Blood lead and cadmium levels of e-waste dismantling workers from inhalation exposure to $PM_{2.5}$ and $PM_{2.5-10}$, Buriram, Thailand

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A Thesis Submitted in Partial Fulfillment of the Requirements
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ระดับตะกั่วและแคดเมียมในเลือดของผู้รื้อแยกขยะอิเล็กทรอนิกส์จากการรับสัมผัสตะกั่วและแคดเมียมใน $PM_{2.5}$ และ $PM_{2.5\text{-}10}$ จังหวัดบุรีรัมย์ ประเทศไทย

ว่าที่ ร.ต.หญิงธิดารัตน์ ศิริชัย

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิทยาศาสตรมหาบัณฑิต
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Field of Study	Hazardous Substance and Environmental Management
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ธิดารัตน์ ศิริชัย : ระดับตะกั่วและแคดเมียมในเลือดของผู้รื้อแยกขยะอิเล็กทรอนิกส์จากการรับสัมผัสตะกั่วและแคดเมียมใน $PM_{2.5}$ และ $PM_{2.5-10}$ จังหวัดบุรีรัมย์ ประเทศไทย. (Blood lead and cadmium levels of e-waste dismantling workers from inhalation exposure to $PM_{2.5}$ and $PM_{2.5-10}$, Buriram, Thailand) อ.ที่ปรึกษาหลัก : ผศ. ดร.ทรรศนีย์ พฤกษาสิทธิ์, อ.ที่ปรึกษาร่วม : ดร.ศิริพร แสงสุธรรม

งานวิจัยนี้มีวัตถุประสงค์เพื่อศึกษาระดับตะกั่วและแคดเมียมในเลือดจากการรับสัมผัสตะกั่วและแคดเมียมผ่านทางการสูดดมอนุภาคฝุ่นขนาดเล็กกว่า 2.5 ไมครอน ($PM_{2.5}$) และฝุ่นขนาดเส้นผ่านศูนย์กลางระหว่าง 2.5 ถึง 10 ไมครอน ($PM_{2.5-10}$) ของกลุ่มผู้ประกอบอาชีพและไม่ได้ประกอบอาชีพรื้อแยกขยะอิเล็กทรอนิกส์ในตำบลแดงใหญ่ อำเภอบ้านใหม่ไชยพจน์ และตำบลบ้านเป้า อำเภอพุทไธสง จังหวัดบุรีรัมย์ ระหว่างเดือนพฤษภาคมถึงเดือนสิงหาคม 2562 ทำการเก็บตัวอย่างเลือดในวันถัดไปหลังจากวันที่เก็บตัวอย่างฝุ่น วิเคราะห์ปริมาณตะกั่วและแคดเมียมในเลือด และความเข้มข้นของตะกั่วและแคดเมียมในฝุ่นทั้งสองขนาดด้วยเครื่อง Inductively Coupled Plasma Mass Spectrometry (ICP-MS) ผลการวิจัยพบว่า ค่าเฉลี่ยของระดับตะกั่วในเลือดของผู้ประกอบอาชีพฯ ในตำบลแดงใหญ่ อำเภอบ้านใหม่ไชยพจน์ ตำบลบ้านเป้า อำเภอพุทไธสง และผู้ที่ไม่ได้ประกอบอาชีพรื้อแยกขยะอิเล็กทรอนิกส์มีค่า 5.63± 2.86, 3.92±1.13 และ 2.84±0.72 µg/dl ตามลำดับ และแคดเมียมในเลือดมีค่า 0.97±0.43, 1.12±0.43 และ 1.15±0.38 µg/l ตามลำดับ โดยระดับตะกั่วในเลือดของกลุ่มผู้ประกอบอาชีพรื้อแยกขยะอิเล็กทรอนิกส์ทั้งสองตำบลสูงกว่ากลุ่มผู้ที่ไม่ได้ประกอบอาชีพรื้อแยกขยะอิเล็กทรอนิกส์อย่างมีนัยสำคัญที่ระดับความเชื่อมั่น 95% แต่ไม่พบความแตกต่างอย่างมีนัยสำคัญของระดับแคดเมียมในเลือดของตัวอย่างทั้งสามกลุ่ม ความเข้มข้นเฉลี่ยของตะกั่วในฝุ่น $PM_{2.5}$ ของกลุ่มผู้รื้อแยกฯ (18.95±23.12 ng/m^3) สูงกว่ากลุ่มผู้ที่ไม่ได้รื้อแยกฯ (12.69±37.40 ng/m^3) เช่นเดียวกันกับค่าความเข้มข้นเฉลี่ยของแคดเมียมใน $PM_{2.5-10}$ ในกลุ่มผู้รื้อแยกฯ (2.03±1.27 ng/m^3) สูงกว่ากลุ่มผู้ที่ไม่ได้รื้อแยกฯ (1.06±0.99 ng/m^3) อย่างมีนัยสำคัญที่ระดับความเชื่อมั่น 95% ในขณะที่ค่าเฉลี่ยความเข้มข้นของตะกั่วใน $PM_{2.5-10}$ และแคดเมียมในฝุ่น $PM_{2.5}$ ของทั้งสองกลุ่ม ไม่แตกต่างกันอย่างมีนัยสำคัญ ปริมาณตะกั่วที่ตรวจพบในเลือดมีความสัมพันธ์เชิงบวกเฉพาะกับปริมาณตะกั่วในฝุ่นอนุภาคขนาด $PM_{2.5}$ ที่รับสัมผัส (r=0.211, p<0.05) การประกอบอาชีพรื้อแยกขยะอิเล็กทรอนิกส์เป็นปัจจัยที่มีนัยสำคัญต่อระดับตะกั่วในเลือด รวมถึงความแตกต่างทางเพศมีอิทธิพลต่อระดับตะกั่วและแคดเมียมในเลือด และการใช้หน้ากาก ถุงมือ และสวมรองเท้าเป็นอุปกรณ์ป้องกันส่วนบุคคลมีแนวโน้มช่วยลดการรับสัมผัสและการสะสมตะกั่วและแคดเมียมในเลือดจากกิจกรรมการรื้อแยกขยะอิเล็กทรอนิกส์

สาขาวิชา การจัดการสารอันตรายและสิ่งแวดล้อม ลายมือชื่อนิสิต ....
ปีการศึกษา 2562 ลายมือชื่อ อ.ที่ปรึกษาหลัก ....
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Thidarat Sirichai : Blood lead and cadmium levels of e-waste dismantling workers from inhalation exposure to $\mathrm{PM}_{2.5}$ and $\mathrm{PM}_{2.5\text{-}10}$, Buriram, Thailand. Advisor: Asst. Prof. TASSANEE CHETWITTAYACHAN, Ph.D. Co-advisor: Siriporn Sangsuthum, Ph.D.

This research aims to investigate blood lead and cadmium levels in associated with inhalation exposure of Pb and Cd in $\mathrm{PM}_{2.5}$ and $\mathrm{PM}_{2.5\text{-}10}$ of the e-waste dismantling workers and non-e-waste dismantling workers in Daeng Yai sub-district, Ban Mai Chaiyapot district, and Ban Pao sub-district, Puttatisong district, Buriram, Thailand, during May to August 2019. Blood samples were collected on the next day after the air sampling. Pb and Cd in blood and air samples were quantitatively analyzed by Inductively Coupled Plasma Mass Spectrometry (ICP-MS). The mean blood lead levels of e-waste workers from Daeng Yai sub-district, and Ban Pao sub-district, and non-e-waste workers were 5.63±2.86, 3.92±1.13 and 2.84±0.72 µg/dl, respectively. The mean blood cadmium levels were found at 0.97±0.43 and 1.12±0.43 µg/l for e-waste workers both sub-districts in respectively, and 1.15±0.38 µg/l for non-e-waste workers. The blood lead levels of e-waste workers were significantly higher than those of non-e-waste workers (p<0.05), while there was no significant difference between the three target groups. The concentration of Pb in $\mathrm{PM}_{2.5}$ exposed by e-waste workers (18.95±23.12 ng/m^3) was found significantly higher than those of non-e-waste workers (12.69±37.40 ng/m^3). For Cd, the mean concentration of Cd in $\mathrm{PM}_{2.5\text{-}10}$ exposed by e-waste workers (2.03±1.27 ng/m^3) were significantly higher than those of non-e-waste worker (1.06±0.99 ng/m^3) ($p < 0.05$). While the mean concentration of Pb in $\mathrm{PM}_{2.5\text{-}10}$ and of Cd in $\mathrm{PM}_{2.5}$ between all groups were not significantly different. Pb concentration in PM2.5 was positively and significantly associated with blood lead levels (r = 0.211, p=0.050). E-waste dismantling occupation was a significantly associated risk factor of blood lead levels. Moreover, gender as a host factor could influence blood lead and cadmium levels. In addition, the workers who wore mask, gloves, and sneakers as personal protective equipment (PPE) could be likely found to pose a lower risk of exposure to lead and cadmium and also lower blood lead and cadmium levels.

Field of Study:	Hazardous Substance and Environmental Management	Student's Signature ....
Academic Year:	2019	Advisor's Signature .... Co-advisor's Signature ....

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CHAPTER I
INTRODUCTION

1.1 Background and significance problem addressed

At present, due to the rapid growth of electrical appliances and electronic equipment in the market, electrical appliances and electronics such as televisions, mobile phones, and computers are growing and expanding worldwide. Therefore, consumers often change old appliances before it will become non-working and end of useful life; finally, it will turn into an electronic scrap called " Electronic waste or E -waste" (Vasanadumrongdee and Manomaivibool, 2015). The amount of electronic waste in the world would be more than 40 million tons per year (Huisman et al., 2008), and the rate of electronic waste has increased rapidly to 4 percentages per year (Ravi, 2012). Similarly, Thailand is experiencing problems with electronic waste: Pollution Control Department reported that hazardous waste from the community was approximately 606,319 tons, and electronic waste accounted for approximately 393,070 tons (65 percentages) in 2016. Moreover, potentially hazardous chemical elements are also components of electrical and electronic equipment; the most common are lead, cadmium, chromium, mercury, copper, manganese, nickel, arsenic, zinc, iron, and aluminium (Grant et al., 2013). Without a good manner of e-waste management, therefore, heavy metals can be released into the environment, becoming an environmental problem and a negative impact on people's health in many areas.

A large amount of electronic waste in Thailand has been improperly disposed because there is no specific legislative enforcement to control informal e-waste management. Currently, local governmental organizations have adopted Public Health Act B.E. 2535 to deal with e-waste in relation to their collection, haulage, or disposal, which can be considered as toxic and hazardous waste from the community in the local area (Department of Health, 2017). However, the existing regulations have not been completely solved informal e-waste dismantling; this problem led to the informal dismantling e-waste in the local community as a household business. According to the Department of Disease Control estimated that Thailand has electronic waste dismantling and inappropriate disposal in the community almost 100 sites located in some provinces for examples, Chonburi, Chiang Rai, Chiang Mai, Nakhon Pathom, Nonthaburi, and Amnat Charoen province, especially Khongchai district, Kalasin province, and Ban Mai Chaiyapot district and Putthisong district, Buriram province (Vassanadumrongdee, 2015). Buriram province has been found to be the second largest of the electronic waste dismantling community of Thailand. Informal dismantling sites in Buriram province have two sub-districts; most of the workers live in Daeng Yai Sub-district, Ban Mai Chaiyapot district, and Ban Pao Sub-district, Putthisong district, which are nearly located. An average income of electronic dismantling has approximately 2,000 – 2,500 USD per year (Puangprasert & Prueksasit, 2019). As a result, many of the residents in this area change careers from agriculture to e-waste dismantling. The workers dismantle electronic waste by inappropriate primitive methods and management systems, including cutting, scattering, splitting, removing, and burning parts of electronic products for sale. In addition, some of the workers do not use any personal protective equipment (PPE) to protect them against the adverse effect of exposure to hazardous substances in heavy metals in electronic waste. Therefore, they can be exposed to heavy metals through inhalation, ingestion, and dermal contact. Exposure to heavy metals through inhalation is caused by inhalation of particulate matter in the air. Then, heavy metals can be absorbed and accumulated in tissue (Park et al., 2017). Puangprasert (2015) studied about inhalation exposure to heavy metals and health risk assessment of separating electronic waste workers in Buriram Province and found that the average concentration of PM_{10} obtained from the day that workers had electronic waste separation activities was 0.0646 mg/m^3. Moreover, the average concentrations of the worker exposure to cadmium, copper, nickel, and lead were 0. 0073±0. 01, 0.2083±0.64, 0.2916±0.37, and 0.1297±0.17 μg/m^3, respectively. Similarly, the study of Xue, Yang, Ruan, and Xu (2012) measured the concentration of heavy metals in TSP (Total Suspended Particulate) and PM_{10} of ambience in the production line for recycling waste printed circuit boards and health risk assessment. Four elements, including Cr, Cu, Cd, and Pb, were detectable. The result found that the concentration of Pb and Cu were the most enriched metals in TSP. Moreover, the concentration of Cu, Pb, Cr, and Cd in PM_{10} were 0.88, 0.56, 0.12, and 0.88 μg/m^3, respectively.

Therefore, four heavy metals, Cr and Pb are released into the ambience of the automatic line more easily in the crush and separation process.

Assessment of exposure to environmental pollutants based on biological monitoring is a scientific method of measurement and assessment of human exposure to environmental chemicals. Moreover, it can provide information to support possible adverse health effects. There are various bio-monitoring to investigate the human exposure to environmental contaminants, determination of the metal level by using metabolites in human tissue and body such as blood, feces, urine, hairs, and nails had been done (Haines & Murray, 2012; Król, Zabiegała, & Namieśnik, 2013) Blood biomarker is measured to determine the concentration of heavy metals, especially, lead and cadmium. Blood lead level (BLL) and blood cadmium level (BCL) are reliable indicators of recent lead and cadmium exposure (Usuda et al., 2011). Lead can be detected in blood within hours of exposure and can remain detected for at least 4 weeks since the half-life of lead in blood is 35 days (Ehrlich et al., 1998; Alli, 2015). Similarly, blood cadmium was used to measure recent exposure to cadmium (Adams & Newcomb, 2013). Lead can be absorbed into the human body through the respiratory system, then 99%of lead is bound to the hemoglobin portion of erythrocytes and is circulated via the vascular system to liver, kidney, bone, and hair. In parts of cadmium, inhalation is considered as the primary route of exposure; 100% of cadmium is absorbed into the blood. Cadmium will bind to albumin as an enzyme in red blood cells and is transported to the liver (Keil, Berger-Ritchie, & McMillin, 2011). Earlier studies have found the concentration of lead and cadmium in the blood of workers in electronic waste site; for example, the study of (Annamalai, 2015) found that the blood lead level of workers in the electronic waste recycling area in India was higher than reference value of the Centers for Disease Control (10 µg/dl). Similarly, the study of Chen et al. (2019) found that the blood lead level of electronic waste workers (as an exposed group) in the electronic waste polluted area in Guiyu, China was higher than the reference group who does not live in area.

Previous studies in other countries have found evidence of blood lead and cadmium levels in workers in e-waste handling areas. Correspondingly, the surveillance of blood lead and cadmium levels of e-waste dismantling workers in

Dang Yai Sub-district, Ban Mai Chaiyapot District, and Ban Pao Sub-district, Putthisong District, Buriram province in 2018 had been performed by Department of Disease Control, Ministry of Public Health. The ranges of blood lead and cadmium levels of workers in Dang Yai Sub-district were found N.D. – 32.7 µg/dl and N.D. – 1.60 µg/l, respectively. Likewise, those of Ban Pao Sub-district was the range of blood lead and cadmium levels of N.D. – 13.1 µg/dl and N.D. – 1.30 µg/l, respectively. However, blood lead and cadmium levels of workers in this area lower than the Thai Biological Exposure Indices (Thai BEIs) value for blood lead and cadmium were 30 µg/dl and 5.0 µg/l, respectively (DDC, 2016). It seems that e-waste dismantling activities could result in the circulation of Pb and Cd in the blood of some workers in these sites. However, an association of blood lead and cadmium levels in correspondence with the workers' exposure during e-waste dismantling through inhalation has not been investigated yet. Therefore, this study aims to determine the concentrations of lead and cadmium in both blood biomarker and their concentration in $PM_{2.5}$ and $PM_{2.5-10}$ of air samples.

1.2 Research Objectives

The main objective of this study is to determine the blood lead and cadmium levels of e-waste dismantling workers from inhalation exposure to $PM_{2.5}$ and $PM_{2.5-10}$. Moreover, there are three sub-objectives in this study as follows;

1) To determine the blood lead and cadmium levels of e-waste dismantling workers.

2) To determine inhalation exposure concentrations of lead and cadmium in $PM_{2.5}$ and $PM_{2.5-10}$ of e-waste dismantling workers.

3) To investigate the correlation between the blood lead and cadmium levels and their concentration in $PM_{2.5}$ and $PM_{2.5-10}$.

1.3 Hypotheses

1) Blood lead and cadmium levels in e-waste dismantling workers would be found higher than those in non-e-waste workers.

2) E-waste dismantling workers would be found expose to lead and cadmium concentrations in $PM_{2.5}$ and $PM_{2.5-10}$ via inhalation route higher than non-e-waste workers.

3) Blood lead and cadmium levels in e-waste dismantling workers would be found positively correlated with exposed lead and cadmium concentrations in $PM_{2.5}$ and $PM_{2.5-10}$.

1.4 Scope of the study

1) Target substances

The target substances in this study are lead (Pb) and cadmium (Cd) that bind to particulate matter (PM) including, fine ($PM_{2.5}$) and coarse particles ($PM_{2.5-10}$) which released from e-waste dismantling processes. Lead is a soft bluish grey metal used as a component of electronic devices such as computer parts, CRT screens, batteries, mobile phone, solders, and circuit boards. Similarly, cadmium is a toxic metal and a component of electronic devices such as batteries, circuit boards, and toners. The health effects of workers via inhalation exposure of lead and cadmium can be determined by blood as a biomarker because Pb and Cd are more readily to be absorbed through the respiratory system and then enter the bloodstream. In this study, blood biomarkers measured to determine exposure to lead and cadmium as they reflect recent exposure.

2) Study areas

This study was conducted at e-waste dismantling areas located at Dang Yai sub-district, Ban Mai Chaiyapot district and Ban Pao sub-district, Putthisong district in Buriram province, Thailand. These studied sub-districts include of 9 and 12 villages, respectively. However, Dang Yai sub-district has 5 e-waste dismantling villages and 7 e-waste dismantling villages for Ban Pao sub-district.

3) Population and target sample

The target population in this study were the local people of Dang Yai sub-district and Ban Pao sub-district. In 2019, Dang Yai Sub-district has 1,091 households, 105 of households are involved in e-waste dismantling activity. Similarly, Ban Pao Sub-district has 1,315 households, and 68 households are involved in e-waste dismantling work. Therefore, the total number of households that are involved in e-waste dismantling activity in both two sub-districts are 173 houses. In addition, these 173 e-waste households compose of family members who are e-waste workers. Each household has approximately four e-waste workers in the house, which means that there are 692 e-waste workers in the study area.

In this study, the number of target samples was calculated by the N4Studies program at 99% confidence level (Bernard, 2000; Srogi, 2006). The calculation result shows that at least 34 subjects of the case and 34 subjects of control were set up as the target samples. The total target subjects of 145 were then assigned that 95 of cases and 50 of control for blood sampling. The target samples in this study were divided into two categories, including the target group for blood samples and inhalation exposure samples.

3.1) Blood samples were collected from a total of 145 target samples that were separated into two groups: case group and control group. The case group was consist of 50 e-waste workers from Dang Yai sub-district and 45 e-waste workers from Ban Pao sub-district, and the control group was consist of 50 non-e-waste worker people who live in non-e-waste dismantling areas in Dang Yai sub-district and do not have occupations that involve with e-waste dismantling activity.

3.2) The target samples for inhalation exposure were taken from 90 people from both two villages that were randomly selected and separated into 70 people for the case group and 20 people for the control group.

4) Sampling technique

4.1) Blood samples (approximately 5 – 8 mL per person) were collected by nurses from the local hospital and stored in a clotted blood tube. Ethylene diamine tetra-acetic acid (EDTA) was added as an anticoagulant.

4.2) Inhalation exposure samples were collected by using personal air samplers connecting to Personal Modular Impactors (PMIs).

4.3) Personal information was collected by using questionnaires and personal interview.

5) Analytical technique

5.1) Lead and cadmium in blood samples were extracted by acid digestion method following the method instructed by Atlanta ATSDR (2012). The samples were analyzed by Special Laboratory Center Co Ltd Sathorn, Thailand. This laboratory passed certified from U.S. Department of Health and Human Services, Centers for Disease Control and Prevention.

5.2) The concentrations of extracted lead and cadmium in the blood were analyzed by inductively Coupled Plasma Spectrometry-Mass Spectrometry (ICP-MS) following the method instructed by Centers for Disease Control and Prevention (2004).

5.3) Lead and cadmium in $PM_{2.5}$ and $PM_{2.5-10}$ samples were extracted by U.S. EPA Method 3051 and further analyzed by ICP-MS.

6) Data Analysis

The SPSS for Windows Release 22.0 (SPSS Inc.) was used for statistical analysis of the data consist of Kolmogrov - Smirnov test (K-S test), Kruskal Walls test, F-test (One way), and Chi-squared ($\chi2$), Mann-whitney u test and Spearman correlation.

1.5 Expected outcomes of the study

1) The baseline data of blood lead and cadmium levels in e-waste dismantling workers from the study area would be obtained.

2) Results of blood lead and cadmium levels found in e-waste dismantling workers from this study would disclose the evidence of harmful effects in human health caused by lead and cadmium exposure during e-waste dismantling processes.

3) The results from this study would be presented to e-waste dismantling workers to raise awareness about the use of PPE and minimize their exposure pathways in order to decrease the involved potential risk that probably occurs from their e-waste dismantling activity.

CHAPTER II

LITERATURE REVIEW

2.1 Definition of electronic waste

Electronic waste (e-waste) or waste electrical and electronic equipment (WEEE) refers to all items of electrical and electronic equipment (EEE) and parts that have been discarded by owners as waste without intent to reuse. Moreover, e-waste can be described as electrical equipment such as computers, televisions, and cell phones that is not working or at the end of its useful life (Vasanadamrongdee and Manomaivibool, 2015).

2.2 The situation of electronic waste in Thailand

Recently, Thailand has been experiencing yearly growth in e-waste problems due to the rapid growth of electrical appliances and electronic equipment. Moreover, these electrical gadgets contain various hazardous substances and heavy metals. In developing countries, including Thailand, e -waste is dismantled improperly by junk shop operators (Vassanadumrongdee, Tanwattana, and Damrongsiri, 2013).

Buranasingha (2016) reported the amount waste from communities, although the amount of waste decreased from approximately 700,000 tons in 2012 to 606,319 tons 2016, the amount of e-waste reached 308,845 tons in 2007 and has tended to increase by 12% each year since (Prompak, 2012). Likewise, the Pollution Control Department, under the Ministry of Natural Resources and the Environment, of Thailand, estimated that the percentages of electronic waste in 2012 to 2015 has increased 7.63% of e-waste. Common types of e-waste are televisions (106,335 tons or 27 percent), air conditioners (74,799 tons or 19 percent), refrigerators (65,765 tons or 17 percent), washing machines (60,492 tons or 16 percent), computers (57,058 tons or 15 percent), and other e-waste such as VCD players, DVD players, mobile phones, and digital cameras (Wittaya-arnumad, 2017). In 2016, the percentages of electronic waste have increased 10.10% (Pollution Control Department, 2016).

The poor e-waste management situation in Thailand, including the unregulated dismantling of e-waste, is worsening each year. In Thailand, there is a rapid growth in the number of informal e-waste separators who dismantle and recover electronic waste mostly comes from households (Thongkaow et al., 2017). At each household, the workers dismantle electronic waste by inappropriate primitive methods and management systems, including cutting, scattering, splitting, removing, and burning parts of electronic products for sale (Buranasingha, 2016). The Department of Disease Control has estimated that Thailand has 100 e-waste dismantling sites, which are located in Krabi, Kalasin, Chonburi, Chiang Rai, Chiang Mai, Nakhon Pathom, Nonthaburi, Buriram, Pathum Thani, PrachinBuri, Phra Nakhon Si Ayutthaya, Ratchaburi, Laem Phun, Samut Prakan, Samut Sakhon, Sa Kaeo, and Amnat Charoen province. The Pollution Control Department reported that Kalasin and Buriram province are the large informal dismantling sites in northeastern Thailand (PCD, 2014). Buriram province is the second-largest e-waste dismantling community in Thailand. Informal dismantling sites in Buriram province consist two adjoining sub-districts. Due to the e-waste dismantling workers have an average income of approximately 2,000 – 2,500 USD per year (Puangprasert & Prueksasit, 2019). Therefore, many of the local household change careers from agriculture to e-waste dismantling. Informal e-waste dismantling community at Daeng Yai Subdistrict, Ban Mai Chaiyaphot District and Ban Pao Subdistrict, Phutthaisong District, Buriram province is considered to be a representative study area.

2.3 Sources of heavy metals from e-waste dismantling processes

Electronic waste dismantling processes can release several hazardous substances due to the hazardous chemical elements that are used as components of electrical and electronic equipment. The most common of these are lead (Pb), cadmium (Cd), chromium (Cr), mercury (Hg), copper (Cu), manganese (Mn), nickel (Ni), arsenic (As), zinc (Zn), iron (Fe), and aluminum (Al) (Grant et al., 2013). Woo, Lee, and Lim (2015) indicated that lead and other trace metals are major components of electronic waste. Herat (2008) and Niu, Wang, Song, and Li (2012) found up to 2 kg of lead in cathode ray tube (CRT) computer monitors (Wittsiepe et al., 2016). Gaidajis, Angelakoglou, and Aktsoglou (2010) and Morf et al. (2007) provide typical concentrations of heavy metals occurring in electronic waste, which are presented in Table 2.1.

Table 2.1 A list of occurrence and typical concentrations of heavy metals in electronic waste

Element	Relationship with e-waste	Typical concentration in e-waste (mg/kg)
Cd	• Rechargeable NiCd batteries • Fluorescent layer (CRT screens) • Printer inks and toners • Photocopying machines (printer drums)	180
Cr	• Magnetic storage materials (disks, tapes, etc.)	9,900
Pb	• Solder • Printed wiring boards • CRT screens, radiation shield • Batteries	2,900
Hg	• Fluorescent lamps (in LCD: backlighting) • Some alkaline batteries • Hg wetted switches	0.68
Ni	• Rechargeable NiCd batteries or NiMH batteries • Electron gun in CRT	10,300

Source: Gaidajis et al. (2010) and Morf et al. (2007)

The study of Annamalai (2015) explained that in developing countries, the e-waste is dismantled manually and releasing nondegradable plastics and persistent chemicals to the environment, thereby contaminating the quality of air, water, and soil. Moreover, Annamalai (2015) mentioned an example of general primitive methods to separate materials from the e-waste as the following:

1) Physical dismantling using tools such as hammers, chisels, screwdrivers, and bare hands to separate different materials

2) Removing components from printed circuit boards by heating over coal-fired grills

3) Stripping of metals in open-pit acid baths to recover gold and other metals

4) Chipping and melting plastics without proper ventilation

5) Burning cables to recover copper, and burning unwanted materials in the open air

6) Disposing of unsalvageable materials in fields and riverbanks.

Similarly, Thailand has the informally electronic dismantling processes. Electronic waste was dismantled and recovered by primitive methods to separate valuable materials, such as physical dismantling by hammer, chisel, and screwdriver, and open burning some components. Moreover, Thongkaow et al. (2017) explained the material flow of e-waste dismantling in rural areas of northeastern Thailand by informal separators as shown in Figure. 2.1.

Figure. 2.1 shows that informally electronic waste dismantling cycle starts from discarding unused electronic products by the consumers. After they are out of order or damaged, they are sent to repair or sold to the recycled junk shop or to informal separators who provide the direct pick-up service. Then, the dismantlers buy the e-waste from recycled junk shop or pick up from households to dismantle. The processes of e-waste dismantling by informal separators begins with piling them up in their residence, then starting disassembly from the large products such as washing machines, refrigerators, and air conditioners first, by removing the external structure made of steel, aluminium, or plastic. Then, the internal parts are separated, such as electric motors, printed circuits boards, and wires. These parts are smashed and separated again to retrieve valuable materials inside, including copper and steel. Moreover, all the wires in particular very small sizes from every electric appliance are taken to burn at open field for copper recovery. Burning of wires is a popular method as it can rapidly extract a large amount of copper, and faster than peeling the wires with a knife.

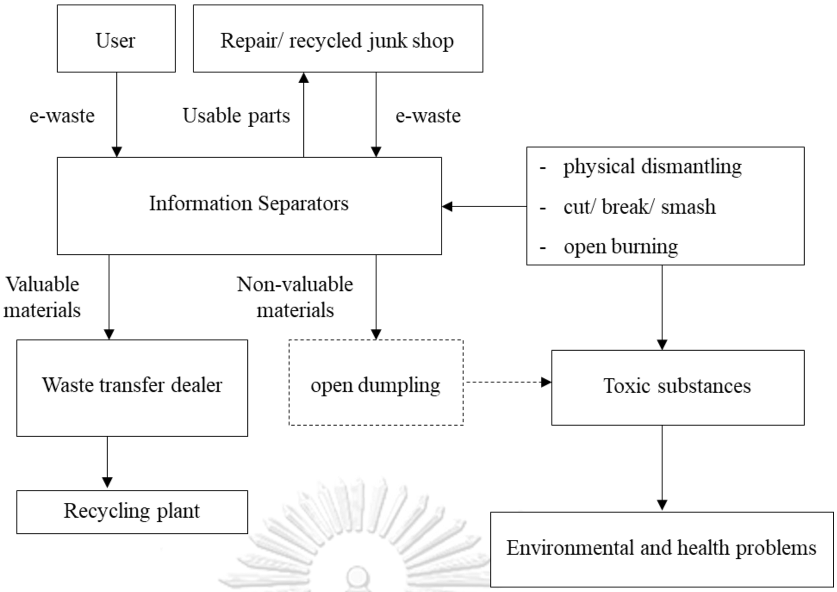


Figure 2.1 The simple diagram of e-waste dismantling by informal separators

(Thongkaow et al., 2017)

Therefore, informal electronic waste dismantling poses direct effects on human health with severe consequences (Cayumil et al., 2016); furthermore, informal e-waste dismantling workers easily expose to toxins emitted from the dismantling and resource recovery processes (Orlins & Guan, 2016).

2.4 Emission of particulate matter containing heavy metals from e-waste dismantling processes

Metals occur in different forms, as ions dissolved in water, as vapors, or as salts or minerals in rock, sand, and soil. Heavy metals may bind with organic and inorganic substances or can be attached with particles in the air. Heavy metals can combine with a variety of particulate matter (PM) forms. Heavy metals like Pb, Cu, and Zn often combine with PM present in the air. Therefore, heavy metals in particulate matter (PM) lead to environmental problems, especially air pollution.

Typically, particulate matter can be categorized based on their size. The five types of PM classified according to size are (1) thoracic particulate matter with an aerodynamic diameter of smaller than 10 μm (PM_{10}), (2) coarse particles ($PM_{2.5-10}$) with an aerodynamic diameter between 2.5 micrometers to 10 micrometers, (3) fine particulate matter with an aerodynamic diameter of less than 2.5 μm ($PM_{2.5}$), (4) ultra-fine particle are fine particles with a diameter of less than 0.1 µm ($PM_{0.1}$), and (5) nanoparticles with a diameter smaller or equal to 0.05 micrometers ($PM_{0.05}$) (U.S.EPA, 2004; Guevara, 2016). Deng et al., (2006) and Park et al., (2002) indicated that the total suspended particles (TSP) in ambient air, especially for fine particles with aerodynamic diameters of less than 2.5 µm ($PM_{2.5}$) have been associated with increased risks of mortality and morbidity.

Xue et al. (2012) studied the concentration of heavy metals in TSP and PM_{10} in ambient air of a production line for recycling printed circuit boards and also carried out health risk assessment. This study showed elevation in the concentrations of four elements, namely Cr, Cu, Cd, and Pb. The samples were analyzed by an inductively coupled plasma atomic emission spectrometry (ICP-AES). The results indicated that the concentration of Pb and Cu were high in TSP. Moreover, the concentration of Cu, Pb, Cr and Cd in PM_{10} were 0.88, 0.56, 0.12 and 0.88 µg/m^3, respectively. Therefore, four heavy metals were released into the ambient air of the automatic process line where crushing and separation processes took place.

The study of Zheng et al. (2016) measured the concentration of heavy metals in $PM_{2.5}$ emitted from diverse e-waste dismantling communities. For this study, the reference area was e-waste dismantling in Guiyu which is in Haojiang, China. Furthermore, the study assessed potential public health risks associated with the heavy metal composition of the $PM_{2.5}$. This study showed elevation in concentrations of four elements: Pb, Cd, Cr and Mn. The air samples were collected with Harvard Impactors on the roof of 3-story buildings. The concentrations of heavy metals in $PM_{2.5}$ were analyzed by graphite furnace atomic absorption spectrometry. The resulting geometric mean concentrations of the heavy metals present in $PM_{2.5}$ indicated that the concentrations of Pb and Cd in the e-waste dismantling area were higher than in the reference area.

Julander et al. (2014) studied inhalation exposure to metals of e-waste recycling workers, and office workers at three formal e-waste recycling plants in Sweden. This study could detect 20 elements include Fe, Zn, Cu, Ni, Cr, Cd, Pb, As, Mn, Sb, V, Co, Mo, W, Ga, In, Hg, Be, Tl, and Pt in particulate matter. The samples were measured using inductively coupled plasma-mass spectrometry (ICP-MS). The result shows that the recycling workers in three e-waste plants were exposed to higher air concentrations of all analyzed metals than those of office workers in the same plants. Moreover, the result found that the concentration of Cr and Pb showed a tendency to be at higher concentrations in the dismantling work task category compared with the categories indoors and outdoors workers.

In addition to the electronic waste site, there are other areas where researchers have measured and found the presence of heavy metals in respirable dust. The study of Gangwar et al. (2019) assessed the concentration of heavy metals in PM_{10} emitted from e-waste burning and industrial areas. A residential area in Morabad, India was considered as the control area for this study. The study showed assessment in six elements, namely Cd, Cr, Cu, Pb, Ni and Zn. The samples were analyzed by inductively coupled plasma optical emission spectroscopy (ICP-OES). Furthermore, the study focused on comparing the distribution of heavy metals and PM_{10} during the summer and monsoon seasons. It was found that the mean mass of PM_{10} in all areas exceeded the recommended value of NAAQS (100 μg/ m^3). Moreover, the concentration of Pb and Cd in PM_{10} in all areas and both seasons were higher than the permissible limits.

Puangprasert and Prueksasit (2019) studied the exposure to heavy metals via inhalation and performed a health risk assessment of workers in Buriram Province who separate electronic waste, and it was found that the concentration of PM_{10} obtained during the day, when workers separated the electronic waste, was 0.0646 mg/ m^3. Moreover, workers were exposed to diverse heavy metals with average concentrations of cadmium, copper, nickel and lead being 0.0073±0.01, 0.2083±0.64, 0.2916±0.37 and 0.1297±0.17 μg/m^3, respectively.

Moreover, Chanthahong and Kanghae (2017) measured the concentration of heavy metals in PM_{10} in non- and e-waste dismantling houses at Daengyai subdistrict, Banmaichaiyaphot District, Buriram province, and they also did a health risk assessment of the residents. They found that the concentration of copper outside the e-waste dismantling houses (0.042 ± 0.030 μg/m^3) was significantly higher than indoors (0.018 ± 0.018 μg/m^3), and the concentration of copper and chromium outside of e-waste dismantling houses (0.042 ± 0.030 and 0.052 ± 0.022 µg/m^3, respectively) were significantly higher than that of non - e-waste dismantling houses (0.014 ± 0.012 and 0.022 ± 0.021 µg/m^3, respectively).

These previous studies are examples of the concentration of heavy metals in particulate matter in different areas. The concentrations of heavy metals from each case study are summarized in Table 2.2.

Table 2.2 Heavy metals in e-waste recycling or dismantling sites from previous studies

Location	**The concentration of heavy metals in particulate matter (µg/m^3)**							**Reference**
	Cd	**Cr**	**Cu**	**Ni**	**Pb**	**Mn**	**Zn**	
E-waste dismantling site, Buriram, Thailand	0.0073±0.01	-	0.2083±0.64	0.2916 ±0.37	0.1297±0.17	-	-	Puangprasert and Prueksasit (2019)
E-waste dismantling village, Buriram, Thailand	0.006	0.052	0.042	0.017	0.041	0.010	1.950	Chanthahong and Kanghae (2017)
Production line for recycling waste printed circuit boards, Jiangsu, China	0.016	0.120	0.880	-	0.560	-	-	Xue et al. (2012)
E-Waste Burning and Industrial Sites, Moradabad, India	4.820	0.0006	50.680	5.010	4.670	0.239	90.470	Gangwar et al. (2019)
E-waste recycling plants, Sweden	0.180	0.450	2.200	0.490	7.000	2.200	14.000	Julander et al. (2014)

As above mentioned, there is evidence that the workers dismantled electronic waste by inappropriate methods and management systems as well as without using any personal protective equipment (PPE can be exposed to heavy metals contaminated in the PM mainly through inhalation. Consequently, heavy metals are able to be absorbed and accumulated in tissue (Park et al., 2017). To investigate harmful effects of the people's exposure to heavy metals, the biological monitoring of how much their amount entering the body can be applied that known as biomarkers.

2.5 Evaluation of heavy metal exposure of e-waste workers

2.5.1 Biological monitoring and biomarkers

Assessments of exposure to environmental pollutants are based on biological monitoring, which is a scientific method to measure and assess human exposure to environmental chemicals. The Foundation for the National Institutes of Health (FNIH) defines a biomarker as a characteristic that can be objectively measured and evaluated as an indicator of normal biological processes, pathogenic processes, or pharmacological responses to a therapeutic intervention. Further, a joint venture on chemical safety, the International Programme on Chemical Safety, which is led by the World Health Organization (WHO) in coordination with the United Nations and International Labor Organization, has defined biomarkers as “any substance, structure or process that can be measured in the body or its products and influence or predict the incidence of outcome or disease”. The WHO has defined biomarkers in environmental risk assessments as almost any measurement reflecting an interaction between a biological system and a potential hazard, which may be chemical, physical or biological. The measured response may be functional, physiological, biochemical at the cellular level or a molecular interaction (Strimbu & Tavel, 2010). Therefore, biomarkers can be used to measure any chemical or toxic substance present in the body.

There are various bio-monitoring to investigate the human exposure to environmental contaminants, determination of the metals level by using metabolites in human tissue and body such as blood, feces, urine, hairs, and nails had been done (Haines & Murray, 2012; Król et al., 2013).

Although there are many types of biomarkers, each type of biomarker has different advantages, limitations of biological matrices. Therefore, the WHO summarizes the advantages and limitations of biological matrices that are commonly used in available human biomonitoring studies to assess environmental exposures in humans as presented in Table 2.3.

Table 2.3 Biological matrices used in available human biomonitoring studies

Matrix	Population	Advantages	Limitations	Compounds measured in the matrix
Blood, serum, plasma	General	In equilibrium with all organs and tissues. Well established standard operating procedures (SOPs) for sampling.	Invasive; trained staff and special materials required. Volume limitation. Special conditions for transport and shipment.	POPs, metals/trace elements, organic compounds, tobacco Smoke, e.g.: alkylphenols, mercury, lead, dioxins, water disinfection byproducts, fluorinated compounds, organochlorine pesticides, organophosphate pesticides, phthalates, PCBs, dioxins.
Urine	General	Non-invasive, easy collection, no volume limitation. Allows analysis of metabolite	Composition of urine varies over time.	Metals/trace elements, organic compounds, tobacco smoke. Metabolites of environmental pollutants, e.g.: mercury, cadmium, arsenic, organochlorine compounds, BPA, organophosphate pesticides, parabens, phthalates, PAHs, benzene.

Hair	General, with few exceptions (i.e.neonates)	Non-invasive; minimum training required for sampling. No special requirements for transport and storage. Information about cumulative exposure during previous months. Segmental analysis is possible.	Hair is exposed to the environment and can be contaminated. Potential variations with subject’s hair colour, hair care or race.	Metals/ trace elements, POPs, e.g.: total mercury, methylmercury, arsenic, cadmium, parabens, organochlorine compounds
Nails	General	Non-invasive, easy collection. No special storage or transport requirements. Provide information about short and long term exposure.	Exposed to the environment and can be contaminated (toenails are less exposed). Less documented for available human biomonitoring applications.	Metals/trace elements, tobacco, e.g.: arsenic, mercury, cadmium, lead
Breast milk	Specific	Provides information about mother and child. Enriched with lipophilic compounds.	Somewhat invasive. Restricted period of availability. Depuration of chemicals during lactation should be considered.	POPs, metals/trace elements, organic compounds, tobacco, e.g.: alkylphenols, BPA, dioxins, BFRs, fluorinated compounds, PCBs, organochlorine pesticides, lead, cadmium, mercury, phthalates

Source: WHO, 2015

Blood biomarkers, measured to determine the concentration of metals/ trace elements (WHO, 2015), especially lead and cadmium. The studied of Sommar et al. (2013) measured lead concentrations in whole blood, plasma and urine as biomarkers for biological monitoring of lead exposure.

Blood biomarker describes different lead biomarkers' variances, day-to-day and between individuals, estimating their fraction of the total variance. The samples were repeated whole blood, plasma and urine of individuals under normal environmental lead exposure. The results showed that lead concentration in whole blood is the best biomarker that has the ability for discrimination between individual's exposure and different mean concentrations for both individuals under high and low lead exposure. Furthermore, urinary and plasma lead also performed acceptably in lead workers, but at low exposures, plasma lead was too imprecise. Urinary adjustments appear not to increase the between-individual fraction of the total variance among lead workers but among those with normal lead exposure. Moreover, blood lead, mainly red cell lead, is a representative of soft tissue lead, and most widely used as measures of body burden and absorbed internal doses of lead (Sakai, 2000). Similarly, the study of Ehrlich et al., 1998; Alli (2015), lead can be detected in blood within hours of exposure and can remain detected for at least 4 weeks since the half-life of lead in blood is 35 days. Similarly, blood cadmium used to measure recent exposure to cadmium, while urine cadmium reflects a much longer history of exposure (Adams & Newcomb, 2013). Therefore, blood lead level (BLL) and blood cadmium level (BCL) are reliable indicators of recent lead and cadmium exposure (Usuda et al., 2011).

Moreover, biomarkers are useful exposure surrogates given their ability to integrate exposures through all routes and to reflect interindividual differences in toxicokinetic processes (Sobus, Pleil, McClean, Herrick, & Rappaport, 2010). The toxicokinetic of inhalation exposure to lead and cadmium, lead can be absorbed into the human body through the respiratory system, then 99% of lead is bound to the hemoglobin portion of erythrocytes and is circulated via the vascular system to liver, kidney, bone, and hair. In parts of cadmium, inhalation is considered as the primary route of exposure, 100% of cadmium is absorbed into the blood. Cadmium will bind to albumin as enzyme in red blood cells and is transported to the liver (Keil et al., 2011).

2.5.2 Toxicokinetic of inhalation exposure to lead

Lead can be absorbed into the body primarily through ingestion and inhalation. Lead ingestion through consumption of contaminated food or drinks can occur in occupationally exposed individuals who do not wash their hands before eating at the workplace. Inhalation of lead may be a major exposure route for workers in lead-related occupations and lead present in inhaled dust could be absorbed. Though lead can be absorbed through both the respiratory and gastrointestinal systems, it is more readily absorbed through the respiratory system, which is a common exposure route in occupationally exposed individuals (Staudinger, 1998; ATSDR, 1999). Toxicokinetic of lead is gathered and reported by Agency for Toxic Substances and Disease Registry (ATSDR), Centers for Disease Control and Prevention (CDC) (ATSDR, 2007)

1) Absorption

Human inhalation exposure to lead through breathing in lead-contaminated air. The occupationally exposed involve in lead smelting such as soldering, steel welding and cutting operations, and battery manufacturing industries are especially likely to be exposed to lead. The form of lead in ambient is organic, which consisting of aerosols of particulates. Inorganic lead can by absorbed various tissues, which depend on particle size. Inorganic lead in submicron particles can be almost completely absorbed through the respiratory tract, while larger particles (>2.5 μm) are swallowed and deposited on the ciliated airways (nasopharyngeal and tracheobronchial). Smaller particles, such as fumes (aerodynamic diameter below 0.1 μm), can be better absorbed than larger particles through inhalation and ingestion routes and have large relative surface areas. Fumes and particles smaller than 5 μm are a concern for human health because they are inhaled more deeply into the lungs and are better absorbed at the alveolar-capillary interface than larger particles. Approximately 50% of the lead deposited in the respiratory tract is absorbed and enters systemic circulation, but less than 8% to 10% of lead deposited in the digestive tract via ingestion is absorbed.

2) Distribution

The distribution of lead in the body is route-independent and the total body burdens of lead in the bones of adults and children are approximately 94% and 73%, respectively. After exposure to lead through inhalation, lead is absorbed at the gastrointestinal or pulmonary tract and then quickly reaches other parts of the body via the blood. After lead enters the bloodstream, most of it is present in the red blood cells. Most of the lead circulated in the blood stream (over 95%) is found in the red blood cells, bound to erythrocyte proteins within the cell, while the remainder is associated with the plasma before it reaches the target organs such as bone and soft tissues (kidneys, lungs, brain, liver, muscles, and heart). Furthermore, lead can bind with sulfhydryl and carboxyl groups in protein as structural and functional components of proteins. Lead can be detected in blood within hours of exposure and based on a one-compartment pharmacokinetic model, blood lead was reported to have an average elimination half-life of 30 days. Therefore, it is thought to primarily represent variations in recent exposure, but in equilibrium with bone lead stores.

3) Metabolism

A variety of complex substances, both protein and non-protein ligands, play an important part in the metabolism of inorganic lead. Albumin and nonprotein sulfhydryls are major extracellular ligands, while in the red blood cells, delta aminolevulinic acid dehydratase (ALAD) is the major intracellular ligand. In addition, lead can form complexes with proteins in the cell nucleus and cytosol. The blood lead level increases due to some conditions such as pregnancy, lactation, menopause, and osteoporosis, resulting in increased bone resorption.

4) Excretion

Absorbed lead can be excreted from the body in many ways. Inorganic lead inhaled as submicron particles are deposited in the bronchiolar and alveolar regions of the respiratory tract, from where it is absorbed and excreted in urine and feces, which are the main routes of excretion. One third of the lead absorbed in the body is excreted in the feces (fecal/urinary excretion ratio of approximately 0.5). The fecal-urinary ratios will be higher in cases of inhalation of larger particle sizes as these particles would be cleared to the gastrointestinal tract. Other routes of excretion are sweat, saliva, hair and nails, and breast milk.

2.5.3 Toxicokinetic of inhalation exposure to cadmium

The major route of occupationally exposed workers is inhalation that exposed through dust and fumes. Inhalation exposure to cadmium was approximately 5 – 50 percentages of the cadmium from breathing that enter the body via the lungs, then be transported in the blood by red blood cells and accumulate in the kidneys and other tissues Toxicokinetic of cadmium is gathered and reported by ATSDR, and CDC (ATSDR, 2012).

1) Absorption

Inhalation exposure to cadmium metal and cadmium salts could occur approximately 25 percentage due to cadmium is not well absorb and low volatility. Cadmium is present in the air as fine suspended particulate matter. Absorption of inhaled cadmium depends on the size of the particulate matter: small particles (approximately 0.1 μm in diameter) tend to infiltrate into the alveoli, while large particles (greater than about 10 μm in diameter) tend to accumulate in the upper respiratory tract. In addition, some cadmium compounds such as cadmium chloride and cadmium sulfate are soluble and therefore their absorption from particles deposited in the respiratory tract, in which the major site of absorption is the alveoli, may be limited.

There is no data available on the distribution of cadmium in the human lung. However, animal studies show that lung retention is the greatest after short-term exposure (5–20% after 15 min to 2 h). After exposure ceases, the initial lung burden declines slowly because of the absorption of cadmium, and the lung is cleared of the deposited particles. The physiology of the human model for predicting the kinetics of inhaled cadmium shows that only about 5% of particles with diameters >10 μm and 50% of particles < 0.1 μm will be deposited, while 50 to 100% of cadmium deposited in the alveoli will ultimately be absorbed.

2) Distribution

The distribution of cadmium in both human and animal bodies, which is related to the route of exposure and duration of exposure, will be discussed as well. Cadmium is transported in the blood by red blood cells and high-molecular-weight proteins such as albumin. Occupational workers exposed to cadmium via inhalation, cadmium was distributed in the liver, kidney, pancreas, and vertebrae and most of it (50 to 70% of the body burden) accumulated in the kidneys and liver. The concentration of cadmium in the liver of occupationally exposed workers increases according to the amount of exposure and duration.

3) Metabolism

The metabolism of cadmium occurs through direct metabolic conversions such as oxidation, reduction or alkylation. Cadmium can occur in the form of ions, cadmium (+2) ion, which can bind with anionic groups (especially sulfhydryl groups (-SH)) in proteins (especially albumin and metallothionein) and other molecules according to the hard-soft acid-base theory.

4) Excretion

Humans generally excrete cadmium very slowly through urine and feces. Approximately 0.007% of cadmium in the body is excreted daily in the form of urine and approximately 0.009% through feces. Cadmium excreted in urine of occupationally exposed workers increases proportionally with the body burden of cadmium, but the amount of cadmium excreted represents only a small fraction of the total body burden unless renal damage is present. Cadmium entering the body via dermal exposure through contact with cadmium in industrial air and/or incidental ingestion through using contaminated hands is mostly eliminated through fecal excretion. Cadmium has a half-time of more than 26 years in the human body and is excreted starting at the 7th day after exposure up to the 30th day after exposure.

The toxicokinetic mechanism of lead and cadmium involving absorption, distribution, metabolism, and excretion, and biomarkers of exposure to lead and cadmium is illustrated in Figure 2.2.

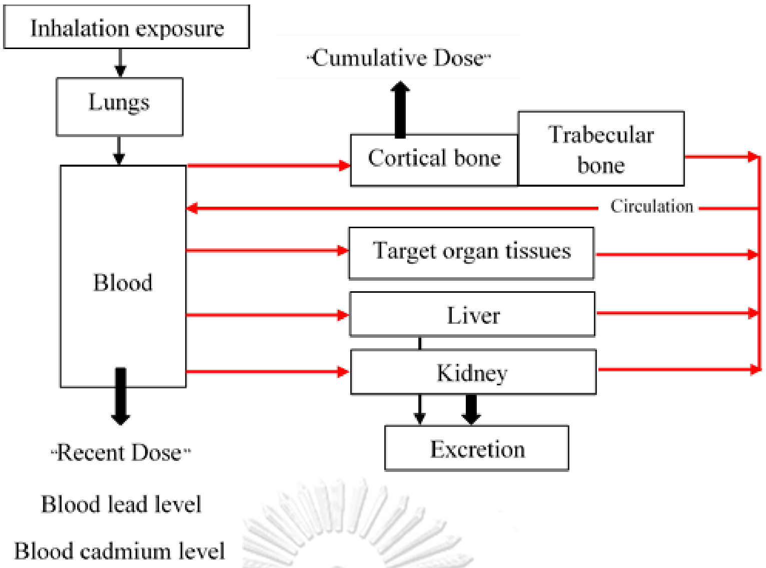


Figure 2.2 The toxicokinetic mechanism of lead and cadmium

O' Flaherty (1993) described the percentages of fractions of lead found in different tissue compartments. After lead entered the body through inhalation exposure, it was absorbed in lungs, then 2 – 5% lead was found in bloodstream. Lead in blood approximately 2 – 8% was transported to target organ tissues include liver and kidney before excretion. Moreover, lead more than 90% accumulated in bone.

The present studies show that blood biomarker can be used to measure the concentration of heavy metals, especially lead and cadmium. There are many studies that assessed lead and cadmium in blood as biomarkers or biomonitoring as follows.

The studied of Mittal et al. (2011) measured blood lead levels of workers in an e-waste recycling area in India. Samples were analyzed by haemogram and renal function tests to determine blood lead levels. They found that all samples had blood lead levels higher than the reference value (10 µg/dl) of the Centers for Disease Control and Prevention (CDC).

Srisaeng and Inmuong (2013) studied risk factors associated with blood lead levels of children under 5 years living in areas with electronic waste separation activity at Dangyai Sub-district, Banmaichaipoj District, Buriram Province. The 132 samples were collected. Personal data (such as gender, age, nutrition status, personal hygiene, underlying diseases, the occupation of the parents, and risk factors associated with eating habits, food and water intake, childcare location, food and water containers, time span of residing in the village, house painting, battery use, and the distance of the house from the e-waste separation plant) were collected from parents of the target children using questionnaires. The blood samples were analyzed by Graphic Furnace Atomic Absorption Spectrometry. The mean blood lead level of the children was 3 µg/dl and blood lead levels ranged from 1.5 to 13.5 µg/dl. Compared to the US CDC standard level of 5 µg/dl, blood lead levels of the children were higher by 14.40%. In this study, 51.52% of the participating children were females, of which 26.52% were between the ages of 2.10 and 3.00 years. Most of the children (75.00%) were of a normal nutritional status, 18.94% had diseases, and 43.94% had parents who were involved in electronic waste separation. Furthermore, the analysis of personal and exposure risk factors did not show a statistically significant correlation between these factors and blood lead levels ($p>0.5$).

In addition, Alli (2015) studied the blood levels of lead and cadmium of occupationally exposed (for example automobile mechanics, generator mechanics, fuel attendants, battery charger, and spray painter) and non-occupationally exposed individuals. The blood levels of lead and cadmium were analyzed by an absorption spectrophotometer (AAS). This study found that blood levels of lead and cadmium in occupationally exposed higher than non-occupationally exposed. Moreover, the mean blood cadmium levels for both the occupationally exposed and non-occupationally exposed in this study were higher than the WHO's permissible range of 0.03 – 0.12 µg/dl of Cd (WHO, 1996). Blood levels of lead and cadmium in the occupationally exposed subjects correlated with age, with the younger age group recording lower values for their levels.

Amankwaa et al. (2017) measured blood lead levels of e-waste workers and non-e-waste workers in informal e-waste site, Ghana. Blood lead levels were analyzed using an Atomic Absorption Spectroscopy (AAS). The results found that the mean of non-e-waste workers (3.54 µg/dl) was slightly higher than e-waste workers (3.49 µg/dl). Therefore, the impact of e-waste recycling is not limited to workers alone.

The study of Wittsiepe et al. (2016) measured the concentrations of lead and cadmium in blood, mercury in hair, and cadmium, chromium, mercury, and nickel in urine between electronic waste workers and non-electronic waste workers in an informal electronic waste site and control area in Accra, Ghana. The blood lead and cadmium samples were analyzed using Graphite Furnace Atomic Absorption Spectrometry (GF-AAS). The result found that the blood lead levels of e-waste workers were higher than control group. As for blood cadmium levels of e-waste workers were as same as the control group.

Chen et al. (2019) studied the concentration of blood lead and cadmium of workers in an e-waste-polluted area in Guiyu and compared with the reference group from Jinping, China. The samples were analyzed by Graphite Furnace Atomic Absorption Spectrometry (GF-AAS). The result found that the concentration of lead in exposed group was higher than reference group, while the concentration of cadmium in exposed group lower than reference group. In addition, this study analyzed human hematological: red blood cells (RBC), hemoglobin (Hb), and platelet count (PLT) and hepatic functions: aspartate aminotransferase (AST), alanine aminotransferase (ALT), lactate dehydrogenase (LDH), gamma glutamyl transferase (GGT), and total bilirubin (TBIL). The concentration of lead and cadmium from the e-waste-polluted area could affect their functions. Besides, age influences the accumulation of cadmium and lead in the blood. It is found that samples older than 40 years have higher GGT, LDH, RBC and Hemoglobin values than the reference group.

Noguchi et al. (2014) studied exposure to lead in workers and children in lead-acid battery recycling craft village, Dong Mai, Vietnam. This study measured the concentration of lead in hair, blood, and urine. The samples were collected in the workers and children, Dong Mai village and two reference sites, Hanoi city and Duong Quang village, respectively. The result found that the lead levels in hair, blood, and urine were higher than those in reference sites. Moreover, blood lead levels of all adults and children exceeded 10 µg/dL, the Centers for Disease Control and Prevention definition of an elevated blood lead level. Therefore, the toxicity of lead was not limited to recycling workers but also in children and women of reproductive age.

Srigboh et al. (2016) used blood and urine as biomonitoring to investigate heavy metals, including Cd, Hg, Pb, Cu, Fe, Mn, Se, and Zn. The samples were collected in the workers at Agbogbloshie electronic waste site, Ghana. The study categorized four main e-waste activities: dealing, sorting, dismantling, and burning e-waste materials. The result found that the levels of many blood and urinary elements were within reference ranges of The National Institute for Occupational Safety and Health (U.S. CDC/NIOSH), but the blood lead levels of workers were higher than the reference level of U.S. CDC/NIOSH. Similarly, the levels of urinary arsenic were higher than the Agency for Toxic Substances and Disease Registry (U.S. ATSDR) value. Moreover, this study found that the workers who burned e-waste tended to have the highest biomarker levels.

Moreover, Arain and Neitzel (2019) reviewed on the studies about blood, hair, and urine as the biomarkers used for assessing communities and workers exposed to metals from e-waste. This study evaluated 19 publications from 2009 to 2018. The reviewed in this study represented exposed to heavy metals of four groups which can be divided into occupationally exposed group (e-waste recycling workers), non-occupationally exposed group (who are exposed to e-waste through other activities), reference group (who may be exposed to one or more types of metal but not through e-waste activities), and control group (who are not believed to be exposed to any significant source of metals). In addition, the reviewed presenting both the formal and informal e-waste recycling in six differences counties, especially e-waste recycling in China and Ghana. The result found that the blood lead levels (BLL) were found in both the formal and informal e-waste recycling sectors. Moreover, the highest BLL were found in both occupationally and non-occupationally exposed groups of a lead acid battery recycling in Vietnam (Noguchi et al., 2014), while other study found that the BLL of non-occupationally male in control group were slightly higher than that of e-waste recycling workers (Dartey et al., 2017). For blood cadmium level were found six publications that measured blood Cd only one reported any values above the 5 µg/L reference level, which was the maximum value in a formal e-waste recycling population in the USA, at 17 µg/L.

Julander et al. (2014) evaluated workers' exposure to metals, using blood, urine, and plasma as biomarkers of exposure in combination with monitoring of personal air exposure at formal recycling plants, Sweden. The samples were compared between recycling workers of three companies and office workers. The result found that recycling workers in three Swedish e-waste plants were exposed to higher air concentrations of all analyzed metals than those of the office workers in the same plants. Moreover, the median of Pb and Cr in blood, Cr and In in plasma, Hg and Pb in plasma of recycling workers were significantly higher than the office workers. Correlation analysis of metals in the inhalable fraction and exposure biomarkers (blood, plasma and urine) showed close to linear correlations also for Sb and V, besides Hg, In, and Pb, supporting occupational exposure to multiple metals at e-waste recycling work.

In 2018, Department of Disease Control (DDC), Ministry of Public Health measured blood lead and cadmium levels of e-waste dismantling workers in Dang Yai Sub-district, Ban Mai Chaiyapot District and Ban Pao Sub-district, Putthisong District, Buriram province. The report reveals that the range of blood lead and cadmium levels of the workers in Dang Yai Sub-district were found N.D. – 32.7 µg/dl and N.D. – 1.6 µg/l, respectively. Likewise, those of Ban Pao Sub-district was the range of blood lead and cadmium levels of N.D. – 13.1 µg/dl and N.D. – 1.3 µg/l, respectively. However, blood lead and cadmium levels of workers in this area lower than the Thai Biological Exposure Indices (Thai BEIs) value for blood lead and cadmium were 30 µg/dl and 0.50 µg/dl, respectively (DDC, 2016).

Goyal et al. (2020) studied blood lead and cadmium levels of occupationally exposed workers of Jodhpur, Rajasthan, India. The blood samples were collected from the workers who worked at manufacturing plant of furniture, metal handicraft and welders, as a exposed group, while people with no history of occupational exposure to heavy metal were set up as a control group. The results found that blood lead and cadmium level were significantly higher in the exposed group (6.51±11.86 µg/dl and 2.48 ± 1.20 µg/l, respectively) than the non-exposed group (2.34 ± 4.66 µg/dl and 1.09 ± 0.73 µg/l, respectively). Moreover, significant age and gender-based differences were found in terms of blood cadmium levels but no such difference was observed in case of blood lead levels. These are examples of previous studies on blood lead and cadmium levels in different areas, which are shown in Table 2.4.

Table 2.4 Blood lead and cadmium levels reported in previous studies

Site	Exposure Group	Blood lead levels (µg/dl)	Blood cadmium levels (µg/l)	Reference
Informal e-waste dismantling site, Dang Yai Sub-district, Buriram, Thailand	Occupational	N.D. – 32.7	N.D. – 1.6	Department of Disease Control (2018)
Informal e-waste dismantling site, Ban Pao Sub-district, Buriram, Thailand	Occupational	N.D. – 13.1	N.D. – 1.4	Department of Disease Control (2018)
Gwangwalada, Abuja, Nigeria	Occupational	45.43±6.93	11.63±1.73	Alli (2015)
	Non-occupational	12.08±2.87	2.03±0.55	
E-waste recycling site, Agbogbloshie, Accra, Ghana	Occupational	10.19	0.55	Wittsiepe et al. (2016)
	Control group	4.43	0.57	
Informal e-waste processing site, Ghana	Occupational	3.49	-	Amankwaa, Adovor Tsikudo, and Bowman (2017)
	Non-occupational	3.54	-	
Informal e-waste recycling, Vietnam	Occupational	4.82	-	Schecter et al. (2017)
	Control group	2.93	-	
E-waste site, Ghana	Occupational	7.93	1.70	Srigboh et al. (2016)
	Non-occupational	3.71	1.40	
Jodhpur, Rajasthan, India	Occupational	6.51 ± 11.86	2.48 ± 1.20	Goyal et al. (2020)
	Non-occupational	2.34 ± 4.66	1.09 ± 0.73	
Thai Biological Exposure Indices	Occupational	30.0	5.0	Department of Disease Control (2016)
Reference value	Occupational	<40.0	<5.0	Casaret et al. (2007) and Tietz and Clin Chem. (1992)
	Non-occupational	<25.0	<1.0	

The effect of lead and cadmium causes kidney damage but lead and cadmium in blood cannot measure kidney function. Thus, creatinine in serum can indicate the effects to kidney function. A creatinine blood test is a method for measure waste product in the body and kidney function. Creatinine is a chemical waste product in the blood that passes through the kidneys to be filtered and eliminated in urine.

Typically, creatinine travels in the blood to the kidneys where it leaves the body in the urine. Blood lead and cadmium levels was positively link with creatinine in blood (Chen et al., 2019). Therefore, high levels in the blood might indicate that the kidneys are not working correctly (Marcin, 2018). When the kidneys function abnormally resulting creatinine accumulating in blood. As a result, serum creatinine levels are commonly used as a surrogate for glomerular filtration rate (GFR) and kidney function (Xue et al., 2012).

2.6 Factors relevant to lead and cadmium in blood

Factors that are relevant to the concentrations of lead and cadmium in blood: the socio-demographic and other factors such as exposure factors, behavior and health factors, and environmental factors of subjects may be associated with the concentration of lead and cadmium in blood.

2.6.1 The socio-demographic factors

Socio-demographic characteristics include, for example, gender, age, sex, education, and migration background. The study of Kira et al. (2016) and Amankwaa et al. (2017) found that gender had been significantly associated with the concentration of cadmium in blood, which the blood cadmium level of men was higher than women. This finding may be accounted for by various factors, such as greater exposure to lead and higher hematocrit values among men and sex differences in lead metabolism (Batariová et al., 2006; Popovic et al., 2005; Skerfving et al., 1999; WHO, 1995). Moreover, The BLL can increase parallel to the hematocrit because approximately 99% of the lead in blood is in the red blood cells (WHO, 1995). Age is another important factor. The blood lead concentration of adults was higher than children (Kira et al., 2016). Lead absorption is influenced by age, among adults, approximately 10% of the ingested lead is absorbed, and absorption may be higher in the fasting condition or in the presence of dietary calcium, phosphate, selenium or zinc deficiency; among children, up to 50% of the ingested lead may be absorbed (WHO, 1995). The increase of the BLL parallel to age might also be explained by the fact that among adults, 94% of the lead present in the body is stored in the bones, while among children, this percentage is 73% (WHO,1995).

2.6.2 Exposure factors

Exposure factors are actions and media that bring us in contact with environmental agents. The study of Amankwaa et al. (2017) found the associated factors about working years and working hours that BLLs have a significant difference in workers. Due to the workers exposed to lead from variables route: ingestion, dermal contact, and inhalation of e-waste contaminants concentrated in the air via dust and smoke are plausible paths way for BLL accumulation. Also, the trend might have resulted from older workers' increased exposure over time coupled with their lower rate of excretion (Hu et al., 2007). Furthermore, the BLLs of workers depending on e-waste occupational variation. Likewise, residence at the site, the blood lead levels of non-e-waste workers who working in e-waste sites, were slightly higher than e-waste workers.

2.6.3 Behavioral and health factors

A person's health is influenced by health behaviors that are part of their individual lifestyle. Behavioral risk factors such as poor eating patterns can have a detrimental effect on health. Sun et al. (2016) found smoking habit as behavior factor, the blood cadmium level of current smokers was significantly higher than never smokers but was not significantly higher in former smokers than never smokers. Moreover, Kira et al. (2016) indicated that alcohol consumption affects the concentration of cadmium in the blood. The blood cadmium concentration was higher among the participants who consumed alcohol at least once per week, compared to the ones who drank up to three times per month. This finding agrees with the results reported by Forte et al. (2011), according to which the blood cadmium levels were 1.3-fold higher among Italians who consumed alcohol regularly compared to the ones who did not drink. Participants' frequency of changing work clothes was also measured as a dummy variable where those who change their clothes every day were expected to record lower levels of lead in their blood compared to those who seldom change their clothes. Therefore, e-waste workers change their clothes every day were lower levels of lead in their blood compared to those who seldom change their clothes (Amankwaa et al., 2017). Iron status is another factor associated with blood cadmium levels; blood cadmium levels of females may be explained by higher absorption due to low iron status (Olsson et al., 2002).

Some factors that are relevant to the concentrations of lead and cadmium in the blood such as factors affecting exposure to lead and cadmium in the environment, behavioral and health factors are summarized in Table 2.5.

Table 2.5 Factors relevant to lead and cadmium levels in blood

Category of factor	Factor	Result	Reference
Socio demographic factors	Gender	Blood cadmium levels of men were higher than those of women.	Kira et al. (2016) and Amankwaa et al. (2017)
	Age	Blood lead concentrations of adults were higher than those of children.	Kira et al. (2016)
Exposure factors	Working hours	Blood lead levels of e-waste workers positively correlated with working hours.	Amankwaa et al. (2017)
	Residence at the site	Blood lead levels of non-e-waste workers working in e-waste sites were slightly higher than those of e-waste workers.	Amankwaa et al. (2017)
Behavioral and health factors	Smoking habit	Blood cadmium levels of current smokers were significantly higher than those of non-smokers.	Sun et al. (2016)
		Blood cadmium concentrations of smokers were four times higher than those of non-smokers.	Kira et al. (2016)
	Alcohol consumption	Blood cadmium concentration was higher among participants who consumed alcohol at least once per week than among those ones who drank up to three times per month.	Kira et al. (2016)
	Frequency of changing work clothes	E-waste workers who changed their clothes every day had lower levels of lead in their blood than those who seldom changed their clothes.	Amankwaa et al. (2017)
	Iron level	Blood cadmium levels in females could be attributable to higher absorption due to low iron levels.	Olsson et al. (2002)

2.7 The analytical method for measuring the concentration of lead and cadmium in blood

Direct instrumental analysis of biological samples is difficult because these samples have complex matrices that consist of a high abundance of proteins, cells, clots, fluids, and chloride-based salts. Each of these components has various elemental compositions. In the sample preparation step, inorganic elements are extracted easily, while others are organically confined to cell structures and need more aggressive extraction or acid-digestion technique to completely decompose and remove the organic substance. For human biomonitoring, whole blood is one of the most accurate biological samples for evaluating human exposure to toxic heavy metals such as lead and cadmium (mainly erythrocytes) that are bound to intracellular proteins. Preparation methods for blood sample are included as follows:

1) Complete acid digestion using closed-vessel microwave digestion

To completely dissolve heavy metals in all organic matter, microwave digestion is a common closed digestion technique that is considered to prevent the loss of volatile elements, although the possibility of contamination in samples is increased by increased specimen handling. The time that is taken to finish a digestion cycle and to prepare a large batch of samples is a significant limitation of microwave digestion. While open digestion systems are simple and suitable for holding very large batches, there is the potential loss of volatile elements including Hg, As, and Se in this system.

2) Acidic dilution

For the acidic dilution method, 0.5% HNO_3, 1% propanol, 0.1% Triton X-100 and 200 ppb Au are also used as a reagent for digestion. These high-purity reagents are required to keep minimum contamination during sample preparation. Nitric acid is added for coagulating proteins and Triton X-100 surfactant can break down cell membranes and retain sample homogeneity. In this method, the elements are stabilized by using a nitric acid solution. The presence of carbon from biological material in the sample can affect the ionization efficiency, especially poorly ionized elements (e.g. As, Se). Therefore, propanol is a miscible organic solvent that is used to buffer this effect by saturating all measured solutions with carbon. Furthermore, gold is added at around 200 ppb to eliminate the memory effects of mercury during the analysis.

3) Alkali dilution

In this method, a 2% ammonium hydroxide solution is used for contributing to an alkaline matrix and preventing the formation of biological material from coagulating. EDTA is a complex agent to stabilize the analyte elements in samples. As explained in the acidic dilution part, propanol, Triton X-100, and 200 ppb Au are used for the same reasons. The alkaline dilution can also stabilize the iodine signal and reduce the memory effect during the iodine analysis.

Various analytical methods have been available for detecting and determining the level of heavy metals in biological samples. The most common analytical methods are employed include anodic stripping voltammetry (ASV), graphite furnace atomic absorption spectrometry (GFAAS), atomic absorption spectroscopy (AAS), inductively coupled plasma-mass spectrometry (ICP/MS). For selecting the suitable analytical method, there are several criteria that are considered: ease of use, sample preparation requirements, selectivity, sensitivity, detection limits of the instrument, multi-analyte capability, speed of analysis, operation time, risk of analytical interferences, and cost. Common laboratory techniques, used for toxic element detecting, are summarized in Table 2.6.

Table 2.6 Overview of common laboratory methodologies used for toxic element testing

Methodology	ASV (Lead only)	AAS	ICP – MS
Principle of detection	Current required to strip plated electrode	Absorption of element-specific wavelength	Mass to charge ratio
CLIA-waived	Yes	No	No
Approximate capital expense (x ~$10,000)	<1x	3 – 6x	15 – 30x
Multi-analyte capability	No	Possible, but not common	Yes
Detection limit	3.3 µg/dL	-	Lowest
Dynamic range	65 µg/dL	-	Highest
Sample preparation	None	Yes-dilution and chemical modifiers common	Yes-dilution with nitric acid common

Source: Keli et al, 2017

CHAPTER III

RESEARCH METHODOLOGY

3.1 Study areas

This study was conducted at e-waste dismantling areas located at Dang Yai sub-district, Ban Mai Chaiyapot district and Ban Pao sub-district, Putthisong district in Buriram province, Thailand. These sub-districts consist of 9 and 12 villages, respectively. There are 5 and 7 of all villages in Dang Yai and Ban Pao sub-district that have e-waste dismantling. The location of the study areas is shown in Figure 3.1.

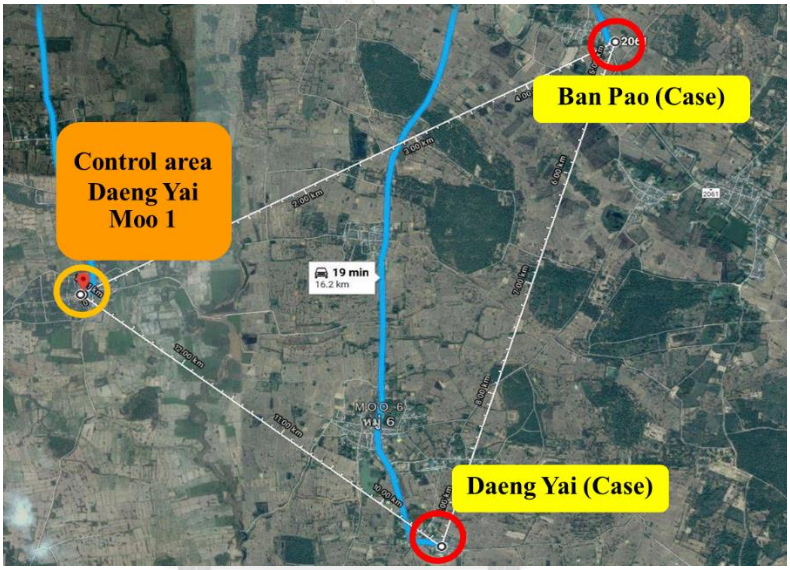


Figure3.3 Location of the study area in Daengyai Sub-district Banmaichaiyaphot district, and Ban Pao Sub-district, Putthisong district, Buriram Province, Thailand

3.2 The population and target samples

The target population in this study were the local people of Dang Yai sub-district and Ban Pao sub-district. In 2019, Dang Yai Sub-district had 1,091 households, of which 105 households are involved in e-waste dismantling activity. Similarly, Ban Pao Sub-district has 1,315 households, and 68 households are involved in e-waste dismantling work. Therefore, the total number of households that are involved in e-waste dismantling activity in both two sub-districts are 173 houses. In addition, these 173 e-waste households consist of family members who work on e-waste dismantling. Each household has approximately four e-waste workers as average, which means that there are 692 e-waste workers in the study area.

In this study, the target sample was calculated according to Yamanae (1973) at the 90% confidence level as Eq 3.1. The calculation result shows that at least 76 subjects from both two villages should set up as the target samples. The total target subjects of 145 are then assigned that were 95 cases and 50 of control for blood sampling.

$$n = \frac{N}{1 + Ne^2} \qquad \text{(Eq. 3.1)}$$

where:

n = Sample size

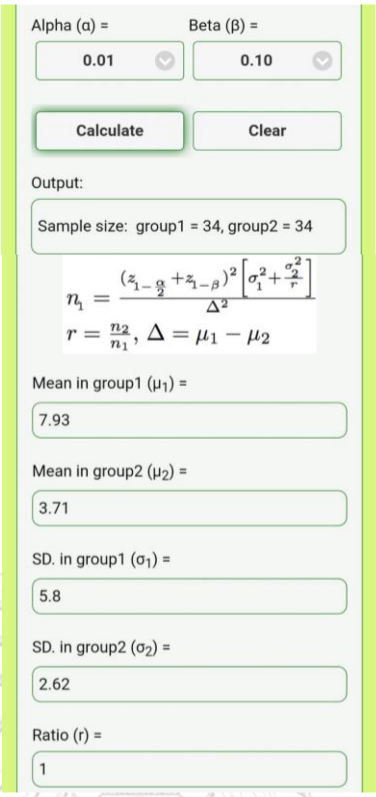
N = Total population

e = Error (At the confidence level of 90% is 0.10)

$$n = \frac{692}{1 + (692)(0.1)^2}$$

$$n = 76$$

Additionally, this study also used the N4Studies program to calculate the sample size (Bernard, 2000; Srogi, 2006). The data from different mean blood levels and standard deviation such as blood lead levels derived from the study of Srigboh et al. (2016), blood lead levels of e-waste (7.93±5.8 µg/dl) and non-e-waste workers (3.71±52.62 µg/dl) at the Agbogbloshie e-waste site in Ghana, was applied for the calculation. The significant level of 99% or Alpha (α) at 0.01 was set for testing two independent means, as shown in Figure 3.2.



Alpha (α) = 0.01

Beta (β) = 0.10

Output:

Sample size: group1 = 34, group2 = 34

$$n_1 = \frac{(z_{1-\frac{\alpha}{2}} + z_{1-\beta})^2 \left[\sigma_1^2 + \frac{\sigma_2^2}{r}\right]}{\Delta^2}$$

$$r = \frac{n_2}{n_1},\ \Delta = \mu_1 - \mu_2$$

Mean in group1 (μ_1) = 7.93

Mean in group2 (μ_2) = 3.71

SD. in group1 (σ_1) = 5.8

SD. in group2 (σ_2) = 2.62

Ratio (r) = 1

Figure 3.4 The N4Studies program for sample size calculation

From the calculation by the program, at least 34 samples were assigned for both target groups. All the subjects of 145 were then requested to sampling either blood or inhalation exposure to Pb and Cd in PM. The total number of both sample types are described below.

1) Blood samples were collected from a total of 145 target samples that were separated into two groups: case group and control group. The case group was consist of 50 e-waste workers from Dang Yai sub-district and 45 e-waste workers from Ban Pao sub-district, and the control group was 50 persons in Dang Yai sub-district who do not have any occupation involving with e-waste dismantling activity and live in the village without disassembly of e-waste.

2) The target samples for inhalation exposure were taken from the same 90 persons who gave the blood samples from both villages. This target subject was

randomly selected and separated into 70 people for the case group and 20 people for the control group.

Moreover, the inclusion criteria for all sampling subjects are defined as follows:

1) The case subject was male or female electronic waste workers.

2) The case subject did not have any occupation that poses to cause a high blood lead level, such as house painters.

3) The control subject was male or female who was non-electronic waste workers or had other occupations.

4) Both groups were between 18 and 65 years old.

5) Both groups were a non-smoker.

6) Both groups were no history of the disease associated with the interpretation of blood lead and cadmium levels and creatinine such as liver disease, kidney disease, and hemolytic anemia, or icteric (3+).

7) Both groups were the person who has good Thai communication skills for an interview with a questionnaire.

3.3 Sampling and data collection

This study was involved with human subject experimentation, which consists of blood samples, personal air samples, and questionnaires. The research ethics on human has been approved from the International Conference on Harmonization - Good Clinical Practice (ICH – GCP), Chulalongkorn University, COA No.217/2561**.**

3.3.1 Blood lead and cadmium level samples collection and storage

Blood samples were collected the next day after the air sampling date. Blood samples (3 ml per person) were collected by nurses from a local hospital and stored in a clotted blood tube, as shown in Figure 3.3. Ethylenediamine tetra-acetic acid (EDTA) was added as an anticoagulant. Each tube was identified and labeled the name of non- and e-waste workers. Blood samples were immediately placed in an icebox at the site of blood collection and transferred to keep in a refrigerator at 4°C.

Figure 3.5 Blood sample collection of target participants

3.3.2 Creatinine samples collection

A 5 ml blood sample was collected by nurses and stored in a clotted blood tube, Figure 3.4. Blood samples were left to settle for approximately 20 minutes. Then, blood samples were centrifuged by using a centrifuge (H-11D, Kokusan Enshinki) at 3,000 rpm for 10 minutes, in which blood samples were separated between red blood cells and serum. The resum of non- and e-waste workers were separated into tubes that identify their names. Serum samples were immediately placed in an icebox and transferred to keep in refrigerator at 0°C. Finally, serum samples were stored until the next analysis step.

Figure 3.6 Serum creatinine collected from the participants

3.3.3 Inhalation exposure sampling

1) Sampling filter preparation

$PM_{2.5}$ and $PM_{2.5-10}$ samples were collected on Polytetrafluoroethylene (PTFE) filters with 37 mm diameter and 2 µm pore size, and 25 mm diameter and 0.2 µm pore size, respectively. Then, both sizes of filters were cleaned by soaking with 25 ml acetone in a beaker for 15 minutes. Then, the filters were dried up on a watch glass in the hood for 10 minutes. The filters were stored in opaque plastic cases and kept in a desiccator at room temperature and 30 to 40% humidity for at least 24 hours before weighing. Finally, each filter was weighed by a 7 digits analytical balance (Mettler-Toledo UMX2 Ultra Microbalance) and was stored in an opaque plastic case until the field sampling.

2) Personal air sampler preparation

A personal air pump (SKC Airchek Sampler Model 224-PCXR8) was charged and calibrated by the primary gas flow calibrator (Defender 530, Drycal TECHNOLOGY) at the flow rate about 3 L/min. The sampling of PM was performed by using a personal air pump connected to Personal Modular Impactors (PMIs), which contained both sizes of filters. The joints between all equipment were wrapped by parafilm to prevent the leakage of the airflow system. This whole set of equipment was ready for sampling in the next step.

3) $PM_{2.5}$ and $PM_{2.5-10}$ sampling method for inhalation exposure of lead and cadmium

The whole set of personal air sampler was installed by attaching with the worker body or placing at the working space at the height of the breathing zone of each worker for approximately 8 hours, as shown in Figure 3.5. After finish sampling, the personal air samplers were measured the airflow rates. The sampled filters were kept in plastic cases and stored in a desiccator for at least 48 hours before weighing. The sampled filters were weighed by the 7 decimal places analytical balance again to obtain the weight after sampling.

Figure 3.7 The Air samples collection of participants

Finally, the sampled filters were calculated the concentrations of particulate matter (PM) following Eq. 3.2 – 3.6;

$$C_{PM} = \frac{M_{PM}}{V_{air}} \quad \text{(Eq. 3.2)}$$

$$M_{PM} = W_{filter,\ post} - W_{filter,\ pre} \quad \text{(Eq. 3.3)}$$

$$W_{filter,\ pre} = (W_{filter,\ pre,1} + W_{filter,\ pre,2} + W_{filter,\ pre,3})/3 \quad \text{(Eq. 3.4)}$$

$$W_{filter,\ post} = (W_{filter,\ post,1} + W_{filter,\ post,2} + W_{filter,\ post,3})/3 \quad \text{(Eq. 3.5)}$$

$$C_{PM10} = C_{PM2.5} + C_{PM2.5\text{-}10} \quad \text{(Eq. 3.6)}$$

where:

C_{PM} = PM concentration (mg/m^3)
$C_{PM2.5}$ = $PM_{2.5}$ concentration (mg/m^3)
$C_{PM2.5\text{-}10}$ = $PM_{2.5\text{-}10}$ concentration (mg/m^3)
M_{PM} = Mass of PM (mg)
V_{air} = Air volume (m^3)
= Flow rate of air (m^3/min) x sampling time (min)
$W_{filter,\ post}$ = Weight of filter after sampling (mg)
$W_{filter,\ pre}$ = Weight of the filter before sampling (mg)

3.3.4 Additional data collection by questionnaire

The questionnaires were used to gather the personal information of non-e-waste workers (control group) and e-waste workers (case group).

1) The questionnaire of the case group was prepared to collect information on their age, underlying disease, occupational disease, or symptoms from lead and cadmium poisoning. Symptoms of lead poisoning are squeamish and vomiting, irritability, muscle pains, and fatigue. In addition, there are some symptoms that can be observed: purple or black color around the gums that are called lead lines. While, irritation of the respiratory tract, dyspnea, chest pains, headache, and muscular weakness are notified as cadmium poisoning. The questionnaire was used to assess the symptoms in association with the exposure of cadmium and lead, as presented in Table 3.1.

Table 3.7 The symptoms of lead and cadmium poisoning in the questionnaire

Symptoms from lead poisoning	Symptoms from cadmium poisoning
Squeamish	Irritation of the respiratory tract
Vomiting	Dyspnea
Irritability	Chest pains
Muscle pains	Headache
Fatigue	Muscular weakness
Purple or black color around the gums	

2) The questionnaire of the control group was used to gather the personal information, which related to their age, the main occupation of their family, drinking water source. Further, some diseases that might affect the detection of lead and cadmium levels in the blood, such as anemia and kidneys disease, were also assessed. Moreover, the observational information of e-waste workers, including working conditions and using PPE, was recorded. The information on the working condition was working hours, working hours within a week, working day, and working period, while using short gloves, mask, and sneakers as PPE was also observed, Figure 3.6. Moreover, the questionnaire interviews and observational information of e-waste and non-e-waste workers are show in Table 3.2.

Figure 3.8 The PPE used by e-waste workers in this study

Table 3.8 The information gathered by questionnaire interviews and observation from e-waste and non-e-waste workers

Participants	**Contents**		
	Personal information	**Working condition**	**Using PPE**
E-waste workers	- Gender - Age - Height - Weight - Symptoms of lead and cadmium poisoning - Medicine - Congenital disease - Smoking status	- Working hour - Working hour within a week - Working day - Working period	- Short gloves - Mask - Sneakers
Non-e-waste workers	- Gender - Age - Height - Weight - Main family occupation - Drinking water source	-	-

All 145 participants were asked to collect blood samples and questionnaires categorized as 50 e-waste workers from Dang Yai sub-district, 45 e-waste workers from Ban Pao sub-district and 50 non-e-waste workers. Besides, within the total participants, 90 participants were requested to collect air samples, which consisted of 36 e-waste workers from Dang Yai sub-district, 34 e-waste workers from Ban Pao sub-district, and 20 non-e-waste workers, as presented in Table 3.3.

Table 3.9 The sample numbers obtained from the participants in this study

Participants	Parameters		
	Blood samples (N = 145)	Air samples (N = 90)	Questionnaires (N = 145)
E-waste ^{DY}	50	36	50
E-waste ^{BP}	45	34	45
Non-e-waste	50	20	50

^{DY} = E-waste workers from Dang Yai sub-district, ^{BP} = E-waste workers from Ban Pao sub-district

3.4 Extraction and Analysis of blood sample

3.4.1 Determination of lead and cadmium in blood samples

Blood samples were analyzed by Special Laboratory Center Co Ltd Sathorn, Thailand. This laboratory passed certified from U.S. Department of Health and Human Services, Centers for Disease Control and Prevention. Blood samples were extracted by acid digestion method following the method instructed by Atlanta ATSDR (2012). The samples were extracted by 0.005% Triton X-100, 0.5% HNO_3 and 12.5 µg/L Rhodium. Then, the samples were analyzed by Inductively Coupled Plasma Spectrometry-Mass Spectrometry (ICP-MS) following the method instructed by Centers for Disease Control and Prevention (2004).

3.4.2 Determination of creatinine in serum

The concentration of creatinine in serum samples was analyzed by Health Sciences Service Unit, the Faculty of Allied Health Sciences, Chulalongkorn University, which passed ISO 15189 and ISO 15190 certifications. The samples were determined following the enzymatic method and assay on the ARCHITECT c Systems™ and the AEROSET System.

3.5 Extraction and analysis of lead and cadmium in $PM_{2.5}$ and $PM_{2.5-10}$

Lead and cadmium in $PM_{2.5}$ and $PM_{2.5-10}$ samples were extracted by acid digestion method following the method of U.S. EPA 3051. The samples were digested by microwave digester (ETHOS one). 10 ml 40% HNO_3 for 1 hour were added into the sampled filters. Then, the extracted solution was transferred to a PTFE beaker and evaporated. The solution was filtered through a PTFE syringe filter. The solution was adjusted by 5 ml DI water in a volumetric flask. Likewise, blank filter digestion was added a blank filter and 10 ml blank acid 65% (HNO_3). The blank solution was extracted by the same extraction method. Finally, the extracted solution was stored in a polyethylene bottle before analysis by Inductively Coupled Plasma Spectrometry-Mass Spectrometry (ICP-MS). The concentrations of lead and cadmium in PM were calculated by Eq. 3.7 – 3.9 as the following;

$$\text{Mass of heavy metal } (\mu g) = \text{concentration of heavy metal } (\mu g/ml) \times \text{volume of sample solution } (ml) \qquad \text{(Eq. 3.7)}$$

$$\text{Concentration of heavy metal in the air } (\mu g/m^3) = \text{mass of heavy metal } (\mu g) \,/\, \text{volume of the air } (m^3) \qquad \text{(Eq. 3.8)}$$

$$\text{Concentration of heavy metal content } (mg/g) = \text{mass of heavy metal } (mg) \,/\, \text{mass of PM } (g) \qquad \text{(Eq. 3.9)}$$

3.6 Associated factors of blood lead and cadmium levels

The personal information of the participants was used for investigating associated factors of blood lead and cadmium levels. Each associated factor used different criteria for investigating the relationship between blood lead and cadmium levels and related factors. The criteria for the dividing between high and low blood lead levels were higher and lower than the median blood lead levels, while those of mean were used for dividing high and low blood cadmium levels.

Also, the criteria of associated factors about personal information would be different depending on the characteristic of each associated factor, as shown in Table 3.4. The criterion of working condition was based on the calculation of median blood lead levels and mean blood cadmium levels; for example, the working hour was divided into ≤8 hours and >8 hours and was investigated the relationship between the working condition and blood levels of the workers. The different criteria were also used to investigate the other working conditions such as working hours within a week, working days, and working period. Likewise, the PPE using of the workers was categorized by wearing and not wearing PPE, and interpreted as either yes or no, respectively.

Table 3.10 The criteria of associated factors and blood levels investigation

Associated factors		Criteria	Measure
Blood levels	- Blood lead levels	- Median	0 = ≤Median, 1 = >Median
	- Blood cadmium levels	- Mean	0 = ≤Mean, 1 = >Mean
Personal information	- Occupation	- Occupation of e-waste	0 = Non-e-waste workers, 1 = E-waste workers
	- Gender	- Male and Female	0 = Female, 1 = Male
	- Age	- 40 years	0 = ≤40 years, 1 = >40 years
	- BMI	- Normal range	0 = Normal range, 1 = Abnormal range
Using PPE	- Short gloves	- Wearing short gloves	0 = Yes, No = 1
	- Mask	- Wearing mask	0 = Yes, No = 1
	- Sneakers	- Wearing sneakers	0 = Yes, No = 1
Working condition	- Working hour	- 8 hours	0 = ≤8 hours, 1 = >8 hours
	- Working hour within a week	- 56 hours a week	0 = ≤56 hours, 1 = >56 hours
	- Working day	- 5 days a week	0 = ≤5 days, 1 = >5 days
	- Working period	- 10 years	0 = ≤10 days, 1 = >10 days

Additionally, the ordinal score was used as a criterion for investigating the relationship between using PPE and blood lead and cadmium levels. Then, the median of blood lead levels and the mean of blood cadmium levels of the workers based on using PPE were calculated, as given in Table 3.5.

Table 3.11 The ordinal score of using PPE

Using PPE	Score
Only mask + gloves	1
Only sneakers + gloves	3
All PPE	0

3.7 Quality Control and quality assurance (QA/QC)

The QA/QC of extraction and analysis processes had been performed to ensure the accuracy of the data reported in this study. The information related to QA/QC is as follows:

1) The %recovery of lead and cadmium in $PM_{2.5}$ and $PM_{2.5-10}$

Standard Reference Materials (SRMs) were extracted through the same extraction method of the sample using 10 ml 65% HNO_3. Seven replicates of SRMs were extracted, and the extracted solution was analyzed by ICP-MS. The concentration of Pb and Cd in the extracted solution was calculated and compared with their concentration in standard reference materials. The acceptable range of %recovery should be 80 – 120%, the %recovery of Pb and Cd of this study is shown in Table 3.6. The %recovery of SRMs extraction of this study was in the acceptable range of the extraction method.

Table 3.12 The %recovery of the extraction method

Replicates	Pb	Cd
1	95.28	109.73
2	95.52	113.85
3	97.67	116.82
4	86.54	95.49
5	98.38	109.09
6	86.53	98.19
7	92.28	98.34
Average	**93.17**	**105.93**

2) Standard curve preparation for determination of lead and cadmium in $PM_{2.5}$ and $PM_{2.5-10}$

The standard solution was analyzed by ICP – MS, and the standard calibration curve was prepared in different ten concentrations of mixed standard heavy metal solution within the range of 0 – 400 ng/ml (ppb). The standard calibration curves are presented in Appendix D. The R^2 values of the standard calibration curves were 0.9991 for Pb and 0.9986 for Cd.

3) Limits of detection (LOD) and Limit of quantification (LOQ)

The limits of detection (LOD) was estimated base on three times the standard deviation, which derived from the digestion of blank for seven times. The blank solution was injected into ICP – MS, mean and standard deviation of the measured data were calculated as the following Eq. 3.10 – 3.11

$$\mathrm{LOD} = 3 \times \mathrm{SD} \quad \text{(Eq. 3.10)}$$

$$\mathrm{LOQ} = 10 \times \mathrm{SD} \quad \text{(Eq. 3.11)}$$

Moreover, the percentage of relative standard deviation (% RSD) was calculated by Eq. 3.12 using SD from standard concentration results.

$$\%\mathrm{RSD} = (\mathrm{SD}/X) \times 100 \quad \text{(Eq. 3.12)}$$

where;

SD = Standard deviation

X = Mean of the standard solution measured for ten times replicating

The quality control results of ICP-MS using for the analysis of blood lead and cadmium levels are summarized in Table 3.7.

Table 3.13 The quality control results of ICP-MS for analyzing blood lead and cadmium levels

Test	**LOD**	**LOQ**
Lead in blood	0.10 µg/dl	0.50 µg/dl
Cadmium in blood	0.03 µg/l	0.10 µg/l

The quality control results of ICP-MS that were used for the analysis of Cd and Pb concentration in $PM_{2.5}$ and $PM_{2.5-10}$ in this study are shown in Table 3.8.

Table 3.14 The quality control results of ICP-MS for analyzing Pb and Cd in PM

Element	**LOD (µg/l)**	**LOQ (µg/l)**	**%RSD**
Pb	1.00	3.33	4.17
Cd	1.00	3.33	9.02

3.8 Data Analysis

The SPSS for Windows Release 22.0 (SPSS Inc.) was used for statistical analysis of the data. The statistical analysis used for data analysis in this study are as follows;

1) The normal distribution of the data was analyzed by Kolmogrov - Smirnov test (K-S test).

2) The difference between the average blood lead levels was compared by Kruskal Walls test.

3) The difference between the average blood cadmium levels was compared by F-test (One way).

4) The difference between the average Pb and Cd in $PM_{2.5}$, and $PM_{2.5\text{-}10}$ of e-waste and non-e-waste workers were compared by Mann-whitney u test.

5) The correlation between the blood lead and cadmium levels and their concentration in $PM_{2.5}$ and $PM_{2.5\text{-}10}$ were analyzed by Spearman correlation.

6) The relationship between associated factors and blood lead and cadmium levels of e-waste and non-e-waste workers were analyzed by Chi-square.

All methods described above can be summarized as the overall research framework, as presented in Figure 3.7.

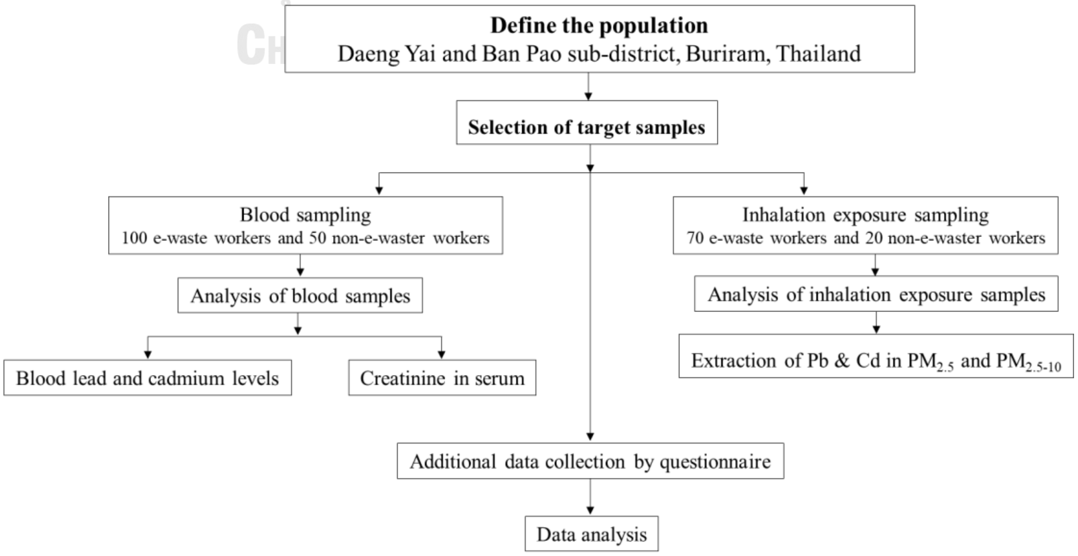


Figure 3.9 The overall framework of the study

CHAPTER IV

RESULTS AND DISCUSSION

4.1 The demographic characteristics and personal background information of participants

4.1.1 Socio-demographic of participants

The results of the questionnaire survey on the demographic characteristics showed that all participants comprised 95 e-waste workers, which were 50 e-waste workers from Dang Yai sub-district, and 45 workers from Ban Pao sub-district. While the participants of non-e-waste workers were 50 persons, as shown in Table 4.1. The gender of e-waste workers from Dang Yai sub-district was 29 females (58%) and 21 males (42%). Their average age was 47.64±10.80 years and aged between 19 to 65 years. The average weight, height, and BMI were 61.52±9.36 kg, 159.60±7.08 cm, and 24.10±3.00 kg/m^2, respectively. Similarly, the gender of e-waste workers from Ban Pao sub-district was 33 females (73.33%) and 12 males (26.67%). Their average age was 49.42±10.81 years and ranged from 24 to 65 years; besides, their average weight, height, and BMI were 62.29±11.35 kg, 158.11±6.98 cm and 24.88±4.80 kg/m^2, respectively. While females and males of non-e-waste workers were 42 (84%) and 8 (16%), respectively. Their average age was 49.76±8.62 years and ranged from 23 to 65 years. The average weight, height, and BMI were 60.94±6.09 kg, 161.50±5.66 cm, and 23.40±2.45 kg/m^2, respectively.

The results of this study found that most participants of e-waste workers and non-e-waste workers were female, while most gender participants of other studies were male (Wittsiepe et al., 2017; Noguchi et al., 2014; Srigboh et al., 2016; Adewale., 2015). The average age of e-waste and non-e-waste workers in this area were higher than the informal e-waste workers in Ghana (Wittsiepe et al., 2017). Likewise, the study of Srigboh et al. (2016) indicated that the age range of e-waste recycling workers in Ghana was 15 to 60 years, which is lower than the age range of workers in this study. From the questionnaire, as shown in Appendix A, the results showed that the majority underlying diseases of all participants are Diabetes Mellitus, Hypertension, Hyperlipidemia, and Hyperthyroidism. The local participants have lived in this area and have been a rice farmer for a long time, and the main occupations of non-e-waste dismantling are agriculture and merchant. However, e-waste dismantling in this area generates an average income of approximately 2,000 – 2,500 USD/ year, which is causing many residents to be interested in e-waste dismantling (Puangprasert and Prueksasit, 2019).

Table 4.15 The general and background personal information of participants in this study

Factors	Number of participants	Range	Mean±SD	Median
Gender				
Female				
E-waste workers ^{DY}	29 (58%)			
E-waste workers ^{BP}	33 (73.33%)			
Non-e-waste workers	42 (84%)			
Male				
E-waste workers ^{DY}	21 (42%)			
E-waste workers ^{BP}	12 (26.67%)			
Non-e-waste workers	8 (16%)			
Age (years)				
E-waste workers ^{DY}		19 – 65	47.64±10.80	49.00
E-waste workers ^{BP}		24 – 65	49.42±10.81	52.00
Non-e-waste workers		23 – 65	49.76±8.62	50.00
Weight (Kg)				
E-waste workers ^{DY}		37.00 – 86.00	61.52±9.36	62.00
E-waste workers ^{BP}		40.00 – 86.00	62.29±11.35	62.00
Non-e-waste workers		50.00 – 72.00	60.94±6.09	61.00
Height (cm)				
E-waste workers ^{DY}		145.00 – 175.00	159.60±7.08	160.00
E-waste workers ^{BP}		148.00 – 172.00	158.11±6.98	160.00
Non-e-waste workers		150.00 – 172.00	161.50±5.66	160.00
BMI (kg/m^2)				
E-waste workers ^{DY}		17.60 – 31.59	24.10±3.00	24.34
E-waste workers ^{BP}		17.78 – 33.33	24.88± 4.80	24.22
Non-e-waste workers		17.65 – 30.30	23.40±2.45	23.12

^{DY} = E-waste workers from Dang Yai sub-district, ^{BP} = E-waste workers from Ban Pao sub-district

4.1.2 Working condition and using PPE of e-waste workers

The results of observation by the questionnaire showed the characteristic of 94 e-waste workers that working conditions mentioned as working hours (hours a day), working day (days a week), working hours within a week (hours a week), and working period (years) are shown in Table 4.2. The results explained that the average working hours of e-waste workers from Dang Yai sub-district were 7.08±1.42 hours a day, ranged from 4 – 9 hours a day, and a median of 8 hours a day. Their average, ranged, and median of the working days were 6.08±1.61 days a week, 2 – 7 days a week, and 7 days a week, respectively. Their working hours within a week averaged as 46.36±14.60 hours a week, in the range of 12 to 63 hours a week and median 56 hours a week. They worked 7.60±4.42 years at average, ranged from a month to 20 years, and a median 10.00 years. Whilst the results found that all working time conditions of e-waste workers from Ban Pao sub-district lower than those of e-waste workers from Dang Yai sub-district. They worked 6.78±2.36 hours a day at average, ranged from 2 – 12 hours a day, and median 6.00 hours a day. Their average, ranged, and a median working day were 5.18±1.95 days/week, 1 – 7 days/week, and 5 days/week, respectively. The average working hours within a week were 36.22±19.26 hours a week, ranged from 3 – 48 hours a week, and a median of 35 hours a week. They worked 7.09±5.36 years at average, ranged from 2 to 12, and a median 6 years.

Table 4.16 Working conditions of e-waste dismantling workers

Factors	Range	Mean±SD	Median
Working hour (hours/day)			
E-waste workers ^{DY}	4 – 9	7.08±1.42	8
E-waste workers ^{BP}	2 – 12	6.78±2.36	6
Working day (days/week)			
E-waste workers ^{DY}	2 – 7	6.08±1.61	7
E-waste workers ^{BP}	1 – 7	5.18±1.95	5
Working hour within a week (hours/week)			
E-waste workers ^{DY}	12 – 63	46.36±14.60	56
E-waste workers ^{BP}	3 – 84	36.22±19.26	35
Working period (years)			
E-waste workers ^{DY}	1 month – 22	7.60±4.42	10
E-waste workers ^{BP}	2 – 12	7.09±5.36	6

^{DY} = E-waste workers from Dang Yai sub-district, ^{BP} = E-waste workers from Ban Pao sub-district

However, the working hour of the e-waste workers in this study are similar to the informal e-waste workers in Southern Thailand, which are less than 8 hours per day. Most e-waste workers in this study had worked in contact with e-waste was less than 10 years. Likewise, most of all participants in Southern Thailand and Ghana also had worked less than 10 years for the working period (Decharat and Kiddee, 2020; Amankwaa et al., 2017). The working conditions were related to exposed heavy metals in biomarkers of workers. Blood biomarkers are used to measure the concentration of heavy metals in the day-to-day and between individuals. Lead can be detected in blood within hours of exposure and can remain detected for at least 4 weeks (Adewale L., 2015). Cadmium in the blood is indicative of recent exposure rather than whole-body burdens and is excreted starting on the 7th day after exposure up to the 30th day after exposure (ATSDR, 2012). Thus, working hours and working hours within a week might be another factor that affects the exposure to heavy metals of the e-waste workers.

Additionally, the e-waste workers in this area could be directly exposed to lead and cadmium because they use inappropriate personal protective equipment (PPE). The observational result in this study revealed that the main PPE of e-waste workers used consists of a mask, glove, and sneakers. The results found that all the e-waste workers from Dang Yai sub-district used a short glove, while 47 workers (94 %) and 35 workers (70 %) wore masks and sneakers, respectively, as presented in Table 4.3. Moreover, the predominant type of mask was a fabric mask, and there were only three workers use either surgical masks or N95 type. Using PPE of e-waste workers from Ban Pao sub-district pointed out that most workers used a short glove, fabric masks (96.00 %), and sneakers (84.00 %).

Table 4.17 The using PPE of e-waste workers participants

Factors	Number of participants
Short glove	
E-waste workers ^{DY}	
No	0 (0.00 %)
Yes	50 (100 %)
E-waste workers ^{BP}	
No	0 (0.00 %)
Yes	45 (100 %)
Mask	
E-waste workers ^{DY}	
No	3 (6.00 %)
Yes	47 (94 %)
E-waste workers ^{BP}	
No	2 (4.00 %)
Yes	43 (96.00 %)
Sneakers	
E-waste workers ^{DY}	
No	15 (30.00 %)
Yes	35 (70 %)
E-waste workers ^{BP}	
No	7 (16.00 %)
Yes	38 (84.00 %)

^{DY} = E-waste workers from Dang Yai sub-district, ^{BP} = E-waste workers from Ban Pao sub-district

However, using the PPE of the workers in this study was better than the informal e-waste dismantling workers in Nigeria (Ohajinwa et al., 2017). The types of masks commonly used by e-waste workers similar to the study of Decharat and Kiddee (2020), which found that they mostly used cloth masks (60.6%). Heavy metals might be exposed to the body various route, especially directly inhalation exposure. However, e-waste workers have used inappropriate PPE for dismantling and separating e-waste, such as mask, short glove, and sneakers. These cannot protect the workers' health. Due to the e-waste workers could directly inhale heavy metals from particulate matter that release from e-waste dismantling processes, using appropriate masks should be recommended.

4.1.3 E-waste types separated by the workers on the day before blood sampling at Dang Yai and Ban Pao sub-districts

The observational survey in this area found that common types of e-waste taken for disassembly were computers, motor, washing machines, electrical fan parts, and small household appliances such as iron, coffee maker, and rice cooker. Moreover, it was found that workers dismantled different types of e-waste. As a result, the e-waste dismantling activities of each worker were different and the amount of exposure to heavy metals was also different. This study classified e-waste types depending on lead and cadmium as a component in e-waste. Regarding e-waste types in this study, it could be classified into 10 categories: printed circuit boards, television, printer, computer, refrigerator, motor, washing machines, electrical fan parts, small household appliances (e.g., iron, toaster, coffee maker), and recyclable waste (e.g., paper, plastic, and glass). The contribution of e-waste types dismantled by the workers on the day before blood sampling at Dang Yai and Ban Pao sub-districts is shown in Figure 4.1 and Figure 4.2.

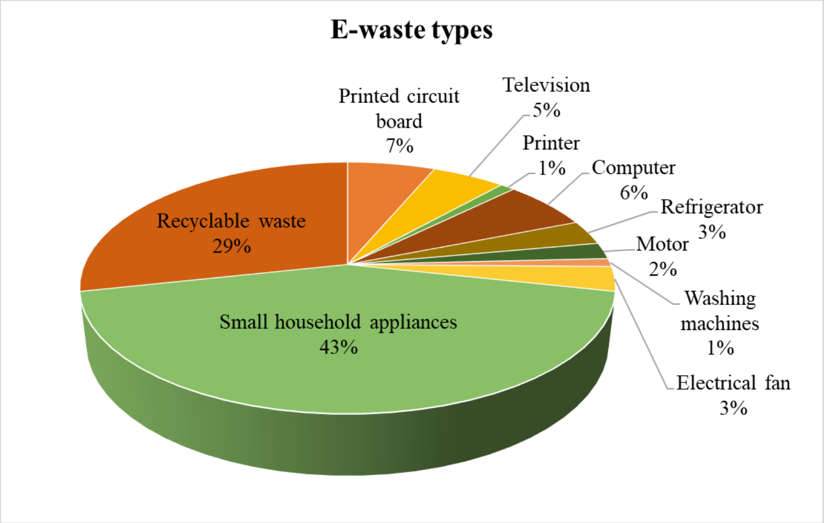


Figure 4. 10 The proportion of e-waste types of workers

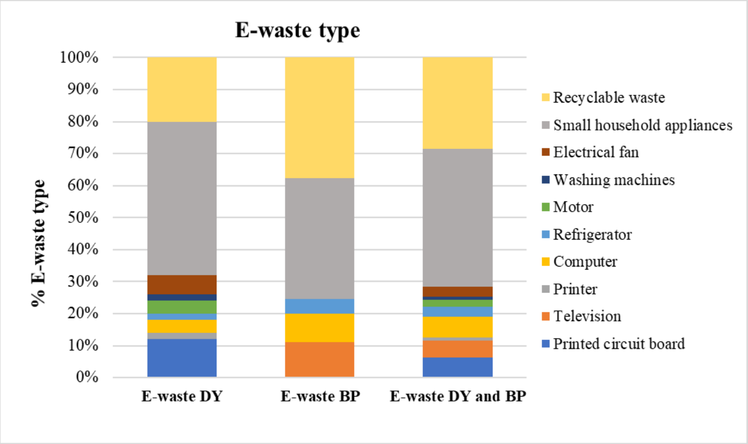


Figure 4.11 The proportion of e-waste types of workers from both sub-districts

Figure 4.1 and Figure 4.2 show that some e-waste types led to direct exposure to Pb and Cd. E-waste types were dismantled up to 7% of printed circuit boards and 5% of television, which are a source of Pb. All printed circuit boards were dismantled by e-waste workers from Dang Yai sub-district, while television was dismantled by e-waste workers from Ban Pao sub-district. Moreover, some e-waste types also provide as a source of Cd, which is 1% of printers was dismantled by the e-waste workers from Dang Yai sub-district, and 6% computer was dismantled by e-waste workers from both sub-districts. On the other hand, approximately 37.78% of e-waste workers from Ban Pao sub-district separated recyclable waste (for example, paper, plastic, and glass). Other e-waste types were small household appliances (for example, iron, toaster, and coffee maker), and approximately 48% and 38% were found separated by e-waste workers from Dang Yai and Ban Pao sub-district, respectively. However, these types of waste are abundant; they are not considered as a source of lead and cadmium. Therefore, some e-waste types might lead to increased risk of exposure to Pb and Cd and resulted in increasing the presence of Pb and Cd in blood.

4.1.4 Symptoms from lead and cadmium poisoning of e-waste workers

From the questionnaire, symptom from lead (e.g., squeamish, vomiting, irritability, muscle pains, fatigue, and purple or black color around the gums) and cadmium poisoning (e.g., irritation of the respiratory tract, dyspnea, chest pains, headache, and muscular weakness) were used to evaluate the symptoms that might be caused by exposure to lead and cadmium. According to the questionnaire, approximately 46% of all workers had no symptoms of lead and cadmium exposure, while 36% of workers had muscle pains. In addition, the number of workers had symptoms of irritability, forgetfulness, and dyspnea, which is 10.53%, 2.10%, and 4.47% of workers, respectively, are shown in Figure 4.3.

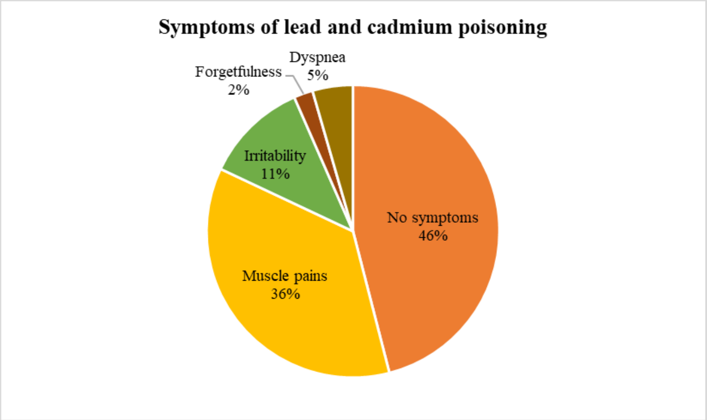


Figure 4.12 Symptoms of the participants related to lead and cadmium poisoning

4.2 The blood lead and cadmium levels of participants

The objective of this study was to investigate blood lead and cadmium levels of e-waste and non-e-waste dismantling workers. One hundred forty-five participants, 50 of whom were e-waste workers from Dang Yai sub-district, Banmaichaiyapot district, 45 of whom were e-waste workers from Ban Pao sub-district, Phutthaisong district, and 50 of whom were non-e-waste workers live in Village No. 1 of Dang Yai sub-district, Buriram province, Thailand. The blood lead level of the subjects is reported in µg/dl, while the unit of blood cadmium levels is µg/l, as presented in Appendix C. Mean blood lead and cadmium levels were compared between sample groups, correspondingly with the standard values. Moreover, blood lead levels of each e-waste worker were investigated concerning e-waste dismantling activities.

4.2.1 Comparison of the blood lead levels between e-waste workers and non-e-waste workers

The results of blood lead levels of e-waste workers and non-e-waste workers analyzed by ICP-MS were shown in Table 4.4. The data shows that the mean (±SD) blood lead levels of e-waste workers from Dang and Ban Pao sub-district were 5.63± 2.86 µg/dl and 3.92±1.13 µg/dl, respectively, while the mean (±SD) blood lead levels of non-e-waste workers as a control group was 2.84±0.72 µg/dl. Blood lead levels among e-waste workers from Dang Yai sub-district, Ban Pao sub-district, and non-e-waste workers were ranged from 1.99 to 19.50, 1.56 to 8.15, and 1.34 to 5.94 µg/dl, respectively. The median blood lead levels of 5.82, 3.66, and 2.82 µg/dl were represented for e-waste workers from Dang Yai sub-district, Ban Pao sub-district, and non-e-waste workers, respectively.

Table 4. 18 The blood lead levels of participants

Participants	**Blood lead levels (µg/dl)**		
	Median	**Mean (S.D.)**	**Range**
E-waste workers ^{DY}	5.82	5.63± 2.86	1.99 – 19.50
E-waste workers ^{BP}	3.66	3.92±1.13	1.56 – 8.15
Non-e-waste workers	2.82	2.84±0.72	1.34 – 5.94

^{DY} = E-waste workers from Dang Yai sub-district, ^{BP} = E-waste workers from Ban Pao sub-district

The normal distribution of blood lead levels was tested using Kolmogorov-Smirnov (K – S test) in the SPSS. The results found that blood lead levels of all participants were non-normal distribution at $p = 0.000$ ($p < 0.05$). Then, the mean blood lead levels were compared by Kruskal Walls Test ($p < 0.05$). The mean blood lead levels of e-waste workers significantly higher than those of non-e-waste workers.

Besides, the mean blood lead levels of the three groups were significantly different at *p* = 0.000, as seen in Figure 4.4. Surprisingly, the maximum blood lead level of both e-waste worker groups was 19.50 µg/dl, which is three-fold higher than the mean.

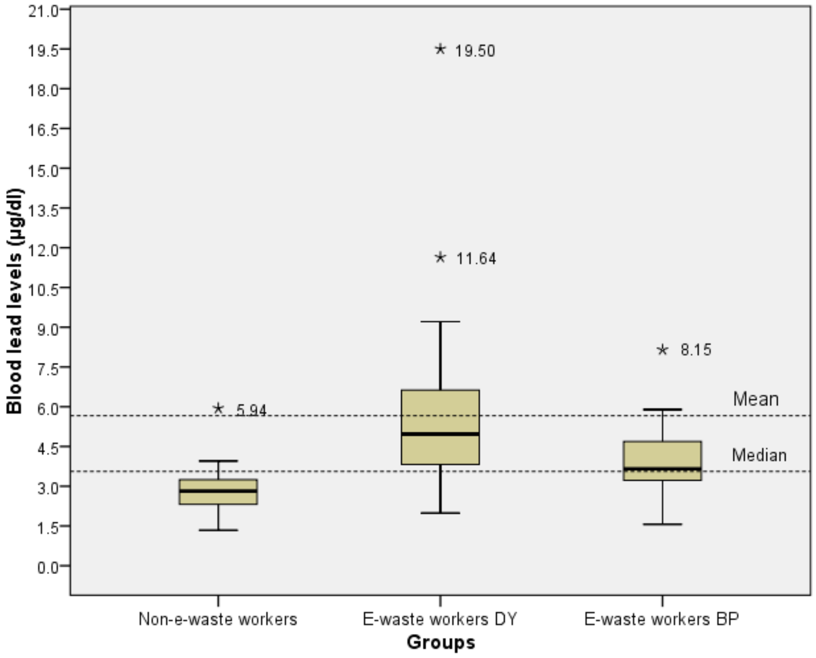


Figure 4.13 Blood lead levels of e-waste and non-e-waste workers (µg/dl)

Interestingly, the individual maximum blood lead level (19.50 µg/dl) could be determined in the worker who used a grinder for cutting the component of e-waste materials. This activity could cause small particles and fumes emission that Pb might bind with organic substances and attached with the particles released in the air (Liu et al., 2017). Moreover, the workers did not wear a mask to avoid direct inhalation exposure. When workers dismantled e-waste by an inappropriate process, this activity might increase the ambient concentration of heavy metals and pose an increasing risk from inhalation exposure. Blood lead levels of the e-waste workers might be caused by the exposure to Pb, which is a component of some electrical devices such as computer parts, CRT screens, and circuit boards. Theoretically, after lead entering the body by inhalation exposure, it will then be transported in blood bloodstream in the form of Pb^{2+}, which binds with sulfhydryl groups (-SH) in proteins in hemoglobin (Hb) by hard-soft acid-base (Pearson, 1968).

This study result is found the same as the study of Julander et al. (2014) that formal e-waste recycling in Sweden caused the significantly higher median blood lead levels of the workers (3.2 µg/dl) than that of the office workers (1.5 µg/dl) ($p < 0.01$). Likewise, informal e-waste dismantling activities in Agbogbloshie, Accra, Ghana, led to high blood lead levels of workers (8.85 µg/dl), which was about 2-fold higher than that of non-workers (4.10 µg/dl). Moreover, blood lead levels of the workers were significantly higher than those of non-workers ($p < 0.01$) (Wittsiepe et al., 2017). Besides, the study of Schecter et al. (2018) reported that the median lead in the whole blood of female Vietnamese recyclers (4.82 µg/dl) was significantly higher than the non-recycler population (2.93 µg/dl). The median blood lead levels (11.449 µg/dl) were significantly higher in the exposed group than those of the control group (9.104 µg/dl) recorded for an e-waste recycling site, China, by Wang et al. (2011).

Regarding the e-waste types separated by the workers on the day before blood sampling at Dang Yai and Ban Pao sub-districts as mentioned in section 4.1.3, blood lead levels of the workers were then plotted in correspondence with their dismantled e-waste (as of ten categories), Figure 4.5. Noticeably, the blood lead levels of the workers dismantled circuit boards were relatively higher than those of the others. Commonly, lead is used as a component in circuit boards (Gaidajis et al., 2010 and Morf et al., 2007); contacting this electronic part could then be a considerable cause of lead elevation in workers' blood. As a result, the workers who separated lead content e-waste could pose a certain health risk as of the observation of higher blood lead levels than other e-waste types separated.

Additionally, the blood lead levels of workers from Dang Yai sub-district were significantly higher than those of Ban Pao sub-district ($p = 0.000$), as seen in Appendix E. This difference in BLL might be due to different amount and types of e-waste being separated between both areas, which the workers in Dang Yai sub-district dismantled e-waste mainly, while a large proportion of the workers in Ban Pao sub-district separated recyclable household waste additional to e-waste such as paper, plastic, and glass bottle.

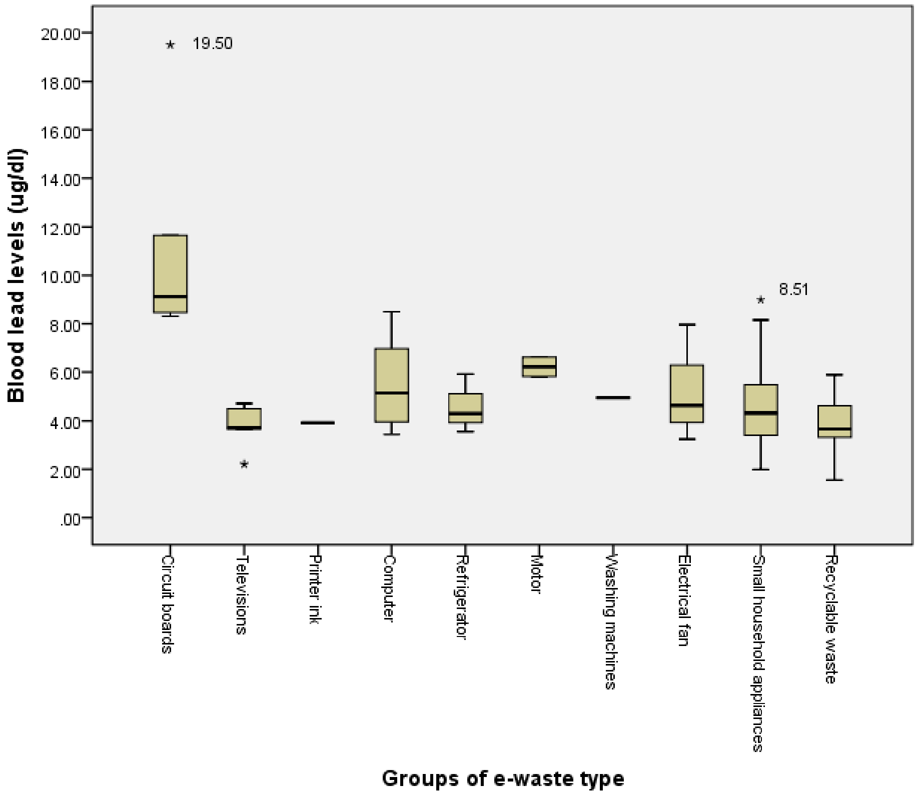


Figure 4.14 Blood lead levels (µg/dl) of the workers corresponding to e-waste being dismantled

Although the blood lead levels of e-waste workers were still lower than the Thai Biological Exposure Indices (Thai BEIs) values for blood lead levels of the occupationally exposed (30 µg/dl) and acceptable level recommended by WHO (< 10 µg/dl) (WHO, 2006), e-waste dismantling activities might increase blood lead levels, the elevated lead exposure among e-waste dismantling workers should be concerned.

4.2.2 Comparison of the blood cadmium levels between e-waste workers and non-e-waste workers

The data of blood cadmium levels of participants were tested and could be classified as normal distribution; parametric testing would then be applied. When comparing mean (±SD) blood cadmium levels between e-waste workers at both sub-districts and non-e-waste workers by One-way ANOVA ($p < 0.05$), the results showed that the mean blood cadmium levels (BCL) of either e-waste or non-e-waste workers were not a statistically significant difference ($p = 0.086$). Mean blood cadmium levels of non-e-waste workers, e-waste workers from Ban Pao and Dang

Yai sub-district were 1.15±0.38, 1.12±0.43, and 0.97±0.43 µg/l, respectively. Their ranged 0.44 to 1.86 µg/l, 0.28 to 2.02 µg/l and 0.28 to 2.73 µg/l, respectively. Unlikely to the blood lead levels, mean blood cadmium levels of non-e-waste workers were slightly higher than those of e-waste workers, as presented in Figure 4.6. Additionally, the medians of blood cadmium levels were 1.18, 1.08, and 0.95 µg/l for non-e-waste, e-waste workers from Ban Pao and Dang Yai sub-district, respectively, as shown in Table 4.5. The highest blood cadmium level (2.73 µg/l) belongs to workers from Dang Yai sub-district, who separated small household appliances and computer parts. As a result, this e-waste worker has a risk of exposure to cadmium, leading to increased blood cadmium levels. However, blood cadmium levels of all target populations in this study were still lower than the Thai BEIs value of 5 µg/l.

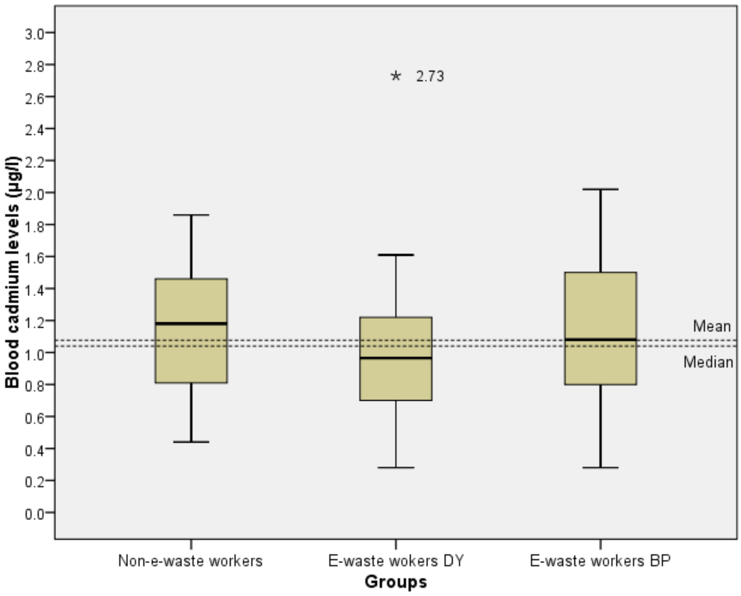


Figure 4.15 Blood cadmium levels of the participants (µg/l)

Table 4.19 The blood lead levels of participants

Participants	**Blood cadmium levels (µg/l)**		
	Median	**Mean (S.D.)**	**Range**
E-waste workers DY	0.95	0.97±0.43	0.28 – 2.73
E-waste workers BP	1.08	1.12±0.43	0.28 – 2.02
Non-e-waste workers	1.18	1.15±0.38	0.44 – 1.86

DY = E-waste workers from Dang Yai sub-district, BP = E-waste workers from Ban Pao sub-district

Comparing blood cadmium levels of this study with some previous studies, the mean blood cadmium levels in this study were slightly lower than those recorded for e-waste workers (1.7 µg/l) and non-e-waste workers (1.4 µg/l) at the Agbogbloshie site, Ghana (Srigboh et al. 2016). In contrast, Wittsiepe et al. (2017) reported that mean blood cadmium levels of non-e-waste workers (0.57 µg/l) were slightly higher than that of e-waste workers (0.55 µg/l), which is similar to the result of this study. There might cause from some host factors, e.g., daily behavior and lifestyle, and occupation, for the slightly higher BCL of non-e-waste workers than the e-waste workers in both Ban Pao and Dang Yai sub-districts.

From total participants of the control group, only 12% have been being housewives and worked as merchants, while the rest persons have been worked as a farmer. Most of the participant in this group is agriculture that they probably exposure to Cd from the soil. Besides, the previous study in this area reported that Cd concentration in soil at the non-separating and reference houses in this village (control site) were higher than those at the e-waste separating houses (Amphalop et al., 2020). Most people living in non-separating and reference houses were encouraged to have their household vegetations and applied some types of livestock manures. Amount of Cd approximately 0.3 – 0.8 mg/kg that is contained in the manures, so the household soil could be contaminated a hight level of Cd (Alloway 2012; Amphalop, Suwantarat, Prueksasit, Yachusri, & Srithongouthai, 2020). As a result, cadmium mostly accumulated in the surface soil of the paddy field (Amphalop et al., 2020). Also, the local people in this area applied agrochemicals, including Cd-containing pesticides and fertilizers (Wu, Luo, Deng, Teng, & Song, 2014; Amphalop et al., 2020). These might cause increased exposure to cadmium of non-e-waste workers. This evidence might support blood cadmium levels of non-e-waste workers were higher than e-waste workers because the non-e-waste workers can intake Cd through inhaling the dust from agricultural occupations, especially by using fertilizers or agrochemicals. These might increase the risk of exposure to cadmium and lead it to is increasing blood cadmium level.

Considering the e-waste taken for disassembly, cadmium is normally one of the major components found in electrical and electronic products, such as rechargeable NiCd batteries, CRT screens, printer inks, and photocopying machines (Wittsiepe et al., 2017). The same as an illustration in Figure 4.3, blood cadmium levels of the workers were displayed separately upon their dismantled e-waste (see Figure 4.6). Regrading to the observational information of e-waste types that the workers separated one day before blood sampling, as mentioned in section 4.1.3, almost half proportion was small household appliances, and 29% accounted for recyclable materials. Meanwhile, the printer ink in printer cartridge containing Cd was found only 1%. Figure 4.7 illustrates that the tendency of blood cadmium levels was not explicitly related to the type of e-waste separated so that the e-waste workers might expose to a small amount of cadmium.

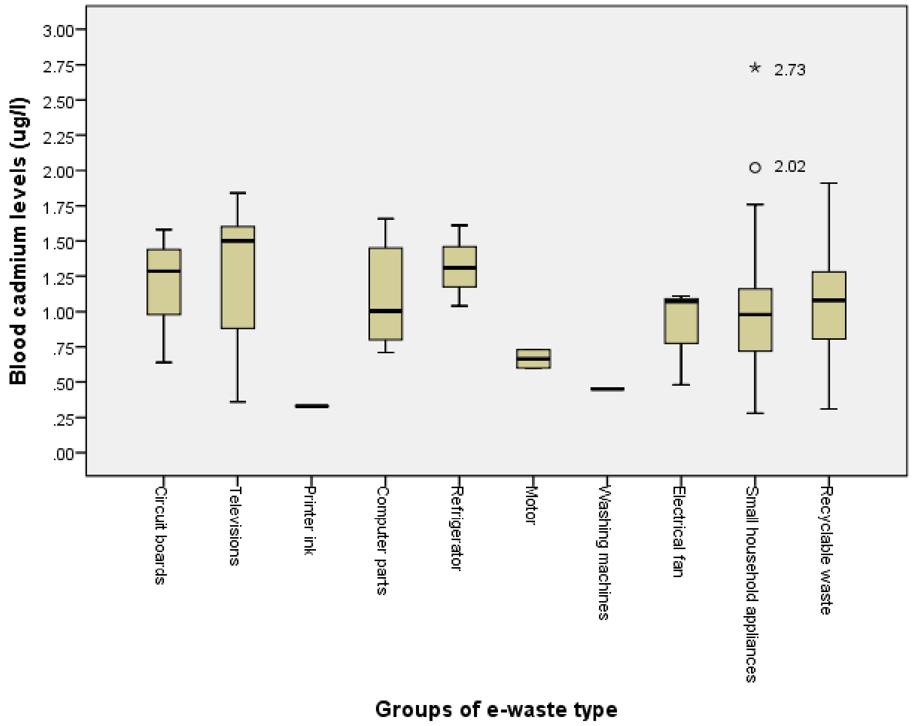


Figure 4.16 The relationship between blood cadmium levels (μg/l) and e-waste type

Blood lead and cadmium levels in this study were compared with the other previous studies, as summarized in Table 4.6. When comparing blood lead and cadmium levels of e-waste and non-e-waste workers in this study with the other studies, the mean concentrations in blood were slightly lower than those of e-waste workers and non-e-waste workers from e-waste site as Ghana and Vietnam. The different e-waste dismantling activities and contributions of e-waste types in each site might result in the variation of blood lead and cadmium levels.

Table 4.20 The comparison of blood lead and cadmium levels in this study with previous studies

Site	Exposure Group	BLLs (µg/dl)	BCLs (µg/l)	Reference
E-waste site in Buriram, Thailand	E-waste worker Non-e-waster worker	4.82±2.37 2.84±0.72	1.09±0.44 1.15±0.38	This study (2020)
E-waste site, Dang Yai Sub-district, Buriram, Thailand	E-waste worker	N.D. – 32.7	N.D. – 1.6	Department of Disease Control (2018)
E-waste site, Ban Pao Sub-district, Buriram, Thailand	E-waste worker	N.D. – 13.1	N.D. – 1.4	Department of Disease Control (2018)
Gwangwalada, Abuja, Nigeria	Occupational Non-occupational	45.43±6.93 12.08±2.87	11.63±1.73 2.03±0.55	Alli (2015)
E-waste recycling site, Agbogbloshie, Accra, Ghana	E-waste worker Non-e-waster worker	10.19 4.43	0.55 0.57	Wittsiepe et al. (2016)
Informal e-waste processing site, Ghana	Occupational Non-occupational	3.49 3.54	- -	Amankwaa et al. (2017)
Informal e-waste recycling, Vietnam	E-waste worker Non-e-waster worker	4.82 2.93	- -	Schecter et al. (2017)
E-waste site, Ghana	E-waste worker Non-e-waster worker	7.93 3.71	1.70 1.40	Srigboh et al. (2016)
Jodhpur, Rajasthan, India	Occupational Non-occupational	6.51 ± 11.86 2.34 ± 4.66	2.48 ± 1.20 1.09 ± 0.73	Goyal (2020)
Thai Biological Exposure Indices	Occupational	30.0	5.0	DDC (2016)
The acceptable level	-	<10.0	0.03 – 0.12	WHO (2006)
Reference value	Occupational Non-occupational	<40.0 <25.0	<5.0 <1.0	Casaret et al. (2007) and Tietz and Clin Chem. (1992)

Typically, chronic exposure to cadmium can cause an effect on renal function, which are chronic renal failure and renal disease (Forte et al., 2011). A creatinine blood test can be utilized to explain this association; This test is a method for measuring waste products in the body and kidney function. Serum creatinine is used as the effect indicator of kidney function. The creatinine blood test was then carried out in this study. Mean (±SD) serum creatinine of the e-waste workers from Dang Yai, Ban Pao sub-district, and non-e-waste workers were 0.98±0.23, 0.90±0.18, and 1.13±0.26 mg/dl, respectively. Those ranges were 0.65 – 1.98, 0.65 – 1.61, and 0.69 – 2.20 mg/dl, respectively, as presented in Table 4.7.

Table 4.21 Serum Creatinine of e-waste and non-e-waste workers

Participants	**Serum Creatinine (mg/dl)**		
	Median	**Mean ± S.D.**	**Range**
E-waste workers ^{DY}	0.94	0.98±0.23	0.65 – 1.98
E-waste workers ^{BP}	0.87	0.90±0.18	0.65 – 1.61
Non-e-waste workers	1.10	1.13±0.26	0.69 – 2.20

^{DY} = E-waste workers from Dang Yai sub-district, ^{BP} = E-waste workers from Ban Pao sub-district

The normal range of serum creatinine is 0.73 -1.18 mg/dl for males and 0.55 -1.02 mg/dl for females (Junge et al., 2004). This study found that 62% of the non-e-waste workers had creatinine levels higher than the normal range, while the corresponding values for e-waste workers from Dang Yai and Ban Pao sub-district were approximately only 20% and 11% , respectively, as presented in Figure 4.8. Although the results of the creatinine blood test show that the non-e-waste workers had higher creatine levels than the e-waste workers. But the correlation between blood cadmium levels and creatinine was no statistical significance with $r = 0.043$ and $p = 0.609$. Additional to heavy metals, impaired kidney function may occur from diseases, medication, and toxins. On the contrary, the impairment of kidney function also affects the elimination of cadmium from the body as well.

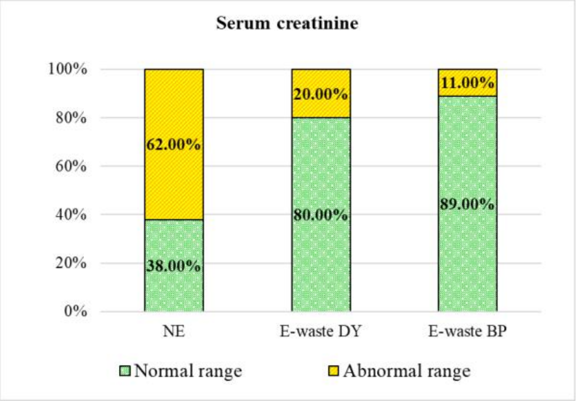


Figure 4.17 The comparison of serum creatinine between non-e-wastes and e-waste workers

4.2.3 Symptoms of e-waste workers related to lead and cadmium poisoning

From the questionnaire, the information was not able to determine whether the worker symptoms caused by exposure to lead and cadmium because their blood levels were lower than the significant levels of observable adverse effects and symptoms. Wani, Ara, and Usmani (2015) indicated that blood lead levels from 25 and 60 μg/dl give rise to neuropsychiatric effects such as delayed reaction times, irritability, and difficulty in concentrating, as well as slowed down motor nerve conduction and headache. Blood cadmium levels greater than 15 μg/l was indicated the body exposure to cadmium and the high risk of cadmium poisoning (Ramathibodi Poison Center, 2002). However, blood lead and cadmium levels of all the workers in the study were below those that were symptomatic. Therefore, this study examines the Pb and Cd concentrations in PM in the next section for investigating the relationship between blood lead and cadmium levels and their possible exposure from e-waste dismantling activities.

4.3 Pb and Cd concentration in particulate matter

The concentration of Pb and Cd in the fine ($PM_{2.5}$) and coarse particles ($PM_{2.5\text{-}10}$) exposed by the participants was investigated. Ninety participants were asked to take personal air sampling, 70 of whom were e-waste workers in both sub-districts, and the rest of 20 was non-e-waste workers (control). The air sampling was taken place in the working area of e-waste workers and the residential area of non-e-waste workers for 8 hours. The normal distribution of the data of Pb and Cd concentration in $PM_{2.5}$ and $PM_{2.5\text{-}10}$ were analyzed using Kolmogorov-Smirnov (K - S test) in the SPSS, and then their mean concentration was compared between the exposed and control group using Mann-Whitney U test ($p < 0.05$). The concentration was reported in ng per m^3 (ng/m^3) unit.

4.3.1 Comparison of exposure to Pb and Cd concentrations in $PM_{2.5}$ and $PM_{2.5\text{-}10}$ between e-waste and non-e-waste workers

The results of Pb and Cd concentration of $PM_{2.5}$ of e-waste and non-e-waste workers were reported in Table 4.8. The data shows that the mean (±SD) and median concentration of Pb in $PM_{2.5}$ of e-waste workers were 18.95±23.12 and 10.51 ng/m^3, ranging from 0.89 to 131.08 ng/m^3, and those of non-e-waste workers were 12.69±37.40 and 1.74 ng/m^3, ranging from 1.34 to 169.33 ng/m^3, respectively. The mean (±SD) and median concentration of Cd in $PM_{2.5}$ of e-waste workers and non-e-waste workers were 4.31±7.71 and 1.67 ng/m^3, ranging from 0.10 to 37.02 ng/m^3, and 2.11±2.40 and 1.70 ng/m^3, ranging from 0.07 to 9.29 ng/m^3, respectively.

Mean (±SD), median, and range of Pb concentration in $PM_{2.5-10}$ were found as 10.45±11.81 and 6.59 ng/m^3, 0.14 to 73.29 ng/m^3 for the e-waste workers, while non-e-waste workers had the mean of 9.30±9.81 ng/m^3, median of 5.02 ng/m^3 and range of 0.35 to 30.72 ng/m^3. For those values of Cd in $PM_{2.5-10}$, 2.03±1.27, 1.75, and 0.03 to 5.95 ng/m^3 were obtained for e-waste workers. Cd concentration in $PM_{2.5-10}$ of non-e-waste workers was 1.06±0.99 ng/m^3 of mean, 0.71 ng/m^3 of the median, 0.03 to 2.76 ng/m^3 of range.

Comparing the concentration of Pb and Cd in $PM_{2.5}$, e-waste workers exposed to Pb at a significantly higher level than those of non-e-waste workers ($p = 0.000$). While the concentration of Cd in $PM_{2.5}$ exposed by both groups was not a significant difference ($p = 0.621$), as illustrated in Figure 4.10 – 4.11. Besides, the concentration of Pb and Cd in $PM_{2.5-10}$ were also compared between e-waste and non-e-waste workers, the concentration of Pb in $PM_{2.5-10}$ of e-waste and non-e-waste workers was not significantly different ($p = 0.836$). In contrast, the concentration of Cd in $PM_{2.5-10}$ of e-waste workers were significantly higher than those of non-e-waste worker ($p = 0.002$).

Table 4.22 Pb and Cd concentration in $PM_{2.5}$ and $PM_{2.5-10}$ inhalation exposure of e-waste and non-e-waste dismantling workers

Heavy metals (ng/m^3)	E-waste group (N=70)			Non-e-waste group (N=20)		
	Mean±SD	Median	Range	Mean±SD	Median	Range
Pb in $PM_{2.5}$	18.95±23.12	10.51	0.89 – 131.08	12.69±37.40	1.74	1.34 – 169.33
Cd in $PM_{2.5}$	4.31±7.51	1.67	0.10 – 37.02	2.11±2.40	1.70	0.07 – 9.29
Pb in $PM_{2.5-10}$	10.45±11.81	6.59	0.14 – 74.29	9.30±9.81	5.02	0.35 – 30.72
Cd in $PM_{2.5-10}$	2.03±1.27	1.75	0.03 – 5.95	1.06±0.99	0.71	0.03 – 2.76

LOD = 3.47 ng/m^3

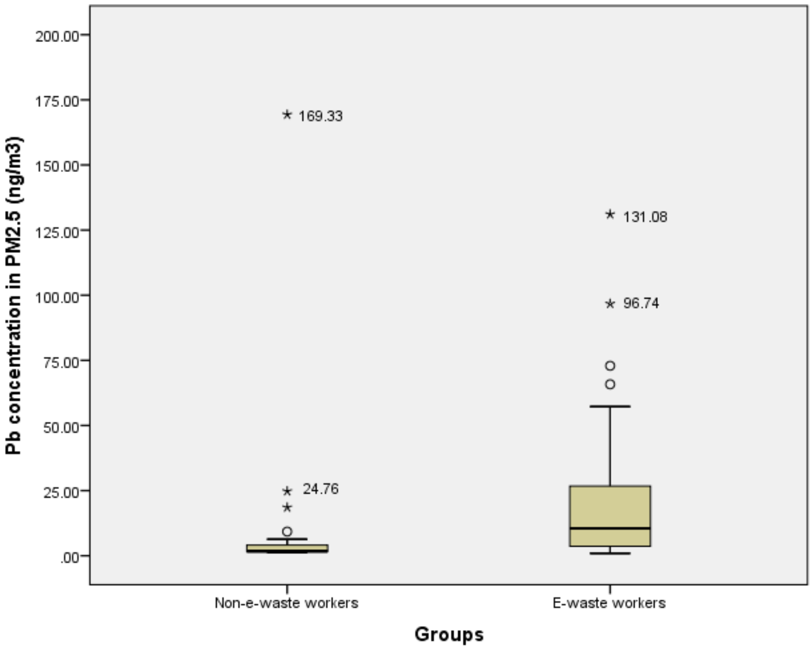


Figure 4.18 Comparison of inhalation exposure to Pb concentrations of $PM_{2.5}$ of non-e-waste and e-waste workers

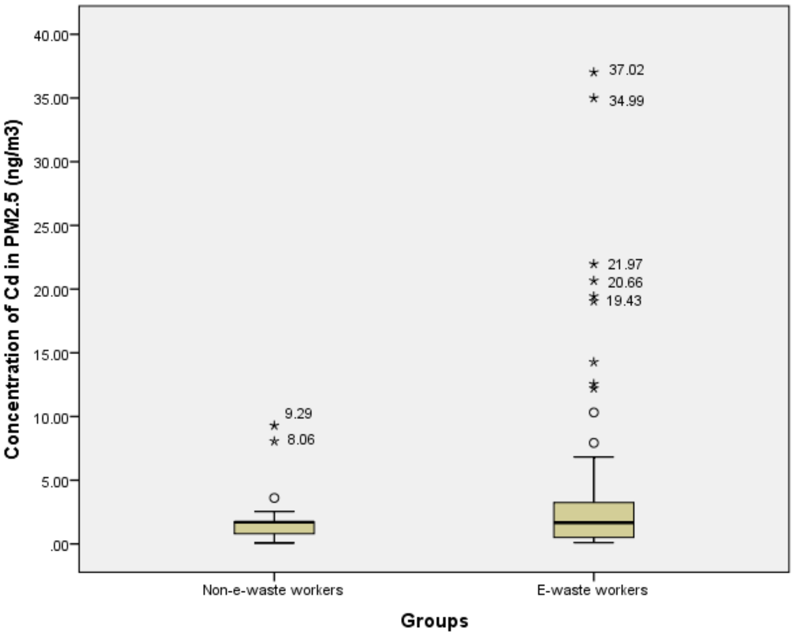


Figure 4.19 Comparison of inhalation exposure to Cd concentrations in $PM_{2.5}$ of non-e-waste and e-waste workers

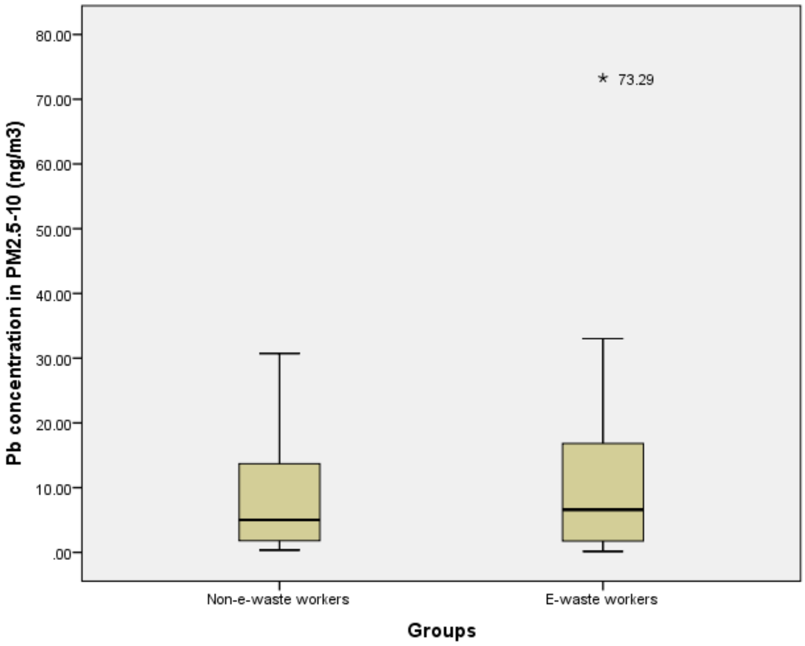


Figure 4.20 Comparison of inhalation exposure to Pb concentrations in $PM_{2.5\text{-}10}$ of non-e-waste and e-waste workers

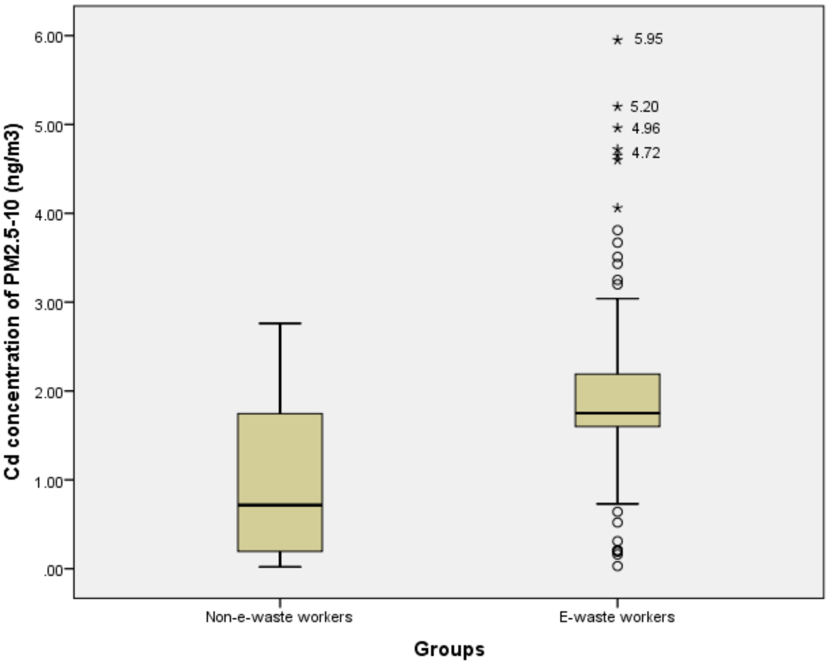


Figure 4.21 Comparison of inhalation exposure to Cd concentrations of $PM_{2.5\text{-}10}$ of non-e-waste and e-waste workers

According to the above results, it was possible that e-waste dismantling activities could lead to elevate the concentration of Pb and Cd in PM to the surrounding air. Typically, Pb is bound with organic substances and attached to the particles (Liu et al., 2017) especially, small particles. Pb can be found in particulate matter with a diameter less than 2.5 μm ($PM_{2.5}$). The study of Zereini et al. (2005) measured heavy metal concentrations in airborne dust and revealed that the main fraction of lead was found in fine particles with a diameter of 2.1 μm (Zereini et al., 2005). Furthermore, Pb in $PM_{2.5}$ and fumes are identified as a hazardous substance to pose human health effect because they are inhaled more deeply into the lungs and better absorbed at the alveolar-capillary interface than larger particles (ATSDR, 2007). On the contrary, Cd is often found in coarse and larger particles; the ratio of Cd compounds in PM_{10}/TSP show enrichment in the PM_{10} fraction (European Commission DG Environment, 2000).

Due to both metals are used as components of electrical and electronic equipment. Pb is one of the major heavy metal pollutants of e-waste, which is a component in circuit boards, cathode-ray tubes, solders, and batteries (Osibanjo and Nnorom, 2007). While, Cd is usually presented in electronics parts, e.g., some switches and solder joints. E-waste-derived Pb and Cd pollution mainly originated from informal e-waste recycling activities, including burning or incineration of e-waste, roasting, acid leaching, and dismantlement (Zeng et al., 2016a; Zeng et al., 2016b, and Alli, 2015).

Regarding the results, it was found that the higher concentration of Pb in $PM_{2.5}$ and Cd in $PM_{2.5\text{-}10}$ exposed by e-waste workers might come from the different dismantling processes. The e-waste dismantling processes to extract valuable material, such as roasting, shredding, and dumping, had resulted in significant heavy metals found in $PM_{2.5}$ (Zheng et al., 2016). The study of Zheng et al. (2016) found that the concentration of Cu, Pb, Cr, and Ni were detected in $PM_{2.5}$ except those of Cd at printed circuit boards manufacturing workshop. Moreover, Pb is released into the ambience of the automatic line more easily in the crush and separation process for recycling waste printed circuit boards (Xue et al., 2012). While, physical dismantling such as cutting, smashing, and breaking of e-waste led to the distribution of coarse particles in the air. Similarly, the previous study found that the process of disassembly used a primitive method without any control can release heavy metals, in particular, Cd, Cu, Ni, and Pb, into the surrounding atmosphere (Puangprasert & Prueksasit, 2019). The exposure concentration of Pb and Cd in PM$_{10}$ of e-waste dismantling workers who dismantled e-waste were 0.1297±0.1746 and 0.0073±0.0084 µg/m^3, respectively. Besides, it found that exposure to Cd of the workers had possible cancer risk levels higher than the acceptable criterion (Puangprasert & Prueksasit, 2019). When comparing Cd concentrations in terms of PM$_{10}$ (see in Table 4.9), Cd concentration in this study (6.30±7.71 ng/m^3) was slightly lower than those of Cd (7.30±8.40 ng/m^3) from the study of Puangprasert and Prueksasit (2019). While Pb concentration in this study (29.25±26.69 ng/m^3) was lower than Pb concentration (129.70±170.00 ng/m^3).

Table 4.23 Pb and Cd concentration in PM$_{10}$ inhalation exposure of e-waste and non-e-waste dismantling workers in this study

Heavy metals (ng/m^3)	E-waste group (N=70)			Non-e-waste group (N=20)		
	Mean±SD	**Median**	**Range**	**Mean±SD**	**Median**	**Range**
Pb in PM$_{10}$	29.25±26.69	22.26	2.77 – 139.66	21.99±36.50	14.38	2.09 – 171.18
Cd in PM$_{10}$	6.30±7.71	3.45	0.31 – 39.65	3.17±3.65	2.68	0.09 – 10.45

Additionally, the study of Xue et al. (2012) indicated that Cu, Pb, Cr, and Cd in PM$_{10}$ were released into the ambient air of the automatic process line where crushing and separation processes took place. It seems that e-waste dismantling activities cause Cd contribution in coarse particles. Moreover, the study of Zheng et al. (2016) reported that the concentration of Pb and Cd in PM$_{2.5}$ emitted from diverse e-waste dismantling communities. As all evidence mentioned above, this can support the higher concentration of Pb and Cd found in the e-waste dismantling area than the reference area. Consequently, e-waste dismantling workers might get exposure to Pb and Cd from inappropriate e-waste dismantling via inhalation exposure, especially Pb in PM$_{2.5}$. The fine particle size range (<2.5 µm) can be almost completely absorbed through the respiratory tract and deeply penetrated the lungs, then lead circulated in the bloodstream.

The exposure concentrations of Pb and Cd in PM were grouped, responding to the e-waste type being dismantled (as shown in Table 4.10 – 4.11 and Figure 4.14 – 4.17). Table 4.10, Figure 4.14, and Figure 4.16 illustrate that dismantling the printed circuit board and televisions could pose higher exposure concentration of Pb than other types of e-waste, and the mean blood lead levels of workers group who dismantled printed circuit board is the highest. In comparison, it seems that the mean concentration of Cd in $PM_{2.5}$ and $PM_{2.5-10}$ exposed by the workers who separated each e-waste type was not much different, as shown in Table 4.11. On the other hand, Figure 4.15 and Figure 4.17 show that blood cadmium levels of workers tended to increase with Cd concentrations in $PM_{2.5}$ and $PM_{2.5-10}$ of each e-waste type. Noticeably, dismantling the refrigerator might be the source of cadmium in the blood and its concentration found in $PM_{2.5}$ and $PM_{2.5-10}$. The previous study found that the workers' exposure to cadmium was caused by removing the compressor from the refrigerator, which used heating to open the compressor pot (Puangprasert, 2018). This statement might support an increased trend of exposure to cadmium and blood cadmium levels. Moreover, the concentrations of Cd in PM showed relatively high deviation. Surprisingly, some of the outliers in $PM_{2.5}$ and $PM_{2.5-10}$ were presented in the samples of the workers dismantled small household appliances (e.g., iron, coffee makers, toaster, vacuum cleaner, and rice cookers) and recyclable waste dismantling which are not considered as the main sources of cadmium. Although the concentration of Cd in $PM_{2.5}$ and $PM_{2.5-10}$ was not corresponding to the type of e-waste clearly, those found in the PM exposed by the e-waste workers was still significantly higher than non-e-waste workers.

Additionally, according to the result found that the concentration of Pb and Cd in $PM_{2.5}$ and $PM_{2.5-10}$ of each e-waste type had a high variation; this could be due to the difference in the working environment such as airflow around the working area as well as the working positions of the workers, which cause air volume was very different (Puangprasert, 2018).

Table 4. 24 Pb concentration in PM$_{2.5}$ and PM$_{2.5-10}$ and blood lead levels in correspondence with e-waste types

E-waste type	[Pb] in PM$_{2.5}$	[Pb] in PM$_{2.5-10}$	BLLs
Printed circuit board (N=3)	26.83±10.97	37.98±31.35	9.66±1.75
Television (N=5)	17.93±14.48	14.92±12.18	4.31±0.52
Computer (N=5)	5.93±2.81	9.20±10.04	4.93±1.40
Refrigerator (N=3)	22.36±28.76	13.41±10.40	4.59±1.21
Motor (N=2)	2.82±1.30	2.20±1.24	6.23±0.57
Washing machines (N=1)	15.76	20.30	4.95
Electrical fan (N=2)	8.67±9.82	13.72±3.59	3.94±1.00
Small household appliances (N=25)	18.11±26.26	8.50±8.86	4.56±1.59
Recyclable waste (N=23)	21.19±23.03	7.85±8.47	3.85±0.93

Table 4.25 E-waste types and Cd concentration in PM$_{2.5}$ and PM$_{2.5-10}$ and their blood levels

E-waste type	[Cd] in PM$_{2.5}$	[Cd] in PM$_{2.5-10}$	BCLs
Printed circuit board (N=3)	2.07±0.47	2.02±0.67	1.18±0.18
Television (N=5)	0.89±0.70	2.62±2.01	1.24±0.60
Computer (N=5)	0.67±0.47	2.81±2.10	1.18±0.38
Refrigerator (N=3)	7.15±11.70	2.81±2.76	1.32±0.29
Motor (N=2)	2.22±0.69	0.68±0.73	0.67±0.09
Washing machines (N=1)	1.50	1.77	0.45
Electrical fan (N=2)	0.10	1.18±0.77	0.80±0.45
Small household appliances (N=25)	4.08±7.25	1.84±1.08	0.98±0.53
Recyclable waste (N=23)	6.81±9.63	2.07±0.89	1.05±0.38

Regrading to the results, it could indicate that dismantling different e-waste types could release different levels of Pb and Cd in PM. As a result, the workers could inhale Pb and Cd in PM$_{2.5}$ and PM$_{2.5-10}$ into the body, which could then be a considerable source of blood lead and cadmium levels elevation.

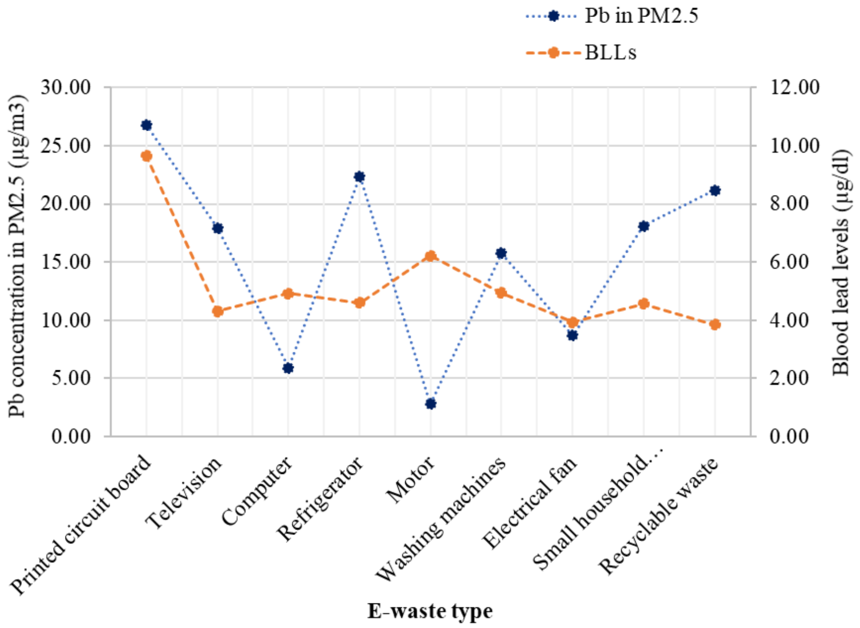


Figure 4.22 Pb concentration in $PM_{2.5}$ corresponding to e-waste being dismantled

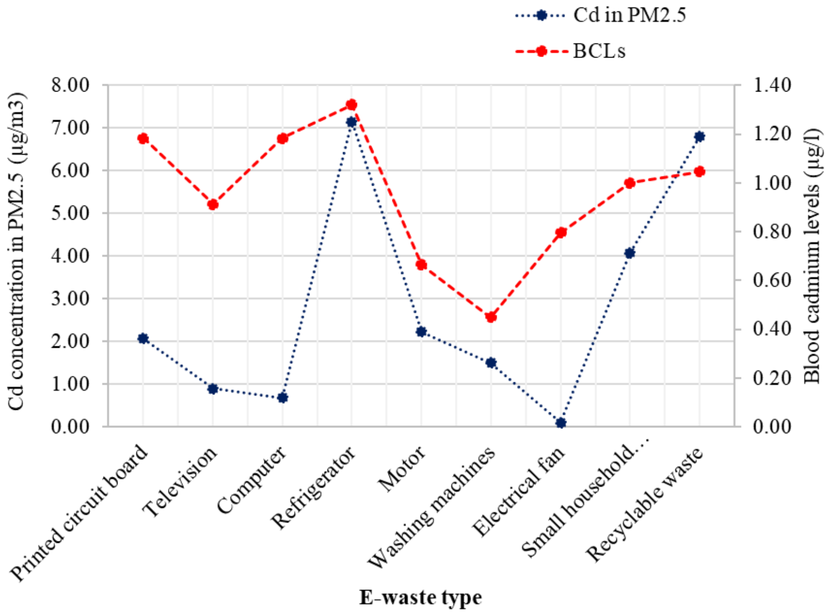


Figure 4.23 Cd concentration in $PM_{2.5}$ corresponding to e-waste being dismantled

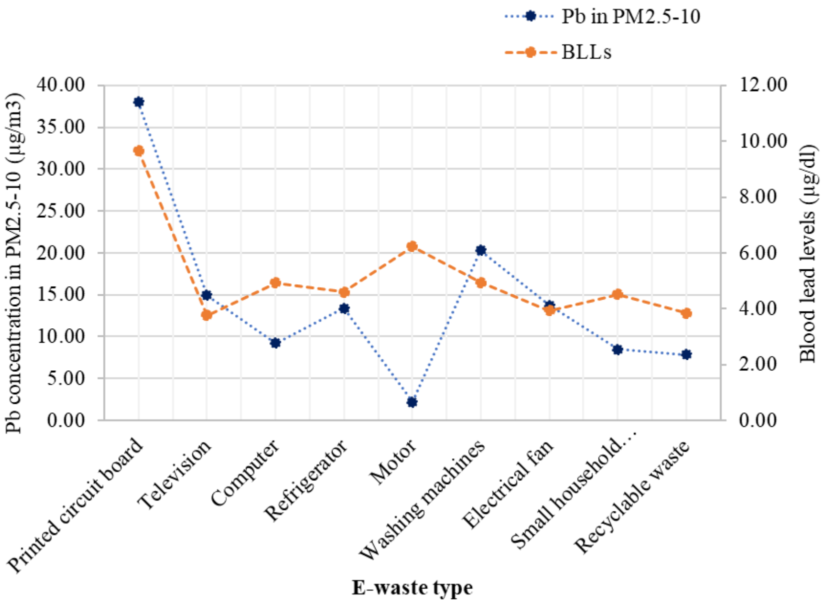


Figure 4.24 Pb concentration in PM$_{2.5\text{-}10}$ corresponding to e-waste being dismantled

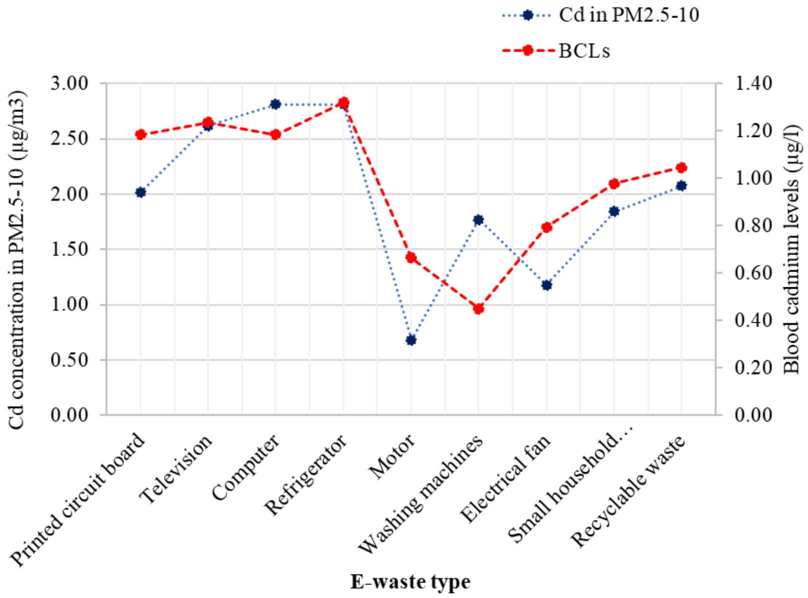


Figure 4.25 Cd concentration in PM$_{2.5\text{-}10}$ corresponding to e-waste being dismantled

Pb and Cd concentration in $PM_{2.5}$ and $PM_{2.5-10}$ in this study were compared with the other studies, as presented in Table 4.12. The Pb and Cd concentrations obtained from $PM_{2.5}$ and $PM_{2.5-10}$ in this study were summed up before comparing them with the previous studies on PM_{10}. The result showed that the inhalation exposure to Pb and Cd concentrations of e-waste workers in this study were slightly lower than the concentration reported by Puangprasert and Prueksasit (2019) and Wongsabsakul (2019). Moreover, the study of Wongsabsakul (2019) reported that the inhalation exposure to Pb and Cd concentrations via PM_{10} of e-waste workers were significantly higher than those of non-e-waste workers similar to this study. The study of Chanthahong and Kanghae (2017) found Pb and Cd concentrations in PM_{10} at the outdoor area of e-waste dismantling house, non-e-waste dismantling house, and control were not different, Pb concentration was slightly higher than those concentration in this study but Cd concentration of both study had same range.

Table 4.26 The comparison of Pb and Cd concentration in $PM_{2.5}$ and $PM_{2.5-10}$ observed in this study with the previous studies

Location	**The concentration of heavy metals in particulate matter (µg/m^3)**		**Reference**
	Pb	**Cd**	
E-waste dismantling site, Buriram, Thailand ($PM_{2.5}$)	0.0190±0.023	0.00413±0.008	**This study**
E-waste dismantling site, Buriram, Thailand ($PM_{2.5-10}$)	0.0105±0.012	0.00203±0.0013	
E-waste dismantling site, Buriram, Thailand (PM_{10})	0.0295±0.027	0.0062±0.0077	
E-waste dismantling site, Buriram, Thailand (PM_{10})	0.368±0.222	0.021±0.013	Wongsabsakul (2019)
E-waste dismantling site, Buriram, Thailand (PM_{10})	0.1297±0.17	0.0073±0.01	Puangprasert and Prueksasit (2019)
E-waste dismantling village, Buriram, Thailand (PM_{10})	0.041±0.030	0.006±0.003	Chanthahong and Kanghae (2017)

4.3.2 Correlation between the concentration of Pb and Cd in $PM_{2.5}$ and $PM_{2.5-10}$ and their concentration in the blood

With respect to the toxicokinetic of Pb and Cd, it was reported that the absorption of inhaled metals depends on particle size. Large particles are swallowed and deposited on the ciliated airways; finally, it is accumulated in the upper respiratory tract. At the same time, small particles tend to infiltrate into the alveoli and deeply into the lungs (ATSDR, 2007). Then Pb and Cd in the form of Pb^{2+} and Cd^{2+}, respectively, can bind with sulfhydryl groups (-SH) group in proteins (mainly albumin and metallothionein) and other molecules according to the hard-soft acid-base theory. This study was then hypothesized that the blood lead and cadmium levels would be related to Pb and Cd in the $PM_{2.5}$ and $PM_{2.5-10}$ released from e-waste dismantling.

Spearman correlation analysis was conducted to examine the relationship between the concentration of Pb and Cd in $PM_{2.5}$ and $PM_{2.5-10}$ and their concentration in the blood of e-waste and non-e-waste dismantling workers. The results showed that only the concentration of Pb in $PM_{2.5}$ was significantly correlated to its concentration in blood at $p = 0.046$ ($p < 0.05$), and it had a positive correlation at $r = 0.211$, as shown in Table 4.13. Whilst Cd concentration in $PM_{2.5}$ and blood cadmium levels were not significantly correlated ($p = 0.406$). Likewise, the concentration in blood of Pb and Cd were not related to their concentration in $PM_{2.5-10}$.

Table 4.27 Correlation between Pb and Cd concentration in $PM_{2.5}$ and $PM_{2.5-10}$ and their concentration in blood of e-waste and non-e-waste dismantling workers

Correlation	*r*	*p*-value
Pb in $PM_{2.5}$ and BLLs	0.211	**0.046***
Cd in $PM_{2.5}$ and BCLs	0.089	0.406
Pb in $PM_{2.5-10}$ and BLLs	-0.008	0.937
Cd in $PM_{2.5-10}$ and BCLs	0.133	0.215

* = Spearman Correlation tests, (p-value < 0.05)
r = Correlation Coefficient

Regarding the significant positive correlation of Pb in $PM_{2.5}$ and blood lead levels, Pb in fine particles might be released from burning printed circuit boards as mentioned above and cutting e-waste by using a grinder for separation the component of e-waste materials. The study of Julander et al. (2014) reported that the highest individual blood lead level originated from workers performing work tasks connected to grinding e-waste materials, which of Pb found in different solders used in electronics. These e-waste dismantling activities might release the Pb in the form of $PM_{2.5}$ and fumes to the environment, resulting in the workers inhaled Pb entering the body; finally, Pb will be circulated in the blood. As mentioned above, this relationship between the concentration of Pb in PM and blood lead levels were supported by the study of Julander et al. (2014), who investigate the relationship between Pb concentration in PM and blood in e-waste dismantling sites in Sweden; moreover, *r*-value reported in Julander's study is better than this study because the sample was taken from the workshop of CRT dismantling, which was a main source of Pb.

Usually, inhaled cadmium is good absorption in small particles, which is approximately 0.1 μm in diameter that tend to infiltrate into the alveoli and bind with anionic groups (-SH group) in proteins (ATSDR, 2007). As for the sizes of the particle measured in this study were $PM_{2.5}$ and $PM_{2.5\text{-}10}$, which was larger than 0.1 μm, the explicit relationship between Cd concentration in $PM_{2.5}$ and $PM_{2.5\text{-}10}$ and blood cadmium levels could not be determined.

Even though Pb and Cd in the PM were supposed to be the dominant cause of their presence in the blood of the workers, other factors such as exposure factors, behavior, lifestyle, and host factors could influence blood lead and cadmium levels as well.

4.4 Associated affecting factors on blood lead and cadmium levels of the participants

This study was conducted with 145 participants, which consisted of 95 e-waste workers and 50 non-e-waste workers. A questionnaire was used to collect all data, and a face-to-face interview was conducted. A questionnaire consisted of 3 parts, (1) general information (gender, age, and BMI), (2) working conditions (working hours, working hours within a week, working days and working period), and (3) using PPE (short gloves, mask, and sneaker). According to the results of blood levels of participants in section 4.2, blood cadmium levels of e-waste workers and non-e-waste workers were not a significant difference; besides, there was no significant correlation between the concentration of cadmium in PM and blood. Thus, not only e-waste dismantling activities but also other factors might influence blood lead and cadmium levels. The previous studies of Kira et al. (2016) and Amankwaa et al. (2017) found that some factors related to the concentration of lead and cadmium in blood, such as socio-demographic factors and behavioral.

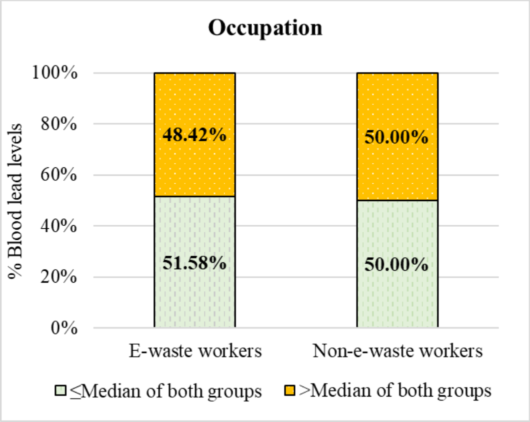
Although blood lead and cadmium levels of all participants were lower than Thai Biological Exposure Indices, those blood levels were still investigated in association with some related host, behavior, and exposure factors by using Chi-square ($\chi2$) test. Pior to analyze the relationship between associated affecting factors and blood lead and cadmium levels of the participants, the normal distribution of the Pb and Cd in blood was examined. It was found that blood lead levels of three sample groups were not a normal distribution, while normal distribution could be obtained for those of cadmium. Thus, median blood lead levels and mean blood cadmium levels were applied as a criterion in the statistical analysis of Chi-square.

4.4.1 General personal information of the participants

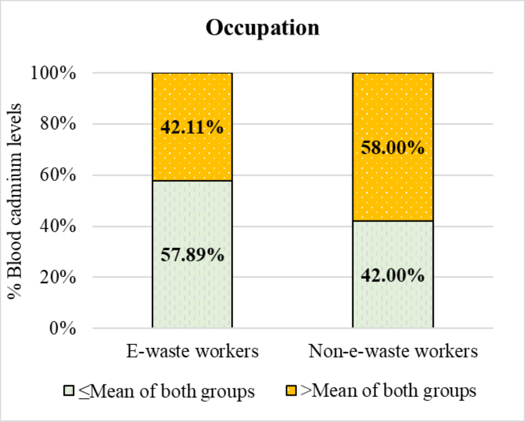
General personal information of 145 participants, which were divided into 95 e-waste workers and 50 non-e-waste workers, was gathered by face-to-face interviews using a questionnaire. This general personal information, termed as associated factors, including gender, age, BMI, and occupation relating to e-waste, were used to examine their relationship to blood lead and cadmium levels. The criteria for the dividing between high and low blood lead and cadmium levels would be different depending on the characteristic of each associated factor. According to associated factors, the age of ≤40 and >40 years, and a normal range and abnormal range of BMI was used as the criteria (Table 4.14). The % contribution of participants in correspondence with that associated factor was compared with the median of blood lead levels and the mean of blood cadmium levels, as shown in Figure 4.18.

Table 4.28 The % contribution of participants in correspondence with socio-demographic, behavior factors, and blood levels

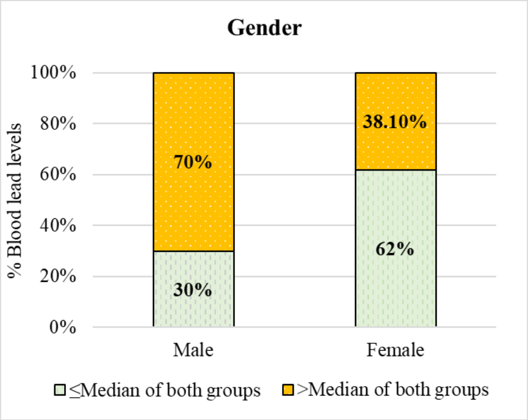
Socio-demographic and behavior factors	Total (N=145)	Blood lead levels		Blood cadmium levels	
		≤median	>median	≤mean	>mean
Occupation					
- E-waste	95 (65.52%)	49 (51.58%)	46 (48.42%)	55 (57.89%)	40 (42.11%)
- Non-e-waste	50 (34.48%)	25 (50.00%)	25 (50.00%)	21 (42.00%)	29 (58.00%)
Gender					
- Male	40 (27.59%)	12 (30.00%)	28 (70.00%)	32 (80.00%)	8 (20.00%)
- Female	105 (74.41%)	65 (61.90%)	90 (38.10%)	59 (56.19%)	46 (43.81%)
Age					
≤ 40 years	25 (12.82%)	15 (60.00%)	10 (40.00%)	14 (56.00%)	11 (44.00%)
> 40 years	120 (61.54%)	60 (50.00%)	60 (50.00%)	62 (56.67%)	58 (43.33%)
BMI					
Normal range	49 (25.13%)	27 (55.10%)	22 (44.90%)	25 (51.02%)	24 (48.98%)
Abnormal range	96 (74.87%)	48 (50.00%)	48 (50.00%)	51 (53.13%)	45 (46.88%)



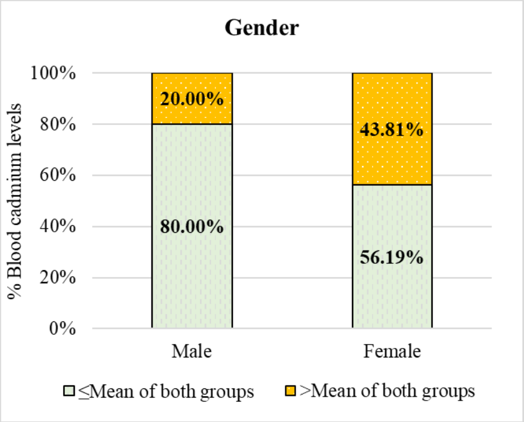
(a) Occupation and BLL



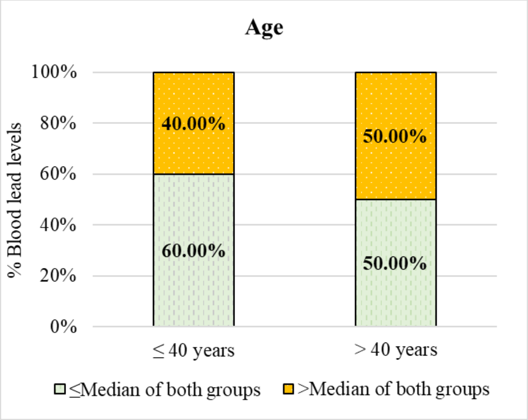
(b) Occupation and BCL



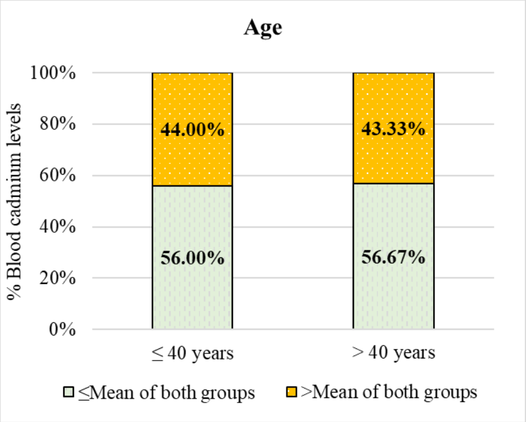
(c) Gender and BLL



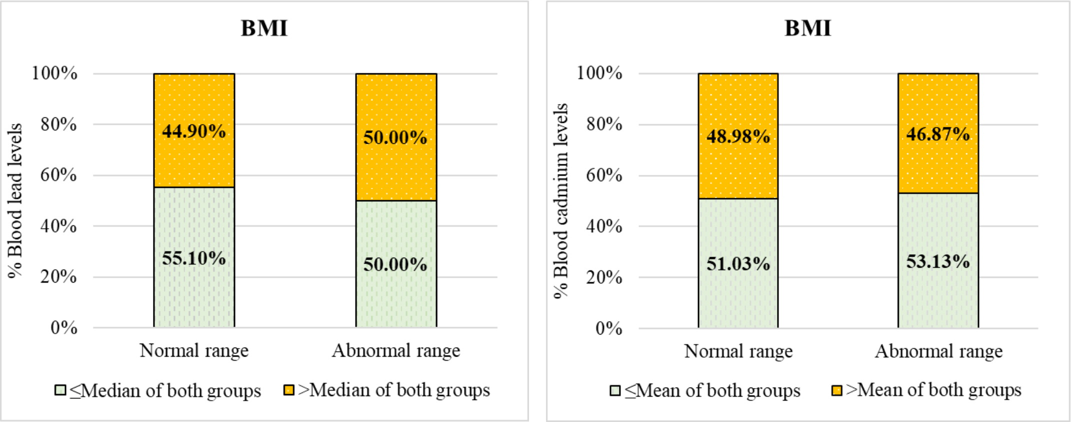
(d) Gender and BCL



(e) Age and BLL



(f) Age and BCL



(g) BMI and BLL (h) BMI and BCL

Figure 4.26 The comparison of % contribution between associated factors and blood lead and cadmium levels

The percentage of the participant who dismantled e-waste and found to have blood lead levels over the median (48.42%) was slightly lower than those of non-e-waste dismantling workers (50.00%) (Figure 4.18). Similarly, blood cadmium levels over the mean of e-waste workers (42.11%) were lower than those of non-e-waste workers (58.00%). The results of the Chi-square test at $p < 0.05$ found that the occupation of e-waste was significantly associated with blood lead levels ($p = 0.000$), see Table 4.15. On the other hand, it was found that the e-waste dismantling occupation was not found to affect blood cadmium levels at $p = 0.069$. This result explained that e-waste occupation could influence on the blood lead levels of the participants. As ATSDR reported that inhalation of lead might be a major exposure route for workers in lead-related occupations, and lead present in inhaled dust could be absorbed (ATSDR, 2007), this might support e-waste dismantling could lead to an increased risk of exposure to Pb. From the study of Julander et al. (2014), which evaluated exposure to metals of e-waste workers using biomarkers (blood, plasma, and urine) in combination with monitoring of heave metals in PM_{10}, Sweden, they found that lead in the blood of e-waste workers were significantly higher than those of office workers. Cd is often present in different types of e-waste, such as printer ink in a printer cartridge, computer, especially batteries, which were not found in this area. For this reason, the e-waste dismantled during the sampling might not be an important source of Cd, which could not be found clearly effect on the variation of blood cadmium levels of the workers. Moreover, 1 to 2 µg of Cd is contained cigarettes, 10% of Cd is inhaled, and approximately 5% is absorbed (Forte et al., 2011). The study of Sun et al. (2016) and Kira et al. (2016) that smoking habit is an important factor which is related to blood cadmium levels. Blood cadmium levels of smokers were four times higher than those of non-smokers. Due to the smoking habit is a factor of direct cadmium exposure, this study then excluded the participants who had smoking before collecting samples. Regrading to Cd concentration in $PM_{2.5-10}$ exposed by the e-waste workers were higher than those of non-e-waste workers, but there was no significant difference. Even though the e-waste dismantling occupation could not have a significant influence on blood cadmium levels, Cd from e-waste dismantling might considerably increase the exposure of the workers.

Table 4.29 The results of Chi-square test between personal characteristic and blood levels

Factors	*p* – value of blood levels	
	Blood lead levels	Blood cadmium levels
Occupation of e-waste	**0.000***	0.069
Gender	**0.001***	**0.008***
Age	0.363	0.693
BMI	0.561	0.810

* = Chi-square test, p value < 0.05)

Moreover, this study found that blood lead and cadmium levels could be significantly different depending on the gender at $p = 0.001$ and $p = 0.008$, respectively. Mean blood lead levels of male workers (6.07 µg/dl) were higher than those of females (4.18 µg/l). These could much relate to the workers' activity that up to 12.90% of male workers dismantled printed circuit boards (Figure 4.19), which mainly comprised of Pb. In comparison, female workers who dismantled e-waste containing Pb was only 3.13% of printed circuit boards. Besides greater exposure to lead of male workers, sex differences in lead metabolism and hematocrit values among male might affect on the BLL; as a result, blood lead levels of male were higher than those of female (Batariová et al., 2006; Popovic et al., 2005; Skerfving et al., 1999; WHO, 1995,Kira et al., 2016).

In addition, males influence cadmium levels in their blood because Cd is absorbed from the intestine via iron transporters, the expression of which is induced by low iron levels of women (Usuda et al., 2011). Accordingly, the effects of cadmium of this study might tend to be absorbed into the body of female workers, resulting in higher levels of cadmium in the blood. The results of this study were similar to the study of Kira et al. (2016); blood lead levels were higher among the male compared to the female. Stojsavljević et al. (2019) indicated that women had significantly higher blood cadmium levels than men. It could be indicated that, in addition to e-waste dismantling activity, gender is another factor in the body metabolism affecting blood levels of lead and cadmium.

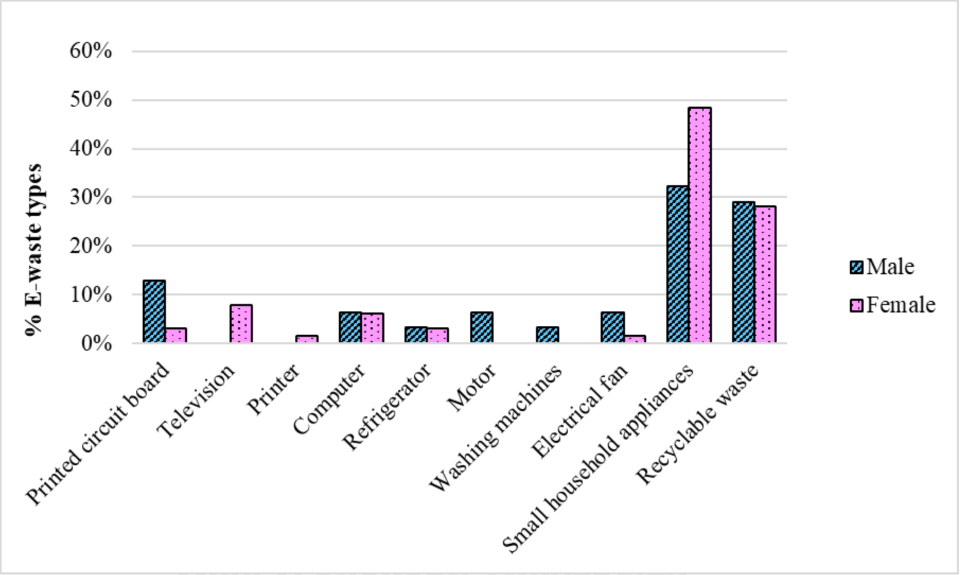


Figure 4.27 The proportion of e-waste types dismantling following gender workers

4.4.2 Working conditions of the participants

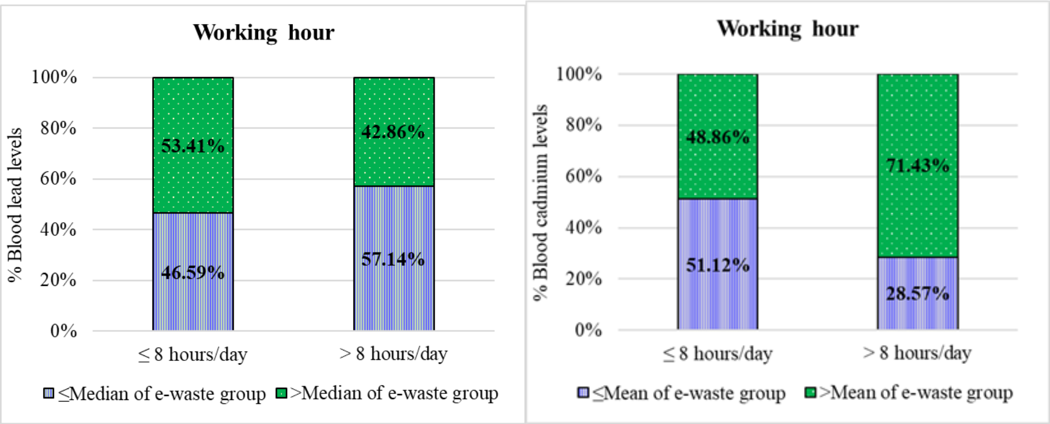
The working condition information of 95 participants, 50 participants of all e-waste workers in Dang Yai sub-district, and 45 participants of all e-waste workers in Ban Pao sub-district, were analyzed to know whether these factors possibly affected the lead and cadmium concentration in the blood of e-waste workers. These data were statistically analyzed using Chi-square, which the calculated mean is used for blood cadmium levels, while the median is used for blood lead levels as it was done in 4.4.1. The associated factors of e-waste workers related to working conditions (working hours, working day, working hours within a week, and working period) and using PPE (short glove, mask, and sneakers) were taken to analyze. The mean of blood cadmium levels and the median of blood lead levels were calculated based on the working time of 8 hours. Then, the working hour was divided into ≤8 hours and >8 hours and was investigated the relationship between the working condition and blood levels of the workers. The other working conditions, such as working hours per week, working days per week, and working period (years), were also investigated by different criteria, as shown in Table 4.16. The % contribution of the participants related to each working condition is presented in Table 4.17 and Figure 4.20.

Table 4.30 Criteria of working condition

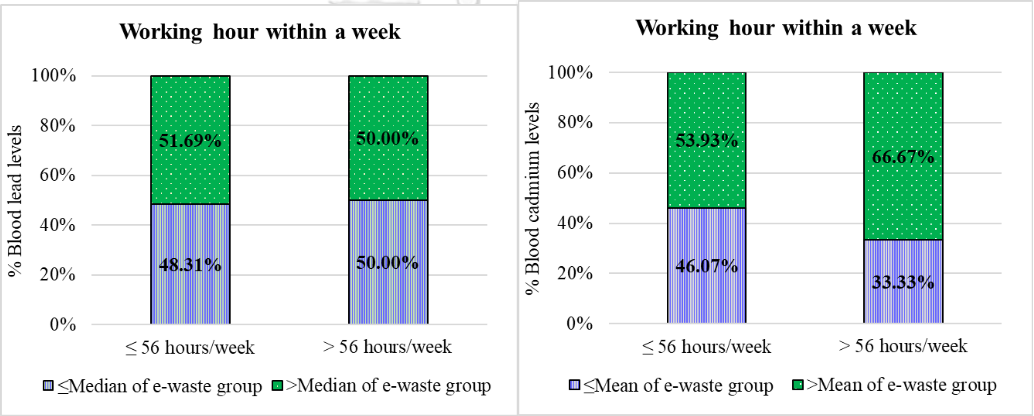
Working condition	Median of blood lead levels (µg/dl)	Mean of blood cadmium levels (µg/l)
8 hours	4.19	0.99
56 hours a week	4.19	0.95
5 days a week	4.13	1.08
10 years	4.26	1.09

Table 4.31 The % contribution of participants in correspondence with working condition and blood levels

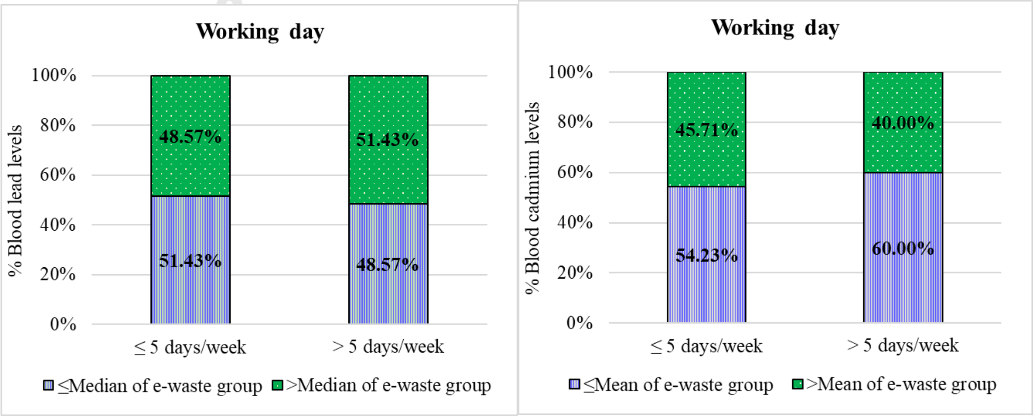
Working condition	Total (N=95)	Blood lead levels		Blood cadmium levels	
		≤median	>median	≤mean	>mean
Working hour					
≤ 8 hours/day	88 (92.63%)	41 (46.59)	47 (53.41%)	45 (51.12%)	43 (48.86%)
> 8 hours/day	7 (7.37%)	4 (57.14%)	3 (42.86%)	2 (28.57%)	5 (71.43%)
Working hour within a week					
≤ 56 hours/week	89 (93.68%)	43 (48.31%)	46 (51.69%)	41 (46.07%)	48 (53.93%)
> 56 hours/week	6 (6.32%)	3 (50.00%)	3 (50.00%)	2 (33.33%)	4 (67.67%)
Working day					
≤ 5 days/week	35 (36.84%)	18 (51.43%)	17 (48.57%)	19 (54.23%)	16 (45.71%)
> 5 days/week	60 (63.16%)	27 (48.57%)	33 (51.43%)	36 (60.00%)	24 (40.00%)
Working period					
≤ 10 years	88 (92.63%)	42 (47.73%)	46 (52.27%)	51 (57.95%)	37 (42.05)
> 10 years	7 (7.37)	3 (42.86%)	4 (57.14%)	5 (71.43%)	2 (28.57%)



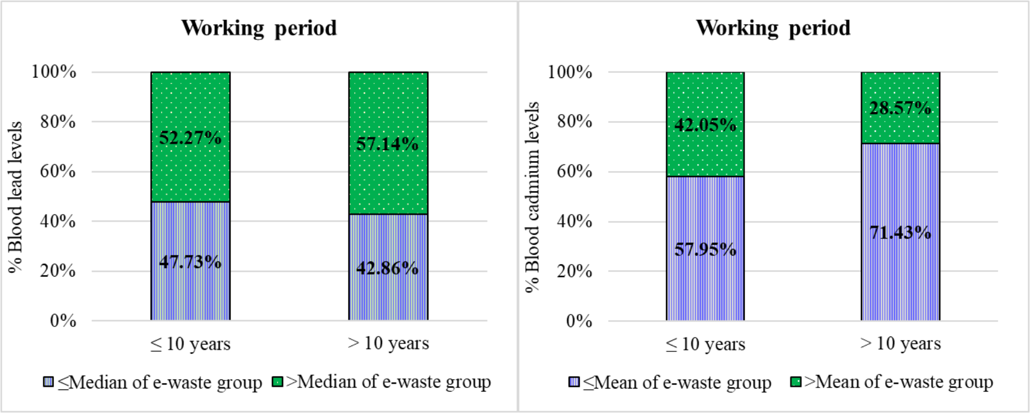
(a) Working hour and BLL (b) Working hour and BCL



(c) Working hour within a week and BLL (d) Working hour within a week and BCL



(e) Working day and BLL (f) Working day and BCL



(g) Working period and BLL (h) Working period and BCL

Figure 4.28 The comparison of %contribution between working condition of workers and blood levels

The percentage of workers who worked more than 8 hours per day and had blood lead and cadmium levels higher than the median and mean accounted for 42.86% and 71.43 %, respectively. For working hours within a week, the workers who had worked more than 56 hours per week were found to have the cadmium in blood higher than those who worked less than 56 hours per week. Working hours per day is one of the important factors because Pb and Cd are able to detect in blood within hours of exposure as daily exposure. Working hours a week and working period were used to examine their accumulation possibility after exposure. However, the proportion of blood lead levels and the percentage of workers who spent time on dismantling e-waste for 5 to 7 days per week were not different. In addition, the proportion between high and low blood lead levels categorized by the working periods (years) showed not much different. While the blood cadmium levels of a large proportion of the workers who have worked for longer than10 years were not shown higher than the mean. It appears that the working hours do not influence either blood lead and cadmium levels.

The results of Chi-square test, as seen in Table 4.18, revealed that all working conditions did not affect the increase of blood lead and cadmium levels. In comparison, the study of Amankwaa et al. (2017) investigated the relationship between blood lead levels and working hours per week of e-waste recycling workers in Ghana, which consisted of burners or recycles, middleman, dismantlers, collector, scrap dealers, and repairers. The data was taken to analyze by the Chi-square test and ranging from weekly working hours between 30 to 105 hours per week. The result found that blood lead levels of e-waste workers positively correlated with weekly working hours. The result implied that the length of time spent on the site of e-waste workers were significant contributory factors to blood lead levels. Unlikely this study, the range of weekly working hours from the study of Amankwaa et al. (2017) was two-fold higher than observed in this study. Thus, it is hard to point out that blood lead and cadmium levels of the e-waste workers depended on the working condition. It might have other stronger affecting factors than the working time observed.

Table 4.32 The significant working condition factors of blood levels

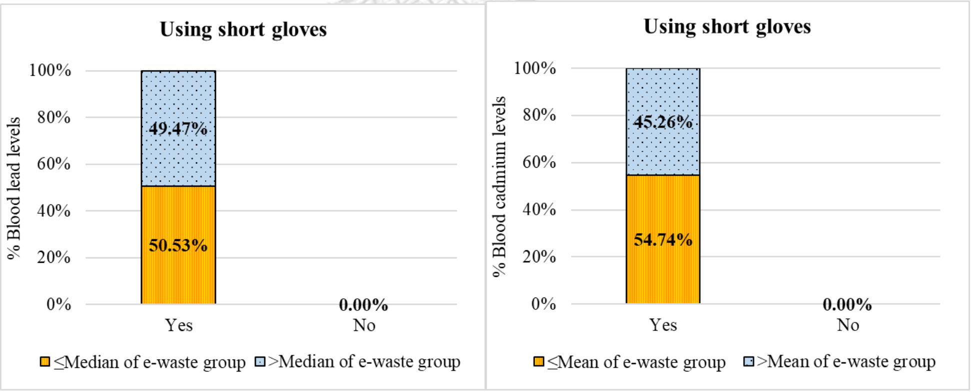
Factors	***p* – value of blood levels**	
	Blood lead levels	**Blood cadmium levels**
Working conditions		
- **Working hour (hours/day)**	0.590	0.250
- **Working hour within a week**	0.894	0.544
(hours/week)	0.545	0.586
- **Working day (days/week)**	0.804	0.486
- **Working period (years)**		

[a] No statistics are compared because the working day is a constant

Additional to working time, using personal protective equipment or PPE of the worker (i.e., short gloves, mask, and sneakers) was also observed. These data were then analyzed to investigate their association with blood lead and cadmium levels of workers. Regarding the survey, it revealed that all workers wore short gloves while some of them did wear a mask and sneakers during working. Before analyzing with the Chi-square test, information on PPE using was converted to an ordinal score as presented in Table 3.3 in section 3. The workers who used all types of PPE would have a low score because of having adequate protection. In contrast, the worker did not wear all types of PPE; the score would then be high, especially without wearing a mask. Then, the median of blood lead levels and the mean of blood cadmium levels of the workers on the basis of using PPE were calculated. The % contribution of participants related to using PPE is presented in Table 4.20. and Figure 4.21.

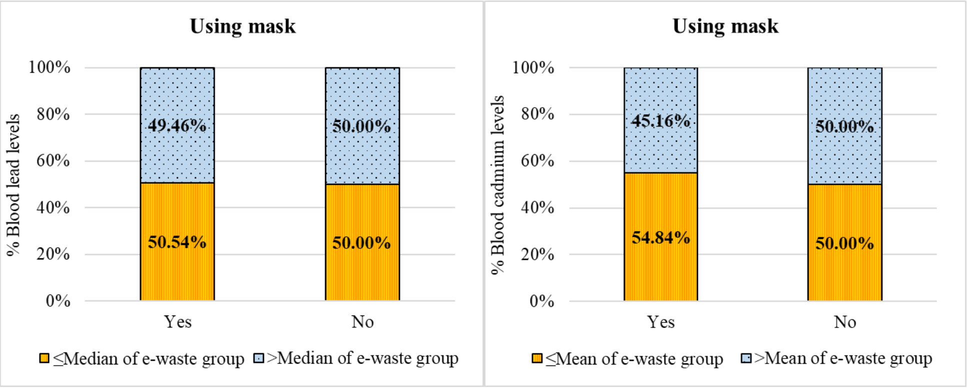
Table 4.33 The information between PPE using and blood levels

Using PPE	Total (N=95)	Blood lead levels		Blood cadmium levels	
		≤median	>median	≤mean	>mean
Short gloves					
- Yes	95 (100.00%)	48 (50.53%)	47 (49.47%)	52 (54.74%)	43 (45.26%)
- No	0 (0.00%)	0 (0.00%)	0 (0.00%)	0 (0.00%)	0 (0.00%)
Mask					
- Yes	93 (97.89%)	47 (50.54%)	46 (49.46%)	51 (54.84%)	42 (45.16%)
- No	2 (2.11%)	1 (50.00%)	1 (50.00%)	1 (50.00%)	1 (50.00%)
Sneakers					
- Yes	74 (77.89%)	37 (50.00%)	37 (50.00%)	42 (56.76%)	32 (43.24%)
- No	21 (22.11%)	8 (38.10%)	13 (61.90%)	10 (47.62%)	11 (52.38%)
Mask & Sneakers					
- Yes	75 (78.95%)	38 (50.67%)	37 (49.33%)	42 (56.00%)	33 (44.00%)
- No	20 (21.05%)	6 (30.00%)	14 (70.00%)	14 (70.00%)	6 (30.00%)

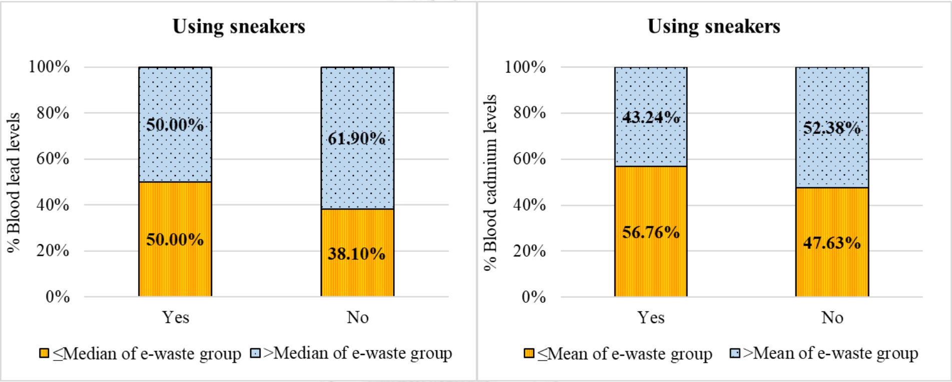


(a) Using short gloves and BLL

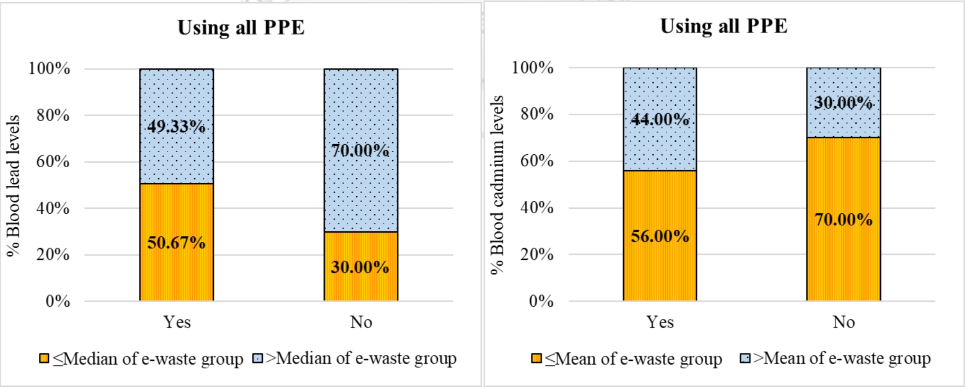
(b) Using short gloves and BCL



(c) Using mask and BLL (d) Using mask and BCL



(e) Using sneakers and BLL (f) Using sneakers and BCL



(g) Using all PPE and BLL (h) Using all PPE and BCL

Figure 4.29 The comparison of % contribution between using PPE of workers and blood levels

From Figure 4.21, the percentages of e-waste workers who wore masks and had blood lead levels and blood cadmium levels lower than the median and mean were

50.54% and 54.84%, respectively. It is similar to those using all PPE (short gloves, mask, and sneakers), the percentage of e-waste workers who had blood lead and cadmium levels lower than the median and mean contributed for 50.67% and 56%, respectively. For using each PPE, the statistical analysis results in a case of using each type of PPE independently showed no significant relationship with blood lead and cadmium levels. In addition, Chi-square tests (Table 4.21) found that workers wearing all PPE, e.g., short gloves, masks, and sneakers were seemed to reduce the risk of exposure to lead and cadmium, leading to their lower presence in the blood. It seems that using short gloves, mask, and sneakers, particularly a mask, might directly protect exposure to Pb from e-waste dismantling activities. Consequently, e-waste workers should be recommended to use appropriate PPE for reducing risk exposure to Pb and Cd. Other research also proved that e-waste dismantling workers were at risk of being exposed to toxic levels of Pb and Cd through inhalation of fumes like the present study.

Table 4.34 The significant using PPE factors of blood levels

Factors	***p* – value of blood levels**	
	Blood lead levels	**Blood cadmium levels**
Using PPE		
- **Short gloves**	-[a]	-[a]
- **Mask**	0.988	0.892
- **Sneakers**	0.335	0.458
- **All PPE**	**0.000***	**0.003***

[a] The statistical analysis was not performed because all workers used short gloves.

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Blood lead and cadmium levels of e-waste dismantling workers in Buriram province, Thailand, were investigated in association with their exposure concentration of Pb and Cd in $PM_{2.5}$ and $PM_{2.5-10}$. Blood samples and personal inhalation exposure samples were collected from the e-waste dismantling workers from Daeng Yai sub-district, Ban Mai Chaiyaphot district, and Ban Pao sub-district, Putthaisong district, and non-e-waste dismantling workers (control group) who lived in Village No.1, Daengyai sub-district, during May to August 2019. The overall results could be concluded as follow:

5.1.1 The blood lead and cadmium levels

1) Mean blood lead levels of e-waste workers from both sub-districts were significantly higher than those of non-e-waste workers ($p = 0.000$), while blood cadmium levels were no statistically significant difference ($p = 0.086$) in which the mean blood cadmium levels of non-e-waste workers were slightly higher than those of e-waste workers. Mean blood lead levels of e-waste workers from Dang and Ban Pao sub-district were 5.63± 2.86 µg/dl and 3.92±1.13 µg/dl, respectively, while the mean blood lead levels of non-e-waste workers as a control group was 2.84±0.72 µg/dl. Mean blood cadmium levels of non-e-waste workers, e-waste workers from Ban Pao and Dang Yai sub-district were 1.15±0.38, 1.12±0.43, and 0.97±0.43 µg/l, respectively.

2) Serum creatinine of 62% of the non-e-waste workers was higher than the normal range, while the corresponding values for e-waste workers from Dang Yai and Ban Pao sub-district were approximately only 20% and 11%, respectively.

5.1.2 Pb and Cd concentrations in $PM_{2.5}$ and $PM_{2.5-10}$

1) Pb concentration in $PM_{2.5}$ of e-waste workers was found significantly higher level than those of non-e-waste workers ($p = 0.000$); in contrast, the concentration of cadmium in $PM_{2.5}$ exposed by both groups was not shown a significant difference ($p = 0.621$). Mean Pb concentration in $PM_{2.5}$ of e-waste and non-e-waste workers were 18.95±23.12 and 12.69±37.40 ng/m^3, respectively. Mean

Cd concentration in $PM_{2.5}$ were 4.31±7.71 ng/m^3 for e-waste workers and 2.11±2.40 ng/m^3 for non-e-waste workers.

2) The mean concentration of Pb in $PM_{2.5-10}$ of e-waste workers (10.45±11.81 ng/m^3) were slightly higher than those of non-e-waste workers (9.30±9.81 ng/m^3), and it was not significantly different ($p = 0.836$). The mean concentration of Cd in $PM_{2.5-10}$ of e-waste workers were significantly higher than those of non-e-waste worker ($p = 0.002$). The mean Cd concentration $PM_{2.5-10}$ of e-waste and non-e-waste workers were 2.03±1.27 and 1.06±0.99 ng/m^3.

3) Pb concentration in $PM_{2.5}$ was positively and significantly associated with blood lead levels ($r = 0.211$, p=0.046). While those of the concentration in $PM_{2.5-10}$ were not significantly related to blood lead levels ($r = -0.008$, $p = 0.937$). For Cd concentration in $PM_{2.5}$ and $PM_{2.5-10}$, significant correlations with blood cadmium levels could not be obtained ($r = 0.089$, $p = 0.406$ and $r = 0.133$, $p = 0.215$, respectively).

5.1.3 Associated affecting factors on blood lead and cadmium levels

E-waste dismantling occupation was a significantly associated risk factor of blood lead levels. Gender was also detectable as the associated risk factors of either blood lead or cadmium levels. Besides, using short gloves, masks, and sneakers could likely help to reduce the risk of exposure to lead and cadmium of the workers.

5.2 Recommendations and suggestions

1) The result of blood lead and cadmium levels of the e-waste and non-e-waste dismantling workers in this study would be the useful baseline data. Although blood lead and cadmium levels of e-waste workers were found lower than Thai Biological Exposure Indices (Thai BEIs) with the values of 30 µg/dl and 5.0 µg/l, respectively, which were higher than the WHO acceptable level (<10 µg/dl for blood lead level and 0.03 – 0.12 µg/l for blood cadmium level). The local administrative organization should communicate and raise awareness of the target people who have potential risk posed by the exposure to Pb and Cd in $PM_{2.5}$ and $PM_{2.5-10}$ emitted from e-waste dismantling activities, especially it might have long-term effects and cause chronic disease.

2) The blood lead levels of e-waste dismantling workers in this study were found to be higher than those of non-e-waste workers. The dismantling workers should be recommended to use appropriate personal protective equipment (PPE) such as N95 masks for protecting exposure to $PM_{2.5}$ and $PM_{2.5-10}$ directly, which can possibly minimize their potential health risk from e-waste dismantling activities.

3) In addition to the e-waste dismantling activities, some associated factors especially gender could influence blood lead and cadmium levels. The male worker should be advised to avoid certain behaviors that lead to increase cadmium in blood such as drinking alcohol.

4) According to the effects of Pb and Cd on the development of children, serious impairment of cognitive development, as well as the level of intelligence, the surveillance of blood lead and cadmium levels in children and pregnant workers should also be performed as susceptible sub-groups in this area.

5) For better health and environmental quality and sustainable solutions for the local community in the long term, the related governmental organization should have the guideline of appropriate methods for informal e-waste dismantling, involving collection, transportation, storage, separation, and disposal of unwanted e-waste residues.

6) For future research, to represent a real situation of personal exposure, the sampling instrument should be installed and attached to the participant’s body. Moreover, working environment should be observed during the sampling, such as wind direction, wind speed, working position as well as types and amount of e-waste.

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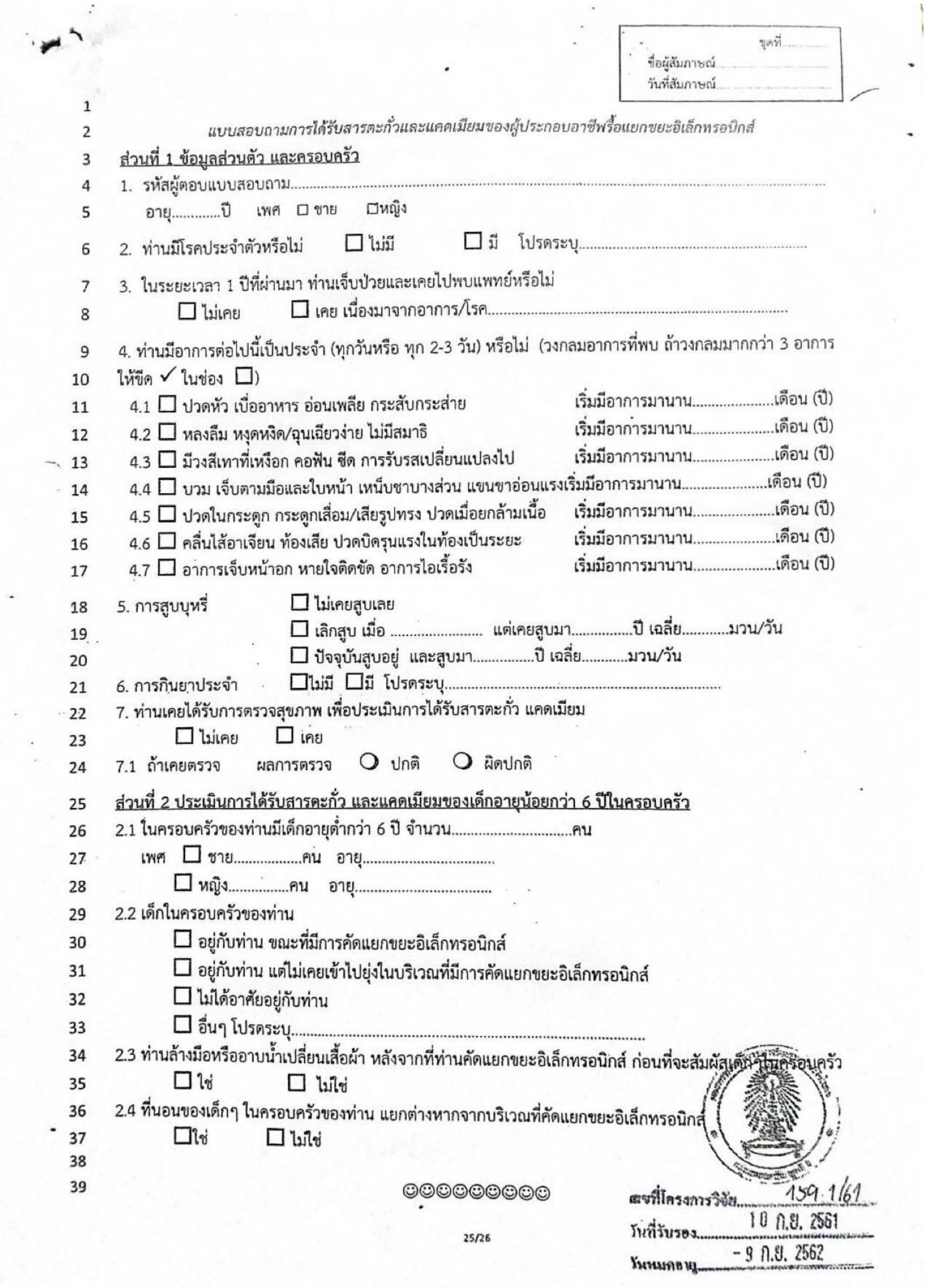
APPENDIX A

PERSONAL INFORMATION OF PARTICIPANTS



ชุดที่..............
ชื่อผู้สัมภาษณ์..............................
วันที่สัมภาษณ์..............................

แบบสอบถามการได้รับสารตะกั่วและแคดเมียมของผู้ประกอบอาชีพรื้อแยกขยะอิเล็กทรอนิกส์

ส่วนที่ 1 ข้อมูลส่วนตัว และครอบครัว

1. รหัสผู้ตอบแบบสอบถาม...
อายุ............ปี เพศ ☐ ชาย ☐หญิง

2. ท่านมีโรคประจำตัวหรือไม่ ☐ ไม่มี ☐ มี โปรดระบุ..

3. ในระยะเวลา 1 ปีที่ผ่านมา ท่านเจ็บป่วยและเคยไปพบแพทย์หรือไม่
☐ ไม่เคย ☐ เคย เนื่องมาจากอาการ/โรค..

4. ท่านมีอาการต่อไปนี้เป็นประจำ (ทุกวันหรือ ทุก 2-3 วัน) หรือไม่ (วงกลมอาการที่พบ ถ้าวงกลมมากกว่า 3 อาการ ให้ขีด ✓ ในช่อง ☐)
4.1 ☐ ปวดหัว เบื่ออาหาร อ่อนเพลีย กระสับกระส่าย เริ่มมีอาการมานาน....................เดือน (ปี)
4.2 ☐ หลงลืม หงุดหงิด/ฉุนเฉียวง่าย ไม่มีสมาธิ เริ่มมีอาการมานาน....................เดือน (ปี)
4.3 ☐ มีวงสีเทาที่เหงือก คอฟัน ซีด การรับรสเปลี่ยนแปลงไป เริ่มมีอาการมานาน....................เดือน (ปี)
4.4 ☐ บวม เจ็บตามมือและใบหน้า เหน็บชาบางส่วน แขนขาอ่อนแรงเริ่มมีอาการมานาน....................เดือน (ปี)
4.5 ☐ ปวดในกระดูก กระดูกเสื่อม/เสียรูปทรง ปวดเมื่อยกล้ามเนื้อ เริ่มมีอาการมานาน....................เดือน (ปี)
4.6 ☐ คลื่นไส้อาเจียน ท้องเสีย ปวดบิดรุนแรงในท้องเป็นระยะ เริ่มมีอาการมานาน....................เดือน (ปี)
4.7 ☐ อาการเจ็บหน้าอก หายใจติดขัด อาการไอเรื้อรัง เริ่มมีอาการมานาน....................เดือน (ปี)

5. การสูบบุหรี่ ☐ ไม่เคยสูบเลย
☐ เลิกสูบ เมื่อ .... แต่เคยสูบมา...............ปี เฉลี่ย...........มวน/วัน
☐ ปัจจุบันสูบอยู่ และสูบมา...............ปี เฉลี่ย...........มวน/วัน
6. การกินยาประจำ ☐ไม่มี ☐มี โปรดระบุ..
7. ท่านเคยได้รับการตรวจสุขภาพ เพื่อประเมินการได้รับสารตะกั่ว แคดเมียม
☐ ไม่เคย ☐ เคย
7.1 ถ้าเคยตรวจ ผลการตรวจ ○ ปกติ ○ ผิดปกติ

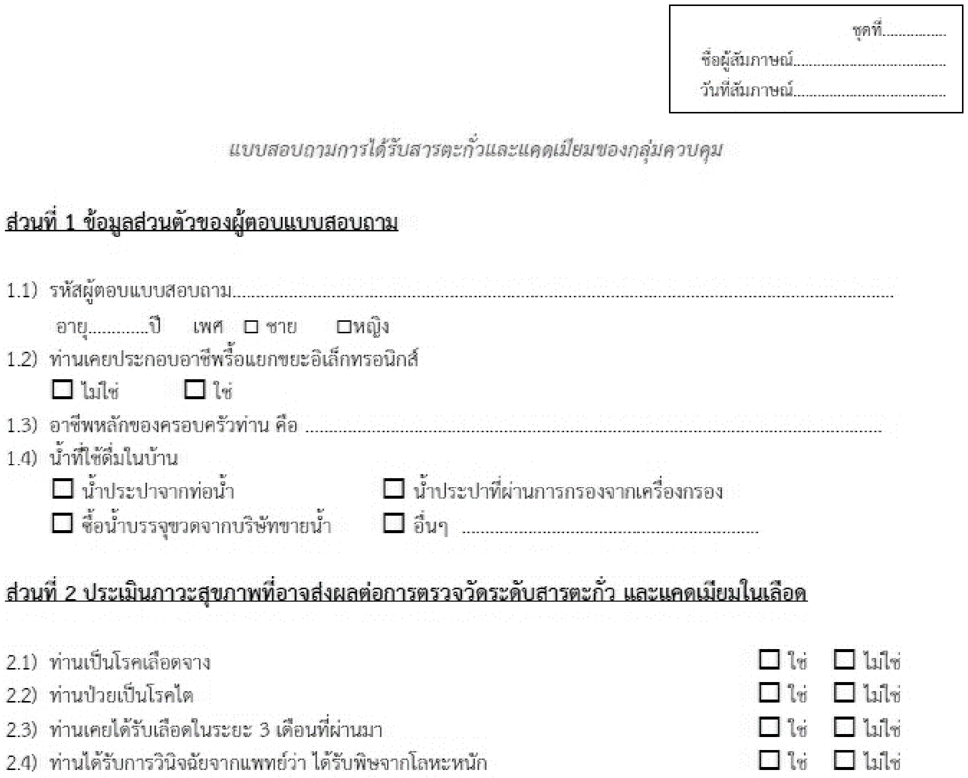
ส่วนที่ 2 ประเมินการได้รับสารตะกั่ว และแคดเมียมของเด็กอายุน้อยกว่า 6 ปีในครอบครัว

2.1 ในครอบครัวของท่านมีเด็กอายุต่ำกว่า 6 ปี จำนวน..............................คน
เพศ ☐ ชาย.................คน อายุ.................................
☐ หญิง...............คน อายุ.................................
2.2 เด็กในครอบครัวของท่าน
☐ อยู่กับท่าน ขณะที่มีการคัดแยกขยะอิเล็กทรอนิกส์
☐ อยู่กับท่าน แต่ไม่เคยเข้าไปยุ่งในบริเวณที่มีการคัดแยกขยะอิเล็กทรอนิกส์
☐ ไม่ได้อาศัยอยู่กับท่าน
☐ อื่นๆ โปรดระบุ..
2.3 ท่านล้างมือหรืออาบน้ำเปลี่ยนเสื้อผ้า หลังจากที่ท่านคัดแยกขยะอิเล็กทรอนิกส์ ก่อนที่จะสัมผัสเด็กๆ ในครอบครัว
☐ ใช่ ☐ ไม่ใช่
2.4 ที่นอนของเด็กๆ ในครอบครัวของท่าน แยกต่างหากจากบริเวณที่คัดแยกขยะอิเล็กทรอนิกส์
☐ใช่ ☐ ไม่ใช่

☺☺☺☺☺☺☺☺☺☺

25/26

เลขที่โครงการวิจัย 159.1/61
วันที่รับรอง 10 ก.ย. 2561
วันหมดอายุ - 9 ก.ย. 2562



ชุดที่...............
ชื่อผู้สัมภาษณ์.....................................
วันที่สัมภาษณ์.....................................

แบบสอบถามการได้รับสารตะกั่วและแคดเมียมของกลุ่มควบคุม

ส่วนที่ 1 ข้อมูลส่วนตัวของผู้ตอบแบบสอบถาม

1.1) รหัสผู้ตอบแบบสอบถาม...
อายุ............ปี เพศ ☐ ชาย ☐หญิง
1.2) ท่านเคยประกอบอาชีพรื้อแยกขยะอิเล็กทรอนิกส์
☐ ไม่ใช่ ☐ ใช่
1.3) อาชีพหลักของครอบครัวท่าน คือ ....
1.4) น้ำที่ใช้ดื่มในบ้าน
☐ น้ำประปาจากท่อน้ำ ☐ น้ำประปาที่ผ่านการกรองจากเครื่องกรอง
☐ ซื้อน้ำบรรจุขวดจากบริษัทขายน้ำ ☐ อื่นๆ ....

ส่วนที่ 2 ประเมินภาวะสุขภาพที่อาจส่งผลต่อการตรวจวัดระดับสารตะกั่ว และแคดเมียมในเลือด

2.1) ท่านเป็นโรคเลือดจาง ☐ ใช่ ☐ ไม่ใช่
2.2) ท่านป่วยเป็นโรคไต ☐ ใช่ ☐ ไม่ใช่
2.3) ท่านเคยได้รับเลือดในระยะ 3 เดือนที่ผ่านมา ☐ ใช่ ☐ ไม่ใช่
2.4) ท่านได้รับการวินิจฉัยจากแพทย์ว่า ได้รับพิษจากโลหะหนัก ☐ ใช่ ☐ ไม่ใช่

APPENDIX B
PERSONAL INFORMATION OF PARTICIPANTS

Table B1 Personal information of non-e-waste

Household	Code	Gender	Age (years)	Weight (kg)	Hight (cm)	BMI (kg/m^2)
H-NE-1	NE 1	Female	52	60.00	150.00	26.67
H-NE-2	NE 2	Male	56	55.00	155.00	22.89
H-NE-3	NE 3	Female	46	72.00	165.00	26.45
H-NE-4	NE 4	Female	25	57.00	160.00	22.27
H-NE-5	NE 5	Female	40	65.00	165.00	23.88
H-NE-6	NE 6	Female	43	51.00	170.00	17.65
H-NE-5	NE 7	Male	47	65.00	172.00	21.97
H-NE-7	NE 8	Female	49	51.00	155.00	21.23
H-NE-8	NE 9	Male	59	56.00	167.00	20.08
H-NE-9	NE 10	Female	48	65.00	160.00	25.39
H-NE-10	NE 11	Female	62	62.00	158.00	24.84
H-NE-11	NE 12	Male	54	65.00	165.00	23.88
H-NE-12	NE 13	Female	65	50.00	155.00	20.81
H-NE-13	NE 14	Female	53	55.00	160.00	21.48
H-NE-14	NE 15	Male	50	67.00	173.00	22.39
H-NE-15	NE 16	Female	49	55.00	155.00	22.89
H-NE-16	NE 17	Female	56	60.00	159.00	23.73
H-NE-17	NE 18	Female	47	55.00	160.00	21.48
H-NE-18	NE 19	Female	46	65.00	158.00	26.04
H-NE-19	NE 20	Female	46	56.00	150.00	24.89
H-NE-20	NE 21	Female	47	59.00	159.00	23.34
H-NE-21	NE 22	Female	23	70.00	152.00	30.30
H-NE-22	NE 23	Male	50	55.00	165.00	20.20
H-NE-23	NE 24	Female	43	65.00	158.00	26.04
H-NE-24	NE 25	Female	57	63.00	160.00	24.61
H-NE-25	NE 26	Female	55	65.00	165.00	23.88

Household	**Code**	**Gender**	**Age (years)**	**Weight (kg)**	**Hight (cm)**	**BMI (kg/m^2)**
H-NE-26	NE 27	Female	43	52.00	162.00	19.81
H-NE-27	NE 28	Female	47	55.00	165.00	20.20
H-NE-28	NE 29	Female	48	62.00	155.00	25.81
H-NE-29	NE 30	Female	63	59.00	155.00	24.56
H-NE-30	NE 31	Female	59	62.00	167.00	22.23
H-NE-31	NE 32	Female	46	65.00	160.00	25.39
H-NE-32	NE 33	Female	48	70.00	175.00	22.86
H-NE-33	NE 34	Female	34	65.00	160.00	25.39
H-NE-34	NE 35	Female	53	55.00	158.00	22.03
H-NE-35	NE 36	Female	52	57.00	164.00	21.19
H-NE-36	NE 37	Female	50	60.00	165.00	22.04
H-NE-37	NE 38	Female	57	67.00	165.00	24.61
H-NE-38	NE 39	Female	41	60.00	162.00	22.86
H-NE-39	NE 40	Female	46	64.00	165.00	23.51
H-NE-40	NE 41	Female	64	65.00	165.00	23.88
H-NE-41	NE 42	Male	51	65.00	170.00	22.49
H-NE-42	NE 43	Female	54	68.00	155.00	28.30
H-NE-43	NE 44	Female	57	58.00	165.00	21.30
H-NE-44	NE 45	Male	43	78.00	169.00	27.31
H-NE-45	NE 46	Female	58	67.00	159.00	26.50
H-NE-46	NE 47	Female	61	65.00	160.00	25.39
H-NE-47	NE 48	Female	53	55.00	160.00	21.48
H-NE-48	NE 49	Female	53	54.00	163.00	20.32
H-NE-49	NE 50	Female	39	55.00	160.00	21.48

Table B2 Personal information of e-waste workers from Dang Yai sub-district

Household	Code	Gender	Age (years)	Weight (kg)	Hight (cm)	BMI (kg/m^2)
H-DY-1	DY 1	Female	56	45.00	145.00	21.40
H-DY-2	DY 2	Female	23	48.00	156.00	19.72
H-DY-2	DY 3	Female	47	55.00	160.00	21.48
H-DY-2	DY 4	Male	50	54.00	165.00	19.83
H-DY-2	DY 5	Male	52	62.00	158.00	24.84
H-DY-2	DY 6	Female	38	65.00	150.00	28.89
H-DY-3	DY 7	Male	51	62.00	165.00	22.77
H-DY-4	DY 8	Female	27	58.00	161.00	22.38
H-DY-5	DY 9	Male	54	58.00	154.00	24.46
H-DY-6	DY 10	Female	40	62.00	155.00	25.81
H-DY-7	DY 11	Female	44	86.00	165.00	31.59
H-DY-7	DY 12	Female	41	64.00	148.00	29.22
H-DY-7	DY 13	Male	44	70.00	165.00	25.71
H-DY-7	DY 14	Male	65	55.00	160.00	21.48
H-DY-7	DY 15	Male	65	40.00	148.00	18.26
H-DY-8	DY 16	Female	53	37.00	145.00	17.60
H-DY-8	DY 17	Male	45	54.00	165.00	19.83
H-DY-9	DY 18	Female	19	48.00	162.00	18.29
H-DY-9	DY 19	Male	44	63.00	160.00	24.61
H-DY-10	DY 20	Female	41	65.00	159.00	25.71
H-DY-10	DY 21	Male	43	63.00	153.00	26.91
H-DY-11	DY 22	Male	63	75.00	165.00	27.55
H-DY-11	DY 23	Female	46	52.00	150.00	23.11
H-DY-12	DY 24	Male	52	59.00	159.00	23.34
H-DY-13	DY 25	Female	46	62.00	160.00	24.22
H-DY-13	DY 26	Female	49	63.00	157.00	25.56
H-DY-14	DY 27	Female	49	60.00	156.00	24.65
H-DY-15	DY 28	Female	53	65.00	156.00	26.71
H-DY-15	DY 29	Female	49	58.00	161.00	22.38
H-DY-15	DY 30	Female	50	65.00	160.00	25.39

Household	**Code**	**Gender**	**Age (years)**	**Weight (kg)**	**Hight (cm)**	**BMI (kg/m^2)**
H-DY-16	DY 31	Female	50	70.00	170.00	24.22
H-DY-17	DY 32	Female	57	72.00	175.00	23.51
H-DY-18	DY 33	Female	50	65.00	160.00	25.39
H-DY-18	DY 34	Female	44	65.00	160.00	25.39
H-DY-18	DY 35	Female	41	55.00	159.00	21.76
H-DY-18	DY 36	Male	44	70.00	165.00	25.71
H-DY-19	DY 37	Male	64	62.00	160.00	24.22
H-DY-19	DY 38	Female	61	55.00	160.00	21.48
H-DY-19	DY 39	Male	36	73.00	172.00	24.68
H-DY-19	DY 40	Female	33	50.00	153.00	21.36
H-DY-19	DY 41	Male	57	80.00	175.00	26.12
H-DY-20	DY 42	Male	50	70.00	167.00	25.10
H-DY-20	DY 43	Female	49	60.00	160.00	23.44
H-DY-21	DY 44	Male	32	75.00	165.00	27.55
H-DY-21	DY 45	Female	49	60.00	160.00	23.44
H-DY-21	DY 46	Female	27	60.00	152.00	25.97
H-DY-21	DY 47	Female	62	67.00	153.00	28.62
H-DY-21	DY 48	Female	63	70.00	156.00	28.76
H-DY-21	DY 49	Male	65	64.00	175.00	20.90
H-DY-21	DY 50	Male	49	60.00	160.00	23.44

Table B3 Personal information of e-waste workers from Ban Pao sub-district

Household	Code	Gender	Age (years)	Weight (kg)	Hight (cm)	BMI (kg/m^2)
H-BP-1	BP 1	Female	30	55.00	155.00	22.89
H-BP-2	BP 2	Female	37	85.00	165.00	31.22
H-BP-2	BP 3	Male	55	65.00	150.00	28.89
H-BP-3	BP 4	Female	45	40.00	150.00	17.78
H-BP-3	BP 5	Female	42	70.00	160.00	27.34
H-BP-3	BP 6	Female	45	50.00	160.00	19.53
H-BP-3	BP 7	Female	65	49.00	155.00	20.40
H-BP-3	BP 8	Female	45	65.00	170.00	22.49
H-BP-4	BP 9	Male	56	62.00	160.00	24.22
H-BP-4	BP 10	Female	53	46.00	160.00	17.97
H-BP-5	BP 11	Female	57	55.00	150.00	24.44
H-BP-5	BP 12	Male	62	80.00	170.00	27.68
H-BP-6	BP 13	Female	52	68.00	167.00	24.38
H-BP-6	BP 14	Female	36	57.00	156.00	23.42
H-BP-6	BP 15	Male	38	86.00	165.00	31.59
H-BP-6	BP 16	Female	30	51.00	152.00	22.07
H-BP-13	BP 17	Female	37	48.00	150.00	21.33
H-BP-14	BP 18	Female	43	73.00	150.00	32.44
H-BP-14	BP 19	Female	37	70.00	165.00	25.71
H-BP-15	BP 20	Female	53	46.00	150.00	20.44
H-BP-15	BP 21	Male	62	80.00	165.00	29.38
H-BP-16	BP 22	Female	60	75.00	150.00	33.33
H-BP-17	BP 23	Female	52	64.00	150.00	28.44
H-BP-18	BP 24	Male	50	53.00	152.00	22.94
H-BP-18	BP 25	Female	48	53.00	152.00	22.94
H-BP-21	BP 26	Male	65	47.00	162.00	17.91
H-BP-21	BP 27	Female	65	67.00	150.00	29.78
H-BP-22	BP 28	Male	62	62.00	160.00	24.22
H-BP-22	BP 29	Male	57	80.00	155.00	33.30
H-BP-22	BP 30	Female	35	60.00	148.00	27.39
H-BP-23	BP 31	Male	45	74.00	168.00	26.22

Household	Code	Gender	Age (years)	Weight (kg)	Hight (cm)	BMI (kg/m^2)
H-BP-23	BP 32	Female	24	58.00	160.00	22.66
H-BP-24	BP 33	Female	37	59.00	160.00	23.05
H-BP-25	BP 34	Female	55	67.00	166.00	24.31
H-BP-26	BP 35	Female	52	65.00	158.00	26.04
H-BP-27	BP 36	Female	57	65.00	150.00	28.89
H-BP-28	BP 37	Male	64	75.00	165.00	27.55
H-BP-29	BP 38	Female	45	55.00	160.00	21.48
H-BP-30	BP 39	Female	49	55.00	160.00	21.48
H-BP-31	BP 40	Female	47	72.00	165.00	26.45
H-BP-32	BP 41	Female	57	72.00	165.00	26.45
H-BP-33	BP 42	Female	62	52.00	150.00	23.11
H-BP-34	BP 43	Female	64	53.00	150.00	23.56
H-BP-35	BP 44	Male	53	66.00	172.00	22.31
H-BP-36	BP 45	Female	39	53.00	162.00	20.20

Table B4 Working condition of e-waste workers from Dang Yai sub-district

Household	Code	Working Conditions			
		Working hour (hours)	Working day (days/week)	Working hour within week (hours/week)	Working period (years)
H-DY-1	DY 1	8.00	7.00	56.00	5.00
H-DY-2	DY 2	7.00	5.00	35.00	3.00
H-DY-2	DY 3	6.00	4.00	24.00	7.00
H-DY-2	DY 4	8.00	7.00	56.00	4.00
H-DY-2	DY 5	4.00	7.00	28.00	9.00
H-DY-2	DY 6	7.00	5.00	35.00	5.00
H-DY-3	DY 7	8.00	7.00	56.00	4.00
H-DY-4	DY 8	7.00	3.00	21.00	1.00
H-DY-5	DY 9	8.00	7.00	56.00	3.00
H-DY-6	DY 10	7.00	3.00	21.00	1.00
H-DY-7	DY 11	8.00	3.00	24.00	10.00
H-DY-7	DY 12	7.00	7.00	49.00	10.00
H-DY-7	DY 13	8.00	7.00	56.00	15.00
H-DY-7	DY 14	6.00	7.00	42.00	6.00
H-DY-7	DY 15	6.00	7.00	42.00	6.00
H-DY-8	DY 16	8.00	7.00	56.00	5.00
H-DY-8	DY 17	7.00	2.00	14.00	3 months
H-DY-9	DY 18	8.00	7.00	56.00	1 months
H-DY-9	DY 19	7.00	7.00	49.00	3.00
H-DY-10	DY 20	8.00	7.00	56.00	10.00
H-DY-10	DY 21	8.00	7.00	56.00	10.00
H-DY-11	DY 22	8.00	7.00	56.00	10.00
H-DY-11	DY 23	8.00	7.00	56.00	10.00
H-DY-12	DY 24	7.00	4.00	28.00	10.00
H-DY-13	DY 25	8.00	7.00	56.00	10.00
H-DY-13	DY 26	8.00	7.00	56.00	10.00
H-DY-14	DY 27	8.00	7.00	56.00	10.00
H-DY-15	DY 28	8.00	7.00	56.00	10.00
H-DY-15	DY 29	8.00	7.00	56.00	10.00
H-DY-15	DY 30	8.00	7.00	56.00	10.00

Household	Code	Working Conditions			
		Working hour (hours)	Working day (days/week)	Working hour within week (hours/week)	Working period (years)
H-DY-16	DY 31	8.00	7.00	56.00	10.00
H-DY-17	DY 32	8.00	7.00	56.00	10.00
H-DY-18	DY 33	8.00	7.00	56.00	10.00
H-DY-18	DY 34	8.00	7.00	56.00	10.00
H-DY-18	DY 35	8.00	7.00	56.00	10.00
H-DY-18	DY 36	8.00	7.00	56.00	10.00
H-DY-19	DY 37	9.00	7.00	63.00	10.00
H-DY-19	DY 38	8.00	7.00	56.00	10.00
H-DY-19	DY 39	4.00	7.00	28.00	10.00
H-DY-19	DY 40	4.00	7.00	28.00	10.00
H-DY-19	DY 41	6.00	7.00	42.00	10.00
H-DY-20	DY 42	9.00	7.00	63.00	10.00
H-DY-20	DY 43	6.00	7.00	42.00	10.00
H-DY-21	DY 44	8.00	7.00	56.00	2.00
H-DY-21	DY 45	8.00	7.00	56.00	20.00
H-DY-21	DY 46	8.00	7.00	56.00	2.00
H-DY-21	DY 47	8.00	6.00	48.00	10.00
H-DY-21	DY 48	4.00	3.00	12.00	10.00
H-DY-21	DY 49	4.00	3.00	12.00	10.00
H-DY-21	DY 50	8.00	7.00	56.00	15.00

Table B5 Working condition of e-waste workers from Ban Pao sub-district

Household	**Code**	**Working Conditions**			
		Working hour (hours)	**Working day (days/week)**	**Working hour within week (hours/week)**	**Working period (years)**
H-BP-1	BP 1	6.00	7.00	42.00	1.00
H-BP-2	BP 2	6.00	7.00	42.00	1.00
H-BP-2	BP 3	6.00	5.00	30.00	6.00
H-BP-3	BP 4	6.00	5.00	30.00	6.00
H-BP-3	BP 5	4.00	3.00	12.00	6.00
H-BP-3	BP 6	6.00	5.00	30.00	6.00
H-BP-3	BP 7	6.00	5.00	30.00	6.00
H-BP-3	BP 8	6.00	3.00	18.00	6.00
H-BP-4	BP 9	6.00	7.00	42.00	6.00
H-BP-4	BP 10	6.00	7.00	42.00	6.00
H-BP-5	BP 11	8.00	3.00	24.00	2.00
H-BP-5	BP 12	6.00	5.00	30.00	1.00
H-BP-6	BP 13	8.00	7.00	56.00	21.00
H-BP-6	BP 14	8.00	7.00	56.00	6.00
H-BP-6	BP 15	8.00	7.00	56.00	10.00
H-BP-6	BP 16	8.00	7.00	56.00	2.00
H-BP-13	BP 17	5.00	5.00	25.00	1.00
H-BP-14	BP 18	7.00	2.00	14.00	10.00
H-BP-14	BP 19	6.00	4.00	24.00	5.00
H-BP-15	BP 20	7.00	5.00	35.00	2.00
H-BP-15	BP 21	7.00	5.00	35.00	2.00
H-BP-16	BP 22	7.00	7.00	49.00	1.00
H-BP-17	BP 23	12.00	7.00	84.00	4.00
H-BP-18	BP 24	6.00	7.00	42.00	10.00
H-BP-18	BP 25	6.00	7.00	42.00	10.00
H-BP-21	BP 26	7.00	7.00	49.00	2.00
H-BP-21	BP 27	3.00	1.00	3.00	10.00
H-BP-22	BP 28	10.00	7.00	70.00	10.00
H-BP-22	BP 29	7.00	5.00	35.00	20.00
H-BP-22	BP 30	7.00	7.00	49.00	22.00

Household	Code	Working Conditions			
		Working hour (hours)	Working day (days/week)	Working hour within week (hours/week)	Working period (years)
H-BP-23	BP 31	8.00	7.00	56.00	8.00
H-BP-23	BP 32	6.00	3.00	18.00	4.00
H-BP-24	BP 33	8.00	1.00	8.00	2.00
H-BP-25	BP 34	6.00	3.00	18.00	7.00
H-BP-26	BP 35	6.00	3.00	18.00	10.00
H-BP-27	BP 36	12.00	5.00	60.00	10.00
H-BP-28	BP 37	12.00	3.00	36.00	20.00
H-BP-29	BP 38	8.00	7.00	56.00	10.00
H-BP-30	BP 39	8.00	7.00	56.00	10.00
H-BP-31	BP 40	2.00	5.00	10.00	5.00
H-BP-32	BP 41	4.00	2.00	8.00	5.00
H-BP-33	BP 42	2.00	2.00	4.00	2.00
H-BP-34	BP 43	2.00	7.00	14.00	5.00
H-BP-35	BP 44	12.00	5.00	60.00	10.00
H-BP-36	BP 45	8.00	7.00	56.00	10.00

Table B6 Using PPEs of e-waste workers from Dang Yai sub-district

Household	Code	Using PPEs		
		Short glove	**Mask**	**Sneaker**
H-DY-1	DY 1	Yes	Yes	No
H-DY-2	DY 2	Yes	Yes	Yes
H-DY-2	DY 3	Yes	Yes	Yes
H-DY-2	DY 4	Yes	Yes	Yes
H-DY-2	DY 5	Yes	Yes	Yes
H-DY-2	DY 6	Yes	Yes	Yes
H-DY-3	DY 7	Yes	Yes	Yes
H-DY-4	DY 8	Yes	Yes	Yes
H-DY-5	DY 9	Yes	Yes	Yes
H-DY-6	DY 10	Yes	Yes	Yes
H-DY-7	DY 11	Yes	Yes	Yes
H-DY-7	DY 12	Yes	Yes	No
H-DY-7	DY 13	Yes	Yes	No
H-DY-7	DY 14	Yes	Yes	Yes
H-DY-7	DY 15	Yes	Yes	Yes
H-DY-8	DY 16	Yes	Yes	Yes
H-DY-8	DY 17	Yes	Yes	Yes
H-DY-9	DY 18	Yes	Yes	Yes
H-DY-9	DY 19	Yes	Yes	Yes
H-DY-10	DY 20	Yes	Yes	Yes
H-DY-10	DY 21	Yes	Yes	Yes
H-DY-11	DY 22	Yes	No	No
H-DY-11	DY 23	Yes	Yes	Yes
H-DY-12	DY 24	Yes	No	No
H-DY-13	DY 25	Yes	Yes	Yes
H-DY-13	DY 26	Yes	Yes	No
H-DY-14	DY 27	Yes	Yes	No
H-DY-15	DY 28	Yes	Yes	No
H-DY-15	DY 29	Yes	Yes	Yes
H-DY-15	DY 30	Yes	Yes	Yes

Household	Code	Using PPEs		
		Short glove	Mask	Sneaker
H-DY-16	DY 31	Yes	Yes	Yes
H-DY-17	DY 32	Yes	Yes	Yes
H-DY-18	DY 33	Yes	Yes	Yes
H-DY-18	DY 34	Yes	Yes	Yes
H-DY-18	DY 35	Yes	Yes	Yes
H-DY-18	DY 36	Yes	Yes	Yes
H-DY-19	DY 37	Yes	No	No
H-DY-19	DY 38	Yes	Yes	No
H-DY-19	DY 39	Yes	Yes	Yes
H-DY-19	DY 40	Yes	Yes	Yes
H-DY-19	DY 41	Yes	Yes	Yes
H-DY-20	DY 42	Yes	Yes	Yes
H-DY-20	DY 43	Yes	Yes	Yes
H-DY-21	DY 44	Yes	Yes	No
H-DY-21	DY 45	Yes	Yes	No
H-DY-21	DY 46	Yes	Yes	No
H-DY-21	DY 47	Yes	Yes	Yes
H-DY-21	DY 48	Yes	Yes	No
H-DY-21	DY 49	Yes	Yes	No
H-DY-21	DY 50	Yes	Yes	Yes

Table B7 Using PPEs of e-waste workers from Dang Yai sub-district

Household	Code	Using PPEs		
		Short glove	**Mask**	**Shoes**
H-BP-1	BP 1	Yes	Yes	Yes
H-BP-2	BP 2	Yes	No	No
H-BP-2	BP 3	Yes	Yes	Yes
H-BP-3	BP 4	Yes	Yes	No
H-BP-3	BP 5	Yes	Yes	Yes
H-BP-3	BP 6	Yes	Yes	Yes
H-BP-3	BP 7	Yes	Yes	Yes
H-BP-3	BP 8	Yes	Yes	Yes
H-BP-4	BP 9	Yes	Yes	Yes
H-BP-4	BP 10	Yes	Yes	Yes
H-BP-5	BP 11	Yes	Yes	Yes
H-BP-5	BP 12	Yes	Yes	Yes
H-BP-6	BP 13	Yes	Yes	Yes
H-BP-6	BP 14	Yes	Yes	Yes
H-BP-6	BP 15	Yes	Yes	Yes
H-BP-6	BP 16	Yes	Yes	Yes
H-BP-13	BP 17	Yes	Yes	Yes
H-BP-14	BP 18	Yes	Yes	Yes
H-BP-14	BP 19	Yes	Yes	Yes
H-BP-15	BP 20	Yes	Yes	Yes
H-BP-15	BP 21	Yes	Yes	No
H-BP-16	BP 22	Yes	No	No
H-BP-17	BP 23	Yes	Yes	Yes
H-BP-18	BP 24	Yes	Yes	Yes
H-BP-18	BP 25	Yes	Yes	Yes
H-BP-21	BP 26	Yes	Yes	Yes
H-BP-21	BP 27	Yes	Yes	Yes
H-BP-22	BP 28	Yes	Yes	Yes
H-BP-22	BP 29	Yes	Yes	Yes
H-BP-22	BP 30	Yes	Yes	Yes

Household	Code	Using PPEs		
		Short glove	Mask	Shoes
H-BP-23	BP 31	Yes	Yes	No
H-BP-23	BP 32	Yes	Yes	Yes
H-BP-24	BP 33	Yes	Yes	Yes
H-BP-25	BP 34	Yes	Yes	Yes
H-BP-26	BP 35	Yes	Yes	No
H-BP-27	BP 36	Yes	Yes	No
H-BP-28	BP 37	Yes	Yes	Yes
H-BP-29	BP 38	Yes	Yes	Yes
H-BP-30	BP 39	Yes	Yes	Yes
H-BP-31	BP 40	Yes	Yes	Yes
H-BP-32	BP 41	Yes	Yes	Yes
H-BP-33	BP 42	Yes	Yes	Yes
H-BP-34	BP 43	Yes	Yes	Yes
H-BP-35	BP 44	Yes	Yes	Yes
H-BP-36	BP 45	Yes	Yes	Yes

APPENDIX C

BLOOD LEVELS AND SERUM CREATININE OF PARTICIPANTS

Table C1 Blood levels and serum creatinine of non-e-waste workers

Household	Code	BLL (μg/dl)	BCL (μg/l)	Serum Creatinine (mg/dl)
H-NE-1	NE 1	3.24	1.30	0.97
H-NE-2	NE 2	2.88	0.44	1.30
H-NE-3	NE 3	3.52	1.48	1.29
H-NE-4	NE 4	2.55	1.45	1.04
H-NE-5	NE 5	2.32	1.41	2.20
H-NE-6	NE 6	3.32	1.24	1.02
H-NE-5	NE 7	3.71	0.87	1.42
H-NE-7	NE 8	2.86	0.50	0.92
H-NE-8	NE 9	3.18	1.58	1.36
H-NE-9	NE 10	2.71	1.48	1.06
H-NE-10	NE 11	2.24	1.59	1.47
H-NE-11	NE 12	2.21	0.93	1.48
H-NE-12	NE 13	2.50	1.55	1.10
H-NE-13	NE 14	2.44	0.98	0.90
H-NE-14	NE 15	3.67	1.13	1.06
H-NE-15	NE 16	5.94	1.03	1.21
H-NE-16	NE 17	2.84	0.96	1.39
H-NE-17	NE 18	1.94	1.04	0.92
H-NE-18	NE 19	2.99	1.17	1.30
H-NE-19	NE 20	2.94	1.52	0.74
H-NE-20	NE 21	2.17	0.64	1.21
H-NE-21	NE 22	3.02	1.40	1.15
H-NE-22	NE 23	3.50	1.36	1.29
H-NE-23	NE 24	2.90	1.30	1.23
H-NE-24	NE 25	1.75	0.81	1.51
H-NE-25	NE 26	2.26	1.59	1.19
H-NE-26	NE 27	2.73	0.90	1.07
H-NE-27	NE 28	2.38	1.86	1.29
H-NE-28	NE 29	2.86	0.64	1.21
H-NE-29	NE 30	2.27	0.66	1.00
H-NE-30	NE 31	3.39	1.56	1.07
H-NE-31	NE 32	2.60	0.64	0.74
H-NE-32	NE 33	2.57	1.46	0.87
H-NE-33	NE 34	2.78	1.17	1.14
H-NE-34	NE 35	3.25	1.29	1.00
H-NE-35	NE 36	3.41	0.69	0.69
H-NE-36	NE 37	1.34	1.30	0.77
H-NE-37	NE 38	1.83	0.81	0.99
H-NE-38	NE 39	2.22	1.30	0.90
H-NE-39	NE 40	2.76	1.79	1.18
H-NE-40	NE 41	2.92	1.21	0.95
H-NE-41	NE 42	2.56	1.13	1.59
H-NE-42	NE 43	2.79	0.73	1.28
H-NE-43	NE 44	2.84	0.51	1.15
H-NE-44	NE 45	3.52	0.72	0.91
H-NE-45	NE 46	2.12	1.19	0.71
H-NE-46	NE 47	3.74	1.78	1.06
H-NE-47	NE 48	2.12	0.97	1.27
H-NE-48	NE 49	3.95	1.63	0.92
H-NE-49	NE 50	3.27	0.68	1.10

Table C2 Blood levels and serum creatinine of e-waste workers from Dang Yai sub-district

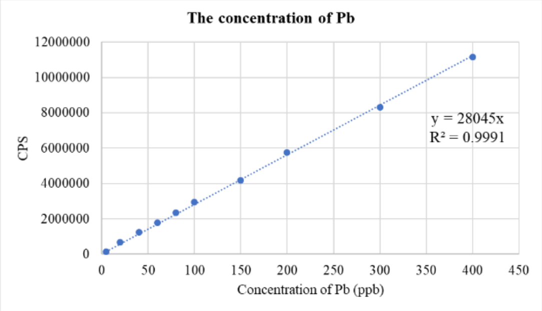
Household	Code	BLL (µg/dl)	BCL (µg/l)	Serum Creatinine (mg/dl)
H-DY-1	DY 1	4.64	0.48	0.82
H-DY-2	DY 2	6.98	0.80	0.78
H-DY-2	DY 3	1.99	0.28	0.88
H-DY-2	DY 4	3.23	1.11	1.16
H-DY-2	DY 5	5.92	1.04	1.43
H-DY-2	DY 6	2.83	0.99	0.77
H-DY-3	DY 7	4.95	0.45	1.10
H-DY-4	DY 8	3.35	0.36	0.87
H-DY-5	DY 9	5.82	0.73	1.05
H-DY-6	DY 10	4.24	1.61	0.74
H-DY-7	DY 11	2.69	2.73	0.91
H-DY-7	DY 12	5.48	0.48	0.86
H-DY-7	DY 13	8.99	0.85	1.11
H-DY-7	DY 14	5.82	0.89	1.01
H-DY-7	DY 15	5.85	0.73	0.80
H-DY-8	DY 16	3.96	1.00	0.90
H-DY-8	DY 17	7.16	1.31	1.01
H-DY-9	DY 18	4.42	0.70	0.82
H-DY-9	DY 19	6.63	0.60	1.35
H-DY-10	DY 20	9.04	1.32	0.76
H-DY-10	DY 21	8.31	0.98	0.98
H-DY-11	DY 22	11.64	1.25	1.02
H-DY-11	DY 23	6.89	0.89	1.05
H-DY-12	DY 24	5.61	0.48	1.39
H-DY-13	DY 25	3.82	1.49	1.05
H-DY-13	DY 26	4.86	1.09	1.00
H-DY-14	DY 27	4.05	1.32	1.13
H-DY-15	DY 28	3.53	0.69	0.88
H-DY-15	DY 29	3.42	1.22	0.90
H-DY-15	DY 30	3.67	0.81	0.92
H-DY-16	DY 31	3.26	1.14	1.98
H-DY-17	DY 32	4.32	1.04	1.01
H-DY-18	DY 33	2.54	1.30	1.13
H-DY-18	DY 34	3.98	0.31	0.95
H-DY-18	DY 35	3.58	0.81	1.08
H-DY-18	DY 36	3.43	0.95	1.44
H-DY-19	DY 37	19.50	0.64	0.83
H-DY-19	DY 38	3.92	0.33	0.80
H-DY-19	DY 39	9.21	1.58	0.90
H-DY-19	DY 40	5.40	1.12	0.73
H-DY-19	DY 41	5.84	1.47	1.07
H-DY-20	DY 42	8.46	1.44	1.15
H-DY-20	DY 43	6.27	0.98	0.68
H-DY-21	DY 44	7.96	1.07	0.97
H-DY-21	DY 45	4.67	1.38	0.78
H-DY-21	DY 46	5.83	0.81	0.65
H-DY-21	DY 47	4.97	0.47	0.69
H-DY-21	DY 48	8.49	0.71	0.80
H-DY-21	DY 49	5.06	0.95	0.86
H-DY-21	DY 50	4.97	1.10	0.97

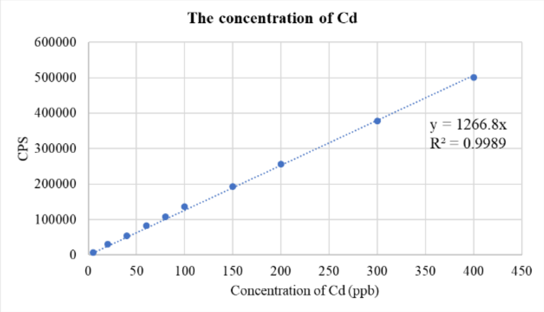
Table C3 Blood levels and serum creatinine of e-waste workers from Ban Pao sub-district

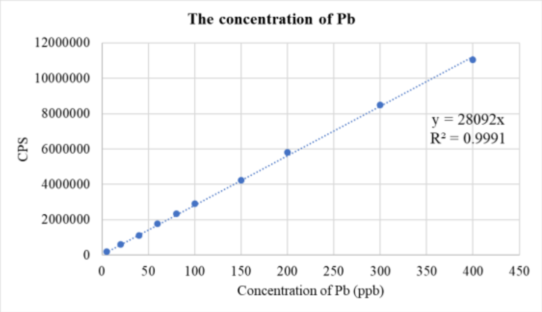
Household	Code	BLL (µg/dl)	BCL (µg/l)	Serum Creatinine (mg/dl)
H-BP-1	BP 1	3.56	1.61	0.86
H-BP-2	BP 2	3.44	1.45	0.95
H-BP-2	BP 3	3.96	1.17	0.99
H-BP-3	BP 4	2.21	1.84	0.73
H-BP-3	BP 5	3.66	1.60	0.76
H-BP-3	BP 6	3.73	1.50	0.74
H-BP-3	BP 7	4.50	0.36	0.76
H-BP-3	BP 8	4.71	0.88	0.99
H-BP-4	BP 9	4.90	0.72	0.89
H-BP-4	BP 10	3.56	0.91	0.77
H-BP-5	BP 11	4.83	1.30	0.88
H-BP-5	BP 12	3.89	0.72	1.00
H-BP-6	BP 13	3.39	0.81	0.75
H-BP-6	BP 14	1.56	0.55	0.65
H-BP-6	BP 15	3.07	0.61	1.05
H-BP-6	BP 16	4.34	0.88	0.73
H-BP-13	BP 17	4.30	1.31	0.84
H-BP-14	BP 18	5.89	1.91	0.78
H-BP-14	BP 19	4.05	0.99	0.90
H-BP-15	BP 20	5.04	1.51	0.81
H-BP-15	BP 21	5.05	1.08	1.16
H-BP-16	BP 22	3.57	2.02	0.75
H-BP-17	BP 23	3.56	1.40	1.05
H-BP-18	BP 24	4.69	0.84	1.22
H-BP-18	BP 25	5.59	1.66	0.87
H-BP-21	BP 26	3.50	1.66	1.08
H-BP-21	BP 27	4.41	1.25	0.97
H-BP-22	BP 28	3.35	0.80	0.87
H-BP-22	BP 29	4.95	0.76	0.94
H-BP-22	BP 30	3.19	0.77	0.83
H-BP-23	BP 31	4.88	1.16	1.26
H-BP-23	BP 32	3.22	0.28	0.87
H-BP-24	BP 33	2.70	0.73	0.82
H-BP-25	BP 34	2.31	1.02	0.91
H-BP-26	BP 35	3.96	1.76	0.69
H-BP-27	BP 36	3.01	1.26	0.85
H-BP-28	BP 37	3.03	1.02	1.61
H-BP-29	BP 38	3.58	0.88	0.73
H-BP-30	BP 39	8.15	1.64	0.93
H-BP-31	BP 40	3.50	0.69	0.85
H-BP-32	BP 41	2.49	1.50	0.76
H-BP-33	BP 42	4.72	1.05	0.71
H-BP-34	BP 43	2.75	0.41	1.05
H-BP-35	BP 44	4.62	1.11	1.11
H-BP-36	BP 45	2.85	1.11	0.82

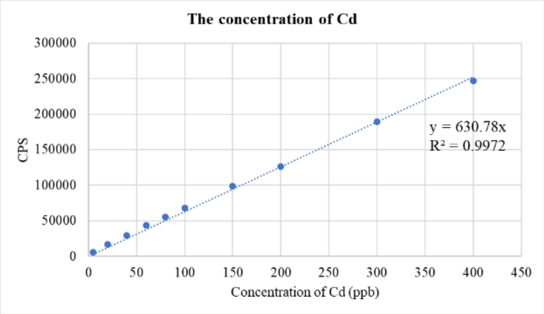
APPENDIX D

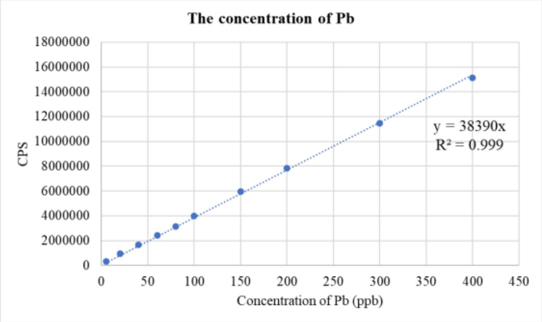
GRAPH PLOTTED OF STANDARD CALIBRATION CURVES

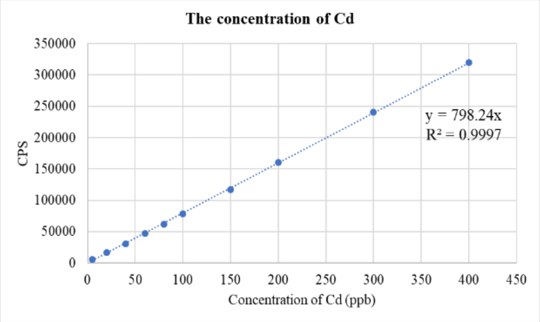








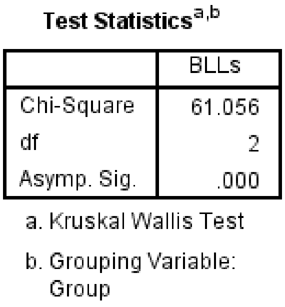




APPENDIX E

STATISTICAL RESULTS FROM SPSS PROGRAM

Table E1 Comparison mean blood lead and cadmium levels of e-waste and non-e-waste workers

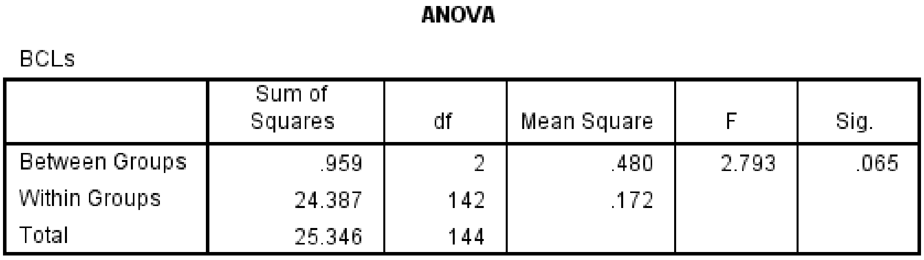


Test Statistics[a,b]

	BLLs
Chi-Square	61.056
df	2
Asymp. Sig.	.000

a. Kruskal Wallis Test

b. Grouping Variable: Group

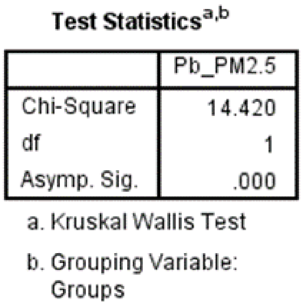


ANOVA

BCLs

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	.959	2	.480	2.793	.065
Within Groups	24.387	142	.172		
Total	25.346	144			

Table E2 Comparison mean Pb and Cd concentration in $PM_{2.5}$ and $PM_{2.5\text{-}10}$ of e-waste and non-e-waste workers

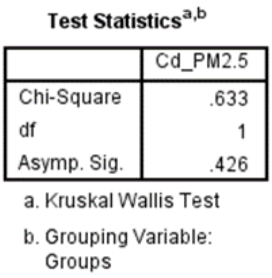


Test Statistics[a,b]

	Pb_PM2.5
Chi-Square	14.420
df	1
Asymp. Sig.	.000

a. Kruskal Wallis Test

b. Grouping Variable: Groups

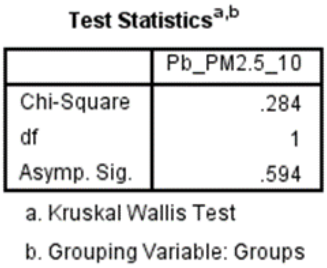


Test Statistics[a,b]

	Cd_PM2.5
Chi-Square	.633
df	1
Asymp. Sig.	.426

a. Kruskal Wallis Test

b. Grouping Variable: Groups

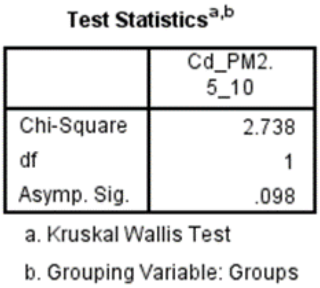


Test Statistics^{a,b}

	Pb_PM2.5_10
Chi-Square	.284
df	1
Asymp. Sig.	.594

a. Kruskal Wallis Test

b. Grouping Variable: Groups



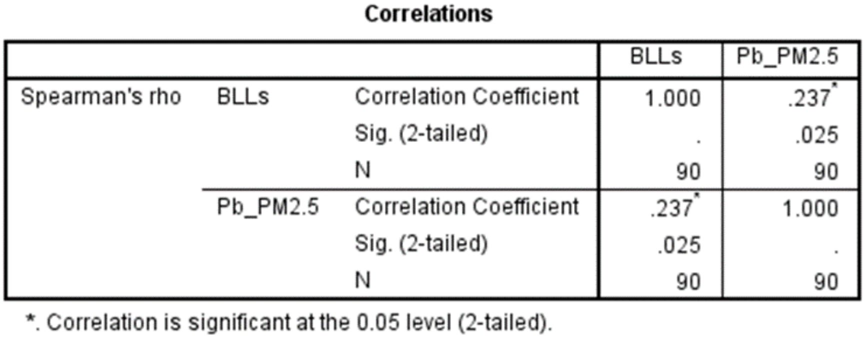
Test Statistics^{a,b}

	Cd_PM2.5_10
Chi-Square	2.738
df	1
Asymp. Sig.	.098

a. Kruskal Wallis Test

b. Grouping Variable: Groups

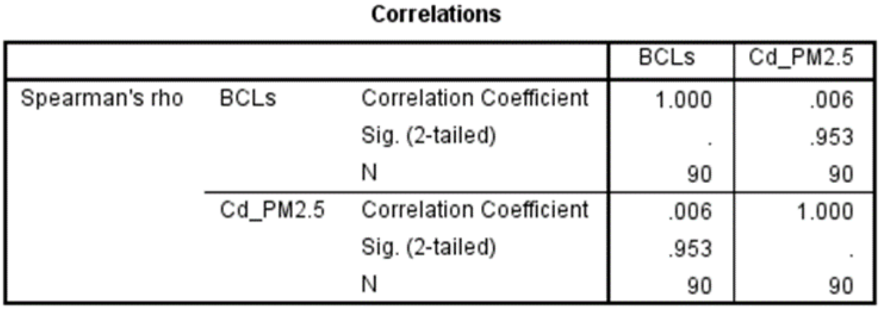
Table E3 Correlation between Pb and Cd in PM2.5 and PM2.5-10 and Blood lead and cadmium levels



Correlations

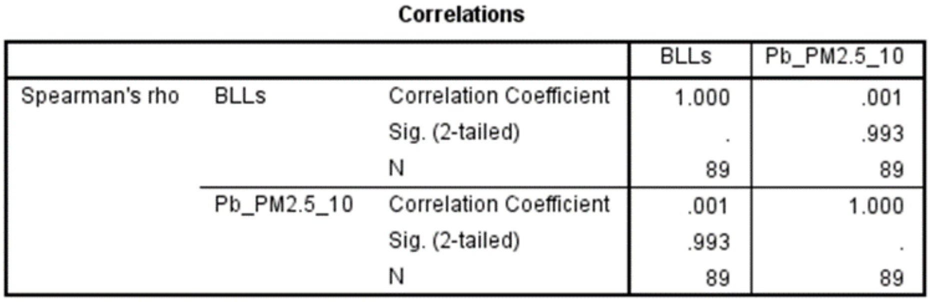
			BLLs	Pb_PM2.5
Spearman's rho	BLLs	Correlation Coefficient	1.000	.237*
		Sig. (2-tailed)	.	.025
		N	90	90
	Pb_PM2.5	Correlation Coefficient	.237*	1.000
		Sig. (2-tailed)	.025	.
		N	90	90

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



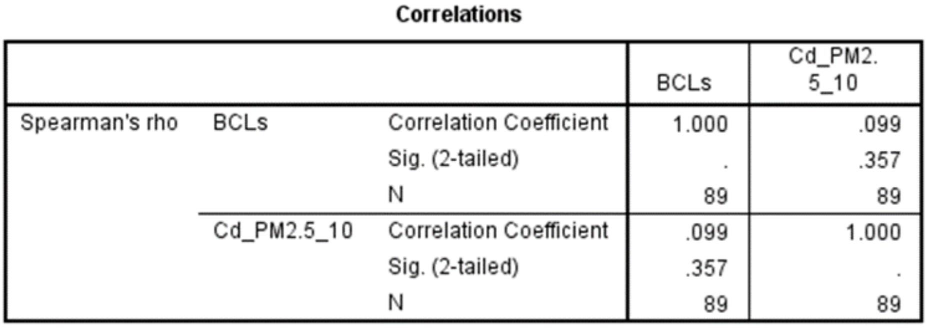
Correlations

			BCLs	Cd_PM2.5
Spearman's rho	BCLs	Correlation Coefficient	1.000	.006
		Sig. (2-tailed)	.	.953
		N	90	90
	Cd_PM2.5	Correlation Coefficient	.006	1.000
		Sig. (2-tailed)	.953	.
		N	90	90



Correlations

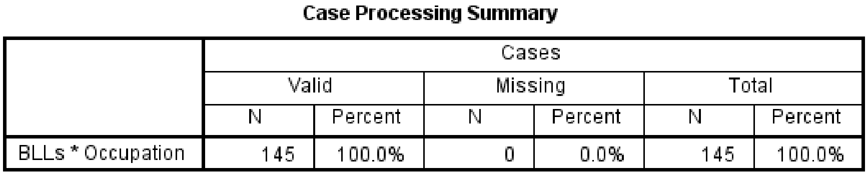
			BLLs	Pb_PM2.5_10
Spearman's rho	BLLs	Correlation Coefficient	1.000	.001
		Sig. (2-tailed)	.	.993
		N	89	89
	Pb_PM2.5_10	Correlation Coefficient	.001	1.000
		Sig. (2-tailed)	.993	.
		N	89	89



Correlations

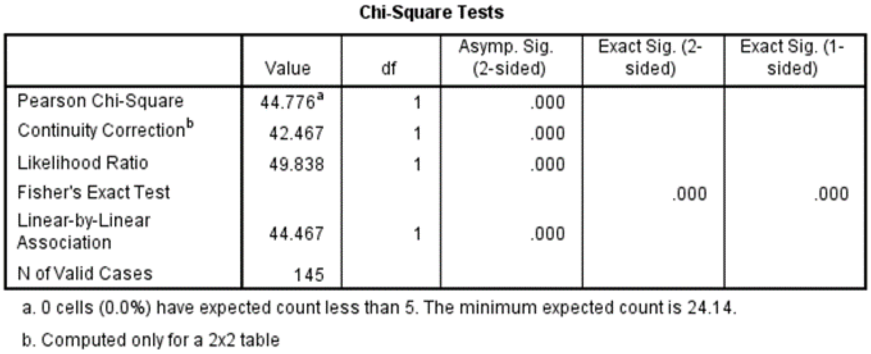
			BCLs	Cd_PM2.5_10
Spearman's rho	BCLs	Correlation Coefficient	1.000	.099
		Sig. (2-tailed)	.	.357
		N	89	89
	Cd_PM2.5_10	Correlation Coefficient	.099	1.000
		Sig. (2-tailed)	.357	.
		N	89	89

Table E4 Associated factors of personal information of e-waste and non-e-waste workers



Case Processing Summary

	Cases					
	Valid		Missing		Total	
	N	Percent	N	Percent	N	Percent
BLLs * Occupation	145	100.0%	0	0.0%	145	100.0%



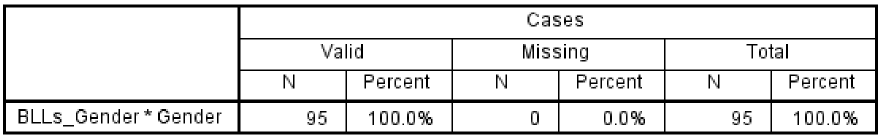
Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	44.776[a]	1	.000		
Continuity Correction[b]	42.467	1	.000		
Likelihood Ratio	49.838	1	.000		
Fisher's Exact Test				.000	.000
Linear-by-Linear Association	44.467	1	.000		
N of Valid Cases	145				

a. 0 cells (0.0%) have expected count less than 5. The minimum expected count is 24.14.

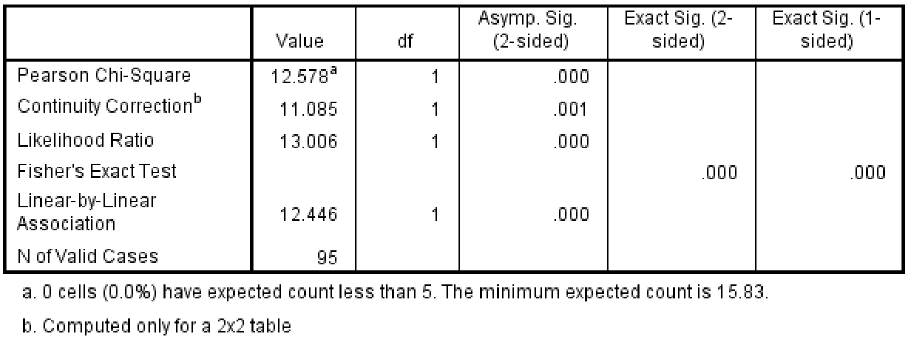
b. Computed only for a 2x2 table

Case Processing Summary



	Cases					
	Valid		Missing		Total	
	N	Percent	N	Percent	N	Percent
BLLs_Gender * Gender	95	100.0%	0	0.0%	95	100.0%

Chi-Square Tests

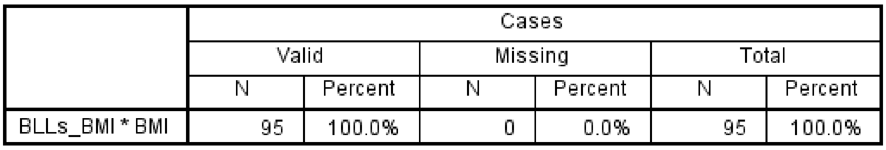


	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	12.578[a]	1	.000		
Continuity Correction[b]	11.085	1	.001		
Likelihood Ratio	13.006	1	.000		
Fisher's Exact Test				.000	.000
Linear-by-Linear Association	12.446	1	.000		
N of Valid Cases	95				

a. 0 cells (0.0%) have expected count less than 5. The minimum expected count is 15.83.

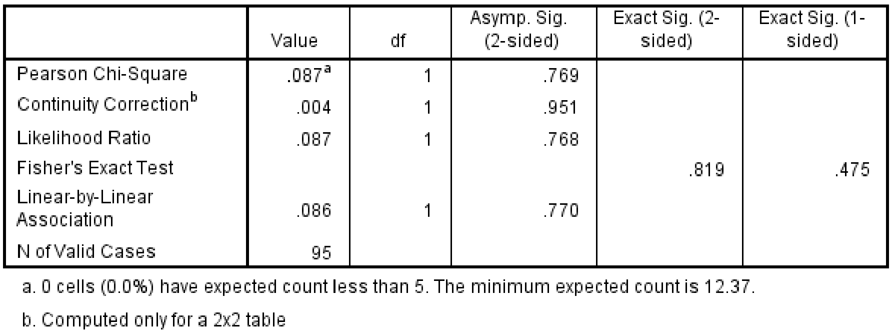
b. Computed only for a 2x2 table

Case Processing Summary



	Cases					
	Valid		Missing		Total	
	N	Percent	N	Percent	N	Percent
BLLs_BMI * BMI	95	100.0%	0	0.0%	95	100.0%

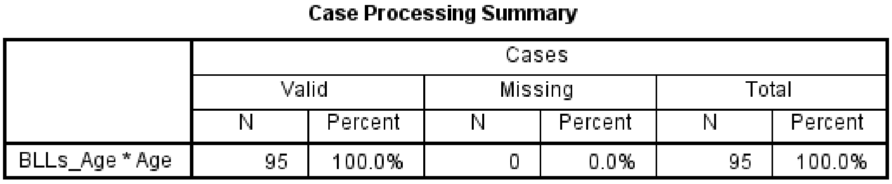
Chi-Square Tests



	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	.087[a]	1	.769		
Continuity Correction[b]	.004	1	.951		
Likelihood Ratio	.087	1	.768		
Fisher's Exact Test				.819	.475
Linear-by-Linear Association	.086	1	.770		
N of Valid Cases	95				

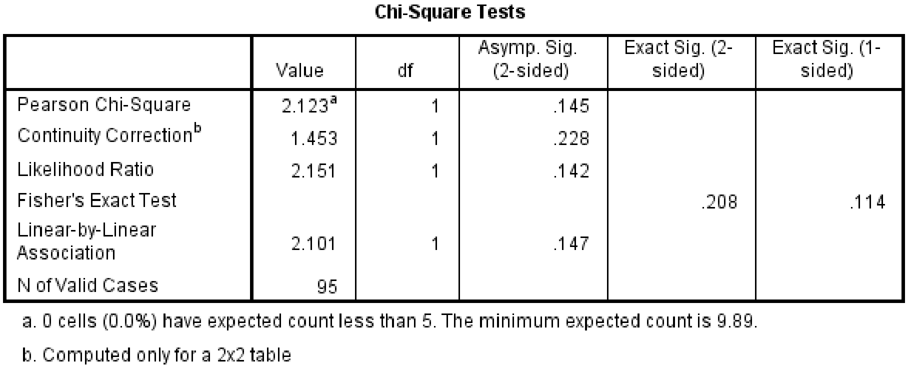
a. 0 cells (0.0%) have expected count less than 5. The minimum expected count is 12.37.

b. Computed only for a 2x2 table



Case Processing Summary

	Cases					
	Valid		Missing		Total	
	N	Percent	N	Percent	N	Percent
BLLs_Age * Age	95	100.0%	0	0.0%	95	100.0%

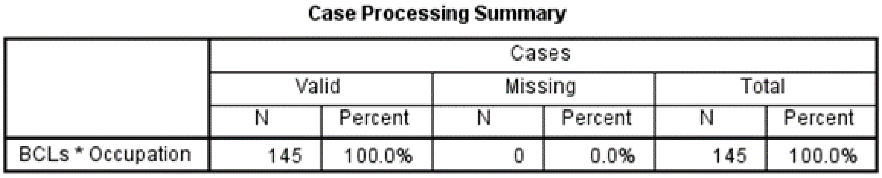


Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	2.123[a]	1	.145		
Continuity Correction[b]	1.453	1	.228		
Likelihood Ratio	2.151	1	.142		
Fisher's Exact Test				.208	.114
Linear-by-Linear Association	2.101	1	.147		
N of Valid Cases	95				

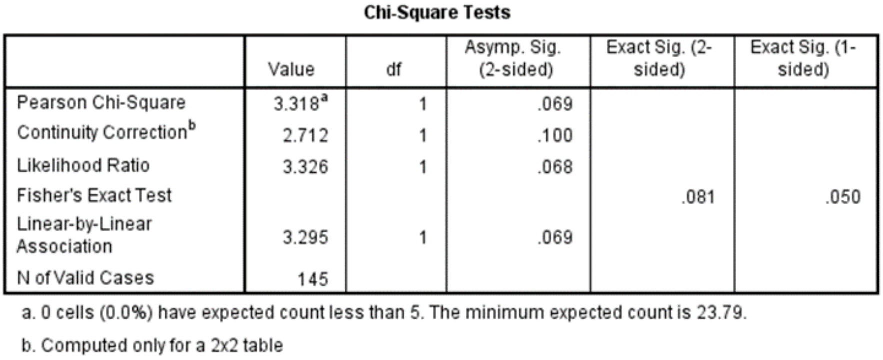
a. 0 cells (0.0%) have expected count less than 5. The minimum expected count is 9.89.

b. Computed only for a 2x2 table



Case Processing Summary

	Cases					
	Valid		Missing		Total	
	N	Percent	N	Percent	N	Percent
BCLs * Occupation	145	100.0%	0	0.0%	145	100.0%

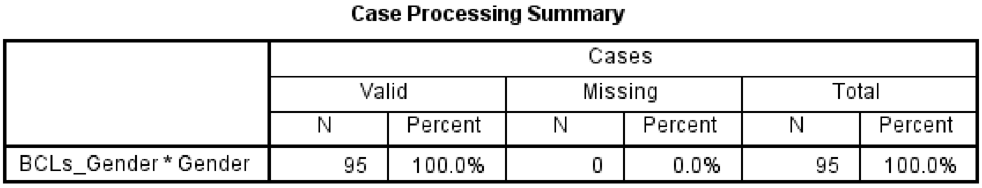


Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	3.318[a]	1	.069		
Continuity Correction[b]	2.712	1	.100		
Likelihood Ratio	3.326	1	.068		
Fisher's Exact Test				.081	.050
Linear-by-Linear Association	3.295	1	.069		
N of Valid Cases	145				

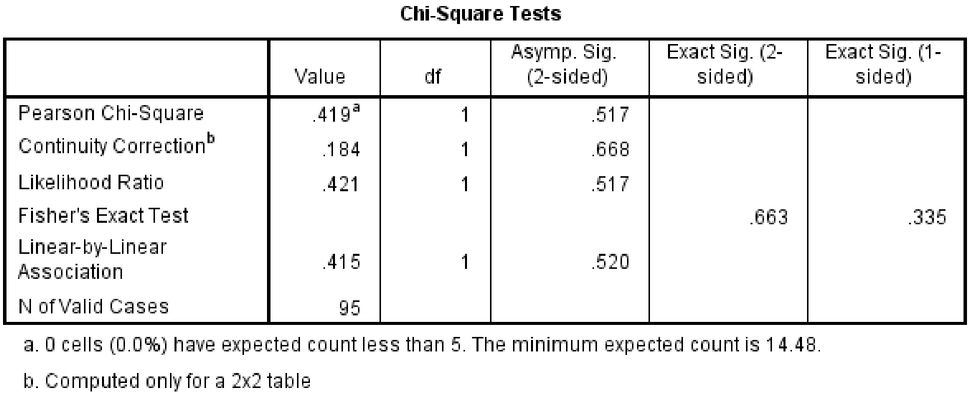
a. 0 cells (0.0%) have expected count less than 5. The minimum expected count is 23.79.

b. Computed only for a 2x2 table



Case Processing Summary

	Cases					
	Valid		Missing		Total	
	N	Percent	N	Percent	N	Percent
BCLs_Gender * Gender	95	100.0%	0	0.0%	95	100.0%

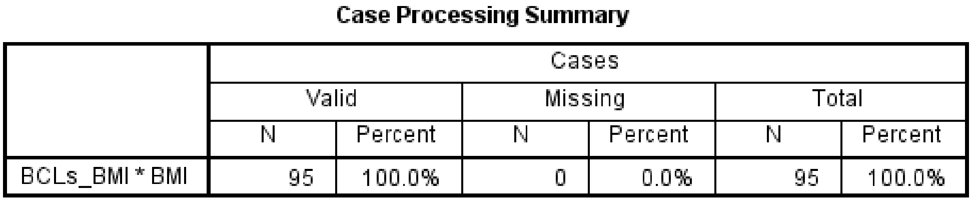


Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	.419[a]	1	.517		
Continuity Correction[b]	.184	1	.668		
Likelihood Ratio	.421	1	.517		
Fisher's Exact Test				.663	.335
Linear-by-Linear Association	.415	1	.520		
N of Valid Cases	95				

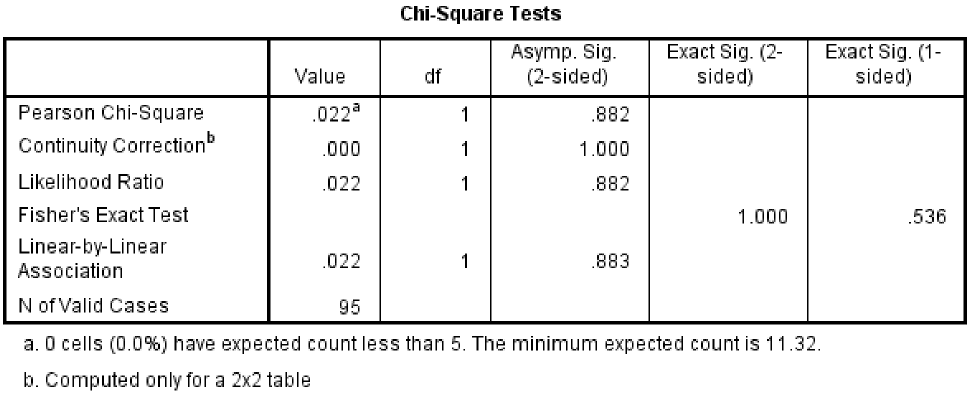
a. 0 cells (0.0%) have expected count less than 5. The minimum expected count is 14.48.

b. Computed only for a 2x2 table



Case Processing Summary

	Cases					
	Valid		Missing		Total	
	N	Percent	N	Percent	N	Percent
BCLs_BMI * BMI	95	100.0%	0	0.0%	95	100.0%

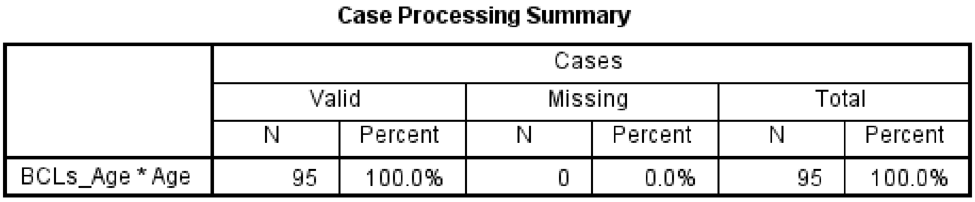


Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	.022[a]	1	.882		
Continuity Correction[b]	.000	1	1.000		
Likelihood Ratio	.022	1	.882		
Fisher's Exact Test				1.000	.536
Linear-by-Linear Association	.022	1	.883		
N of Valid Cases	95				

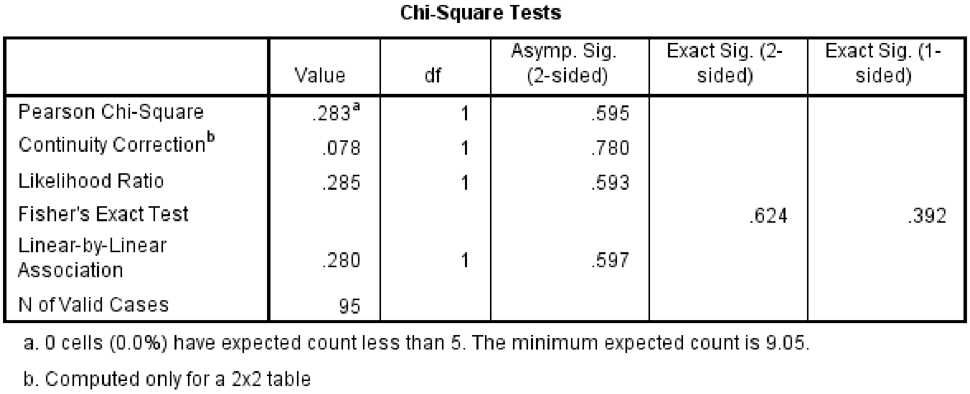
a. 0 cells (0.0%) have expected count less than 5. The minimum expected count is 11.32.

b. Computed only for a 2x2 table



Case Processing Summary

	Cases					
	Valid		Missing		Total	
	N	Percent	N	Percent	N	Percent
BCLs_Age * Age	95	100.0%	0	0.0%	95	100.0%



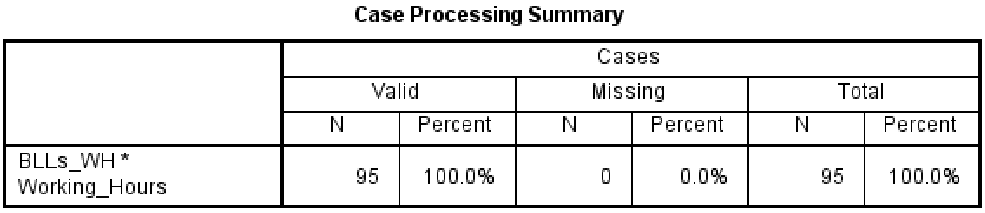
Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	.283[a]	1	.595		
Continuity Correction[b]	.078	1	.780		
Likelihood Ratio	.285	1	.593		
Fisher's Exact Test				.624	.392
Linear-by-Linear Association	.280	1	.597		
N of Valid Cases	95				

a. 0 cells (0.0%) have expected count less than 5. The minimum expected count is 9.05.

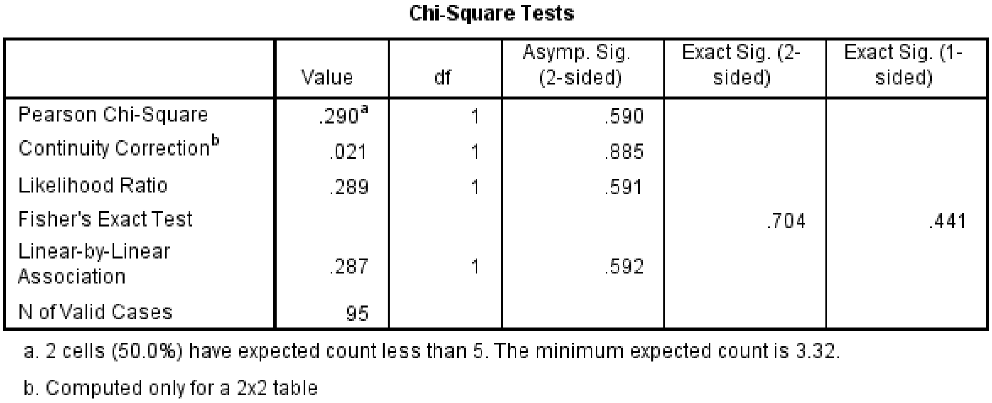
b. Computed only for a 2x2 table

Table E5 Associated factors of working conditions of e-waste workers



Case Processing Summary

	Cases					
	Valid		Missing		Total	
	N	Percent	N	Percent	N	Percent
BLLs_WH * Working_Hours	95	100.0%	0	0.0%	95	100.0%

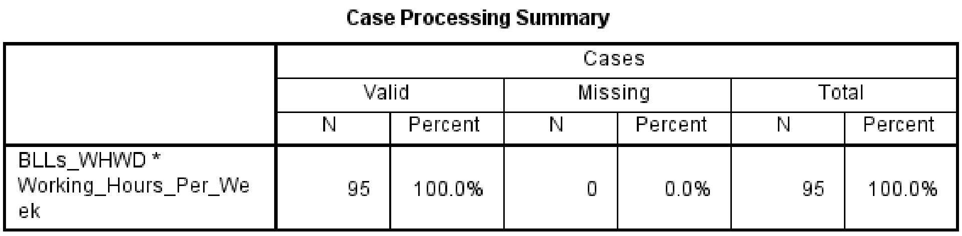


Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	.290[a]	1	.590		
Continuity Correction[b]	.021	1	.885		
Likelihood Ratio	.289	1	.591		
Fisher's Exact Test				.704	.441
Linear-by-Linear Association	.287	1	.592		
N of Valid Cases	95				

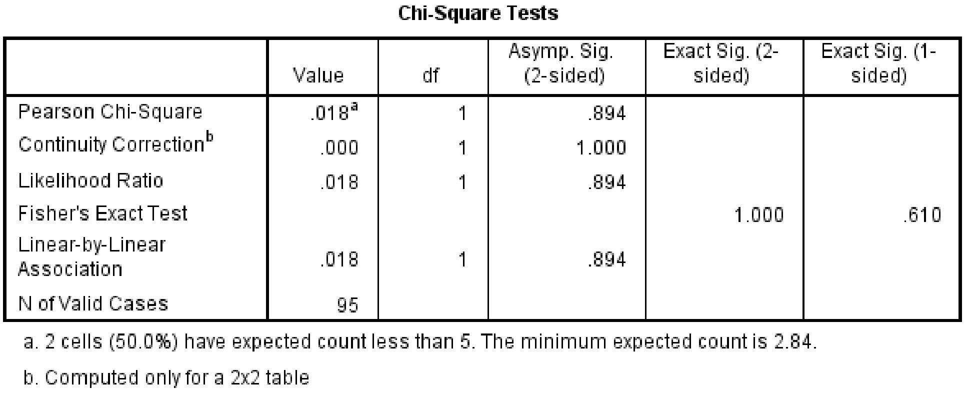
a. 2 cells (50.0%) have expected count less than 5. The minimum expected count is 3.32.

b. Computed only for a 2x2 table



Case Processing Summary

	Cases					
	Valid		Missing		Total	
	N	Percent	N	Percent	N	Percent
BLLs_WHWD * Working_Hours_Per_Week	95	100.0%	0	0.0%	95	100.0%

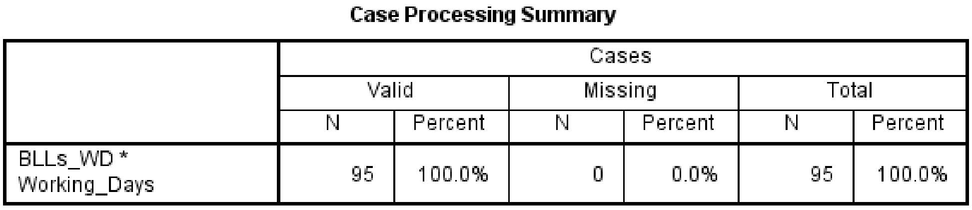


Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	.018[a]	1	.894		
Continuity Correction[b]	.000	1	1.000		
Likelihood Ratio	.018	1	.894		
Fisher's Exact Test				1.000	.610
Linear-by-Linear Association	.018	1	.894		
N of Valid Cases	95				

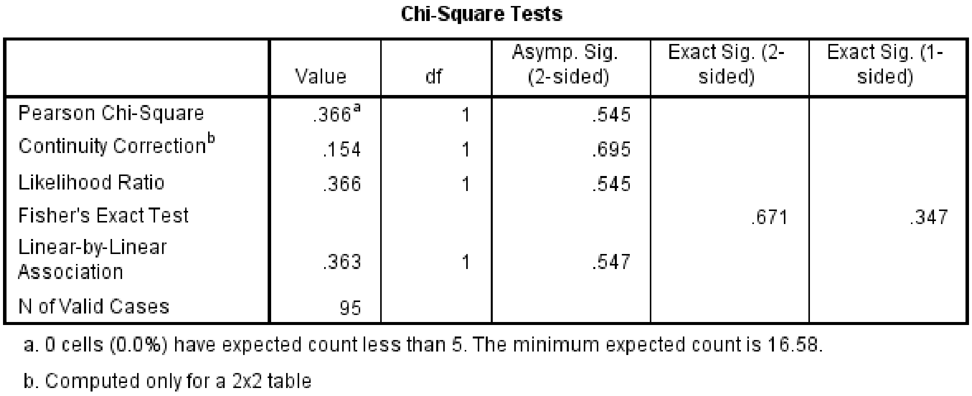
a. 2 cells (50.0%) have expected count less than 5. The minimum expected count is 2.84.

b. Computed only for a 2x2 table



Case Processing Summary

	Cases					
	Valid		Missing		Total	
	N	Percent	N	Percent	N	Percent
BLLs_WD * Working_Days	95	100.0%	0	0.0%	95	100.0%

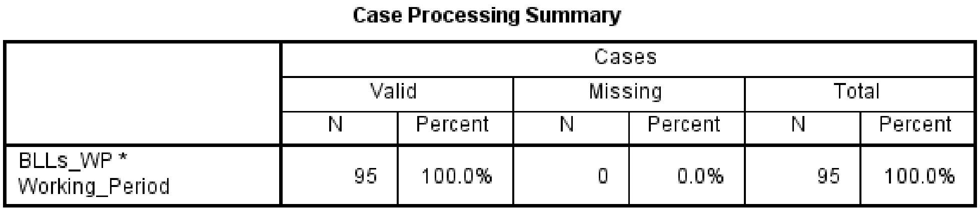


Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	.366[a]	1	.545		
Continuity Correction[b]	.154	1	.695		
Likelihood Ratio	.366	1	.545		
Fisher's Exact Test				.671	.347
Linear-by-Linear Association	.363	1	.547		
N of Valid Cases	95				

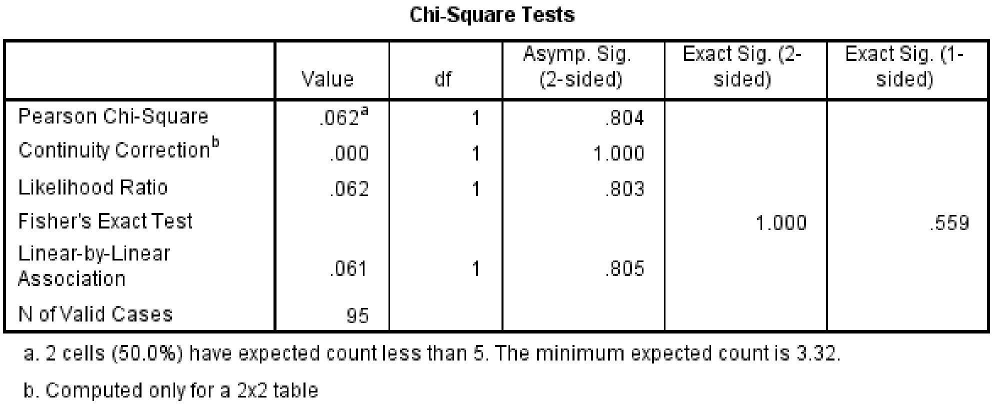
a. 0 cells (0.0%) have expected count less than 5. The minimum expected count is 16.58.

b. Computed only for a 2x2 table



Case Processing Summary

	Cases					
	Valid		Missing		Total	
	N	Percent	N	Percent	N	Percent
BLLs_WP * Working_Period	95	100.0%	0	0.0%	95	100.0%

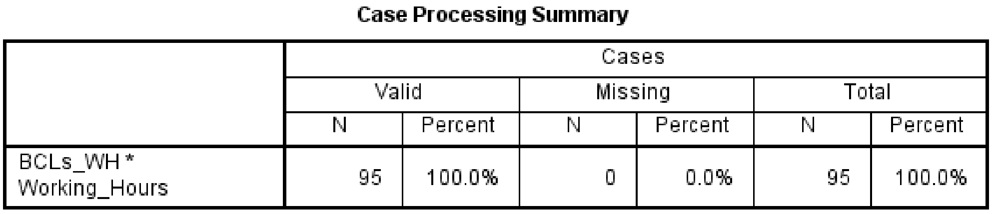


Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	.062[a]	1	.804		
Continuity Correction[b]	.000	1	1.000		
Likelihood Ratio	.062	1	.803		
Fisher's Exact Test				1.000	.559
Linear-by-Linear Association	.061	1	.805		
N of Valid Cases	95				

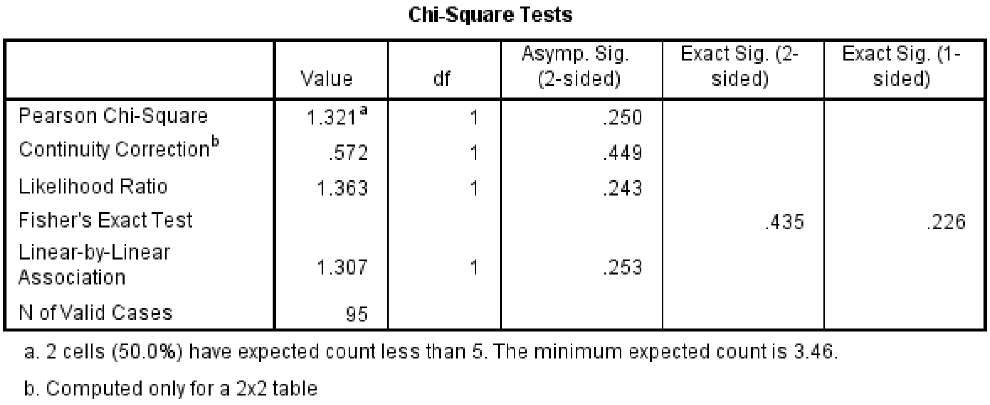
a. 2 cells (50.0%) have expected count less than 5. The minimum expected count is 3.32.

b. Computed only for a 2x2 table



Case Processing Summary

	Cases					
	Valid		Missing		Total	
	N	Percent	N	Percent	N	Percent
BCLs_WH * Working_Hours	95	100.0%	0	0.0%	95	100.0%

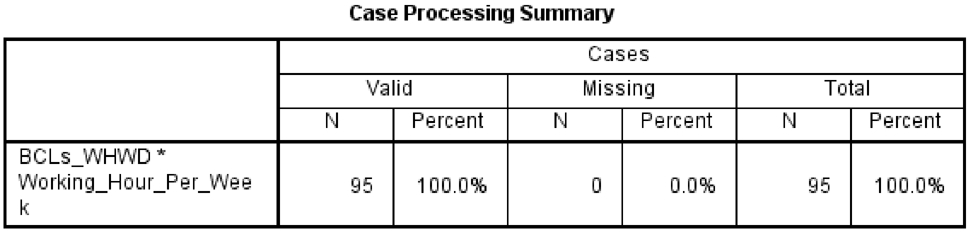


Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	1.321[a]	1	.250		
Continuity Correction[b]	.572	1	.449		
Likelihood Ratio	1.363	1	.243		
Fisher's Exact Test				.435	.226
Linear-by-Linear Association	1.307	1	.253		
N of Valid Cases	95				

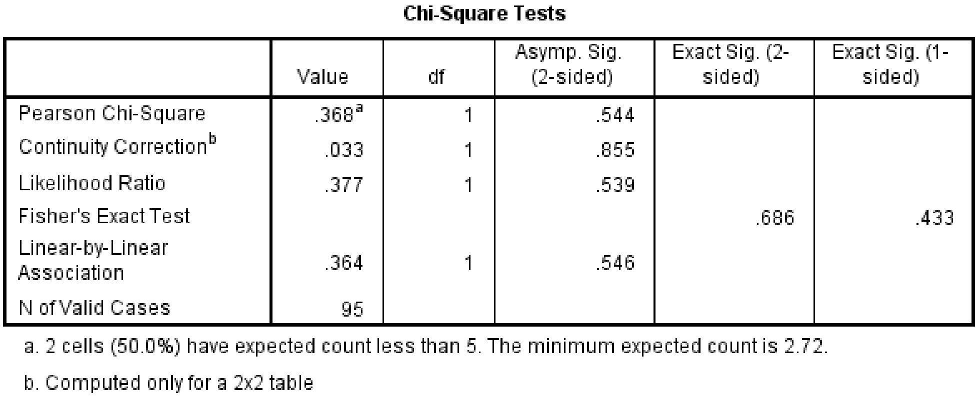
a. 2 cells (50.0%) have expected count less than 5. The minimum expected count is 3.46.

b. Computed only for a 2x2 table



Case Processing Summary

	Cases					
	Valid		Missing		Total	
	N	Percent	N	Percent	N	Percent
BCLs_WHWD * Working_Hour_Per_Week	95	100.0%	0	0.0%	95	100.0%

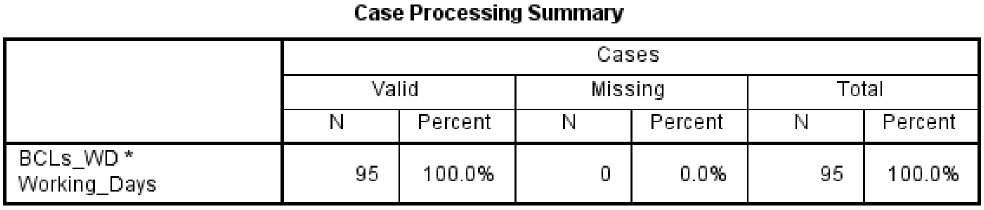


Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	.368[a]	1	.544		
Continuity Correction[b]	.033	1	.855		
Likelihood Ratio	.377	1	.539		
Fisher's Exact Test				.686	.433
Linear-by-Linear Association	.364	1	.546		
N of Valid Cases	95				

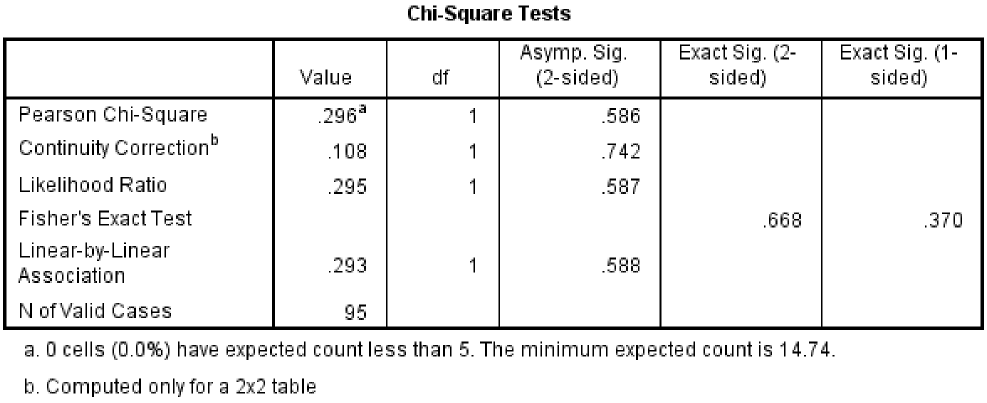
a. 2 cells (50.0%) have expected count less than 5. The minimum expected count is 2.72.

b. Computed only for a 2x2 table



Case Processing Summary

	Cases					
	Valid		Missing		Total	
	N	Percent	N	Percent	N	Percent
BCLs_WD * Working_Days	95	100.0%	0	0.0%	95	100.0%

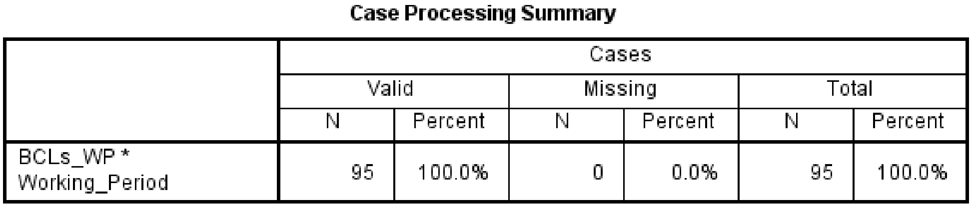


Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	.296[a]	1	.586		
Continuity Correction[b]	.108	1	.742		
Likelihood Ratio	.295	1	.587		
Fisher's Exact Test				.668	.370
Linear-by-Linear Association	.293	1	.588		
N of Valid Cases	95				

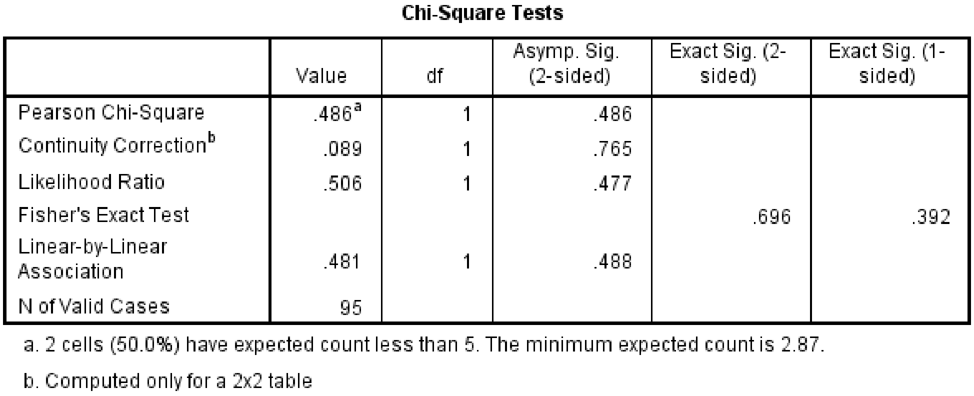
a. 0 cells (0.0%) have expected count less than 5. The minimum expected count is 14.74.

b. Computed only for a 2x2 table



Case Processing Summary

	Cases					
	Valid		Missing		Total	
	N	Percent	N	Percent	N	Percent
BCLs_WP * Working_Period	95	100.0%	0	0.0%	95	100.0%



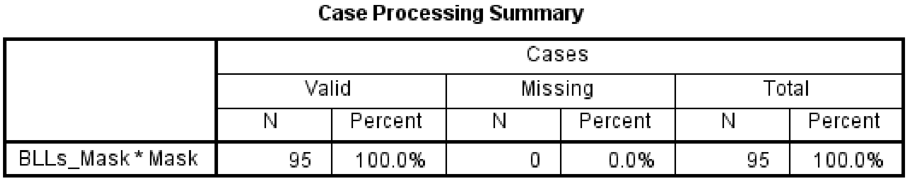
Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	.486[a]	1	.486		
Continuity Correction[b]	.089	1	.765		
Likelihood Ratio	.506	1	.477		
Fisher's Exact Test				.696	.392
Linear-by-Linear Association	.481	1	.488		
N of Valid Cases	95				

a. 2 cells (50.0%) have expected count less than 5. The minimum expected count is 2.87.

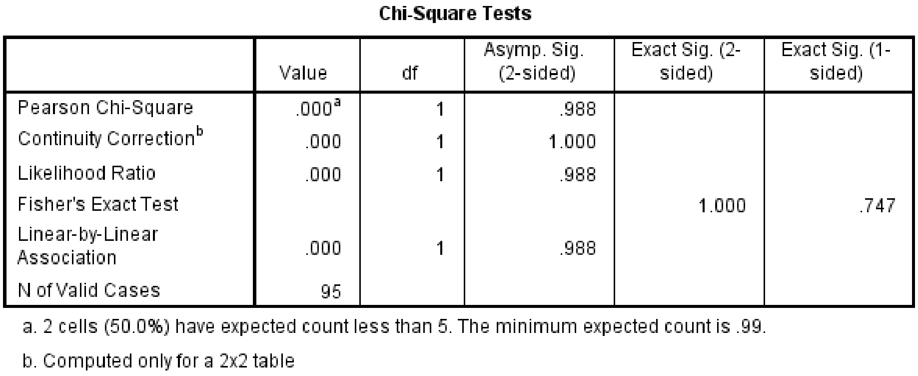
b. Computed only for a 2x2 table

Table E6 Associated factors of using PPE of e-waste workers



Case Processing Summary

	Cases					
	Valid		Missing		Total	
	N	Percent	N	Percent	N	Percent
BLLs_Mask * Mask	95	100.0%	0	0.0%	95	100.0%

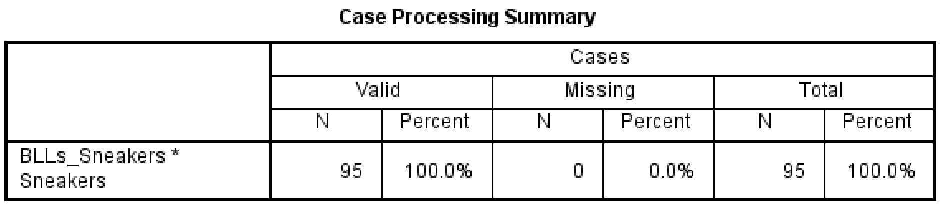


Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	.000[a]	1	.988		
Continuity Correction[b]	.000	1	1.000		
Likelihood Ratio	.000	1	.988		
Fisher's Exact Test				1.000	.747
Linear-by-Linear Association	.000	1	.988		
N of Valid Cases	95				

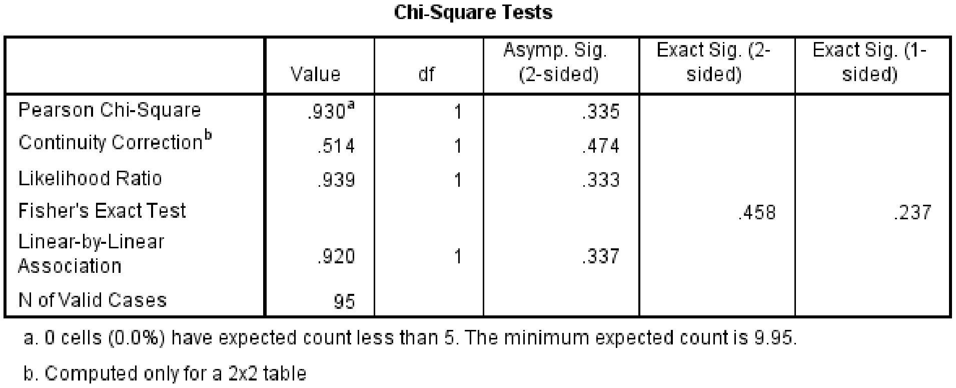
a. 2 cells (50.0%) have expected count less than 5. The minimum expected count is .99.

b. Computed only for a 2x2 table



Case Processing Summary

	Cases					
	Valid		Missing		Total	
	N	Percent	N	Percent	N	Percent
BLLs_Sneakers * Sneakers	95	100.0%	0	0.0%	95	100.0%

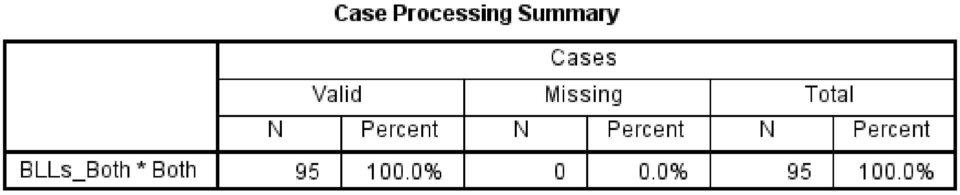


Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	.930[a]	1	.335		
Continuity Correction[b]	.514	1	.474		
Likelihood Ratio	.939	1	.333		
Fisher's Exact Test				.458	.237
Linear-by-Linear Association	.920	1	.337		
N of Valid Cases	95				

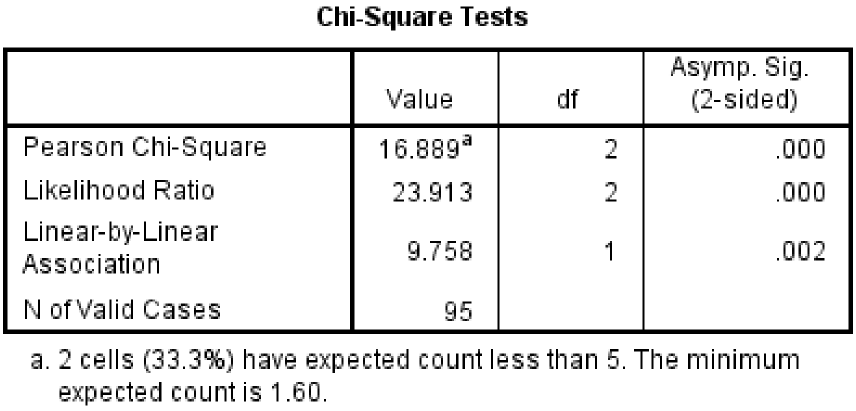
a. 0 cells (0.0%) have expected count less than 5. The minimum expected count is 9.95.

b. Computed only for a 2x2 table



Case Processing Summary

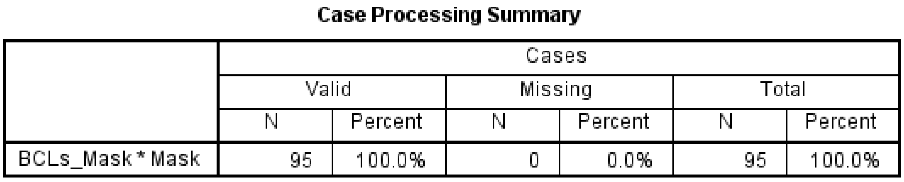
	Cases					
	Valid		Missing		Total	
	N	Percent	N	Percent	N	Percent
BLLs_Both * Both	95	100.0%	0	0.0%	95	100.0%



Chi-Square Tests

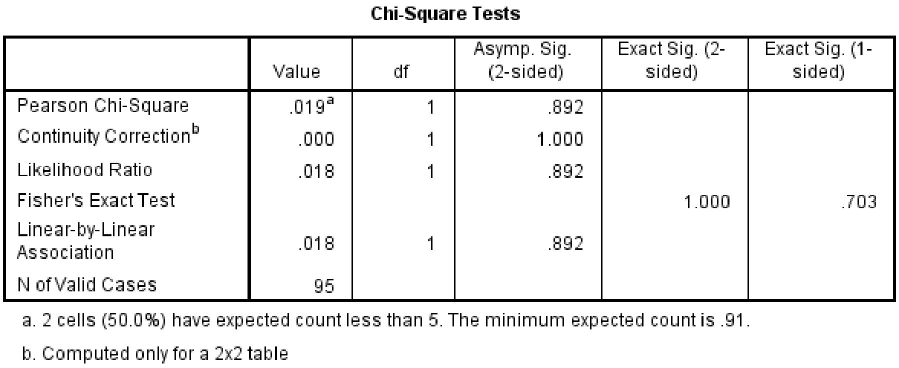
	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	16.889[a]	2	.000
Likelihood Ratio	23.913	2	.000
Linear-by-Linear Association	9.758	1	.002
N of Valid Cases	95		

a. 2 cells (33.3%) have expected count less than 5. The minimum expected count is 1.60.



Case Processing Summary

	Cases					
	Valid		Missing		Total	
	N	Percent	N	Percent	N	Percent
BCLs_Mask * Mask	95	100.0%	0	0.0%	95	100.0%

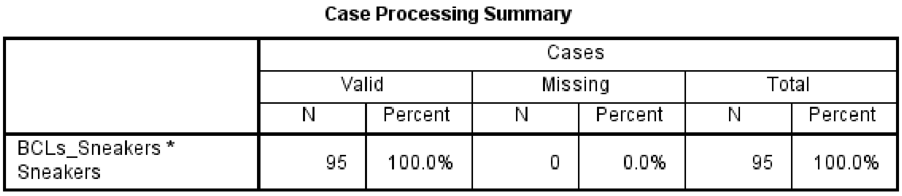


Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	.019[a]	1	.892		
Continuity Correction[b]	.000	1	1.000		
Likelihood Ratio	.018	1	.892		
Fisher's Exact Test				1.000	.703
Linear-by-Linear Association	.018	1	.892		
N of Valid Cases	95				

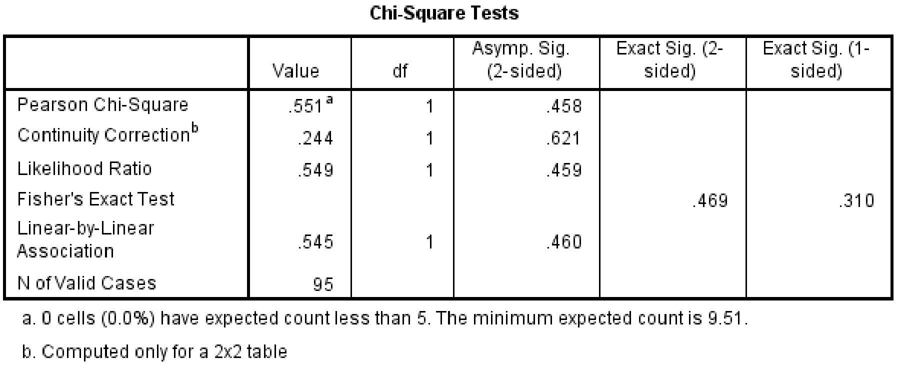
a. 2 cells (50.0%) have expected count less than 5. The minimum expected count is .91.

b. Computed only for a 2x2 table



Case Processing Summary

	Cases					
	Valid		Missing		Total	
	N	Percent	N	Percent	N	Percent
BCLs_Sneakers * Sneakers	95	100.0%	0	0.0%	95	100.0%

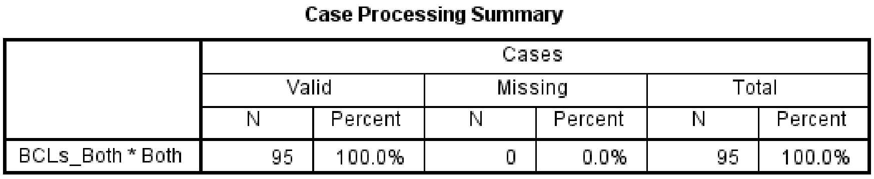


Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	.551[a]	1	.458		
Continuity Correction[b]	.244	1	.621		
Likelihood Ratio	.549	1	.459		
Fisher's Exact Test				.469	.310
Linear-by-Linear Association	.545	1	.460		
N of Valid Cases	95				

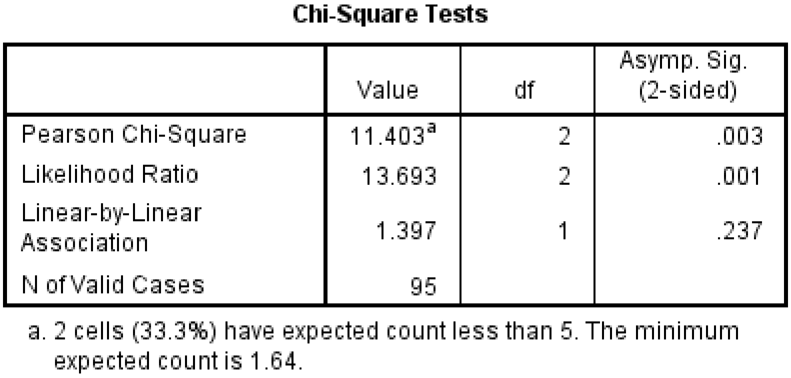
a. 0 cells (0.0%) have expected count less than 5. The minimum expected count is 9.51.

b. Computed only for a 2x2 table



Case Processing Summary

	Cases					
	Valid		Missing		Total	
	N	Percent	N	Percent	N	Percent
BCLs_Both * Both	95	100.0%	0	0.0%	95	100.0%



Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	11.403[a]	2	.003
Likelihood Ratio	13.693	2	.001
Linear-by-Linear Association	1.397	1	.237
N of Valid Cases	95		

a. 2 cells (33.3%) have expected count less than 5. The minimum expected count is 1.64.

VITA

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AWARD RECEIVED	Best Peper Award of International Conference on 2020 the 3rd International Conference on Sustainable Development of Water and Environment (ICSDWE2020)