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Predicting Blood Lead Levels among Children Living in Households Making Fishing Nets with Lead Weights in Phuket and Phang Nga Provinces

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Abstract

This study aimed to validate the Integrated Exposure Uptake Biokinetic (IEUBK) model, the computed risk assessment tool, by comparing the predicted blood lead levels and the observed one among children aged 1-7 years old in households making fishing nets, and to develop a predictive model based on environmental lead level in Phuket and Phang Nga Provinces, in the South of Thailand. We identified children in households, which made fishing nets and participated in the Office Disease Prevention and Control 11 Blood Lead Levels Surveillance System (BLLSS). We collected blood lead information, surveillance address and samples from the environment such as soil, water and dust. We calculated the predicted value by using IEUBK program and the site-specific model and compared with observed value to calculate Mean Absolute Error (MAE) and Mean Absolute Percent Error (MAPE). Forty children from different households were recruited. Geometric mean observed blood lead level was 7.6 µg/dL. We found 45% of households with excess lead in surface dust, and 19% in water. The MAE and MAPE of IEUBK model revealed a substantial difference between the observed and predicted values. The site-specific model, including soil, dust in the bed and workwear as predictive variables, had more accuracy predictive capacity. However further study of the IEUBK in other scenarios is needed.

Keywords: child, lead, Thailand

Introduction

Lead exposure results in neurobehavioral impairment in young children due to their hand-to-mouth activities and higher absorption rate than adults.[1] The US Centers for Disease Control and Prevention (CDC) has stated that there is no safe blood lead level for children.[2] The major sources of lead exposure in Thailand are ambient lead contamination in the environment and take-home exposures such as living with parents who are involved in lead manufacture, and in-house exposure such as attaching lead weights during making net process.[3]

The Office of Disease Prevention and Control 11 (ODPC 11), responsible for the upper southern coast of Thailand, established a sentinel blood lead levels surveillance system (BLLSS) in 2013. The BLLSS aimed to focus on children who lived in households making fishing nets. Population under surveillance was children aged 1-7 years old who lived in households making fishing nets.[4] Seven fisheries communities were purposively selected in the upper Southern Thailand. Children who lived in households where their parents made fishing nets were invited to participate. Local nurses took blood sampling from children and sent the blood samples to the Reference Laboratory and Toxicology Center, Department of Disease Control (DDC), Ministry of Public Health (MOPH). In 2014, data from the surveillance indicated that 61% of children aged 1-7 years old in Phang Nga Province had blood lead levels≥ 10 µg/dL.[4]

The Integrated Exposure Uptake Biokinetic (IEUBK) model, designed by the US Environmental Protection Agency (EPA), is a simulation risk assessment program to integrate exposure from lead in air, water, soil, dust and other sources in a pharmacokinetic equation to compute and predict the blood lead level distribution for children in site-specific lead levels and the probability that children in that environment having a blood lead level that exceeds a defined threshold.[5,6] The IEUBK model has been empirically validated, upgraded and widely applied in Greece, Hungary, Ghana and China.[7-12]

This study aimed to validate the IEUBK model by comparing the predicted blood lead levels in children using its site-specific model against the observed blood lead level from the BLLSS and to develop a predictive model based on environmental lead level in households making fishing nets in two provinces in Southern Thailand.

Methods

Study Design and Population

A cross-sectional study design was conducted using secondary data from the BLLSS combined with primary data collection on-site of environmental samples. All participants were selected from the BLLSS that was gathered in 3 sites: Paklok Subdistrict, Thalang District, Phuket Province; Bang Muang Subdistrict, Takuapa District, Phang Nga Province; and Kura Subdistrict, Kuraburi District, Phang Nga Province. All study sites are located on the Andaman Sea coast.

Sample Size, Assumptions and Sampling

Number of children sampled was calculated by using single calculation for correlation formula

$$C = 0.5 * \ln[(1+r)/(1-r)] = 0.436$$

$$N = [(Z\alpha+Z\beta)/C] *2 + 3$$

Giving alpha = 0.05, power = 0.8, and lowest correlation coefficient from review literature = 0.41[8]

This resulted in a sample size of 40 children. Quota sampling was applied into the 3 communities including 17 for Takuapa District, 17 for Kuraburi District, and 6 for Thalang District. Of 54 children under the BLLSS from 48 different houses, 45 children from 40 different houses could be traced to collect data.

Data Collection

Health volunteers surveyed and informed parents who made fishing net to bring their children aged 1-7 years old to participate in the study. All parents consented to the child's participation and provided their household address. All blood and environmental samples were tested at the Reference Laboratory and Toxicology Center, which was the reference laboratory of the DDC, MOPH, Thailand in 2015.

Blood Samples

Children aged 1-7 years old, living in households making fishing nets in the study sites, were invited to participate in the study. After parents /guardians consented to the child's participation, 3-ml venous blood samples were drawn in EDTA tubes by nurses from community hospitals.[14] All blood samples were kept at 4 degree Celsius until analysis by Graphite Furnace Atomic Absorption Spectroscopy (GFAAS).[15]

Environmental Media Collection

Sampling of environmental media was collected at each participant's house. All samples were collected according to the user's guidance for IEUBK by EPA and guidelines from Division of Occupational and Environmental Diseases, Thailand.[13,14] All specimens were tested at the Reference Laboratory and Toxicology Center, the DDC, MOPH by Flame Atomic Absorption Spectrometry Method.[16]

Outdoor soil sampling

Soil sampling was conveniently collected from 10 points in each participant's house. The one kilogram of soil samples was mixed and put in polyethylene bags. All soil samples were kept at 4 degree Celsius until analysis by Flame Atomic Absorption Spectrometry Method.[16] The Pollution Control Department (PCD) defined standard level for soil lead concentration as below 400 mg/kg.[14]

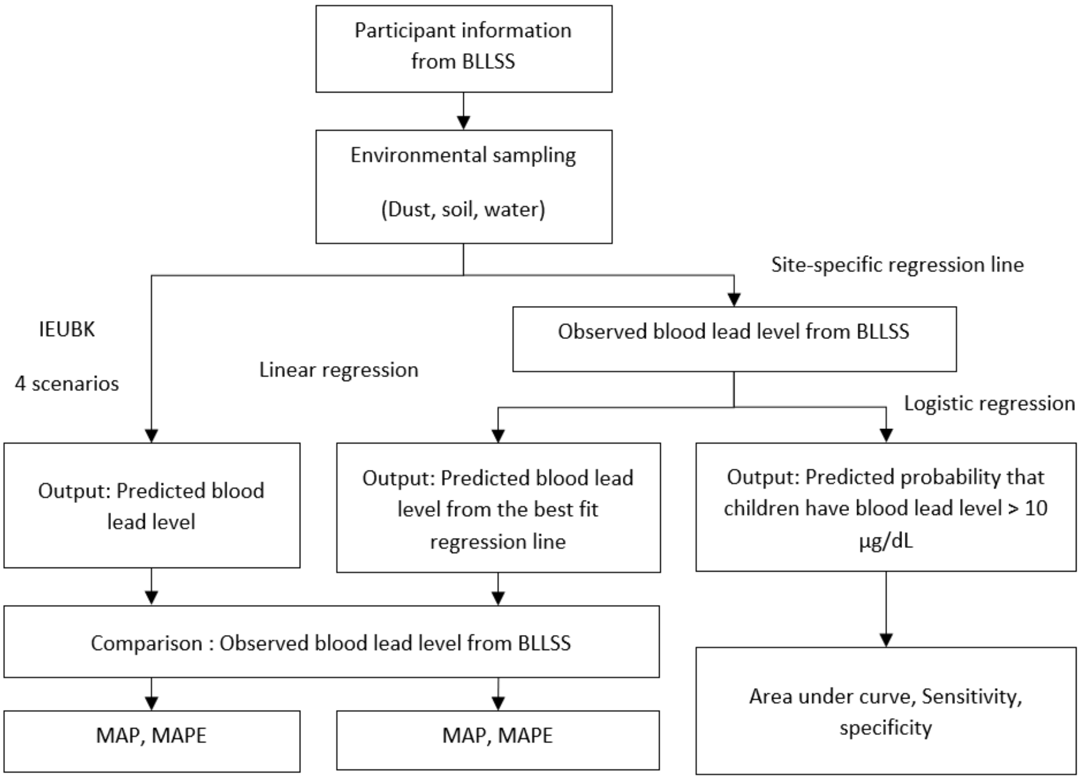

Figure 1 Overview of data analysis method

Tap water sampling

In houses with tap water, 500-ml water samples were collected from running water. For those houses using groundwater, 500-ml water samples were collected from the well. The water containers were cleansed and washed twice or thrice with sampling water, then 1-2 ml of nitric acid was added after each sample. All water samples were kept at 4 degree Celsius until analysis by Flame Atomic Absorption Spectrometry Method.[16] The PCD defined standard level for water lead concentration as below 0.05 mg/dL.[14]

Indoor residential dust sampling.

Surface dust sampling was collected from three areas of each house: bed, clothes hanging areas and parents' workwear. If the workwear was already washed, dust was collected in the making fishing net area. Beryllium paper was used to wipe an area of 100 cm^2 in the three places. The samples were kept in polyethylene tubes at room temperature prior to laboratory analysis.[14] All dust samples were tested by Flame Atomic Absorption Spectrometry Method.[16] The PCD defined standard level of dust lead loading for lead operating area as 26.9 µg/100 cm^2.[14]

IEUBK Model Validation and Statistical Analyses

The demographic data and laboratory results were divided into two separate parts for analysis, IEUBK model and site-specific predictive models. (Figure 1) The IEUBK model (Windows® version 1.1 build 11) was downloaded from US EPA website. Batch mode in IEUBK was used for analyzing predicted blood lead level. Environmental lead values from soil, water and dust were put in four different scenarios. The scenarios included (1) soil, water, dust and default air lead (0.1 µg/m^3), (2) soil, dust, default air lead and default water lead (4 µg/L), (3) water, dust, default air lead and default soil lead (estimated from dust lead), and (4) dust, default water lead, default air lead and default soil lead.

The correlation between predicted and observed blood lead level was analyzed using STATA V.10. Mean Absolute Error (MAE) and Mean Absolute Percent Error (MAPE) were calculated to quantify the difference between predicted and observed blood lead levels. Values close to 0 indicated that the predicted approximated to the observed blood lead levels. These were calculated using the following formula.

Table 1 Demographic data and blood lead level of children from household sampling

Characteristics	Total (n=45)	Study site		
		Thalang District (n=8)	Takuapa District (n=19)	Kuraburi District (n=18)
Sex				
Male (%)	23 (51.1%)	4 (50.0%)	13 (68.4%)	6 (33.3%)
Female (%)	22 (48.9%)	4 (50.0%)	6 (31.6%)	12 (66.7%)
Age				
Mean age ± SD (years)	3.93 ± 1.6	4.4 ± 0.6	3.7 ± 0.4	3.9 ± 0.4
1-3 years	18 (40.0%)	2 (25.0%)	10 (52.6%)	6 (33.3%)
4-7 years	27 (60.0%)	6 (75.0%)	9 (47.4%)	12 (66.7%)
Blood lead Level				
Geometric mean blood lead level (µg/dL)	7.6	7.2	3.8	16.0
Less than 5 µg/dL	7 (15.6%)	2 (25.0%)	5 (26.3%)	0
5.0-9.9 µg/dL	13 (28.9%)	4 (31.6%)	6 (31.6%)	3 (16.7%)
10.0-24.9 µg/dL	19 (42.2%)	2 (25.0%)	5 (15.8%)	12 (66.7%)
More than 25.0 µg/dL	6 (13.3%)	0	3(18.8%)	3 (16.7%)

$$\text{Mean Absolute Error (MAE)} = \frac{\sum|E_t|}{n}$$

$$\text{Mean Absolute Percent Error (MAPE)} = \frac{\sum\left|\frac{E_t}{A_t}\right|*100}{n}$$

Where E_t = Observed blood lead levels - Predicted blood lead levels

A_t = Observed blood lead levels

n = Number of house samplings

Developing Predictive Model

Age, gender, blood and environmental lead levels from soil, water and indoor dust were used to develop a predictive model of log blood lead level by using multiple linear regression. A binary logistic regression model was developed to predict probability that children would have blood lead levels≥ 10 µg/dL. We selected variables into the model by using stepwise backward elimination using the criteria of *P*-value> 0.1 out of model. MAE and MAPE were also calculated for the multiple linear regression model. Sensitivity, specificity and area under ROC curve were also calculated from multiple logistic regression.

Results

Demographic Data of Children

According to the BLLSS, 45 children from 40 different houses were tested for blood lead levels since five of the children were siblings. Forty different houses could be traced for their exact address. Mean age of children in the study was 3.9 ± 1.6 years old. The geometric mean blood lead level was 7.6 µg/dL. Six children had extreme blood lead levels≥ 25 µg/dL. The geometric mean blood lead levels in Kuraburi District was 16.0 µg/dL. (Table 1)

Environmental Samples

A total of 193 specimens were collected from 40 households. Of the soil samples, 33/40 (82.5%) were collected; five houses did not contribute soil samples because the house was located on mangrove and two houses were built on cement ground. All houses contributed water samples and dust wipe sample specimens. (Figure 2)

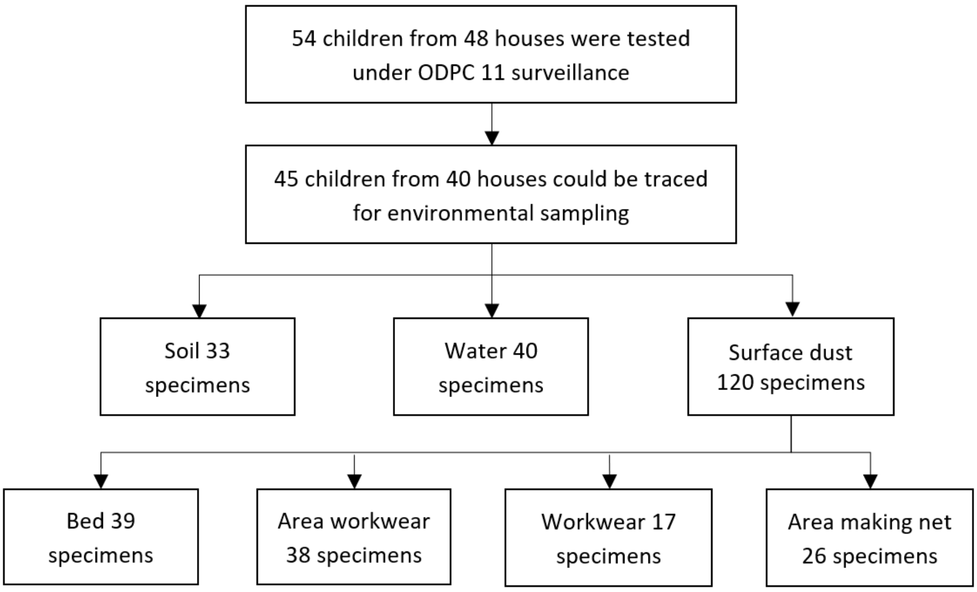

Figure 2 Children and environmental sampling

Lead concentration in soil in the study sites did not exceed the PCD threshold. However, median lead concentration in soil in Kuraburi District was higher than that of the other two sites. For water 8/40 samples (20.0%) had lead concentrations above the PCD threshold. Additionally, Kuraburi District had largest proportion of water samples (29.4%) which exceeded the standard. (Table 2)

Of the surface dust lead samples, 45% (18/40) of households had one sample exceeding the dust standard. The making fishing nets area revealed the highest median dust lead load, followed by workwear. (Table 3)

Table 2 Outdoor soil and water lead level sampling in households making trawl net in Phuket and Phang Nga Provinces

Area	Outdoor soil (mg/kg)				Water (mg/L)			
	n	Median	Range	Number of specimens exceed standard# (%)	n	Median	Range	Number of specimens exceed standard* (%)
Total	33	40.7	4.4-371.1	0	40	0.001	0.001-1.2	8 (19.1%)
Thalang District	7	31.6	20.0-41.2	0	7	0.004	0.003-1.05	1 (14.2%)
Takuapa District	14	40.4	4.4-371.1	0	16	0.001	0.001-1.2	2 (12.5%)
Kuraburi District	12	62.9	27.6-112.6	0	17	0.001	0.001-0.30	5 (29.4%)

Note: # Standard level for soil lead level for residency and agriculture by Department of Pollution Control: not exceed 400 mg/kg
** Standard level for water lead level in surface water and consumption by Department of Pollution Control: not exceed 0.05 mg/L*

Blood Lead Level Prediction by IEUBK Model

Overall predicted blood lead levels by IEUBK model showed lower blood lead levels than the observed blood lead levels. Geometric means of the predicted blood lead level were highest in scenario 3 (6.9 mg/dL), followed by scenario 1 (5.4), scenario 4 (4.5), and scenario 2 (3.4), respectively. We detected the differences between observed and predicted blood lead level, using MAE and MAPE. The lowest difference by MAE and MAPE was scenario 3, accounting for 9.2 and 59.0%, followed by scenario 4 (9.3, 58.2%), scenario 2 (10.3, 65.4%) and scenario 1 (10.1, 65.5%). (Table 4)

Table 3 Indoor dust lead loading in households making trawl net in Phuket and Phang Nga Provinces

Area	Indoor residential dust loading (µg/100 cm^2)			
	n	Median	Range	Number of specimens exceed standard$^{\beta}$ (%)
Child's bed	39	2.1	0.001-190.8	3 (7.3%)
Parents' workwear	17	4.2	0.001-297.3	4 (22.2%)
Area where workwear was left	38	6.4	0.001-241.2	10(25%)
Making fishing net areas	26	8.86	0.6-132.8	9 (34.6%)
Total	120	4.03		26 (21.7%)

Note: $^{\beta}$ Standard level dust lead loading for lead operating area = 26.9 µg/100 cm^2

Site Specific Multiple Linear Regression Model

The best fit predictive model after being adjusted for age, lead level in soil, water, child's bed, area making net, and area clothes left to predict log blood lead level is shown as the following equation:

*Log blood lead = 1.284566 + 0.1765779*age(year) + 0.0070465*lead level in soil + 0.0234221*dust lead loading at bed - 0.0140896*dust lead loading at area clothes left.*

The model showed that age, soil lead, dust lead at bed, and dust lead at area clothes left provided the most accurate predictive ability. MAE was 4.8 (0.01-15.8) and MAPE was 40.5% (0.08%-161.5%). Adjusted R-squared was equal to 60.7.

Site Specific Multiple Logistic Regression Model

To predict probability that children had blood lead levels≥ 10 µg/dL, the model was developed by automatically selecting variables including lead level in soil, water, child's bed, area making net, and area clothes left. The predictive model associated with lead level in soil only and did not show statistical significance. Sensitivity for this predictive model was 60% while specificity showed 83% and area under ROC curve was approximately 0.82.

Discussion

In this study we found that the geometric mean of predicted values of the blood lead levels in children in households making fishing nets with lead weights ranged from 3.4 to 6.9 µg/dL, while the observed blood lead level from the BLLSS was 7.6 µg/dL. Additionally, the environmental samples of soil, water and surface dust were collected and calculated at 40.7 mg/kg, 0.001 mg/L and 4.0 µg/100 cm^2, respectively, which was 28.3% (34/120) exceeded the standard.

From results of blood lead levels and environmental lead levels in our study, we are fairly confident that a primary source of exposure was from attaching lead weight with fishing net. The findings indicated that the 84.4 % of the children showed blood lead levels greater than 5 µg/dL which is the recommended reference level from the US National Health and Nutrition Examination Survey (NHANES). Additionally, the geometric mean of blood lead levels was similar to the study of blood lead levels among children in Umpang District, Tak Province in 2010 which showed 7.71 µg/dL. Primary source of exposure came from lead-contaminated water from a nearby lead smelter.[17]

Regarding to environmental lead level, our results

Table 4 Types of environmental variables filled into each scenario

Scenario (Environment parameter filled)	n	Geometric mean of predicted blood lead levels (µg/dL)	Correlation between predicted and observed value	Absolute Error			Absolute Percent Error		
				Min	Max	MAE[a]	Min	Max	MAPE[b]
Scenario 1 (soil, water, dust)	35	5.4	-0.057	0.2	36.1	10.1	6.1	92.3	65.5
Scenario 2 (soil, dust)	45	3.4	0.731*	0.2	36.0	10.3	6.1	91.3	65.4
Scenario 3 (dust, water)	35	6.9	-0.042	0.2	34.0	9.2	6.1	88.5	59.0
Scenario 4 (dust)	45	4.5	0.664*	0.2	33.8	9.3	6.1	90.1	58.2

*Note: *Statistical significance at alpha< 0.05*

[a] Mean Absolute Error

[b] Mean Absolute Percent Error (MAPE)

indicated that primary source of exposure might come from indoor dust especially in the making fishing net area as well as workwear and laundry area. Sahmel et.al mentioned that handling fishing weights contributed to deposition of lead on hand, then, 24% of lead on hand is ingested by biting lead split-shot hand during homemade fishing weights process.[18]

We found marked differences between observed and predicted blood lead level by MAP and MAPE. This might be a result of measurement errors in collecting specimens or laboratory analysis.[19] Another reason for the discrepancy may be that default values in IEUBK model may not be appropriate in empirical situation. Hu et. al., 2013 showed some difference between predicted and observed lead levels in Chinese children resulting from the differences in metabolic rate, ingestion rate, and diet variables, compared to the US children.[20] Although the IEUBK model was developed in 1990 and has been widely applied in the US and several studies globally, experience with the application is still limited in Thailand.[21] Only one study applied IEUBK model for risk assessment and to set up cleaning goal in old lead smelting area, Klity mine.[22] The strengths of this initial study to validate the IEUBK model is the use of site-specific data in a high-risk population.

In this study, we might only suspect attaching fishing weights was the primary source of exposure since there was no comparison group. We would encourage further study to collect information on other houses in community to ensure that there was no other source in the community rather than fishing nets. Additionally, we were unable to collect fishing weights to analyze their components as well as children's food that might result in underestimation of the IEUBK prediction.

Conclusion

This is the first study to explore the relationship between blood and environmental lead levels in households making fishing nets. The IEUBK model might not be appropriate to predict blood lead levels in this site-specific area due to underestimation. Site specific predictive model showed that indoor dust loading was highly predictive in the regression model, making it highly likely that the process of attaching lead weights to fishing nets could be a source of lead exposure. Nonetheless further study in this area is needed to better understand the variations in blood lead level that are the results of metabolic rate, ingestion rates and other predictors of elevated blood lead level in Thai children

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