 4 (manganese). Outputs reported in this table show risk characterization of noncancer effects from exposure to manganese in tap water and well water returned HQ values that were less than 1, a result indicative that adverse effects due to manganese exposure may be assumed acceptable.

Table 4 The outputs of manganese exposure assessment and risk characterization

Results	Non-cancer effects			
	Tap water		Well water	
Age group	CDI (mg/kg-day)	HQ	CDI (mg/kg-day)	HQ
0-3	0.0032	0.02	0.0076	0.05
3-6	0.0027	0.02	0.0063	0.05
6-9	0.0022	0.02	0.0052	0.04
9-16	0.0039	0.03	0.0093	0.07
16-19	0.0014	0.01	0.0033	0.02
19-35	0.0078	0.06	0.0185	0.13
35-65	0.0145	0.10	0.0343	0.24
>65	0.0024	0.02	0.0057	0.04

3.3.2) Non-cancer and Cancer risk effects - Arsenic

The CDI and risk characterizations for arsenic via drinking water are reported per age group in Table 5. Outputs in Table 5 include Non-cancer effects and Cancer effect for this species. Similar to results for manganese (Table 4), risk characterization of noncancer effects from exposure to arsenic in tap water and well water returned HQ values that were less than 1, a result indicative that adverse effects due to arsenic exposure may be assumed acceptable. Also summarized in Table 5, the increased cancer risk (CR) of being exposed to inorganic arsenic by water consumption in different age groups ranged from 5.1 $x10^{-13}$ (16 to 19 yr Age group) to 5.2 10^{-12} (35 to 65 Age group). . The cancer risk computed did not exceed the acceptable of 1 in 1,000,000. In conclusion, risk estimates of both noncancer and cancer effects for arsenic do not exceed the risk level.

Table 5 The outputs of arsenic in tap water exposure assessment and risk characterization

	Non-cancer effects		Cancer effects	
Age group	CDI (mg/kg/day)	HQ	CDI (mg/kg/day)	CR
19-35	0.000056	0.19	0.000056	2.8 $x10^{-12}$
35-65	0.000104	0.35	0.000104	5.2 $x10^{-12}$
>65	0.000017	0.06	0.000017	8.7 $x10^{-13}$

4. Discussion

Among the fourth classified sources, bottled water, rain, and tap constitute a major proportion of main source of drinking water in this area which relatively same as Thailand's source of drinking water (Thaihealth, 2015). Manganese and arsenic concentration may differ between raw water and treated water as well as the depth of water well. The possible health effects associated with a consumption of drinking water containing 2 mg/L of manganese for a life time is concerned (US.EPA 2004).The adverse effects of manganese exposure from drinking water, possibly in concentration of 28 mg/l (WHO,2011). The effective village bottled water production as well as water supply treatment should be maintained for sustain drinking water quality. Water and foods are major potential sources of arsenic exposure. In addition, the greatest exposure to manganese is usually from food (US.EPA2004). Hence ,more research is needed to assess the variation of inorganic arsenic and manganese in different types of food in this area.

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