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Health Risk Assessment on High Groundwater Arsenic Concentration among Adult and Children in Beranang Subdistrict, Malaysia

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ABSTRACT

Beranang, one of the rural areas of Selangor which still depends on the groundwater as a secondary source of water for drinking and other purposes apart from treated water. The main objective of this study was to evaluate the health risk assessment of arsenic ingestion through groundwater consumption among Beranang residents in Selangor. Five houses with a functioning electrical pump-assisted tube well were chosen for the sampling, which occurred in February 2019. The groundwater samples were taken at each sampling point and stored at room temperature during transport to the laboratory within 24 hours. The groundwater samples were analyzed using the ICP-MS method. Both hazard quotient (HQ) and lifetime cancer risk (LCR) were calculated based on the formula provided by the US EPA (United States Environment Protection Agency). Arsenic concentration in the groundwater samples was higher than the WHO Drinking Guideline and Malaysia Raw Water Standard in all houses. The mean concentration was 46.90 µg/L with maximum and minimum concentrations of 54.40 µg/L and 23.70 µg/L, respectively. The concentration was approximately 2- to 6- fold in all houses with 100% prevalence of contaminated tube wells. The health risk degree of children was higher than that of adults on the whole, indicating that children

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suffer much higher risks than adults. The health risk degree through oral exposure was higher than dermal exposure. Despite the fact that the groundwater is not suitable for drinking, however, there is no health risk through dermal exposure.

Keywords: Arsenic, groundwater, hazard quotient, health risk assessment, lifetime cancer risk

INTRODUCTION

Arsenic is a metalloid that occurs naturally as one of the most abundant elements in the earth's crust and is a component of more than 200 minerals (Mandal & Suzuki, 2002). In the groundwater, this heavy metal can be derived from natural sources as a result of weathering and erosion of bedrock and ore deposits (Demirak et al., 2006; Muhammad et al., 2010). The pollution of groundwater by arsenic may also be due to human activities, for examples; agricultural sectors involve the use of fertilizers and pesticides, mining activities, land development, the addition of solutes to groundwater systems, or human-induced flow-system changes (Avila-Sandoval et al., 2018). High concentration of arsenic in the groundwater can cause deterioration of drinking water quality and is adverse to human health. Arsenic is classified as a class A carcinogen based on sufficient evidence from human data (United States Environment Protection Agency, 1991).

Human exposure to arsenic occurs mainly through ingestion of arsenic-contaminated drinking water (Rahman et al., 2009). Groundwater contamination by arsenic is one of the major environmental health concerns in many countries, especially within communities that are still dependent on the tube wells as their primary source of drinking water (Chen & Ahsan, 2004; Muhammad et al., 2011; Wongsasuluk et al., 2014). The contamination of groundwater by arsenic in Bangladesh in 2000 was the largest poisoning of a population in history. It is estimated that approximately half of the 125 million people of the Bangladeshi population are at risk of drinking contaminated water (Smith et al., 2000).

Arsenic contamination in drinking water is of great concern for public health because of its effects on human health. Pregnant women and their fetuses are at risk of intoxication; previous human and animal studies have shown reproductive and developmental toxicity due to arsenic exposure (Abdul et al., 2015). In addition to acute poisoning, arsenic causes skin, lung, and bladder malignancy and has non-cancer effects on the integumentary, cardiovascular, pulmonary, nervous, endocrine, and reproductive systems (Brown & Ross, 2002).

In Malaysia, rural areas make up 70% of the total land area (231,180 square km or 23 million hectares) consisting of agricultural areas, forests, village settlements, beaches and islands. Rural community is defined as a settlement that covers all types of villages and small settlements of less than 10,000 people, features agricultural sectors and natural resources such as forest and water bodies. According to Statistic Canada 1996, rural and small town refers to individuals in towns or municipalities outside of the commuting zone of larger urban centers with 10,000 or more population (Department of Statistic Malaysia, 2010). As for 2018, there were 7.8 million rural residents which comprised 24.4% of total Malaysia population, and majority of them were *Bumiputra*, and age between 15 - 30 years old. While in Selangor state, there were 435,900 rural residents which comprised 6.7% of total population (Ministry of Rural Development Malaysia, 2018). Beranang is an example of rural area in Hulu Langat district. It was gazetted as one of the seven sub-districts of Hulu Langat district in the National Land Code (Hulu Langat Land Office, 2018).

National coverage of water supply was 95.3% of the total population in 2016, and increased to 95.5% in 2017, with greater portion of the urban population has access to water supply as compared to rural population (Ministry of Rural Development Malaysia, 2018). Over the years, there are increasingly frequent occurrences of dry spells and water crises in Peninsular Malaysia, particularly Malacca and Selangor, and some parts of East Malaysia (Ahmed et al., 2014). Due to frequent occurrence of water crisis, the affected residents struggled for secondary source of water supply. In Beranang, the residents spent out-of-pocket money for electrical pump-assisted tube wells to overcome the crisis.

Access to information about the health risk assessment of arsenic exposure in Malaysia is limited despite reported cases of arsenic-related skin cancer due to groundwater consumption in 1990s (Jidon, 1993). The health risk assessment is used to determine whether exposure to arsenic, at any dose, can cause an increase in the incidence of adverse effects on human health. Therefore, the main objective of this study was to evaluate the health risk assessment of groundwater Arsenic consumption among Beranang residents in Selangor.

METHODS

This is a cross-sectional study that was conducted in February 2019 in Beranang, Hulu Langat, Selangor among houses equipped with shallow electrical pump-assisted tube wells.

Study Location Background

Hulu Langat district is the fifth largest (out of nine total districts) in Selangor, Malaysia. This district covers the area of 82,620 hectares and consists of seven sub-districts (Ampang, Beranang, Cheras, Hulu Langat, Hulu Semenyih, Semenyih and Kajang). Beranang was chosen due to its proximity to UKM Community Health Service Centre for undergrad and postgrad training and desirable population who consumed groundwater from the tube well until present despite having primary source of water supply from tap water. Beranang covers 6,184 hectares area of total 14,071 population (Department of Statistic Malaysia, 2000). The land use pattern of Beranang is mainly resident housing area and agriculture consists of palm oil plantation, rubber plantation, vegetables and local fruits. Beranang river is one of the principle tributaries of Langat River. Some parts of this sub-district are mainly a forest area. The industrial sectors are distributed in the industrial hub-zone which is located three km from the study area.

Sample Collection and Laboratory Analysis

Five houses equipped with shallow electrical pump-assisted tube wells with a depth of 10 to 30 meters were purposely chosen for groundwater sampling in this study as shown in Figure 1. The coordinates of each house are as follows: House 1: 2.886748°N, 101.882698°E, House 2: 2.889236°N, 101.886726°E, House 3: 2.889438°N, 101.886581°E, House 4: 2.888878°N, 101.886177°E and House 5: 2.888853°N, 101.885757°E. The equipment used included a 60 mL volume dispensing bottle.

Groundwater collection bottles with plastic caps were used. The bottles were washed with 2.0% nitric acid (HNO_3) for 24 hours followed by a rinse with deionized water to prevent contamination. For each house, two 60 mL samples of groundwater were taken; tap spout after purging of the water and kept at room temperature, then transported immediately to the laboratory within 24 hours. During preparation, 2 mL of concentrated nitric acid and 5 mL hydrochloric acid (HCl) were added to the filtered water samples and heated gently at 95°C until the remaining volume of the solution was between 15 and 20 mL. The solutions were then allowed to cool before dilution with ultra-pure water to a volume of 100 mL. Subsequently, samples were filtered using 0.45 μm syringe filters. All reagents were of analytical reagent grade. Ultra-pure water was used for all dilutions. The element standard solutions from Perkin Elmer that were used for the calibrations were prepared by diluting

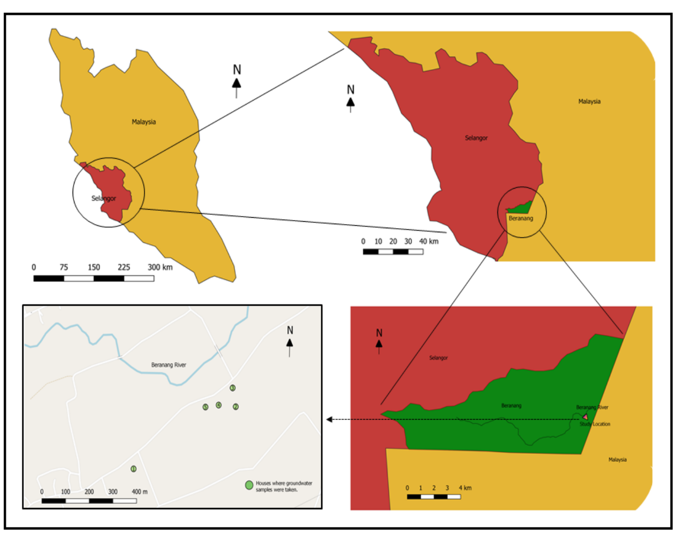

Figure 1. Study location

the multi-element Inductively Coupled Plasma Mass Spectrometry (ICP-MS) Calibration Standard 3 solutions of 10 mg/mL. The preparation and analysis of samples was done in UKM environment laboratory using an ICP-MS ELAN 9000 machine.

Exposure Scenarios

Several exposure scenarios were simulated (Table 1 and Table 2)

1. Scenario 1 - Oral exposure of arsenic: Ingestion through drinking from well water
2. Scenario 2 - Dermal exposure of arsenic: Whole body contact through bathing using well water
3. Scenario 3 - Dermal exposure of arsenic: Hands contact through washing dishes using well water
4. Scenario 4 - Dermal exposure of arsenic: Combined hands and feet contact through washing vehicle using well water

The wells are mostly secondary sources of drinking water for those homes. Since the major consumption for drinking is still from treated water, therefore, the groundwater intake rate for an individual would be approximately 1 L per day for adult and 0.5 L for children (United States Environment Protection Agency, 2019). From verbal survey, all house respondents use groundwater for other domestic purposes as well. Among all domestic activities, a person is mostly in contact with groundwater through bathing, washing dishes and washing vehicles. Watering plants using well water for instance, do not expose the person toward groundwater. Hence, the dermal absorbed dosage (DAD) is calculated for such major events in routine daily activities.

While bathing, the whole-body surface area is in contact with the water. While washing dishes, only both hands are in contact with the water. Same goes to washing car, where both hands and feet are wet with groundwater during the activity. Surface area of the skin are differed between adult and children, where adult have larger surface area than children. Different body parts have different size of surface area. For example, feet have larger surface area than hands (United States Environment Protection Agency, 2011). Average person including adult and children, he or she having shower for 15 minutes, 2 times per day (in the morning and the evening); washing dishes for 15 minutes, 3 times per day (every meal - breakfast, lunch and dinner); washing vehicle for 30 minutes, once per week.

Most of the rural residents spend their time at the village area and mainly involve in agriculture activities, hence, the exposure towards arsenic among consumer would be 350 days per year for 30 years. The exposure duration for children is 6 years (United States Environment Protection Agency, 2004). The average body weight for Asian population is lesser than the average weight for Caucasian, the author chose 60 kg as reasonable body weight for adult and 15 kg for children (Du et al., 2013; Lim et al., 2000). The average

Table 1
Specific Assumptions for Exposure for Adult

Factor	Definition	Standard Unit	Scenario Specific Assumption				Reference
			Ingestion	Dermal Absorption			
			Scenario 1	Scenario 2	Scenario 3	Scenario 4	
C	Concentration of arsenic	µg/L					This study
IR	Intake rate of water	(L/day)	1	-	-	-	US EPA 2019
K_p	Dermal permeability coefficient of arsenic in water	cm/hour	-	1.00E-03	1.00E-03	1.00E-03	US EPA 2004
T_{event}	Event duration (hour/event)	(hour/event)	-	0.25	0.25	0.5	This study
SA	Surface area of the skin	cm^2	-	20,600 (Whole body)	1,070 (Hands)	2,440 (Hands and Feet)	US EPA 2011
EV	Exposure event	(event/day)	-	2	3	1/7 (Once per week)	This study
EF	Exposure frequency	days/year	350	350	350	350	This study
ED	Exposure duration	years	30	30	30	30	US EPA 2004
BW	Average body weight	kg	60	60	60	60	Du et al. 2013, Lim et al 2000
$AT_{noncarc}$	Average time (Non-carcinogen)	days	ED x 365 days	ED x 365 days	ED x 365 days	ED x 365 days	US EPA 2004
AT_{carc}	Average time (carcinogen)	days	70 years × 365 days	70 years × 365 days	70 years × 365 days	70 years × 365 days	US EPA 2004

*US EPA = United States Environment Protection Agency

Table 2
Specific Assumptions for Exposure for Children

Factor	Definition	Standard Unit	Scenario Specific Assumption				Reference
			Ingestion	Dermal Absorption			
			Scenario 1	Scenario 2	Scenario 3	Scenario 4	
C	Concentration of arsenic	μg/L					This study
IR	Intake rate of water	(L/day)	0.5	-	-	-	US EPA 2019
K_p	Dermal permeability coefficient of arsenic in water	cm/hour	-	1.00E-03	1.00E-03	1.00E-03	US EPA 2004
T_{event}	Event duration (hour/event)	(hour/event)	-	0.25	0.25	0.5	This study
SA	Surface area of the skin	cm^2	-	10,800 (Whole body)	500 (Hands)	1,250 (Hands and Feet)	US EPA 2011
EV	Exposure event	(event/day)	-	2	3	1/7 (Once per week)	This study
EF	Exposure frequency	days/year	350	350	350	350	This study
ED	Exposure duration	years	6	6	6	6	US EPA 2004
BW	Average body weight	kg	15	15	15	15	Du et al. 2013, Lim et al 2000
$AT_{noncarc}$	Average time (Non-carcinogen)	days	ED x 365 days	ED x 365 days	ED x 365 days	ED x 365 days	US EPA 2004
AT_{carc}	Average time (carcinogen)	days	70 years × 365 days	70 years × 365 days	70 years × 365 days	70 years × 365 days	US EPA 2004

*US EPA = United States Environment Protection Agency time used in non-carcinogen risk calculation for children is 2190 days (6 years x 365 days), for adult is 10,950 days (30 years x 365 days), while in non-carcinogen risk calculation for children or adult is 25,550 days (70 years x 365 days) (United States Environment Protection Agency, 2004).

Health Risk Assessment

Average Daily Dosage through Ingestion. Average daily dose (ADD) of arsenic in drinking water was calculated by the following Equation 1 (United States Environment Protection Agency, 1989):

$$ADD = \frac{C \times IR \times EF \times ED \times F_c}{BW \times AT} \quad [1]$$

Where,
- ADD = Average daily dosage (mg/kg-day)
- C = Concentration of toxicant (µg/L)
- IR = Intake rate of water (L/day)
- ED = Exposure duration (Year)
- EF = Exposure frequency (Days/year)
- F_c = The factor for conversion from µg to mg (0.001)
- BW = Body weight (kg)
- AT = Average time (Days)

Dermal Absorbed Dosage. Dermal absorbed dosage (DAD) of arsenic through water contact was calculated based on the formula given by US EPA as following Equation 2 (United States Environment Protection Agency, 2004):

$$DAD = \frac{C \times K_p \times T_{event} \times SA \times EV \times EF \times ED \times F_{c1} \times F_{c2}}{BW \times AT} \quad [2]$$

Where,
- DAD = Dermal absorbed dosage (mg/kg-day)
- C = Concentration of toxicant (µg/L)
- K_p = Dermal permeability coefficient of arsenic in water (cm/hour)
- T_{event} = Event duration (hour/event)
- SA = Surface area of the skin (cm^2)
- EV = Event frequency (Event/day)
- EF = Exposure frequency (Days/year)
- ED = Exposure duration (Year)
- F_{c1} = The factor for conversion from µg to mg (0.001)
- F_{c2} = The factor for conversion of unit (L/1000 cm^3) (0.001)
- BW = Body weight (kg)
- AT = Average time (Days)

Hazard Quotient (HQ) Estimation. For non-carcinogenic effects, the risk is expressed as a hazard quotient (HQ), the ratio between the exposure and the reference dose (RfD). The HQ value above 1 is considered to be a health risk. The RfD is based on the assumption that thresholds exist for certain toxic effects. The oral reference dose for arsenic is 0.0002 mg/kg-day, while the dermal absorption reference dose is 0.000190 mg/kg-day. The formula for estimating target HQ through ingestion is following Equation 3 (United States Environment Protection Agency, 1989):

$$HQ = \frac{ADD}{RfD} \quad [3]$$

Where, HQ = Hazard quotient (unitless)
ADD = Average daily dosage (mg/kg-day)
RfD = Reference dose (mg/kg-day)

The formula for estimating target HQ through dermal absorption is following Equation 4 (United States Environment Protection Agency, 2004):

$$HQ = \frac{DAD}{RfD} \quad [4]$$

Where, HQ = Hazard quotient (unitless)
DAD = Dermal absorbed dosage (mg/kg-day)
RfD = Reference dose (mg/kg-day)

Lifetime Cancer Risk (LCR) Estimation. The lifetime cancer risk (LCR) was used to assess carcinogenic effect of the toxicant exposed to the human. The LCR was calculated using the formula provided by the US EPA (United States Environment Protection Agency, 1996). The ADD was calculated the same way that had been mentioned in the section above. The cancer slope factor for oral arsenic exposure is 1.50 $(mg/kg\text{-}day)^{-1}$, while cancer slope factor for dermal arsenic exposure is 3.66 $(mg/kg\text{-}day)^{-1}$ (United States Environment Protection Agency, 1991). The risk is expressed as an excess probability of contracting cancer over a lifetime of 70 years. A one in a million (1.00E-06) cancer risk means that if one million people are exposed, one additional cancer case would be expected. The US EPA cancer risk considered acceptable for regulatory purposes is within the range of 1.00E-06 to 1.00E-04. The formula for estimating target LCR through ingestion is as following Equation 5 (United States Environment Protection Agency, 1989):

$$LCR = ADD \times CSF \quad [5]$$

Where, LCR = Lifetime cancer risk (unitless)
ADD = Average daily dose (mg/kg-day)
CSF = Cancer slope factor $(mg/kg\text{-}day)^{-1}$

The formula for estimating target LCR through dermal absorption is as following Equation 6 (United States Environment Protection Agency, 2004):

$$LCR = DAD \times CSF \quad [6]$$

Where, LCR = Lifetime cancer risk (unitless)
DAD = Dermal absorbed dosage (mg/kg-day)
CSF = Cancer slope factor $(mg/kg\text{-}day)^{-1}$

RESULTS

Arsenic Concentration in Groundwater

Surprisingly, arsenic concentration in the groundwater was found to be higher than WHO Guidelines for Drinking Water Quality (10.00 µg/L), Malaysia Recommended Raw Water Quality (10.00 µg/L), and Malaysia Drinking Water Quality Standard (10.00 µg/L), in all houses (Figure 2). The mean concentration of arsenic was 46.90 µg/L, the highest concentration recorded was 54.40 µg/L in house 4 and the lowest concentration was 23.70 µg/L in house 1.

Estimation of Potential Health Risks

Non-Cancer Risk Assessment. The HQ values for each of the scenario; drinking, bathing, washing dishes and washing vehicle among adult and children are listed in Table 3. In general, children have higher risk of non-carcinogenic effect compared to adult in all four

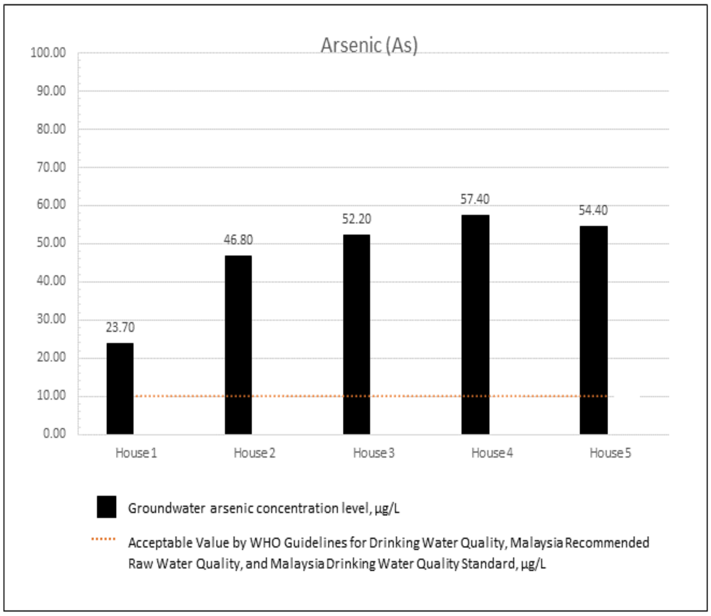

Figure 2. Groundwater arsenic concentration level in each house

scenarios. Out of total houses, member of house 4 have the highest risk. Scenario 1 posed the highest risk, followed by scenario 2, scenario 3, and scenario 4 accordingly. As shown, the HQ values were more than one for all houses in scenario 1 with the range between 1.89E+00 and 4.59E+00 among adult, and the range of 3.79E+00 and 9.17E+00 among children. The risk of getting arsenic related disease in long term is higher than those who do not consume the groundwater.

The HQ values were less than one in scenario 2. The HQ values for adult range between 2.05E-02 and 4.97E-02. The HQ values for children ranged between 4.31E-02 and 1.04E-01. The HQ values were less than one in scenario 3. The HQ values for adult ranged between 1.60E-03 and 3.87E-03. The HQ values for children were range between 3.00E-03 and 7.24E-03. The HQ values were less than one in scenario 4. The HQ value for adult were range between 3.47E-04 and 1.72E-03. These activities (bathing, washing dishes and washing vehicles) do not pose any risk of developing arsenic related disease. Therefore, these activities are considered safe when in contact with groundwater.

Cancer Risk Assessment. The LCR values for each of the scenario; drinking, bathing, washing dishes and washing vehicles among adult and children are listed in Table 4. In general, adult have higher risk of getting arsenic related malignancy as compared to children, contradict with the non-cancer risk assessment findings as mention above, due to short duration of exposure among children (6 years) compared to adult (30 years).

The LCR values for scenario 1 among adult ranged from 2.43E-4 to 5.90E-4, these values were beyond the acceptable range. The risk of developing arsenic related malignancy are between 2.4 and 5.9 in 10,000 adult population. The LCR values for drinking scenario among children were unacceptable in all houses except house 1. The LCR value in house 2, house 3, house 4 and house 5 were range between 1.92E-4 and 2.36E-4. The risk

Table 3

Arsenic concentration and hazard quotient for each scenario among adult and children

House	Arsenic Conc. (µg/L)	RfD_{inges} (mg/kg-day)	RfD_{derm} (mg/kg-day)	Ingestion	
				Scenario 1	
				HQ Adult	HQ Children
1	*23.70	2.00E-04	1.90E-04	1.89E+00	3.79E+00
2	*46.80	2.00E-04	1.90E-04	3.74E+00	7.48E+00
3	*52.20	2.00E-04	1.90E-04	4.17E+00	8.34E+00
4	*57.40	2.00E-04	1.90E-04	4.59E+00	9.17E+00
5	*54.40	2.00E-04	1.90E-04	4.35E+00	8.69E+00

Table 3 *(Continued)*

House	Dermal Absorption					
	Scenario 2		Scenario 3		Scenario 4	
	HQ Adult	HQ Children	HQ Adult	HQ Children	HQ Adult	HQ Children
1	2.05E-02	4.31E-02	1.60E-03	3.00E-03	3.47E-04	7.12E-04
2	4.05E-02	8.50E-02	3.16E-03	5.90E-03	6.86E-04	1.41E-03
3	4.52E-02	9.48E-02	3.52E-03	6.59E-03	7.65E-04	1.57E-03
4	4.97E-02	1.04E-01	3.87E-03	7.24E-03	8.41E-04	1.72E-03
5	4.71E-02	9.88E-02	3.67E-03	6.86E-03	7.98E-04	1.63E-03

*Exceed the limit of WHO Guideline (Drinking Water) and Malaysia Guideline (Raw Water)

Table 4

Arsenic concentration and lifetime cancer risk for each scenario among adult and children

House	Arsenic Conc. (µg/L)	CSF_{inges} (mg/kg-day)	CSF_{derm} (mg/kg-day)	Ingestion	
				Scenario 1	
				LCR Adult	LCR Children
1	*23.70	1.50	3.66	2.43E-04	9.74E-05
2	*46.80	1.50	3.66	4.81E-04	1.92E-04
3	*52.20	1.50	3.66	5.36E-04	2.15E-04
4	*57.40	1.50	3.66	5.90E-04	2.36E-04
5	*54.40	1.50	3.66	5.59E-04	2.24E-04

Table 4 *(Continued)*

House	Dermal Absorption					
	Scenario 2		Scenario 3		Scenario 4	
	LCR Adult	LCR Children	LCR Adult	LCR Children	LCR Adult	LCR Children
1	2.45E-05	2.57E-06	4.77E-07	1.78E-07	1.04E-07	4.24E-08
2	4.83E-05	5.07E-06	9.42E-07	3.52E-07	2.04E-07	8.38E-08
3	5.39E-05	5.65E-06	1.05E-06	3.93E-07	2.28E-07	9.35E-08
4	5.93E-05	6.22E-06	1.16E-06	4.32E-07	2.51E-07	1.03E-07
5	5.62E-05	5.89E-06	1.09E-06	4.09E-07	2.38E-07	9.74E-08

*Exceed the limit of WHO Guideline (Drinking Water) and Malaysia Guideline (Raw Water) of developing arsenic related malignancy are between 1.9 and 2.4 in 10,000 children population.

The LCR values for scenario 2 were acceptable for both adult and children population. The LCR values for adult range between 2.45E-05 and 5.93E-05. The risk of developing arsenic related malignancy are between 2.5 and 5.9 in 100,000 adult population. The LCR values for children range between 2.57E-06 and 6.22E-06. The risk of developing arsenic related malignancy are between 2.6 and 6.2 in 1000,000 children population.

The LCR values for scenario 3 were acceptable for both adult and children population. The LCR values for adult range between 4.77E-07 and 1.16E-06. The risk of developing arsenic related malignancy are between 4.8 and 11.6 in 10,000,000 adult population. The LCR values for children range between 1.78E-07 and 4.32E-07. The risk of developing arsenic related malignancy are between 1.8 and 4.3 in 10,000,000 children population.

The LCR values for scenario 4 were acceptable for both adult and children population. The LCR values for adult range between 1.04E-07 and 2.51E-07. The risk of developing arsenic related malignancy are between 1.0 and 2.5 in 10,000,000 adult population. The LCR values for children range between 4.24E-08 and 1.03E-07. The risk of developing arsenic related malignancy are between 4.2 and 10.3 in 100,000,000 children population. The risk was too minimal and negligible.

DISCUSSIONS

Possible Source of Contamination

The study found, unexpectedly, that the groundwater of all houses was contaminated with arsenic. It may be due to combination of natural and anthropogenic source mainly from agricultural activities such as palm oil plantation and rubber plantation using pesticides and fertilizer. The use of phosphate fertilisers is also one of the causes of release of arsenic into the groundwater system. Laboratory studies suggest that phosphate that is used on soils contaminated by leaded arsenate can produce arsenic into groundwater. A study done in Kedah state found that the high concentration of arsenic in groundwater in the area was believed to be attributed to by activities of agricultural development using phosphate fertilisers and pesticides (Shamsuddin et al., 2019). There are no arsenic related mining activities in the study area, indicating that mining contamination is not the cause of the high-arsenic groundwater.

Arsenic concentration in the groundwater exceeded the WHO guideline for drinking water. The arsenic level was tremendously high by approximately 2- to 6-fold in all houses with 100% prevalence of contaminated tube-wells, a maximum concentration level of

57.40 µg/L. Highest levels of arsenic in groundwater were reported in other parts of Asia such as Afghanistan (500 µg/L), Bangladesh (2500 µg/L), Nepal (150 µg/L) , Pakistan (2580 µg/L), China (500 µg/L), Taiwan (1820 µg/L), and Mongolia (500 µg/L), in which the contaminations were mostly due to natural process; reductive dissolution and alluvial sedimentation (Ali et al., 2019). While in Malaysia, a study done in Sabah state revealed higher levels of arsenic of the well water samples than the values in the WHO health-based guidelines with the prevalence of tube wells contaminated with arsenic was 19%, a maximum concentration of 22.80 µg/L, however, the source of contamination was not mentioned (Kato et al., 2010).

Exposure Rate among House Respondents

The main difference in health risk among exposed house respondents is due to the difference in the daily average exposure dose. The higher the daily average exposure dose, the higher will be the risk. Adults and children in the model have obvious different factors which contribute to the value of average daily intake (exposure). These main factors include; intake rate, exposure duration, body surface area and body weight as calculated according to the standard equations. The average daily exposure dose of groundwater arsenic for adults is higher than that for children. Average daily intake through oral exposure is higher than dermal exposure due to dermal permeability of arsenic in the water may limit the absorption of arsenic into the body as compared to oral ingestion. Oral absorption kinetics has generally been described as a simple first-order process in most arsenic models, reflecting the rapid appearance of arsenic in the blood following oral administration. Bio-accessibility of inorganic arsenic in water through oral ingestion is almost 100% (Kenyon & Clewell III, 2015). Arsenic absorption through dermal depends on the body surface area which in contact with groundwater arsenic. The larger body surface area, the higher concentration of arsenic will be absorbed.

Degree of Health Risk among Exposed House Respondent

The non-carcinogenic risk of arsenic for children is significantly higher than the risk for adults. In general, HQ for children was 2 times more than HQ for adult in all scenarios, and in all houses. The non-cancer risk was mainly caused by oral exposure which is, approximately 90 times, 1180 times, and 5400 times as compared to whole body dermal exposure, hands dermal exposure and combined hands and feet dermal exposure respectively.

In contrast with non-carcinogenic risk, the risk for adult is higher than the risk for children. In general, LCR for adult was 2.5 times more than children through oral exposure, hands dermal exposure, and combined hands and feet dermal exposure. While, LCR for adult was much higher, 10 times more than children through whole body dermal contact in view of enormous difference of average daily exposure. The body surface area for adult is 20600 cm^2 and body surface area of children is 10800 cm^2. The carcinogenic risk is mainly caused by oral exposure which is, approximately 10 times, 50 times, and 2300 times as compared to whole body dermal exposure, hands dermal exposure and combined hands and feet dermal exposure respectively.

Study done in China showed similar trend for degree of health risk between adult and children, where the non-cancer risk and cancer risk were mainly caused by oral exposure, which are, approximately 200 times and 100 times higher than the dermal exposure respectively (Zhang et al., 2019).

Health Effect of Arsenic

Low to moderate levels of arsenic exposure (10 - 300 µg/L) through drinking water has adverse health effects to human include skin lesions, cardiovascular disease, neurological complications, diabetes, respiratory complications, hepatic and renal dysfunction including mortality due to chronic diseases. An estimation of approximately 100 million population all around the world are exposed to arsenic levels more than 50 µg/L. Symptoms of acute exposure develop rapidly, usually exposed to high dose (concentration) of arsenic, whereas clinical symptoms of chronic arsenic exposure develop over a prolonged period of lower concentration arsenic exposure. In acute arsenic intoxication, organ damage could occur and may lead to death (Abdul et al., 2015).

Arsenic is a well-known teratogen and affects foetus development. Arsenic affects the male and female sex organs and may cause fertility issues in both genders. Spontaneous abortions, still birth, perinatal mortality, neonatal mortality, low birth weight, and preterm birth were reported to have a strong association with low to moderate (<1 - 3585 µg/L) concentration of arsenic ingestion during pregnancy (Abdul et al., 2015). Moreover, arsenic ingestion (<100 µg/L) may lead to tumorigenesis in various body parts such as skin, bladder, kidneys, lungs and liver. Effects of arsenic exposure are distinctly divided into four stages. They are preclinical, clinical, internal complications and malignancy stages (Abdul et al., 2015). In this study, all house respondents have high risk of developing health effect of arsenic through chronic oral exposure.

Arsenic Removal Technology

Tube well water is still an option for drinking and other domestic purposes in other rural areas of Malaysia. There are various cost-effective techniques for arsenic removal from drinking water. The US EPA has identified the best available technologies with maximum arsenic removal of more than 95%; ion exchange, activated alumina, reverse osmosis, modified coagulation, modified lime softening, electrodialysis reversal, and oxidation/

filtration (Han et al., 2003). For the treatment of shallow tube well water with a depth of 10 to 30 metres in rural areas of Malaysia, the main concern would be the cost of tube well maintenance and reagent and residue handling. Effective and applicable water treatment technology for arsenic removal with the existing infrastructure of tube wells in a rural setting such as ALCAN activated alumina and BUET activated alumina have advantages: almost all arsenic removed, no costly filter media or maintenance is needed, affordable and readily available hardware, it improves colour and taste of the water as iron is removed, and iron can be a visible indicator for arsenic presence and help with water quality monitoring (Van Halem et al., 2010).

Groundwater and Health Monitoring

The monitoring of groundwater quality should be done continuously by various agencies such as the Drinking Water Quality Surveillance Unit, the Engineering Services Division, the Ministry of Health Malaysia, and the Department of Environment Malaysia. Collaboration between the agencies in terms of sharing of information is vital to ensure effective groundwater quality surveillance. Health monitoring should be done periodically among high-risk groups to look for arsenic-related diseases and malignancies. This can be carried out by the nearest district health office. We suggest the extension of this activity to other parts of Malaysia where the consumption of groundwater is still practised. Frequent and effective health education about disease prevention can be given to targeted groups in the population by the health promotion team of district health offices.

Limitation

The purposive sampling method was used to select the houses equipped with a tube well because not many of the houses use well water as their drinking water supply. The purpose of this study was to assess the existing (few, but at risk) houses that use well water. A very small number of samples is not suitable for random sampling. Furthermore, this self-funded study also limits the number of samples because of laboratory costs. Structured survey was not done as the main objective of the study was to assess the possible health risk of Arsenic exposure among the residents who have been using well water for quite long time (chronic effect). The simulation scenarios proposed in this study was based on the verbal survey from respondent of all purposely chosen house. Despite the estimated exposure rate (from simulation scenarios) being weak, this information can be used for risk communication for affected residents and the calculation to measure the risk can be used in similar situation in the future. Due to the lack of long-term monitoring data, the consistency of the groundwater arsenic content is undetermined in term of time period.

CONCLUSIONS

There are crucial conclusions that can be summarized from the finding of this study. The data demonstrate high groundwater arsenic contamination in Beranang, Hulu Langat district, Selangor. The health risk degree of children was higher than that of adults on the whole, indicating that children suffer much higher risks than adults. The health risk degree through oral exposure was higher than dermal exposure. As for dermal exposure, the risk degree through whole body contact was higher than limbs contact. Groundwater arsenic in the study area mainly originates from the agriculture activities using pesticides and fertilizers. The naturally high arsenic concentration in the existing groundwater could be burdened by intense industrialization, rapid urbanization and land usage come to place.

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