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Factors Contributing to Children's Lead, Cadmium, and Arsenic Exposures using Human Biomonitoring and Environmental Data in Southern Thailand

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An abstract of

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Rollins School of Public Health of Emory University

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Abstract

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By Pornpimol Kodsup

Lead, cadmium, and arsenic are toxic substances (Heavy metal and metalloid: HMM) with wide-ranging health effects, including neurodevelopmental decrements, behavioral problems, and cancer, respectively. Children who live in a fishing community with high HMM-related activities are considered to be at higher risk for exposure and resulting outcomes than children who live in areas without fishing-related activities. This epidemiological study was conducted in two communities (i.e., commercial fishing communities and a non-fishing city in southern Thailand) to investigate the associated risks of exposure in children. The study's primary goals were to determine the potential sources of lead, cadmium, and arsenic exposures in both communities and to determine associated exposure risk factors in children using questionnaire and biomonitoring data.

Cross-sectional, analytical studies were undertaken among 60 children who attended local children development center or kindergarten. The total of 30 urine samples, 11 drinking water, and 11 of domestic water, were randomly collected from each community for lead, cadmium, and arsenic content analysis. The parental KAP and children's direct exposure survey and hygiene and sanitation evaluation were administered to obtain information about socio-economic status and risk factors for lead, cadmium, and arsenic exposures.

In fishing community, geometric mean urinary lead, cadmium, and arsenic were 1.02 ± 1.42 ng/mL, 1.02 ± 1.45 ng/mL, and 3.93 ± 1.69 ng/mL, when the city was found to have 0.88 ± 1.46 ng/mL, 0.32 ± 1.38 ng/mL, and 4.02 ± 1.60 ng/mL, respectively. The fishing community's geometric mean creatinine corrected urinary HMM levels were found to be higher than the city. No statistically significant associations were found between log-transformed urinary lead, cadmium, or arsenic levels and drinking water or domestic water. Pearson correlations suggested that, in fishing community, lead and arsenic sources were not the same. However, cadmium sources were the same with lead or arsenic sources; HMM sources were the same for the city.

Our study demonstrated the patterns of lead, cadmium, and arsenic exposures in children by integrating biomonitoring, environmental, and questionnaire data. The results revealed that seasonal factors had more impact on the outcome than geological locations. The factors that influenced lead exposure were parental individual income, parental education level, hygiene and sanitation scores, and children's direct exposure. Factors influencing arsenic exposures were secondhand smoking and seafood consumption before the urine sample collection day. In addition, we found the number of parental cigarettes smoked significantly affected the magnitude of cadmium exposures. For intervention purposes, we suggested that, for children who live in a high risk area, the HMM annual check-up during a medical visit at school and parental survey should be done. In addition, we provided hygiene and sanitation intervention materials and HMM guidelines to the parents of children in both study areas.

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I. Background and significance

Source of exposures to lead, cadmium, and arsenic in children

Children have a potential risk of exposure to lead, cadmium and arsenic contaminations from many pathways such as para-occupational contamination (take-home contamination), direct exposure through everyday activities, hand-to-mouth behavior, and non-occupational contamination such as contaminated food, water, and smoking. This exposure can occur through multiple routes including digestion, dermal absorption, and inhalation. Hygiene, sanitation, and infrastructure conditions may contribute a certain level of lead, cadmium, and arsenic contaminations in children. The World Health Organization (WHO) has listed ten chemicals of major public health concern, which includes lead, cadmium, and arsenic, which are potential human carcinogens and may inflict acute organ damage. (Tchounwou et al., 2012).

Lead

Lead is a bluish-white lustrous metal, which is a relatively poor conductor of electricity, very resistant to corrosion, and tarnishes upon exposure to air. Lead can be found in natural elements such as soil, and water, as well as inside homes and various consumer goods. The natural level of lead in soil ranges from 50 to 400 parts per million, (Environmental Protection Agency, 2017). The purported proportional lead contamination pathways are through uptake of food (65 percent), water (20 percent), and air (15 percent) (Lenntech, nd). However, the human body absorbs higher levels of lead through inhalation. (NIOSH, 2018). Lead is extensively used in car batteries, pipes bearing, the glass of computer and television screens to shield the viewer from radiation as well as sewage discharge, aging metal pipes, and leaching from landfills (UNEP-CEP, 2008).

Lead is also heavily used in some occupational activities such as production of fishing equipment, spray painting, welding, and pesticides application. Lead is present in foods such as vegetables, fruit, meats, grains, seafood, soft drinks and wine, and cigarettes. Lead can enter water through corroded pipes and polluted environments. In air, people can be exposed to lead derived from vehicle exhaust from leaded gasoline, industrial sources such as smelters, contaminated landfills, lead manufacturing, and recycling industries. (WHO, 1993). As a study by WHO revealed, even though the contamination and disease burden have been steadily declining, the occupational and community exposures to lead persist in many places around the world (Järup, 2003, p. 167; Landrigan et al., 2017, p. 17).

Cadmium

Cadmium can be found in the earth's crust, manure, tobacco products and pesticide formulations. It is a lustrous, silver-white, malleable metal that can be cut with knife but tarnishes in air. Cadmium is used mainly for pigments, coatings and plating, and as stabilizers for plastics. It can be used as metal coating protection against sea to improve the metal's corrosive resistance. Cadmium is released into the air through forest fires, released into water through weathering of rocks and some is released through human activities such as smoking, outdoor burning, and fertilizer. Cadmium uptake can occur through food such as mushrooms, liver, shellfish, cocoa powder, and seaweed. Another pathway that induces a significant cadmium concentration in the environment is smoking. People who breathe in cadmium can severely damage their lungs. When cadmium contaminates soil, it can be extremely dangerous due to the uptake through food. In water cadmium can bioaccumulate in shellfish and fish. However salt-water organisms are more resistant to cadmium poisoning than freshwater organisms. (Lenntech, n.d.).

Arsenic

Arsenic is widely present in nature. It is a toxic metalloid. Arsenic is more toxic when it is in inorganic forms. It has been used for pest control, wood preservation, etc. In the environment, atmosphere, water and soil can be contaminated through industrial uses. (American Academy of Pediatrics, 2009). Food and seafood can naturally contain organic arsenic (nontoxic form), however, the inorganic form can accumulate in foods through the arsenic containing soil and water. Children eat and drink more than adults per body weight. Hence, when they consume arsenic contaminated foods and water, resulting in more arsenic per uptake. (Dartmouth, 2018).

Source of exposures to lead, cadmium, and arsenic in southern Thailand

The geographical location of the southern region of Thailand has established differences in people's occupations. The occupation that distinguishes the south from other regions in the country is the industrial fishing business. This type of business and related business activities involve lead, cadmium, and arsenic in their operations. Hence, they are a primary source of lead, cadmium, arsenic exposure in workers and people who live in the community. When occupational exposures are combined with other factors such as hygiene and sanitation, infrastructure status, environmental factors such as water source, parental education, socioeconomic status, and diet, the magnitude of the contamination of the community people can be quite large especially for children. Previous reports have identified low- and middle- income countries as ones with higher prevalence of exposures to heavy metals and metalloids (HMM). (Järup, 2003, p. 167). Another environmental setting in this region that is interesting to assess lead, cadmium, and arsenic contamination is the area that is close to the limestone mountains, however it does not have exposure from commercial fishing activities.

Fishing community

Ban Tub Lamu is a small, coastal community with high fishing and tourism activities located in Phang-Nga province in southern Thailand. Approximately 2,596 people (1,833 households) currently reside in this community. Geographically, the fishing community is located by the Andaman sea coast and ocean wind constantly passes through this area. Seasonally during monsoon season (June and September), tropical storms and rain commonly occur in this area. The geographical and seasonal factors may affect the contamination exposure and concentration level of the heavy metals. (Hong Yao, et al., 2014)

Most of the people living in this area work in the local commercial fishing industry, agriculture and recreational business. People who live in Ban Tub Lamu may have increased risk of lead (Pb), cadmium (Cd), and arsenic (As) exposures due to the occupational activities such as heavy metals exposure sources, the lack of knowledge about hygiene and sanitation, diet, and the poor condition of the community's infrastructure.

City of Phang-Nga

City of Phang-Nga is the capital of Phang-Nga province. The city is located near the gulf of Phang-Nga, surrounded by limestone mountains. Approximately 7,063 people (3,983 households) resides in the city. Most people who work in the city are contractors (24.66 percent), government and company employees (17.51 percent), house wives (12.97 percent), business owners (11.13 percent), farm owners (0.79 percent), and others (45.65 percent). Approximately 2,596 people (1,833 households) currently reside in this community. Due to the distinct geographical location and age of city infrastructure, children who live in the city may have increased risk of lead (Pb), cadmium (Cd), and arsenic (As) exposures due to lead, cadmium, and arsenic particles settling process, diet, and water source. In the 15th century, Phang-Nga province bloomed from the tin mining industry and rubber plantations, later on it became an international trading center. (Know Phangnga, 2016). The mining, industrial operations, metal refineries, petrochemical production, power plants, and electronics manufacturing largely attributed to heavy metal exposures in human. Moreover, the mining and associated activities are one of the most important sources of contamination in surface water and soil. (Myung Chae Jung, 2008). In the past 60 years, even though there are no active tin mines found in the province, but the surface water from tin mines has been using in the city's plumbing system as the source of domestic water for its people. From the study in 2003, tin is found to have association with lead, cadmium, and arsenic. (Railsback, 2003). Hence, the low level exposure of the substance can become a public health burden in future.

There are many research studies on the individual effects of these HMM; however, real-world exposure in fishing community and the city are from multiple sources and represent mixtures of these chemicals. Certain job activities and lower levels of education have reportedly contributed to high levels of lead was found in fishing workers (40 ug/dL). Environmental Protection Agency (EPA) has indicated cadmium is a probable human carcinogen, causes renal effects and tumors in the respiratory system in places such as the lungs, trachea, and bronchus with cancer deaths at the inhalation unit risk 1.8 x 10^{-3} per ug/m^3. However, the OSHA's permissible workplace Cd limit is 5 µg/m^3 (fumes). People in this province consume rice daily and seafood four times per week due to location and their occupation. In 2017, the Center of Excellence on Environmental Health and Toxicology in Thailand reported the Arsenic Codex limits for brown rice at 200 ug/kg and white rice 350 ug/kg. Arsenic is characterized as a type A human carcinogen. Based on Ministry of Natural Resources and Environment (Pollution Control Department), for drinking water, the maximum allowable concentration of lead is 50 ng/mL, cadmium 5 ng/mL, and arsenic 50 ng/mL. For ground water, the maximum allowable concentration of lead is 50 ng/mL, cadmium 10 ng/mL, and arsenic 50 ng/mL. (Pollution Control Department, 1999)

The population of fishing community and the city consist of native Thais and immigrant workers from Burma, especially in fishing community. Workers engaging in fishing activities generally have poor hygiene conditions and are mostly uneducated. Lead, cadmium, and arsenic exposure in their children is likely derived from direct exposure (water, air/dust, contaminated food, and passive-smoking) and para-occupational exposures. Geographical variables, socio-economic factors, and personal lifestyles may lead to differences in the magnitude, duration and frequency of exposures; evaluation of these factors is crucial for mitigating metal exposures in the future. This study is the first step in a larger overall agenda to implement the regulations to prevent new exposures and to manage/ mitigate existing Lead, cadmium, and arsenic exposure in the Phang-Nga province, especially in susceptible populations like children.

Children are particularly at risk of being exposed to HMM that their parents carry to their homes because of their unique behaviors while they continue to be exposed to these chemicals during their daily activities. Children also have greater susceptibility to the toxic effects of these exposures than do adults, because they may be exposed prenatally, eat more food, drink more water, and breathe more air per unit of body weight, and spend more time in a single environment, such as the home. They are also more likely to have nutritional deficiencies that lead to increased absorption of these chemicals. Children have more years of future life and thus a longer time to develop delayed consequences of early exposures, potentially even including lead-related dementia. In addition, children have a lack of control over the circumstances of their environment, and thus, cannot remove themselves from the exposure. Parental knowledge, attitude and practice about Lead, cadmium, and arsenic exposures will help us better understand the drivers of these exposures and ultimately the health risk associated with them in these environmental settings.

Health effects of lead, cadmium, and arsenic in children

Lead

Lead is a neurologically disruptive chemical that has been a global public health concern, especially in young children populations because normal brain development and growth is extremely dynamic in the first 2 years of life. During rapid brain development, children’s brains are highly vulnerable to lead toxicity. Children aged about two years old, are more susceptible to exposures than older children, through their hand-to-mouth behavior, they more likely put lead-contaminated hands, toys, batteries, keys, or paint chips in their mouths. Children’s gastrointestinal tracts absorb lead more than adults. (Denoon, 2007). When lead is absorbed, it is stored in blood, bones, and tissues and excreted in urine. The biological half-life of lead in blood is 28-36 days, however lead has a much longer biological half-life in bone of about 10 years (Griffing et al. 1975; Rabinowitz et al. 1976; ATSDR 2005) and can be stored for more than 30 years. (EPA, n.d). Stored lead is a source of continual internal exposure that can cause health issues later on in life. (NIOSH, 2018). Inorganic lead is not metabolized in liver. Most of the organic lead that is ingested is absorbed and compounds are metabolized in liver. (ATSDR 2017) Children can absorb 50 percent of ingested lead after a meal (ATSDR 2010) and up to 100 percent on an empty stomach. (ATSDR 2017). A high level of lead exposure can damage kidneys, nervous and reproductive systems, cause convulsions, coma, and death. (Bureau of Family Health, n.d.) The symptoms can be diagnosed from a blue line around the gums. Lead can also cause high blood pressure and anemia. (Amal A. Hegazy, et. al, 2010) For fetuses and young children, lead is harmful to their developing brains. At later ages, lead can cause irreversible consequences such as learning disabilities, behavioral problems, and lower IQ and /or developmental delays. (WHO, 1993). WHO estimated in 2012 that lead was responsible for causing mild-to-moderate mental developmental delays of 0.6 million children annually (Landrigan et al., 2017, p. 17). Inhalation and ingestion are the primary ways in which these contaminants enter the body; lead can affect most of organs and reside in teeth and bones for decades (Meyer, Brown, & Falk, 2008). Children can absorb lead four to five times more than adults and they are more sensitive to lead exposure because of to their developing brains and nervous systems. (Meyer et al., 2008). According to WHO, children who survive severe lead poisoning may suffer lifelong consequences, including behavioral disorders, physical disabilities, and learning impairments (World Health Organization, 2017b).

Cadmium

Health effects that can be caused by cadmium are stomach pains, severe vomiting, and diarrhea, bone fracture, reproductive failure and possibly infertility, central nervous system and immune system damages, possible DNA damage or cancer development, and psychological disorders. Cadmium levels in the atmosphere are significantly higher when people smoke. (Lenntech, n.d.) Through inhalation, cadmium is transported into the lungs and then throughout the body through blood. Depending on the particle size, about 10 – 50 percent of the inhaled dose is absorbed. Cadmium exposure can derive from food through ingestion passes through the gastrointestinal tract. Most orally ingested cadmium, individuals absorb about 6 percent of ingested cadmium, in those with iron deficiency, maybe absorbed up to 9 percent. Cadmium, specifically in drinking water (5 percent) is more easily absorbed than food (2.5 percent). Dermal absorption of cadmium is not a significant route of exposure, about 0.5 percent can be absorbed through the skin. (ASTDR, 1999). The effects of cadmium exposure through multiple routes can increase by existing levels in the body and additional daily uptake. Through blood circulation, cadmium is transported to the liver and then kidneys. Cadmium can damage kidney filtering mechanisms and further kidney damage. In humans, cadmium has a biological half-life in kidneys of 6 – 38 years and 4 – 19 years in liver.

(ATSDR, 1999). The cadmium biological half-life of the urinary cadmium concentration has about 13.6 (9.0 – 28.2 years) and for creatinine-adjusted urinary cadmium there were about 14.2 years (11.2 – 19.4 years). (Suwazono, et. al, 2009). It takes accumulated cadmium in kidneys a very long time to be excreted from body.

Arsenic

Arsenic is a naturally occurring HMM. It is widely distributed in the earth's crust. The EPA has ranked inorganic arsenic as a human carcinogen. Through ingestion, accumulated arsenic causes skin cancer. (ATSDR, 1999). Arsenic can cross the placenta, hence infants can be exposed to it through pregnancy, which can affect infant growth and development and cause health issues later on. (Dartmouth n.d.). According to the Agency for Toxic Substances & Disease Registry (ATSDR), arsenic has a biological half-life of 10 hours (Rossman, 2007). Long-term uptake of large quantities of arsenic contaminated drinking water may cause skin conditions, skin cancer, and lung cancer. The health effects that arsenic can cause are lower IQ, impaired brain development, growth problems, breathing problems, an unhealthy immune system, and cancer as an adult. The systems that can be affected by arsenic dermal (skin), gastrointestinal (digestive), hepatic (liver), neurological (nervous system), respiratory. (Lenntech, n.d.).

Human biomonitoring and biomarkers of lead, cadmium, and arsenic exposures

Biomonitoring

Biomonitoring is the assessment of human exposure to environmental chemicals by measuring the chemicals, their metabolites or reaction products in human specimens such as blood or urine. A metabolite is a chemical alteration of the original compound produced by body tissues. Blood, serum, and urine levels reflect the amount of the chemical that gets into the body irrespective of routes of exposure. The measurement of an environmental chemical in a person's blood or urine is a measure of exposure. The amount of chemicals that enter the body though ingestion, inhalation, and dermal absorption and the chemicals' metabolite transformation and elimination mechanisms determine the amount of chemicals in blood, serum, and urine, however the concentration level of the chemical does not determine the exposure source or route. (CDC, 2019). A level measured in a biological matrix does not necessarily reflect the disease and requires separate studies. (CDC, 2019)

Biomarkers of urinary lead, cadmium, and arsenic

Lead

The Fourth National Report on Human Exposure to Environmental Chemicals Updated Tables, January 2019, Volume One, survey cycle 2015 -2016, reported that among 486 samples, the urinary lead concentration in children aged 3-5 years old had a geometric mean (95% confidence interval) of 0.26 ug/L (0.23 - 0.29). The creatinine corrected urinary lead data collected from 485 children in the U.S. from 2011 – 2016) in children aged 3-5 years old had a geometric mean (95% confidence interval) ug/L of 0.590 ug/L (0.532 – 0.654). The Center for Disease Control and Prevention have said there is no safe level for this element, however a blood lead level at 10 ug/L is a concerned health effect level.(CDC, n.d.). The Environmental Protection Agency has identified lead as a probable human carcinogen, however further evidence in humans is required for the assessment (EPA, 1988). (Table 1)

Cadmium

The Fourth National Report on Human Exposure to Environmental Chemicals Updated Tables, January 2019, Volume One, survey cycle 2015-2016, reported the geometric mean urinary cadmium of children ages 3 – 5 years among 486 subjects, a valid estimate of the geometric mean was not calculated due to the proportion of limit of detection (LOD) was too high to provide a valid result, more than 60 percent of samples had concentrations below the LOD (0.036 ug/L). For urinary cadmium (creatinine-corrected) the geometric mean was not calculated due to the urinary cadmium geometric mean was below the LOD. The higher urinary cadmium concentration was found in older ages (6 years old and older). Comparing between sex, females had higher urinary cadmium concentration than males, Asians had highest concentration comparing with other races. (CDC, 2019). Based on the EPA cadmium non-cancer assessment, a dose of 5×10^{-3} mg/kg marks the point of departure (POD). The reference dose of cadmium in water is $5x10^{-4}$ mg/kg-day. Cadmium health effects are manifested as the presence of abnormal quantities of protein in the urine called proteinuria. Therefore, the POD and reference dose of cadmium in food are 1×10^{-2} and $1x10^{-3}$ mg/kg-day respectively, at this level the significant proteinuria can occur. For cancer risk assessment, cadmium is considered a probable human carcinogen and the estimated carcinogenic risk from inhalation exposure is 1.8×10^{-3} per ug/m^3, this dose can cause cancer in lung, trachea, bronchus cancer, or deaths (Thun et al., 1985). (Table 1)

Arsenic

When arsenic undergoes bio methylation in the liver and approximately 70 percent of arsenic is excreted in urine. Most of a single, low-level dose is excreted within a few days after ingestion for example organic arsenic in seafood, completely excreted within 48 hours of the last meal. (ATSDR, 2010). The Fourth National Report on Human Exposure to Environmental Chemicals Updated Tables, January 2019, Volume One, survey cycle 2015 -2016, the geometric mean urinary arsenic level of children ages 3 – 5 years among 486 subjects was 4.05 ug/L (3.58 - 4.58). The report also revealed that males had higher urinary arsenic concentration than females. For urinary arsenic (creatinine-corrected), the geometric mean was 9.31 ug/L (8.18 – 10.6), females had higher concentration than males. Comparing between races, the Asians had the highest urinary arsenic than other races. (CDC, 2019) According to the EPA arsenic cancer assessment, carcinogenic risk from oral exposure is 1.5 per mg/kg-day; drinking water risk is 5×10^{-5} per ug/L. The quantitative estimate of carcinogenic risk from inhalation exposure is 4.3×10^{-3} per ug/kg-day. Exposure to arsenic at this concentration level and higher can cause health effect such as a lung cancer. (Brown and Chu, 1983a,b,c; Lee-Feldstein, 1983; Higgins, 1982; Enterline and Marsh, 192). The reference dose of non-cancer assessment through oral exposure is 3×10^{-4} mg/kg-day, and the POD is 8×10^{-4} mg/kg-day. (EPA, 1998). (Table 1)

Hypotheses

A central part of this study is the Knowledge, Attitudes and Practices (KAP) survey (Appendix 1) which is intended to understand and characterize parental understanding of HMM exposures and potential outcomes in children in a fishing community and another city in southern Thailand. The research findings will aid the development of potential mitigation strategies for these exposures. The primary goals of the surveys are to 1) Evaluate geographical and exposure frequency with qualitative elements collected from questionnaires and KAP surveys such as socio-demographic, diet, and HMM exposure frequency data to better understand the sources of exposures and effect modifiers of HMM exposure in two different areas: a) a fishing community (Ban Tub Lamu) and b) the close-by city of Phang-Nga., 2) Evaluate the effect of water (domestic and drinking water) used in fishing community and the city on HMM concentrations in children's and 3) Evaluate the sources and factors that influence the urinary HMM concentrations in children between fishing communities and the city of Phang-Nga, southern Thailand (captured via biomonitoring of urine samples). The hypotheses are

1. The children who live in fishing community have higher HMM concentration than those who live in the city, due to the effects of geographical location and other qualitative factors (such as para-occupational contamination, hygiene and sanitation, socio-demographic, diet, and daily activities).
2. The primary HMM sources are drinking water and domestic water, and the fishing community has higher water HMM concentration than the city.
3. There are differences in factors and sources of HMM that influence the urinary concentrations in children between fishing community and the city.

II. Methods

Our study protocol received IRB approval from both Emory's IRB (IRB00102980) and Phang-Nga Provincial Public Health Office before the participant recruitment process begin.

Participant recruitment

We conducted the study in two locations in Phang-Nga province to represent different type of community based on occupational activities. The study population is a pair of parent and children who lived in fishing community and the city of Phang-Nga. Our inclusion criteria were children age two to five years old, who physically lived in the fishing community since birth and attended the local children development center and their parents or legal guardians who physically have lived in the fishing community for minimum of six years by the time of the study period was initiated and urine samples were collected. Another group of subject is the children age two to five years old, who physically lived in the city of Phang-Nga since birth and attended the city of Phang-Nga Kindergarten school and their parents or legal guardians who physically lived and worked in the city minimum of six years by the time of the study period was initiated and urine samples were collected. Urine samples were collected from June to July, 2018. The reaserch team included provincial health officers and local volunteers. The field staff training period was held at each location in June 2018, a week later the community meeting at each location for participant recruitment. The house visit date and time were scheduled at the meeting.

Exposure assessment

Survey

The survey was designed to capture possible factors that may contribute to the lead, cadmium, and arsenic exposures in children from para-occupational (bring home contamination) and children's lead, cadmium, and arsenic direct exposures via ingestion, absorption, and inhalation routes. The survey (see Appendix 1) consists of four sections: section 1; Family members' questionnaire consists of A) Household roster and B) Socioeconomic Status, section 2; Parental Knowledge, Attitude, and Practice on lead, cadmium, and arsenic, section 3; Child's development: anthropometry and seven day activities and diet report, and section 4; Hygiene and sanitation evaluation form. Recruitment will include an initial community meeting and prescreening followed by a scheduled appointment for consent and intake. For privacy and identity protection, all subjects were assigned a code. Including both locations, the total sample size is 120 people, for each location 60 people (30 parents and 30 children).

Water sample collection

For each group, a total of 22 water samples will be collected: 11 drinking water samples, 11 domestic water (10 households and one children center/ kindergarten in each location). A total of water samples from two groups is 44 samples. The water sample was collected during the house visit.

Drinking and domestic water sample collection

The drinking water samples were collected according to the EPA quick drinking water collection: sampling for metals contaminants guidelines. (EPA, 2005). The tube and cap will be rinsed three times before adding water to the tube. A 50 ml. water sample will be collected in a polypropylene tube and stored in the freezer at the Phang-Nga provincial hospital laboratory at - 20 Celsius degrees. Each sample was labeled using a combination of English alphabets and a number. The two field blanks were used at each location during water collection period for quality control purposes, each blank tube was filled with 50 ml. of Q water from the Laboratory of Exposure Assessment and Development for Environmental Research (LEADER) of Rollins School of Pucblic Health of Emory University. All water and four field blanks were shipped to the LEADER laboratory.

Outcome assessment

Human biomonitoring samples

The urine samples were collected in children aged two - five years old, 30 children in each group, for a total of 60 samples. The individual urine samples (50 mL) were collected in lead-free polypropylene tubes. All tubes were prepared for minimizing lead contamination using the Centers for Disease Control and Prevention guidelines. (CDC, 1997). Each tube was labeled using a combination code to protect subjects' privacy and identification. All urine sample tubes were stored in a freezer at -20 celsius degrees at the Phang-Nga provincial hospital laboratory then shipped to the LEADER laboratory.

Statistical analysis

All parameters were analyzed descriptively. Point estimates of the geometric mean (GM), median and distribution percentiles were evaluated for urinary lead, cadmium, and arsenic. A urine value below the lower limit of detection (LOD) was substituted with the imputed value of LOD value divided by square root of two (Hornung & Reed, 1990). Since the data were not normally distributed, natural log transformation was performed. The urinary levels of lead, cadmium, and arsenic between locations, mean of natural log and the 5^{th}, 25^{th}, 50^{th}, 75^{th}, and 95^{th} percentile were compared using ANOVA and t-tests. Further analysis was conducted using Linear Regression to test the association between each parameter and the logarithm of the urinary lead, cadmium, and arsenic concentration to assess which pair would display a linear and significant relationship. Pearson correlations between the natural log of each urinary HMM were assessed to indicate characteristics of a possible exposure sources of each metal if they are from the same source in each location.

III. Results

Basic demographic data

A total of 60 urine samples, 44 water samples, and 60 surveys from 60 pairs of parents and children (total of 120 people) were collected. The urinary and water HMM concentrations are described in Table 2 - Table 4, respectively. Socioeconomic, and other questionnaire data are described in Table 5. We found that children in the fishing community had higher levels of creatinine-corrected HHM levels than those of children in the city: The GM urinary creatinine-corrected HMM levels of children in the fishing community were higher than those of children in the city (Table 3). The values found in this study were compared to the values reported in CDC's Fourth National Report on Human Exposure to Environmental Chemicals, Updated Tables, January 2019, Volume One (Table 3).

Exposure summary

Water

Drinking water: As listed in the Table 4, the average lead and arsenic concentration in drinking water in the fishing community were lower that the city (Drinking water lead: fishing community: 0.1850 ± 0.2588 ng/mL and the city:0.3492 ± 0.2301 ng/mL ; Drinking water arsenic: fishing community: 0.1817 ± 0.0591 ng/mL and the city: 0.5912 ± 0.5413 ng/mL, respectively). The mean drinking water lead and arsenic were not significantly different between locations ($p\text{-value}_1$ 0.1314 and $p\text{-value}_2$ 0.7328, respectively). The cadmium concentration in both locations were below the level of detection (< 0.02 ng/mL).

Domestic water: The mean lead and arsenic concentration in domestic water in the fishing community were lower that the city. (Domestic water lead: fishing community: 0.5263 ± 0.8425 ng/mL and the city: 3.3411 ± 7.5926 ng/mL; Domestic water arsenic: fishing community: 0.1720 ± 0.1184 ng/mL and the city: 0.5912 ± 0.5413 ng/mL, respectively). The mean domestic water lead was not significantly different between locations (p-value 0.1795). However, a significant difference in mean of the arsenic concentration between locations (p-value 0.0208). The cadmium concentration in both locations were below the level of detection (< 0.02 ng/mL). (Table 4)

Hygiene and sanitation

The hygiene and sanitation scores (HSS) and house-cleaning frequency were evaluated as potential predictors for the urinary HMM concentrations in children. The fishing community had lower mean HSS scores than the city (fishing community: 22.03 ± 6.52 scores and city: 24.40 ± 8.78 scores) indicating they had poorer hygiene and sanitation practices. On average, people who lived in the fishing community cleaned their houses 6.80 ± 1.6 times per week when people who lived in the city cleaned their houses 5.80 ± 1.95 times per week. (Table 5)

Socioeconomic status

***Individual income**:* The individual income of parent who lived in fishing community was lower than the individual income of parent in the city (fishing community: 7,916 ± 5589 baht and city: 12603 ±11351 baht) (Table 5).

***Parental education**:* The average parental education level in fishing community was middle school whereas the average parental education in the city was undergraduate level indicating higher educational attainment in city families. Overall, the fishing community's socioeconomic level was lower than the city.

The parental HMM knowledge: Parental HMM knowledge was separately evaluated using a KAP survey from the parental education to minimize bias from assuming that parents who have higher education are more knowledgeable about lead, cadmium, and arsenic. Parents who lived in the finishing community had lower mean HMM knowledge scores than parents that lived in the city (Lead: fishing community: 5.13 ± 4.1 and city: 7.27 ± 4.25; Cadmium: fishing community: 0.93 ± 1.66 and city: 3.07 ± 3.54; Arsenic: fishing community: 0.97 ± 1.00 and city: 1.2 ± 0.66).

Infrastructure: The infrastructure parameter includes the age of house and pipe. We found that both the fishing community's and city's infrastructure had an average age of 11 – 15 years.

Children's heavy metals direct exposures

This parameter assessed by including the multiple direct contact pathways of exposure: 1) Direct dermal or oral contact with items that contained lead, cadmium, and arsenic such as lead paint chip, keys, toys, and batteries; and 2) Visits to places conducting lead-, cadmium-, and arsenic-related activities such as metal welding shop, boatyard and electronic repair shop. From the survey report, we found that, the frequency of both types of direct contact between fishing community and city was significantly different ($p\text{-value}_1$ 0.0335 and $p\text{-value}_2$ 0.0014). The mean direct dermal and oral contact of children who lived in the fishing community was lower than children who lived in the city. (Fishing community: 2.13 ± 1.28 times and the city: 1.4 ± 1.33 times). The mean visits to places conducting HMM-related activities for children who lived in the fishing community was higher than children who lived in the city (fishing community: 5.9 ± 4.24 times and city: 2.93 ± 2.36 times).

Second Hand Smoking (SHS)

Parents in the fishing community smoked cigarettes three times more than parents who lived in the city (Table 5). Similarly, children who lived in the fishing community were exposed to outdoor smoking more than children who lived in the city. The ratio of smokers: non-smokers was five times higher in the fishing community than in the city.

Diet

In this study, we assumed that diet is a major contributor of total arsenic contamination in children. The diet information was collected from parental survey and children's daily activity report. The three major food types evaluated were seafood, rice, and flour-ingredient snacks. (Table 5)

Seafood: One of the rich organic arsenic sources is seafood. The mean seafood consumption per week was four times per week and was not different between fishing community and the city. Within three days prior to sample collection, 90 and 83 percent of children in the fishing community and city, respectively, consumed seafood.

Rice and Flour-ingredient snack: Children who lived in the fishing community, consumed less rice and flour-ingredient snack per day than the children who lived in the city. (Rice: fishing community: two times/day and city: three times/day; Flour-ingredient snack: fishing community: four times/day and city: five times/day)

Outcome summary

The distribution of urinary lead, cadmium, and arsenic were right-skewed, geometric means (GM) and geometric standard deviations (GSD) were calculate. Therefore, log-transformed of urinary lead, cadmium, and arsenic were used in statistical analyses.

Lead

Fishing community-urinary lead: The geometric mean, geometric standard deviation, and the 95% confidence intervals (GM ± GSD (lower CI, upper CI)) of urinary lead of 30 children who lived in a fishing community was 1.022 ± 1.42 (0.90, 1.16) ng/mL. The median and 95th percentile urinary lead concentration were 0.99 and 3.60 ng/mL respectively. Females had higher geometric mean urinary lead concentrations than males. (females: 1.10 ± 1.53 (0.87,1.38) ng/mL and males: 0.95 ± 1.28, (0.83, 1.10) ng/mL (Figure 2 and Table 2).

City-urinary lead: The geometric mean, geometric standard deviation, and the 95% confidence intervals (GM ± GSD (lower CI, upper CI)) of urinary lead of 30 children who lived in the city was 0.88 ± 1.46 (0.76,1.02) ng/mL. The median and 95th percentile geometric urinary lead were 0.73 and 2.99 ng/mL respectively. Females had higher geometric mean urinary lead concentrations than males (females: 0.95 ± 0.72 ng/mL and males: 0.82 ± 0.73 ng/mL.

We found that children in the fishing community had geometric mean urinary lead concentrations that were higher than children in the city; however, the difference was not significant (p-value 0.1182).

Females had higher geometric mean urinary lead than males in both locations, specifically females who lived in the fishing community had a highest geometric mean urinary creatinine corrected lead level (Figure 2 and Table 2)

Cadmium

Fishing community-urinary cadmium: The geometric mean, geometric standard deviation, and the 95% confidence intervals (GM ± GSD (lower CI, upper CI)) of urinary cadmium of children who lived in the city was 1.02 ± 1.45 (0.27,0.35) ng/mL. The median and 95th percentile geometric urinary cadmium were 0.06 and 0.23 ng/mL respectively. Males had geometric mean urinary cadmium higher than females. (females: 0.30 ± 1.44 ng/mL and males: 0.32 ± 1.47 ng/mL). (Figure 2 and Table 2)

City-urinary cadmium: The geometric mean, geometric standard deviation, and the 95% confidence intervals (GM ± GSD (lower CI, upper CI)) of urinary cadmium of children who lived in the city was 0.33 ± 1.38 ng/mL. The median and 95th percentile geometric urinary cadmium were 0.08 and 0.25 ng/mL respectively. Males had geometric mean urinary cadmium level higher than females (females: 0.33 ± 1.33 ng/mL and males: 0.30 ± 1.42 ng/mL).

We found that children in the fishing community had geometric mean urinary cadmium concentrations that were higher than children in the city; however the difference was not significant (p-value 0.1182). Males had higher geometric mean urinary lead than females in both locations, specifically males who lived in the fishing community had a highest geometric mean creatinine corrected urinary cadmium level (Figure 2 and Table 2)

Arsenic

Fishing community-urinary arsenic: The geometric mean, geometric standard deviation, and the 95% confidence intervals (GM ± GSD (lower CI, upper CI)) of urinary arsenic in 30 children who lived in fishing community was 3.93 ± 1.69 (3.23,4.78) ng/mL. The median and 95th percentile geometric urinary arsenic were 4.10 and 2.83 ng/mL respectively. Males had geometric mean urinary arsenic level higher than females (females: 3.31 ± 1.81 ng/mL and males: 4.67 ± 1.49 ng/mL). (Figure 2 and Table 2)

City-urinary arsenic: The geometric mean, geometric standard deviation, and the 95% confidence intervals (GM ± GSD (lower CI, upper CI)) of urinary arsenic in 30 children who lived in the city was 4.02 ± 1.60 ng/mL. The median and 95th percentile geometric urinary arsenic were 0.08 and 0.25 ng/mL respectively. Females had geometric mean urinary arsenic level higher than males (females: 4.32 ± 1.60 ng/mL and males: 3.74 ± 1.60 ng/mL).

We found that children in the fishing community had geometric mean urinary arsenic concentration lower than children in the city, whereas, the geometric mean creatinine corrected urinary arsenic concentration of children who lived in the fishing community was higher than the children in the city; however, the difference was not significant (p-value 0.0687). Males who lived in a fishing community had the highest geometric mean urinary arsenic than other groups. (Figure 2 and Table 2)

Potential HMM exposure sources correlation

We examined the correlation between the urinary lead, urinary cadmium, and urinary arsenic to assess the potential common sources of HMM exposures (Figure 3). Pearson correlations demonstrated positive liner relationships between urinary lead*cadmium (r = 0.4480, p-value 0.0131) and urinary cadmium*arsenic (r = 0.4305, p-value 0.0176), however the correlation between urinary lead*arsenic was not significant (r = 0.3146, p-value 0.0904). Pearson correlations in urine samples from city children showed positive linear relationships between lead*cadmium (r = 0.4651, p-value 0.0096), lead*arsenic (r = 0.5828, p-value 0.0007) and cadmium*arsenic (r = 0.5755, p-value 0.0009). (Figure 3)

Associations between urinary HMM and potential exposures

Water

Drinking and domestic water: No significant linear relationship between HMMs at either location were observed in drinking water or domestic water. (Figures 4, 5, 6, and 7)

Hygiene and sanitation

Hygiene and sanitation scores and house cleaning frequency: As the HSS score increased, urinary lead levels were lower. For example, there was a 20 percent lower urinary lead level in participants in the upper quartile of HSS scores as compared to the lower quartile (p-value 0.0024). Similarly, with cadmium, an 11 percent reduction was observed between these two quartiles. Sampling location did not alter this association. No relation between urinary arsenic and HSS score was observed. House cleaning also showed no associations with urinary HMM concentrations (Table 5).

Socioeconomic status

Individual income: According to the Linear regression analysis, the results revealed the negative association between the individual income and the log-transformed urinary lead across two communities (p-value < 0.0001). However, we did not find the significant relationship in urinary cadmium (p-value 0.8735) and urinary arsenic (p-value 0.9666). (Table 5).

Parental education and HMM knowledge: **The results** showed a decreasing trend of log-transformed urinary lead (p-value 0.0122) and cadmium (p-value 0.2956) as parental education is higher (from middle school to doctorate). The percentage of urinary lead reduction was higher in a group of higher parental education, reduction range varied between 9 – 24 percent (p-value < 0.0001). The results from Linear regression analysis revealed that geographical locations did not have effect on the association between log-transformed urinary lead, cadmium, and arsenic and parental education.

When we specifically focused on the effect of parental HMM knowledge, the results showed a negative association between parental lead and cadmium knowledge and its log-transformed urinary HHM level, however did not show a significant linear relationship ($p\text{-value}_1$ 0.0959 and $p\text{-value}_2$ 0.7806, respectively). Nonetheless, the association between parental education level and arsenic knowledge did not show a clear trend and was not statistically significant. (p-value 0.1853). (Table 5).

Infrastructure: The relationship between the urinary HMM and the infrastructure age, the increasing trend of the relationship displayed in log-transformed urinary HMM, however they were not significant. (lead: $p\text{-value}_1$ 0.3708; cadmium: $p\text{-value}_2$ 0.6292; arsenic: $p\text{-value}_3$ 0.3754). We also examined the relationship between the age of infrastructure and domestic water HMM in each location, we found the increasing trend of domestic water lead and infrastructure's age in both communities, however the domestic water arsenic in the city had a decreasing trend when the infrastructure's age is higher. No relationship was significant. (Table 5).

Children's direct exposure

Children's direct contact and visit HMM sources: The geographical location did not have effect on the association between the children's direct exposure and the urinary HMM. The effect of visiting the HMM sources on the log-transformed urinary lead was significant (p- value 0.0003) however, not significant with the direct contact. The Linear Regression analysis found that children who visited the HMM sources five times a week, the average log-transformed urinary lead concentration increased by 44 percent compared to those who never been to the HMM related sources, (p-value 0.0249) which equivalents to 1.368 ng/dL. The association between children' visiting the HMM sources on the log-transformed urinary cadmium was not significant (p – value 0.9164). However, the investigators found the deceasing trend of the association. On the opposite findings, we did not find a significant linear relationship between the exposure and log-transformed urinary arsenic (p – value 0.2133) but we were able to capture the positive trend of the association, however, we could not assume that the visit HMM sources is a primary factor that influence that arsenic exposure in these children.

However, when compared the relationship among the HMM direct exposure and log-transformed urinary HMM, we found the evidence of a positive trend in urinary lead, and negative trend in urinary cadmium and urinary arsenic., which expressed the direct contact activities mostly were lead sources. (Table 5).

Second Hand Smoking (SHS)

Indoor SHS: Comparing the effect of the indoor SHS on the urinary HMM concentration between smoking parents and non-smoking parents across the communities, we found that urinary HMM concentrations in children whose parents smoked were higher than the non-smoking group. (lead: 2 percent higher in lead, cadmium: 9.8 percent higher, and arsenic: 18 percent higher). The effect of indoor SHS on the log-transformed urinary lead, urinary cadmium, and urinary arsenic, among children who lived in city were greater than children who lived in fishing community, 2 percent (p-value 0.8126), 4 percent (p-value 0.8197), and 30 percent (p-value 0.1290), respectively. However, they were not significant. (Table 5).

Outdoor SHS: The investigators further analyzed the effect of outdoor SHS exposure on children's urinary HMM, we did not find the significant relationship with the log-transformed urinary HMM (p-value > 0.05). (Table 5).

Parental indoor cigarette smoked per day: We did not find an association between the parental indoor number of cigarette smoked per day and the log-transformed urinary lead across communities (p-value 0.8044). However, found a significant positive association with the log-transformed urinary cadmium and urinary arsenic when the number of cigarettes smoked at least four per day (p-value < 0.0001). (Table 5).

Diet

Based on our findings, the results revealed as followings, a positive association was found between urinary arsenic concentration and seafood consumption three days before urine sample collection (p-value 0.0079), however, the log-transformed urinary arsenic concentration was not significantly associated by the amount of seafood consumed per week. The association between seafood consumption rate per week and log-transformed urinary arsenic in both locations were the same. The research team further assessed the effect of the seafood at different consumption rates, the results exhibited no evidence of the association. When we further investigated the effect of rice and flour-ingredient snack consumption rate on the log-transformed urinary arsenic concentration exposure, we found that there was no significant association between these parameters, even though the consumption rate between the communities was significantly different (p-value 0.0101). (Table 5).

IV. Discussions

Feasibility

This study is the first HMM exposure study using combined environmental pathways and biomonitoring exposure assessment approaches to identify sources of HMM contamination in children. In addition, knowledge, activities and practice were evaluated to assess any potential predictors of exposure to urinary or water HMM levels.

Our study strategy is unique because we recruited participants based on the maximum time spent in each environmental setting. The apparent advantage of this study was the ability to identify the sources of heavy metals in different environmental settings to determine the effect of para-occupational contamination and contaminants direct exposure in children. The biomonitoring matrix used in this study was urine which was considered minimally invasive to the subjects. The data that were collected can be used to identify both individual and community exposure. We suggested development of a HMM management protocol that could help to manage the sources of exposure and mitigate exposure risk and the adoption of HMM knowledge and hygiene and sanitation guidelines to the Provincial Public Health office. We felt that the implementation of such procedures including an annual HMM evaluation could be part of a person's annual community public health visit routine. We found that this study was beneficial to both public health officials and people in the communities and the protocol was modest enough to implement, prevent and protect people from being exposed to these hazardous HMM.

Discussion

As reported in NHANES 2015-2016 in children aged three-five years old, the urinary lead geometric mean (0.26 µg/dL) was lower than those from previous cycles. (CDC, 2019; CDC, 2012*a*; Pirkle et al., 1998). Temporal declines in children's BLLs have been found in other developed countries (Wilhelm et al., 2006). Our urinary GM lead levels were higher than NHANES 2015 – 2016 (Table 2). The range of urinary lead across both communities varied from 0.82 - 1.10 ng/mL. A study in Thai children aged two to six years old in 1993 found the range of blood lead level were between 4.75 – 5.00 ug/dL. (Thai Pediatrics, n.d.) and 13 ug/dL in a child who lived in a battery recycling area in northern Thailand in 2017. (Thai PBS News, 2017). Surveillance data reported by U.S. State Childhood Lead Programs also show a decline in the percentage of children younger than 6 years of age who had BLLs of 10 µg/dL or higher. Risk factors, including minority race or ethnicity; urban residence; residing in housing built before the 1950's; and low family income were found associated with high prevalence of BLLs greater than 10 ug/dL. (CDC, 1991; CDC, 2002; Jones et al., 2009). Recently, the CDC has adopted its expert advisory panel recommendation to use a reference level based on the 97.5 percentile blood lead estimate in U.S.

children ages 1-5 years old. This value will be used to identify children with excessive lead exposure (CDC, 2012*b*). The terminology "blood lead level of concern" will no longer be used. (CDC, 2019).

The urinary cadmium creatinine corrected level from 0.11 - 0.26 ug/g creatinine, which our finding level is lower than the study in Japan. The researchers reported cadmium level as low as approximately 1 ug/g of creatinine was associated with renal tubular effect (Akesson et al., 2005; Ezaki et al., 2003; Jarup et al., 2000; Moriguchi et al., 2004; Noonan et al., 2002). However, two studies of women in Japan whose geometric mean urinary cadmium creatinine corrected were 1.26 and 3.46 ug/g creatinine, considering as lower exposures, they found no correlation between renal tubular effect markers and blood or urine cadmium levels (Ezaki et al., 2003; Horiguchi et al., 2004*b*). From the study in 2002 found that female normally had higher blood and urine cadmium levels compared to men of similar ages, with peak values observed in the fifth to sixth decades (CDC, 2012; Horiguchi et al., 2004*b*; Olsson et al., 2002; Wennberg et al., 2006), our study found similar results in children who lived in city however, found the opposite results in the fishing community.

Based on the U.S. population in the National Health and Nutrition Examination Survey (NHANES) 2019, the survey conducted in 2015-2016, geometric mean urinary arsenic was 4.05 ng/mL (3.58 – 4.58) when our study found the geometric mean urinary arsenic was lower, 3.95 ng/mL (2.38 – 5.61). According to other studies, urinary arsenic levels reflect recent exposures and are moderately to highly correlated with arsenic intakes from drinking water and dietary sources (Ahsan et al., 2000; Calderon et al., 1999; Pellizzari and Clayton, 2006; WHO, 2001) which we did not find a high correlation with drinking water but significantly correlated with seafood consumption. Daily variation in creatinine-corrected urinary arsenic is relatively small when intake is constant (Calderon et al., 1999). Urinary arsenic levels were a better predictor for risk of arsenical skin lesions than were arsenic levels in drinking water in Bangladesh (Ahsan et al., 2000).

HMM pathways

Water

Domestic and drinking water: From our investigation, people in fishing community and the city used domestic water for cleaning and shower, as it was confirmed by the Linear Regression analysis, drinking water through ingestion or domestic water through dermal absorption did not have significant effect on the HMM exposures. According to ATSDR study, dermal absorption is not a significant route for these HMM contamination. (ATSDR, 1999), as well as the level of lead, cadmium, and arsenic in drinking water found below the Thai pollution control department's maximum allowable concentration that showed in Table 2, we can conclude that domestic and drinking water were not primary pathways that contributed to lead, cadmium, and arsenic exposures, which these findings were opposite from our hypotheses. However, the higher water lead and arsenic concentration in the city may come from the old tin mine contaminations while less fishing related activities were conducted during the time of sample collection.

Dominant HMM exposure contributors

From one of our hypotheses, we expected the geological location as the commercial fishing community was one of the primary factors the strongly affects the association between the exposure sources and urinary HMM concentration level. However, we found the mean of some parameters were different between locations, but the association between each relationship did not depend on the geological locations. For example, we found that children who lived in the city were exposed to the HMM direct contact more than those who lived in the fishing community (p-value 0.0335), however, when we assessed the association between the covariate and the outcome, we did not find a significant relationship in each location. The explanation of this specific event will be discussed in the limitation section.

The trend of effects between the outcome and the influential factors are displayed in Table 6, even though some relationships were not statistically significant however, the trend of associations gave us a concept of how all factors interact in the environment, as well as the findings can be used to assist further investigations.

Socioeconomic

Individual income: The results from the Linear Regression analysis confirmed that the higher individual income had negative effect on the lead contamination. Across both communities, in the family whose parental income per capita was between 10,000 – 60,000 baht/month, the urinary lead concentration was declined by 30 – 35 percent, respectively. However, individual income was not a primary factor the influent cadmium and arsenic exposures. World Health Organization (WHO) reported the estimated 90 percent of children with elevated lead levels live in low-income regions (World Health Organization, 2010b, p. 35).

Infrastructure: According to our findings, we discovered that it was one of the contributors that had an effect on a higher level of urinary lead, cadmium, and arsenic. The same results found in many developed and developing countries. (EPA, n.d.). Several studies reported that the old pipe can release lead, cadmium, and arsenic to water. (EPA, 2007). Based on a study in China, the collected indoor dust can affect human health through inhalation. (Yangbing Li, 2018). Most of inhaled lead is absorbed in the lower respiratory tract (ATSDR, 2017). Moreover, children ingested lead contaminated food can absorb about 50 percent of ingested lead and up to 100 percent on an empty stomach. (ATSDR, 2010). Several studies have shown that urinary arsenic levels are not correlated with low levels of arsenic measured in house dust or in washings taken from hands (Hysong et al., 2003; Pellizzari and Clayton, 2006; Shalat et al., 2006). However, the higher occupational inhalational exposures were found correlated with levels in air such as arsenic fume and dust. (Jakubowski et al., 1998; Offergelt et al., 1992; Vahter et al., 1986), which lead to higher prevalence of para-occupational contamination in children.

Parental education and HMM knowledge: is essential to prevent parents' normal habit of taking children to these metals sources. In our study, we found that children whose parents had completed their middle school education had lower urinary HMM and were brought to these metals-containing places less than those children whose parents completed education lower than middle school level. The same trend was found in Jamaican population, children whose parents had high school education and higher had less heavy metal than those who were born to parents who completed lower than higher school education. (Mohammad H. Rahbar et al., 2015). Based on the study from ATSDR, people who do not live near cadmium emitting industries or nonsmokers, the primary sources of cadmium exposures are from smoking, food. (ATSDR 2015), and occupational exposures (Michigan University 2015). Relating the individual income to the age of infrastructure and parental education parameters, poor families are more likely to live in older houses and near industrial plants that handle lead. (World Health Organization, 2010b, p. 35). In the most poverty-stricken countries, lead smelting factories employ the poorest populations who often do not knowledge about the hazards and lack of the financial means to receive sufficient medical treatment (World Health Organization, 2010b, p. 35). From the study in Jamaican children, the investigators reported that socioeconomic status and sociodemographic indicators, such as parental education, occupation, or income are strongly correlated with child development. However, SES have inverse association with developmental disabilities. (Fombonne E., Simmons H., Ford T., Meltzer H., Goodman R. 2003; Victora C.G., Wagstaff A., Schellenberg J.A., Gwatkin D., Claeson M., Habicht J.P. 2003).

Hygiene and sanitation

The results from our investigation revealed that the lead and cadmium contamination was affected by the hygiene and sanitation. The urinary HMM concentration reduction occurred when the HSS scores were higher, the urinary lead and cadmium reduced 20 and 11 percent respectively (p-value 0.0024). From the literature review, the lead and cadmium concentration level in workers in southern Thailand, associated with their hygienic behaviors, (p-value < 0.001). (Somsiri Decharat, 2016). Based on our results, the lack of consistency in the association between log-transformed urinary arsenic and HSS, the primary pathways of arsenic exposure were diet and smoking, rather than hygiene and sanitation.

Children's direct exposure

Visiting the heavy metals containing places was found to be another primary influential factor to children's lead and exposure, mainly through inhalation. This factor had a stronger effect on the children's urinary HMM than their hand-to-mouth behavior. The route of lead exposure affects the body absorption rate, for example, the lead dust results in higher absorption than the amount of digested lead from paint chips. (ATSDR, 2017). On the other hand, from our statistical analysis results suggested that reducing the visit to less than five times per week may result in less lead exposure (p – value 0.0003). Children who visited the heavy metals sources more than five times a week, the geometric mean urinary lead concentration increased up to 44 percent compares to those who never been exposed to the sources, (p-value 0.0249) which equivalents to 1.368 ng/dL. In addition, children have a lack of control over the circumstances of their environment, and thus, cannot remove themselves from the exposure.

The parental daily activities dictate places children will be visiting each day. The parental judgement on this matter requires their education and HMM knowledge.

Second Hand Smoking (SHS)

Almost half of the world's children are exposed to second-hand tobacco smoke (SHS), 50 - 70 percent of children in South East Asia were exposed to the SHS. (Lando HA, et al. 2010). The children's indoor SHS exposure was identified to be a source of lead, cadmium, and arsenic, precisely, it is a significant source of arsenic across the communities. This finding can be traced back to the comparison between the indoor SHS group and non-indoor SHS group. The urinary arsenic concentration in SHS group was found to have the highest ratio comparing to urinary lead and urinary cadmium. Moreover, the parental number of cigarettes smoked per day had a significant association with the urinary arsenic across the communities. However, outdoor SHS exposure was a significant source of cadmium in children across the communities. From the literature review, the similar result was found in the study among 821 Chinese children who were exposed to parental SHS, found to have increased lead (β (95% CI): 0.53 (0.99-5.14), p-value 0.023) and cadmium (β (95% CI): 0.43 (0.14-0.73), p-value 0.003) levels in their hair. (Li L, et al. Eur J Pediatr. 2018).

Diet

Based on arsenic biological half-life, the arsenic-organic form will be excreted out through urine within three days. The urinary arsenic concentration found in those who consumed seafood within three days prior urine collection, mostly was organic arsenic compounds. Seafood intake was a major determinant of increased urine concentrations of total arsenic (Cullen and Reimer 1989; Francesconi and Kuehnelt 2004) and markedly increased urine concentrations of total arsenic, DMA, arsenobetaine in U.S. population six years old and older. (Choi et al. 2010; Heinrich-Ramm et al. 2002; Lai et al. 2004; Le et al. 1994; Ma and Le 1998). Seafood also a common source for lead and cadmium, the study of lead and cadmium concentration found in seafood in Southern Thailand varied from 0.05 – 0.45 and 0.03 - 0.21 mg/kg, respectively, which is under the Thai regulatory limits (≤ 0.5 mg/kg) (Suchada Sornprasit et al., 2017). According the urinary arsenic level in children in both study sites, we assumed that seafood was a primary source of organic arsenic whereas rice and flour ingredient-snack were primary sources of the inorganic arsenic exposures. Moreover, the children urinary arsenic concentration was suspected to have organic arsenic content more than an inorganic form. From other studies, the main sources of inorganic arsenic for general populations worldwide are drinking water and food (rice, grains, and vegetables) (EFSA CONTAM 2009; IPCS (International Programme on Chemical Safety) 2001; National research council 1999; Chakraborti et al.). Zhang et al. (1999) also found that rice contributed to 30 percent of cadmium burden. In arsenic excretion patterns, at steady stage about 40 percent of rice derived arsenic was excreted via urine. (A.A. Meharg et al. 2014). Some studies showed that dietary factors such as seafood consumption especially lobster and crabs has also been implicated as a major source of exposure to lead. (ATSRD 2007; Gale N.L., Adams C.D., Wixson B.G., Loftin K.A., Huang Y.W. 2002; Meador J.P., Ernest D.W., Kagley A.N. A 2004; Rahbar M.H., White F., Agboatwalla M., Hozhabri S., Luby S. 2002). The significant difference in blood concentration was found between those who eat shellfish and who did not (p-value 0.05). From our study, we found that seafood consumption is a potential source of lead, cadmium, and arsenic.

Limitations

In our study, there are several issues of limitations including the field sample collection, sample size and statistical power, bias influenced by cultural manners, measurement bias and recall bias. Firstly, since the primary investigator had two months of sample collection in Thailand in June and July which is a monsoon season. Moreover, during that time, there was a tropical depression storm passed through the region which resulting in travel delay between study sites, rescheduling house visit, as well as students were absent for urine sample collection at school due to sickness. The heavy rain days may affect the concentration of lead, cadmium, and arsenic in the environment, especially we found that most of the exposures are from inhalation. It is possible that the HMM concentration measured in urine and water were lower than the rest of the year, hence affects the significance of the association between the exposure and outcome parameters. Similarly, the research in China on seasonal and spatial effect on heavy metal contamination, found that potential risks in different seasons decreased in the order: the early rain season, dry season, and late season, which the period of our study was during the early rain season. (Hong Yao, Xin Qian, Hailong Gao, Yulei Wang, Bisheng Xia, 2014). Therefore, boatyard was considered as a high exposure source for lead, cadmium, and arsenic, due to the occupational activities. Workers who worked at the boatyard were found blood lead level was 40 ug/dL (C. Thanapop, A. 2007) which can result in higher possibility of children getting exposed to the HHM through para-occupational contamination (take-home contamination). However, during monsoon season, majority of commercial fishing company were temporarily closed, and boat-repaired activities such as welding, spray painting, caulking were minimally occurred in the boatyard. With combination of rainfalls and reduced HMM activities though out the sample collection period, caused measurement bias and consequently affected the lower HMM concentration in urine and environment.

Secondly, we had some constraints in study design related to number of participants. In this study, we purposefully selected children aged two – five years, who went to the local children development center or elementary school. Moreover, we specified that each study location recruits 50 percent female and 50 percent male to capture the possible maximum HMM exposure in the area and be able to assess the variation of sex on urinary HMM concentration, as well as parents must live and work in the area at least 5 years. Hence, the participant recruitment process was challenging to find a pair of parent and child who meet the required criteria, as a result the research team encountered the limited number of the sample size (30 pairs per location), which might not provide enough statistical power to detect the difference between locations. For the research to achieve reliable results and high statistical power the appropriately sized study is important. The ability to detect a difference between study groups when a difference truly exists. An insufficient sample size is more likely to produce false negatives and inconsistent results. (Nayak B. 2010). Based on the number of children in the fishing community, aged two to five years old was 33 children, our samples represented 91 percent of the population. However, in the city of Phang-Nga location, due to limited number of children who meet the requirement, we were able to recruit 30 children. On the other hand, even though the city site had more numbers of qualified children to be randomized, however, many children lived in the same neighborhood or had their names on the house registration but their physical address are outside of the study area perimeter, hence we withdrew them from the study.

Thirdly, measurement bias from cultural manners. Each family will be scheduled and notified before the research team arrived to their homes. Culturally, Thai people are respectful and offer hospitality to their visitors, as such the condition of the house will be different from normal condition which affects the hygiene and sanitation assessment and causes the score to be higher in some cases. The investigators minimized the bias by making notes on their forms, if we suspected the anomaly for outcome interpretation.

Lastly, recall bias that occurred during survey interview such as the participants quickly responded “yes” or “no” to the questions relating to parental HMM (lead, cadmium, and arsenic) knowledge section or the misunderstanding of arsenic, due to most Thais understand arsenic as the rodenticide chemical, assuming they did not allow their children to be exposed to the chemical, that results induced the measurement bias in arsenic knowledge section which lead to unclear association between parental arsenic knowledge and the urinary arsenic concentration level in both locations. Moreover, some sensitive questions were carefully asked to avoid embarrassment or offend the interviewees such as personal hygienic behavior, children’s daily activities, smoking, income. The primary investigator needed to cautiously interpret the association and took these factors into consideration to minimize the negative and/or positive false bias.

Although there are several limitations in our study, the findings may be profitable to provide a specific information that encourage the Provincial Public Health Office and Municipality Office staff to implement the sustainable intervention to mitigate the exposure of lead, cadmium, and arsenic in children and improve life quality of people in the communities using the scientific knowledge as guidelines.

Conclusions and recommendations

Conclusions

Our study indicates that evaluating geographical and exposure frequency with qualitative elements using biomonitoring may be a good method to identify the source of lead, cadmium, and arsenic exposures and the factors contributing to exposure in children. We showed evidence that data from our study provide the clarity to our hypotheses including the effect of geographical location, parental education, and other factors on HMM contamination as well as identify the potential pathways and routes of the exposure. From the information listed in Table 1, the children's urinary lead, cadmium, and arsenic in the fishing community and city in southern Thailand showed a higher burden compared to international studies such as NHANES that was reported in 2019 from year 2011 - 2016. The correlation between urinary lead, urinary cadmium, and urinary arsenic in the fishing community indicated the sources of lead and cadmium are the same.

Even though the significant difference in urinary HMM between the fishing community and the city, were not found, however, the geometric mean HMM creatinine corrected suggested the most susceptible group among these children were female children who lived in the fishing community were the most susceptible to lead, male children who lived in the fishing community were the most susceptible to cadmium and arsenic.

From Table 6, we were able to determine the primary factors that contribute to lead exposure in children in southern Thailand were parental low income and education level, aging infrastructure, visit the HMM sources, poor hygiene and sanitation, and number of cigarette smoked in a household. The factors that affect the magnitude of cadmium and arsenic exposures were number of cigarettes smoked in a household per day and aging infrastructure. However, we suspected that children's seafood consumption within three days prior the urine sample collection is a potential confounder, which had the effect on the total urinary arsenic (p-value 0.0079). In fishing community lead and cadmium were found to have co-factors which are aging infrastructure, children' second hand smoking (SHS). However, the source of arsenic exposure may be from seafood consumption. Whereas, in the city, lead, cadmium, and arsenic were found to come from the same sources which is similar to the fishing community; aging infrastructure, children' second hand smoking (SHS), and seafood consumption.

Finding a measurable amount of cadmium in blood or urine does not imply that the levels of cadmium cause an adverse health effect. Biomonitoring studies on levels of cadmium provide physicians and public health officials with reference values so they can determine whether people have been exposed to higher levels of cadmium than are found in the general population. Biomonitoring data can also help scientists plan and conduct research on exposure and health effects. (CDC, 2019)

Recommendations for future research

The results of this study primarily provide background data of sources of exposure as well as a brief overview of a pattern of risk factors that influence the lead, cadmium, and arsenic contamination in children who live in two different environmental settings in southern Thailand.

However, the low levels of these biomarkers do not mean the children are safe. We would suggest conducting further studies both epidemiological studies and methodology research. Since biomonitoring data in this study could not inform us about health outcomes, further epidemiological studies will be required and changing the type of biomonitoring to blood to precisely identify HMM level in blood as we as the risk factors such as dust, food, and urinary cotinine need to by further analyzed the contamination to specify the pathways and routes. The understanding of the association between the parental and children's HMM level is also necessary to define the para-occupational effect on children's exposure.

Moreover, we need to improve the research methodology by additionally capture the HMM urinary concentration outside of the monsoon season, due to the high activities in commercial fishing community usually occur during winter through Summer. According the study in China, the metals accumulated in the environment were the main possible sources in dry season. (Hong Yao, Xin Qian, Hailong Gao, Yulei Wang, Bisheng Xia, 2014). We should be able to evaluate the actual effect of geological location and parental occupation on the children's exposure as well as their own direct exposure at higher concentration.

Policy recommendations

Due to the findings of our study, it allows the stakeholders and susceptible population to better understand the sources and risk factors in the areas. Prioritizing the proper public health intervention strategies to mitigate the exposures and manage heavy metals contamination is a great benefit from this study. To successfully implement the intervention, the collaborations between organizations such as the Thai Ministry of Public Health, the Thai Ministry of Education, the Bureau of Occupational and Environmental Diseases and Bureau of Epidemiology, who are responsible for public health surveillance, the Provincial Public Health Office, District municipality office, schools, and local communities. Based on Lancet Commission report suggested that the intelligence gains over the lifespans of children born since 1980 may be valued at over $6 trillion (2017, p. 5). These benefits far outweigh the costs of phasing out lead as a fuel additive. Due to no safe level for lead (CDC, n.d.) and carcinogenic properties for cadmium and arsenic (Thun et al., 1985; Brown and Chu, 1983a,b,c; Lee-Feldstein, 1983; Higgins, 1982; Enterline and Marsh, 192)., the HMM annual check-up for children who live in a high risk area and parental survey should be done during the school annual medical visit. Also, this approach can be used as a tool to monitor and evaluate the effectiveness of the implementation of policies and interventions. In addition, generalizing this approach into other populations is necessary for instance, different region of Thailand, area with higher risk of contamination.

Intervention recommendations

Higher income countries have already enacted effective, scientifically-backed regulations, such as the European Union's Registration, Evaluation, Authorization and Restriction of Chemicals. Similar laws can be adapted by countries lacking adequate surveillance of pollution risks. Balancing economic development with pollution control and prevention will be key to ensuring the long-term safety of public health and the environment. Preventive measures include 1).

Environmental standards, 2). Enforcement of occupational health standards. 3). Surveillance of potentially exposed population groups, especially the vulnerable ones (small children, pregnant women, workers). 4). Smoking control, 5). Hygiene and sanitation standards, 6). Aging infrastructure maintenance guidelines, 7). Screening of children for blood levels over acceptable limit and referral for medical care as necessary.

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Tables

Table 1. Exposure Sources and Potential Health Outcomes

Metal	Exposure Sources	Health Outcomes	POD	RfD
Lead (Pb)	Lead fishing weights, welding, cutting of old painted metal, dust, and old water pipe systems, battery, and contaminated water	Neurodevelopment and deficits, Attention Deficit Hyperactivity Disorder (ADHD) and antisocial behavior, which in turn, increase the likelihood of conduct disorder, criminal activity, and drug abuse miscarriage, stillbirths, and infertility.		
Cadmium (Cd)	Cigarette smoke, burning coal, phosphate fertilizer, contaminated water and food	Multi-tissue carcinogen, Liver cancer, Renal failure, clinical renal Fanconi syndrome, Lung cancer, Pancreas, Breast cancer, Endometrium, Urinary bladder-cancer, and Respiratory system	**(Non-cancer)** **Dose in water** 5×10^{-3} (mg/kg/day) **(Cancer)** 1.8×10^{-3} (mg/kg/day)	(Non-cancer) Dose in water 5×10^{-4} (mg/kg/day)
Arsenic (As)	Contaminated food (e.g, rice, vegetables and seafood) and drinking water, tobacco and phosphate fertilizer	A long-term exposure to arsenic from drinking water and food can cause cancer; dermal and respiratory system, and skin lesions. It has also been associated with cardiovascular disease and diabetes. In utero and early childhood exposure has been linked to negative impacts on cognitive development and increased deaths in young adults. Increased mortality from multiple internal organ cancers (liver, kidney, lung, and bladder).	8×10^{-4} (mg/kg/day)	3×10^{-4} (mg/kg/day)

Table 2. Geometric mean urinary lead, urinary cadmium, and urinary arsenic concentration in the fishing community and city in southern Thailand, 2018

Parameters	N	Urinary Lead				Urinary Cadmium				Urinary Arsenic			
		GM± GStd Dev			95% CI	GM± GStd Dev			95% CI	GM± GStd Dev			95% CI
Fishing Community (ng/mL)													
Total	30	1.02	±	1.42	(0.90,1.16)	1.02	±	1.45	(0.27,0.35)	3.93	±	1.69	(3.23,4.78)
Female	15	1.10	±	1.53	(0.87,1.38)	0.30	±	1.44	(0.24,0.36)	3.31	±	1.81	(2.38,4.59)
Male	15	0.95	±	1.28	(0.83,1.10)	0.32	±	1.47	(0.26,0.40)	4.67	±	1.49	(3.74,5.82)
City (ng/mL)													
Total	30	0.88	±	1.46	(0.76,1.02)	0.32	±	1.38	(0.28,0.36)	4.02	±	1.60	(3.37, 4.80)
Female	15	0.95	±	0.72	(1.24,1.64)	0.33	±	1.33	(0.28,0.40)	4.32	±	1.60	(3.33,5.61)
Male	15	0.82	±	0.73	(0.92,1.24)	0.30	±	1.42	(0.25,0.37)	3.74	±	1.60	(2.88,4.85)
Both communities (ng/mL)													
Total	60	0.95	±	1.45	(0.86, 1.04)	0.31	±	1.41	(0.30,0.34)	3.97	±	1.64	(3.5,4.51)
Female	30	1.02	±	0.86	(1.21, 1.64)	0.31	±	1.39	(0.28,0.35)	3.78	±	1.72	(3.08,4.63)
Male	30	1.13	±	0.73	(0.97, 1.27)	0.31	±	1.44	(0.27,0.36)	4.18	±	1.56	(3.54,4.93)
Data Source	**N**	**(2011-2016)**				**(2015-2016)**				**(2015-2016)**			
NHANES (ng/mL)	#	0.26			(0.23-0.29)	*				4.05			(3.58-4.58)

*Not calculated: proportion of results below limit of detection was too high to provide a valid result. (NHANES, 2019)

Table 3. Geometric mean urinary lead, urinary cadmium, and urinary arsenic creatinine corrected in the fishing community and city in southern Thailand, 2018

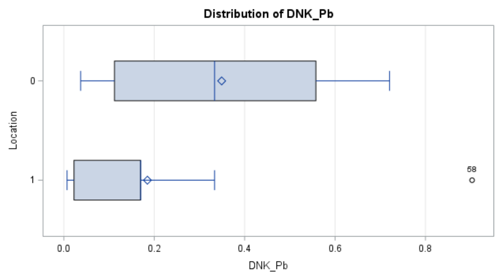
Parameters	N	Urinary Lead Creatinine Corrected				Urinary Cadmium Creatinine Corrected				Urinary Arsenic Creatinine Corrected			
		GM (ug/g)			95% CI	GM (ug/g)			95% CI	GM (ug/g)			95% CI
Fishing Community (ug/g creatinine)													
Total	30	2.87	±	2.11	(2.17,3.79)	0.18	±	2.03	(0.14,0.24)	63.56	±	2.6	(44.75,90.28)
Female	15	**3.60**	±	2.46	(2.17,5.87)	0.17	±	1.63	(0.13,0.23)	45.36	±	2.95	(24.91,82.59)
Male	15	2.31	±	1.63	(1.76,3.02)	**0.19**	±	2.44	(0.11,0.31)	**89.06**	±	1.9	(62.35,127.22)
City (ug/g creatinine)													
Total	30	1.87	±	1.94	(1.46,2.40)	0.18	±	1.8	(0.14,0.24)	61.71	±	2.16	(46.31,82.34)
Female	15	2.06	±	2.27	(1.31,3.25)	0.18	±	1.87	(0.13,0.26)	64.86	±	2.17	(44.16,104.30)
Male	15	1.70	±	1.58	(1.32,2.20)	0.17	±	1.75	(0.13,0.23)	56.12	±	2.17	(36.50,86.28)
NHANES	**N**	**(2011-2016)**				**(2015-2016)**				**(2015-2016)**			
Total (ug/g creatinine)	485	0.59			(0.532-0.654)	*				9.31			(8.18-10.6)

*Not calculated: proportion of results below limit of detection was too high to provide a valid result. (NHANES, 2019)

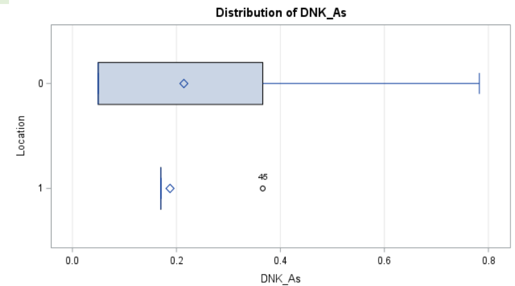
Table 4. Water Lead, cadmium, and arsenic concentration in fishing community and city compare with the Maximum Allowable Level (ng/mL) in southern Thailand, 2018

Drinking Water

Location	N	Lead (ng/mL)					Cadmium (ng/mL)					Arsenic (mL)				
		Mean	Std.	Min.	Max.	MAL*	Mean	Std.	Min.	Max.	MAL*	Mean	Std.	Min.	Max.	MAL*
Fishing community	11	0.11	0.26	0.01	0.90	**50**	0.02	0.00	0.02	0.02	**5.00**	0.06	0.00	0.07	0.07	**50**
City	11	0.35	0.23	0.04	0.58	**50**	0.02	0.00	0.02	0.02	**5.00**	0.22	0.24	0.06	0.78	**50**
Total	22	0.23	0.27	0.01	0.90	**50**	0.02	0.00	0.02	0.02	**5.00**	0.14	0.19	0.06	0.78	**50**



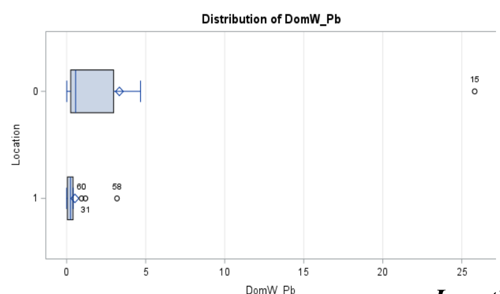
LOD



Domestic Water

Location	N	Lead (ng/mL)					Cadmium (ng/mL)					Arsenic (mL)				
		Mean	Std.	Min.	Max.	MAL*	Mean	Std.	Min.	Max.	MAL*	Mean	Std.	Min.	Max.	MAL*
Fishing community	11	0.71	0.90	0.01	3.19	**50**	0.02	0.00	0.02	0.03	**10.00**	0.11	0.10	0.05	0.40	**50**
City	11	3.34	7.60	0.01	25.82	**50**	0.03	0.04	0.02	0.15	**10.00**	0.59	0.54	0.06	1.80	**50**
Total	22	2.03	5.44	0.01	25.82	**50**	0.02	0.03	0.02	0.03	**10.00**	0.35	0.45	0.05	1.80	**50**

*Maximum Allowable Level (MAL) ng/mL (Pollution Control Department, 1999)



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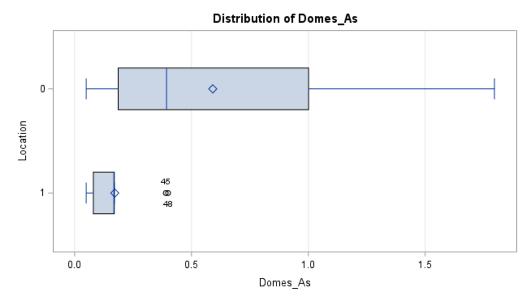


Location 0 = City   Location 1 = Fishing Community

Table 5. Data collected from parents in the fishing community and city in southern, Thailand

Parameters	N	Mean	Std Dev	Min	Max	25th	50th	75th	95th
Individual Income/Family	60	10259.48	9180	1666.70	66667	5000.00	9143	12500.00	23250.00
Fishing Community	30	7916.19	5589	1666.70	25000	4285.71	6500	10000.00	24000.00
City	30	12602.78	11351	2400.00	66667	7000.00	12000	14000.00	22500.00
Hygiene and Sanitation	60	23.22	7.76	2	34	19	25	29.5	32.5
Fishing Community	30	22.03	6.52	4	34	18	22.5	26	31
City	30	24.40	8.78	2	33	24	26.5	30	33
House Cleaning Frequency	60	6.30	1.67	2	8	5	7	8	8
Fishing Community	30	6.80	1.16	4	8	6	7	8	8
City	30	5.80	1.95	2	8	4	6.5	8	8
Parental Education *	60	4	1.68	1	7	3	4	6	6.5
Fishing Community	30	3	1.42	1	7	2	3	4	6
City	30	5	1.33	2	7	4	5.5	6	7
Parental Lead Knowledge									
Lead	60	6.2	4.28	0	15	1	6.5	10	12
Fishing Community	30	5.13	4.1	0	13	1	5.5	8	12
City	30	7.27	4.25	0	15	4	9	10	12
Cadmium	60	2	2.95	0	10	0	0	3	8
Fishing Community	15	0.93	1.66	0	7	0	0	2	4
City	15	3.07	3.54	0	10	0	1.5	7	9
Arsenic	60	1.08	0.85	0	5	1	1	1	2
Fishing Community	30	0.97	1	0	5	0	1	1	2
City	30	1.2	0.66	0	3	1	1	2	2
Infrastructure *									
Pipe Age	60	3	1	1	4	2	3	4	4
Fishing Community	30	3	1	1	4	2	3	4	4
City	30	3	1	1	4	2	3	4	4
House Age	60	3	1	1	4	2	3	4	4
Fishing Community	30	3	1	1	4	2	3	4	4
City	30	3	1	1	4	2	3	4	4
Children's Metals Exposure (per week)									
Visit Pb, Cd, and As Sources	60	4.42	3.72	0	17	2	4	6	12.5
Fishing Community	30	5.9	4.24	0	17	0	0	2	4
City	30	2.93	2.36	0	8	0	1.5	7	9
Direct Exposure (per week)	60	1.77	1.35	0	6	1	1	2	4
Fishing Community	30	1.4	1.33	0	6	1	1	2	4
City	30	2.13	1.28	0	5	1	2	3	4
***Outdoor smoking exposure**	60	1.83	1.37	0	7	1	2	2	4.5
Fishing Community	30	2.23	1.5	0	7	2	2	3	4
City	30	1.43	1.41	0	7	1	1	1	5
Number of cigarette smoked (per day)	60	4.25	5.61	0	20	0	3	5	20
Fishing Community	30	5.73	6.09	0	20	3	4	6	20
City	30	2.76	4.73	0	20	0	0.15	3	10
Diet (per day)									
Seafood Consumption	60	3.61	1.74	0.25	7	3	3	4.5	7
Fishing Community	30	3.6	1.63	2	7	2	3	4	7
City	30	3.63	1.88	0.25	7	3	3	5	7
Rice Consumption	60	2.75	1.45	1	9	2	3	3	6
Fishing Community	30	2.2	0.81	1	3	2	2	3	3
City	30	3.3	1.73	1.5	9	3	3	3	6
Floured Snack Consumption	60	4.87	1.94	1	7	3	4.5	7	7
Fishing Community	30	4.4	1.52	2	7	3	4	5	7
City	30	5.33	2.21	1	7	3	7	7	7

*Parental Education; level 1 = no education , level 2 = primary school , level 3 = middle school , level 4 = high school , level 5 = undergraduate, level 6 = master's degree, level 7 = doctorate
* Infrastructure (years);level 1 = 1 - 5 , level 2 = 6-10 , level 3 = 11-15 , level 4 = 16 – up,
*Outdoor smoking exposure (per week)

Table 6. Trends of association between Urinary lead, cadmium, and arsenic and each parameter

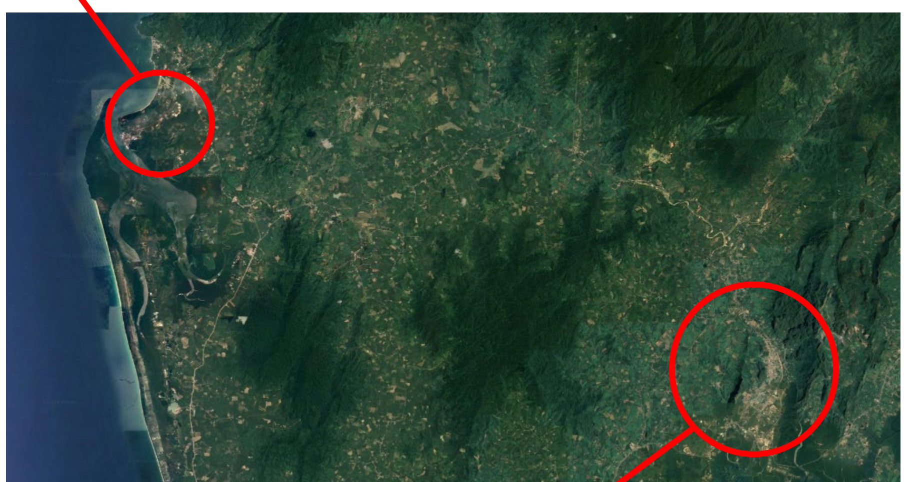
Parameter	Lead	Cadmium	Arsenic
(1) Socioeconomic status - Individual income	Negative (p< 0.0001)	* (p-value 0.8735)	* (p-value 0.9666)
-Parental education	Negative (p-value 0.0122)	Negative (p-value 0.2956)	* (p-value 0.1853)
-Infrastructure Pipe age (year) House age (year)	Positive (p-value 0.3708) Positive (p-value 0.2546)	Positive (p-value 0.6292) Positive (p-value 0.9740) ***in house aged 15 yrs+***	Positive (p-value 0.3754) Positive (p-value 0.8274) ***in house aged 11 yrs+***
(2) Hygiene and sanitation score (HSS)	Negative (p-value 0.0024)	Negative (p-value 0.0628)	* (p-value 0.7080
(3) Children' direct exposure -Visit lead, cadmium, arsenic sources	Positive (p-value 0.0003)	* (p-value 0.9164)	* (p-value 0.2133)
-Direct contact with lead, cadmium, and arsenic directly	* (p-value 0.1198)	* (p-value 0.0685)	* (p-value 0.4546)
-Second hand smoke (SHS)	Positive (p-value 0.8126)	* (p-value 0.8197)	* (p-value 0.1290)
-Outdoor smoking	* (p-value 0.0753)	* (p-value 0.0663)	* (p-value 0.9490)
-Parental cigarettes smoked/day	Positive (p-value 0.8044)	Positive (p-value <0.0001)	Positive (p-value <0.0001)
(4) Diet -Seafood consumption 3 days before urine collection			Positive (p-value 0.0079)
-Seafood consumption frequency per week			* (p-value 0.1337)
-Rice consumption			* (p-value 0.5249)
-Flour ingredient snack			* (p-value 0.6897)

** Not a clear trend*

Figures

Figure 1. Maps of study locations in southern Thailand

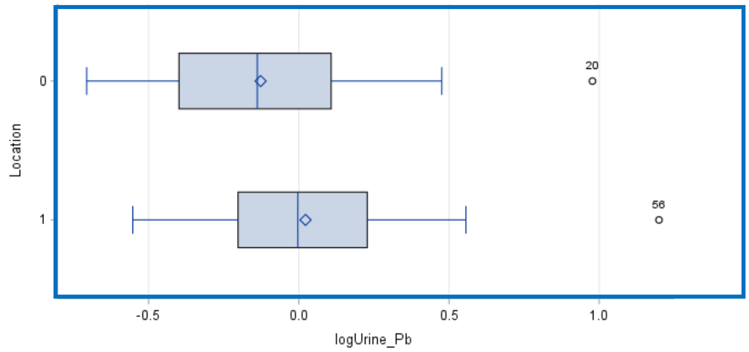
1a). Ban Tub Lamu Fishing Community



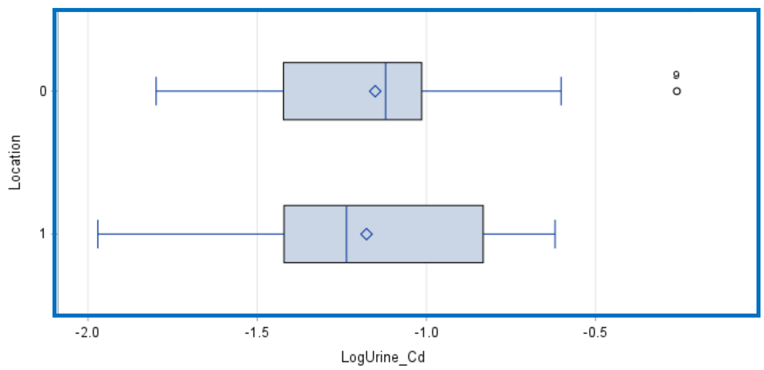
1b). City of Phang-Nga

Figure 2. Log-transformed lead, cadmium, and arsenic (HMM) in fishing community and city of Phang- Nga in sounthern Thailand, 2018

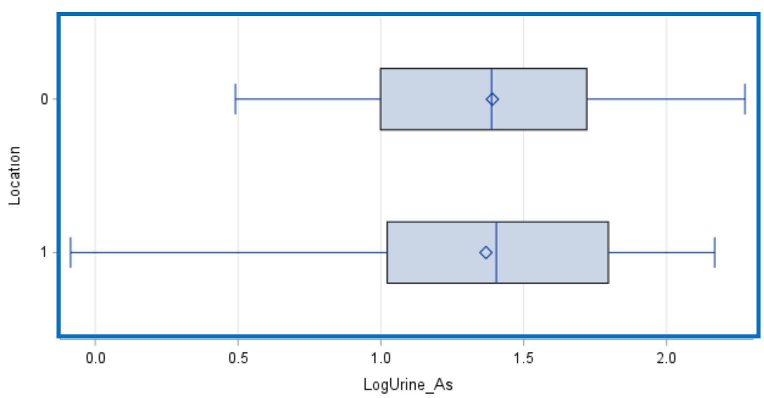
Lead



Cadmium



Arsenic



Location 0 = City of Phang-Nga and Location 1 = Fishing Community

Figure 3. Correlation between log-transformed urinary lead, cadmium, and arsenic in fishing community and city of Phang-Nga in southern Thailand, 2018

Fishing Community

Pearson Correlation Coefficients, N = 30
Prob > |r| under H0: Rho=0

	logUrine_Pb	LogUrine_Cd	LogUrine_As
logUrine_Pb logUrine_Pb	1.00000	0.44794 0.0131	0.31458 0.0904
LogUrine_Cd LogUrine_Cd	0.44794 0.0131	1.00000	0.43046 0.0176
LogUrine_As LogUrine_As	0.31458 0.0904	0.43046 0.0176	1.00000

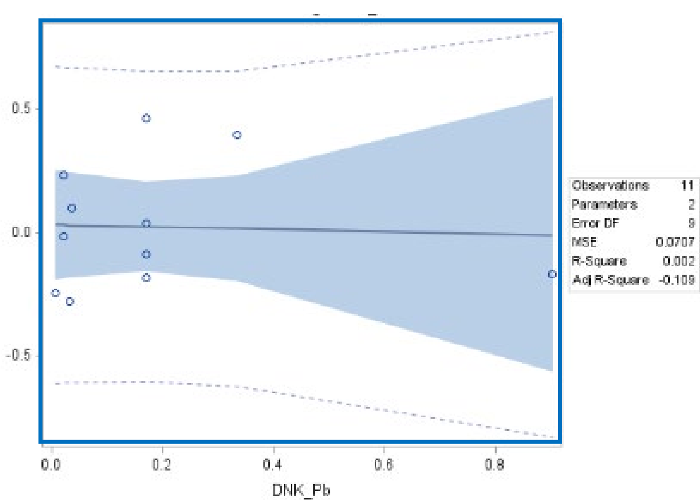
City

Pearson Correlation Coefficients, N = 30
Prob > |r| under H0: Rho=0

	logUrine_Pb	LogUrine_Cd	LogUrine_As
logUrine_Pb logUrine_Pb	1.00000	0.46513 0.0096	0.58284 0.0007
LogUrine_Cd LogUrine_Cd	0.46513 0.0096	1.00000	0.57547 0.0009
LogUrine_As LogUrine_As	0.58284 0.0007	0.57547 0.0009	1.00000

Figure 4. Association between log-transformed urinary lead and water lead in fishing community in southern Thailand, 2018

4a). Drinking water lead



4b). Domestic water lead

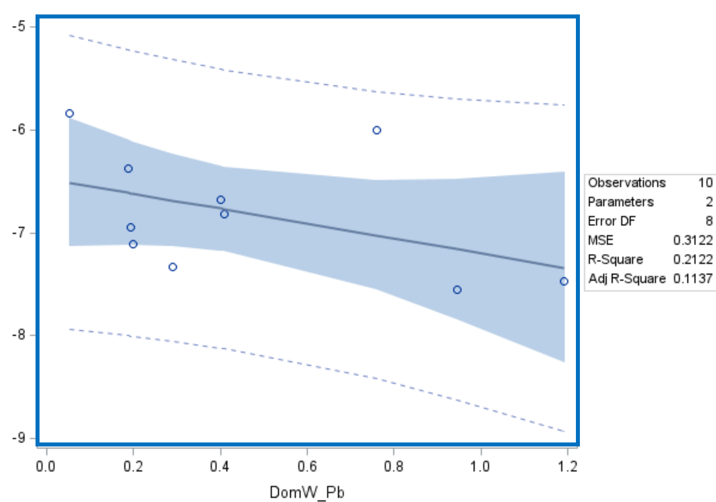
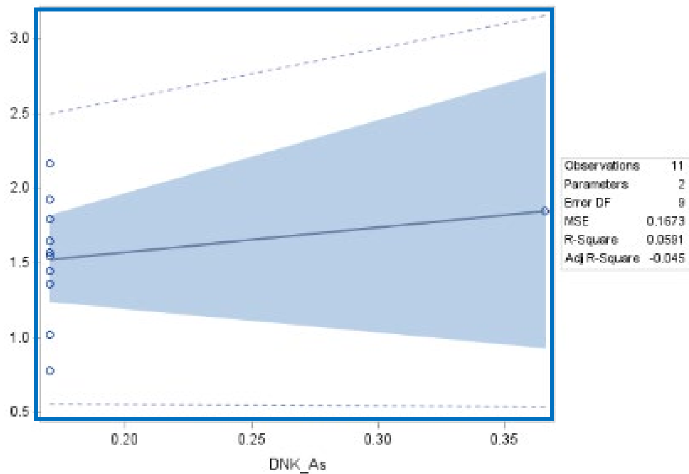


Figure 5. Association between log-transformed urinary arsenic and arsenic water in fishing community, southern Thailand in 2018

5a). Drinking water arsenic



5b). Domestic water arsenic

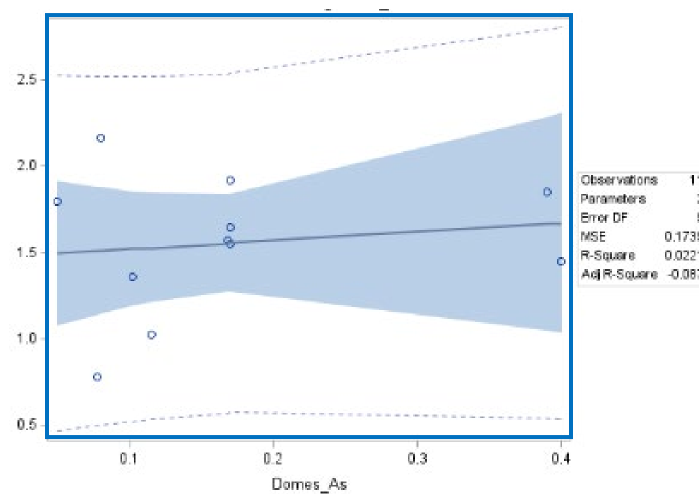
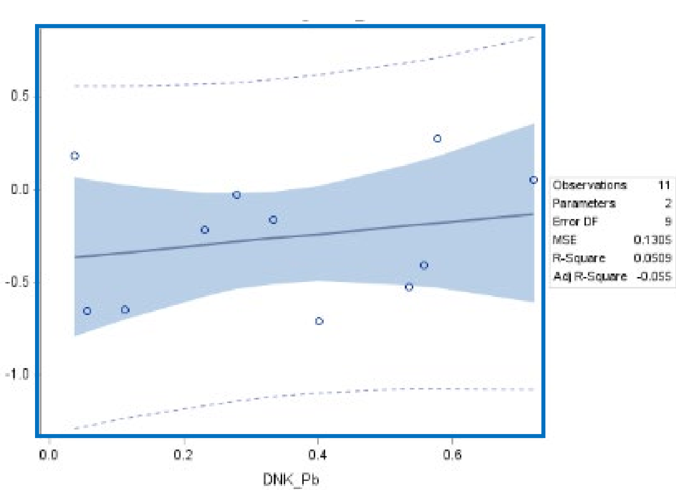


Figure 6. Association between log-transformed urinary lead and water lead in city of Phang-Nga in southern Thailand, 2018

6a). Drinking water lead



6b). Domestic water lead

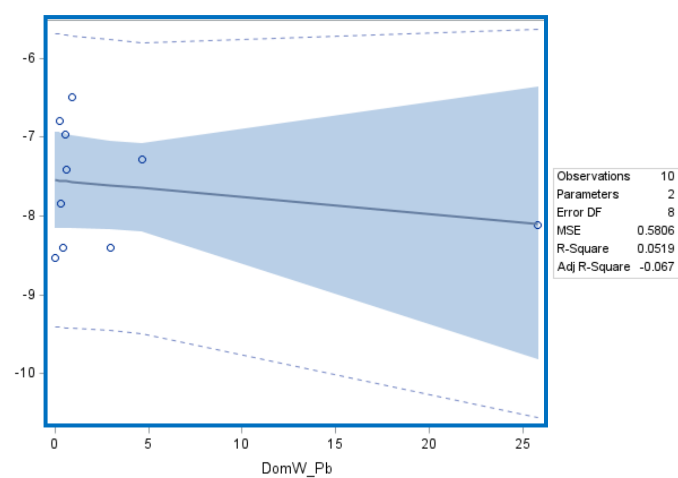
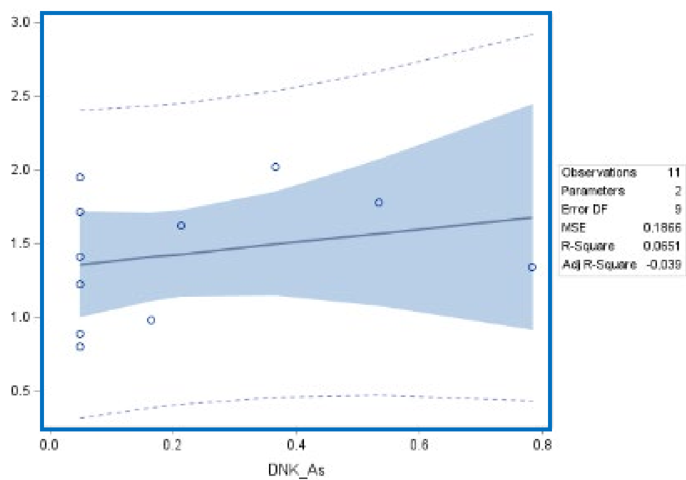
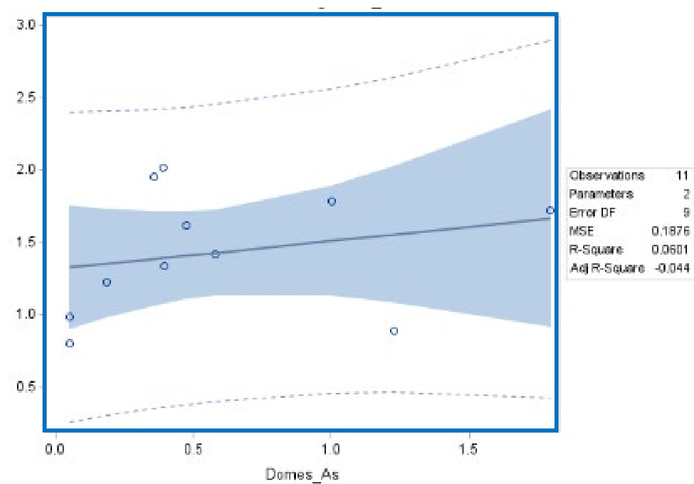


Figure 7. Association between log-transformed urinary arsenic and water arsenic in city of Phang-Nga in southern Thailand, 2018

7a). Drinking water



7b). Domestic water



Appendices

Appendix 1. Parental Knowledge, Attitude, and Practice survey

Parental Knowledge, Attitude, and Practice influencing Children's Lead, Cadmium, and Arsenic Exposures in a Commercial Fishing Community and Understanding Lead, Cadmium, and Arsenic Exposures and their Predictors using Human Biomonitoring in Southern Thailand

Environmental Health Department, Rollins School of Public Health, Emory University

ID: TLM ___ ___ ___ Date (dd/mm/yy): ____ / ____ / ____

Introductory statement

Hello. My name is Pornpimol Kodsup. I am an MPH student at Rollins School of Public Health at Emory University, Atlanta, GA, USA. I am a primary researcher for this study and would like to provide you information about the research study we are conducting and see if you are interested in participating.

The purpose of this research is to help us to understand the parent's knowledge, attitude, and practice about lead, cadmium, and arsenic and potential contamination sources in Ban Tub Lamu that may influence lead, cadmium, and arsenic contamination in children in your community. There are total of 120 people participate in this study. This survey will take approximately 30 minutes and will cover a range of topics about your family, your daily activities, your child's daily activities, your knowledge about lead, cadmium, and arsenic and your opinion about the effect of these elements on your child's health.

If you voluntarily agree to participate, you do not need to answer questions if you feel uncomfortable. During the study period, all of yours and your child's data will be stored and secured with password and the unique code will be used instead. This study starts from June 2019 and October 2020.

Middle School	______	_______	_______	_______
Primary School	______	_______	_______	_______

INSTRUCTIONS FOR THE INTERVIWER TEAM:

PLEASE DO NOT PROCEED WITH QUESTIONS IF THE RESPONDENT DOES NOT COMPLETE THE CONSENT TO PARTICIPATE IN THIS RESEARCH STUDY.

IF THE CONSENT FORM IS NOT SIGNED PLASE DO NOT PROCEED TO ENTER THE DATA

TIME BEGUN [___/___] [___/___] (24 hour time)

(PLEASE SEE NEXT PAGE)

ID: TLM ___ ___ ___

Section1: Family Member's Questionnaire

A) Household Roster

LINE NO.	*	SEX	AGE	RELATIONSHIP TO RESPONDENT	#	Occupation		Education Level
						Position	Monthly Income	Level
Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9
	Mark an * If you are the respondent	Is (family member) male or female	How old are you?	What is relationship to the respondent	Mark an # if family member is working	Please specify position at work	Please choose from options below	Please choose from options below
1			[___/___]					
2			[___/___]					
3			[___/___]					
4			[___/___]					
5			[___/___]					
6			[___/___]					

CODES FOR Q3: 01 = male , 02 = female

CODES FOR Q5: 01= wife/husband 02= son/daughter 03=father/mother 04= grandchild 05= grandparent 06=grandparent 07= mother/father in-law 08= son/daughter in-law 09= brother/sister in-law 10=other

CODES FOR Q8: 11 = (1 - 10,000 bahts) 12= (10,001 - 20,000 bahts) 13= (20,001 - 30,000 bahts) 14= (30,001 - 40,000 bahts) 15 = (40,001 - 50,000 bahts) 16 = (> 50,001 bahts)

CODES FOR Q9: 20 = Elementary School 21= Middle School 22= High School 23 = Bachelor's Degree 24 = Graduated Degree

B) Socioeconomic Status

Instruction for the interviewer, this section is to evaluate the respondent's socioeconomic status by condition of the house construction.

NO.	QUESTION	Response	SKIP
B1	Do you know, how many years your house has been built? ---------- you can give an estimate number.	A. 1-5 years………………………...1 B. 6 – 10 years…………………….2 C. 11 – 15 years.…………………..3 D. More than 15 years ……..……4	
B2	What is/are types of your house material?	A. Wood……………..……….…….1 B. Metal ………………..……...….2 C. Cement ……………..……….3 D.Other……………………….4	
B3	When was the last time you painted Your house? (please write down the number of years or months or days)	A. [___/___/___] years ………………………….…………..1 B. [___/___/___] months……..…. 2 C. [___/___/___] days……. ……..3 D. Never been pained ……………4	

(PLEASE SEE NEXT PAGE)

ID: TLM ___ ___ ___

Section 2: Parental Knowledge, Attitude, and Practice on Lead, Cadmium, and Arsenic

C). Lead, Cadmium, and Arsenic Knowledge, Attitude, and Practice

C.1 Parent's KNOWLEDGE Section: Lead

NO.	QUESTION	RESPONSE	SKIP
C.1a	*Now, I am going to ask you a few questions about Lead and your knowledge---normally many people are not familiar with "Lead", please feel free to let me know if you don't know the answer or would like for me to repeat the question.*		
C.1b	Have you ever heard of Lead?	Yes……………………………………1 No………………………………..……0 I don't know/not sure……………..…88	 ➔ C.2b ➔ C.2b
C.1c	*It is normal that people don't know about all of the Lead sources, please give all answers based on your understanding*…Do you know where is/are source(s) of lead? For respondent: Please feel free to ask for clarification if you are unsure about the definition of the activity. For interviewer, please clarify the answer based on the actual activities that happen in their community i.e. in a boat yard and land field, etc.	Welding ………………………………1 Spray painting ……………………….2 Fishing equipment…………………...3 Fuel……………………………..…..4 Old pipe……………………………..…5 Water …………………………………6 Soil……………………………………..7 Dust……………………………………8 Food………………….………………9 Fertilizer……………………….………10 Fruit……………………………………11 None of the above……………………12 All of the above……………………….13 I don't know/not sure………………...88	
C.1d	Do you think… can Lead cause health problem?	Yes…………………………….……1 No………………………………………0 I don't know/not sure…………..……88	
C.1e	Do you think what type of health problem Lead can cause?....please choose all that applies.	A. Heart Disease…………..………1 B. Cancer……………….……..……2 C. Neurological Development Deficit …………………………….………….3 None of the above……………………4 All of the above……………………….5 I don't know/not sure………………...88	
C.1f	Do you think… you have Lead residues in your house?	Yes………………………………..……1 No………………………………………0 I don't know/not sure…………..……88	

(PLEASE SEE NEXT PAGE)

ID: TLM ___ ___ ___

Section 2: Parental Knowledge, Attitude, and Practice on Lead, Cadmium, and Arsenic (continued)

C.2 Parent's KNOWLEDGE Section: Cadmium

NO.	QUESTION	RESPONSE	SKIP
C.2a	*Now, I am going to ask you a few questions about Cadmium and your knowledge--- normally many people are not familiar with "Lead", please feel free to let me know if you don't know the answer or would like for me to repeat the question.*		
C.2b	Have you ever heard of Cadmium?	Yes……………………………………1 No…………………………….……..……0 I don't know/not sure…………….…88	 ➔ C.3b ➔ C.3b
C.2c	*It is normal that people don't know about Cadmium sources, please give all answers based on your understanding*……. Do you know where is/are source(s) of Cadmium? For respondent: Please feel free to ask for clarification if you are unsure about the definition of the activity. For interviewer, please clarify the answer based on the actual activities that happen in their community i.e. in a boat yard and land field, etc.	Welding ………………………………1 Spray painting ………………………2 Fishing equipment…………………...3 Fuel………………………………..….4 Old pipe…………………………..….5 Water …………………………………6 Soil……………………………….…...7 Dust…………………………….……8 Food……………………………….…9 Fertilizer………………………………10 Fruit……………………………………11 None of the above……………………12 All of the above………………………13 I don't know/not sure………………...88	
C.2d	Do you think… can Cadmium cause health problem?	Yes……………………………….….…1 No………………………………………0 I don't know/not sure……………..……88	
C.2e	Do you think what type of health problem Cadmium can cause?....please choose all that applies.	A. Heart Disease……………...………1 B. Cancer………………………..….….2 C. Neurological Development Deficit ………………………………….………3 None of the above……………………4 All of the above………………………..5 I don't know/not sure………………...88	
C.2f	Do you think… you have Cadmium residues in your house?	Yes…………………………………..….1 No………………………………………0 I don't know/not sure……………..……88	

(PLEASE SEE NEXT PAGE)

ID: TLM ___ ___ ___

Section 2: Parental Knowledge, Attitude, and Practice on Lead, Cadmium, and Arsenic (continued)

C.3 Parent's KNOWLEDGE Section: Arsenic

NO.	QUESTION	RESPONSE	SKIP
C.3a	*Now, I am going to ask you a few questions about Arsenic and your knowledge---normally many people are not familiar with "Arsenic", please feel free to let me know if you don't know the answer or would like for me to repeat the question.*		
C.3b	Have you ever heard of Arsenic?	Yes……………………………………1 No…………………………………..……0 I don't know/not sure……………..…88	
C.3c	*It is normal that people don't know about Cadmium sources, please give all answers based on your understanding*……. Do you know where is/are source(s) of Arsenic? For respondent: Please feel free to ask for clarification if you are unsure about the definition of the activity. For interviewer, please clarify the answer based on the actual activities that happen in their community i.e. in a boat yard and land field, etc.	Welding ………………………………1 Spray painting ……………………….2 Fishing equipment…………………...3 Fuel……………………………..…..4 Old pipe…………………………..….5 Water …………………………………6 Soil……………………………………..7 Dust……………………………………8 Food……………………………………9 Fertilizer………………………………10 Fruit……………………………………11 None of the above……………………12 All of the above………………………13 I don't know/not sure………………...88	
C.3d	Do you think… can Arsenic cause health problem?	Yes…………………………………….1 No………………………………………0 I don't know/not sure…………..……88	
C.3e	Do you think what type of health problem Arsenic can cause? Please choose all that applies.	A. Heart Disease…………..………1 B. Cancer……………………..…….2 C. Neurological Development Deficit ……………………………….…………3 None of the above……………………4 All of the above………………………..5 I don't know/not sure………………...88	
C.3f	Do you think… you have Arsenic residues in your house?	Yes…………………………………….1 No………………………………………0 I don't know/not sure…………..……88	

(PLEASE SEE NEXT PAGE)

ID: TLM ___ ___ ___

Section 2: Parental Knowledge, Attitude, and Practice on Lead, Cadmium, and Arsenic (continued)

D.2 Parent's ATTITUDE Section: Lead, Cadmium, and Arsenic

For interviewers: this section is to assess the parent's attitude that may influence the child's Lead, Cadmium, and Arsenic exposure

NO.	QUESTION	RESPONSE	SKIP
D.2a	*Now, I am going to ask you a few questions about your thoughts about Lead, Cadmium, and Arsenic contamination in your community and your house. These questions will help us to understand how Lead Cadmium, and Arsenic residues travel within from other places to your house and others in the area. Please feel free to let me know if you don't know the answer or would like for me to repeat the question.* Do you think where/what items in your house would be contaminated by Lead, Cadmium, and Arsenic? ***For interviewer: This question is to assess that the respondent is able to identify the source of domestic Lead.***	A. Bedroom……………………………………..1 B. Bathroom……………………………………..2 C. Living room……………………………………3 D. Outside your house………………………….4 E. Others……………………………………….5 F. I don't know/not sure……………………..……88	
D.2b	Where in your community… do you think it is a source of Lead, Cadmium, and Arsenic?...please write down the name of places.	…………………………………………………….. …………………………………………………….. …………………………………………..……..…..	
D.2c	Do you think from your daily activities (at work, home, local market, other places), is it possible that you bring Lead, Cadmium, and Arsenic residues to your house?	Yes……………………………………………………..1 No……………………………………………………0 I don't know/not sure…………………………...…88	→ D.2d
D.2d	Do you think from the Pb, Cd, and As residues you bring home, will they affect your child's health?	Yes……………………………………………………..1 No……………………………………………………0 I don't know/not sure…………..…………………88	
D.2e	Have you ever smoked?	Yes……………………………………………………..1 No……………………………………………………0	→ D.2f → D.2g
D.2f	How many cigarettes do you smoke per day, with in the last 3 months?	A. 1 – 5 cigarettes …………………..…………1 B. 6 – 10 cigarettes ………………………………..2 C. 11 – 15 cigarettes ……………………………3 D. 16 – 20 cigarettes ……………………………4 E. More than 20 cigarettes ……………………….5 F. Occasionally (1-5 cigarettes per 3 months)…………………………………....……6 G. None……………………………………………88	

(PLEASE SEE NEXT PAGE)

ID: TLM ___ ___ ___

Section 2: Parental Knowledge, Attitude, and Practice on Lead, Cadmium, and Arsenic (continued)

D.2 Parent's ATTITUDE Section: Lead, Cadmium, and Arsenic

NO.	QUESTION	RESPONSE	SKIP
D.2g	Do you think your child get exposed to Lead, Cadmium, and Arsenic from daily activities?	Yes……………………………………….1 No………………………………………..0 I don't know……………………………88	

E.3 Parent's PRACTICE Section: Lead, Cadmium, and Arsenic

NO.	QUESTION	RESPONSE	SKIP
E.3a	*Now, I am going to ask you about the weekly cleaning routine, this question helps us to understand the weekly rotation of existing Lead, Cadmium, and Arsenic residues inside your house*… How often you sweep the floor weekly?	A. 1 – 5 times ....1 B. 6 – 10 times ....2 C. 11 – 15 times ....3 D. 16 – 20 times ....4 E. More than 20 times........................5 F. None..88 G. I cannot remember.......................90	
E.3b	How often you mop the floor and wipe the dust off your furniture per week?	A. 1 – 5 times ....1 B. 6 – 10 times ....2 C. 11 – 15 times ....3 D. 16 – 20 times ....4 E. More than 20 times........................5 F. None..88 G. I cannot remember.......................90	
E.3c	How often you wash your clothes per week?	A. 1 – 5 times ....1 B. 6 – 10 times ....2 C. 11 – 15 times ....3 D. 16 – 20 times ....4 E. More than 20 times..........................5 F. None..88 G. I cannot remember.......................90	
E.3d	After coming home from work… where do you leave your clothes? Please specify the area. Please choose all choices apply. If you answer E. Others, please specify the area here…………………………………………………………….…… ………………………………………………………………… ………………………………………… ………………………………………………………….	A. Bedroom……………………….1 B. Bathroom……………………...2 C. Living room……………………3 D. Outside your house…………..4 E. Others…………………………..5 F. I cannot remember…………….88	

(PLEASE SEE NEXT PAGE)

Section 2: Parental Knowledge, Attitude, and Practice on Lead, Cadmium, and Arsenic (continued)

E.3 Parent's PRACTICE Section: Lead, Cadmium, and Arsenic

NO.	QUESTION	RESPONSE	SKIP
E.3e	I am going to ask you a question that will help us understand your child's activities when they are not at school…do you allow your child to touch or play with any of these items? Please select all applies.	A. Battery (for Flash light, toys, remote control, etc) ……..……………..………1 B. Colourful Plastic Toys..…….…….2 C. Paint Chip…………….……………3 D. Rusted Toys at Playground ……..4 E. None of the above…………………5 F. All of the above……………………..6 G. I don't know………..……………..88	
E.3f	Do you allow your child to eat or drink food at someone else's houses?	Yes…………………………………….1 No……………………………………0 I cannot remember…………….……88	
E.3g	Now, I would like to ask you some questions about your task at work…this will help us understand the exposure of Lead, Cadmium, and Arsenic that possibly will be brought home from your clothes, bag, shoes, hat, and other personal belongings…. Do you by chance touch any of finishing equipment when you are at work?	A. Yes ………… ……………………………………1 B. No……………………………………………2 C. I don't work at fishing industry?……………………………………………3 D. I don't know ……………………………88	
E.3h	Now, I would like to ask you some questions about your activity at home…this will help us understand the exposure of Lead, Cadmium, and Arsenic that possibly will be transferred from place to place inside your house from your clothes, bag, shoes, hat, and other personal belongings…. Do you by chance touch any of finishing equipment when you are at home?	A. Yes ………… ……………………………………1 B. No……………………………………………2 C. I don't have fishing equipment at home..?……………………………………………3 D. I cannot remember…………………………88	
E.3i	Do you wash your hands before you leave work?	A. Yes ………… ……………………………………1 B. No……………………………………………2 C. I cannot remember………………………88	
E.3j	Do you wash your hands when you get home?	A. Yes ………… ……………………………………1 B. No……………………………………………2 C. I cannot remember………………………88	
E.3k	Do you take a shower when you get home?	A. Yes ………… ……………………………………1 B. No……………………………………………2 C. I cannot remember………………………88	

(PLEASE SEE NEXT PAGE)

Section 2: Parental Knowledge, Attitude, and Practice on Lead, Cadmium, and Arsenic (continued)

E.3 Parent's PRACTICE Section: Lead, Cadmium, and Arsenic

NO.	QUESTION	RESPONSE	SKIP
E.3l	Do you leave your shoes outside your house?	A. Yes ………… ……………………………1 B. No…………………………………………2 C. I cannot remember…………………88	
E.3m	Now, I would like to ask you some questions about your child's activity when they are home…this will help us understand the exposure of Lead, Cadmium, and Arsenic that possibly will be brought home from your clothes, bag, shoes, hat, and other personal belongings…. Does your child wash his/her hands before leaving school?	A. Yes ………… ……………………………1 B. No…………………………………………2 C. I am not sure……………………………3 D. I don't know ……………………………88	
E.3n	Does your child wash his/her hands when he/she gets home?	A. Yes ………… ……………………………1 B. No…………………………………………2 C. I cannot remember…………………….3 D. I don't know……………………………88	
E.3o	Does your child take a shower right after when he/she gets home?	A. Yes ………… ……………………………1 B. No…………………………………………2 C. I cannot remember…………………88	
E.3p	Does your child leave his/her shoes outside the house?	A. Yes ………… ……………………………1 B. No…………………………………………2 C. I cannot remember…………………88	
E.3q	Does your child play outside the house or neighborhood?	A. Yes ………… ……………………………1 B. No…………………………………………2 C. I cannot remember…………………88	
E.3r	Do you think your knowledge about Lead, Cadmium, and Arsenic affects your child's potential contamination?	A. Yes ………… ……………………………1 B. No…………………………………………2 C. Maybe………………………………………3 D. I don't know……………………………88	

(PLEASE SEE NEXT PAGE)

ID: TLM ___ ___ ___

Section 3: Child's physical development

Child's Information

Instruction for the interviewer: This section is to assess the child physical development. Please take a measurement using a given measuring tape, see below for necessary items to be measured. For a child's date of birth please ask the parents.

A child's date of birth [_____ /_____ / ______] (dd/mm/yy)

Height: [_____/_____/_____/______] (cm)

Weight: [_____/_____/_____ . ______/______] (kg)

Head circumference: [_____/_____/____. ______/______] (cm)

Upper arm circumference: [_____/_____/_____. ______/______] (cm)

"These are the questions that I wanted to ask you. Thank you very much for talking with me today. We very much appreciate your help in this research study"

TIME FINISHED [___/___] [___/___] (24 hour time)

(LAST PAGE)

Appendix 2. Water, Hygiene, and Sanitation Evaluation Form

ID ______________________

Water, Hygiene, and Sanitation Evaluation Form

1. The house is in good condition, strong, and steady (House structure, doors, windows are in good condition, no cracks or breaks) _______________ pass _____________ fail

2. Inside a home: clean, organized, no pile of items (no spider web, areas are properly used, and items are in places they belong, no excess amount of items, clean up at least once a week. For carpet and curtain: clean once every month. For air conditioner, should be cleaned at least once every 6 months) ________________ pass _____________ fail

3. Indoor air flows well and enough day light ________________ pass _____________ fail

4. Clean and well-kept yard, no trash or sewer water around the house ________________ pass ________________fail

5. In case you have pet, the pet area is clean, litter box is separated from common used areas, no animal waste or odor inside the house. ________________ pass _____________ fail

6. Toilet and bathroom's construction are in good condition for use. (floor, ceiling, toilet, toilet flush handle are clean, no stain, spider web, dust, or slippery). Toilet facility should be clean at least once a week. In case there is elderly, disable, or pregnant woman in the house, a flat toilet is highly recommended to be used) ________________ pass _____________ fail

7. Inside the bathroom, no mosquitos, water container is completely closed, in clean condition, water bowl for cleaning after is clean, water is clear no sediment on the bottom. All items are well-kept. ________________ pass _____________ fail

8. Bathroom: air flow well and enough sun light during a day. ________________ pass _____________ fail

9. Doors: all doors, knobs, and locks are in good condition. ________________ pass _____________ fail

10. Sewer pipe, waste storing container are in good condition, no crack, completely closed. ________________ pass _____________ fail

11. Bathroom location, not in blind spot, hard to access, or harmful to the users. ________________ pass _____________ fail

12. Bedroom: clean, organized, no spider web, bedding items are clean and well-kept, air flow well, no odor, must be cleaned once a week. ________________ pass _____________ fail

13. Bedroom (s) has/have nets to protect everyone in the house from mosquitos and insects. ________________ pass _____________ fail

14. Kitchen area: separate from other areas, air flow well and enough sun light. All cooking equipment is neatly kept and clean. ________________ pass _____________ fail

15. Food preparation process must be 60 cm. above the floor. ________________ pass _____________ fail

16. Raw meat, vegetables, fruits must be washed before cooking or eat. ________________ pass _____________ fail

17. Cooked food is kept in a refrigerator or food cabinet, away from insects. ________________ pass _____________ fail

18. Properly use the ingredients and canned food. ________________ pass _____________ fail

19. Food containers made from non-harmful materials, clean, and well kept. ________________ pass _____________ fail

20. Domestic water is available all year and clean. ________________ pass _____________ fail

21. Containers for keeping domestic water are clean, closed with lids, and regularly cleaned. ________________ pass _____________ fail

22. Trashes are separated by type for the municipality truck pickup, no trash sporadically left inside the house. ________________ pass _____________ fail

23. Trach can is in a good condition, lid, and no crack ________________ pass _____________ fail

24. Waste water is treated before releasing into the environment. If the house is located close to the sewer canal, all solid trashes must be filtered out and put in trash cans. ________________ pass _____________ fail

25. No open container to reduce the possibility of mosquitos to lay eggs. ________________ pass _____________ fail

26. Pest control: must be done regularly, using net to keep insects away from food and humans. ________________ pass _____________ fail

27. Hazardous substance: kept away from children, in a proper place with minimal exposure to humans, animals, and environment. ________________ pass _____________ fail

28. Power cords, protectors. Electronic devices are in good condition. ________________ pass _____________ fail

29. All family members wash their hands every time before eating and after using bathroom. ________________ pass _____________ fail

30. During meal, using serving spoons to take food from the containers. ________________ pass _____________ fail

31. Family members use their own drinking water container. ________________ pass _____________ fail

32. In case one of the family members is sick, others must wear a medical mask to reduce the infection. ________________ pass _____________ fail

33. Family members attend the community event hosted by public health office to improve the environmental health. ________________ pass _____________ fail

34. Family members and activities occur in this house do not cause any inconvenience to neighborhood and community such as releasing waste/ smelt water directly to the river or loud noises. ________________ pass _____________ fail

Appendix 3. IRB 00102980

EMORY UNIVERSITY | Institutional Review Board

TO: Pornpimol Kodsup, MPH Candidate
Principal Investigator
Environmental Health

DATE: April 26, 2018

RE: **Amendment Approval**

AM1_IRB00102980

IRB00102980
Parental Knowledge, Attitudes, and Practices influencing Children's Lead Exposure in a Commercial Fishing Community in Southern Thailand and Understanding Lead Exposures and their Predictors using Human Biomonitoring

Thank you for submitting an amendment request. The Emory IRB reviewed and approved this amendment under the expedited review process on **4/26/2018**. This amendment includes the following:

- Consent V4 (English), undated

Important note: If this study is NIH-supported, you may need to obtain NIH prior approval for the change(s) contained in this amendment before implementation. Please review the NIH policy directives found at the following links and contact your NIH Program Officer, NIH Grants Management Officer, or the Emory Office of Sponsored Programs if you have questions.

Policy on changes in active awards: http://grants.nih.gov/grants/guide/notice-files/NOT-OD-12-129.html

Policy on delayed onset awards: http://grants.nih.gov/grants/guide/notice-files/NOT-OD-12-130.html

In future correspondence with the IRB about this study, please include the IRB file ID, the name of the Principal Investigator and the study title. Thank you.

Sincerely,

Sam Roberts, BA
Research Protocol Analyst, Sr.
This letter has been digitally signed

Appendix 4. Phang-Nga Provincial Health Office IRB

สำนักงานสาธารณสุขจังหวัดพังงา
กระทรวงสาธารณสุข

เอกสารรับรองการพิจารณาจริยธรรมการวิจัยในคน
โดย คณะกรรมการจริยธรรมการวิจัยจังหวัดพังงา

ชื่อโครงการ การศึกษาเปรียบเทียบ ความรู้ ทัศนคติ และการปฏิบัติตนของผู้ปกครองที่ส่งผลต่อการรับสัมผัสสารตะกั่วของเด็ก ภายในชุมชนอุตสาหกรรมการประมงและชุมชนเมือง รวมถึงปัจจัยอื่นๆที่มีผลต่อการรับสัมผัสสารตะกั่ว โดยวิธีการตรวจวัดทางชีวภาพ กรณีศึกษาจังหวัดพังงา

(Parental Knowledge, Attitudes, and Practices influencing Children' Lead Exposure in Commercial Fishing Community and Understanding Lead Exposures and their Predictors using Human Biomonitoring in Southern Thailand.

รหัสโครงการ : ......๗/๖๑...

ชื่อหัวหน้าโครงการ.....นางสาวพลพิมล กดทรัพย์ ....

หน่วยงานที่สังกัด Department of Environment Health, Rollins School of Public Health, Emory University.USA.

ผลการพิจารณา

- ☐ เป็นโครงการวิจัยที่เข้าข่ายยกเว้น
- ☑ อนุมัติ
- ☐ อนุมัติโดยมีเงื่อนไข
- ☐ ปรับปรุงโครงการวิจัย แล้วเสนอคณะกรรมการผู้ทบทวนหลัก (Reviewer) ลงทะเบียนใหม่
- ☐ ไม่อนุมัติ

ขอรับรองว่าโครงการดังกล่าวข้างต้น ได้ผ่านการพิจารณาเห็นชอบตามหลักการพิจารณาจริยธรรมของ

- ☑ Belmont Report
- ☐ Nuremburg Code
- ☐ Declaration of Helsinki
- ☐ ข้อบังคับแพทย์สภาว่าด้วยการรักษาจริยธรรมแห่งวิชาชีพเวชกรรม พ.ศ.๒๕๔๙

วันที่รับรอง ..๑๘....พฤษภาคม ๒๕๖๑......................................

วันที่สิ้นสุดการรับรอง ..๑๗.....พฤษภาคม ๒๕๖๒...........................

ลงนาม...

(นางสาวอุไรวรรณ ตันฑอาริยะ)

นักวิชาการสาธารณสุขเชี่ยวชาญ (ด้านส่งเสริมพัฒนา)

รักษาราชการแทน นายแพทย์สาธารณสุขจังหวัดพังงา

Appendix 5. Phang-Nga Provincial Health Office letter of support

Ref 0032.009/ 1827

Phang-Nga Provincial Public Health Office
Petkasem Road, Phang-nga Province 82000

10 April 2561

To Ms. Pornpimol Kodsup

I am writing this letter to support your study, titled "Parental Knowledge, Attitudes, and Practices influencing Children's Lead Exposure in a Commercial Fishing Community and Understanding Lead Exposuresand their Predictors using Human Biomonitoring in Southern Thailand",which will be held in June 2018 through June 2019 at two child development centers located in Tum NumPhud and Ban Tub Lamu, in Phang- Nga province.

As the Chief Medical Officer of Phang-Nga province who is responsible for overseeing and directing public health related programs and activities within the province, I think your study is very important. Certainly, it will provide much needed knowledge for the design of public health programs that could reduce and prevent lead exposures among young children. I would like to express my support, as well as those from public health officers working on site, for your study. If needed, I will work with the local authorities to provide you with access to the communities to conduct your research.

Should you have any questions or concern, please do not hesitate to let me know. I can be reached via phone number 0 7648 1721

I look forward to the success of your study.

Best Regards,

(Mr.Sawek Gerdlarp)
On duty Chief Medical Officer
For Phang-Nga Provincial Public Health office

Appendix 6. Consent form

Consent Form

Cross sectional study of the potential lead exposure in children in commercial fishing area compares between groups in Ban Tub Lamu, Phang-nga Province, Thailand

Ban Tub Lamu is a small community that has high fishing and tourism activities. These activities introduce people in the community to lead exposure for example fishing industry, boatyard, contaminated water and an old pipe system. Based on the activities in the area, people especially children potentially have exposed to lead. The effect of lead on children's health is important issue that everyone need to understand and rise awareness in the community to prevent the further lead contamination by understanding the source of the exposure.

This survey is to understand Ban Tub Lamu community, individual's daily life style, occupation, socioeconomic status, hygiene knowledge, Lead knowledge, sources of drinking and domestic water to understand the potential of lead exposure in the area. I am available to answer any questions the subject may have about the survey.

If you decide to participate in my project, you will complete a short survey and return it to the research staff. This survey may take about 5 minutes to complete.

Participating in a survey will help the researchers to understand the nature of the community and influence the decision of further study on lead exposure in children in Ban Tub Lamu community. The copy of the survey results to participants upon request.

There is no risk and/or discomforts to the subject that can reasonably be expected as a result of participating in this study. Your identification will be confidential and there will be a small gift for each participant.

Contact Information:

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You are free to refuse to participate in this research project or to withdraw your consent and discontinue participation in the project at any time without penalty or loss of benefits to which you are otherwise entitled. Your participation will not affect your relationship with the institution(s) involved in this project.

My return of this survey implies my consent to participate in this research and I have been given a second copy of this form to keep for my records.

I understand about all mentioned above and willing to participate in this survey.

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Participant's Name Date