Assessment of Human Health Risk Associated with Arsenic in Fly Ash from Mae Moh Lignite Power Plant

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Abstract

Human health risks, both cancer and non-cancer, associated with arsenic in fly ash produced as by-products of the operations of Mae Moh Electricity Generating Power Plant, were qualitatively and quantitatively evaluated. The route of exposure was selected to be ingestion (drinking) of river water by local villagers who live downstream of the Mae Chang River from the plant to where the River meets the Wang River. The assessment processes consisted of data collection, data evaluation, exposure assessment, toxicity assessment, and risk characterization. Graphite Furnace Atomic Absorption Spectrophotometry (GFAAS) was used to measure the concentrations of total inorganic arsenic in water samples. International standards, databases, and procedures established by the United States Environmental Protection Agency (US EPA) were applied, together with local parameters.

The result of the human health risk assessment associated with arsenic in fly ash showed that all estimated risks were within acceptable ranges, however it is noted that the maximum cancer risk and the maximum non-cancer risk occurred to the same group of the population, namely, Hua Sua village babies, age 0 – 1, who daily consumed relatively large amounts of water. To lower such risks, either arsenic concentration in water has to be lowered by better plant's treatment, or the consumption rate has to be reduced by drinking from alternative sources of water, or both. One factor, influencing the overall risks, which can be obtained from the results of the study, was the distance along the Mae Chang River away from the plant; the greater the distance, the lower the arsenic concentration, and thus lower exposure and lesser risks.

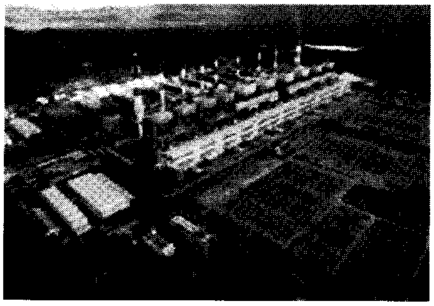
Keywords: Human Health Risk Assessment, Arsenic, Fly Ash, Graphite Furnace Atomic Absorption Spectrophotometry, Mae Moh Power Plant

1. Introduction

Since its first operation in 1964, Mae Moh Power Plant, Lampang province of Thailand, has been generating a large amount of electricity, currently a total of 2,400 mega-watts (MW), approximately 25% of national production to be distributed to the North, Northeast and Central regions of Thailand [1,2]. Such production requires a daily input of about 40,000 tons of lignite coal that consequently is turned into by-products after the heating process.

Among these by-products, fly ash receives the most attention from the industry and researchers due to its considerable amount of production of approximately 8,000 tons a day, its possibility for contamination of the environment and human health, and its potentially desirable characteristics for reutilization.

Fly ash is very small in particle size, in a range of 1 to 150 microns [3] and has high metal concentrations, especially arsenic (As), which is classified by the United States Environmental Protection Agency (US EPA) as Class A human carcinogen, and is at the top of the most hazardous substances list, based on 'sufficient evidence' from human data [4,5]. [6] investigated geochemistry and mineralogy of Mae Moh fly ash through the sequence of electrostatic precipitators ashes and found the maximum concentration of 352 ppm (As), along with many other metals.



Electricity Generating Units 4 – 13

Mae Moh Reservoir, Station Village

Currently, fly ash is either transported through belt conveyors to a landfill site or sold to buyers from the cement/concrete industry. However, fly ash residue at the plants has to be treated through the ash-water treatment system before discharging into natural water, the Mae Chang River. The Mae Chang River runs westwards through many villages and meets the Wang River approximately 50 km from the plant. While the discharge complies with all regulations set by the Pollution Control Department [7], total inorganic arsenic concentrations in water seem to be elevated when compared with the surrounding background [8]. Such elevated concentrations may pose additional risk to the population living downstream. The purpose of this paper is to investigate the cancer and non-cancer risks due to ingestion of the river water, a predominant route of human exposure, using international standards established by the US EPA, adjusted with local parameters.

2. Materials and Methods

Materials

Tools:

- Graphite Furnace Atomic Absorption Spectrophotometry (GFAAS), standard setting, with equipment and chemicals for total inorganic arsenic measurement
- Related United States Environmental Protection Agency (US EPA) manuals, databases, and other information

Data Requirement: (adapted from [9])

- For Exposure Assessment (source generation, environmental transport, exposure analysis, population determination)
- For Hazard Identification and Dose-Response Assessment (epidemiological studies, animal bioassays, short term tests, structure/activity relationship, dose-response functions)

Methods

Data Collection: (preliminary data, extensive site survey, sample collection)

Preliminary Data	Sources
Precipitation, intensity, wind	Related Governmental Departments
Geological/topographic data	Army Survey, Geological Resource Department
Current and Future Land use	Land Development Department
Population characteristics: number, distribution, water consumption, distance from source, etc.	Ministry of Interior, Site visit

Table 1: List of Preliminary Data and Sources

Extensive Site Survey

This phase focuses on primary and local data by interviewing key informants, getting data unable to obtain previously, verifying data for higher accuracy. Data are obtained from local governmental agencies/ organizations, enterprise (EGAT), and local people.

Sample Collection

Samples of river water were collected at many points at villages along the Mae Chang River from the power plant to the Wang River, with proper procedures, together with interviews for local water consumption activities/patterns. The details of sample collection and procedure are given in [8].

Concentrations of total inorganic arsenic were then analyzed by GFAAS. Three grab samples were collected at each point, all during daytime in the summer month of April, 2002.

2.1 Determination of Total Inorganic Arsenic Concentrations by Graphite Furnace Atomic Absorption Spectrophotometry (GFAAS)

The following determination of total inorganic arsenic concentration follows a technique by Jackson, 1958, cited in [10]. This method will be used to determine total inorganic arsenic concentrations of the water samples collected. All chemicals used are analytical grade and Milli-Q water (Millipore) is used throughout the process.

Step	Temperature (°C)	Ramp/Hold Time (sec)	Argon gas flow (ml/min)
1. Drying	120	10/30	250
2. Pyrolysis	1,200	10/30	250
3. Cooling	20	5/5	250
4. Atomization	2,300	0/5	Stop flow
5. Clean up	2,400	1/5	250

Acid blanks are analyzed in order to assess possible contamination. Standard solution, 100 g/l As, is prepared using diluted standard 1,000 mg/l As as sodium arsenate ($Na_2HaSO_4.7H_2O$) with 1% nitric acid. Palladium 1,000 mg/l was used as matrix modifier. AAS (Perkin-Elmer Analyst) and graphite tubes with L' vov platforms are used to determine arsenic concentration.

The radiation source was As electrodeless-discharge lamp operated at over 300 mA; the wavelength is 193.5 nm and a 0.7 nm spectral band width is used. The operating conditions for analysis are as follows:

2.2 Human Health Risk Assessment:

1. Exposure Assessment:

The magnitude of actual and/or potential human ingestion of arsenic in water, as well as the exposed population, the frequency and duration of these exposures is estimated. Central Tendency Exposure (CTE) and Reasonable Maximum Exposure (RME) are determined.

2. Toxicity Assessment:

This stage considers: 1) the types of adverse effects associated with chemical exposures; 2) the relationship between magnitude of exposure and adverse effects; and 3) related uncertainties such as the weight of a particular chemical's carcinogenicity in humans. The US EPA relies heavily on existing toxicity information developed for specific chemicals. Toxicity assessment consists of two steps, hazard identification and dose-response assessment. Hazard identification involves determining whether exposure to an agent can cause an increase in the incidence of an adverse health effect, such as cancer and birth defect.

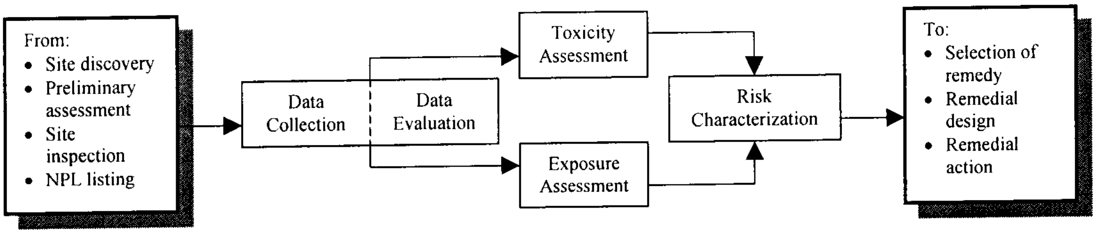


Figure 1: Human Health Risk Evaluation Process [4]

Dose-response assessment is a process of quantitatively evaluating the toxicity information and characterizing the relationship between the dose of the contaminant administered or received and the incidence of adverse health effects in the exposed population at different exposure levels. Concentrations of total inorganic arsenic from experimental analysis are relevant to both steps of this stage of assessment.

3. Risk Characterization:

In risk characterization, summary and combination of outputs of exposure and toxicity assessments to characterize baseline risks (both in quantitative expressions and qualitative statements) are laid out. During this stage, chemical-specific toxicity information is compared against both measured contaminant exposure levels and those levels measured by GFAAS.

3. Results and Discussion

Ingestion exposure pathways

Possible ingestion exposure locations are shown in Figure 2 below. The four stars in Figure 2 and Table 2 represent villages with existence of river water ingestion.

GFAAS Results

Samples of consumed river water were taken and analyzed for concentrations of total inorganic arsenic, and summarized, in ascending order of distance of the villages from the power plant, along the direction of the flow of Mae Chang River, in Table 2 below [8] and plotted in Figure 3. The U.S. EPA current standard for arsenic in drinking water is 10 ppb [11].

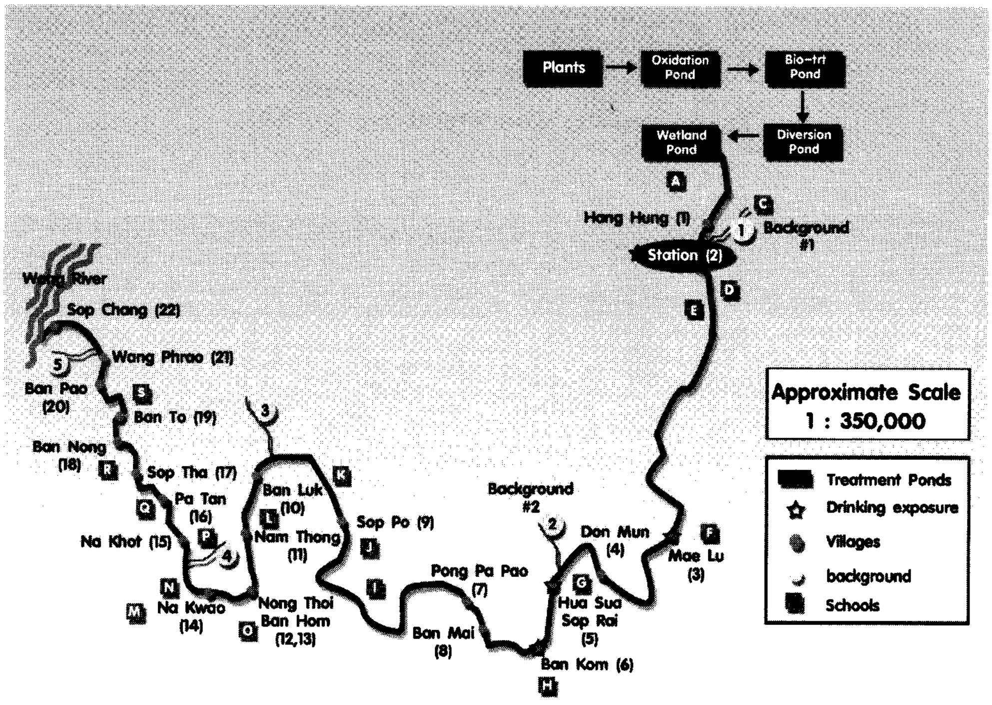


Figure 2: Approximate Locations of Sample Collection Points along the Mae Chang River

Table 2: Arsenic Concentrations in Water

Sample #	Village (away from the plant)	Distance from Plants (km)	Direction from Plants	Avg As Conc (ppb)
1	**Hang Hung**	3	S 70° W	28.7
2*	**Mae Moh Station**	6.5	S 55° W	32.8
3*	**Mae Lu**	13.5	S 35° W	13.4
4	**Don Mun**	17	S 30° W	14.6
5*	**Hua Sua/Sop Rai**	19	S 35° W	12.4
6*	**Ban Kom**	20.5	S 35° W	10.3
7	**Ban Mai1/Ban Mai8**	23	S 42.5° W	11.5
8	**Pong Pa Pao**	23.5	S 37.5° W	9.0
9	**Sop Po**	26.5	S 50° W	8.5
10	**Luk/Luk Tai**	30	S 50° W	10.1
11	**Nam Thong**	31	S 52.5° W	8.9
12	**Nong Thoi**	32.5	S 52.5° W	7.8
13	**Ban Hom**	33	S 52.5° W	7.8
14	**Na Kwao**	34	S 50° W	5.4
15	**Na Khot**	34	S 55° W	6.2
16	**Pa Tan Nua/ Pa Tan Tai**	34.5	S 60° W	6.4
17	**Sop Tha**	35	S 55° W	7.1
18	**Ban Nong 4/ Ban Nong 9**	37	S 60° W	2.4
19	**Ban To**	37.5	S 62.5° W	3.5
20	**Ban Pao**	39	S 62.5° W	6.6
21	**Wang Phrao**	41	S 65° W	2.0
22	**Sop Chang**	42.5	S 67.5° W	1.3

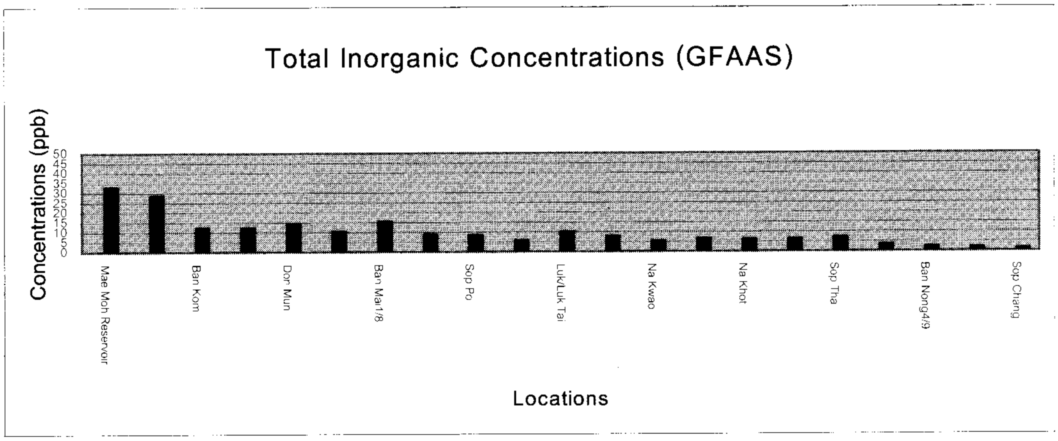


Figure 3: Plot of Inorganic Arsenic Concentrations in River Water by Village

Information on number of population classified by age in each village was acquired from the local sanitary department organization that performs regular head counts and yearly census. Assumptions for local villagers include:

Age 0 – 1 Stay home with parents, grandparents or relatives, possibly exposed to ingestion (drinking water) and dermal contact (bath)

Age 1 – 4 Stay home and go with parents to farm, possibly exposed to ingestion (water,

	fish) and dermal contact (swimming, farming, shower)
Age 5 – 14	Go to schools during weekdays, stay home or go to farms with parents during weekends, possibly exposed to ingestion (water and fish) and dermal contact (swimming, farming, shower)
Age 15 – 59	Work during weekdays and weekends for farmers, others work during weekdays, stay home during weekends, possibly exposed to ingestion (water and fish) and dermal contact (swimming, farming, shower)
Age 60 and over	Stay home, possibly exposed to ingestion (water and fish) and dermal contact (shower)

All children, between 5 – 14 years of age, are assumed to go to school during weekdays for 8 hours a day (8 am – 4 pm). All schools are not exposed to drinking of river water (acquired by interviews).

Residential population daily consumption (drinking) rates, by village, with CTE and RME, are summarized in Table 3 below:

Table 3: Water Consumption (drinking) Rate by Village and Age Group (from interviews)

Drinking Rates	Station/ Mae Moh	Ban Kom/ Mae Tha	Hua Sua/ Mae Tha	Mae Lu/ Mae Tha
Population	721	536	1038	1040
Age 0 – 1	.25-.75L CTE-RME	.5-1.5L	.5-1.5L	.5-1L
Age 1 – 5	0.5-1.5L	1-1.5L	.75-1.5L	.5-1L
Age 5 – 14	1.5-2.5L	1-2.5L	1-2.5L	1-2L
Age 14 – 60	2-2.5L	1.5-2L	1.5-2.5L	1.5-3L
Age 60 – 80	1.5-2L	1.5-2L	1-2L	1-2L

According to Table 3, total population and water drinking rates for all 4 villages were recorded. The Population aged 14 - 60 have the highest drinking rates because they are in working agesd, while infants up to 1 year of age have the lowest rates due to their inactivity.

Background Concentrations

Based on topographic and geological information, background points are selected to represent a group of villages. Samples for background are taken from waterways in that area that do not have an influence from Mae Chang River, i.e. water flows by gravity from these points to the Mae Chang River due to their higher elevations. Arsenic concentrations of backgrounds are summarized in Table 4:

Table 4: Background Concentrations

Background Location	Representing Villages	Total Inorg As Conc
1 Hang Hung	Mae Moh Station	2.6 ppb
2 Hua Sua	Ban Kom/ Hua Sua/ Mae Lu	4.4 ppb

(no standards are set for backgrounds)

Quantification of Exposure

The basis for calculating human intake levels from exposure to inorganic arsenic is presented here, with each parameter described. A quantified intake represents daily dose of a chemical taken into body, averaged over some appropriate period of time, and is expressed in units of milligrams per kilogram of body weight per day (mg/kg-day). The primary source of exposure equations comes from U.S. EPA's '*Risk Assessment Guideline for Superfund* (RAGS)' [12]. It is noted the World Health Organization (WHO) sets a standard of total arsenic ingestion at 2 μg/kg body weight daily or 15 μg/kg body weight weekly [13].

Ingestion (drinking water) – Residential Population:

$$I = \frac{CW \times IR \times EF \times ED}{BW \times AT}$$

Where:

CW= Chemical Concentration in Water (mg/l)
Site-specific, measured or modeled value

IR = Ingestion Rate (liters/day)
Population specific: interview/survey

EF = Exposure Frequency (days/year)
Pathway-specific value
ED = Exposure Duration (years)
70 years (lifetime; by convention)
interview/survey
BW= Body Weight (kg) 70 kg (adult, average; [12]), Age-specific value
AT = Averaging Time (period over which exposure is averaged, days)
Pathway-specific period of exposure

Calculation of Cancer Risks

Cancer risks are defined as *'incremental probability that an individual will develop cancer during his or her lifetime due to chemical exposure under the specific scenarios evaluated in human health risk assessment.'* The 'incremental' implies the risk above the background cancer risk experienced by all individuals in the course of daily life. For example, approximately one in four Americans die of cancer, therefore, the background cancer is 0.25, or 250,000 in one million [14]. The incremental risk is a measure of an additional estimated risk due to a specific exposure. Cancer risks are expressed as a unitless probability such as 10^{-6}, or one in a million of one individual developing cancer over a lifetime, above background risk.

Excess (additional) risks for exposure pathways (oral ingestion) are calculated using intake estimates, a lifetime average or reasonable maximum daily doses. Estimated intakes and a Cancer Slope Factor (CSF) are combined to calculate excess cancer risk according to the following equation:

$$\underset{\text{(unitless)}}{\textbf{Cancer Risk}} = \underset{\text{(mg/kg-day)}}{\textbf{Intake}} \times \underset{\text{(mg/kg-day)}^{-1}}{\textbf{CSF}}$$

For the ingestion exposure route, the estimated oral intake ('applied' or 'administered' doses) is multiplied by $CSFs_{oral}$, which are applicable to applied/administered doses) [11,14]

Since the human health risk assessment was prepared in accordance with current US EPA guidelines, the estimated risks are compared to the US EPA's acceptable range of 10^{-6} to 10^{-4} [15], which represents one case in every 1,000,000 and 1 case in 10,000 populations, respectively. The summary of cancer risks is presented in Tables 5 – 8.

Calculation of Non-cancer Risks

Non-cancer risks are expressed in terms of 'hazard quotients' rather than as probabilities as shown in an equation below [16]:

$$\underset{\text{(HQ, unitless)}}{\textbf{Hazard Quotient}} = \frac{\textbf{Intake}\text{ (mg/kg-day)}}{\textbf{RfD}\text{ (mg/kg-day)}}$$

A hazard quotient compares the estimated daily exposure or average daily dose of a chemical to an acceptable reference dose (RfD) derived by US EPA.

Table 5:
Summary of Risks for Hang Hung Village

Station	CTE		RME	
Age	Risk	HQ	Risk	HQ
0-1	2.16E-06	0.004800	1.17E-05	0.026075
2-4	1.74E-06	0.003864	5.21E-06	0.011584
5-14	1.80E-06	0.004003	4.04E-06	0.008968
15-59	1.53E-06	0.003401	2.43E-06	0.005401
60 - 80	1.04E-06	0.00231	1.73E-06	0.003841

Table 6:
Summary of Risks for Mae Lu Village

Mae Lu	CTE		RME	
Age	Risk	HQ	Risk	HQ
0-1	2.04E-06	0.004541	9.35E-06	0.020767
2-4	8.47E-07	0.001882	3.25E-06	0.007225
5-14	6.01E-07	0.001336	2.01E-06	0.004470
15-59	5.73E-07	0.001274	1.76E-06	0.003902
60 - 80	3.45E-07	0.000766	1.07E-06	0.002377

Table 7:
Summary Risks for Hua Sua Village

Hua Sua	CTE		RME	
Age	Risk	HQ	Risk	HQ
0-1	1.89E-06	0.004202	1.19E-05	0.026433
2-4	1.21E-06	0.002688	4.23E-06	0.009393
5-14	5.83E-07	0.001296	2.21E-06	0.004901
15-59	5.48E-07	0.001218	1.33E-06	0.002966
60 – 80	3.34E-07	0.000742	9.54E-07	0.002120

Table 8:
Summary Risks for Ban KomVillage

Ban Kom	CTE		RME	
Age	Risk	HQ	Risk	HQ
0-1	1.57E-06	0.003491	9.61E-06	0.021356
2-4	1.26E-06	0.002788	3.22E-06	0.007151
5-14	4.70E-07	0.001045	1.71E-06	0.003797
15-59	4.42E-07	0.000981	8.55E-07	0.001900
60 – 80	3.99E-07	0.000887	7.40E-07	0.001644

For the ingestion exposure route, an estimate oral intake (applied or administered dose) is divided by RfD_{oral}, which is applicable to applied/administered dose. An acceptable HQ is any value no greater than one. The summary of non-cancer risks, specified by village and age group, is also presented in Table 5 to Table 8 above:

Discussion

Since the risk assessment was prepared in accordance with current US EPA risk assessment guidelines, the estimated cancer risks are compared to the US EPA's acceptable cancer risk of 1×10^{-6} to 1×10^{-4} [17]. Of all residential population studied, four villages were exposed to ingestion (drinking) of the plant's downstream water.

Cancer risks for the four villages were found to be 3.34×10^{-7} to 1.19×10^{-5}, while non-cancer risks' hazard quotients were between 0.000742 and 0.026433. These cancer risk estimates represent approximately 3 in 10,000,000 and 1 in 10,000,000 case(s) of cancer, respectively, and are within the US EPA's acceptable range of risks.

The estimated hazard quotients were also well below the acceptable limit of 1.0. Therefore, considering only total inorganic arsenic and only water ingestion exposure for this particular group of population with certain water consumption behavior, all villagers are expected to encounter relatively low excess cancer and non-cancer risks by US EPA standards.

Considering the WHO standard of 15 μg/kg of body weight per week in food, an average 70-kg person would be allowed approximately 1 mg of total arsenic. This amount is equivalent to 50 liters of drinking water with 20 ppb of arsenic, which is much more than the total consumption in a week for a normal human being. Therefore, predicted risks associated with current water drinking rates for all populations are within an acceptable limit given by WHO.

Many factors contributed to excess risks. Among the most influential factors are the total inorganic arsenic concentrations in river water and the water consumption rates of local population, and to some degree, the distance from the plant to exposure points along the river.

The factor of distance was observed from the fact that the concentration of total inorganic arsenic in water dissipated downstream [Figure 2]. Assuming that the same water consumption pattern exists, population further away from the plant is at less risk than those who live closer, based on the assessment of arsenic ingestion alone.

4. Conclusions and Recommendations

The paper focused on the predominant route of exposure, which was ingestion of river water by a population who might be facing additional risks associated with fly ash production from Mae Moh Power Plant. Cancer and non-cancer risks were assessed for residential population in villages and quantified by age group and village. In this particular case, all risks were determined to be within the acceptable range set by the US EPA for ingestion of inorganic arsenic in river water. Lowering these risks is a combination effort belonging to enterprises and individuals.

A recommendation for a future study is to extend the scope of this study to cover other routes of exposure (inhalation and dermal contact) and possibly other substances.

5. Acknowledgement

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