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Factors Influencing Blood Cadmium and Mercury Concentrations in Residents of Agro-Industries along Nam Phong River, Thailand

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Abstract

This cross-sectional analytical study aimed to determine the blood levels of cadmium (B-Cd) and mercury (B-Hg) and identify the factors influencing heavy metal accumulation in residents of agro-industries along the Nam Phong River. Quantitative data were collected, and systematic random sampling was used to obtain 420 samples for questionnaire interview and serum heavy metal testing for B-Cd and B-Hg. Multiple regression analysis was used to identify factors influencing the accumulation of heavy metals in the population and report mean differences, 95% confidence intervals and p-values. The results indicated that B-Cd levels were within the recommended safety limits for human health (5 µg/dL). However, 4.29% of respondents had Hg levels higher than the recommended safety limits for human health (10 µg/dL). Factors influencing Cd levels included sex (mean difference=0.13 µg/L, 95% CI: 0.03-0.24, p-value=0.02) and smoking (mean difference=0.14 µg/L, 95% CI: 0.09-0.19, p-value<0.001). Factors influencing Hg levels included smoking (mean difference=1.06 µg/L, 95% CI: 0.52-1.61, p-value<0.001), fish consumption (mean difference=1.11 µg/L, 95% CI: 0.22-2.01, p-value=0.01) and river snail consumption (mean difference=0.56 µg/L, 95% CI: 0.03-0.19, p-value=0.03).

Keywords: heavy metals; cadmium; mercury; human health; agro-industries

1. Introduction

Heavy metals such as cadmium (Cd) and mercury (Hg) occur as natural constituents of the Earth's crust and are also byproducts of human activity. Heavy metals are released into the environment via both natural and anthropogenic processes. The main sources of Cd and Hg in landfills are smelters, iron and steel plants, electroplating wastes, and battery production (USEPA, 2007; Khan *et al*., 2011). People may be exposed to heavy metals through food, water, air and commercial products in their workplace and other environments. Most heavy metals are potentially harmful to many organisms at different levels of exposure and absorption; low concentrations of heavy metals can be toxic in humans (Alluri *et al*., 2007). The health effects of long-term exposure to low levels of Cd include kidney and lung damage and increased risk of bone fractures; Cd is also classified as a carcinogen for humans (Nordberg *et al*., 2007). Exposure to Hg compounds is toxic to the nervous system and kidneys, as well as damaging to fetal development. Heavy metals in aquatic systems are a serious environmental concern, as they are nonbiodegradable and persistent (Khan *et al*., 2008). The process through which metals accumulate and pass through the food chain up to higher levels is called biological magnification (Mansour and Sidky, 2003; Muchuweti *et al*., 2006). The Nam Phong River is one of Thailand's most important water resources that flows through many districts in the country's northeast region. The region is involved in farming activities and intensive agro-industries (e.g., pulp and paper mills, sugar refineries, whiskey factories and furniture factories). Pollution of the Nam Phong River by accidental releases of chemical residues from the industries located along the river have been reported (Khon Kaen University, 1995). Increasing heavy metal accumulation in fish and shellfish due to growth in the industrial and agricultural sectors may worsen the health of people in watershed areas (Priprem *et al*., 2007; Singh *et al*., 2010). Through consumption, bioaccumulation of heavy metals in fish could result in bio-transference and biomagnification of hazardous heavy metals in humans (Mansour and Sidky, 2003). Reports on heavy metal levels in aquatic plants and fish are very useful for environmental monitoring and identifying heavy metal contamination in water (Jia and Chen, 2013). However, heavy metal levels have not been regularly reported or monitored. Therefore, this study aims to identify factors influencing heavy metals accumulation in residents of agro-industries along Nam Phong River.

2. Materials and Methods

2.1 Study areas and subjects

This study included 420 samples from human subjects (Cd and Hg levels in human blood) who had been living near industrial settings (pulp and paper mill, sugar refinery, whiskey factory, furniture factory and electronic component factory) within 10 kms of the Nam Phong River bank in Khon Kaen Province.

2.2 Data collection tool

The questionnaire was constructed to collect data on demographics and health risk behaviors related to heavy metal exposure.

2.3 Blood collection

Registered nurses drew 10 mL venous blood samples; 3 mL was stored into BD Vacutainer® tubes with ethylene diamine tetraacetic acid (EDTA) anti-coagulant, whereas the remaining 3 mL was stored in a normal tube. Blood samples were immediately transported in a cool box to the laboratory and then stored at 2-5 °C for future analysis.

2.4 Determination of Cd and Hg

To determine Cd level, 4.8 and 8.6 µg/L of Cd standard solution (1000 ug/mL in 4% HNO_3, lot S110425003 traceable to NIST) was prepared; to determine Hg level, 10, 20 and 30 µg/L standard Hg solution (1000 ug/mL in 4% HNO_3, lot S110203005 traceable to NIST) was prepared. Seronorm™ Trace Element Whole Blood L1 lot 0903106 was used for Internal Quality Control for Cd. Seronorm™ Trace Element Whole Blood L2 lot 1103129 was used for Internal Quality Control for Hg. Graphite furnace atomic absorption spectrometry was used to measure Cd (with Varian equipment; Spectr AA-600 GTA100). Hg was measured using a cold vapor atomic absorption spectrometry by mercury analyzer (CETAC Technologies INC. M-6000 A).

2.5 Data analysis

STATA version 11.0 software was used to describe the concentration of heavy metals in the blood and the characteristics of participants, including the percentage, mean, standard deviation, median, minimum, maximum, and 50^{th}, 75^{th}, 90^{th} and 95^{th} percentiles. Associations between independent variables and the levels of toxic metals (Cd and Hg) were determined using multiple regression analysis to determine the adjusted mean differences with a 95% confidence interval.

2.6 Research ethics

The protocols were submitted to and approved by the Ethical Committee of Khon Kaen University. (Reference No. HE 552186).

3. Results and Discussion

3.1 Characteristics of the residents of agro-industries along the Nam Phong River

Demographic data are presented in Table 1. Females comprised 58.10% of the study sample. Ages ranged from 20 to 67 years, with an average age of 46±8 years. The majority of the subjects were farmers (53.57 %), and 62.86 % had completed a primary education. Overall, 21.38 % of participants were past and current smokers; most smokers (87.38%) reported smoking less than 5 cigarettes per day. The average duration of living in the study area was 35.85 ± 15.57 years. The median distance from residential areas to the nearest industry site was 3 kms (min, max: 0.05, 10 kms). The median distance from a residential area to the Nam Phong river basin was 3 kms (min, max: 0.01, 15 kms). All respondents consumed fish, and most (86.43%) consumed fish exceeding 3 meals per week. In addition, 66.67% of respondents consumed river snail exceeding 3 meals/week.

The results suggest both occupational and environmental exposure to heavy metals. Overall, 17.62% of the study population experienced occupational exposure. Occupational exposures were classified into 5 categories according to source. Of the population that experienced occupational exposure, 27.02% were exposed to dyes, 35.13% to batteries/

Table 1. Characteristics of the residents of agro-industries along the Nam Phong River (n=420)

Characteristics	Number	%	95% CI
Average age: 46± 8 years old			
Average duration of inhabitant in areas: 35.85 ± 15.57 years			
Sex			
Female	244	58.10	53.21-62.86
Male	176	41.90	57.13-46.78
Education Attainment			
Primary school	264	62.86	58.03-67.49
Higher	156	37.14	32.50-41.96
Distance from residential areas to the nearest industry (kms)			
≤ 5	337	80.24	76.10-83.94
> 5	83	19.76	16.05-23.89
Median (Min, Max): 3(0.05, 10)			
Distance from residential area to the Nam Phong river bank (kms)			
≤ 5	315	75.00	70.57-79.07
> 5	105	25.00	20.92-29.42
Median (Min, Max): 3(0.01, 15)			
Smoker			
No	326	77.62	73.32-81.51
Yes (past and current smoke)	94	21.38	18.47-26.67
Occupational exposure			
No	346	82.38	78.39-85.90
Yes	74	17.62	14.09-21.60
Environmental exposure (smell, smoke, dust/chemical dust)			
No	15	3.57	2.01-5.82
Yes	405	96.43	94.17-97.98
Fish consumption more than 300 grams (meal/ week)			
≤ 3	57	13.57	10.44-17.22
> 3	363	86.43	82.77-89.55
River snail consumption more than 300 grams (meal/week)			
≤ 3	140	33.33	28.83-38.06
> 3	280	66.67	61.93-71.16
Utilization of the water resource (agriculture and consumption)			
No	126	30.00	25.56-34.63
Yes	294	70.00	65.36-74.34

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solder, 13.51% to painting, 27.02% to color spray/garage melting, and 2.70% due to working at gasoline station. Environmental exposure, due to the industrial setting, included smell, smoke and dust/chemical dust and was found in almost all respondents (96.43%); 70% of respondents consumed or used the river water for agriculture.

3.2. Blood Cd and Hg (B-Cd and B-Hg) concentrations of the residents of agro-industries along Nam Phong River

The B-Cd and B-Hg concentrations of the respondents are shown in Table 2. The median value of heavy metals, 95% CI and range of Cd and Hg were 0.89 µg/L, 0.93-1.03 (range: 0.26-3.46), and 4.7 µg/L, 5.0-5.48 (range: 0.90-17.50), respectively. These data indicated that B-Cd concentrations were within the recommended safety limits for human health (5 µg/dL, ATSDR, 1999a); however, 4.29% of the respondents had Hg concentrations exceeding the recommended safety limits for human health (10 µg/dL, ATSDR, 1999b).

3.3. Factors influencing heavy metals concentration among residents of agro-industries along the Nam Phong River

Bivariate analysis showed a statistically significant association between independent variables and blood heavy metal levels. Bivariate analysis was selected for the multivariate model process, which reported the regression coefficient or mean difference and 95% confidence interval (95% CI). Multivariate analysis using multiple regression analysis showed statistically significant associations between independent variables and blood heavy metal levels (p-value<0.05).

3.3.1. Factors influencing with Cd concentrations in residents of agro-industries along the Nam Phong River

The results of bivariate analysis of the independent variables and B-Cd concentrations are shown in

Table 2. B-Cd and B-Hg concentrations (μg/L) in residents of agro-industries along Nam Phong River (n =420)

Metals	Mean ± SD	Median	Range	95% CI	Percentile			
					50th	75th	90th	95th
Cd	0.97 ± 0.45	0.89	0.26-3.46	0.93-1.03	0.89	1.18	1.53	1.86
Hg	5.25 ± 2.46	4.70	0.90-17.50	5.01-5.48	4.70	6.50	8.65	9.70

Table 3. The magnitude of association between B-Cd concentrations and potential confounders was evaluated using multiple regression (Table 4). Two characteristics were associated with B-Cd concentration: sex (mean difference=0.13; 95% CI: 0.03-0.24, *p*-value=*0.02*) and smoking (mean difference=0.14; 95% CI: 0.09-0.1, *p*-value< *0.001*).

The median value of B-Cd concentration was 0.89 μg/L. This concentration is higher than that reported in the Canadian Survey (Haines and Murray, 2012), Korean population (Lee *et al*., 2012), the general population of the United States (CDC, 2009), and Tunisian (Khlifi *et al*., 2015) and Swedish adults (Bjermo *et al*., 2013). However, the B-Cd concentration in this study was within the recommended safety limits for human health (5 μg/dL, ATSDR, 1999a). B-Cd levels among males were statistically significantly higher than among females (mean difference=0.13; 95% CI: 0.03-0.24; p-value =0.02). The results are similar to several studies (Afridi *et al*., 2011; Akintujoye *et al*., 2013). The explanation for this is that more men have jobs in the industrial sector, including mining, welding, plating, soldering and painting, putting them at a higher risk of Cd exposure. A second explanation is that there are more male smokers than female smokers (Vichit-vadakan, 2003; Lerdpiromluk, 2004). In this study, it was found that B-Cd levels among past and current smokers were higher than in non-smokers (mean difference=0.14; 95% CI: 0.09-0.190, *p*-value < *0.001*); other studies have had similar findings. Cigarette smoke is a major source of Cd exposure. Biological monitoring in the general population has shown that cigarette smoking may cause a significant increase in B-Cd level, the concentrations in smokers being on average 4-5 times higher than concentrations among non-smokers (Gil *et al*., 2011; Järup, 2003). The Swedish adult survey (Bjermo *et al*., 2013) and an Italian study (Forte *et al*., 2013) has also reported higher levels of B-Cd of smokers. This is explained by the fact that the tobacco plant naturally accumulates relatively high concentrations of Cd in its leaves. Moreover, the plant has special properties that allow for the absorption of Cd from soil to tobacco leaves (Chiba and Masironi, 1992; Olga *et al*.,

Table 3. Crude analysis of factors influencing with B-Cd level in residents of agro-industries along Nam Phong River (n=420).

Variables	Number	Mean±S.D.	Regression coefficient	95% CI	p-value
Sex					
Female (reference)	244	0.95±0.02	1		
Male	176	1.00±0.03	0.05	-0.03 to 0.14	0.23
Smoking					
No (reference)	326	0.91±0.02	1		
Yes	94	1.17±0.05	0.25	0.14 to0.35	<0.001
Distance from residential area to the Nam Phong river bank (kms)					
≤ 5 (reference)	15	0.83±0.07	1		
>5	405	0.97±0.02	0.14	-0.09 to 0.37	0.23
Utilization of the water resource (agriculture and consumption)					
No (reference)	126	0.92±0.03	1		
Yes	294	0.99±0.02	0.07	0.02 to 0.17	0.14
Occupational exposure (Smelter)					
No (reference)	402	0.96±0.02	1		
Yes	18	1.17±0.14	0.21	0.00 to 0.42	0.05

Table 4. Factors influencing with B-Cd concentration (μg/dL) in residents of agro-industries along the Nam Phong River (n=420)

Factors	Number	Mean±SD	Regression coefficient		95% CI	p-value
			Crude	Adjusted		
Sex						
Female (reference)	244	0.95±0.44	1	1		
Male	176	1.00±0.47	0.05	0.13	0.03-0.24	0.02
Smoking						
No (reference)	326	0.91±0.42	1	1		
Yes	94	1.17±0.51	0.25	0.14	0.09-0.19	<0.001

Table 5. Crude analysis of factors influencing with B-Hg level of residents of agro-industries along Nam Phong River (n=420)

Variable	Number	Mean±SD	Regression coefficient	95% CI	p-value
Sex					
Female (reference)	244	4.94±1.56	1		
Male	176	5.68±0.18	0.74	0.27-1.21	0.002
Smoking					
No (reference)	326	5.01±0.13			
Yes	94	5.59±1.64	0.72	0.18-1.11	0.006
Alcohol consumption					
No (reference)	220	4.95±0.17			
Yes	200	5.76±0.23	0.72	0.21-1.23	0.005
Fish consumption exceeding 300 grams/meal (3 meals/week)					
≤ 3 (reference)	36	3.88±1.50	1		
> 3	384	5.39±2.49	1.51	0.67 -2.34	<0.001
River snail consumption exceeding 300 grams/meal (3 meals/week)					
≤ 3 (reference)	140	4.69±2.12	1		
> 3	280	5.54± 2.46	0.85	0.35-1.34	<0.001
Freshwater prawn consumption exceeding 300 grams/meal (3 meals/week)					
≤ 3 (reference)	136	4.70±2.11	1		
> 3	284	5.52±2.57	0.82	0.32-1.32	0.001

2012; Lugon-Moulin *et al*., 2006). Thus, smoking tobacco is an important source of exposure because Cd aerosols with small particles, such as those found in smoke, are more easily absorbed than larger particles. In heavy smokers, the daily intake may exceed that from food (Järup, 2003; Shih *et al*., 2003). Cd is a major toxic metal and has toxic effects on the kidney and the skeletal and respiratory systems; it is also classified as a human carcinogen (Takiguchi *et al*., 2003). Cd accumulates primarily in the kidneys, and it has a biological half-life of 10-35 years in humans (WHO, 2008). This accumulation may lead to renal tubular dysfunction, which results in increased excretion of low molecular weight proteins in the urine. This is generally irreversible (Yang and Shu, 2015). The results of this study suggest that smoking could be a major exposure source of Cd, as there was increased B-Cd concentration among smokers.

3.3.2. Factors influencing with Hg concentrations in residents of agro-industries along Nam Phong River

Results of the bivariate analysis of independent variables and B-Hg concentrations are shown in Table 5. The magnitude of association between B-Hg concentrations and potential confounders was evaluated using multiple regression (Table 6). Three characteristics were associated with B-Hg concentrations: smoking (mean difference=1.06; 95% CI: 52-1.61, *p*-value *<0.001*), fish consumption exceeding 300 grams/meal (3 meals/week) (mean difference=1.11; 95% CI: 0.22-2.01, *p*-value=*0.01*) and river snail consumption exceeding 300 grams/meal (3 meal/week) (mean difference=0.56; 95% CI 0.03-1.09, *p*-value=*0.01*).

Table 6. Factors influencing with B-Hg concentration (μg/dL) in residents of agro-industries along Nam Phong River (n =420)

Factors	Number	Mean±SD	Regression coefficient Crude	Regression coefficient Adjusted	95% CI	p-value
Smoking						
No (reference)	326	5.01±0.13	1	1		
Yes	94	6.09±0.26	1.08	1.06	0.52-1.61	<0.001
Fish consumption exceeding 300 grams/meal (3 meals/week)						
≤ 3 (reference)	36	3.88±0.25	1	1		
> 3	384	5.38±0.12	1.50	1.11	0.22-2.01	0.01
River snail consumption exceeding 300 grams/meal (3 meal/week)						
≤ 3 (reference)	136	4.69± 0.18	1	1		
> 3	284	5.54±0.15	0.85	0.56	0.03-1.09	0.03

The results indicated that the median value of B-Hg concentration was 4.70 µg/L. The B-Hg level in this study was within the recommended safety limits for human health (10 µg/L) (ATSDR, 1999b). This concentration is higher than those found in several studies, such as in the human biomonitoring study of the Korean population (3.23 µg/L) (Lee and Kim, 2010), the German Human Biomonitoring Commission (reference value 2 µg/L, Schulz *et al.*, 2011) and the population of Canada (0.70 µg/L, Haines and Murray, 2012). The median B-Hg level in the present study is significantly higher when compared to those found in studies in European countries in which a higher amount of fish is traditionally consumed, such as Sweden (Bjermo *et al.*, 2013) and Italy (D' Ilio *et al.*, 2013). The explanation for this is that Thai people like to eat the abdominal part of fish, which contains adipose tissue. The adipose tissue accumulates higher levels of Hg than the muscle but lower levels than the liver (Priprem *et al.*, 2007; Kawakami *et al.*, 2012). Despite low levels of chronic exposure, Hg can have chronic effects on human health. The central nervous system is the target for elemental Hg toxicity in humans. Effects include erythrism (increased excitability), irritability, excessive shyness, insomnia, severe salivation, gingivitis and tremors. Chronic exposure to elemental Hg also affects the kidneys in humans, leading to proteinuria. Moreover, acrodynia is a rare syndrome found in children exposed to elemental Hg compounds. It is characterized by severe leg cramps, irritability, paresthesia (a sensation of prickling on the skin), painful pink fingers and peeling hands, feet and nose. The absence of gender difference in the B-Hg levels among our respondents was consistent with other studies (Haines and Murray, 2012; Wennberg *et al.*, 2006). In contrast, a Canadian study found that males had higher B-Hg levels than females (Bjermo *et al.*, 2013). This study found that higher B-Hg levels in past and current smokers than in non-smokers. Other studies have found no significant association between smoking and B-Hg level (Khlifi *et al.*, 2015; Bjermo *et al.*, 2013).

Fish, and especially freshwater fish, are a primary source of Hg exposure in several countries (Lee *et al.*, 2012). When compared to data from other countries, such as Sweden (Bjermo *et al.*, 2013), in which large quantities of fish are traditionally consumed, the B-Hg level is significantly higher in this study, as well among the Korean population (Lee *et al.*, 2012). This could be explained by higher freshwater fish/seafood consumption among Asian populations. This study found significant associations between B-Hg levels and fish and river snail consumption. B-Hg levels were statistically significantly higher in respondents who consumed fish exceeding 3 times per week (>300 grams/meal) than in those who consumed fish less than 3 times per week (mean difference=1.11; 95 % CI: 0.22-2.01, *p*-value=*0.01*). B-Hg levels were also statistically significantly higher in respondents who consumed river snail exceeding 3 times per week (>300 grams/meal) than in those who consumed river snail less than 3 times per week (mean difference=0.56; 95 % CI: 0.03-0.19, *p*-value=*0.03*). The association between fish consumption and the B-Hg level found in this study was similar to findings reported in several other studies (Bjermo *et al.*, 2013; Lye *et al.*, 2013). Nam Phong River, there are fish farming cage (Channa striatus, Oreochromis niloticus and Clarias macrocephalus). These fish are regular components of the local people's diets, they are at a risk of Hg exposure.

4. Conclusions

The results show that the B-Cd concentration was within the recommended safety limits for human health (5 µg/dL), 4.29% of the respondents had B-Hg levels that exceeded the recommended safety limits for human health (10 µg/dL). Furthermore, this concentration is higher than those reported in other studies. B-Cd concentration was significantly associated with smoking and gender whereas important factors for B-Hg concentration were fish and river snail consumption. Other factors, such as distance from a residential area to the Nam Phong river bank, utilization of water resources (agriculture and consumption) and occupational and environmental exposure were not significantly associated with either the Cd or Hg of the respondents.

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