HUMAN HEALTH RISK ASSESSMENT OF CADMIUM EXPOSURE THROUGH RICE CONSUMPTION IN MAE TAO, MAE SOT DISTRICT, TAK PROVINCE

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การประเมินความเสี่ยงด้านสุขภาพจากการรับสัมผัสแคดเมียมผ่านการบริโภคข้าวของประชากร
ในพื้นที่ตำบลแม่ตาว อำเภอแม่สอด จังหวัดตาก

นางสาวปริญญ์ สุวัฒวิตยากร

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิทยาศาสตรมหาบัณฑิต
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Thesis Title	HUMAN HEALTH RISK ASSESSMENT OF CADMIUM EXPOSURE THROUGH RICE CONSUMPTION IN MAE TAO, MAE SOT DISTRICT, TAK PROVINCE
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Field of Study	Hazardous Substance and Environmental Management
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ปริญญ์ สุวัฒวิตยากร : การประเมินความเสี่ยงด้านสุขภาพจากการรับสัมผัสแคดเมียมผ่านการบริโภคข้าวของประชากรในพื้นที่ตำบลแม่ตาว อำเภอแม่สอด จังหวัดตาก (HUMAN HEALTH RISK ASSESSMENT OF CADMIUM EXPOSURE THROUGH RICE CONSUMPTION IN MAE TAO, MAE SOT DISTRICT, TAK PROVINCE) อ.ที่ปรึกษาวิทยานิพนธ์หลัก: เพ็ญรดี จันทร์ภิวัฒน์, 105 หน้า.

พื้นที่ตำบลแม่ตาว อำเภอแม่สอด จังหวัดตาก เป็นพื้นที่ปนเปื้อนแคดเมียมในดินนาและเมล็ดข้าวในปริมาณที่สูง ประชากรในพื้นที่นี้จึงได้รับผลกระทบทางสุขภาพจากการรับสัมผัสแคดเมียม งานวิจัยนี้มีวัตถุประสงค์เพื่อ 1) วิเคราะห์ความเข้มข้นของแคดเมียมในตัวอย่างเมล็ดข้าวซึ่งเก็บจากครัวเรือนใน 6 หมู่บ้านของพื้นที่ตำบลแม่ตาว อำเภอแม่สอด จังหวัดตาก โดยใช้เครื่องมือ Inductively coupled plasma mass spectrometry (ICP-MS) และ 2) ประเมินความเสี่ยงด้านสุขภาพจากการรับสัมผัสแคดเมียมผ่านการบริโภคข้าวของประชากร ผลการศึกษาพบว่า ความเข้มข้นเฉลี่ยของแคดเมียมที่ตรวจพบในตัวอย่างเมล็ดข้าวทั้งสิ้น 159 ตัวอย่าง (0.2843 มิลลิกรัมต่อกิโลกรัม) มีค่าต่ำกว่าค่ามาตรฐานของแคดเมียมในข้าว (0.4 มิลลิกรัมต่อกิโลกรัม) ที่กำหนดโดยโครงการมาตรฐานอาหารระหว่างประเทศ (Joint FAO/WHO Food Standards Programme หรือ CODEX) อย่างไรก็ตาม ผลการศึกษาพบตัวอย่างเมล็ดข้าวที่มีความเข้มข้นของแคดเมียมสูงกว่าค่ามาตรฐานถึงร้อยละ 19.5 ของตัวอย่างเมล็ดข้าวทั้งหมด นอกจากนี้ ค่าเฉลี่ยความเข้มข้นแคดเมียมในตัวอย่างเมล็ดข้าวสารหอมมะลิและข้าวสารเหนียวนั้นไม่มีความแตกต่างอย่างมีนัยสำคัญ ($p>0.05$) แต่พบว่าค่าเฉลี่ยความเข้มข้นแคดเมียมในตัวอย่างเมล็ดข้าวทั้ง 2 ชนิดที่ปลูกในพื้นที่ตำบลแม่ตาวมีค่าสูงกว่าข้าวที่ซื้อจากร้านค้าทั่วไปประมาณ 1.48 เท่าเมื่อเปรียบเทียบค่าเฉลี่ยความเข้มข้นแคดเมียมในตัวอย่างเมล็ดข้าวที่เก็บจากแต่ละหมู่บ้าน พบว่าตัวอย่างเมล็ดข้าวจากหมู่ที่ 2 บ้านแม่ตาวกลาง (0.4151 มิลลิกรัมต่อกิโลกรัม) และหมู่ที่ 4 บ้านแม่ตาวสันโรงเรียน (0.5097 มิลลิกรัมต่อกิโลกรัม) มีค่าสูงกว่าค่ามาตรฐานของแคดเมียมในข้าว (0.4 มิลลิกรัมต่อกิโลกรัม) ประมาณ1.04 เท่า และ 1.27 เท่า ตามลำดับ ผลการศึกษาอัตราการรับสัมผัสแคดเมียมผ่านการบริโภคข้าวทั้ง 3 รูปแบบพบว่า อัตราการรับสัมผัสแคดเมียมจากการบริโภคข้าวเหนียวอย่างเดียวมีค่าสูงที่สุด (2.26×10^{-3} มิลลิกรัมต่อกิโลกรัมต่อวัน) รองลงมาเป็นการบริโภคทั้งข้าวหอมมะลิและข้าวเหนียว (1.39×10^{-3} มิลลิกรัมต่อกิโลกรัมต่อวัน) และการบริโภคข้าวหอมมะลิอย่างเดียว (6.30×10^{-4} มิลลิกรัมต่อกิโลกรัมต่อวัน) ตามลำดับ ผลการศึกษายังพบว่า ความเข้มข้นของแคดเมียมในข้าวและอัตราการบริโภคข้าวนั้นส่งผลต่ออัตราการรับสัมผัสแคดเมียมจากการบริโภคข้าวทั้ง 3 รูปแบบ ในส่วนของผลการศึกษาความเสี่ยงต่อสุขภาพที่ก่อให้เกิดโรคอื่น ๆ ที่ไม่ใช่มะเร็งจากการบริโภคข้าวทั้ง 3 รูปแบบ พบว่า ค่าเฉลี่ยระดับความเสี่ยงด้านสุขภาพของประชากรที่บริโภคข้าวเหนียวอย่างเดียวมีค่าสูงที่สุด (2.2633) รองลงมาคือประชากรที่บริโภคข้าวทั้ง 2 ชนิด (1.3870) และประชากรที่บริโภคข้าวหอมมะลิอย่างเดียว (0.6303) ตามลำดับ ผลการศึกษาทั้งหมดแสดงให้เห็นว่าประชากรในพื้นที่ตำบลแม่ตาวที่บริโภคข้าวเหนียวอย่างเดียวและบริโภคข้าวทั้ง 2 ชนิดในชีวิตประจำวันนั้นมีความเสี่ยงจากการรับสัมผัสแคดเมียมผ่านการบริโภคข้าว

สาขาวิชา การจัดการสารอันตรายและสิ่งแวดล้อม	ลายมือชื่อนิสิต ....
ปีการศึกษา 2560	ลายมือชื่อ อ.ที่ปรึกษาหลัก ....

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KEYWORDS: CADMIUM, RICE, HEALTH RISK ASSESSMENT, HARZARD QUOTIENT, FOOD CONSUMPTION, FOOD SAFETY

PARIN SUWATVITAYAKORN: HUMAN HEALTH RISK ASSESSMENT OF CADMIUM EXPOSURE THROUGH RICE CONSUMPTION IN MAE TAO, MAE SOT DISTRICT, TAK PROVINCE. ADVISOR: ASST. PROF. PENRADEE CHANPIWAT, Ph.D., 105 pp.

Mae Tao sub-district is located in the Mae Tao watershed, an important Cd contaminated area in Thailand. This study was conducted to i) investigate total Cd concentration in rice from households in the Mae Tao sub-district and ii) estimate health risks from Cd exposure through rice consumption. A total number of 159 rice samples were collected from households in all 6 villages of the Mae Tao sub-district. These rice samples were digested with concentrated nitric acid and analyzed by the inductively coupled plasma mass spectrometry (ICP-MS). Biodata information and rice consumption behavior were surveyed from the local residents at the same time of rice sample collection to estimate health risks. The results found that the average total Cd concentration in all rice samples (0.2843 mg kg^{-1}) were within the CODEX maximum standard for Cd in rice (0.4 mg kg^{-1}). However, about 19.5% of all rice samples had Cd concentration exceeded the CODEX maximum standard for Cd in rice. There were no significant difference in total Cd concentration between white jasmine rice and sticky rice ($p>0.05$). However, locally grown rice usually contained higher total Cd concentration than the purchased rice by 1.48 times. When compare the total Cd concentration in each village, the average total Cd concentrations in rice samples from Mae Tao Klang (village No.2) (0.4151 mg kg^{-1}) and Mae Tao San Rongrian (village No.4) (0.5097 mg kg^{-1}) exceeded the CODEX maximum standard by about 1.04 and 1.27 times, respectively. The Cd exposure from the only sticky rice consumption pattern was the highest (2.26×10^{-3} mg kg^{-1} day^{-1}), followed by both types of rice consumption pattern (1.39×10^{-3} mg kg^{-1} day^{-1}) and the only white jasmine rice consumption pattern (6.30×10^{-4} mg kg^{-1} day^{-1}). The Cd exposure in each rice consumption pattern was mainly influenced by the total Cd concentration in rice and the ingestion rate of the local residents. According to the health risk assessment between different rice consumption patterns, the average HQ value of the only sticky rice consumption pattern was the highest (2.2633), followed by both types of rice consumption pattern (1.3870) and the only sticky rice consumption pattern (0.6303). The overall results indicate that the local residents who consumed only sticky rice and both types of rice on a daily basis could experience non-carcinogenic health impacts from Cd exposure through rice consumption.

Field of Study:	Hazardous Substance and Environmental Management	Student's Signature	....
		Advisor's Signature	....
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CHAPTER 1

INTRODUCTION

1.1 Background of the study

Rice (*Oryza sativa*) is one of the essential energy source for human around the world because it has high fiber and nutrients to energize human body. The Organization for Economic Co-operation and Development collaborated with the Food and Agriculture Organization of the United Nations (OECD/FAO) reported that the average global rice production and consumption between 2013 to 2015 were 493.4 and 490.8 million tons, respectively (OECD/FAO, 2016). The world average rice consumption was about 54.8 kg per capita per year (OECD/FAO, 2016). In addition, the report concluded that the trend of rice consumption will increase around 1 to 3% per year in the future. For Asian countries, rice is the main species of food crops that cultivated in this region (Huang et al., 2013). The report from OECD/FAO also mentioned that the average rice production and rice consumption in Asia between 2013 and 2015 were 438.2 and 420.8 million tons, respectively (OECD, 2016a). Thus, it can be simply implied that this region is the world largest rice production and rice consumption. In the case of Thailand, the average rice consumption between 2013 to 2015 was 100.9 kg per capita per year. This amount of rice consumed ranks as the fifth highest rice consumption in Asia after Bangladesh, Vietnam, Indonesia, and Philippines (OECD, 2016b). Although rice is the popular energy source that human consumes worldwide, it is one of the main source of pollutants especially heavy metals that human exposed and could lead to significant human health impacts. Therefore, the standard maximum levels of 0.2 mg kg^{-1} and 0.4 mg kg^{-1} were established for arsenic (As) and cadmium (Cd) in rice, respectively (CODEX, 2011).

Cd is one of toxic heavy metals which can be either intentionally or accidentally released from anthropogenic activities such as electrical and mining industries (U.S.EPA, 2000a). Once released, Cd can cause contamination in soil and water, and finally it can be taken up to food chain through aquatic animals and food crops. Therefore, Cd may cause harmful effects to human body through the ingestion of food which was produced from the contaminated area. After ingestion, Cd can be accumulated in human body and, later on, it may cause acute and chronic effects to several organ and systems, particularly kidney and skeleton system (ATSDR, 2012). Moreover, Cd can cause renal tubular dysfunction, high level of protein in urine, and osteoporosis (WHO, 2010). Since the effects of Cd to human body is of high level, it is important to set up the maximum level of Cd in several types of food. For example, the Joint FAO/WHO Food Standards Programme which is also known as CODEX Committee on Contaminants in Foods has established standard maximum level of Cd concentration for rice at 0.4 mg kg^{-1} (CODEX, 2011). Therefore, the study on Cd contamination in rice is under a spotlight during the last few decades. For example, Cd concentration in 484 rice grain samples from five polluted areas in China (Hubei, Liaoning, Yunnan, Guangdong and Guizhou) with the levels of 0.249 to 1.167 mg kg^{-1} were undeniably exceeded the maximum allowable Cd concentration of China (0.2 mg kg^{-1}) (Ke et al., 2015). This study also found that rice grain samples from Guizhou, southwest of China, had higher Cd concentrations than other study areas because of contamination of Cd caused by mining and smelting industries in the area (Ke et al., 2015). The study of Cd concentration in rice samples from paddy field in Nigeria found that Cd concentration (0.39-1.98 mg kg^{-1}) were about 4.95 times higher than the CODEX standard of Cd (Ihedioha et al., 2016).

In Thailand, Mae Tao sub-district in Tak province is one of the agricultural areas which has been reported as Cd contamination areas for about 2 decades. Therefore, food crops particularly rice which was cultivated in this area was found with elevated Cd concentration. Cd contamination in paddy soils and rice grain in this area was firstly revealed in 2005 by the International Water Management Institute (IWMI) (IWMI, 2005). Soil collected from Phratat Pha Daeng sub-district and Mae Tao Mai village contained Cd concentrations ranged from 0.1 to 284 mg kg^{-1} which exceeded the EU maximum standard of 3.0 mg kg^{-1} of Cd in soil. While Cd concentrations in rice grain samples ranged from 0.01 to 7.75 mg kg^{-1} in which the maximum concentration was about 19.4 times higher than the CODEX maximum standard of 0.4 mg kg^{-1} (IWMI, 2005). Since the report of IWMI has revealed, several studies were conducted to monitor Cd concentrations in contaminated agricultural areas, particularly paddy fields. For example, Thongsri et al. (2009) found that Cd was the highest concentration which accumulated into jasmine rice root (2.67 mg kg^{-1}). In addition, Sriprachote et al. (2012) analyzed Cd concentrations in household rice samples and found about 0.04 to 1.75 mg kg^{-1} of Cd in rice. Since Cd contamination in rice grain was reported, the study of health impact from Cd exposure through rice consumption was then conducted by using urine as a biomarker. According to Swaddiwudhipong et al. (2007), urinary Cd levels in local adult residents who live in Cd contaminated areas were determined. The results showed that around 4.9% of total residents surveyed had urinary Cd level ranged from 5 to 10 μg g^{-1} creatinine, and 2.3% of total surveyed had urinary Cd level over 10 μg g^{-1} creatinine, which exceeded the American Conference of Governmental Industrial

Hygienists (ACGIH) maximum standard of 5 µg g^{-1} creatinine. This study also reported higher urinary Cd levels in local adult residents who consumed rice locally grown in contaminated area than those who did not consume rice from contaminated area. Therefore, it could be concluded that rice is one of the major source of Cd exposure in local residents. The study of health impact through rice consumption in the Cd contaminated area was also conducted by Honda et al. (2010). The results showed about 1.83 and 1.79 times of urinary Cd in local male and female residents who consumed homegrown rice higher than those who did not consume homegrown rice. In addition, urinary Cd level in farmers who work and consume rice in this area were higher than other residents by about 2.07 times in men and 1.52 times in women. This indicated that contaminated rice consumption can increase adverse health effects from Cd exposure. Therefore, the solutions for reducing health impacts from Cd exposure were proposed by the Pollution Control Department (PCD) and Ministry of Agriculture (MOA) (Padungtod et al., 2006). PCD and MOA suggested that rice cultivation in the contaminated area should be prohibited and other alternative hyperaccumulation plants should be cultivated in order to reduce Cd exposure via rice ingestion (Padungtod et al., 2006). Although, Cd concentrations in rice grain and solutions to reduce human health impacts have been reported, there are some limitations and gaps which yet needed to be done for the better understanding on human health impacts from rice ingestion. One of the limitations are the lack of actual Cd concentrations in rice grain and the amount of rice that local residents consumed. In addition, non-carcinogenic health risk especially from rice ingestion has never been estimated in this area. Therefore, human health risk assessment of Cd exposure through rice consumption in this area should be conducted to fulfill those limitations.

1.2 Objectives

1. To determine Cd concentrations in rice colleted from households in the Mae Tao sub-district.
2. To assess health risk from rice consumption in general population of the Mae Tao sub-district.

1.3 Hypotheses

1. Cd concentrations contained in both locally grown and purchased rice collected from households in the Mae Tao are higher than the CODEX standard (0.4 mg kg^{-1}).
2. Non-carcinogenic health impacts (HQ>1) are expected to affect local residents living in the Mae Tao who consumed rice on a daily basis.
3. Health risks in local residents who consumed locally grown rice are significantly higher than those who consumed rice purchased from local markets such as Mae Sot central market and department stores.

1.4 Scope of the study

This study can be divided into two parts as shown in Figure 1.

First part is the determination of Cd concentrations in rice. A total of 159 rice samples were randomly collected from the local households in all villages of the Mae Tao sub-district, Mae Sot district. The total amount of sample size as prescribed above was calculated according to the sample size calculation recommended by Israel (2013). After collection, all rice samples were ground by a blender and sieved through a 425 µm sieve. After that, rice samples were digested by an acid digestion method as recommended by Phan et al. (2013) and analyzed for total concentration of Cd using an inductively coupled plasma mass spectrometry (ICP-MS).

Second part is the health risk assessment of rice consumption. The concentration of Cd in rice determined from the first part was used to estimate the negative health impacts from rice consumption of each local individual. The biodata information including age, body weight, gender, rice consumption behavior (ingestion rate, exposure duration, exposure frequency, source of rice consumed), occupation and smoking behavior were interviewed using a questionnaire at the same time of rice sample collection. After that, health risks in terms of non-carcinogenic risks were calculated using a hazard quotient (HQ) equation. Results of health risk assessment of Cd exposure from rice consumption in the Mae Tao sub-district are expected to be communicated to local residents and public to raise an awareness of Cd exposure through rice ingestion on a daily basis.

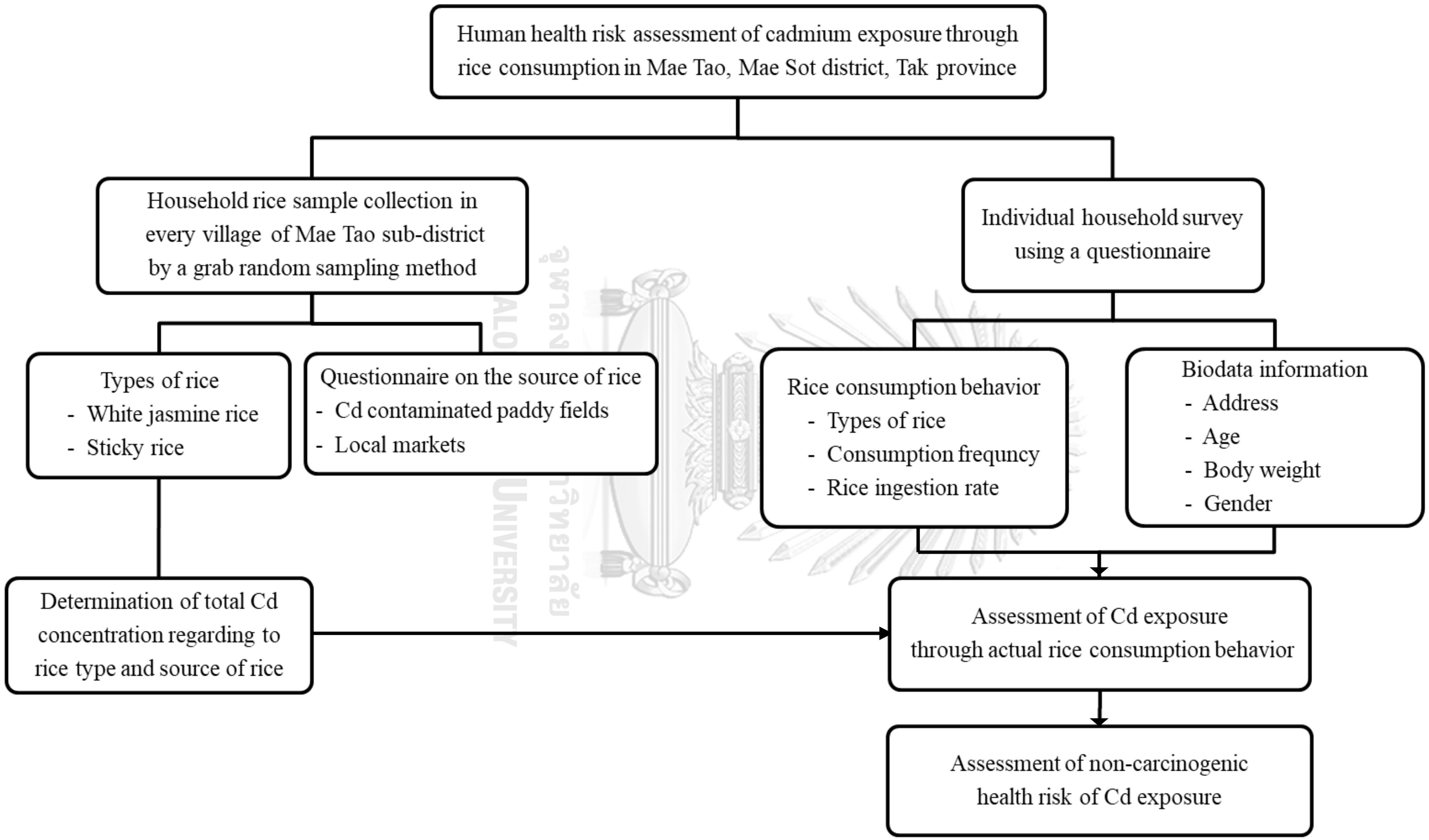

Figure 1 Scope of the study

CHAPTER 2

LITERATURE REVIEW

There are four parts in the literature review including i) background of the study area, ii) Cd contamination in the Mae Tao watershed, iii) health effects from Cd exposure, and iv) health risk assessment as following.

2.1 Background of the study area

Mae Tao watershed locates in the Mae Sot district, Tak province. There are three sub-districts in the Mae Sot district: Mae Tao, Mae Ku and Phratat Pha Daeng (DPIM, 2016). Mae Tao watershed consists of two main creeks including Mae Tao creek and Mae Ku creek (DPIM, 2016). These creeks originate from the Thanon Thong Chai mountain and flow from the east to west. Mae Tao creek flows through Mae Tao and Phratat Pha Daeng sub-districts while Mae Ku creek flows through Phratat Pha Daeng and Mae Ku sub-districts (Figure 2). Both creeks finally run to the Mei river, the border line of Thailand and Myanmar (Kosolsaksakul et al., 2014).

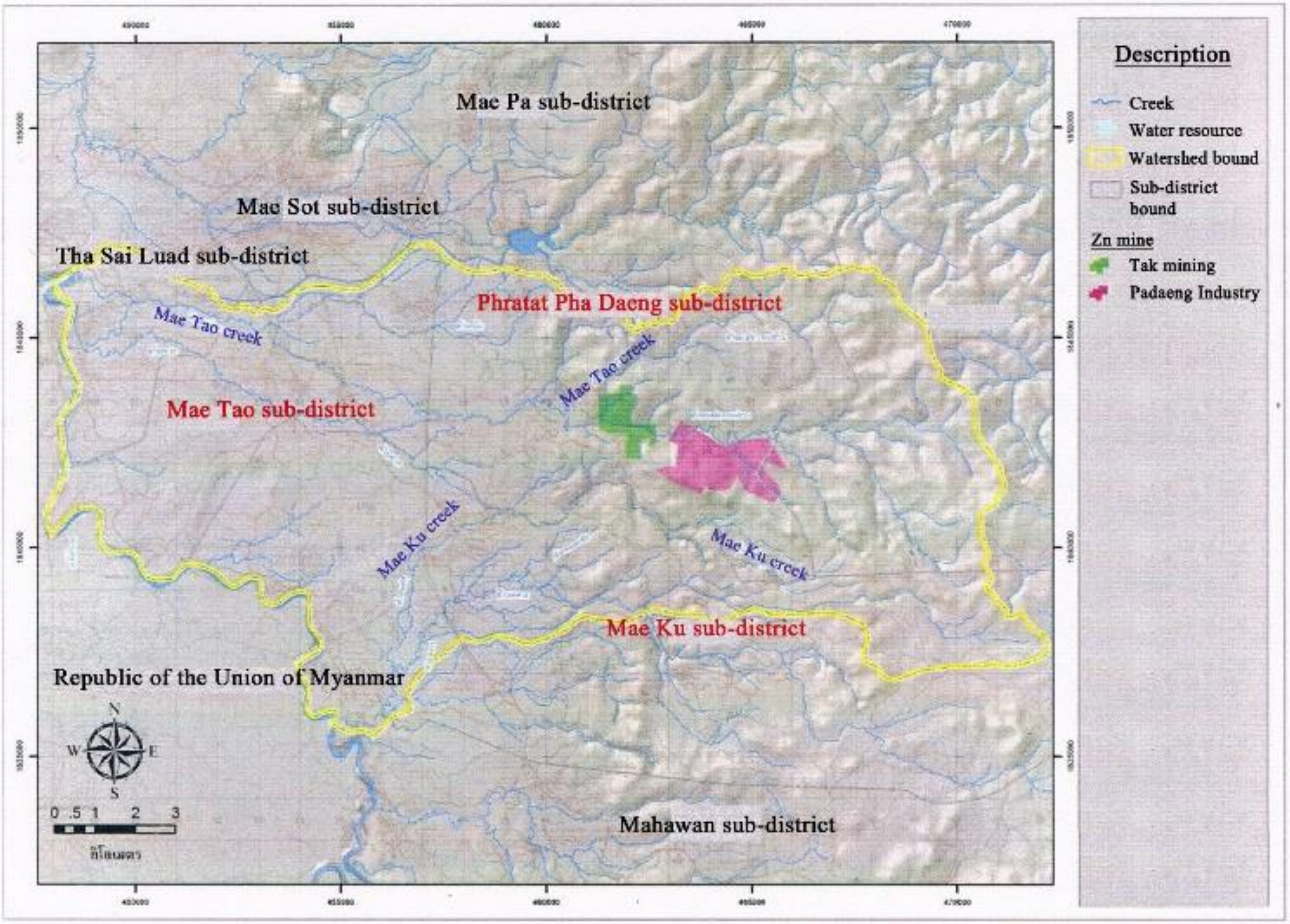

Figure 2 Boundary of the Mae Tao watershed

Source: DPIM (2016)

Based on the geological information, Mae Sot district is one of both Zn and lead (Pb) potential areas (DPIM, 2016). Therefore, the Thai government has offered a concession to investors for mining industries operation (DPIM, 2010). Tak Mining Company Limited and Padaeng Industry Public Company Limited were two mining companies that located in the Mae Tao watershed. These two mining operations were permanently closed since 2003 and June 2016, respectively. The Padaeng Industry Public Company Limited was the largest Zn mine in Southeast Asia and has been operated in this area for more than 30 years (Akkajit, 2015). The production capacity of Zn was about 110,000 metric tons per year (Akkajit, 2015). Waste generation from Zn mine, including Cd as a by-product (U.S.EPA, 2000a), and natural soil erosion in potential Zn mineral area were reported to be the significant sources of soil, water and plant contamination in this area (Simmons et al., 2005; DPIM, 2010; Kosolsaksakul et al., 2014; Sriprachote et al., 2014; Akkajit, 2015).

Mae Tao watershed is the best rice production area in Mae Sot because of fertile minerals and water resources (Kosolsaksakul et al., 2014). Both Mae Tao and Mae Ku creeks which flow through Zn mine operations in the upstream areas are the significant water resources for irrigation to paddy fields in the downstream areas (DPIM, 2015; DPIM, 2016). Therefore, rice cultivated in this area was found with high levels of Zn and Cd. In addition, the toxic health impacts of Zn and Cd were diagnosed in many local residents who live in the contaminated areas (IWMI, 2005; Kosolsaksakul et al., 2014; Akkajit, 2015).

During 2002 to 2004, the IWMI in collaboration with the MOA has conducted a survey and investigation on Cd concentrations in rice grain and soil in the Phratat Pha Daeng sub-district and the Mae Tao Mai village and found levels of Cd concentration in both rice grain and soil exceeded the CODEX and EU maximum standards (IWMI, 2005). According to the IWMI report, Cd concentrations in rice grain were in the range of 0.01 to 7.75 mg kg^{-1} which exceeded the maximum standards of CODEX (0.4 mg kg^{-1}) (IWMI, 2005). As in soil samples, Cd concentrations ranging from 0.1 to 284 mg kg^{-1} were also over the EU maximum standard level of soil of 3.0 mg kg^{-1} (IWMI, 2005). These results indicated that local residents living in the Mae Tao watershed may be affected and are at risk of Cd exposure.

Mae Tao is one of the sub-districts in the Mae Tao watershed. It consists of six villages including Mae Tao Tai, Mae Tao Klang, Mae Tao Phae, Mae Tao San Rongrian, Mae Tao San Pae and Don Chai (DPIM, 2015). A summary of population and households in Mae Tao sub-district is shown in Table 1. According to the DPIM (2015), Cd concentrations in rice from the Mae Tao sub-district ranged from 0.41 to 3.87 mg kg^{-1} which was about 9.68 times higher than the CODEX maximum standard. The average Cd concentrations in rice from all villages were higher than the CODEX maximum standard. Most of rice with Cd concentration higher than the CODEX maximum standard were from the Mae Tao Klang (Village No.2) and the Mae Tao Phae (Village No.3). The accumulation of Cd in water, soil and sediment in this area was expected to be a main source of high level of Cd in agricultural products and plants cultivated in the area. Since most of local residents in the Mae Tao sub-district are farmers, and rice is the main agricultural product which is grown and locally consumed, local residents in the Mae Tao sub-district are expected to obtain health impacts from Cd exposure through rice consumption (Swaddiwudhipong et al., 2007).

Table 1 Total number of population and households in Mae Tao sub-district

Village No.	Village name	Population			Total number of households
		Male	Female	Total	
1	Mae Tao Tai	552	487	1,039	360
2	Mae Tao Klang	814	781	1,595	620
3	Mae Tao Phae	734	721	1,455	627
4	Mae Tao San Rongrian	390	389	779	293
5	Mae Tao San Pae	396	345	741	266
6	Don Chai	452	459	911	367
	Total	3,338	3,182	6,520	2,533

Source: MOI (2016)

2.2 Cd contamination in the Mae Tao watershed

Zn and Cd are minerals which generally coexist (DPIM, 2015; DPIM, 2016). Therefore, Zn mine operation and natural soil erosion from the potential Zn mineralized areas could be the main sources of Zn and Cd contamination in this area (DPIM, 2015; DPIM, 2016). Elevated Cd concentrations were determined in both agricultural soil as well as both Mae Tao and Mae Ku creeks. As most of agricultural areas are paddy fields in which the cultivation mainly relies on water from both creeks, paddy soil and rice were also contaminated with Cd. Therefore, several studies were conducted to monitor Cd concentrations in several environmental media as following (DPIM, 2004; IWMI, 2005; Unhalekhaka and Kositanont, 2008; DPIM, 2010; Sriprachote et al., 2012; Pluemphuak et al., 2014; Sriprachote et al., 2014; Akkajit, 2015).

2.2.1 Surface water

Cd contamination in surface water with concentrations higher than surface water quality standard (0.05 mg L^{-1}) is one of the environmental problems of concerned in the Mae Tao watershed. Therefore, several studies as shown in Table 2 were conducted to monitor Cd concentrations in surface water in the Mae Tao watershed (Moonthongnoi and Arunlertaree, 2008; DPIM, 2015; DPIM, 2016).

In 2004, the DPIM investigated Cd concentrations in surface water surrounding Zn mining area and found that surface water had Cd concentrations lower than 0.05 mg L^{-1}. This result was in accordance with the report of the Department of Water Resource (DWR) who found Cd concentration in surface water samples lower than 0.05 mg L^{-1} (DPIM, 2015). Mahidol University also reported Cd concentrations less than 0.05 mg L^{-1} in surface water from the Mae Tao, Mae Sot, and Mae Ku creeks (DPIM, 2015). Moreover, study by the PCD also reported that Cd concentrations in surface water collected from the Mae Tao, Mae Ku, Phratat Pha Daeng and Tha Sai Luad sub-districts with the average value of 0.001 mg L^{-1} were lower than the standard of Cd in surface water (DPIM, 2015).

In the case of a variation of Cd concentration in surface water by season, a study from Mahidol University reported different Cd concentrations in surface water collected from the Mae Tao, Mae Sot, and Mae Ku creeks during both summer and rainy seasons (DPIM, 2015). Cd concentrations in surface water collected in rainy season contained higher Cd concentration than surface water collected in summer because high rainfall in rainy season resulted in soil erosion and the distribution of Cd into the surface water (DPIM, 2015). This result was in accordance with the study of Moonthongnoi and Arunlertaree (2008) who found the maximum Cd concentration in surface water in rainy season about 5.33 times higher than the summer season. Based on results from previous studies, it can be concluded that surface water in the Mae Tao watershed generally contained Cd concentrations lower than the standard of Cd in surface water (0.05 mg L^{-1}) and surface water in rainy season had higher Cd concentration than the summer season.

Table 2 Cd concentrations in surface water

No.	Investigator (Year of study)	Study area	Cd concentrations ($mg\ L^{-1}$)	Results	Reference
1	DPIM (2004)	Ponds surrounding Zn mining area*	<0.05	Cd concentrations were within surface water quality standard (0.05 $mg\ L^{-1}$).	DPIM (2015)
2	DWR (2004)	Mae Tao creek (20 samples)	<0.001-0.003	Cd concentrations were within surface water quality standard (0.05 $mg\ L^{-1}$).	DPIM (2015)
3	Mahidol University (2004)	Mae Tao, Mae Ku and Mae Sot creeks (11 sampling sites)*	<0.05	Cd concentrations in rainy season were higher than summer season due to natural soil erosion and high Cd mobility during rainfall events.	DPIM (2015)
4	Moonthongnoi and Arunlertaree (2008)	Mae Tao creek (8 sampling sites)*	0.005-0.006[a] 0.026-0.032[b]	- Cd concentrations in surface water from both summer and rainy seasons were within surface water quality standard (0.05 $mg\ L^{-1}$). - The maximum Cd concentration in surface water in rainy season was 5.33 times higher than summer season.	Moonthongnoi and Arunlertaree (2008)

Note: [a] Summer season
[b] Rainy season
* Number of samples was not identified

Table 2 Cd concentrations in surface water (Cont.)

No.	Investigator (Year of study)	Study area	Cd concentrations ($mg\ L^{-1}$)	Results	Reference
5	PCD (2013)	Mae Tao, Mae Ku, Phratat Pha Daeng, and Tha Sai Luad sub-districts (20 sampling sites)*	0.001	Cd concentrations were within surface water quality standard (0.05 $mg\ L^{-1}$).	DPIM (2015)

Note: [a] Summer season
[b] Rainy season
[*] Number of samples was not identified

2.2.2 Sediment

The studies on Cd contamination in sediment in the Mae Tao watershed were conducted by many research groups (Padungtod et al., 2006; Thamjedsada and Chaiwiwatworakul, 2012; Akkajit, 2015; Kitana et al., 2015; Weeraprapan et al., 2015; DPIM, 2016). According to these previous studies, Cd concentration in sediment ranged from 0.5 to 326 mg kg^{-1}. The maximum Cd concentration in sediment was about 108.7 times exceeded the EU maximum standard (3.0 mg kg^{-1}) of Cd in soil. The summary of Cd concentrations in sediment from previous studies is shown in Table 3.

According to the report by the DPIM (2016), Cd contamination in sediment is caused by rainfall and natural soil erosion. Cd which is absorbed on the soil particles can be transported into the creek and deposited to the bottom of the creek as contaminated sediment. Weeraprapan et al. (2015) found that pH of surface water from Mae Tao creek was in the range of 7.97 to 8.16 in which it is the pH range that Cd could not be dissolved. In addition, low Cd concentration in sediment was found in the upstream of the creek before flowing through Zn mining areas. An increase in Cd concentration was found in sediment collected around Zn mining areas as well as the downstream of mining areas (Weeraprapan et al., 2015). These results were in accordance with the report of the PCD who found higher levels of Cd in sediment around Zn mining areas and downstream areas compared to the upstream of the Mae Tao creek (Padungtod et al., 2006).

In the case of Cd concentration in sediment by season, Thamjedsada and Chaiwiwatworakul (2012) reported different Cd concentrations in sediment collected in the dry and wet seasons. The maximum Cd concentrations in sediment collected in wet season were about 8.95 times higher than Cd concentrations in sediment collected in dry season. The reason behind this is the greater flow rate in wet season than the dry season. Cadmium which is attached to the soil can be easily transported along with surface runoff in wet season. In addition, Cd concentrations in sediment collected from the downstream of Zn mining areas were higher than other sampling sites in both wet and dry seasons (Thamjedsada and Chaiwiwatworakul, 2012). Therefore, it could be concluded that one of the Cd contamination sources in this area is Zn mining activities.

Based on previous studies (Table 3), it can be concluded that Cd could be adsorbed onto the soil particles can be transported into the creek and deposited as the contaminated sediment. The paddy fields which received irrigation from the creek could consequently receive and become contaminated with Cd contaminated sediment. In addition, high water flow rate in wet season may enhance contaminated soil erosion and leading to higher Cd concentration in sediment.

Table 3 Cd concentrations in sediment

No.	Investigator (Year of study)	Study area	Cd concentrations (mg kg^{-1})	Results	Reference
1	PCD (2004)	Mae Tao creek*	0.5-326	The maximum Cd concentrations were found in sediment collected from the nearby areas of Zn mines.	Padungtod et al. (2006)
2	Naresuan University (2007)	Mae Tao creek*	1.02-30.20[a] 0.50-33.40[b]	Cd concentrations in sediment in wet season were higher than dry season.	DPIM (2016)
3	Thamjedsada and Chaiwiwatworakul (2012)	Mae Tao creek (10 sampling sites)*	12.58[a] 5.67-112.6[b]	- The maximum Cd concentration in sediment in wet season was about 8.95 times higher than dry season. - Cd concentrations in sediment in downstream of Zn mines increased in both dry and wet season.	Thamjedsada and Chaiwiwatworakul (2012)

Note: [a] Dry season
[b] Wet season
* Number of samples was not identified

Table 3 Cd concentrations in sediment (Cont.)

No.	Investigator (Year of study)	Study area	Cd concentrations (mg kg^{-1})	Results	Reference
4	Weeraprapan et al. (2015)	Mae Tao creek (4 sampling sites)*	0.84-7.86	Cd concentrations in sediment in downstream of Zn mines were higher than the upstream.	Weeraprapan et al. (2015)
5	Kitana et al. (2015)	Mae Tao creek*	2.9260-3.2888	Cd concentrations in sediments were higher than the EU maximum standard of Cd in soil (3.0 mg kg^{-1}).	Kitana et al. (2015)

Note: [a] Dry season
[b] Wet season
* Number of samples was not identified

2.2.3 Agricultural soil

In 2005, the IWMI reported about elevated Cd concentration in soil (IWMI, 2005). The results showed that Cd concentration in 85% of agricultural soil samples in this study exceeded the EU maximum standard of 3.0 mg kg^{-1}. Later on, several studies have reported about high level of Cd concentrations in agricultural soil (Simmons et al., 2005; Unhalekhaka and Kositanont, 2008; DPIM, 2010; Pluemphuak et al., 2014; Sriprachote et al., 2014; DPIM, 2015; DPIM, 2016). The minimum and maximum Cd concentrations in agricultural soil from the Mae Tao watershed from these studies were 0.5 and 284 mg kg^{-1}, respectively. The maximum Cd concentration in agricultural soil was about 94.7 times higher than the EU maximum standard (3.0 mg kg^{-1}). The summary of Cd concentrations in agricultural soil from previous studies is shown in Table 4.

In the case of the distribution of Cd level, Simmons et al. (2005) reported a relationship between Cd levels in paddy soils and the distance from an irrigation channel. They found low Cd concentrations (0.3±0.015 mg kg^{-1}) in soil samples collected from non-irrigated paddy fields (Simmons et al., 2005). This study also reported that elevated Cd concentration in paddy soil was associated with irrigation water from the Mae Tao creek which may transport suspended sediment containing Cd to the paddy fields.

The study of Unhalekhaka and Kositanont (2008) determined Cd concentrations in agricultural soils from upstream and downstream areas of the Mae Tao and Mae Ku creeks which flow through Zn mine areas. It was found that Cd concentrations in agricultural soil from the upstream of the Mae Tao and Mae Ku creeks were 8.45 and 7.55 mg kg^{-1}, respectively. While at the downstream, higher concentrations of Cd in soil were found in both Mae Tao (22.50 mg kg^{-1}) and Mae Ku (34.95 mg kg^{-1}) creeks.

This may cause by the transportation of Cd contaminated sediment from the upstream to the downstream of both creeks. Thus, Cd could be transported to paddy fields by irrigation water from both creeks and then accumulated in the soil. These results were in accordance with the report from Pluemphuak et al. (2014) and Sriprachote et al. (2014) who found the increasing of Cd concentration in agricultural soil from upstream to downstream areas. In addition, these two studies reported about 15.62 times of Cd in the soil higher than the EU maximum standard (3.0 mg kg^{-1}). Particularly, Sriprachote et al. (2014) determined Cd concentration in four groups of soil in the Pha Te village including forest soil, upland soil, upper paddy soil and lower paddy soil. The upper paddy soil and lower paddy soil were soils from paddy fields which received irrigation water from the Mae Tao creek. The study found higher Cd concentrations in the upper and lower paddy soils than soil collected from forest and upland areas. The results clearly indicated the contamination of Cd in the areas along the Mae Tao creek. The potential source of Cd may originate from the upstream area.

Table 4 Cd concentrations in agricultural soil

No.	Investigator (Year of study)	Study area	Cd concentrations (mg kg^{-1})	Results	Reference
1	Simmons et al. (2005)	Mae Tao creek within Phratat Pha Daeng sub-district (334 samples)	0.5-284	- The maximum Cd concentration in paddy soil was about 94.7 times higher than the EU maximum standard (3.0 mg kg^{-1}). - Cd contamination in paddy soil was in accordance to the distance from the creek. High Cd concentrations were found in paddy soils near the creek.	Simmons et al. (2005)
2	Unhalekhaka and Kositanont (2008)	Mae Tao and Mae Ku creeks (6 sampling sites)*	8.45-22.5[a] 7.55-34.95[b]	Cd concentration in both creeks increased along the distance from upstream to downstream.	Unhalekhaka and Kositanont (2008)

Note: [a] Mae Tao creek
[b] Mae Ku creek
[c] Upstream soil
[d] Midstream soil
[e] Downstream soil
* Number of samples was not identified

Table 4 Cd concentrations in agricultural soil (Cont.)

No.	Investigator (Year of study)	Study area	Cd concentrations (mg kg^{-1})	Results	Reference
3	Pluemphuak et al. (2014)	Mae Tao and Phratat Pha Daeng sub-districts (96 samples)	15.35-36.20[c] 12.00-7.67[d] 11.45-46.87[e]	The maximum Cd concentration in paddy soil in downstream was about 15.62 times higher than the EU maximum standard (3.0 mg kg^{-1}).	Pluemphuak et al. (2014)
4	Sriprachote et al. (2014)	Pha Te village in Phratat Pha Daeng sub-district*	0.63-30.4	Cd concentration in upper and lower paddy soil which received irrigation water from Mae Tao creek were higher than soils from forest and upland areas.	Sriprachote et al. (2014)

Note: [a] Mae Tao creek
[b] Mae Ku creek
[c] Upstream soil
[d] Midstream soil
[e] Downstream soil
[*] Number of samples was not identified

2.2.4 Rice grain

According to previous studies (IWMI, 2005; Simmons et al., 2005; Sriprachote et al., 2012; Pluemphuak et al., 2014), the minimum and maximum Cd concentrations in rice from the Mae Tao watershed were about 0.01 and 9.27 mg kg^{-1}, respectively. The proportion of rice grain samples with Cd concentrations exceeded the CODEX maximum standard (0.4 mg kg^{-1}) were in the range of 50 to 90% (IWMI, 2005; Simmons et al., 2005; Sriprachote et al., 2012). The maximum Cd concentration was 3.09 times higher than the CODEX maximum standard. The summary of Cd concentration in rice from the Mae Tao watershed is shown in Table 5.

The study of Sriprachote et al. (2012) found that the difference in Cd concentrations in rice grain depended on the distance from paddy fields to the Mae Tao creek. Cd concentrations in rice grain cultivated in paddy fields near the main line of the Mae Tao creek were higher than Cd concentrations in rice grain from paddy fields which received irrigation water from the canal of the Mae Tao creek (Sriprachote et al., 2012). This result was in accordance with the report of Simmons et al. (2005) as shown in Table 5. Therefore, a main cause of Cd contamination in rice could be related to the irrigation water from the Mae Tao creek. According to Table 5, the trend of Cd concentrations in rice grain from the Phratat Pha Daeng sub-district (Study No.1 to No.3) decreased by time. On the other hand, Cd concentrations in rice grain from the Mae Tao sub-district reported by Pluemphuak et al. (2014) were relatively higher than other previous reports. The reason behind this is the accumulation of high Cd in soil by time as well as the influence of soil properties to Cd absorption in rice such as organic matter and soil texture etc. (Pluemphuak et al., 2014). However, low number of rice samples collected in this study may contribute to the high variation of Cd concentrations in rice grain. Recently, the study of the DPIM (2015) reported that the average Cd level in rice grain from 6 villages in Mae Tao sub-district was 2.78 times higher than the CODEX maximum standard. The summary of Cd concentration in rice from the Mae Tao sub-district reported by the DPIM (2015) is shown in Table 6.

Table 5 Cd concentrations in rice

No.	Investigator (Year of study)	Study area	Cd concentrations (mg kg^{-1})	Results	Reference
1	IWMI (2005)	Phratat Pha Daeng sub-district (1,067 samples)	0.01-7.75	The maximum Cd concentration in rice was 19.38 times higher than the CODEX maximum standard (0.4 mg kg^{-1}).	IWMI (2005)
2	Simmons et al. (2005)	Phratat Pha Daeng sub-district (524 samples)	0.05-7.7	- The maximum Cd concentration in rice was 19.25 times higher than the CODEX maximum standard (0.4 mg kg^{-1}). - Source of Cd concentration was from irrigation water from Mae Tao creek.	Simmons et al. (2005)
3	Sriprachote et al. (2012)	Pha Te village in Phratat Pha Daeng sub-district (23 samples)	0.04-1.75	- The maximum Cd concentration in rice was 4.4 times higher than the CODEX maximum standard (0.4 mg kg^{-1}). - Cd concentrations in rice were related to the distance from paddy fields to the creek. High Cd concentrations in rice were found in rice cultivated near the Mae Tao creek.	Sriprachote et al. (2012)
4	Pluemphuak et al. (2014)	Paddy fields in Mae Tao sub-district (12 samples)	7.15-9.27	- The maximum Cd concentration in rice was 3.09 times higher than the CODEX maximum standard (0.4 mg kg^{-1}) - Different paddy soil properties between the upper, mid, and downstream of Mae Tao creek are the main cause of the different Cd concentrations in rice grain.	Pluemphuak et al. (2014)

Table 6 Cd concentration in rice grain collected from the Mae Tao sub-district

Village No.	Village name	Total number of sample	Cd concentrations (mg kg^{-1})		
			Minimum	Maximum	Average
1	Mae Tao Tai	6	0.42	1.42	0.89
2	Mae Tao Klang	39	0.41	3.22	0.93
3	Mae Tao Phae	20	0.48	3.49	1.43
4	Mae Tao San Rongrian*	2	0.85	1.16	1.01
5	Mae Tao San Pae*	5	0.46	3.87	1.45
6	Don Chai*	2	0.68	2.08	1.38
	Total	74	0.41	3.87	1.11

Note: *High error of the results was obtained due to the small number of sample

2.3 Health effects from Cd exposure in the Mae Tao watershed

Since Cd contamination in various environmental media, particularly Cd in rice, were reported, health impacts from Cd exposure in the contaminated areas of the Mae Tao watershed have become a problem of interests. Several studies were conducted to investigate health impacts from rice ingestion in the Mae Tao watershed.

In 2005, IWMI reported the weekly intake (WI) of Cd from rice consumption in the Phratat Pha Deang sub-district and Mae Tao Mai village. This study reported that the WI of Cd from rice consumption in women and men exceeded the provisional tolerable weekly intake (PTWI) of Cd in foods established by the joint FAO/WHO Expert Committee on Food Additives (JECFA) at 7 µg kg^{-1} body weight (IWMI, 2005). The WI of women and men who were older than 50 years old and consumed rice cultivated in the contaminated area which received irrigation from the Mae Tao creek were in the range of 19.92 to 41.73 and 19.56 to 40.96 µg kg^{-1} body weight, respectively (IWMI, 2005). While the WI of women and men who consumed rice cultivated in the contaminated area which received irrigation from the Mae Ku creek were 14.0 and 18.0 µg kg^{-1} body weight, respectively (IWMI, 2005). After that, studies of health impacts from Cd exposure through rice ingestion using urine as a biomarker were conducted by Swaddiwudhipong et al. (2007), Honda et al. (2010), Swaddiwudhipong et al. (2010) and Swaddiwudhipong et al. (2015). The summary of health effects from Cd exposure in the Mae Tao watershed from previous studies is shown in Table 7.

Urine is one of biomarkers which can be used to evaluate Cd exposure in human (Akkajit, 2015). Generally, the urinary cadmium in person who are not excessively expose to cadmium is usually lower than 2 µg g^{-1} creatinine (Swaddiwudhipong et al., 2007). The American Conference of Governmental Industrial Hygienists (ACGIH) has established exposure limit for urinary Cd at 5 µg g^{-1} creatinine (Swaddiwudhipong et al., 2007). While, the WHO set up the exposure limit for urinary Cd at 5.24 µg g^{-1} creatinine (Akkajit, 2015). Swaddiwudhipong et al. (2007) surveyed the effects of Cd exposure in local residents in 2004. The study was mainly conducted in 12 villages which paddy fields received irrigated water from both Mae Tao and Mae Ku creeks. The results found that about 88% of local residents consumed rice which was cultivated in contaminated areas. Meanwhile, the proportion of local residents who did not consume rice cultivated in contaminated areas was about 12%. These results were in accordance with the study of Honda et al. (2010) who also found the percentages of local residents who consumed and did not consume rice cultivated in contaminated areas of about 93.83% and 6.17%, respectively. In the case of urinary Cd level, this study reported that around 7.8% of local residents who consumed rice cultivated in contaminated areas had urinary Cd level over the ACGIH exposure limit (5 µg g^{-1} creatinine) and 6% of local residents who consumed purchased rice had urinary Cd level over the ACGIH exposure limit (Honda et al., 2010).

In 2009, changes of Cd exposure in local residents in contaminated areas were followed up to compare results with the study conducted in 2004 (Swaddiwudhipong et al., 2010). This study reported the reduction in the proportion of local residents who consumed rice cultivated in contaminated areas from 88% to 50.5% comparing to the study conducted in 2004 (Swaddiwudhipong et al., 2010). However, the proportion of local residents who consumed rice cultivated in contaminated areas and had urinary Cd more than 2 µg g^{-1} creatinine was found to be increased from 55.5% to 61.3%. Meanwhile, the proportion of local residents who consumed rice purchased from other areas and had urinary Cd higher than 2 µg g^{-1} creatinine was decreased from 46.7% to 35.6% (Swaddiwudhipong et al., 2010).

In the case of gender, the study of Honda et al. (2010) found that women who consumed rice cultivated in contaminated areas had higher urinary Cd level than men. The finding from this study agreed well with the study of Swaddiwudhipong et al. (2007) which also found the proportion of men and women who had urinary Cd level higher than 5 µg g^{-1} creatinine of about 5.7 and 8.5%, respectively. Urinary Cd level in both genders who consumed rice cultivated in contaminated area were about 5.46 µg g^{-1} creatinine in men and 5.83 µg g^{-1} creatinine in women which were higher than the ACGIH exposure limit (5 µg g^{-1} creatinine) (Honda et al., 2010).

The study of health effects from Cd exposure between the population in Cd contaminated and non-contaminated areas was also conducted by Swaddiwudhipong et al. (2015). The results showed about 71.2% of surveyed population from contaminated areas consumed homegrown rice. Meanwhile, only 0.9% of surveyed people from non-contaminated areas consumed rice grown in contaminated areas. This study reported a significant difference in the mean urinary Cd levels in surveyed population from both areas. The mean urinary Cd level in surveyed population from contaminated areas was about 2.96 µg g^{-1} creatinine. While those surveyed people from non-contaminated areas had about 0.6 µg g^{-1} creatinine of Cd in urine. In addition, the significant difference in the proportion of surveyed population with urinary Cd more than 2 µg g^{-1} creatinine from both areas was also found. The proportion of surveyed population with urinary Cd level more than 2 µg g^{-1} creatinine from contaminated areas was about 66.7%, whereas the proportion of surveyed population from non-contaminated area with urinary Cd more than 2 µg g^{-1} creatinine was only about 5.1%. Based on the previous studies, it can be concluded that rice contaminated with Cd was the main source of Cd exposure to population living in Mae Tao watershed. In addition, local residents who consumed locally grown rice had urinary Cd level higher than those who did not consume locally grown rice (Swaddiwudhipong et al., 2007).

Table 7 Health effects from Cd exposure in the Mae Tao watershed

No.	Investigator (Year of study)	Study area	Urinary Cd ($\mu g\ g^{-1}$ creatinine)	Results	Reference
1	Swaddiwudhipong et al. (2007)	12 villages in Mae Tao watershed (7,697 subjects)	2.1 ± 2.9	- 7.2% of total subjects had urinary Cd levels over the ACGIH exposure limit (5 $\mu g\ g^{-1}$ creatinine). - The mean urinary Cd of people who consumed rice from contaminated areas was higher than people who did not consume rice in other areas.	Swaddiwudhipong et al. (2007)
2	Swaddiwudhipong et al. (2010)	12 villages in Mae Tao watershed (6,748 subjects)	2.4 ± 2.3	The mean urinary Cd in people who consumed local rice was about 1.14 times higher than the previous study in 2007.	Swaddiwudhipong et al. (2010)
3	Honda et al. (2010)	Mae Tao watershed (795 subjects)	5.46^{a} 5.83^{b}	The mean urinary Cd of women who consumed rice from contaminated areas was about 1.07 times higher than men.	Honda et al. (2010)

Note: [a] Urinary Cd level in men
[b] Urinary Cd level in women
[c] Contaminated area
[d] Uncontaminated area

Table 7 Health effects from Cd exposure in the Mae Tao watershed (Cont.)

No.	Investigator (Year of study)	Study area	Urinary Cd ($\mu g\ g^{-1}$ creatinine)	Results	Reference
4	Swaddiwudhipong et al. (2015)	3 villages in Mae Tao watershed and 3 non-contaminated areas in Mae Sot district (1,433 subjects)	2.96 ± 2.46^{c} 0.60 ± 2.19^{d}	The mean urinary Cd of people who lived in contaminated areas was about 4.93 times than people who lived in non-contaminated areas.	Swaddiwudhipong et al. (2015)

Note: [a] Urinary Cd level in men
[b] Urinary Cd level in women
[c] Contaminated area
[d] Uncontaminated area

2.4 Human health risk assessment

Human health risk assessment is a significant process to evaluate how the chemicals affect human health by considering various parameters, for example, chemical concentration, route of exposure, exposure duration, exposure frequency and some personal information such as age and body weight (U.S.EPA, 2014). In principle, human health risk assessment contains four steps as following.

2.4.1 Hazard identification

Hazard identification is the first step of health risk assessment. The objective of this step is to evaluate the type of hazard that occurred from chemical exposure and how chemicals affect human health (U.S.EPA, 2014). Hazard of particular chemical exposure can by identified by using chemical properties, route of exposure, duration of exposure, chemical form etc. (U.S.EPA, 2014).

2.4.2 Dose-response assessment

After hazard identification, a relationship between health effects and the amount of chemical exposure can be estimated using the process of dose-response assessment (U.S.EPA, 2014). Due to insufficient dose-response data in human, this step has to, sometime, extrapolate animal toxicity data to humans, especially in the case of carcinogenicity. In the case of non-carcinogenic effects, a reference dose (RfD) which is the amount of chemical in contact to human body per day without health impacts is an indicator of dose and response relationship.

2.4.3 Exposure assessment

The exposure assessment is a step that estimate the exposure rate of chemicals that human exposes from the environment (U.S.EPA, 1992). For oral exposure, concentration of chemical (C), ingestion rate (IR), exposure duration (ED), body weight (BW) and average time (AT) as shown in Eq.1 are necessary parameters for the estimation of chemical exposure rate (U.S.EPA, 1992).

$$\text{Exposure rate} = [C \times IR \times ED] / [BW \times AT] \qquad \text{(Eq. 1)}$$

Where;

C = Concentration of chemical (mg kg^{-1})

IR = Mass or volume of the chemical agent that person intake in a period of time (kg day^{-1})

ED = Period of time the person is in contact with the chemical (year × 365 days)

BW = Body weight over the averaging time (kg)

AT = Average exposure time (year × 365 days)

2.4.4 Risk characterization

Risk characterization is a final step to determine the probability of health impacts that can affect human health by the integration of three previous steps (U.S.EPA, 2000b). Non-carcinogenic health risks that individual may suffer can be characterized in term of hazard quotient (HQ). In general, HQ can be estimated based on the values of exposure rate and RfD as shown in Eq.2 (U.S.EPA, 1989).

$$HQ = \text{Exposure rate} / RfD \quad \text{(Eq. 2)}$$

Where;

HQ = Hazard quotient

RfD = A reference dose

The HQ value less than the value of 1 generally indicates safe exposure and the absence of potential non-carcinogenic health effects in human. Whereas, the HQ value over than 1, theoretically, indicates the potential chronic health impacts that individual may be affected as a results of particular chemical exposure (U.S.EPA, 2000b; U.S.EPA, 2003).

CHAPTER 3

METHODOLOGY

3.1 Study area and sample collection

The study areas in this present study are all 6 villages of the Mae Tao sub-district (Figure 3) namely; Mae Tao Tai, Mae Tao Klang, Mae Tao Phae, Mae Tao San Rongrian, Mae Tao San Pae, and Don Chai. As of August 2016, there were totally 2,533 registered households in the sub-district. The numbers of households in each village are summarized in Table 1. As clearly shown in Figure 3, Mae Tao Phae and Don Chai villages locate in the areas which were identified by the PCD as the moderate (3 to 30 mg kg^{-1}) to high Cd contamination (>30 mg kg^{-1}). The other 4 remaining villages locate in the moderate contaminated areas.

In order to collect the appropriate number of samples, the sample size determination (Eq. 3) as recommended by Israel (2013) was conducted.

$$n = Ne^2 / (1 + Ne^2) \qquad \text{Eq. 3}$$

Where; n = Sample size

N = Population size

e = Level of precision (confidence level)

According to Eq. 3, the total number of households of the Mae Tao sub-district were used as the population size. A 0.1 of the precision level was used to ensure that the obtained sample size could represent all households with the confident level of 90%. In addition, the assumption that 1 rice sample should be obtained from each representative household was applied. As a result, it was found that at least 97 rice samples should be collected. When considering the appropriate amount of samples which should be collected from each village, about 5% of total number of households in each village was selected. Finally, the numbers of rice samples that should be randomly collected from households in each village were summarized in Table 8

For the sample collection, types of rice sample collected were followed the local residents' consumption behavior. Therefore, white jasmine and sticky rice samples were finally collected. A total of 159 samples including both types of rice as shown in Table 9 were collected. As can be seen from Table 9, the higher amount of rice samples were collected from Mae Tao Klang (Village No.2) and Mae Tao Phae (Village No.3). This is due to the high concentrations of Cd in rice grain as reported by the DPIM in 2015 (Table 6). At each sampling household, a grab random sampling was applied. Approximately 200 g of rice sample were collected in a clean plastic bag, kept in a dry container, and delivered to a laboratory.

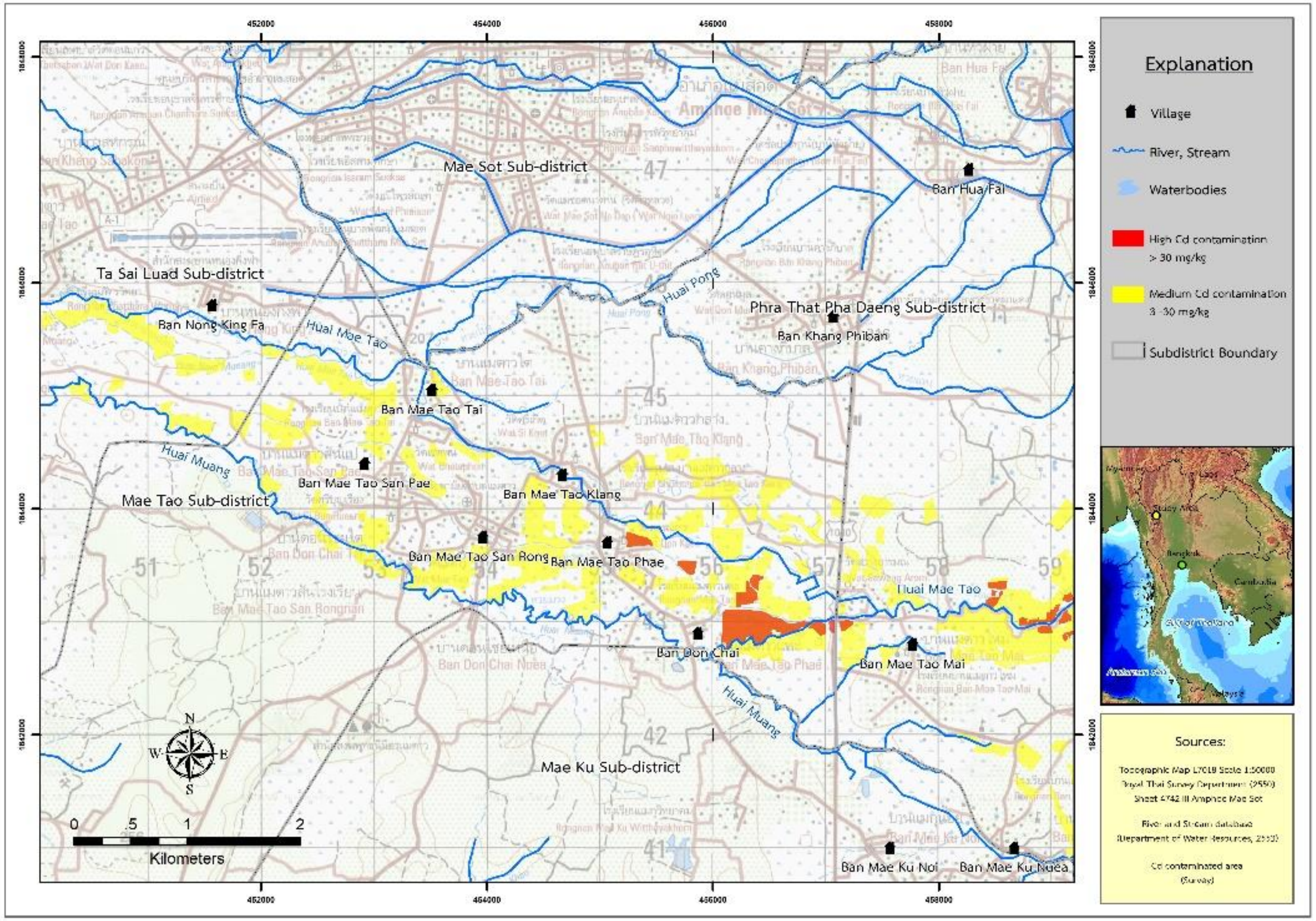

Figure 3 Location of all 6 villages in the Mae Tao sub-district

Table 8 Expected total number of rice samples which should be collected from each village

Village No.	Village name	Expected total number of rice samples
1	Mae Tao Tai	18
2	Mae Tao Klang	31
3	Mae Tao Phae	31
4	Mae Tao San Rongrian	15
5	Mae Tao San Pae	13
6	Don Chai	18
	Total	126

Table 9 Total number of rice samples collected from each village

Village No.	Village name	Type of rice		Total number of samples
		White jasmine rice	Sticky rice	
1	Mae Tao Tai	9	6	15
2	Mae Tao Klang	20	13	33
3	Mae Tao Phae	31	21	52
4	Mae Tao San Rongrian	14	10	24
5	Mae Tao San Pae	9	7	16
6	Don Chai	12	7	19
	Total	95	64	159

3.2 Questionnaire survey

At the same time of sample collection, biodata information and rice consumption behavior were surveyed from at least 1 inhabitant from each household where rice sample was collected. A paper of questionnaire (Appendix A) was used for each inhabitant. A total number of 91 inhabitants living in the Mae Tao sub-district were surveyed in this study. The biodata information including age, body weight, gender, rice consumption behavior (amount, type, frequency, and source of rice consumed), occupation, and smoking behavior were interviewed. All information obtained were used to estimate human health risks from rice consumption.

3.3 Sample preparation

After delivery to the laboratory, all rice samples were dried in a hot air oven at 60°C for 2 hours (Fang et al., 2014). Then, samples were ground by a blender and sieved through a 425 µm sieve, which was conducted in the same manner as a standard reference material (SRM) preparation. Next, sieved rice samples were dried in the oven at 85°C until a constant weight was obtained (FDA, 2012). Then, rice samples were digested according to Phan et al. (2013). In brief, about 0.1 g of rice sample was weighed into a clean 15 mL plastic tube. After that, 1 mL of concentrated nitric acid (Carlo Erba 67-69% superpure for trace analysis) was added into the tube. Afterward, sample was left at the room temperature for 48 hours. After digestion, 9 mL of deionized water was added to adjust volume of the extractant to 10 mL. Finally, the solution was filtrated by a 0.45 µm syringe filter to a new fresh tube and kept at 4°C until further analysis by the ICP-MS (Agilent 7500C).

3.4 Sample analysis

The digested rice samples were analyzed by the ICP-MS (Agilent 7500C). The detection limit of Cd was 1 µg L^{-1}. The SRM of rice flour (NIST SRM 1568a) was treated, digested and prepared for analysis as the same manner as samples for method validation. In addition, the SRM of trace elements in water (NIST SRM 1643e) was used to verify the accuracy and precision of the instrument analyses. The recovery of sample digestion was 73.92%. While, the recovery of sample analysis was 118%. The results of accuracy and precision in this study were within acceptable range of 50% to

120% which was recommended by the Association of Official Agricultural Chemists (AOAC) (AOAC, 2012). Therefore, all results in this present study were accurately acquired.

3.5 Health risk assessment

In this study, Cd exposure through the ingestion pathway was determined using Eq. 4 (U.S.EPA, 1992).

$$\text{Exposure rate} = [C \times IR \times ED] / [BW \times AT] \quad \text{(Eq. 4)}$$

Where;

C = Total concentration of Cd in rice (mg kg^{-1})

IR = Dry weight of rice that individual consumed per day (kg day^{-1})

ED = Period of time that individual consumed rice (years × 365 days)

BW = Body weight over the averaging time (kg)

AT = Average exposure time (years × 365 days)

According to Eq.4, the concentration of total Cd in rice (C) were determined from rice samples collected from households in 6 villages of the Mae Tao sub-district. Data on the rice consumption behavior from the household survey were used as both types of rice ingestion rate (IR), exposure duration (ED), body weight (BW), and average exposure time (AT). As this study focused on the potential development of non-carcinogenic effects at the time of study, the values of both ED and AT were then equal. In case of invalid body weight for some local residents, the body weight of population within the same age range of the Mae Tao sub-district which was reported by the Mae Sot District Health Office (Appendix B) was used (MOPH, 2016).

After that, the exposure rate of Cd through rice consumption obtained from Eq. 4 and oral reference dose (RfD) of Cd in food (1×10^{-3} mg kg^{-1} day^{-1}) which was recommended by U.S.EPA (2000a) were used to calculate the potential non-carcinogenic health impacts which could be developed and affected health status of local residents. The potential non-carcinogenic risk can be indicated by the value of hazard quotient (HQ) as shown in Eq.5.

$$HQ = \text{Exposure rate} / RfD \qquad \text{(Eq. 5)}$$

Where;

HQ = Hazard quotient

RfD = Oral reference dose of Cd in food

For the non-carcinogenic health risk interpretation, the HQ value less than 1 (HQ<1) indicates that the individual is safe from the chemical dietary exposure. In contrast, the HQ value over than 1 (HQ>1) indicates the potential development of non-carcinogenic health effects from the chemical dietary exposure in the individual.

3.6 Statistical analyses

All statistical analyses were performed using the Statistical Package for the Social Science for Windows (SPSS) version 22. Values of minimum, maximum, mean, median, and standard error of the mean (SE) were calculated to present Cd concentrations in rice collected from each village. A normality of total Cd concentrations in rice was tested by the Kolmogorov-Smirnov test ($n \geq 50$). Due to the non-normal distribution of the data, the significant differences in total Cd concentrations in rice regarding types of rice and sources of rice consumed as well as Cd exposure rate and health risks between genders were analyzed by the Mann-Whitney

U test. While, the significant differences in total Cd concentrations in rice from 6 villages were analyzed by the Kruskal-Wallis one-way ANOVA. In addition, the spearman correlations, correlation analysis for the non-normal distribution data, were performed to determine the relationships between Cd exposure rates and Cd concentrations in rice grain as well as rice ingestion rate, body weight, and exposure duration in different rice consumption patterns. A P-value of 0.05 was used to determine the significant level.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Total Cd concentrations in rice

The total Cd concentrations in rice samples collected from households in the Mae Tao sub-district are summarized in Table 10. Cd concentrations in rice grain ranged from non-detectable (ND) to 2.5974 mg kg^{-1}. The average Cd concentration in all rice samples was below the CODEX maximum standard for Cd in rice (0.4 mg kg^{-1}). However, about 19.50% of total rice samples had Cd concentration exceeded the CODEX maximum standard. There were 19.79% and 19.05% white jasmine and sticky rice samples, respectively, containing Cd higher than the CODEX standard.

According to the types of rice, the average Cd concentration in both white jasmine rice and sticky rice were within the CODEX maximum standard. The average total Cd concentration in sticky rice was about 1.09 times higher than the average total Cd concentration in white jasmine rice. However, there was no significant difference ($p>0.05$) in total Cd concentration between white jasmine rice and sticky rice collected from the Mae Tao sub-district (Table 10). The total Cd concentrations in this present study were compared to the previous research which was conducted in Thailand. The maximum total Cd concentration in this study (2.5974 mg kg^{-1}) (Table 10) were approximately 2.96 times and 2.98 times lower than the maximum total Cd concentration in rice samples from the Phratat Pha Daeng sub-district, another Cd contaminated area in the Mae Sot district, reported by the IWMI (2005) and Simmons et al. (2005), respectively. While, the maximum level of total Cd from the Phratat Pha Daeng sub-district (1.75 mg kg^{-1}) reported by Sriprachote et al. (2012) was approximately 1.48 times lower than the maximum concentration of total Cd in all rice samples found in this present study. According to the results of total Cd concentration in agricultural soils and rice grain from the Phratat Pha Daeng sub-district, the differences in total Cd concentration in rice between this study and previous studies can be influenced by the total Cd concentrations in agricultural soil. According to the study of Kosolsaksakul et al. (2014), a linear relationship between total Cd concentration in agricultural soils and rice grain (R^2=0.715) was found in the Mae Tao watershed (Kosolsaksakul et al., 2014). Recently, Pluemphuak et al. (2014) reported that total Cd concentrations in rice from paddy fields in the Mae Tao sub-district were in the range of 7.15 to 9.27 mg kg^{-1} which was much higher than range of total Cd in rice locally cultivated in the Cd contaminated area in this present study (ND to 2.5974 mg kg^{-1}) as shown in Table 11. In addition, the differences in total Cd concentrations in rice samples may also cause by the differences in the sample size of rice studied in each study. The sample size in the study of Pluemphuak et al. (2014) (n=12) was lower than rice sample size collected in this present study (n=159). Comparing to a previous study on market rice in Thailand, the total Cd concentration in white jasmine rice (0.017 mg kg^{-1}) and sticky rice (0.037 mg kg^{-1}) collected in Bangkok (Hensawang and Chanpiwat, 2017) were lower than the total Cd concentration in white jasmine rice (0.2740 mg kg^{-1}) and sticky rice (0.2999 mg kg^{-1}) found in this present study by about 16.11 times and 8.11 times, respectively. It is because many of the rice samples in this study were grown in the Cd contaminated areas.

Table 10 Total Cd concentrations in rice collected from the Mae Tao sub-district

Type of rice	Statistical values	Concentration (mg kg^{-1})	Sample containing Cd higher than CODEX standard (%)
White jasmine rice (n=96)	Minimum	ND	19.79
	Maximum	1.9411	
	Average	0.2740	
	Median	0.1923	
	SE	0.0358	
Sticky rice (n=63)	Minimum	ND	19.05
	Maximum	2.5974	
	Average	0.2999	
	Median	0.1430	
	SE	0.0637	
Total (n=159)	Minimum	ND	19.50
	Maximum	2.5974	
	Average	0.2843	
	Median	0.1759	
	SE	0.0331	

Note: ND means concentration is less than 0.1 mg kg^{-1}

In case of the source of rice consumed, the information on sources of rice consumed was interviewed from the local residents using the questionnaire (Appendix A) at the same time of rice sample collection. According to the surveyed information, there were 2 sources of rice that the local residents consumed including 1) rice locally grown in the Mae Tao sub-district and 2) rice purchased from the local markets in Mae Sot district, department stores, or stores outside the Mae Tao sub-district. It should be noted that most of local residents know that the paddy fields and agricultural areas in the Mae Tao sub-district are contaminated with Cd. Therefore, some of them do not consume locally grown rice. According to that fact, some of the local residents purchase rice from local markets, department stores, or stores outside the area. Most of them believe that the purchased rice is not contaminated by Cd. As a result, Cd exposure through rice consumption can be reduced. While some of the local residents still consume locally grown rice. For those local farmers who do not consume their homegrown rice, rice is then sold to the local markets. Afterward, local farmers/residents who earn the money from rice selling usually purchase rice from the store they think it would sell uncontaminated rice as described earlier.

The average total Cd concentration in either locally grown rice or purchased rice were within the CODEX maximum standard. However, about 23.08% and 14.71% of the total locally grown rice and purchased rice, respectively, had total Cd concentrations exceeded the CODEX maximum standard. There was a significant difference between total Cd concentration in locally grown rice and purchased rice samples ($p<0.05$). Table 11 shows that locally grown rice contained higher average total Cd concentration than rice purchased from the local markets outside the Mae Tao sub-district by about 1.48 times. The difference in total Cd concentration in locally grown rice and purchased rice can be influenced by the difference in total Cd concentration in agricultural soils in the Mae Tao sub-district in the case of locally grown rice and the purchased rice which is believed to be cultivated outside the Cd contaminated fields. According to Figure 3, all 6 villages of Mae Tao sub-district locate in the moderate to high Cd contamination areas. Therefore, those Cd in the soils could contribute to high Cd concentration in the locally grown rice. The study conducted by Moradi et al. (2015) confirmed that the total Cd concentration in agricultural soil is positively related to total Cd concentration in rice grain. In case of purchased rice, the average total Cd concentration in purchased rice found in this study (0.2214 mg kg^{-1}) was about 11.65 times higher than the average total Cd concentration in market rice collected in Bangkok (0.019 mg kg^{-1}) (Hensawang and Chanpiwat, 2017). It is because rice samples in this study were grown in the Cd contaminated areas where rice samples collected in the previous study were cultivated in the other areas which are not identified as Cd contaminated areas.

Table 11 Total Cd concentrations in locally grown rice and purchased rice

Sources of rice	Statistical values	Concentration (mg kg^{-1})	Sample containing Cd higher than CODEX standard (%)
Locally grown rice (n=91)	Minimum	ND	23.08
	Maximum	2.5974	
	Average	0.3286	
	Median	0.1964	
	SE	0.0456	
Purchased rice (n=68)	Minimum	ND	14.71
	Maximum	1.9411	
	Average	0.2214	
	Median	0.1132	
	SE	0.0433	

Note: - ND means concentration is less than 0.1 mg kg^{-1}
- Locally grown rice means rice cultivated in the Mae Tao sub-district area
- Purchased rice means rice purchased from the local markets, department stores, or stores outside the Mae Tao sub-district

In case of rice samples collected from different villages (Table 12), there were significant differences between total Cd concentration in rice samples collected from each village ($p<0.05$). As shown in Table 12, wide variations in total Cd concentrations in all rice samples from each village were found. The average total Cd concentrations in all rice samples collected from village No. 2 (Mae Tao Klang) and No. 4 (Mae Tao San Rongrian) exceeded the CODEX maximum standard by about 1.03 times and 1.27 times, respectively. While rice samples collected from other four remaining villages contained average Cd concentrations lower than the CODEX standard.

Regarding to types of rice samples by village, the average total Cd concentration in white jasmine rice samples only from village No. 2 exceeded the CODEX maximum standard by about 1.10 times. Furthermore, only the average total Cd concentration in sticky rice from village No.4 was higher than the CODEX maximum standard around 1.83 times. Regarding to each village location in relation to the zoning of moderate and high Cd contamination zones shown in Figure 3, some areas of village No.2 were reported as the high Cd contamination area with total Cd concentration in soils over 30 mg kg^{-1}. Therefore, rice cultivated in paddy fields in village No.2 could contain total Cd concentration higher than rice cultivated in paddy fields in other villages. In case of Cd concentration in rice grown in village No.4, the soils in this village were reported as the moderate Cd contamination area with total Cd concentration in soils ranging from 3 to 30 mg kg^{-1} (Figure 3). As a consequence, high Cd concentration in rice cultivated in this village can be observed. According the report by the DPIM (2015) and the location of all villages in the Mae Tao sub-district (Figure 3), village No.2 locates near Mae Tao creek, and village No. 4 locates near Muang creek. The agricultural fields in these 2 villages obtain irrigation water from these creeks in which they share the same upstream origin located close to the abandoned Zn mines. The sediment containing high Cd concentrations in both creeks can be transported along with the irrigation water. Finally, Cd contaminated sediment may contaminate the paddy soils and later on taken up to the rice. Therefore, the elevated total Cd concentration in both soils and rice grain can be observed. The results of total Cd concentration in rice (Table 6) reported by the DPIM (2015) clearly confirmed the earlier assumption as the high range of total Cd concentration in rice grain collected from village No.2 (0.41 to 3.22 mg kg^{-1}) and village No.4 (0.85 to 1.16 mg kg^{-1}) were found and were well in accordance with the results found in this study (Table 12). Table 12 clearly indicates that local residents living in village No.2 and No.4 may expose to higher amount of Cd than the residents in other villages especially in the case of white jasmine rice and sticky rice consumption, respectively.

Table 12 Total Cd concentrations in rice samples collected from all villages in the Mae Tao sub-district

Village No.	Village name	Total Cd concentration (mg kg^{-1})				
		Minimum	Maximum	Average	Median	SE
		White jasmine rice (n=96)				
1	Mae Tao Tai	ND	0.3822	0.1218	0.1221	0.0407
2	Mae Tao Klang	0.1193	1.9169	0.4387	0.3233	0.0927
3	Mae Tao Phae	ND	1.3807	0.2111	0.1115	0.0424
4	Mae Tao San Rongrian	ND	0.8418	0.3693	0.2679	0.0596
5	Mae Tao San Pae	ND	0.3563	0.1241	0.1225	0.0441
6	Don Chai	ND	1.9411	0.3258	0.1861	0.1514
		Sticky rice (n=63)				
1	Mae Tao Tai	ND	0.4964	0.2322	0.2540	0.0946
2	Mae Tao Klang	0.1078	1.6123	0.3789	0.2345	0.1209
3	Mae Tao Phae	ND	0.5642	0.1299	ND	0.0428
4	Mae Tao San Rongrian	ND	2.5974	0.7060	ND	0.3043
5	Mae Tao San Pae	ND	0.3139	0.1617	0.1928	0.0456
6	Don Chai	ND	1.4596	0.2696	0.1247	0.2002
		Total rice samples (n=159)				
1	Mae Tao Tai	ND	0.4964	0.1586	0.1322	0.0419
2	Mae Tao Klang	0.1078	1.9169	0.4151	0.2898	0.0726
3	Mae Tao Phae	ND	1.3807	0.1702	ND	0.0365
4	Mae Tao San Rongrian	ND	2.5974	0.5096	0.1793	0.1353
5	Mae Tao San Pae	ND	0.3563	0.1406	0.1796	0.0312
6	Don Chai	ND	1.9411	0.3051	0.1716	0.1175

Note: ND means concentration is less than 0.1 mg kg^{-1}

4.2 Local rice consumption behavior

The rice consumption behavior was observed from totally 91 local residents living in the Mae Tao sub-district. According to the survey, approximately 58.2% of local residents generally consume both white jasmine rice and sticky rice. Practically, white jasmine rice is consumed as breakfast while, sticky rice is consumed as lunch and dinner. While, approximately 34.1% and 7.7% of them consume only either white jasmine rice or sticky rice, respectively. Therefore, the study on rice consumption pattern in this study was divided into 3 patterns including 1) only white jasmine rice consumption, 2) only sticky rice consumption, and 3) both types of rice consumption. The rice ingestion rates of the local residents for each consumption pattern are summarized in Table 13.

According to Table 13, the ingestion rate of the local residents who consumed only white jasmine rice ranged from 0.0445 to 0.2668 kg day^{-1} (average: 0.1287 ± 0.0107 kg day^{-1}). There were 11 men and 20 women consumed rice in this pattern.

In case of only sticky rice consumption (Table 13), the ingestion rate ranged from 0.2215 to 0.5764 kg day^{-1} (average: 0.3450 ± 0.0538 kg day^{-1}). There were only 7 local residents (2 men and 5 women) consumed rice in this pattern.

Regarding to both types of rice consumption (Table 13), the local residents generally consume white jasmine rice for breakfast, and sticky rice for lunch and dinner. The ingestion rate of white jasmine rice ranged from 0.0222 to 0.1778 kg day^{-1} (average: 0.0476 ± 0.0037 kg day^{-1}). While, the ingestion rate of sticky rice ranged from 0.0738 to 0.7685 kg day^{-1} (average: 0.2133 ± 0.0180 kg day^{-1}). There were 53 local residents (18 men and 35 women) consumed rice in this pattern. Therefore, it can be concluded that most of local residents in the Mae Tao sub-district mainly consume both types of rice for their daily consumption.

Table 13 Rice ingestion rate of the local residents in the Mae Tao sub-district

Rice consumption pattern	Statistical values	Rice ingestion rate (kg day^{-1})	
		White jasmine rice	Sticky rice
Only white jasmine rice (n=31)	Minimum	0.0445	-
	Maximum	0.2668	-
	Average	0.1287	-
	Median	0.1334	-
	SE	0.0107	-
Only sticky rice (n=7)	Minimum	-	0.2215
	Maximum	-	0.5764
	Average	-	0.3450
	Median	-	0.2882
	SE	-	0.0538
Both types of rice (n=53)	Minimum	0.0222	0.0738
	Maximum	0.1778	0.7685
	Average	0.0476	0.2133
	Median	0.0445	0.1477
	SE	0.0037	0.0180

4.3 Exposure and health risk assessment of Cd through different rice consumption patterns

The exposure rate and health risk assessments of Cd through rice consumption in this study were evaluated based on total Cd concentrations in all 159 rice samples (Appendix C). When total Cd concentration was lower than the ICP-MS detection limit of 1 µg L^{-1}, the total Cd concentration in rice which was equal to 0.1 mg kg^{-1} was used to assess exposure rate and health risk. Both Cd exposure rate and health risk assessments in the population in this study were evaluated individually based on the individual's actual rice consumption behavior and the total Cd concentration in rice collected from the particular individual's household. Regarding to the different rice consumption patterns reported in the previous section, the results of Cd exposure and health risk assessments in this study can be then classified into 1) only white jasmine rice consumption, 2) only sticky rice consumption, and 3) both types of rice consumption.

4.3.1 Only white jasmine rice consumption

1) Exposure assessment

The exposure rate of Cd exposure through only white jasmine rice consumption in the surveyed local residents in the Mae Tao sub-district are shown in Table 14. The exposure rate of Cd in local residents who consumed only white jasmine rice ranged from 7.80×10^{-5} to 2.27×10^{-3} mg kg^{-1} day^{-1}. The average Cd exposure rate of 6.30×10^{-4} mg kg^{-1} day^{-1} was within the RfD of Cd dietary exposure (1×10^{-3} mg kg^{-1} day^{-1}) recommended by U.S.EPA (2000a). Comparing to the previous study (Simmons et al., 2005) which was conducted in the Cd contaminated area in the Phratat Pha Daeng sub-district, another Cd contaminated areas in Mae Sot district, the range of Cd exposure rate through only white jasmine rice consumption in this study (7.80×10^{-5} to 2.27×10^{-3} mg kg^{-1} day^{-1}) (Table 14) was approximately 5.15 times lower than the range of Cd exposure in the local residents of the Phratat Pha Daeng sub-district (2.86×10^{-3} to 1.17×10^{-2} mg kg^{-1} day^{-1}). It is because the range of total Cd concentration in rice grain (<0.05 to 7.7 mg kg^{-1}) from the Phratat Pha Daeng sub-district was higher than range of total Cd concentration in white jasmine rice found in this present study (ND to 1.9411 mg kg^{-1}) (Table 10). Therefore, the higher level of Cd exposure in the local residents in the Phratat Pha Daeng sub-district was found.

The exposure rate of Cd through only white jasmine rice consumption in this study was also compared with the other previous studies conducted in the contaminated area in the other countries. For examples, the average Cd exposure through rice consumption of the residents near the metal abandoned mines of Korea (1.95×10^{-4} mg kg^{-1} day^{-1}) (Ji et al., 2013) was approximately 3.23 times lower than the average Cd exposure rate through only white jasmine rice consumption found in this present study (6.30×10^{-4} mg kg^{-1} day^{-1}) (Table 14). It is because the average total Cd concentration in Korean rice (0.051 mg kg^{-1}) was lower than the average Cd concentration in white jasmine rice in this study (0.2740 mg kg^{-1}) (Table 11). While, the Cd exposure through rice consumption of the population in the industrial regions of Iran ranging from 4.7×10^{-4} to 5.3×10^{-4} mg kg^{-1} day^{-1} (Moradi et al., 2015) was approximately 4.28 times higher than the range of Cd exposure through only white jasmine rice consumption in this present study (7.80×10^{-5} to 2.27×10^{-3} mg kg^{-1} day^{-1}). Recently, another study in Iran reported the average Cd exposure through rice consumption of 1.42×10^{-3} mg kg^{-1} day^{-1} (Ghoreishy et al., 2018) which was 2.25 times higher than the average Cd exposure through only white jasmine rice consumption in this present study (6.30×10^{-4} mg kg^{-1} day^{-1}).

In the case of Thai exported rice, several studies were conducted to assess Cd exposure through rice consumption. For example, the average Cd exposure rate through Thai rice consumption in Kuwait population (1.40×10^{-4} mg kg^{-1} day^{-1}) (Jallad, 2015) was about 4.50 times lower than the average Cd exposure rate through only white jasmine rice consumption reported in this present study (6.30×10^{-4} mg kg^{-1} day^{-1}) (Table 14). In contrast, the average Cd exposure rate in Iran (6.36×10^{-4} mg kg^{-1} day^{-1}) (Naseri et al., 2015) was higher than the average Cd exposure through only white jasmine rice consumption found in this present study. The differences in Cd exposure between this study and other previous studies may be influenced by various factors such as total Cd concentration in rice grain, level of Cd contamination in paddy soils, and the consumption behavior in each study area (Yuan et al., 2014; Dai et al., 2016).

In case of Cd exposure rate in male and female (Table 14), Cd exposure through only white jasmine rice consumption in men ranged from 1.24×10^{-4} to 1.96×10^{-3} mg kg^{-1} day^{-1}. While, the Cd exposure in women ranged from 7.80×10^{-5} to 2.27×10^{-3} mg kg^{-1} day^{-1}. The average Cd exposure of men (7.76×10^{-4} mg kg^{-1} day^{-1}) and women (5.50×10^{-4} mg kg^{-1} day^{-1}) who consumed only white jasmine rice were well within the RfD of Cd dietary exposure (1×10^{-3} mg kg^{-1} day^{-1}) recommended by U.S.EPA (2000a). When comparing Cd exposure rate between men and women, although there was no significant difference in Cd exposure between genders ($p>0.05$), the average Cd exposure of men (7.76×10^{-4} mg kg^{-1} day^{-1}) was about 1.41 times higher than the average Cd exposure of women (5.50×10^{-4} mg kg^{-1} day^{-1}). This is due to the fact that men generally require more energy from food than women. In this present study, it was found that the average ingestion rate of white jasmine rice in men (0.1485 kg day^{-1}) were higher than in women (0.1178 kg day^{-1}) as shown in Appendix D. Moreover, as shown in Appendix D, the average Cd concentration in rice that men exposed (0.2756 mg kg^{-1}) was about 1.34 times higher than the average Cd concentration in rice that women exposed (0.2052 mg kg^{-1}). Therefore, men were found to be exposed to higher Cd than women.

When comparing the results in this study to the previous study conducted in the rice collected from local markets in Bangkok, the average Cd exposure rate in men who consumed white jasmine rice in Bangkok (3.83×10^{-5} mg kg^{-1} day^{-1}) (Hensawang and

Chanpiwat, 2017) was approximately 20.26 times lower than the average Cd exposure through only white jasmine rice consumption in men found in this present study (7.76×10^{-4} mg kg^{-1} day^{-1}). Similarly, the average Cd exposure in women who consumed white jasmine rice consumption in Bangkok (3.24×10^{-5} mg kg^{-1} day^{-1}) (Hensawang and Chanpiwat, 2017) was about 16.98 times lower than the average Cd exposure through only white jasmine rice consumption in women in this present study (5.50×10^{-4} mg kg^{-1} day^{-1}). The reason behind this is the lower average total Cd concentration in white jasmine rice collected from markets in Bangkok (0.017 mg kg^{-1}) (Hensawang and Chanpiwat, 2017) than the average total Cd concentration in white jasmine rice that men (0.2756 mg kg^{-1}) and women (0.2052 mg kg^{-1}) in this present study exposed by about 16.21 times and 12.83 times, respectively.

Table 14 Exposure rates and non-carcinogenic health risks of Cd through only white jasmine rice consumption of the local residents in the Mae Tao sub-district

Gender	**Statistical value**	**Exposure rate (mg kg^{-1} day^{-1})**	**HQ**
Male (n=11)	Minimum	1.24×10^{-4}	0.1235
	Maximum	1.96×10^{-3}	1.9571
	Average	7.76×10^{-4}	0.7757
	Median	4.21×10^{-4}	0.4214
	SE	2.12×10^{-4}	0.2118
Female (n=20)	Minimum	7.80×10^{-5}	0.0780
	Maximum	2.27×10^{-3}	2.2710
	Average	5.50×10^{-4}	0.5502
	Median	2.81×10^{-4}	0.2812
	SE	1.39×10^{-4}	0.1387
Total (n=31)	Minimum	7.80×10^{-5}	0.0780
	Maximum	2.27×10^{-3}	2.2710
	Average	6.30×10^{-4}	0.6303
	Median	3.09×10^{-4}	0.3085
	SE	1.16×10^{-4}	0.1164

2) Health risk assessment

According to the non-carcinogenic health risks (Table 14), the HQ values of surveyed local residents who consumed only white jasmine rice ranged from 0.0780 to 2.2710. The average HQ value (0.6303) in all surveyed local residents (n=31) in this rice consumption pattern was within the threshold value of 1 (HQ<1). However, about 19.35% of the local residents who consumed only white jasmine rice (Appendix E) were found with HQ values higher than the threshold value of 1 (HQ>1). It can be implied that white jasmine rice consumption in local residents is not safe for all surveyed inhabitants.

Comparing to the previous studies conducted in the other contaminated area, the range of HQ values of Cd exposure through rice consumption in the population from Dabaoshan mine in China (2.61 to 6.25) (Zhuang et al., 2009) was about 2.75 times higher than the range of HQ values of Cd exposure through only white jasmine rice consumption in this present study (0.0780 to 2.2710). It is because the range of total Cd concentrations in the Chinese rice (0.38 to 7.0 mg kg^{-1}) was approximately 2.69 times higher than the range of total Cd concentrations in white jasmine rice in this present study (ND to 2.5974 mg kg^{-1}). The differences in total Cd concentration are the main cause of different Cd exposure rates and HQ values between this study and the one in China. Comparing to the average HQ value of Cd exposure through rice consumption in Korea (0.1730) (Ji et al., 2013) which was 3.64 times lower than the result of HQ in local residents who consumed only white jasmine rice in this present study (0.6303), the different Cd exposure in Korea (1.95×10^{-4} mg kg^{-1} day^{-1}) was then lower than this present study (6.30×10^{-4} mg kg^{-1} day^{-1}). According to these results, the different HQ values as found from the different Cd contaminated areas can be caused by the differences in Cd exposure rates in the individuals which may be affected by the total Cd concentration in rice, ingestion rate, and the body weight of the population in each study area.

In case of the non-carcinogenic health risks between male and female (Table 14), the average HQ values in men (0.7757) and women (0.5502) were within the threshold value of 1 ($HQ<1$). Though, there were no significant differences in Cd exposure and HQ values between genders ($p>0.05$), the average HQ value in men was higher than the average HQ value in women. As it was mentioned earlier, higher average ingestion rate of white jasmine rice for men (0.1485 kg day^{-1}) and higher average total Cd concentration in white jasmine rice that men exposed (0.2756 mg kg^{-1}) can be considered as the variables contribute to higher Cd exposure rate and HQ value in men than women. As the results, men had higher chance to obtain non-carcinogenic health risks from Cd exposure through rice consumption than women. The results of non-carcinogenic health risks for only white jasmine rice consumption between men and women in this present study was in accordance with the study of Hensawang and Chanpiwat (2017) who also found the higher HQ value through white jasmine rice consumption in men than in women.

4.3.2 Only sticky rice consumption

1) Exposure assessment

The exposure rates of Cd exposure through only sticky rice consumption of surveyed local residents (n=7) in the Mae Tao sub-district is shown in Table 15. Since the population in this group is small, the difference in the exposure rates between genders was not analyzed. The exposure rates ranged from 3.89×10^{-4} to 8.72×10^{-3} mg kg^{-1} day^{-1}. The average Cd exposure rate through only sticky rice consumption pattern of surveyed local residents (2.26×10^{-3} mg kg^{-1} day^{-1}) which was exceeded the RfD of Cd dietary exposure (1×10^{-3} mg kg^{-1} day^{-1}) recommended by U.S.EPA (2000a) indicated that consumption of sticky rice is also not safe in this area.

2) Health risk assessment

Regarding to the non-carcinogenic health risks (Table 15), the HQ values of the local residents who consumed only sticky rice ranged from 0.3886 to 8.7244. Interestingly, the average HQ value (2.2633) exceeded the threshold value of 1 (HQ>1). This indicates that the local residents who consumed only sticky rice consumption could obtain non-carcinogenic adverse health effects from Cd exposure through rice consumption. According to Appendix E (Table 7), 4 local residents were found with the HQ values over the threshold limit (HQ>1). This equals to about 57.14% of the total local residents who consumed rice in this rice consumption pattern (n=7). Considering the HQ value of the local residents who had HQ exceeded the threshold limit of 1, the total Cd concentration in rice that those local residents exposed ranging from 0.2771 to 0.9846 mg kg^{-1} were higher than the total Cd concentration in rice (non-detectable concentration) that other local residents with HQ lower than 1 were exposed. In addition, those rice samples with high Cd concentration are the locally grown rice. Thus, it can be implied that locally grown rice can contribute to higher potential health risk of Cd in the local residents who consumed only sticky rice.

Since the sample size of the local residents who consumed only sticky rice is small (n=7), the non-carcinogenic health risks of Cd exposure between genders through only sticky rice consumption was not conducted.

Table 15 Exposure rates and non-carcinogenic health risks of Cd through only sticky rice consumption of the local residents in the Mae Tao sub-district

Local residents	Statistical value	Exposure rate (mg kg^{-1} day^{-1})	HQ
Total (n=7)	Minimum	3.89×10^{-4}	0.3886
	Maximum	8.72×10^{-3}	8.7244
	Average	2.26×10^{-3}	2.2633
	Median	1.60×10^{-3}	1.5970
	SE	1.11×10^{-3}	1.1067

4.3.3 Both types of rice consumption scenario

1) Exposure assessment

The exposure rates of Cd through both types of rice consumption of surveyed local residents in the Mae Tao sub-district is shown in Table 16. The Cd exposure rates ranged from 1.44×10^{-4} to 9.57×10^{-3} mg kg^{-1} day^{-1}. The average Cd exposure through both types of rice consumption of surveyed local residents (1.39×10^{-3} mg kg^{-1} day^{-1}) which exceeded the RfD of Cd dietary exposure (1×10^{-3} mg kg^{-1} day^{-1}) recommended by U.S.EPA (2000a) also indicates the unsafe consumption of this rice consumption pattern.

In case of Cd exposures in the different genders (Table 16), the Cd exposures of men who consumed both types of rice ranged from 3.12×10^{-4} to 9.57×10^{-3} mg kg^{-1} day^{-1}. While, the Cd exposure rates of women ranged from 1.44×10^{-4} to 6.47×10^{-3} mg kg^{-1} day^{-1}. There was a significant difference between Cd exposure in male and female ($p<0.05$). The average Cd exposure rate of men (1.98×10^{-3} mg kg^{-1} day^{-1}) was approximately 1.83 times higher than the average Cd exposure of women (1.08×10^{-3} mg kg^{-1} day^{-1}). The reason behind this is because the average ingestion rate of white jasmine rice (0.0618 kg day^{-1}) and sticky rice in men (0.3015 kg day^{-1}) were about 1.56

times and 1.81 times, respectively, higher than the average ingestion rates of white jasmine rice (0.0397 kg day^{-1}) and sticky rice in women (0.1667 kg day^{-1}) as shown in the Appendix D (Table 5). In addition, the average total Cd concentrations in white jasmine rice (0.3408 mg kg^{-1}) and sticky rice that men exposed (0.4747 mg kg^{-1}) were about 1.43 times and 1.83 times, respectively, higher than the average total Cd concentrations in white jasmine rice (0.2390 mg kg^{-1}) and sticky rice for women (0.2597 mg kg^{-1}). Thus, men who consumed both types of rice were found with higher Cd exposure rates than women who consumed both types of rice.

2) Health risk assessment

According to the non-carcinogenic health risks (Table 16), the HQ values of both types of rice consumption ranged from 0.1435 to 9.5677. The average HQ value for both types of rice consumption scenario (1.3870) which exceeded the threshold value of 1 (HQ>1) indicates that the local residents who consumed both types of rice could suffer from the development of adverse health effects from Cd exposure through rice consumption. According to the Table 8 in Appendix E, approximately 35.85% of surveyed local residents who consumed both types of rice had HQ values exceeded the threshold value of 1 (HQ>1). Considering the HQ value of surveyed local residents who had HQ exceeded the threshold limit of 1, the average total Cd concentrations in white jasmine rice (0.4215 mg kg^{-1}) and sticky rice (0.6508 mg kg^{-1}) that those local residents exposed were higher than the average total Cd concentrations in white jasmine rice (0.1709 mg kg^{-1}) and sticky rice (0.1271 mg kg^{-1}) that other local residents who had HQ value below the threshold limit of 1 in this rice consumption pattern exposed. Higher total Cd concentrations in both types of rice that those local residents exposed were mainly found in the locally grown rice. Interestingly, the maximum HQ value found in this present study (9.5677) was related to the maximum total Cd concentration (2.5974 mg kg^{-1}) which was found in the locally grown rice. This indicates that locally grown rice contributes to higher health risk from Cd exposure through rice consumption in the local residents who consumed both types of rice.

Considering between two types of rice, the average ingestion rate of sticky rice consumption (0.2133 kg day^{-1}) (Table 13) was about 4.48 times significantly higher than the average ingestion rate of white jasmine rice (0.0476 kg day^{-1}) ($p<0.05$). In addition, the average total Cd concentration in sticky rice that local residents exposed (0.3148 mg kg^{-1}) was approximately 1.21 times higher than the average of total Cd concentration in white jasmine rice (0.2607 mg kg^{-1}). Therefore, it can be implied that the consumption of sticky rice can influence to adverse health impacts from Cd exposure more than white jasmine rice consumption.

In case of non-carcinogenic health risks between male and female (Table 16), the HQ values of men who consumed both types of rice ranged from 0.3116 to 9.5677. While, the HQ values of women ranged from 0.1435 to 6.4667. The average HQ values of men (1.9759) and women (1.0841) exceeded the threshold value of 1 indicated that the surveyed local residents in both genders could be affected by non-carcinogenic health effects of Cd from both white jasmine rice and sticky rice consumption. When comparing between male and female, there was a significant difference in HQ values between these two genders ($p<0.05$). The average HQ value in men for both types of rice consumption (1.9759) as shown in Table 16 was 1.82 times significantly higher than the average HQ value in women (1.0841) ($p<0.05$). Therefore, men who consumed both types of rice are expected to be affected by the Cd non-carcinogenic health impacts more than women. As it was mentioned earlier, the ingestion rate and total Cd concentration in both types of rice can contribute to the higher Cd exposure rates and HQ values in men than women. To be more specific, the sticky rice consumption is the main factor contributing to the potential non-carcinogenic health impacts in this both types of rice consumption pattern.

Table 16 Exposure rates and non-carcinogenic health risks of Cd through both types of rice consumption of the local residents in the Mae Tao sub-district

Gender	Statistical value	Exposure rate (mg kg^{-1} day^{-1})	HQ
Male (n=18)	Minimum	3.12×10^{-4}	0.3116
	Maximum	9.57×10^{-3}	9.5677
	Average	1.98×10^{-3}	1.9759
	Median	1.19×10^{-3}	1.1936
	SE	5.66×10^{-4}	0.5656
Female (n=35)	Minimum	1.44×10^{-4}	0.1435
	Maximum	6.47×10^{-3}	6.4667
	Average	1.08×10^{-3}	1.0841
	Median	5.12×10^{-4}	0.5121
	SE	2.49×10^{-4}	0.2488
Total (n=53)	Minimum	1.44×10^{-4}	0.1435
	Maximum	9.57×10^{-3}	9.5677
	Average	1.39×10^{-3}	1.3870
	Median	6.90×10^{-4}	0.6897
	SE	2.56×10^{-4}	0.2563

4.4 Comparison of Cd exposure and non-carcinogenic health risks between different rice consumption patterns

According to the results of Cd exposure rates and non-carcinogenic health risks as a result of the different rice consumption patterns reported in the previous section (Part 4.3), it can be summarized that the average values of both Cd exposure and non-carcinogenic health risk through only sticky rice consumption pattern (Cd exposure rate, HQ value) was the highest (2.26×10^{-3} mg kg^{-1} day^{-1}, 2.2633), followed by both types of rice consumption (1.39×10^{-3} mg kg^{-1} day^{-1}, 1.3870) and only white jasmine rice consumption (6.30×10^{-4} mg kg^{-1} day^{-1}, 0.6303). This indicates that the local residents who consumed only sticky rice could expose to the highest potential adverse non-carcinogenic health effects from Cd through rice consumption comparing to the other 2 remaining rice consumption patterns (only white jasmine rice and both types of rice consumption).

4.4.1 Only sticky rice consumption and both types of rice consumption

Comparing the results between only sticky rice consumption pattern and both types of rice consumption pattern, the average values of both Cd exposure and non-carcinogenic health risk (Cd exposure rate, HQ value) of only sticky rice consumption (2.26×10^{-3} mg kg^{-1} day^{-1}, 2.2633) (Table 15) were about 1.63 times higher than those values for the only sticky rice consumption (1.39×10^{-3} mg kg^{-1} day^{-1}, 1.3870) (Table 16). When considering the sticky rice consumption in both rice consumption patterns, the average sticky rice ingestion rate for only sticky rice consumption (0.3450 kg day^{-1}) were about 1.09 times higher than the average sticky rice ingestion rate for both types of rice consumption (0.2133 kg day^{-1}). However, it should be noted that the average total Cd concentration in sticky rice (0.3148 mg kg^{-1}) from the both types of rice consumption was higher than the average total Cd concentration in sticky rice (0.2733 mg kg^{-1}) from the only sticky rice pattern. Therefore, the higher values of Cd exposure rate and non-carcinogenic health risk in the local residents who consumed only sticky rice were obtained. As the results, it is possible to summarize that rice ingestion rate is the major factor affecting the differences in Cd exposure and non-carcinogenic health risk in these 2 rice consumption patterns.

4.4.2 Only sticky rice consumption and only white jasmine rice consumption

When comparing Cd exposure and non-carcinogenic health risks between only sticky rice consumption pattern and only white jasmine rice consumption pattern, the average Cd exposure and non-carcinogenic health risk (Cd exposure rate, HQ value) for only sticky rice consumption (2.26×10^{-3} mg kg^{-1} day^{-1}, 2.2633) (Table 15) was significantly higher than the average Cd exposure and HQ value for only white jasmine rice consumption (6.30×10^{-4} mg kg^{-1} day^{-1}, 0.6303) (Table 14) by about 3.58 times ($p<0.05$). This may be caused by the higher average rice ingestion rate (0.3450 kg day^{-1}) (Table 13) and higher average Cd concentration in sticky rice (0.2733 mg kg^{-1}) that the local residents of the only sticky rice consumption pattern consumed. The average rice ingestion rate for the only sticky rice consumption (0.3450 kg day^{-1}) was 2.68 times significantly higher than the average rice ingestion rate for the only white jasmine rice consumption (0.1287 kg day^{-1}) ($p<0.05$). In addition, the average total Cd concentration in sticky rice (0.2733 mg kg^{-1}) from the only sticky rice consumption pattern was about 1.19 times higher than the average total Cd concentration in white jasmine rice (0.2306 mg kg^{-1}) from the only white jasmine rice consumption pattern. As a consequence, higher values of Cd exposure and non-carcinogenic health risk in the local residents who consumed only sticky rice were obtained. This indicates that rice ingestion rate and total Cd concentration in rice that the local residents consumed can influence the differences in Cd exposure and non-carcinogenic health risk in these 2 rice consumption patterns.

4.4.3 Both types of rice consumption and only white jasmine rice consumption

Comparing the Cd exposure and non-carcinogenic health risks between both types of rice consumption pattern and only white jasmine rice consumption pattern, the average Cd exposure and non-carcinogenic health risk (Cd exposure rate, HQ value) for both types of rice consumption (1.39×10^{-3} mg kg^{-1} day^{-1}, 2.2633) (Table 16) was about 2.21 times higher than the average Cd exposure and HQ value for only white jasmine rice consumption (6.30×10^{-4} mg kg^{-1} day^{-1}, 0.6303) (Table 14). Though, the average white jasmine rice ingestion rate for both types of rice consumption (0.0476 kg day^{-1}) was about 2.70 times lower than the average white jasmine rice ingestion rate for only white jasmine rice consumption (0.1287 kg day^{-1}), the average total Cd concentration in white jasmine rice (0.2607 mg kg^{-1}) from both types of rice consumption pattern was about 1.13 times higher than the average total Cd concentration in white jasmine rice (0.2302 mg kg^{-1}) from the only white jasmine rice consumption pattern. Therefore, higher Cd exposure and non-carcinogenic health risk in the local residents who consumed both types of rice than the only white jasmine rice consumption pattern were obtained. This indicates that total Cd concentration in rice is the main contributor to the differences in Cd exposure and non-carcinogenic health risk in these 2 rice consumption patterns.

4.5 Factors affecting the level of non-carcinogenic health risks regarding to rice consumption pattern

4.5.1 Only white jasmine rice consumption

The correlations between factors which could affect the non-carcinogenic health risk (HQ value) as a result of only white jasmine rice consumption are presented in Table 17. The results showed a very strong positive significant correlation between HQ value and total Cd concentration in white jasmine rice ($p<0.05$, $R=0.843$). A moderate positive significant correlation was found between HQ value and ingestion rate ($p<0.05$, $R=0.483$). In contrast, a strong negative significant correlation was found between body weight and age ($p<0.05$, $R=-0.657$). According to the results obtained, total Cd concentration was the major factor affecting the level of HQ value in this only white jasmine rice consumption pattern. This simply means that the non-carcinogenic health risk is increased when the population exposed to the higher Cd concentration in white jasmine rice grain. This results were in consistent with the results of Cd exposure and non-carcinogenic health risk through the only white jasmine rice consumption as shown in Table 14.

In case of the relationship between HQ value and ingestion rate ($p<0.05$, $R=0.483$), although the correlation coefficient between HQ value and ingestion rate was lower than the correlation coefficient between HQ value and total Cd concentration in white jasmine rice ($p<0.05$, $R=0.843$), the level of relationship still indicates the higher possibility of non-carcinogenic health impact development as a result of higher rice ingestion rate.

In case of the relationship between age and body weight ($p<0.05$, $R=-0.657$), according to the exposure rate equation (Eq.1) presented in the literature review, it can be implied that the older local residents usually had higher exposure rate compared with the younger local residents with the same body weight. While, the local residents with higher body weight usually had lower exposure rate compared with the local residents who had lower body weight in the same age. Therefore, the negative correlation between age and body weight can influence the differences in Cd exposure and non-carcinogenic health risk in only white jasmine rice consumption pattern.

Table 17 Correlations between factors that could affect the potential non-carcinogenic health risk in the only white jasmine rice consumption pattern

	Total Cd concentration	**Ingestion rate**	**Age**	**Body weight**	**HQ**
Total Cd concentration	1.000				
Ingestion rate	0.084	1.000			
Age	0.182	-0.097	1.000		
Body weight	0.090	0.251	-0.657*	1.000	
HQ	0.841*	0.483*	0.192	0.045	1.000

Note: * Correlation is significant at the 0.05 level (2-tailed)

4.5.2 Both types of rice consumption

The correlations between factors which could affect the non-carcinogenic health risk (HQ value) as a result of both types of rice consumption are summarized in Table 18. There was a moderate positive significant correlation between HQ and total Cd concentration in white jasmine rice (p<0.05, R=0.576). While, a strong positive significant correlation was found between HQ and total Cd concentration in sticky rice (p<0.05, R=0.629). In addition, a moderate positive significant correlation was found between HQ value and sticky rice ingestion rate (p<0.05, R=0.528). In case of body weight, there were weak positive significant correlations between white jasmine rice ingestion rate (p<0.05, R=0.358) and sticky rice ingestion rate (p<0.05, R=0.308). In contrast, the result showed a strong negetive correlation between body weight and age (p<0.05, R=-0.740). Meanwhile, a weak positive significant correlation was found between both types of rice ingestion rate (p<0.05, R=0.384). According to the levels of all significant relationships obtained, the total Cd concentration in sticky rice was the most important variable affecting the level of HQ value in both types of rice consumption pattern. It means that the non-carcinogenic health risk is increased when the population consumed sticky rice consumption.

Interestingly, the relationship between the HQ value and the total Cd concentration in sticky rice showed stronger correlation coefficient (R=0.629) than the relationship between the HQ value and the total Cd concentration in white jasmine rice (R=0.576). It can be implied that, in this both types of rice consumption, the consumption of sticky rice could influence the level of HQ value more than the consumption of white jasmine rice. Moreover, the HQ value for both types of rice consumption pattern showed a moderate positive relationship with sticky rice ingestion rate (R=0.528). It is because the ingestion rate of sticky rice in the local residents was higher than the the ingestion rate of white jasmine rice as shown in Table 13. Therefore, sticky rice ingeation rate can also influence the level of HQ value for this rice consumption pattern.

In case of the relationships between body weight and both types of rice ingestion rate, the results showed positive correlation because the local residents who had higher body weight usually require more energy for their activities from rice consumption than those residents who had lower body weight. This can contributes to the higher rice ingestion rate in the local residents who had higher body weight. Therefore, it can be implied that the local residents who had higher body weight may expose to higher health risks than those who had lower body weight. Considering between both types of rice ingestion rate, the relationship between body weight and white jasmine rice ingestion rate showed higher correlation coefficient (R=0.358) than the relationship between body weight and sticky rice ingestion rate (R=0.308). This indicates that white jasmine rice consumption in this rice consumption pattern can contribute to higher health risk in the local residents who had higher body weight. However, it should be noted that the influence of body weight on the non-carcinogenic health risks was lower than the influence of total Cd concentration in sticky rice and sticky rice ingestion rate in this type of rice consumption pattern. In case of the relationship between body weight and age, the result was in accordance with the \relationship between body weight and age for only white jasmine rice consumption pattern.

According to the relationship between the white jasmine rice ingestion rate and the sticky rice ingestion rate ($p<0.05$, R=0.384). The result indicates that when one type of rice consumption is increased, the consumption rate of another type of rice is also increased, which may in return affect the Cd exposure and HQ in this rice consumption pattern.

Table 18 Correlations between factors that could affect the potential non-carcinogenic health risk in the both types of rice consumption pattern

	Total Cd concentration[a]	**Total Cd concentration[b]**	**Ingestion rate[a]**	**Ingestion rate[b]**	**Age**	**Body weight**	**HQ**
Total Cd concentration[a]	1.000						
Total Cd concentration[b]	0.406*	1.000					
Ingestion rate[a]	0.089	0.027	1.000				
Ingestion rate[b]	0.217	0.096	0.384*	1.000			
Age	-0.013	-0.131	-0.199	-0.048	1.000		
Body weight	-0.048	0.133	0.352*	0.308*	-0.740*	1.000	
HQ	0.576*	0.629*	0.274	0.528*	-0.084	-0.026	1.000

Note: [a] White jasmine rice
[b] Sticky rice
* Correlation is significant at the 0.05 level (2-tailed)

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

This present study was conducted to i) determine total Cd concentration in rice grain collected from households located in 6 villages of the Mae Tao sub-district, Tak province and ii) estimate potential non-carcinogenic health risks from Cd exposure through the actual rice consumption pattern. The results found in this present study can be summarized as following.

1. Locally grown rice significantly contained higher total Cd concentrations than purchased rice by approximately 1.48 times.
2. Total Cd concentrations in sticky rice were about 1.09 times higher than total Cd concentrations in white jasmine rice.
3. Rice samples collected from village No.2 and village No.4 contained the highest total Cd concentrations because the soil in these 2 villages were previously determined as high and moderate Cd contamination, respectively. In addition, the irrigation water from the Mae Tao creek for rice cultivation could be the source of Cd contaminated sediment transportation into the paddy fields and then, contaminated to the rice production.
4. HQ values of Cd exposure through only sticky rice consumption and both types of rice consumption higher than the threshold value of 1 (HQ>1) indicated that the local residents who consumed rice in these 2 rice

consumption patterns could be affected by the adverse non-carcinogenic health impacts from Cd.

5. Comparing all 3 rice consumption patterns, only sticky rice consumption patterns showed the highest HQ value. Therefore, the local residents who consumed only sticky rice had the highest chance to be affected by the non-carcinogenic health risk from Cd exposure.
6. The total Cd concentration in rice was the most important factor affecting the non-carcinogenic health risks from Cd exposure through only white jasmine rice pattern and both types of rice consumption pattern.
7. In case of both types of rice consumption pattern, the total Cd concentration in sticky rice is the main factor affecting the potential non-carcinogenic health risks from Cd exposure.
8. The local residents in Mae Tao sub-district should consume rice purchasing from local markets, department stores, or stores outside the Mae Tao sub-district to reduce the potential Cd exposure and non-carcinogenic health impact development.

5.2 Recommendations for future work

According to the results shown above, the following recommendations are the point of concerns for the better understanding in health risks from Cd exposure through rice consumption in this area.

1. Children and adolescent should be included into the health risk assessment study.
2. The size of studied population and rice samples should be increased to assure the more accurate results of total Cd concentration in rice, data on actual rice consumption behavior, and health risk from Cd exposure.

3. The Cd bioavailability in rice should be studied in order to obtain the more accurate Cd concentration in rice that could be actually exposed and absorbed into the body of local residents.

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APPENDIX

APPENDIX A

A survey form on rice consumption pattern

in Mae Tao sub-district, Mae Sot district, Tak province

This survey is a part of Master's degree thesis in Hazardous Substances and Environmental Management, Chulalongkorn University

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Personal information

Name:

…………………………………………………………………………………………

Gender: ☐ Male ☐ Female

Age: ………………… year

Weight: ………………….. kg

Address:

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Rice consumption information

1. How often do you consume rice per day?

   Answer: …………………….. time(s).

2. The amount of rice consumed (per time)

   Answer: ………………plate(s) and ……………ladle(s) per plate.

3. Sources of rice consumed :

   ☐ Purchased from markets or department stores

   ☐ Cultivated within the Mae Tao sub-district

4. Do you know about cadmium contamination in rice in the Mae Tao sub-district?

   ☐ Know ☐ Not know

5. Do you smoke? ☐ Yes ☐ No

6. Do you work nearby Zn mining area? ☐ Yes ☐ No

7. Do you drink water from the Mae Tao creek? ☐ Yes ☐ No

Note:

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APPENDIX B

Table 1 Body weight of the population living in the Mae Tao sub-district

Age range	**Body weight (kg)**				
	Minimum	**Maximum**	**Average**	**Median**	**SD**
Male (n=1,222)					
15-24 years (n=62)	40.00	92.00	60.50	59.50	11.47
25-60 years (n=783)	40.00	109.00	63.50	62.00	11.23
Above 60 years (n=377)	26.00	91.00	57.00	56.00	10.27
Female (n=1,438)					
15-24 years (n=51)	28.00	91.50	54.70	53.00	11.90
25-60 years (n=1,000)	32.50	104.00	58.00	57.00	9.66
Above 60 years (n=387)	27.00	91.00	50.90	50.00	10.27
Total (n=2,660)					
15-24 years (n=113)	28.00	92.00	57.90	55.00	11.98
25-60 years (n=1,783)	32.00	109.00	60.40	59.00	10.72
Above 60 years (n=764)	26.00	91.00	53.90	54.00	10.75

Source: MOPH (2016)

APPENDIX C

Table 2 Total Cd concentrations in all rice samples collected from the Mae Tao sub-district

Village No.	Sample code	Type of rice	Source of rice	Cd concentration ($mg\ kg^{-1}$)	
				R1	**R2**
1	M1-01A1	White jasmine rice	Locally grown	0.3945	0.3699
	M1-01A2	Sticky rice	Purchased	0.2614	0.2466
	M1-02A2	Sticky rice	Locally grown	0.3675	0.3700
	M1-03A1	White jasmine rice	Purchased	ND	ND
	M1-04A1	White jasmine rice	Locally grown	0.0671	ND
	M1-05A1	White jasmine rice	Locally grown	0.1095	0.1145
	M1-05A2	Sticky rice	Locally grown	0.4983	0.4944
	M1-06A1	White jasmine rice	Purchased	0.2137	0.2120
	M1-06A2	Sticky rice	Purchased	ND	ND
	M1-07A1	White jasmine rice	Purchased	ND	ND
	M1-08A1	White jasmine rice	Locally grown	ND	ND
	M1-08A2	Sticky rice	Locally grown	ND	ND
	M1-09A1	White jasmine rice	Purchased	0.1332	0.1312
	M1-10A1	White jasmine rice	Locally grown	0.2370	0.2327
	M1-11A1	White jasmine rice	Locally grown	0.1461	0.1407
2	M2-01A1	White jasmine rice	Locally grown	0.3301	0.3266
	M2-01A2	Sticky rice	Locally grown	0.1315	0.1159
	M2-02A1	White jasmine rice	Locally grown	0.1935	0.1890
	M2-02A2	Sticky rice	Locally grown	0.2632	0.2616
	M2-03A1	White jasmine rice	Locally grown	0.1407	0.2546
	M2-03A2	Sticky rice	Locally grown	0.2873	0.2924
	M2-04A1	White jasmine rice	Locally grown	0.3709	0.3328
	M2-04A2	Sticky rice	Locally grown	0.1030	0.1126
	M2-05A1	White jasmine rice	Purchased	0.1192	0.1194
	M2-05A2	Sticky rice	Purchased	0.1622	0.1487
	M2-06A2	Sticky rice	Locally grown	0.2373	0.2357
	M2-07A1	White jasmine rice	Locally grown	0.4235	0.3810
	M2-08A1	White jasmine rice	Purchased	0.4065	0.3937
	M2-09A1	White jasmine rice	Locally grown	0.1296	0.1258
	M2-09A2	Sticky rice	Locally grown	0.1347	0.1308
	M2-10A1	White jasmine rice	Purchased	0.3096	0.3247
	M2-10A2	Sticky rice	Purchased	0.2373	0.2318

Note: ND means total Cd concentration is less than 0.1 $mg\ kg^{-1}$

R1 and R2 mean the duplicate sample analysis

Table 2 Total Cd concentrations in all rice samples collected from the Mae Tao sub-district (Cont.)

Village No.	Sample code	Type of rice	Source of rice	Cd concentration (mg kg^{-1})	
				R1	**R2**
2	M2-11A1	White jasmine rice	Locally grown	0.5759	0.5342
	M2-12A1	White jasmine rice	Locally grown	0.3164	0.3203
	M2-12A2	Sticky rice	Purchased	0.3604	0.4761
	M2-13A1	White jasmine rice	Locally grown	1.8896	1.9442
	M2-13A2	Sticky rice	Purchased	1.5988	1.6258
	M2-14A1	White jasmine rice	Locally grown	0.1142	0.1100
	M2-15A1	White jasmine rice	Locally grown	0.1903	0.1775
	M2-15A2	Sticky rice	Purchased	0.2133	0.2137
	M2-17A1	White jasmine rice	Locally grown	0.2059	0.2087
	M2-17A2	Sticky rice	Locally grown	1.0168	0.9524
	M2-18A1	White jasmine rice	Locally grown	0.5120	0.5200
	M2-18A2	Sticky rice	Locally grown	0.1575	0.1502
	M2-19A1/1	White jasmine rice	Purchased	1.0912	1.0638
	M2-19A1/2	White jasmine rice	Purchased	0.2923	0.3106
	M2-20A1	White jasmine rice	Locally grown	0.7155	0.7016
	M2-21A1	White jasmine rice	Locally grown	0.3770	0.3709
3	M3-01A1	White jasmine rice	Locally grown	1.4746	1.2868
	M3-02A1	White jasmine rice	Purchased	ND	ND
	M3-02A2	Sticky rice	Purchased	ND	ND
	M3-03A2	Sticky rice	Locally grown	ND	ND
	M3-04A1	White jasmine rice	Locally grown	0.2477	0.2514
	M3-04A2	Sticky rice	Locally grown	0.5704	0.5580
	M3-05A1	White jasmine rice	Purchased	0.3870	0.3815
	M3-05A2	Sticky rice	Purchased	ND	ND
	M3-06A1	White jasmine rice	Locally grown	ND	ND
	M3-06A2	Sticky rice	Locally grown	ND	ND
	M3-07A1	White jasmine rice	Locally grown	0.3298	0.3199
	M3-08A1	White jasmine rice	Purchased	ND	ND
	M3-08A2	Sticky rice	Purchased	0.1494	0.1366
	M3-09A1	White jasmine rice	Locally grown	ND	ND
	M3-09A2	Sticky rice	Locally grown	ND	ND
	M3-10A1	White jasmine rice	Locally grown	0.7673	0.7556

Note: ND means total Cd concentration is less than 0.1 mg kg^{-1}

R1 and R2 mean the duplicate sample analysis

Table 2 Total Cd concentrations in all rice samples collected from the Mae Tao sub-district (Cont.)

Village No.	Sample code	Type of rice	Source of rice	Cd concentration ($mg\ kg^{-1}$)	
				R1	R2
3	M3-10A2	Sticky rice	Locally grown	0.4961	0.5069
	M3-11A1/1	White jasmine rice	Purchased	ND	ND
	M3-11A1/2	White jasmine rice	Locally grown	0.4326	0.4458
	M3-12A1	White jasmine rice	Purchased	0.4042	0.4270
	M3-12A2	Sticky rice	Purchased	ND	ND
	M3-13A1	White jasmine rice	Purchased	ND	ND
	M3-14A1	White jasmine rice	Locally grown	ND	ND
	M3-14A2	Sticky rice	Locally grown	ND	ND
	M3-15A1	White jasmine rice	Purchased	ND	ND
	M3-15A2	Sticky rice	Purchased	ND	ND
	M3-16A1	White jasmine rice	Purchased	ND	ND
	M3-16A2	Sticky rice	Purchased	ND	ND
	M3-17A1	White jasmine rice	Locally grown	0.5173	0.5088
	M3-17A2	Sticky rice	Locally grown	0.1795	0.1826
	M3-18A1	White jasmine rice	Purchased	ND	ND
	M3-18A2	Sticky rice	Purchased	ND	ND
	M3-19A1	White jasmine rice	Purchased	0.1139	0.1125
	M3-20A1	White jasmine rice	Purchased	ND	ND
	M3-21A1	White jasmine rice	Purchased	ND	ND
	M3-22A1	White jasmine rice	Locally grown	0.4618	0.4743
	M3-22A2	Sticky rice	Locally grown	ND	ND
	M3-23A1	White jasmine rice	Locally grown	0.2003	0.1865
	M3-23A2	Sticky rice	Locally grown	ND	ND
	M3-24A1	White jasmine rice	Purchased	ND	ND
	M3-25A1	White jasmine rice	Purchased	0.2360	0.2358
	M3-26A1	White jasmine rice	Locally grown	0.3198	0.3203
	M3-26A2	Sticky rice	Locally grown	0.2809	0.2840
	M3-27A1	White jasmine rice	Purchased	ND	ND
	M3-28A1	White jasmine rice	Purchased	0.1124	0.1106
	M3-29A1	White jasmine rice	Purchased	ND	ND
	M3-29A2	Sticky rice	Purchased	0.2707	0.2835
	M3-30A1	White jasmine rice	Purchased	0.2153	0.2041

Note: ND means total Cd concentration is less than 0.1 $mg\ kg^{-1}$

R1 and R2 mean the duplicate sample analysis

Table 2 Total Cd concentrations in all rice samples collected from the Mae Tao sub-district (Cont.)

Village No.	Sample code	Type of rice	Source of rice	Cd concentration (mg kg^{-1})	
				R1	**R2**
3	M3-30A2	Sticky rice	Purchased	0.5305	0.5327
	M3-31A1	White jasmine rice	Purchased	ND	ND
	M3-31A2	Sticky rice	Purchased	ND	ND
	M3-32A2	Sticky rice	Locally grown	0.2537	0.2410
4	M4-01A1	White jasmine rice	Purchased	0.8025	0.7983
	M4-01A2	Sticky rice	Purchased	ND	ND
	M4-02A1	White jasmine rice	Locally grown	0.1455	0.1566
	M4-02A2	Sticky rice	Locally grown	ND	ND
	M4-03A1	White jasmine rice	Purchased	0.4724	0.4492
	M4-03A2	Sticky rice	Purchased	ND	ND
	M4-04A2	Sticky rice	Locally grown	ND	ND
	M4-05A1	White jasmine rice	Purchased	0.3226	0.3475
	M4-06A1	White jasmine rice	Locally grown	0.8445	0.8391
	M4-06A2	Sticky rice	Locally grown	1.6668	1.6632
	M4-07A1	White jasmine rice	Purchased	ND	ND
	M4-08A1	White jasmine rice	Purchased	0.1514	0.1544
	M4-09A2	Sticky rice	Locally grown	1.0316	0.9934
	M4-10A1	White jasmine rice	Locally grown	0.1373	0.1428
	M4-10A2	Sticky rice	Locally grown	1.6771	1.6447
	M4-11A1	White jasmine rice	Locally grown	0.1574	0.1584
	M4-11A2	Sticky rice	Locally grown	ND	ND
	M4-12A1	White jasmine rice	Locally grown	0.1964	0.2052
	M4-13A1	White jasmine rice	Locally grown	0.8449	0.8316
	M4-13A2	Sticky rice	Locally grown	2.5432	2.6517
	M4-14A1	White jasmine rice	Locally grown	0.6077	0.6053
	M4-15A1	White jasmine rice	Purchased	0.1285	0.1328
	M4-16A1	White jasmine rice	Purchased	0.3542	0.3525
	M4-16A2	Sticky rice	Purchased	0.1283	0.1201
5	M5-01A1	White jasmine rice	Locally grown	0.3603	0.3522
	M5-01A2	Sticky rice	Locally grown	0.3299	0.2978
	M5-02A1	White jasmine rice	Locally grown	0.1234	0.1216
	M5-02A2	Sticky rice	Locally grown	0.1920	0.1936

Note: ND means total Cd concentration is less than 0.1 mg kg^{-1}
R1 and R2 mean the duplicate sample analysis

Table 2 Total Cd concentrations in all rice samples collected from the Mae Tao sub-district (Cont.)

Village No.	Sample code	Type of rice	Source of rice	Cd concentration (mg kg^{-1})	
				R1	R2
5	M5-03A1	White jasmine rice	Locally grown	0.2124	0.2208
	M5-03A2	Sticky rice	Purchased	0.1703	0.1663
	M5-04A1	White jasmine rice	Locally grown	0.1941	0.1876
	M5-04A2	Sticky rice	Locally grown	0.1990	0.1937
	M5-05A1	White jasmine rice	Locally grown	0.2306	0.2305
	M5-05A2	Sticky rice	Locally grown	0.2695	0.2521
	M5-06A1	White jasmine rice	Locally grown	ND	ND
	M5-07A1	White jasmine rice	Purchased	ND	ND
	M5-08A1	White jasmine rice	Locally grown	ND	ND
	M5-08A2	Sticky rice	Locally grown	ND	ND
	M5-09A1	White jasmine rice	Locally grown	ND	ND
	M5-09A2	Sticky rice	Locally grown	ND	ND
6	M6-01A1	White jasmine rice	Locally grown	ND	ND
	M6-02A1	White jasmine rice	Purchased	0.1756	0.1676
	M6-02A2	Sticky rice	Purchased	1.4435	1.4757
	M6-03A1	White jasmine rice	Purchased	1.9621	1.9200
	M6-03A2	Sticky rice	Purchased	ND	ND
	M6-04A1	White jasmine rice	Purchased	0.1874	0.1643
	M6-04A2	Sticky rice	Purchased	0.1640	0.1563
	M6-05A1	White jasmine rice	Locally grown	0.2011	0.1915
	M6-05A2	Sticky rice	Locally grown	0.1242	0.1252
	M6-06A1	White jasmine rice	Purchased	0.3766	0.3842
	M6-07A1	White jasmine rice	Locally grown	ND	ND
	M6-07A2	Sticky rice	Locally grown	ND	ND
	M6-08A1	White jasmine rice	Locally grown	0.1762	0.1729
	M6-08A2	Sticky rice	Locally grown	0.1421	0.1436
	M6-09A1	White jasmine rice	Purchased	0.2896	0.2910
	M6-10A1	White jasmine rice	Purchased	0.3344	0.3315
	M6-11A1	White jasmine rice	Purchased	0.2346	0.2587
	M6-11A2	Sticky rice	Purchased	ND	ND
	M6-12A1	White jasmine rice	Purchased	ND	ND

Note: ND means total Cd concentration is less than 0.1 mg kg^{-1}
R1 and R2 mean the duplicate sample analysis

APPENDIX D

Table 3 The data on gender, age, body weight (BW), total Cd concentration in rice, and rice ingestion rate (IR) of each surveyed local resident in the only white jasmine rice consumption pattern

Village No.	Address No.	Gender	Age (year)	BW (kg)	[Cd] (mg kg^{-1})	IR (kg day^{-1})
1	291	Female	73	50	ND	0.1334
	305	Male	50	62	ND	0.1334
	205	Male	74	56	0.1322	0.0667
	299	Female	53	57	0.2349	0.1334
	152	Male	57	62	0.1434	0.1334
2	253	Female	78	50	0.4001	0.2668
	230	Female	60	57	0.3183	0.1334
	3	Female	52	57	0.1797	0.1334
	355	Male	57	62	0.7085	0.1334
3	2	Male	71	56	1.3807	0.0667
	763	Female	65	50	ND	0.1334
	763	Female	65	50	0.4392	0.1334
	275/1	Female	27	57	ND	0.1000
	431	Female	28	57	0.1132	0.1334
	1	Female	52	57	ND	0.1334
	99	Female	53	57	ND	0.1334
	341	Female	44	57	ND	0.0667
	306	Male	72	56	0.2359	0.1000
	100	Male	58	70	0.1115	0.2001
4	212	Female	49	63	0.3350	0.0445
	262	Male	86	54	ND	0.0667
	4	Female	32	69	0.1529	0.1334
	146/1	Female	66	45	0.2008	0.1334
	70	Male	56	62	0.6065	0.2001
	194	Female	44	57	0.1307	0.1334
5	229	Male	44	62	ND	0.2668
	11	Female	63	50	ND	0.0667

Note: ND means total Cd concentration is less than 0.1 mg kg^{-1}

Table 3 The data on gender, age, body weight (BW), total Cd concentration in rice, and rice ingestion rate (IR) of each surveyed local resident in the only white jasmine rice consumption pattern (Cont.)

Village No.	**Address No.**	**Gender**	**Age (year)**	**BW (kg)**	**[Cd] (mg kg^{-1})**	**IR (kg day^{-1})**
6	2	Female	48	57	ND	0.0445
	17	Female	52	57	1.9411	0.0667
	219	Female	60	57	0.2903	0.1000
	46	Male	28	62	0.3329	0.2668

Note: ND means total Cd concentration is less than 0.1 mg kg^{-1}

Table 4 The data on gender, age, body weight (BW), total Cd concentration in rice, and rice ingestion rate (IR) of each surveyed local resident in the only sticky rice consumption pattern

Village No.	Address No.	Gender	Age (year)	BW (kg)	[Cd] (mg kg^{-1})	IR (kg day^{-1})
1	383	Female	63	50	0.3688	0.2215
2	72	Female	61	50	0.9846	0.4430
3	109	Female	56	57	ND	0.2215
	440	Female	46	57	0.2825	0.4430
	277	Male	78	50	0.2771	0.2882
4	32	Male	57	63	ND	0.5764
	138	Female	53	57	ND	0.2215

Note: ND means total Cd concentration is less than 0.1 mg kg^{-1}

Table 5 The data on gender, age, body weight (BW), total Cd concentration in rice, and rice ingestion rate (IR) of each surveyed local resident in both types of rice consumption pattern

Village No.	Address No.	Gender	Age (year)	BW (kg)	[Cd] (mg kg^{-1})		IR (kg day^{-1})	
					WR	SR	WR	SR
1	122	Female	44	57	0.3822	0.2540	0.0445	0.1477
	264	Female	57	57	0.1120	0.4964	0.0667	0.1477
	106	Female	76	50	0.2129	ND	0.0445	0.1477
	287	Female	60	57	ND	ND	0.0445	0.1477
2	209	Female	76	50	0.3284	0.1237	0.0445	0.2954
	304	Male	76	56	0.1912	0.2624	0.0222	0.3842
	255	Male	60	62	0.1976	0.2898	0.0445	0.3842
	255	Female	57	57	0.1976	0.2898	0.0445	0.2954
	359	Female	62	50	0.3519	0.1078	0.0333	0.2954
	350	Male	58	62	0.1193	0.1554	0.0222	0.1921
	350	Female	84	50	0.1193	0.1554	0.0222	0.1477
	244	Female	47	57	0.1277	0.1328	0.0222	0.1477
	233	Female	48	57	0.3172	0.2345	0.0445	0.1477
	85	Female	66	50	1.9169	1.6123	0.0445	0.1477
	70/1	Female	63	50	0.1839	0.2135	0.0445	0.0738
	72	Female	40	57	0.2073	0.9846	0.0445	0.2954
	167	Male	62	57	0.5160	0.1539	0.0889	0.5764
3	42	Female	60	57	ND	ND	0.0445	0.1477
	256	Female	49	57	0.2496	0.5642	0.0445	0.1477
	269	Male	68	56	0.3843	ND	0.0667	0.1921
	338	Female	63	50	ND	0.1430	0.0445	0.1477
	101	Female	59	57	ND	ND	0.0445	0.0738
	375	Male	55	62	0.7614	0.5015	0.0445	0.3842
	11	Male	70	56	0.4156	ND	0.0222	0.1921
	316	Female	76	50	ND	ND	0.0445	0.1477
	300	Female	77	50	ND	ND	0.0222	0.1477
	444	Male	21	59.5	ND	ND	0.1778	0.7685

Note: ND means total Cd concentration is less than 0.1 mg kg^{-1}

WR and SR mean white jasmine rice and sticky rice, respectively

Table 5 The data on gender, age, body weight (BW), total Cd concentration in rice, and rice ingestion rate (IR) of each surveyed local resident in both types of rice consumption pattern (Cont.)

Village No.	Address No.	Gender	Age (year)	BW (kg)	[Cd] ($mg\ kg^{-1}$)		IR ($kg\ day^{-1}$)	
					WR	SR	WR	SR
3	235	Female	66	50	0.5130	0.1810	0.0333	0.0738
	166	Male	70	56	ND	ND	0.0445	0.1921
	50	Male	62	56	0.4680	ND	0.0667	0.5764
	354	Female	64	50	0.1934	ND	0.0333	0.1477
	79	Female	70	50	0.2097	0.5316	0.0222	0.1477
	517	Male	42	58	ND	ND	0.0445	0.1921
4	82	Female	54	57	0.8004	ND	0.0445	0.1477
	65	Male	50	58	0.8418	1.6650	0.0445	0.1921
	122	Female	63	50	0.1400	1.6609	0.0222	0.1477
	234	Female	45	57	0.1579	ND	0.0445	0.1477
	22	Male	59	58	0.8383	2.5974	0.0667	0.1921
	263	Female	52	57	0.3533	0.1242	0.0667	0.2954
5	197	Male	62	56	0.3563	0.3139	0.0667	0.3172
	197	Female	57	57	0.1225	0.1928	0.0445	0.2954
	208	Female	63	50	0.2166	0.1683	0.0445	0.1477
	25	Male	62	56	0.1908	0.1964	0.0445	0.1586
	210	Female	51	58.5	0.2306	0.2608	0.0445	0.1477
	20	Male	73	56	ND	ND	0.0445	0.1921
	12	Male	53	62	ND	ND	0.1334	0.1921
6	275	Male	39	62	0.1716	1.4596	0.0889	0.1921
	250	Female	37	57	0.1759	0.1602	0.0445	0.1477
	11	Female	33	57	0.1963	0.1247	0.0222	0.1477
	34	Female	53	57	ND	ND	0.0445	0.1477
	16	Female	42	57	0.1745	0.1428	0.0222	0.1477
	16	Female	75	57	0.1745	0.1428	0.0445	0.1477
	372	Female	35	57	0.2466	ND	0.0222	0.1477

Note: ND means total Cd concentration is less than 0.1 $mg\ kg^{-1}$

WR and SR mean white jasmine rice and sticky rice, respectively

APPENDIX E

Table 6 Average daily dose (ADD) of Cd exposure and non-carcinogenic health risk (HQ) of each surveyed local resident in the only white jasmine rice consumption pattern

Village No.	Address No.	Gender	Age (year)	BW (kg)	ADD (mg kg^{-1} day^{-1})	HQ
1	291	Female	73	50	2.67×10^{-4}	0.2668
	305	Male	50	62	2.15×10^{-4}	0.2151
	205	Male	74	56	1.57×10^{-4}	0.1574
	299	Female	53	57	5.50×10^{-4}	0.5496
	152	Male	57	62	3.09×10^{-4}	0.3085
2	253	Female	78	50	2.13×10^{-3}	2.1346
	230	Female	60	57	7.45×10^{-4}	0.7449
	3	Female	52	57	4.20×10^{-4}	0.4204
	355	Male	57	62	1.52×10^{-4}	1.5243
3	2	Male	71	56	1.64×10^{-3}	1.6443
	763	Female	65	50	2.67×10^{-4}	0.2668
	763	Female	65	50	1.17×10^{-3}	1.1716
	275/1	Female	27	57	1.76×10^{-4}	0.1755
	431	Female	28	57	2.65×10^{-4}	0.2649
	1	Female	52	57	2.34×10^{-4}	0.2340
	99	Female	53	57	2.34×10^{-4}	0.2340
	341	Female	44	57	1.17×10^{-4}	0.1170
	306	Male	72	56	4.21×10^{-4}	0.4214
	100	Male	58	70	3.19×10^{-4}	0.3188
4	212	Female	49	63	2.36×10^{-4}	0.2364
	262	Male	86	54	1.24×10^{-4}	0.1235
	4	Female	32	69	2.96×10^{-4}	0.2956
	146/1	Female	66	45	5.95×10^{-4}	0.5952
	70	Male	56	62	1.96×10^{-3}	1.9571
	194	Female	44	57	3.06×10^{-4}	0.3058
5	229	Male	44	62	4.30×10^{-4}	0.4303
	11	Female	63	50	1.33×10^{-4}	0.1334

Table 6 Average daily dose (ADD) of Cd exposure and non-carcinogenic health risk (HQ) of each surveyed local resident in the only white jasmine rice consumption pattern (Cont.)

Village No.	**Address No.**	**Gender**	**Age (year)**	**BW (kg)**	**ADD ($mg\ kg^{-1}\ day^{-1}$)**	**HQ**
6	2	Female	48	57	7.80×10^{-5}	0.0780
	17	Female	52	57	2.27×10^{-3}	2.2710
	219	Female	60	57	5.09×10^{-4}	0.5095
	46	Male	28	62	1.43×10^{-3}	1.4324

Table 7 Average daily dose (ADD) of Cd exposure and non-carcinogenic health risk (HQ) of each surveyed local resident in the only sticky rice consumption pattern

Village No.	**Address No.**	**Gender**	**Age (year)**	**BW (kg)**	**ADD (mg kg^{-1} day^{-1})**	**HQ**
1	383	Female	63	50	1.63×10^{-3}	1.6338
2	72	Female	61	50	8.72×10^{-3}	8.7244
3	109	Female	56	57	3.89×10^{-4}	0.3886
	440	Female	46	57	2.20×10^{-3}	2.1955
	277	Male	78	50	1.60×10^{-3}	1.5970
4	32	Male	57	63	9.15×10^{-4}	0.9149
	138	Female	53	57	3.89×10^{-4}	0.3886

Table 8 Average daily dose (ADD) of Cd exposure and non-carcinogenic health risk (HQ) of each surveyed local resident in both types of rice consumption pattern

Village No.	Address No.	Gender	Age (year)	BW (kg)	ADD (mg kg^{-1} day^{-1})	HQ
1	122	Female	44	57	9.56×10^{-4}	0.9562
	264	Female	57	57	1.42×10^{-3}	1.4171
	106	Female	76	50	4.85×10^{-4}	0.4847
	287	Female	60	57	3.37×10^{-4}	0.3371
2	209	Female	76	50	1.02×10^{-3}	1.0227
	304	Male	76	56	1.88×10^{-3}	1.8761
	255	Male	60	62	1.94×10^{-3}	1.9379
	255	Female	57	57	1.66×10^{-3}	1.6559
	359	Female	62	50	8.72×10^{-4}	0.8715
	350	Male	58	62	5.24×10^{-4}	0.5244
	350	Female	84	50	5.12×10^{-4}	0.5121
	244	Female	47	57	3.94×10^{-4}	0.3938
	233	Female	48	57	8.55×10^{-4}	0.8551
	85	Female	66	50	6.47×10^{-3}	6.4667
	70/1	Female	63	50	4.79×10^{-4}	0.4788
	72	Female	40	57	5.26×10^{-3}	5.2637
	167	Male	62	57	2.36×10^{-3}	2.3607
3	42	Female	60	57	3.37×10^{-4}	0.3371
	256	Female	49	57	1.66×10^{-3}	1.6564
	269	Male	68	56	8.01×10^{-4}	0.8007
	338	Female	63	50	5.11×10^{-4}	0.5112
	101	Female	59	57	2.08×10^{-4}	0.2075
	375	Male	55	62	3.65×10^{-3}	3.6540
	11	Male	70	56	5.08×10^{-4}	0.5081
	316	Female	76	50	3.84×10^{-4}	0.3843
	300	Female	77	50	3.40×10^{-4}	0.3398
	444	Male	21	59.5	1.59×10^{-3}	1.5905
	235	Female	66	50	6.09×10^{-4}	0.6095

Table 8 Average daily dose (ADD) of Cd exposure and non-carcinogenic health risk (HQ) of each surveyed local resident in both types of rice consumption pattern (Cont.)

Village No.	Address No.	Gender	Age (year)	BW (kg)	ADD (mg kg^{-1} day^{-1})	HQ
3	166	Male	70	56	4.22×10^{-4}	0.4225
	50	Male	62	56	1.59×10^{-3}	1.5866
	354	Female	64	50	4.24×10^{-4}	0.4243
	79	Female	70	50	1.66×10^{-3}	1.6634
	517	Male	42	58	4.08×10^{-4}	0.4079
4	82	Female	54	57	8.83×10^{-4}	0.8834
	65	Male	50	58	6.16×10^{-3}	6.1604
	122	Female	63	50	4.97×10^{-3}	4.9680
	234	Female	45	57	3.82×10^{-4}	0.3822
	22	Male	59	58	9.57×10^{-3}	9.5677
	263	Female	52	57	1.06×10^{-3}	1.0569
5	197	Male	62	56	2.20×10^{-3}	2.2023
	197	Female	57	57	1.09×10^{-3}	1.0947
	208	Female	63	50	6.90×10^{-4}	0.6897
	25	Male	62	56	7.08×10^{-4}	0.7078
	210	Female	51	58.5	8.34×10^{-4}	0.8335
	20	Male	73	56	4.22×10^{-4}	0.4225
	12	Male	53	62	5.25×10^{-4}	0.5250
6	275	Male	39	62	3.12×10^{-4}	0.3116
	250	Female	37	57	2.06×10^{-4}	0.2063
	11	Female	33	57	1.44×10^{-4}	0.1435
	34	Female	53	57	2.23×10^{-4}	0.2230
	16	Female	42	57	1.58×10^{-4}	0.1577
	16	Female	75	57	2.26×10^{-4}	0.2257
	372	Female	35	57	2.29×10^{-4}	0.2293

VITA

Parin Suwatvitayakorn was born on April 8, 1993. She graduated the high school studied from Horwang School, Bangkok. She graduated Bachelor's degree of Science in Chemistry from the Department of Chemistry, Faculty of Science, Chulalongkorn University. Her senior project was the method development for determination of nickel by automated multi-step flow analysis coupled with electrochemical detection. She participated as an internship student in the IERI 2017 Fall Internship Program at Gwangju Institute of Science and Technology (GIST), Gwangju, Republic of Korea, from September 2017 to February 2018 (6 months).