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MERCURY CONTAMINATION IN ENVIRONMENT SURROUNDING COAL-FIRED POWER PLANT

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ABSTRACT: Fossil fuels combustion has been widely known of their emission containing various heavy metals and gaseous substances. This study is to investigate the distribution of mercury (Hg) in environmental media surrounding the lignite coal-fired power plant in Lampang province, Thailand. Samples of surface soil and waters were collected within the vicinity of the power plant in order to analyze mercury contamination. Also, Hazard Quotient (HQ) will be determined to estimate environmental potential risks in this area of concern. Mercury contents in surface soil samples were observed in the range of 65 – 1338 µg/kg. The results also revealed that the distribution of mercury contamination in surface soils partly correlate with monsoon domination or distance from the power plant. Some samples of surface water and ground water in this area contained mercury concentration in the range of 0.1 µg/l – 0.2 µg/l. These mercury contents were further considered for environmental potential risks by HQ calculation. The environmental potential risks of mercury content in surface soil samples and water samples were classified as no environmental hazard (HQ < 1).

Keywords: Mercury, Lignite, Coal-Fired Power Plant, Environmental Potential Risks, Health Risks Assessment

1. INTRODUCTION

The coal-fired power plant has been widely known for an important source of air pollution due to its emission from fossil fuel burning contains several pollutants, i.e., gases, particulate matters, heavy metals, or some substances such as dioxin, radiation, etc. These pollutants can affect respiratory, circulatory, neural, hormonal and reproductive systems, as well as, can stimulate some diseases and carcinogenic effect in human organs. Approximately, ninety percent of accumulated mercury in human body is organic mercury (methyl mercury), which is highly toxic and stable for quite long period. Pregnant women and young children are the most sensitive groups, as well as, the accumulated mercury can be passed on from mother to daughter [1].

At present, Thailand's economic and industrial sector has expanded greatly in recent years, resulting in increasing of electricity demand. Currently, natural gas accounts for 70 percent of fuel used in electricity generation due to its high efficiency, low pollutants emission and local supply. Coal was responsible for the second contribution of fuel used in power plant (about 20 percent). In contrast, the global fuels consumption was mainly coal combustion, which accounted for about 40 percent, while natural gas combustion was only about 20 percent [2]. However, the natural gas reserve in Thailand is predicted to be adequate for only next ten years from now while the demand of natural gas in other industries also continues to rise. Therefore, the alternatives to replace natural gas in power plant such as coal, petroleum, biomass, nuclear energy, etc., are considered [3]. Lignite coal is the majority of coal reserves in Thailand, which is considered as low quality coal due to its low heat content and high humidity, high ash, and sometimes high sulfur content. The largest source of lignite in Thailand is located in Mea Moh district, Lampang province. Besides lignite, the higher quality coals found in Thailand is sub-bituminous and bituminous. Anthracite is also found, but with a very small amount, in Loei province area. Although a variety of coal species is found in Thailand, most of them are low quality coals (lignite and sub-bituminous) [4].

The Mae Moh Coal-fired Power Plant in Lampang province is the largest one in Southeast Asia using coal-lignite as fuel. This power plant consists of ten generating units with a total capacity of 2,400 MW, representing about 20% of the capacity of Thailand. This power plant distributed electricity to the North, the Central and the Northeast of Thailand with using coal as the fuel of about 16 million tons per year [5]. Several studies have been reported about toxic elements contaminated in emission from coal-fired power plant [6-9]. The Mae Moh power plant was also reported of high concentrations of As, Pb and Hg in its fly ash samples [10]. Although, this power plant installed flue gas desulfurization (FGD) to reduce air pollutants from their flue gas, the contamination of heavy metals in their ashes and

particulates were still observed [11]. Mercury contamination in environmental media and some plants in the surrounding area of Mae Moh power plant were reported elsewhere [12], but not clear enough to indicate the source of contaminated mercury.

However, there is quite a few of information about the distribution and environmental risk of mercury emitted from the coal-fired power plant in this area. The aim of this study is to investigate the contaminant concentrations of mercury in surface soil, surface water and groundwater as well as the potential environmental risks and food safety in the vicinity of this coal-fired power plant.

2. MATERIALS AND METHODS

The study area is designated to be within the 30-km radius surrounding of the Mae Moh coal-fired power plant with 2400 MW capacity. This study area covers several districts of Lampang Province including Maung Lampang, Mae Moh, Mae Tha and Long District of Prae Province. This area named as Mae Moh basin is one of important basins in Thailand due to large coal reserve has been found here[13]. This Mae Moh basin has a pan shape (syncline) with average ground level of 320 meters above mean sea level. The northern part of Mae Moh basin is mostly covered with mountain and forest (about 80 percent of the districts) while the others of approximately 4,000 hectares are lowlands for cultivation. Soil characteristics are generally classified as sandy soil. The climate is quite roasting in the summer, cold in the winter and a little chance of rain about 60-80 days/year [14] due to the rain shadow. The predominant wind direction in this area is usually blowing along the SW/NE direction and the wind speed is in the range of 0.5 - 3.6 m/s.

The site of coal-fired power plant is mostly flat in the valley surrounded by mountains easily causing high air pressure and temperature inversion [15]. According to several studies [11-12], the atmosphere in this area was sometimes difficult for normal dispersion of air pollution. The major pollution released by the coal-fired power plant is mostly from fuel combustion for steam generation. Besides gaseous pollutions emitted from fossil fuel burning, some metals as components in the fuel also escape along and disperse into the atmosphere. These emitted metals eventually deposit and can be accumulated on surface soil and water in the surrounding area.

Sampling sites in this study were located in different directions and distances within the radius of 30 km from the coal fired power plant as shown in Fig. 1 equipped with the representative wind rose of this area. Fourteen sampling stations for surface soil (twelve for contaminated sites and two for background sites) and three sampling stations for surface water and groundwater were designated. Samples collection for this study were conducted during August 8 – 11th, 2015.

2.1 Sampling Methods

Surface soil samples (0-15 cm depth) were collected from the rice field by applying the 'random sampling' procedure [16] with using clean disposable gloves, a stainless steel spade and a plastic scoop. Each soil sample weighted not less than 1 kg, was packed in plastic bag and kept in ice box at 4 ºC. For each station, representative soil sample were mixed and homogenized from three subsamples grabbed from three different points with approximately 3 m. distance from each other. Samples were air dried under shade and hot air oven at 103 – 105^{o}C. They were further crushed and sieved to obtain not larger than 2 mm size of soil particles [17]. Then, they were analyzed on the basis of dry weight (dw).

The deposition of air pollution may contaminate aquatic compartment such as reservoir and streams nearby the coal-fired power plant, as well as, indirectly contaminate groundwater. Three sites of water samples were selected in the vicinity of the power plant. High density bottles and a Kemmerer water sampler were used to collect water samples from reservoir, streams and wells (that in use for household consumption). All water samples for mercury analysis must be preserved with conc. HNO_3 acid (pH < 2) and kept in ice box at 4ºC during transportation to the laboratory and before analysis.

2.2 Sample Analysis and Quality Control

Analysis of THg content was performed by Cold Vapor Atomic Absorption Spectrometry (CVAAS) with detection limit of 0.001 µg/L. Samples were digested according to the procedure of the Wetland Biochemistry Institute, Lousiana State University [18-19]. About 0.5-2 g of dried samples were weighed and digested with concentrated 5 ml H_2SO_4 + 5 ml HNO_3. Then, the digested solutions were washed and made up to be 100 ml with deionized water (DI), and 10 ml $SnCl_2$ solution were added prior CVAAS analysis. Mercury concentrations were determined against a set of Hg standard solutions. Quality assurance was maintained by inserting a blank at the beginning of each sample run.

The accuracy of analytical procedure was calibrated by using three replicate samples of standard reference materials (SRM 1646a for sediment) from U.S. Department of Commerce, National Institute of Standard and Technology (NIST) and 4 samples of blank. The Method

Detection Limit (MDL) was calculated (by 3.143 multiplies the standard deviation of the seven reagent blank samples in the sample batch) and used as a tool for verification of all Hg analysis.

Evaluation of the potential environmental risks was estimated numerically using the Hazard Quotient (HQ) as presented by equation (1). If the HQ value was > 1, then, it indicates a state of risk to the environment. The equation (1) is the ratio of the estimated exposure to the effect concentration representing a safe environmental concentration or screening benchmark [20].

HQ = EEC / Screening Benchmark (1)

EEC = estimated (maximum) environmental contaminant concentration in the samples at site (e.g. mg contaminant/kg soil).
Screening Benchmark = maximum allowable of mercury concentration; if the contamination concentration is below this level, the contaminant is not likely to cause harmful effects.

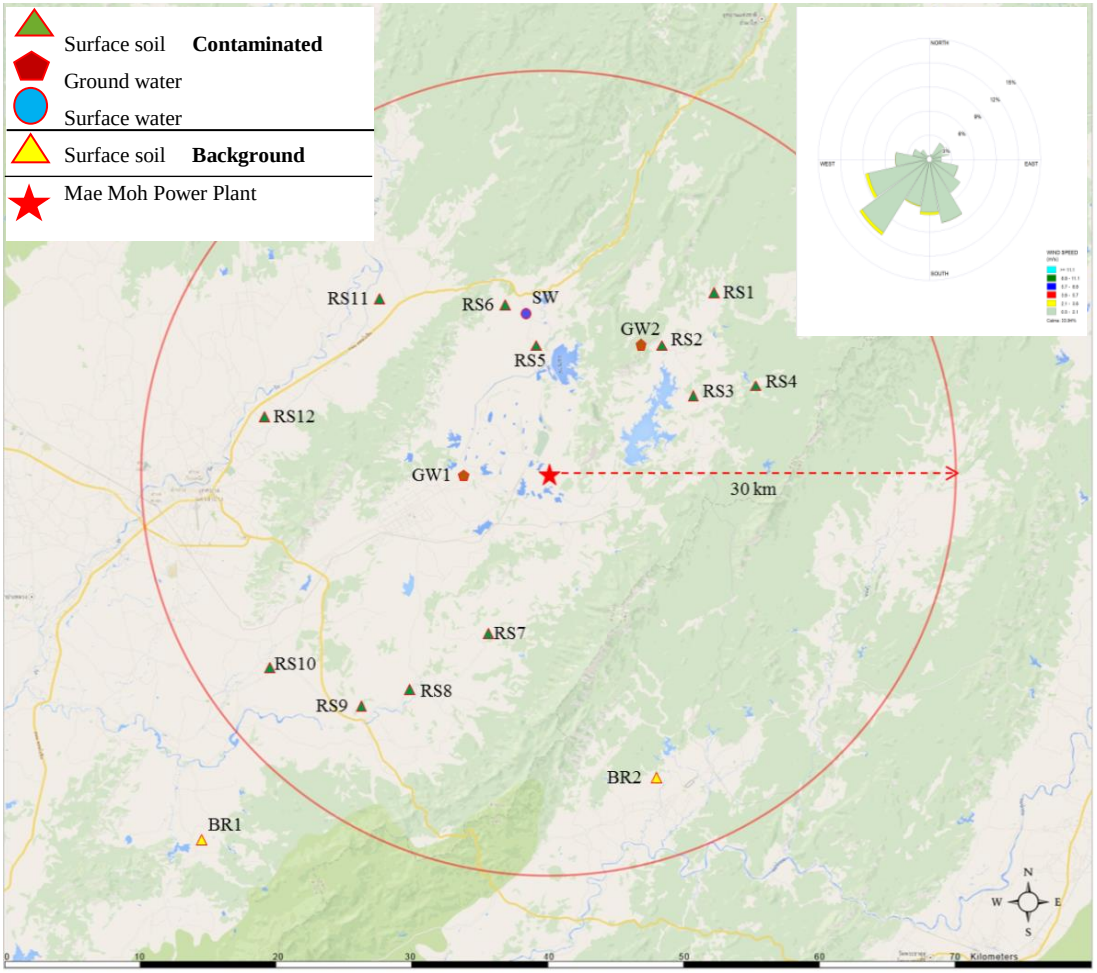

Fig. 1 The sampling locations within the radius of 30 km from the Mae Moh Power Plant

3. RESULTS AND DISCUSSION

3.1 Mercury Concentrations in Surface Soil

Due to characteristics of soil such as texture and organic matter (OM) strongly influence the concentration of contaminated heavy metals in soil [21], these soil samples were analyzed for their characteristics as shown in Table 1. Total mercury (THg) concentrations in surface soil samples from paddy fields around the coal-fired power plant are graphically shown in Figure 2. The results show that THg concentrations in samples taken from this study area during August 8 – 11th, 2015 did not exceed the critical value for Hg content in soil of 23,000 µg/kg announced by the Thai Soil Quality Standards for Residential and Agriculture. The highest THg level in surface soil of 1,338 µg/kg was found in station RS9, which 23 km. distance from the power plant in Southwest direction. The characteristic of soil in this station (RS9) was silt-clay, which heavy metal preferably attached to. The second high THg level of 1,050 µg/kg was found in stations RS4 located at 18 km. in

Northeast direction of the power plant. Those two high THg stations exhibited that the spatial distribution of pollution tends to consistent to the predominant wind direction [22].

The other high THg levels of 261 and 248 µg/kg were found at stations BR1 and RS12, respectively. Surprisingly, station BR1 was initially expected to be a representative of background site due to its long distance (39 km.) from the power plant. However, there were some activities, especially, maintenance of nearby highway that might possibly affect the result. Also, station RS12 was not expected of this high THg level due to it was not in the predominant Southwest-Northeast (SW-NE) wind direction of this area. Anyway, there is a small crematory placed nearby that may interfere the sampling though there was no any operation during the sampling period. The other THg levels of surface soils were in the range of 65 to 99 µg/kg. These THg levels from this study indicate some contamination of mercury in surface soil of this area, especially, some were even higher than Hg concentrations in soils around a coal-fired power plant in China (606 µg/kg) [23] and Serbia (100 µg/kg) [24], where their amounts were already higher than the average content of Hg in world soil.

3.2 Mercury Concentrations in Water

Table 2 shows the THg concentrations found in water samples, two of which were sampling from groundwater wells while another was sampling from surface water. Groundwater sample from station GW1, the nearest station to the power plant, contained THg concentration of 0.2 µg/l while another groundwater sample (GW2) contained lower THg concentration of 0.1 µg/l (Figure 2). Only one sample of surface water (SW) had THg concentration of 0.2 µg/l. The THg results in all water samples did not exceed the critical level of 1 µg Hg/l of Thai Ground water quality Standards and the critical level of 2 µg Hg/l of Thai Surface Water Quality Standard.

Mercury is the most volatile element during the coal combustion process [25]. Its emission and speciation depended on the Hg concentration in the fuels, type of coals, and flue gas temperature and composition [26]. Mercury emitted from coal combustion is transported through the atmosphere and deposited onto the ground as wet or dry precipitation. The Hg in the environment may be transformed by microorganisms into methyl-mercury, a highly toxic form [27]. However, mercury content in coal-lignite or other coals used in this power plant have not been clarified.

Table 1 Total mercury (THg) and soil characteristic of surface soil samples.

Station	Location	Distance from PP* (km)	THg (µg/kg dw)	Sand (%)	Silt (%)	Clay (%)	pH	OM (%)	OC (%)	CEC (cmol/kg)
Contaminated sites										
RS1	Na Chae	18	70	46	43	11	6	1.3	0.7	5.7
RS2**	Sob Chang	13	-	-	-	-	-	-	-	-
RS3	Na Sak	12.5	78	34	41	26	6	2.5	1.5	13.9
RS4	Pong Thaen	17	1050	26	49	26	5.9	1.9	1.1	10.7
RS5	Ban Dong	10	77	24	56	21	5.6	2.9	1.7	12.4
RS6	Hua Fai	13	66	31	48	21	5.6	1.8	1.1	8.9
RS7	Pha Maew	14	99	56	29	15	6.5	1.9	1.1	9.1
RS8	Hau Sua	18	70	21	58	21	5.9	2.1	1.2	11.1
RS9	Pong Papao	23	1338	5	46	49	6.8	5.6	3.2	42.6
RS10	Mae Tha Luang	24.5	65	35	35	31	7.1	2.9	1.7	22.8
RS11	Ban Sadet	18	68	16	64	21	6.1	2	1.2	13.3
RS12	Pichai	22	248	34	47	20	6.7	3.1	1.8	16.4
Background sites										
BR1	Mae Tha	39	261	31	41	28	7.2	2.7	1.5	17.6
BR2	Na Phai Lom	24	94	41	40	19	5.2	2.1	1.2	9.3

Note : *PP – The coal-fired power plant.
** Surface soil was disturbed because of plant seedlings during the period of sampling.

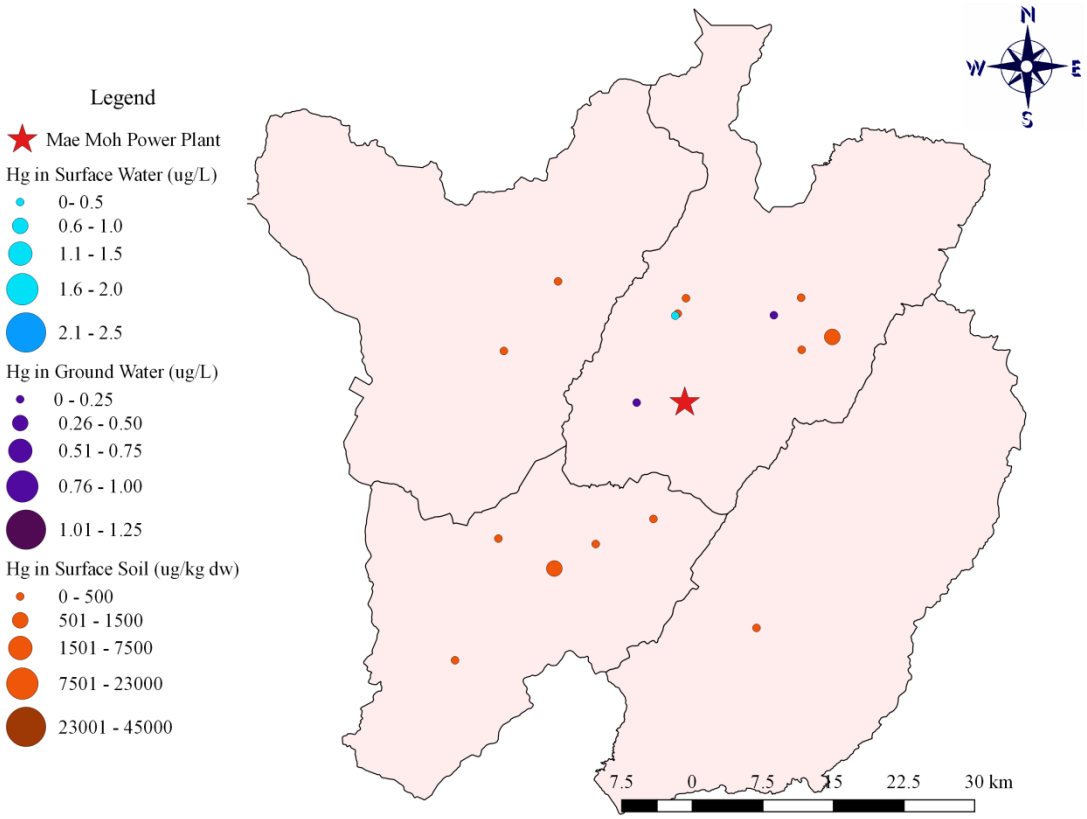

Fig. 2 Total mercury concentration around coal-fired power plant

Table 2 Total mercury (THg) and characteristic of water samples

Station	Location	Distance from PP* (km)	THg (µg/l)	pH	DO (mg/l)	TS (mg/l)	SS (mg/l)	TDS (mg/l)	Conduct (uS/cm)	Turbidity (NTU)
					Ground Water					
GW1	Huy King	6	0.2	6.7	2.7	298	6	313	460	0.9
GW2	Sob Jang	13	0.1	6.4	-	291	6	293	430	0.3
					Surface Water					
SW	Hua Fai	12	0.2	7.5	3.3	125	97	84	124	29.6

Note : *PP – The coal-fired power plant.

3.3 Environmental Risks Assessment

The potential environmental risks assessment was calculated by using Hazard Quotient (HQ) indicated in equation (1). In this study, HQ calculation of surface soil used the screening benchmark of 23,000 µg/kg based on Thai Soil Quality Standards for Residential and Agriculture notified by Pollution Control Department [28], and their results were illustrated in Figure 3. The potential environmental risks evaluation in surface soil of fourteen sampling stations were found in the range of 0.003 – 0.058. These results illustrated that all sampling stations in this study were classified as no environmental hazard (HQ < 1).

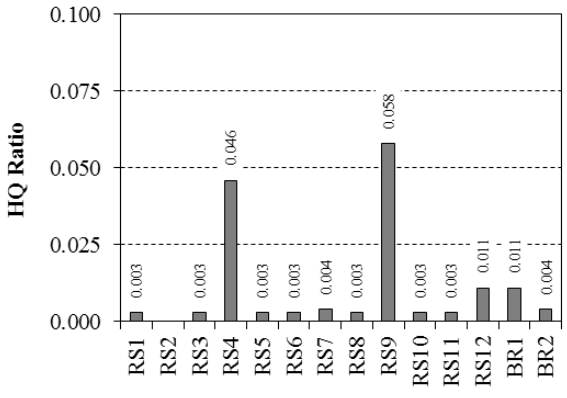

Fig. 3 HQ levels in surface soil samples.

For water samples, the screening benchmarks based on Thai Groundwater quality Standards [29] and Thai Surface Water Quality Standard [30] announced by Pollution Control Department were used for HQ calculation, results of which were shown in Figure 4. In case of groundwater samples, the potential environmental risk evaluations were observed as 0.24 and 0.11 in samples from stations GW1 and GW2, respectively. In addition, HQ level of 0.11 was also found in surface water samples. This could be said that the potential environmental risk evaluations of those water samples were still classified as no environmental hazard (HQ < 1).

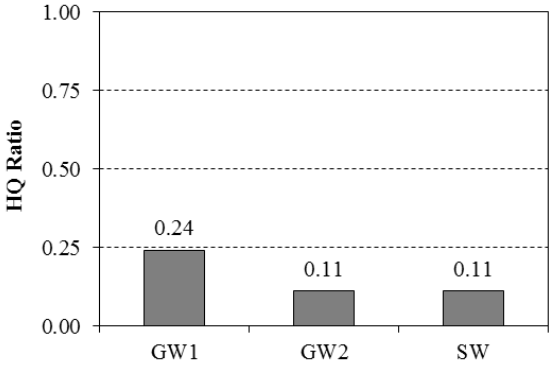

Fig. 4 HQ levels in water samples

4. CONCLUSION

Although the concentrations of THg in surface soil of paddy fields around the coal-fired power plant in this study did not exceed the critical Hg value of Thai Soil Quality Standards for Residential and Agriculture (23,000 µg/kg), these results still illustrated some level of mercury content in this area (65 – 1338 µg/kg). The spatial distribution of THg in surface soil tends to consistent to the predominant SW-NE wind direction. That is, sampling stations located in northeast direction (RS4) and southwest direction (RS9) from the power plant observed higher level of mercury in surface soil (1050 and 1338 µg/kg, respectively). Nevertheless, the potential environmental risks evaluations in surface soil were still classified in the range of 'no environmental hazard' (HQ < 1). Similarly, THg concentrations in water samples (0.11 – 0.24 µg/l) did not exceed the critical values both of groundwater and surface water standards (1 and 2 µg/l, respectively). Therefore, the potential environmental risks evaluations in water samples were also classified as 'no environmental hazard'. However, higher THg concentrations in some stations should be concerned. Anyway, this sampling was only one time sampling, the further sampling and monitoring in this area was planned and scheduled.

4. ACKNOWLEDGEMENTS

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