SPATIAL AND TEMPORAL VARIATION OF HEAVY METALS IN PM10 AND PM2.5 SURROUNDING E-WASTE DISMANTLING COMMUNITY IN BURIRAM PROVINCE

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การแพร่กระจายเชิงพื้นที่และเวลาของโลหะหนักในฝุ่น PM10 และ PM2.5 บริเวณชุมชนที่มีการคัดแยกขยะอิเล็กทรอนิกส์ จังหวัดบุรีรัมย์

น.ส.สิริวิภา จันทหงษ์

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิทยาศาสตรมหาบัณฑิต
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Thesis Title	SPATIAL AND TEMPORAL VARIATION OF HEAVY METALS IN PM10 AND PM2.5 SURROUNDING E-WASTE DISMANTLING COMMUNITY IN BURIRAM PROVINCE
By	Miss Siriwipha Chanthahong
Field of Study	Environmental Science
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สิริวิภา จันทหงษ์ : การแพร่กระจายเชิงพื้นที่และเวลาของโลหะหนักในฝุ่น PM10 และ PM2.5 บริเวณชุมชนที่มีการคัดแยกขยะอิเล็กทรอนิกส์ จังหวัดบุรีรัมย์. (SPATIAL AND TEMPORAL VARIATION OF HEAVY METALS IN PM10 AND PM2.5 SURROUNDING E-WASTE DISMANTLING COMMUNITY IN BURIRAM PROVINCE) อ.ที่ปรึกษาหลัก : ผศ. ดร.ทรรศนีย์ พฤกษาสิทธิ์

การศึกษาการแพร่กระจายเชิงพื้นที่และเวลาของโลหะหนักใน PM_{10} และ $PM_{2.5}$ บริเวณชุมชนที่มีการคัดแยกขยะอิเล็กทรอนิกส์ในจังหวัดบุรีรัมย์ ในระหว่างเดือนเมษายนและกันยายน มีวัตถุประสงค์เพื่อหาปริมาณโลหะหนักที่พบและเปรียบเทียบระหว่างจุดที่ไม่มีการคัดแยกขยะอิเล็กทรอนิกส์ (NS) จุดที่มีการคัดแยกขยะอิเล็กทรอนิกส์ (ES) และบ่อทิ้งขยะ (OD) รวมถึงระบุแหล่งที่มาที่เป็นไปได้ของโลหะหนัก ได้แก่ As, Cr, Cu, Cd , Ni, Mn, Pb, Zn และ Fe ซึ่งทำการวิเคราะห์ปริมาณโลหะหนักในฝุ่นด้วยเครื่อง ICP-MS จากผลการศึกษาพบว่าค่าเฉลี่ยของฝุ่น $PM_{2.5}$ และ PM_{10} มีค่าสูงสุดที่จุด NS (33.8 ±18.8 $\mu g/m^3$) และจุด OD (57.6 ±17.5 $\mu g/m^3$) ตามลำดับ และจากผลวิเคราะห์สหสัมพันธ์แบบเพียร์สันของ $PM_{2.5}$ พบว่าปริมาณฝุ่นส่วนใหญ่มีความสัมพันธ์ระหว่างจุด ES กับ NS และพื้นที่อ้างอิง (RF) ในขณะที่ PM_{10} พบความสัมพันธ์กับจุด NS ในบางตัวอย่าง สำหรับปริมาณโลหะหนักในฝุ่น $PM_{2.5}$ แสดงให้เห็นว่า As, Cd, Cr, Mn, Pb, Zn และ Fe พบปริมาณสูงที่สุดที่จุดบ่อทิ้งขยะ (0.230 ±0.093, 1.426 ±0.736, 9.604 ±17.111, 16.083 ±4.924, 56.021 ±28.563, 278.118 ±31.945 และ 264.858 ±69.649 ng/m^3) ในขณะที่ Cu และ Ni มีค่าสูงสุดในจุดที่ไม่มีการคัดแยกขยะอิเล็กทรอกนิกส์ (46.655 ±20.339 ng/m^3) และจุดที่มีการคัดแยกขยะอิเล็กทรอกนิกส์ (22.540 ±21.114 ng/m^3) ตามลำดับ ส่วนโลหะหนักที่ปนเปื้อนใน PM_{10} มี As และ Zn ที่พบว่ามีค่าใกล้เคียงกันในทุกจุดเก็บตัวอย่าง As (2.195 - 6.070 ng/m^3) และ Zn (1272.275 - 8418.981 ng/m^3) ในขณะเดียวกันพบว่า Cr, Cu, Ni, Pb และ Fe มีปริมาณสูงในจุดที่ไม่มีการคัดแยกขยะอิเล็กทรอนิกส์ (5.918 ±8.318, 103.233 ±22.825, 1.972 ±1.062, 31.979 ±23.042 และ 655.740 ±330.848 ng/m^3 ตามลำดับ) จากการศึกษาการแพร่กระจายเชิงเวลาพบว่าในช่วงฤดูฝนจะพบปริมาณโลหะหนักมากกว่าในฤดูร้อน ส่วนปัจจัยทางอุตุนิยมวิทยา ได้แก่ ความเร็วลม อุณหภูมิ และความชื้นสัมพัทธ์ มีความสัมพันธ์เชิงลบหรือแปรผกผันกับปริมาณโลหะในฝุ่นทั้งสองขนาด สำหรับองค์ประกอบในฝุ่น $PM_{2.5}$ และ PM_{10} พบว่ามี Zn เป็นองค์ประกอบสูงสุดร่วมกับ Fe ในทุกจุดเก็บตัวอย่าง ส่วนโลหะหนักที่เหลือพบในองค์ประกอบของฝุ่นที่มาจากจุดเก็บตัวอย่างบริเวณที่มีการคัดแยกขยะอิเล็กทรอกนิกส์ และเมื่อวิเคราะห์จำแนกแหล่งกำเนิดของโลหะหนักในฝุ่นด้วยเทคนิค PCA และ EF พบว่า Fe และ Cr ในฝุ่น $PM_{2.5}$ มาจากแหล่งกำเนิดธรรมชาติ ในขณะที่ Cd, Cu, Ni, Pb, Zn และ As มีแหล่งกำเนิดจากกิจกรรมการคัดแยกขยะอิเล็กทรอนิกส์ในพื้น ส่วน Cr, As และ Zn ในฝุ่น PM_{10} มีแหล่งกำเนิดจากธรรมชาติ ส่วน Pb, Ni และ Cd เป็นธาตุที่มีอยู่เดิมในพื้นที่นี้ ในขณะที่ Fe และ Cu มีแหล่งกำเนิดมาจากกิจกรรมการคัดแยกขยะอิเล็กทรอนิกส์ ดังนั้นการศึกษานี้สามารถระบุได้ว่ากิจกรรมการคัดแยกขยะอิเล็กทรอนิกส์สามารถพิจารณาเป็นแหล่งกำเนิดของการปนเปื้อนโลหะหนักในฝุ่น PM_{10} และ $PM_{2.5}$ ในพื้นที่การศึกษานี้ได้

สาขาวิชา วิทยาศาสตร์สิ่งแวดล้อม ลายมือชื่อนิสิต

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ปีการศึกษา 2562 ลายมือชื่อ อ.ที่ปรึกษาหลัก

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KEYWORD: spatial and temporal variation of heavy metals, E-waste dismantling activity, chemical composition of particulate matter

Siriwipha Chanthahong : SPATIAL AND TEMPORAL VARIATION OF HEAVY METALS IN PM10 AND PM2.5 SURROUNDING E-WASTE DISMANTLING COMMUNITY IN BURIRAM PROVINCE. Advisor: Asst. Prof. TASSANEE CHETWITTAYACHAN

Spatial and temporal variation of heavy metals in PM_{10} and $PM_{2.5}$ surrounding e-waste dismantling community at Buriram Province were investigated during April and September. The aims of this study were to monitor and compare between those found at non- (NS) and e-waste dismantling house (ES) and open dump area (OD), and identify potential sources of heavy metals including As, Cr, Cu, Cd, Ni, Mn, Pb, Zn and Fe. The heavy metals in PM were analyzed by ICP-MS. The results showed that average $PM_{2.5}$ and PM_{10} were highest at NS (33.8 ±18.8 μg/m^3) and OD (57.6 ±17.5 μg/m^3), respectively. $PM_{2.5}$ was significantly correlated between ES with NS and reference area (RF), while those of PM_{10} has found some correlation with NS. For $PM_{2.5}$, As, Cd, Cr, Mn, Pb, Zn, and Fe were highest at open dump area (0.230 ±0.093, 1.426 ±0.736, 9.604 ±17.111, 16.083 ±4.924, 56.021 ±28.563, 278.118 ±31.945, and 264.858 ±69.649 ng/m^3, respectively) while Cu and Ni were highest at non-e-waste dismantling (46.655 ±20.339 ng/m^3) and e-waste dismantling house (22.540 ±21.114 ng/m^3). Heavy metals contaminated in PM_{10} shows the similarity of As (2.195 - 6.070 ng/m^3) and Zn concentration (1,272.275 - 8,418.981 ng/m^3) at all sampling sites. While Cr, Cu, Ni, Pb, and Fe were found highly at non-e-waste dismantling house (5.918 ±8.318, 103.233 ±22.825, 1.972 ±1.062, 31.979 ±23.042, and 655.740 ±330.848, respectively). The temporal variation of heavy metals was explicitly found higher in September than in April. Meteorological factors, including wind speed, temperature, and relative humidity, had negative relationships with metals variation in PM. For the composition in $PM_{2.5}$ and PM_{10} at all sampling sites, Zn had the highest compositions along with Fe, and the rest metals were mostly higher at the e-waste dismantling area. The integrated results between PCA and EF analysis show that Fe and Cr in $PM_{2.5}$ were originated from a natural, while those of Cd, Cu, Ni, Pb, Zn, and As could be initiated from an e-waste dismantling in this area. For PM_{10}, Cr, As, and Zn was originated from natural and Pb, Ni, and Cd had existed in the background environment. At the same time, Fe and Cu were originated from e-waste dismantling activities. Consequently, this study can be indicated that e-waste dismantling activities led to more heavy metals contamination in $PM_{2.5}$ and PM_{10}.

Field of Study:	Environmental Science	Student's Signature .....
Academic Year:	2019	Advisor's Signature .....

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CHAPTER I
INTRODUCTION

1.1 Statement of the problems

Electronic waste or e-waste is an end-of-life electronics, electric appliances that are not working, or the user does not want it anymore (Vassanadumrongdee, 2015a). Later, e-waste will end up at some corner of the room, abandoned at a dump site, or sales to the trader who will sell e-waste to the dismantler or separator sections. From the accumulative of e-waste in Thailand over the previous years, there seems like the number is still expanding from 359,070 tons to 414,600 tons from 2012 to 2018, respectively (Pollution Control Department (PCD), 2013, 2019). Not only coming from all over Thailand, but the increasing of e-waste also derived from developed countries. The estimated number of imported e-waste in Thailand was 64,400 tones for 2017 and seemed to be increasing following in the first five months of 2018, which were reached 37,000 - 52,200 tons (Chantanusornsiri, 2018; Senet, 2018). E-waste is frequently transferred to some developing countries, including Thailand, where there are inadequate of the facility or an appropriate system to handle these discarded e-waste problems. Legally imported e-waste will be shifted to the recycle plants while illegal imported will be transferred to the junk shop or dismantling sections.

Presently in Thailand, there is more area that initiative provided e-waste dismantling activities to be their second occupational. Banmaichaiyaphot district, Buriram Province, is the second largest e-waste dismantling area in Thailand. From the observation in 2019, there are 105 informal separators in Daengyai subdistrict and 68 separators in Banpao subdistrict that have performed or registered as e-waste separator section. They will buy a bunch of e-waste from the junk shop or junk trader, and then the dismantling process will be done to separate that e-waste into various categories items. The process for separate e-waste in Daengyai and Banpao were similar; they use the informal e-waste dismantling methods include 1) using physically dismantling tools such as hammers, screwdrivers, chisels, and bare hands to separate materials, 2) burning cables to recover copper, burning unwanted plastics

and foams in the open air (Thongkaow, Prueksasit, & Siriwong, 2017a; Vassanadumrongdee, 2015a)

The study at an e-waste dismantling site located at Buriram province, Northeastern Thailand in 2016-2017, showed 12 types of e-waste. Most of the e-waste was found to be electronic appliances used in households, for example, fan, television (CRT), washing machine, refrigerator. Then other electric appliances were also observed but in a small quantity, including rice cooker, desktop computer, CD/VCD players, microwave, printer, iron, electric jar pot, air conditioner mechanical tools, and electric toys (Thongkaow et al., 2017a). E-waste contains several hazardous substances and heavy metals, batteries, circuit boards, cathode-ray tubes (CRT screens) and LCD screens, and lead capacitors contain lead, arsenic, cadmium, chromium, zinc, brominated flame retardant (M.D. Jalal Uddin, 2012). The study of heavy metals content in parts of e-waste has shown that printed wiring board (PWB) of CPU and CRT screen contains high concentrations of lead and copper (Kehinde, Osibanjo, & Nnorom, 2015). There are annual global number estimated for some heavy metal that emit in e-waste disposal area, Cu (820,000 tons/year), Ni (206,000tons/year), Cr (198,000 tons/year), Zn (102,000 tons/year) and Pb (58,000 tons/year) (Robinson, 2009). According to heavy metals contained in parts of e-waste, then primitive e-waste dismantling activities can cause emission of heavy metals contaminated particulate and generate airborne pollution in e-waste dismantling communities.

There are Cr, Cu, Cd, Ni, Pb, and Zn that commonly found in PM_{10} and $PM_{2.5}$ collected at e-waste dismantling sites, while As, Mn, Fe also found in some studies (Deng et al., 2006; Gangwar, Singh, Kumar, Chaudhry, & Tripathi, 2016b; Oguri et al., 2018; Puangprasert & Prueksasit, 2019; Xue, Yang, Ruan, & Xu, 2012; Zeng et al., 2016). These toxic heavy metals can easily accumulate in the human body through the inhalation of contaminated air and dust, and consequence in cause serious harm to humans, for example, lung cancer, kidney dysfunction, cognitive impairment, and chronic bronchitis neurological effects (World Health Organization (WHO), 2007). Typically, e-waste dismantling worker and residents can expose heavy metals via inhalation and caused harmful effects to their body because the larger particles (> 10 μm diameter) are filtered by hair in the nostrils, but small particles such as PM_{10} and

$PM_{2.5}$ can pose the most significant problems, because they can get deep into lungs, and some may even get into the bloodstream.

There is a study found heavy metals in the dust at 1, 4, 8, 16, and 24 kilometers away from the e-waste recycling center, and the concentrations decrease with increasing distance, indicating that e-waste is the source contribute heavy metals in the e-waste recycling area (Wu et al., 2016). These heavy metals contaminated dust can disperse to another area nearby their sources, which involving with meteorological factors. Meteorological factors such as temperature, wind direction and speed, relative humidity, and rain rate can influence air movement and fate of pollutants. Heavy metals such as Pb, Cd, and Mn contaminated in $PM_{2.5}$ were determined highest at winter and lowest in summer in the informal e-waste recycling site of China, showing the impaction of variation of meteorological condition (Zeng et al., 2016). Additionally, e-waste dismantling houses in Daengyai and Banpao subdistrict were randomly located neighboring non-e-waste dismantling houses. Other than e-waste dismantling activities, there are open dumping sites in both subdistrict which can cause air pollution due to dismantler will burn electronic wires and residues to separate the precious metals such as copper. Therefore, meteorological data must be observed to understand the pollution patterns in the area better. Then, the spatial and temporal distribution will be expressive the distribution of heavy metals from e-waste dismantling site to the surrounding area.

According to the above evidence of current e-waste dismantling houses widespread location in the communities in Northeastern Thailand, particularly in Banmaichaiyaphot and Phutthaisong District, Buriram province; the results from the previous study in Daengyai subdistrict show heavy metal that presented at e-waste dismantling houses were also found at non-e-waste dismantling houses (Chanthahong, Kanghae, & Prueksasit, 2017). It is possible that heavy metals in particulate matters could disperse from an e-waste dismantling houses to the ambient air in the vicinity area due to the location format of e-waste dismantling houses and non-e-waste dismantling houses are close to each other. Consequently, the residents living in non-e-waste dismantling houses nearby might face contaminated air and have the probability of exposure to heavy metals in the particulate matter as well. Up to the present, the concentration and distribution of heavy metals contaminated particulate

matter in ambient air at e-waste, non-e-waste dismantling, and open dumpsite in this area has not been studied. Therefore, this study aims to monitor the concentration of heavy metals in PM_{10} and $PM_{2.5}$ in the ambient air and to compare between those found at non- and e-waste dismantling house and open dump area. Furthermore, it is important to understand the influences of spatial and temporal distribution and the compositions of heavy metals in PM.

1.2 Objectives

1) To characterize the spatial and temporal distribution of heavy metals in PM_{10} and $PM_{2.5}$ at e-waste dismantling houses and the surrounding areas in Daengyai and Banpao, Banmaichaiyaphot District, Buriram province.
2) To investigate that the distribution of heavy metals in PM_{10} and $PM_{2.5}$ in the study area is influenced by the e-waste dismantling

1.3 Research hypothesis

1) E-waste dismantling houses have the most of heavy metal concentrations in PM_{10} and $PM_{2.5}$ and decrease with increasing distances.
2) PM_{10}, $PM_{2.5}$ and heavy metal concentrations are higher in summer and lower in rainy at all sampling sites.
3) Heavy metals in PM_{10} and $PM_{2.5}$ in the surrounding area are corresponding to heavy metals at E-waste dismantling house.

1.4 Scope of the study

1) PM_{10}, $PM_{2.5}$ samples were collected at e-waste dismantling house and the surrounding area, including non-e-waste dismantling, open dump area in Daengyai and Banpao Subdistrict, Banmaichaiyaphot and Phutthaisong District, and reference area in Daengyai, Buriram province.
2) PM_{10}, $PM_{2.5}$ were collected in 2019 during summer (April) and rainy (September) using high and low volume air sampler, respectively. Air sampler was performed 24 hours at each sampling site for 7 days consecutively.

3) Meteorological data including temperature, relative humidity, wind direction, wind speed, and precipitation were collected hourly at the open dump area of both Daengyai and Banpao subdistrict, and reference area at Wat E Sarn primary school in Daengyai by using DAVIS Vantage Pro2 wireless weather station.
4) Heavy metals in $PM_{2.5}$ and PM_{10} were digested with microwave digestion, and the concentration of As, Cr, Cu, Cd, Ni, Mn, Pb, Fe, and Zn were determined by inductively coupled plasma mass spectrometry (ICP-MS)
5) The concentration of according heavy metals was used to analyze the chemical profile or composition of heavy metals in PM via Enrichment factors and PCA analysis.

1.5 Expected benefits

1) To acknowledge the current status of ambient air quality disturbed by heavy metal contaminated particulate matters from the e-waste dismantling house in Daengyai and Banpao, Banmaichaiyaphot District, Buriram province.
2) To obtain the basic data of the heavy metal content in ambient air from e-waste dismantling activities for local administrative and improve the quality of life of workers or residents in Daengyai and Banpao subdistrict.
3) To assure that e-waste dismantling activities are releasing heavy metals into ambient air and leading to find a solution for air quality management or restrict e-waste dismantling activities.

CHAPTER II
LITERATURE REVIEW

2.1 Informal e-waste dismantling situation in Thailand

Recently, Thailand is facing e-waste problems that the quantity of e-waste has been growing every year due to rapidly rising in the production and consumption of electricals appliances. The number of e-waste in Thailand had been increased from 359,070 tons in 2012 to 414,600 tons in 2017 or approximately 2.2% per year, with electronic waste accounting up to 64.8% of all the hazardous waste occurring in municipal waste. Additionally, Thailand has been ratified to be a member of the Basel Convention, which is the comprehensive global environmental agreement on the control of trans-boundary movements and disposal of hazardous waste on 24 November 1997 and has been enforced since 22 February 1998. However, there are many electronic wastes imported from other countries to Thailand, which cause smuggling transfer e-waste to landfill in several areas and contamination of hazardous and heavy metals in e-waste dismantling or recycling area (Pollution Control Department, 2013, 2018). A large proportion of e-waste derived from the community and other countries has been delivered to e-waste dismantling operators in the rural areas. There are still inappropriate operations of e-waste dismantling and has no regulation for e-waste management directly in such areas. Along with there is no e-waste collection and disposal guideline and including there are complaints from the public concerning environmental problems from e-waste dismantling business.

Typically, numerous facility establishments for e-waste management have no system that can efficiently manage, control, and prevent impact on the environment. According to e-waste contained mostly hazardous and various types of heavy metals that pose to release to the environment, this will then be harmful to the environment and people's health. Most local people handle e-waste without an appropriate management system, in particular non-valuable parts of e-waste, which has been discarded with non-hazardous municipal solid waste (Buranasingh, 2016; Pollution Control Department, 2018). In 2018, the e-waste management system in Thailand had been promoted to local governmental and relevant organizations for arrangement the

e-waste collection and disposal in each village and community provided by Department of Environmental Quality Promotion (DEQP). An e-waste collection center of each province should be established to transfer to recycling and disposal facilities properly. However, this system is still not enough to cope with this problem due to no legal regulation to sort out e-waste from general waste and to enforce the private sectors to take their responsibility for the management of waste electrical and electronic equipment (WEEE) (Pollution Control Department, 2018).

The Department of Disease Control had estimated the number of e-waste dismantling site in Thailand which found almost 100 sites such as at Krabi, Kalasin, Chonburi, Chiang Mai, Lamphun, Nakhon Pathom, Nonthaburi, Pathum Thani, Buriram, Prachin Buri, Phra Nakhon Si Ayutthaya, Ratchaburi, Samut Prakan, and Amnat Charoen province. However, this amount was not included some junk shops that have a self-operating system of e-waste dismantling and burning (Vassanadumrongdee, 2015a). Besides, the Northeast of Thailand is one of the largest e-waste improper dismantling places. For example, Daengyai subdistrict, Banmaichaiyaphot District, and Banpao subdistrict, Puthaisong District, Buriram Province, there was 130 e-waste dismantling houses in 2017. From a recent survey in 2019, there are 105 registered informal e-waste separators in Daengyai subdistrict and 68 in Banpao subdistrict. The estimated number of e-waste entry to this area in 2017, including desktop computer, fan, refrigerator, washing machine, television (CRT screen), were 1.88, 5.37, 8.26, 10.06, and 12.33 ton/year/household, respectively (Thongkaow, Prueksasit, & Siriwong, 2017b)

The e-waste dismantling process by informal separators in the rural areas in Thailand is shown in Figure 2.1. First, a consumer buys the electrical or electronic products, and it will be sent to repair or sold to the recycled junk shop or directly to informal separators who provide the pick-up service after they are out of order or unused. Improper or unsafe e-waste dismantling by these informal sectors or separators is a major e-waste stakeholder in Thailand (Pookkasorn & Sharp, 2016). They do pile up e-waste in their residence, then start the manually dismantling from the large products such as washing machines, refrigerators, and air conditioners by using their hand or with the hammer to remove the external components made of steel, aluminum, or plastic and foam. After that, the internal parts are separated, they

would burn the wire and plastic products for separate copper and iron which could release copper fumes, dioxin and furan dust. Smashing computer and television screens (CRT screens) can release heavy metals such as lead, barium and cadmium into the air. Splitting compressor air conditioner and refrigerator are done to remove copper, and coolant is disposed to the land. An electronics board is collected and sold to micro-enterprises or small traders (Thongkaow et al., 2017b; Vassanadumrongdee, 2015b). All e-waste dismantling sites in Thailand has similar primitive dismantling activities, as stated above.

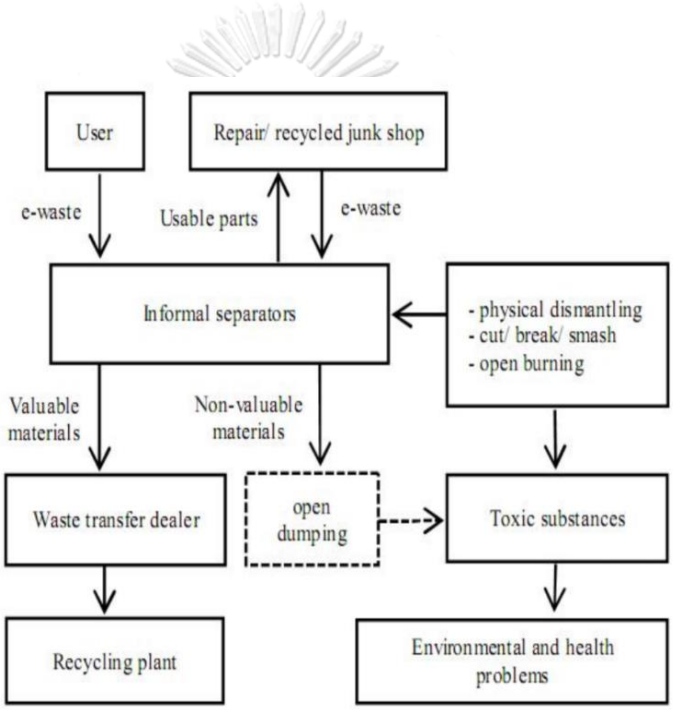


Figure 2.1 The simple diagram of e-waste dismantling by informal separators (Thongkaow et al., 2017b)

2.2 Heavy metals emission from electronic waste

Electronic waste or e-waste is defined as electrical or electronic products that have become unwanted, non-working, and have reached the end of their useful life (Vassanadumrongdee, 2015a). E-waste includes small and large household appliances, information technology and telecommunications equipment, lighting equipment, electrical and electronic tools, toys, and leisure and sports equipment, medical devices, monitoring and control instruments, and automatic dispensers.

The e-waste surveyed at the e-waste dismantling site located at Buriram province, Northeastern Thailand in 2016-2017, showed that 12 types of e-waste had been entered in this area. Most of the e-waste was found to be electronic appliances used in households, for example, fan, CRT screen, washing machine, refrigerator. Then other electric appliances such as rice cookers, desktop computers, CD/VCD players, microwave, printer, iron, electric jar pot, air conditioner mechanical tools, and electric toys were also found but in a small amount (Thongkaow et al., 2017b)

There have twenty-six common components that can be found in the e-waste items and can be classified as follows:

- metal
- motor or compressor
- cooling and plastic
- insulation
- glass and Liquid Crystal Display (LCD)
- rubber, wiring and electrical
- transformer
- magnetron
- textile
- circuit board
- fluorescent lamp, incandescent lamp
- heating element, thermostat
- Brominated Flame Retardants (BFRs)-containing plastic, batteries
- fluorocarbons (CFC/HCFC/HFC/HC)
- external electric cables
- refractory ceramic fibers
- radioactive substances
- electrolyte capacitors

Considering all components in e-waste, heavy metals, including lead, arsenic, cadmium, chromium, and zinc, can be found in many parts, for example, batteries, circuit boards, LCD, and CRT screens, and lead capacitors (M.D. Jalal Uddin, 2012). E-waste contains a broad range of toxic metals such as As, Cu, Pb, Sn, Ni, Fe, Al, Cd,

Zn, Mn, Hg, and Cr (Jinhui, Huabo, & Pixing, 2011; Peter, Shiva Nagendra, & Nambi, 2018). The study of heavy metals content in parts of e-waste has shown that PWB of CPU and CRT screen contained high concentrations of lead and copper (Olubanjo, Osibanjo, & Chidi, 2015). CRT is used for an old television model and desktop personal computer, but consumer demand for LCD televisions and computer monitors. Subsequently, more CRTs are disposed or sold to waste dealers and junk shops and currently influence the e-waste problems such as more CRT will be dismantled and cause more heavy metals contaminated in PM then distribute to the surrounding area. Also, iron and copper are two of the most recoverable quantity of materials in personal computer and television (M.D. Jalal Uddin, 2012). Cadmium, lead, and nickel was mainly found from printed circuit boards (PCBs) in the study of the major components of particle emitted during the recycling of waste PCBs in a typical e-waste workshop of South China (Bi et al., 2010). The assessment of heavy metal (Cr, Cu, Cd, Pb) in the ambience of the production line for recycling waste PCBs have found that lead and copper were the most enriched metals then followed by Cr and Cd (Xue et al., 2012). Moreover, there was annual global estimated in 2009 of emission for some heavy metal in e-waste, Cu (820,000 tons/year), Ni (206,000tons/year), Cr (198,000 tons/year), Zn (102,000 tons/year) and Pb (58,000 tons/year) (Robinson, 2009).

Heavy metals are originated from natural and anthropogenic and presented in varying concentrations in all ecosystems. They are found in elemental form and other various chemical compounds. Some are volatile and attached to fine particles that can be widely transported on very large scales (Ilyin, Berg, Dutchak, & Pacyna, 2004; Jan et al., 2015). Heavy metals are extremely persistent in the environment, e.g., in air, soil, water, and organism's bodies as well; they are non-biodegradable and thus readily accumulate to toxic levels (Kayastha, 2014). Heavy metals content in electronic waste that can be released from e-waste dismantling activities is summarized in Table 2.1.

Table 2.1 Heavy metals contamination in e-waste components

Heavy metals	Sources
Americium, Am	Smoke detectors
Antimony, Sb	Flame retardants, plastics, circuit boards, CRT screens, LCD screens, computer parts, televisions and mobile phones
Arsenic, As	Circuit boards, CRT screens, LCD screens, plasma screens, doping material for Si
Barium, Ba	Getters in CRTs, LCD screens, plasma screens
Beryllium, Be	Silicon-controlled rectifiers, Circuit boards, wires
Cadmium, Cd	Batteries, circuit boards, plastics, toners
Chromium, Cr	Computers, circuit boards, CRT screens, LCD screens, plasma screens, data tapes and floppy disks
Copper, Cu	Wiring, circuit boards, CRT screens, rotor or motor rotation
Gallium, Ga	Semiconductors
Indium, In	LCD displays, circuit boards
Lead, Pb	Batteries, CRT screens, LCD screens, circuit boards, solder, hard disks
Lithium, Li	Batteries
Mercury, Hg	Fluorescent lamps, batteries, switches
Nickel, Ni	Batteries, CD player, hard disks, LCD screens, circuit boards
Selenium, Se	Circuit boards, rectifier
Silver, Ag	LCD screens, circuit boards, solder, switches, wiring
Tin, Sn	Solder, LCD screens
Zinc, Zn	CD player, CRT screens, hard disks, circuit boards, plasma screens

Source: (Robinson, 2009; Vassanadumrongdee, 2015a)

Typically, e-waste dismantling workers and residents can expose heavy metals via inhalation and caused harmful effects to their body, for example, lung cancer, kidney dysfunction, cognitive impairment, and chronic bronchitis neurological effects. The larger particles (> 10 μm diameter) are filtered by hair in the nostrils. But small particles, i.e., PM_{10} can easily accumulate in the human body through the inhalation of contaminated air and dust and pose the greatest problems because they can get deep into the lungs, and some may even get into the bloodstream. PM_{10} and $PM_{2.5}$ are small enough to penetrate the thoracic region of the respiratory system. The health effects of inhalable PM are widely documented, and the effects are corresponding to the exposure period over both short term (hours, days) and long term (months, years). The health effects are included as follows (World Health Organization (WHO), 2013):

- respiratory and cardiovascular morbidity such as aggravation of asthma, respiratory symptoms, and an increase in hospital admissions.
- mortality from cardiovascular and respiratory diseases and lung cancer.

Moreover, heavy metals adhered to the particles can be released into the ambience during the recycling process (W. Fang, Y. Yang, & Z. Xu, 2013). E-waste dismantling with primitive dismantling methods such as cut, break, smash, and open burning will release heavy metals contaminated particles into the ambient air and other matrices in the environment (Vassanadumrongdee, 2015a). The concentration of heavy metals contaminated in PM at e-waste recycling or dismantling sites in previous studies is shown in Table 2.2. Consequently, heavy metals can contaminate in particulates which come from e-waste activities, and e-waste workers or people that live nearby this source can expose to these heavy metals. For heavy metals, harmful effects that can cause serious conditions to human health via inhalation are listed in Table 2.3. Therefore, the workers should attach great importance to wear safety equipment during the separation process according to the effects of heavy metal on humans, as mentioned above.

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

Sampling point	Location	Heavy metals concentrations in outdoor air (µg/m^3)								References
		As	Cd	Cr	Cu	Mn	Ni	Pb	Zn	
Production line for recycling PCBs waste	Jiangsu, China	-	0.016	0.12	0.88	-	-	0.56	-	(Xue et al., 2012)
E-waste processing area	Bui Dau, Vietnam	-	0.0001	-	0.018	0.030	-	0.036	0.120	(Oguri et al., 2018)
Production line for CRT waste recycling	Shanghai, China	-	0.007	0.11	0.30	-	0.10	3.0	7.9	(Wu et al., 2016)
E-waste burning and industrial sites	Moradabad, India	-	4.820	0.0006	50.68	0.239	5.01	4.670	90.47	(Gangwar, Singh, Kumar, Chaudhry, & Tripathi, 2016a)
Informal e-waste recycling site	Guiyu, Southeast China	-	0.0057	0.0045	-	0.017	-	0.16	-	(Zeng et al., 2016)
E-waste recycling area	Guiyu and Haojiang, China	-	0.0056	0.0065	-	0.022	-	0.153	-	(Zeng et al., 2016)
Open burning and other e-waste recycling operations	Guiyu, Southeast China	0.006	0.007	1.152	0.126	0.025	0.007	0.392	0.924	(Deng et al., 2006)
E-waste dismantling community	Daengyai subdistrict, Banmaichaiyaphot District, Buriram, Thailand	-	0.0073	-	0.2083	-	0.3499	0.1297	-	(Puangprasert & Prueksasit, 2019)

Table 2.3 Effects of some heavy metals on human health via inhalation

Pollutants	Effect on human health	References
As	Lung cancer is considered to be the critical effect following inhalation. An increased incidence of lung cancer has been seen in several occupational groups exposed to inorganic arsenic compounds.	(World Health Organization (WHO), 2000)
Cd	Cadmium can travel long distances from the source of emission by atmospheric transfer. It is readily accumulated in many organisms, notably molluscs and crustaceans.	(World Health Organization (WHO), 2010)
Cr	As the bronchial tree is the major target organ for the carcinogenic effects of chromium (VI) compounds, and cancer primarily occurs following inhalation exposure, uptake in the respiratory organs is of great significance with respect to the cancer hazard and the subsequent risk of cancer in humans	(World Health Organization (WHO), 2000)
Cu	Long-term exposure to copper dust can irritate your nose, mouth, and eyes, and cause headaches, dizziness, nausea, and diarrhea. Intentionally high intakes of copper can cause liver and kidney damage and even death	(Agency for Toxic Substances and Disease Registry (ATSDR), 2004)
Mn	Respiratory effects such as pneumonitis and pneumonia and reproductive dysfunction such as reduced libido are also frequently reported features of occupational manganese intoxication	(World Health Organization (WHO), 2000)
Ni	Severe lung damage has been recorded following acute inhalation exposure to nickel carbonyl. Renal effects and dermatitis presumably relate both to nickel uptake by both inhalation and ingestion, in addition to cutaneous contact for dermatitis. The respiratory tract is also a target organ for allergic	(World Health Organization (WHO), 2000)

Pollutants	Effect on human health	References
	manifestations of nickel exposure.	
Pb	Lead in the body is distributed to the brain, liver, kidney, and bones, particularly harmful to young children.	(World Health Organization (WHO), 2018)
Zn	The majority of the effects seen will occur within the respiratory tract	(Agency for Toxic Substances and Disease Registry (ATSDR), 2005)

2.3 Identification of ambient air quality related to heavy metal contamination

Ambient air is atmospheric air in its natural state, not contaminated by air-borne pollutants. Air pollution will occur if there is a change in the composition of the ambient air. Manufacturing processes and the burning of fossil fuels has directly impacted ambient air quality by releasing a high level of industrial and chemical pollutants into the atmosphere (Sherwin, 2017). The World Health Organization (WHO) defines ambient air pollution as potential harmful pollutants emitted by industries, households, cars, and trucks. All of the pollutants, fine particulate matter has the greatest effect on human health.

Particulate matter (PM) is a mixture with physical and chemical characteristics varying by location. Fine particulate matter such as particle with a diameter of less than 10 μm (PM_{10}) and particles with a diameter of less than 2.5 μm ($PM_{2.5}$) is a widespread air pollutant and suspended in the air. The difference between PM_{10} and $PM_{2.5}$ is the diameter size of the particles. PM_{10} is more considered as a coarse particulate matter, and their sources are including from crushing or grinding processes and also from dust stirred up by vehicles on the road. Meanwhile, $PM_{2.5}$ is smaller and about 3 percent of the diameter of human hair. Common sources of $PM_{2.5}$ are from all types of combustion, motor vehicle combustion, power plant, forest fires, agriculture burning, and resident wood burning. When compared with PM_{10}, $PM_{2.5}$ is lighter so they can get deeper into the lung and causing adverse health effects. The comparison of the diameter between PM_{10} and $PM_{2.5}$ is shown in Figure 2.2. Common chemical

constituents of PM include sulfates, nitrates, ammonium, carbon, crustal material, inorganic ions, and metals (World Health Organization (WHO), 2013). These PM can cause serious health problems in particular when people inhale those contaminated by metals. Thus, there should have some legal criteria for the PM to protect public health and the environment.

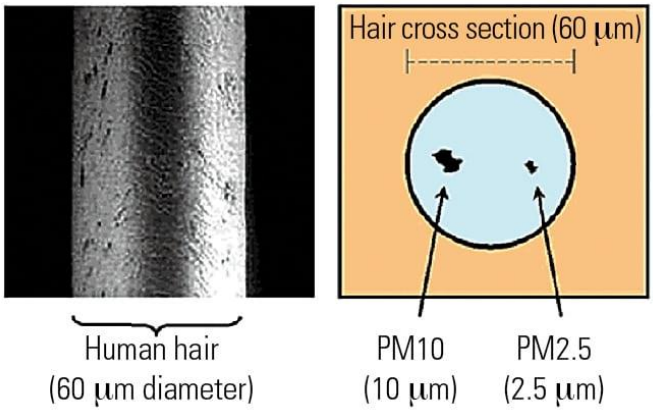


Figure 2.2 The difference size of particulate matters compared with human hair (Neville, 2012)

National Ambient Air Quality Standards (NAAQS) is a legal limit placed on levels of air pollutants in the ambient air that cannot be exceeded during a given time in a specific geographical area. It is necessary to monitor these pollutants to ensure compliance with the Air Quality Standard. Thailand Ambient Air Quality Standards has been set for the criteria pollutants, including PM_{10}, $PM_{2.5}$, TSP, CO, NO_2, SO_2, O_3, and Pb. These pollutants are the most dangerous due to their strongest evidence for public health concerns (Centers for Disease Control and Prevention (CDC), 2019). Therefore, the annual standard for one of the most dangerous pollutants, $PM_{2.5}$ and PM_{10} are shown in Table 2.4.

Table 2.4 Thailand Ambient Air Quality Standards of PM

Pollutants	**Thailand Ambient Air Quality Standards**	
	24-hr Average (μg/m^3)	**Annual Average (μg/m^3)**
$PM_{2.5}$	50	25
PM_{10}	120	50

Source: (Pollution control department, 2010)

Not only PM that has been concerned but also heavy metals contaminated in PM. Heavy metals are important components of PM, and they have complex pollution features. They can attach to the surface of PM, if compare PM_{10} with $PM_{2.5}$, $PM_{2.5}$ has a greater surface area per unit mass. The more surface area per unit, the more allowing PM to accumulate heavy metals more effectively (Li, Qian, & Wang, 2013). There are standard or reference values for atmospheric Pb, Cd, As, Ni, and Cr (VI) concentrations, as shown in Table 2.5, provided by European Union and the Ambient Air Quality Standards of China, as well as Thailand's National Ambient Air Quality Standards (NAAQS) (European Communities, 2001; Zhang et al., 2018). Ambient heavy metal concentrations and the extent of adverse effects caused by heavy metals in PM remain uncertain. It is necessary to investigate more and analyze heavy metals in fine PM to improve the usefulness of monitoring atmospheric heavy metals.

Air pollution is a major environmental risk to health, and ambient air pollution can cause by smoke, dust, gases, fumes, aerosols and odorous substances, and PM. PM can be directly emitted into the air (primary PM) or be formed in the atmosphere from gaseous precursors such as sulfur dioxide, oxides of nitrogen, and non-methane volatile organic compounds (secondary particles). It can have both man-made (anthropogenic) and natural sources. Anthropogenic sources include combustion engines, solid-fuel (coal, heavy oil, and biomass) combustion for energy production in households and industry, other industrial activities. Soil and dust re-suspension is also a contributing source of PM, particularly in arid episodes of long-range transport of dust (World Health Organization (WHO), 2013)

Table 2.5 Standard values for heavy metals in atmospheric

Heavy metals	Standard concentration of heavy metals				
	European Communities (ng/m^3)			Thailand's NAQQS (ng/m^3)	Chinese's NAQQS (ng/m^3)
	Rural areas	Urban and traffic-related sites	Industrial sites	Ambient air (1-month average)	Ambient air
Pb	-	-	-	1500	500
Cd	0.1 - 0.4	0.2 - 2.5	20.0	-	5
As	0.2 - 1.5	0.5 - 3.0	50.0	-	6
Ni	0.4 - 2.0	1.4 - 13	50.0	-	-
Cr (VI)	-	-	-	-	0.025

Source: (European Communities, 2001; Pollution Control Department (PCD), 2010; Zhang et al., 2018)

As described above in the e-waste dismantling situation, Thailand has become a dumpsite for electronic waste or e-waste, such as computers, printers, televisions, keyboards, routers, and other photocopying machines, especially at the Northeast and the number of e-waste were increasing every year. This e-waste is come from developed countries and also from Thailand. Subsequently, e-waste dismantling becomes a routine work or main job besides rice growing at Northeast's rural area. Recycling or dismantling activities of e-waste can release heavy metal, as be seen in Table 2.1, and cause air pollution within that location. Mostly air pollution in rural areas in Thailand is from automobiles around that area, agricultural waste burning, and cooking by using charcoal. Nevertheless, when e-waste dismantling activities have entered the rural area, then it becomes one of the main sources of air pollution, especially heavy metals contribution. Thus, the guideline concentration of particulate matters and heavy metal will help to define the contamination of heavy metal from e-waste activities in this study area. Likewise, Thailand has to take legal action to manage and control this pollution and its sources.

2.4 Spatial and temporal distribution

Spatial is an adjective of the word “space” and temporal means time-related or duration, so spatial and temporal distribution analysis is an analysis that considers the factors of location and time simultaneously. Also, spatial distribution is essentially the environment and statistical analysis of geographic data of the earth’s surface. The investigation of spatial and temporal distribution will help to understand more about emission sources and the direction of the interested air pollutants due to the pollution that varies with time and space. Some studies use a spatial distribution model to investigate the relationship between the amount of population and particulate matter concentration (Yao & Lu, 2014). Spatial and temporal distribution can be affected by various factors which will be stated as follows:

2.4.1 The distance from sources of pollutant

The concentration of pollutants at their source is usually the highest, and the pollutants can disperse into the surrounding area. If the distance between the surrounding area and sources is less or that area is closed with the source, then it will be received more levels of pollutants. There is a study that investigates four heavy metals of Pb, Cr, As, and Cd in indoor and outdoor dust samples at residential houses in the e-waste recycling area, Southeast China. The result shows Pb, Cr and Cd concentrations are decreased with the increased distance away from the e-waste recycling center, indicating the contribution of heavy metals from the e-waste recycling area. The represented graph of decreased levels with increased distance from a point source is shown in Figure 2.3, where C1 to C5 means the radiuses of the sampling circle at 1, 4, 8, 16, and 24 km, respectively (Wu et al., 2016).

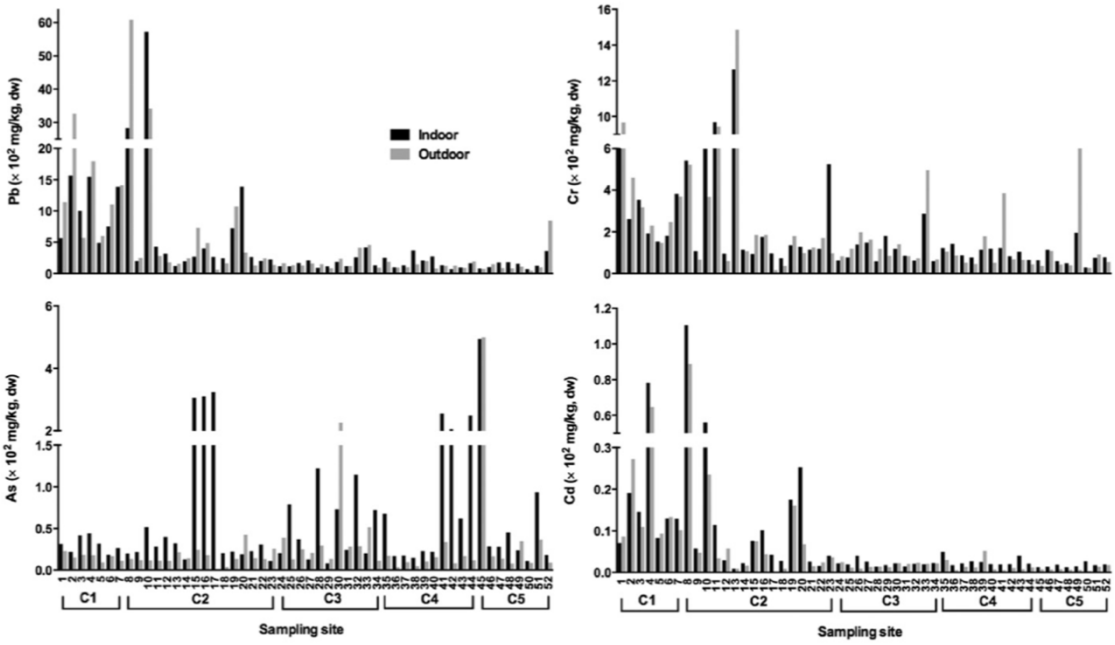


Figure 2.3 Concentrations of heavy metals in the indoor and outdoor dust sample (Wu et al., 2016)

The study of the temporal and spatial distribution of PM_{10} and $PM_{2.5}$ in Changchun, China was showed that PM concentrations in most season were found concentrated mainly in the central urban area, northern, and western areas of Changchun. This may occur due to anthropogenic activities outside the region, such as high contribution from vehicles and more population in the central urban area. Additionally, the spatial distribution result was obtained by the Kriging interpolation method, which can be seen in Figure 2.4, and representing that PM concentration was higher in the north and west (J. Wang, Xie, & Fang, 2019).

The above evidence indicates the importance of the distance from pollution sources. The closer to the source, the higher pollutants will be observed; increasing the distance between the receptor and source of pollutants or provide a buffer zone will decrease the exposure to humans and the environment. Thus, the spatial and temporal distribution will be affected by the distance between the point source and the surrounding area.

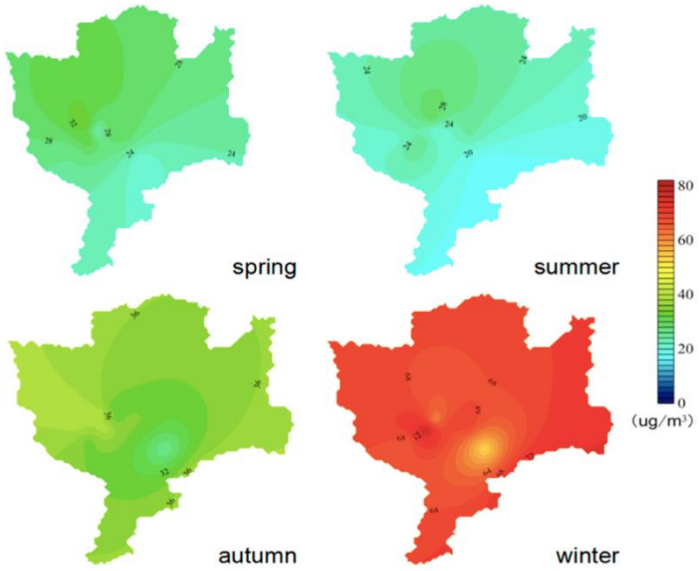


Figure 2.4 Spatial distribution of al average concentration of $PM_{2.5}$ (J. Wang et al., 2019)

2.4.2 Meteorological factors

The meteorological condition is the main factor that has an influence on the spatial and temporal distribution of PM and heavy metals level and also air quality in that area. Nonetheless, the levels and types of pollutants are also influenced by emission source strength, how land is used, the chemistry governing how these pollutants form in the atmosphere, and weather conditions (U.S. Global Change Research Program, 2016). Ambient particulate matter concentrations can be affected by dispersion processes, removal mechanisms, and chemical formation of atmospheric particles, which depend on meteorological factors parameters such as temperature, wind speed, relative humidity and rainfall rate (Galindo, Varea, Gil-Moltó, Yubero, & Nicolás, 2010). Also, the fate of air pollutants is manipulated by air movements; if the air is calm, then pollutants cannot disperse in consequent of the pollutant elevation (Queensland Government, 2017).

The pollutants will be distributed following the wind direction; the wind will increase the distribution of pollutants and also decrease the concentration of pollutants. Therewith the turbulence in ambient air can cause the spreading of pollution in with all directions so that the pollutants will be diluted. The polluted air

will be surrogated by other air and bringing the polluted air to other areas. However, if the turbulence occurs closer to the surface area, it will create a resuspension of pollutants or dust. Moreover, the change in temperature, if the thermal inversion has occurred, which is the state of air temperature does not decrease with height, then it will stop atmospheric convection and lead the air in that area to become stable. Consequently, the diffusion of pollutants is restricted.

There is a study about spatio-temporal variations and factors of provincial $PM_{2.5}$ pollution in eastern China that was used geostatistical analysis (GIS) and the HYbrid Single-Particle Lagrangian Integrated Trajectory (HYSPLIT) model. The result of temporal variations showed a high $PM_{2.5}$ level in winter and low in summer, as showed in Figure 2.5. As same as the studies about temporal characteristics of toxic fine particulate matter ($PM_{2.5}$) emissions from a 30-year old municipal solid waste (MSW) dumpsite and ambient air heavy metals in $PM_{2.5}$ in an informal electronic-waste recycling site of China, the result shows the daily average concentrations of $PM_{2.5}$ were found highest at winter and lowest at summer (Peter, Shiva Nagendra, et al., 2018; Zeng et al., 2016).

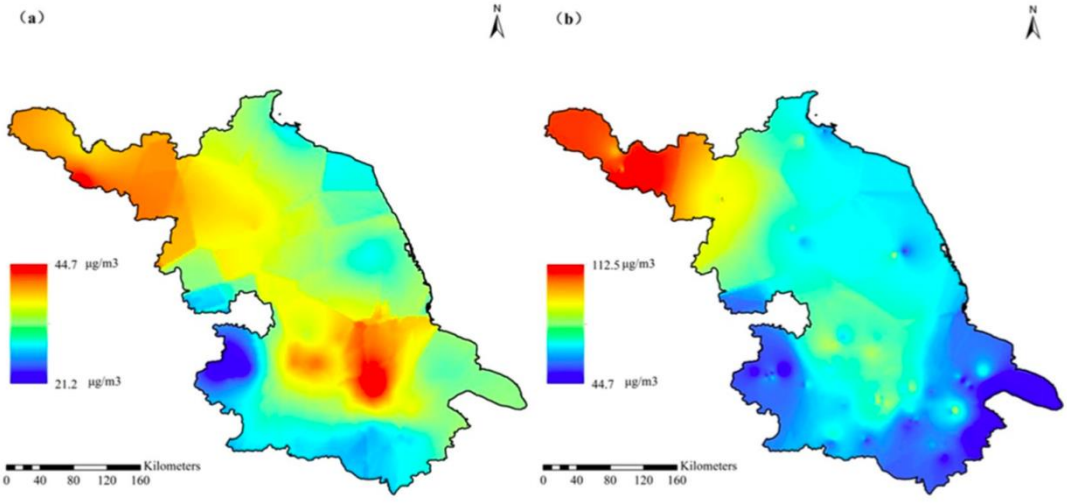


Figure 2.5 Spatial distribution of $PM_{2.5}$ concentration in summer (a) and winter (b) of 2017 for Jiangsu, China (X. Sun et al., 2019)

Wind speed and direction had an influence on $PM_{2.5}$ and heavy metals according to the result of higher $PM_{2.5}$, and heavy metals levels were observed at the old municipal solid waste dumpsite in India when the wind blew from the dumpsite towards the monitoring station. The wind rose plotted over the study area in Figure 2.6 was shown influences of wind speed and direction to PM distribution. Also, the result shows the impact of temperature, humidity, and rainfall on PM and heavy metal concentrations that were higher during winter and lower in summer and monsoon seasons. It might be due to rainfall, as water molecules are small and highly polar, they can attract ten to hundreds of tiny particles and substances (Peter, Shiva Nagendra, et al., 2018).

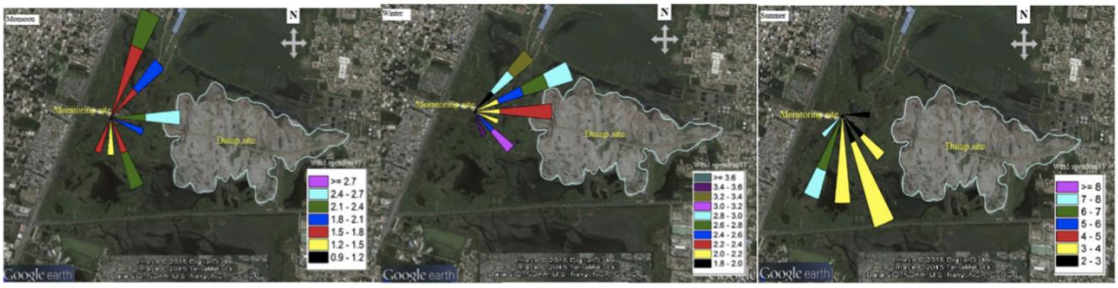


Figure 2.6 The predominant wind directions during the sampling period of monsoon, winter and summer (Peter, Shiva Nagendra, et al., 2018)

However, some studies showed that rainfall affects differently when it comes to different sizes of particles, coarse particles (particles with diameter more than 10: $PM_{>10}$ and $PM_{2.5\text{-}10}$) were scavenged (removal of the particle from the atmosphere) more than fine particles ($PM_{2.5}$) (Feng & Wang, 2012). For water vapor content of the air reported as a percentage of the saturation vapor pressure of water at a given temperature, this is the relative humidity, and it is generally higher during April. More increasing relative humidity (RH) results in the more moisture particles accumulation in the atmosphere. Suspended particulate matters in the air will be adhered to moisture particles and grown enough to deposit to the ground surface. Thus, the dry deposition will occur and reduce PM concentrations in ambient air (Hernandez, Berry, Wallis1, & Poyner1, 2017; Lou et al., 2017). Additionally, the relationship between RH and concentrations of PM will be presented in Figure 2.7.

There are some studies carried out in the urban area for investigating the impact of meteorological characteristic on the PM_{10} and $PM_{2.5}$; the result shows that PM_{10} and $PM_{2.5}$ concentrations are strongly associated with low wind speed (<1 m/s), low air temperature (20-25 °C) and high humidity (80-90%) (Srimiruganandam & Nagendra, 2013). In 2008, the study of the influence of meteorological conditions on PM_{10} concentrations in Kathmandu valley, Nepal was indicated that rainfall, humidity, and wind speed are the most important factors influencing the PM_{10} concentrations (Giri, Krishna Murthy, & Adhikary, 2008).

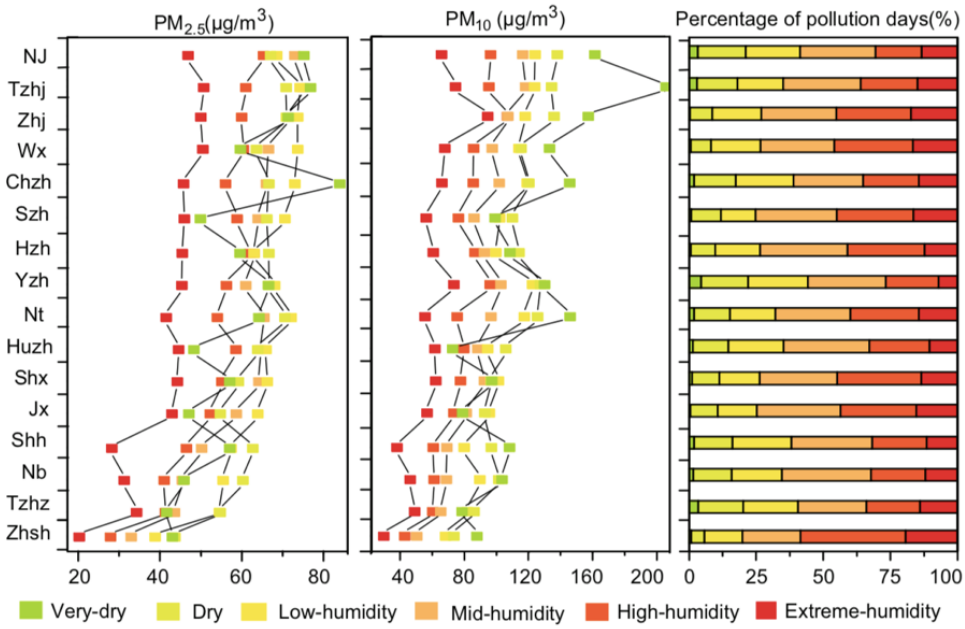


Figure 2.7 Relationship between $PM_{2.5}$ and PM_{10} concentrations and relative humidity (RH) in 16 cities in China (Lou et al., 2017)

Therefore, meteorological data was used to supports distinguish the source of pollutants and to explain the temporal distribution of heavy metals and PM in ambient air. Furthermore, mostly heavy metal and PM concentrations have a negative correlation with temperature, wind speed, relative humidity, and rainfall rate (Papatsara, Somnimirt, & Wanchai, 2019; Peter, Nagendra, & Nambi, 2018; X. Sun et al., 2019).

2.4.3 Topographical factors

The topography is characteristic of a certain land such as plain and plateaus area, a land that has high or low trapped by a warmer air layer above the valley in a certain weather condition, and then pollution levels can build up. The pollutants emitted from the sources on the mountain or at plateaus are more easily disperse than at valleys because the air movement will be blocked by hills, mountains, and buildings. The topography factors with temperature inversion condition for the valley area is shown in Figure 2.8.

For urban areas from the study of Ju Wang, Xin Xie, and Chunsheng Fang, as mentioned in 2.4.1, the result also showed that the concentration of PM in central urban areas was higher than the surrounding area. This indicated that the density of high-rise buildings can influences slower wind speeds and hinder the distribution of PM (Wang et al., 2019). Therefore, if the study area is a plain or plateaus area, the disperse of pollutants from the point source will easily distribution than other areas, and the concentration of PM should lower than an urban area.

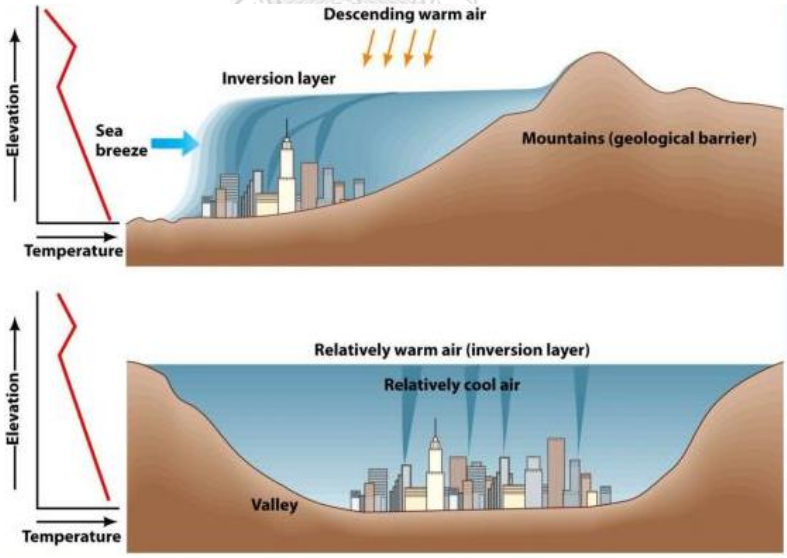


Figure 2.8 Schematic diagram of trapping pollution by topographical factors

2.5 Source identification

The air pollution in a rural area is partially caused by naturals such as forest fire, coal fires, dust storm, spores, pollens, fur, and other sources types of particulate matters. However, the pollution in the rural area is not only from natural activities but also from human activities (anthropogenic sources) as well. The characteristic of this study area in Daengyai and Banpao subdistrict is rural and flat terrain areas. The local people usually do some activities that can be the typical sources of air pollution like burning of wheat and paddy straw or crop residue, which typically occur in May onward, coal cooking, and slight automobile.

PM_{10} and $PM_{2.5}$ are able to be considered as the main pollutants in rural areas. The chemical component of PM is site-dependent, and its variation is different corresponding to emission sources, as shown in Table 2.6. The elements that usually come from the soil are Al, Si, and Fe, while As, Se, Ti are released from coal-burning. The source involving iron and steel industries can emit Mn, Cr, Fe, and Zn. Some previous studies had determined the PM and heavy metals concentration in rural areas, as summarized inTable 2.7. Additionally, the most common found in PM in rural areas were Mn and Zn. Therefore, an investigation of background heavy metals concentration in the study area will support criteria to identify additional sources of heavy metals emission.

From the information on the amount of e-waste gathered in Daengyai subdistrict, Buriram, Thailand, television (CRT), washing machine, and refrigerator were found to be the most quantities in this e-waste community. Heavy metals such As, Cr, Cu, Pb, and Zn were found contaminated in PM that the samples were collected at e-waste dismantling area (Deng et al., 2006; Oguri et al., 2018; Puangprasert & Prueksasit, 2019; Wu et al., 2016; Xue et al., 2012) Consequently, these heavy metals can be identified in particulate matters collected in this area.

Table 2.6 The composition of particulate matter from various emission sources

Emission Sources	Marker Elements
Soil	Al, Si, Sc, Ti, Fe, Sm, Ca
Road dust	Ca, Al, Sc, Si, Ti, Fe, Sm
Sea salt	Na, Cl, Na^{+}, Cl^{-}, Br, I, Mg, Mg^{2+}
Oil burning	V, Ni, Mn, Fe, Cr, As, S, SO_4^{2-}
Coal burning	Al, Sc, Se, Co, As, Ti, Th, S
Iron and steel industries	Mn, Cr, Fe, Zn, W, Rb
Non-ferrous metal industries	Zn, Cu, As, Sb, Pb, Al
Glass industry	Sb, As, Pb
Refuse incineration	K, Zn, Pb, Sb
Biomass burning	K, C_{ele}, C_{org}, Br, Zn
Automobile gasoline	C_{ele}, Br, Ce, La, Pt, SO_4^{2-}, NO_3^{-}
Automobile diesel	C_{org}, C_{ele}, S, SO_4^{2-}, NO_3^{-}
Secondary aerosols	SO_4^{2-}, NO_3^{-}, NH_4^{+}

Source: (johnson, 2011)

C_{ele}: Elemental Carbon

C_{org}: Organic Carbon

* Marker elements are arranged by priority order

Table 2.7 Particulate matters and heavy metals concentration measured in the rural areas from the previous studies

Pollutants ($\mu g/m^3$)	Sampling site				
	Ban Thumhin border patrol police school in Ratchaburi, Thailand (Benjawan Thongriw, 2015)	Echi village in the South of Taiyuan, China (K. Liu et al., 2017)	Rural site Chank in Lahore, Pakistan (Z. A. Nasir, 2015)	Rural site in Molna Northen India (V. Tyagi, Gurjar, Joshi, & Kumar, 2012)	Outdoor PM at Ban Thumhin border patrol police school in Ratchaburi, Thailand (Jampahom, 2016)
PM_{10}	27,220	-	-	283.40	52.00
$PM_{2.5}$	-	149.34	-	-	-
As	-	1.64	-	-	-
Cd	$3.16x10^{-3}$	1.80	35.05	-	-
Cr	$2.47x10^{-2}$	116.17	-	$2.04x10^{-3}$	$3.00x10^{-3}$
Cu	$4.63x10^{-2}$	114.96	0.56	-	$1.00x10^{-2}$
Mn	$7.40x10^{-2}$	165.05	0.98	$8.00x10^{-5}$	$1.90x10^{-2}$
Fe	2.66	-	-	$3.00x10^{-2}$	$5.60x10^{-1}$
Ni	$6.63x10^{-1}$	13.21	151.34	-	$5.80x10^{-2}$
Pb	-	319.64	9.32	-	-
Zn	$7.56x10^{-1}$	301.93	1.36	$7.13x10^{-3}$	$6.6x10^{-2}$

2.6 Enrichment factor

Enrichment factor (EF) is an analysis of source contribution for elements that will be used for e-waste dismantling houses in this study. EF is widely used in heavy metal pollution evaluation and source apportionment. EF was used to calculate for each elemental species based on the usual concentration in the environment using the reference element. The interpretation of EF at the value of 1 or higher will be considered as a significant contribution of elements to the ambient atmosphere from anthropogenic sources. The EF can be calculated using equation (2.1):

$$EF_x = \frac{[C_M/C_N]_{sample}}{[C_M/C_N]_{baseline}} \quad (2.1)$$

where EF_x is the enrichment factor value of element x

C_M is the concentration of the metal in the sample

C_N is the concentration of the normalizer in the sample

C_M is the concentration of the metal in the non-polluted sample

C_N is the concentration of the normalizer in the non-polluted sample

The selection of an appropriate reference element in EF calculation is very important; it should be a stable element, particularly in the ambient air. The elements such as Al, Fe, Mn, and Ti were used as marker species for the reference element source (Pant et al., 2015). Mn in the PM at a remote area of this study will be used as the reference element. Mn is a general component of clay minerals and also the earth's crust. It was considered as an acceptable reference element for EF computation (Deely & Fergusson, 1994; Srithawirat, Talib Latif, & Razman Sulaiman, 2016). If EF value is more than 1, it will be considered that the presented element x in PM is influenced by anthropogenic sources. Moreover, the description of dominance sources that contaminated in PM can be classified as five categories regarding the study of (F. Xu et al., 2015) which assigned based on the enrichment factor including as follow:

$EF \leq 2$, low enrichment

$2 < EF \leq 5$, moderate enrichment

$5 < EF \leq 20$, high enrichment

$20 < EF \leq 40$, very high enrichment

From previous studies, the study of inhalable toxic particulate emissions from an old municipal solid waste dumpsite and neighborhood revealed that the highest enrichment factor (EF > 10) in winter indicating significant contributions from old municipal solid waste dumpsite for As, Cd, Cu, Ni, Pb, Se, and Zn could be found (Peter, Shiva Nagendra, et al., 2018). Whereas the elements such as Ba, Fe, and Mn with lower EF were attributable to crustal sources. From the study on characterization of heavy metals and brominated flame retardants in the indoor and outdoor dust of e-waste workshops, the results show that EFs value for Co and Cr both indoor and outdoor samples were all lower than 1, which indicated a predominant source of crustal than other anthropogenic sources (Qin-TaoLiu et al., 2003). EF values for Ni and Zn in indoor dust were higher than 2, moderate enrichment, and were derived from e-waste recycling activities, while the EF values of Ni and Zn of outdoor samples were lower than 2. For Cu, Pb, and Cd in outdoor samples showed "significant enrichment" with the mean EF values of 11.6, 19.6, and 16.2, respectively. The EFs of Cd were within the grade "very high enrichment" with a mean value 23.0 and Pb and, for Cu and Pb had "extremely high enrichment" with mean EF value 56.5 and 64.8, respectively (F. Xu et al., 2015). Therefore, enrichment factor calculation is help to distinguish the possibility of heavy metals source and segregate between heavy metals given from humans activity or contributed from natural in that environment.

2.7 Principal component analysis

Principal component analysis (PCA) is a statistical procedure to simplify the complexity in high-dimensional data while retaining trends and patterns by transforming the data into fewer dimensions or new significant variables called principal component (PC), and each common factors represent different sources (Lever, Krzywinski, & Altman, 2017). Thus, PCA analysis will be implemented to identify common sources of heavy metals in PM.

The PCA was used to investigate the differenced and similarities of brominated flame retardants (BFRs) and heavy metals profiles in the dust of e-waste workshop (F. Xu et al., 2015). The result shows that the first two principal components explained 66.0 and 22.8 % of the total variability of the metals in indoor,

which means the metals were classified into two clusters. A group of Cu, Pb, and Sb had high loading on PC2, and a group of Co, Cr, Mn, Ni, Zn, and Cd had high loadings on PC1, which similar to the outdoor dust result. This result indicated a common source and behavior of the metals within groups from e-waste recycling activities. A previous study confirmed that the principal component axis could be interpreted as the indicator of pollution or crust (Fujimori et al., 2012). By the plotted of the component scores in Figure 2.9, there are two significant principal components include PC1, which represent the metal pollution group (Zn, Ni, Co, As, and Pb), and PC2 represented the crust-derived group (Mn and Fe). While Ag was noticed at the lowest of PC1 and PC2, indicating that it is not a pollution metal and not derived from crust but will be categorized as an enrichment metal in the study area.

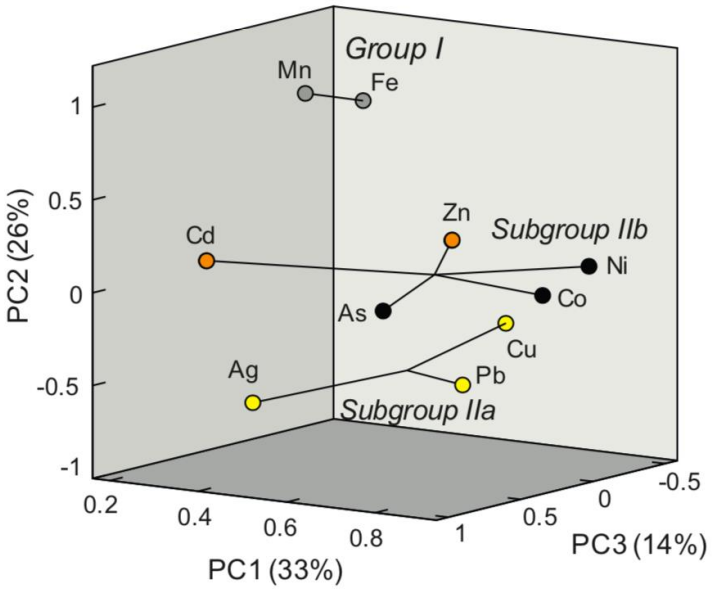


Figure 2.9 Principal component analysis of 10 elements in dust shown as a clustered three-dimensional scatter plot (Fujimori et al., 2012).

The study of heavy metals in indoor dust from e-waste recycling, rural and urban areas in South China had investigated the spatial characteristics of the contaminant sources by using PCA analysis. Cd and Pb showed similar loadings to octa-BDE and deca-BDE found in e-waste of circuit boards and electricity meters, indicating that Cd and Pb were also released from e-waste (He et al., 2017).

Hence, PCA analysis and EF computed both are the process to characterize source identification. If the result of PCA and EF have similar data such as a group of heavy metals, then it can be used to confirm the sources of that pollutant.

CHAPTER III
METHODOLOGY

3.1 Study Area

In this study, seven sampling sites in Banmaichaiyaphot District, Buriram province in the northeast of Thailand, were chosen as a study area, namely Daengyai subdistrict e-waste dismantling house (DY01ES), non-e-waste dismantling house (DY02NS), open dump area (DY03OD) and reference area (DY00RF). For Banpao subdistrict, sampling sites include e-waste dismantling house (BP01ES), non-e-waste dismantling house (BP02NS), open dump area (BP03OD), and the location of all sampling points are shown in Figure 3.10. The selection of the reference area was considered by the area is a non-e-waste dismantling activity and far from the e-waste dismantling site. From a recent survey in 2019, there are 105 registered traders of informal electronic waste dismantling as their work in Daengyai subdistrict and 68 registered traders in Banpao subdistrict, and there is no zoning provided for e-waste dismantling houses separately. Thus, e-waste dismantling houses are still distributed randomly throughout non-e-waste dismantling houses in the village area, and the distance between each site is shown in Table 3.8.

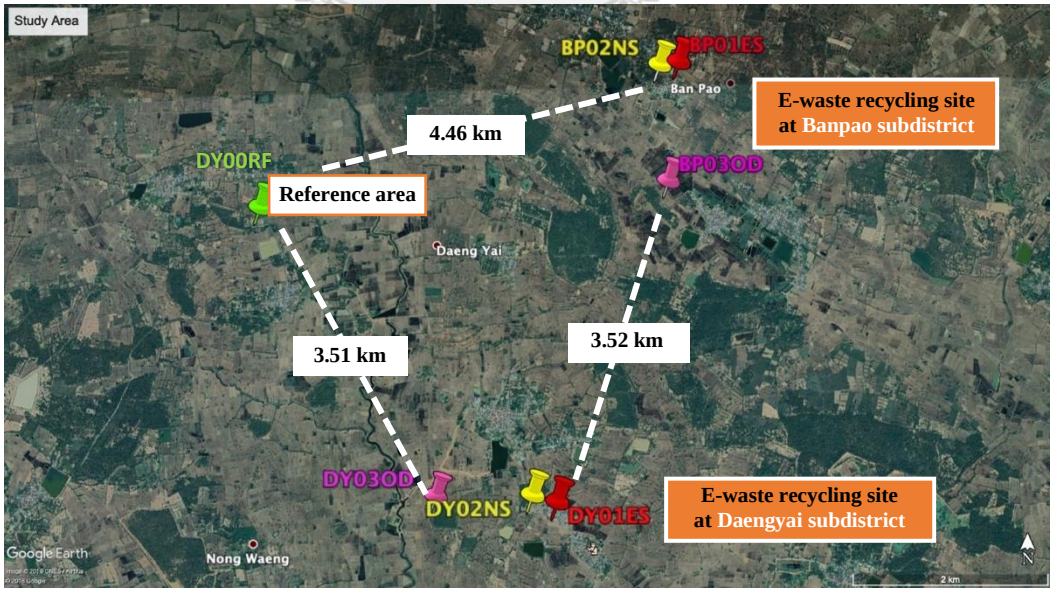


Figure 3.10 Location of the sampling points in Daengyai and Banpao subdistrict, Buriram Province.

Table 3.8 The distance between each sampling sites

Sampling sites	Distance between sampling sites (m)			
	Daengyai		Banpao	
	NS	OD	NS	OD
E-waste dismantling house (ES)	260	1,250	200	1,270
Non-e-waste dismantling house (NS)	-	990		1,240

3.2 Sample Preparation and Collection

3.2.1) Sampling preparation

- Filter preparation

For $PM_{2.5}$, 46.2 mm PTFE filters were immersed in acetone for 10 to 15 minutes and then were placed on a watch glass for 5 minutes. After that, filters were stored in an electronic dehumidification system desiccator at room temperature and humidity below 30% for at least 2 days approximately. For PM_{10}, 8" x 10" quartz fiber filter was kept in desiccator at least 24 hours before weighing.

- Gravimetric analysis

A mass of $PM_{2.5}$ on each filter was measured by a 7 digits Ultra-Microbalance (UMX2, Mettler® Toledo) with 0.001 mg. sensitivity at Department of Environmental Science, Faculty of Science, Chulalongkorn University. Prior to weighing a filter, standard pendulums of 100 and 200 mg were balanced for quality control. Next, a filter was weighed 3 times for calculating the average weight. After most, those pendulums were weighted again. Finally, the weighed $PM_{2.5}$ filter was placed into a filter cassette and sealed with parafilm. For the quantity of PM_{10}, Envi Research and Technology company was provided the measurement using 4 digits microbalance with 0.0001 g. sensitivity. Then PM_{10} filters were kept in a ziplock plastic bag before taking to sampling sites.

3.2.2) Sampling and samples storage

$PM_{2.5}$, $PM_{10,}$ and meteorological data were collected during two periods; summer (April 2019) and rainy (September 2019). At each subdistrict, there are three different sampling points, including non-e-waste dismantling house, e-waste dismantling house, and open dump site. Additionally, a reference sampling point was collected at Wat E San primary school, Daengyai subdustrict, approximately 3.5 km

away from the e-waste dismantling community of Daengyai. The sampling was performed for 7 days consecutively in each, and then there were 98 samples in total. $PM_{2.5}$, PM_{10} sampling was conducted by Envi Research and Technology company.

- $PM_{2.5}$ sampling

For $PM_{2.5}$ collection, a federal reference method (FRM) low volume air sampler was used. The particulates were collected at a flow rate of 16.7 m^3/min for 24 hours (Quality Assurance Guidance Document 2.12 by US-EPA) (U.S. Environmental Protection Agency (US-EPA), 2016). After air samples had been collected, the 46.2 mm PTFE filters were returned to weigh at the laboratory and were conditioned as same as before sampling until taking for further extraction.

- PM_{10} sampling

PM_{10} was collected by using a PM_{10} high volume air sampler, which is a federal reference method (FRM) instrument design. The sampler was operated for 24 hours at a flow rate of 1.13 m^3/min. The air stream passes through a size-selective inlet to separate out the particulate matter larger than 10 micrometers and to ensure that only PM_{10} is deposited onto the 8" x 10" quartz filter paper (Compendium of Methods IO-2.1 for the Determination of Inorganic Compounds in Ambient Air by US-EPA) (U.S. Environmental Protection Agency (US-EPA), 1999a). After sampling, this quartz filter was kept in a plastic ziplock bag and was returned to weigh by Envi Research and Technology company. The filter will be conditioned as same as before sampling and was taken to the laboratory for heavy metals extraction.

- Meteorological data

DAVIS Vantage Pro2 wireless weather station was used to collect meteorological data such as temperature, relative humidity, precipitation, wind speed, and wind direction in summer and rainy seasons. The meteorological measurement device was installed on a telescopic mast and was placed 10 m above the ground at three sampling points, including Daengyai's open dumpsite (DY03OD), Banpao's open dumpsite (BP03OD), and reference area (DY00RF).

3.3) Determination of PM concentrations

After weighing the sample filters, PM_{10} and $PM_{2.5}$ concentrations were calculated using the equations (3.1)-(3.3) as follows:

$$\text{Mass of } PM_{10/2.5}\ (\mu g) = W_{post}(\mu g) - W_{pre}(\mu g) \quad (3.1)$$

$$\text{Air volume } (m^3) = \text{air flow rate } (m^3/\text{min}) \times \text{sampling time (min)} \quad (3.2)$$

$$PM_{10/2.5} \text{ concentration } (\mu g/m^3) = \frac{\text{mass of } PM_{10/2.5}\ (\mu g)}{\text{air volume } (m^3)} \quad (3.3)$$

where W_{post} = Weight of the post sampling filter

W_{pre} = Weight of the pre sampling filter

Mass of $PM_{10/2.5}$ = Mass of PM_{10} or Mass of $PM_{2.5}$

$PM_{10/2.5}$ concentration = PM_{10} concentration or $PM_{2.5}$ concentration

3.4) Determination of heavy metals concentration in PM samples

3.4.1) Recovery test

The recovery percentage was determined for quality control and quality assurance of the laboratory before heavy metals extraction. Standard Reference Material (SRM) is a material which contains the element that traceable to international standard. The analysis of SRM is the method to determine the accuracy of the digestion method by reporting in %recovery. SRM (1648a-Urban Particulate Matter) was digested with the same method of PM_{10} and $PM_{2.5}$ extraction. Then, extracted heavy metal from SRM was analyzed by inductively coupled plasma mass spectrometry (ICP-MS) that has readability of detection limit at 0.1 ppt (ng/L). Lastly, the result of heavy metal concentrations was compared with the certified concentration of SRM. The percentage recovery of each element was calculated using the equation (3.4). The accepted percentage recovery was ranged between 80 – 120%.

$$\%\text{Recovery} = \frac{C_E - C_B}{C_{SRM}} \times 100\% \quad (3.4)$$

where C_E = Concentrations of heavy metal retrieved from SRM extraction (mg/kg)

C_B = Concentrations of heavy metal in blank extracted solution (mg/kg)

C_{SRM} = Certified concentration of heavy metal in SRM, (mg/kg)

3.4.2) Analysis of heavy metals concentration in PM

- Limit of detection (LOD) and Limit of quantification (LOQ)

The lowest concentration that can be determined to be statically different from a blank is the limit of detection (LOD). Limit of quantification (LOQ) is the concentration, which quantitative results may be obtained (U.S. Environmental Protection Agency (US-EPA), 2000). First, Limits of detection (LOD) and Limit of quantification (LOQ) were obtained by measuring the signal of the blank solution for all 10 times via ICP-MS. Then, the standard deviation of the measured data was calculated by using the following equation (3.5) and (3.6):

$$\text{LOD} = 3 \times \text{standard deviation} \quad (3.5)$$

$$\text{LOQ} = 10 \times \text{standard deviation} \quad (3.6)$$

- Relative standard deviation (%RSD)

The accuracy of ICP-MS was examined through the calculation of relative standard deviation percentage (%RSD), as shown in equation 3.7. Typically, a considered acceptable value of %RSD is 0 ± 5% for a given sample set using ICP-MS (Jost Chemical, 2016).

$$\%\text{RSD} = \frac{\text{SD}}{\text{X}} \times 100 \quad (3.7)$$

where SD = Standard deviation

X = Mean of the blank solution measured for 10 times replicating

- Heavy metals extractions

The flow chart of the overall extraction method is shown in Figure 3.11. For heavy metal contaminated in $PM_{2.5}$ extraction, the filter samples were digested in a microwave digester (CEM MARS-5). Sample preparation and extraction were performed following the method of "Microwave Digestion of Airborne Particulate Matter Collected on Filters Using CEM MARS-5" provided by Environmental Canada. The 10 mL of extraction solution (40% HNO_3) was added into the filter and let them stay for at least 30 min before digestion (step I: 600 W at 165℃ for 11 min, step II: 1,200 W at 175℃ for 20 min and cool down around 30 min). Next, the extracted solution was transferred to a PTFE beaker and evaporated to 1 mL. The solution was filtered through a 0.45 µm PTFE syringe filter, then was adjusted the volume to 10 mL in a volumetric flask by Milli-Q water. In each round of digestion, a blank extracted solution was prepared by using a blank filter sample and blank acid (40%HNO_3) with the same extraction method. Finally, the solution was stored in a polyethylene bottle before further analysis by inductively coupled plasma mass spectrometry (ICP-MS) (Environment Canada, 2013).

For heavy metals contaminated in $PM_{10,}$ microwave digester (CEM MARS-5) was used for the extraction. Sample preparation and extraction were performed following the methods for the determination of inorganic compounds in ambient air by USEPA (microwave extraction procedure: USEPA-Method IO-3.1 1999). The 8" x 10" Quartz filter was cut into 1" x 8" strip using a paper cutter board. Prior to cut each sample filter, plastic film was wrapped on a board surface to prevent contamination. Also, a cutting blade was wiped with a clean dry Kimwipe® to prevent sample cross-contamination. Three of 1" x 8" strips per one sample were taken to extract. Next, 10 mL extraction solution (5.55% HNO_3/16.75% HCl) was added into the filter and let them stay for at least 30 min before digestion (step I: 1200 W at 175℃ for 17.5 min, step II: 1,200 W at 185℃ for 13 min and cool down around 30 min). The extracted solution was filtered through a 0.45 µm PTFE syringe filter and was adjusted the volume to 25 mL in a volumetric flask by Milli-Q water. In each round of digestion, the blank extracted solution was prepared by using a blank filter sample and blank acid (5.55% HNO_3/16.75% HCl) with the same extraction method. When extraction

was completed, the solution was stored in a polyethylene bottle before further analysis by Inductively coupled plasma optical emission spectrometry (ICP-MS) (U.S. Environmental Protection Agency (US-EPA), 1999b).

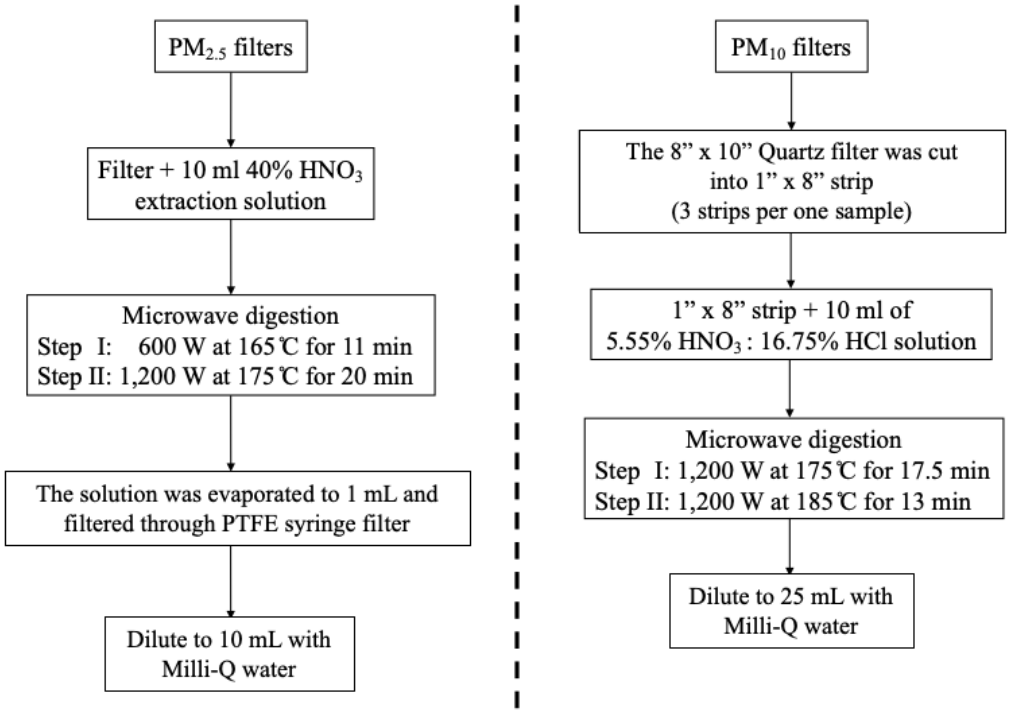


Figure 3.11 Digestion procedure of $PM_{2.5}$ and PM_{10} samples

- Determination of heavy metal concentrations

All extracted samples were analyzed by ICP-MS. First, a standard calibration curve was be prepared in different concentrations (5 to 1000 μg/L) of the mixed standard heavy metal solution including As, Cd, Cr, Cu, Mn, Ni, Pb, Zn, and Fe. Then, the concentration of heavy metal was reported in ppb (μg/L). Afterward, heavy metal concentrations in $PM_{2.5}$ and PM_{10} were calculated using the following equations:

$$\text{Mass of heavy metal (μg)} = \text{heavy metal concentration (μg/mL)} \times \text{sample solution volume (mL)} \quad (3.8)$$

$$\text{Concentration of heavy metal in the air}(\mu g/m^3) = \frac{\text{mass of heavy metal}(\mu g)}{\text{air volume } (m^3)} \quad (3.9)$$

$$\text{Heavy metal content in } PM_{10/2.5}\ (mg/g) = \frac{\text{mass of heavy metal (mg)}}{\text{mass of } PM_{10/2.5}\ (g)} \quad (3.10)$$

where Heavy metal content in $PM_{10/2.5}$ = Heavy metal content in PM_{10} or Heavy metal content in $PM_{2.5}$

Mass of $PM_{10/2.5}$ = Mass of PM_{10} or Mass of $PM_{2.5}$

3.5 Data analysis

Statistical analysis of the data was performed using the SPSS program (version 22). The following statistical analysis used in this study are as follows:

3.5.1 Descriptive statistics

Analysis of the distribution of general data such as mean and standard deviation.

3.5.2 Analytical statistics

(1) Analysis of the mean difference in concentrations of heavy metals, PM_{10} and $PM_{2.5}$ between non- and e-waste dismantling houses and between sampling period using the t-test method

(2) Analysis of the different concentrations of heavy metals, PM_{10} and $PM_{2.5}$ at all sampling sites by One Way ANOVA analysis

(3) Pearson's correlation and multiple regression were applied to investigate the correlation between meteorological factors and the distribution of heavy metals in PM_{10} and $PM_{2.5}$

(4) Principal Components Analysis (PCA) analysis was used to define the group of heavy metals and indicate their sources by minimize the dimensionality of large data sets of variables and transforming into a smaller number of latent factors that still contain most of the information in the original data sets.

3.6 Sources identification

The relative main sources of dust or heavy metals and anthropogenic sources for each element in aerosol was determined by calculating enrichment factors and interpreted together with principal component analysis**.**

Enrichment factor (EF) was used to assess the contamination of the heavy metals in particulate matters. The EF of heavy metals was base on the standardization of measuring elements against a reference element, as expressed in equation 3.11. Mn in the PM at a remote area of this study was used as the reference element. EF values are indicated the similarity of the elements, especially in the particulate matter, which is originated from the natural environment or remote area far from human communities and anthropogenic sources.

$$EF_x = \frac{[C_x/C_{ref}]_{dust}}{[B_x/B_{ref}]_{background}} \quad (3.11)$$

where EF_x is the enrichment factor value of element x

C_x is the concentration of the element of interest

C_{ref} is the concentration of the reference element for normalization

B_x is the concentration of the element in the PM at the remote area

B_{ref} is the concentration of the reference element used for normalization in the PM at the remote area

If EF value is more than 1, it was considered that the presented element x in PM is influenced by anthropogenic sources, especially e-waste dismantling activities. Moreover, the description of dominance sources that contaminant in PM was used as five contamination categories by Xu et al. (2015) which assigned based on the enrichment factor including as follow:

EF ≤ 2, low enrichment

2 < EF ≤ 5, moderate enrichment

5 < EF ≤ 20, high enrichment

20 < EF ≤ 40, very high enrichment

According to the objectives of this study, to characterize the spatial and temporal distribution and identify sources of heavy metals in PM_{10} and $PM_{2.5}$. The methodology, as mentioned above, was provided to achieve the research objectives. Thus, a summary flow chart of all methodology from air sampling & meteorological observations to data analysis can be shown in Figure 3.12.

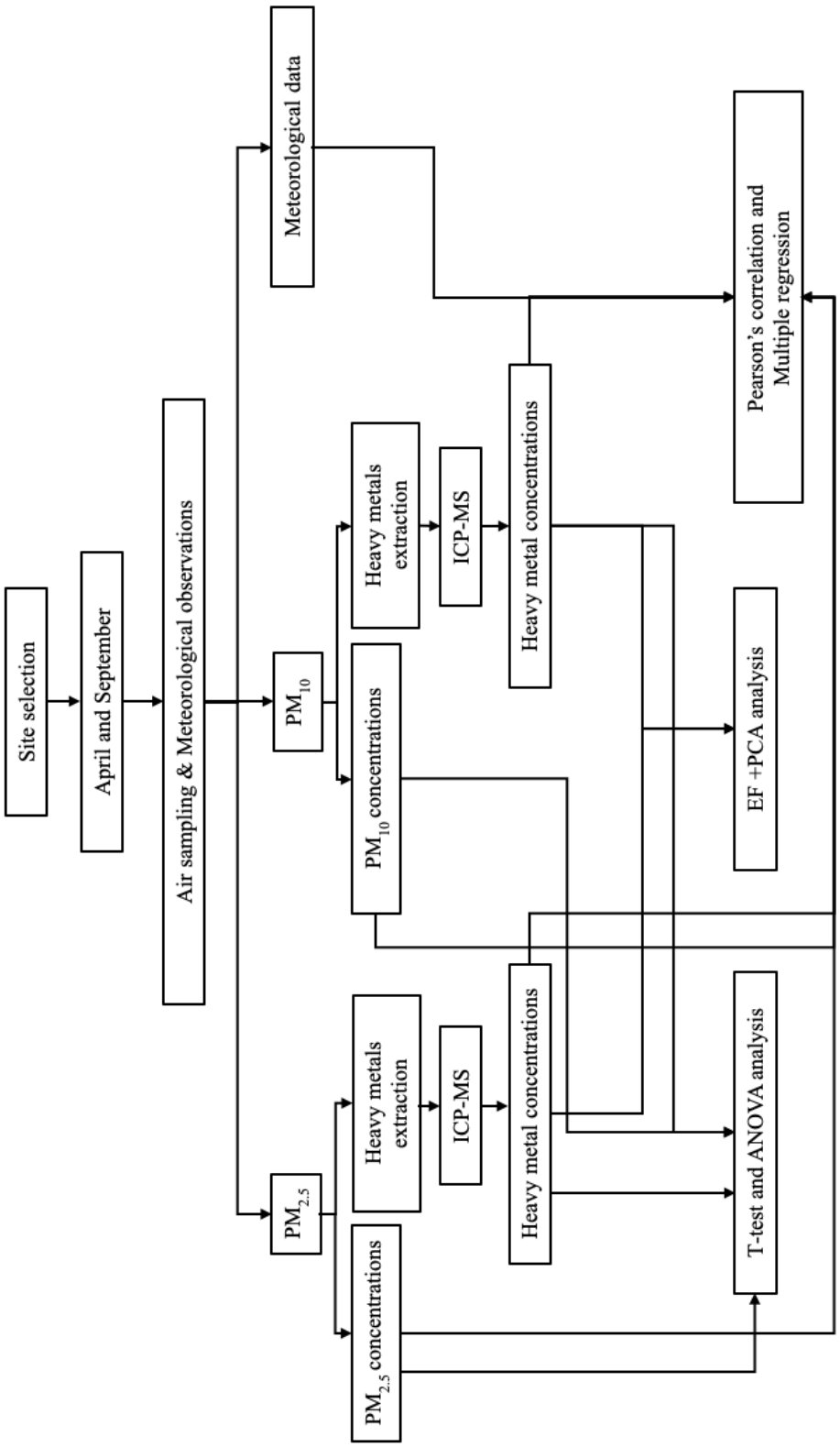


Figure 3.12 Summary of heavy metal concentrations in $PM_{2.5}$ and PM_{10} analysis

CHAPTER IV
RESULTS AND DISCUSSIONS

4.1 PM concentrations

$PM_{2.5}$ and PM_{10} concentrations in the ambient air at e-waste dismantling communities, Banmaichaiyaphot and Phutthaisong District, Buriram province were investigated. E-waste dismantling house and the surrounding area, including non-e-waste dismantling, open dumping area in Daengyai and Banpao Subdistrict, and reference area in Daengyai, Buriram province, were selected as sampling sites. The collection of PM had been performed for 24 hours at each sampling site for 7 days consecutively during summer (28 April - 4 May 2019) and rainy (25 September - 2 October 2019). However, the precipitation in September did not occur, so the sampling times were described as of April and September instead. All PM concentration results were summarized and explained as follows.

4.1.1 Comparison of $PM_{2.5}$ and PM_{10} concentration between all sampling sites of each sampling period

Particulate matter concentrations in ambient air were examined at four different sampling sites, including e-waste dismantling house, non-e-waste dismantling house, open dump area, and reference area. The results of 24-hours average $PM_{2.5}$ and PM_{10} concentrations in ambient air at e-waste dismantling, non-e-waste dismantling, open dump area, and reference area are shown in Table 4.9.

For $PM_{2.5}$ concentrations in April at e-waste dismantling, non-e-waste dismantling, open dump, and reference area were 17.4 ±3.3, 17.8 ±4.3, 20.4 ±6.0, and 16.0 ±4.2 $\mu g/m^3$, respectively (the concentrations of $PM_{2.5}$ in April is presented in appendix A-1). From this result, $PM_{2.5}$ level at open dump area was highest and followed by those of non-e-waste dismantling house, e-waste dismantling house, which has slightly different in concentration, and reference area as the lowest level. When it comes to September, $PM_{2.5}$ at those sampling sites were 42.0 ±9.3, 49.5 ±13.7, 41.0 ±10.8 and 36.7 ±8.4 $\mu g/m^3$, respectively (the concentrations of $PM_{2.5}$ in September is shown in appendix A-2). Not the same as April, non-e-waste

dismantling house was the highest $PM_{2.5}$ level in September instead and followed by e-waste dismantling house, open dump area, and reference area, respectively.

Table 4.9 Summary of average PM concentrations of e-waste, non-e-waste dismantling and reference area

Sample sites	Sampling period	PM concentrations (mean ±SD) (μg/m³)					
		$PM_{2.5}$	$PM_{2.5}$ standard		PM_{10}	PM_{10} standard	
			Thailand	WHO		Thailand	WHO
E-waste dismantling	April	17.4 ±3.3[a]	50	25	38.6 ±6.9[a]	120	50
	September	42.0 ±9.3[b]			60.6 ±18.5[b]		
	Mean	29.7 ±14.3			49.6 ±17.7		
Non-e-waste dismantling	April	17.8 ±4.3[a]			46.4 ±14.8[a]		
	September	49.5 ±13.7[b]			64.3 ±15.6[b]		
	Mean	33.8 ±18.9			55.4 ±17.5		
Open dump area	April	20.4 ±6.0[a]			49.8 ±12.9[a]		
	September	41.0 ±10.8 [b]			65.4 ±18.4[b]		
	Mean	30.7 ±13.5			57.6 ±17.5		
Reference area	April	16.0 ±4.2[a]			27.3 ±3.3[a]		
	September	36.7 ±8.4[b]			48.7 ±11.2[b]		
	Mean	26.3 ±12.5			38.0 ±13.7		

Remark: [a],[b] If the right superscripts were different alphabets, it means PM concentrations between April and September s were statistically significant differences.

Sources: (Pollution Control Department (PCD), 2010; World Health Organization (WHO), 2006)

The higher $PM_{2.5}$ level at the open dump in April might be due to the burning activities, which was one of the e-waste dismantling processes. E-waste, such as wires, plastics, foam, and CRT screens was discarded, and all compiled at an open dumping area. A compile of electric wires was burned for collecting copper, and this activity could have an impact on $PM_{2.5}$ distribution in the open dump area. As same as the result from the study of respirable particulate matter among workers in relation to their e-waste open burning activities in Buriram Province, Thailand, which had found a higher range of $PM_{2.5}$ concentration than $PM_{2.5-10}$ that were collected from directly e-waste burning activities (Bungadaeng, Prueksasit, & Siriwong, 2019). This could imply the influences of e-waste components burning activities, which have contributed to PM levels in this study area. However, the higher $PM_{2.5}$ concentration

at non-e-waste dismantling house was also observed; this might due to other activities such as cooking by using charcoal as a fuel and burning some fallen leaves which both had been done in open area that could lead to a greater level of $PM_{2.5}$. There is a study reported about $PM_{2.5}$ and PM_{10} concentration could be raised when cooking charcoal briquettes were heated with higher temperatures (H.-L. Huang, Lee, & Wu, 2016). These indoor activities could indicate the higher PM levels at non-e-waste dismantling house, and in addition, there might be some PM dispersing from e-waste dismantling house located nearby as well. Comparing with the air quality standard, $PM_{2.5}$ concentrations in September s were found to exceed the ambient air guideline by WHO (25 $\mu g/m^3$) at all sampling sites but not exceeded the standard concentration of $PM_{2.5}$ (24 hours) in Thailand (50 $\mu g/m^3$) (Pollution Control Department (PCD), 2010; World Health Organization (WHO), 2006).

For PM_{10} levels in April, the results showed the highest concentrations at open dump area followed by non-e-waste dismantling, e-waste dismantling, and reference area (49.8 ±12.9, 46.4 ±14.8, 38.6 ±6.9, and 27.3 ±3.3 $\mu g/m^3$, respectively). Similarly, PM_{10} level at the open dump area in September was the highest level but slightly higher than non-e-waste dismantling house and then followed by e-waste dismantling house and reference area (65.4 ±18.4, 64.3 ±15.6, 60.6 ±18.5, and 48.7 ±11.2 $\mu g/m^3$, respectively). Both PM_{10} concentrations in April and September were highest at the open dump area, which could indicate the influence of burning activities in this area. Moreover, there also had charcoal furnace with craft clay locating nearby the sampling station that could lead the higher contribution of PM in the open dump area as well. The report of PM_{10} concentration at illegal e-waste burning in Moradabad city, India was also shown similar result that the highest level of 24-h average PM_{10} was found at e-waste burning site (243.310 ±22.729 $\mu g/m^3$) when compared with residence area (193.187 ±17.020 $\mu g/m^3$) (Gangwar et al., 2019). Additionally, only PM_{10} levels at non-e-waste dismantling house and open dumpsite in September that was exceeded the guideline by WHO (50 $\mu g/m^3$) but not exceed the standard concentration in Thailand (120 $\mu g/m^3$) (Pollution Control Department (PCD), 2010; World Health Organization (WHO), 2006).

According to PM concentrations in Table 4.9, there were higher concentrations in September at all sampling sites (e-waste dismantling house, non-e-waste dismantling

house, open dump area, and reference area). When the amount of $PM_{2.5}$ and PM_{10} data were applied for statistical analysis of the T-test, there were significant differences at 95% confidence level for both PM concentrations between April and September at all sampling sites. The rising of $PM_{2.5}$ and PM_{10} levels in September could possibly cause by other activities more than e-waste dismantling in the study area such as other anthropogenic sources such as forest fire, agricultural waste burning, and there still has some people smuggled burning the sugarcane fields, the stubble of rice, weeds and some leaf waste in the surrounding area. These anthropogenic sources and also the e-waste dismantling activities within the sampling area could lead to an elevation of PM in September.

The differences of PM concentrations between e-waste dismantling house, non-e-waste dismantling house, open dump area, and reference area at each sampling period were examined using One-way ANOVA. The results showed a significant difference ($p<0.05$) only between the $PM_{2.5}$ level at the open dump area and the references area in April (One-way ANOVA results of $PM_{2.5}$ are shown in Appendix C-1). While in September, $PM_{2.5}$ levels were found a significant difference between non-e-waste dismantling house and open dump area, and between non-e-waste dismantling house and reference area. For PM_{10} concentrations in April, it showed a statistically significant difference in e-waste dismantling house with open dump area and reference area (One-way ANOVA results of PM_{10} are shown in Appendix C-2). For non-e-waste dismantling house, the result showed significantly different from the reference area. The concentration of PM_{10} at the open dump area also showed a significant difference from the reference area. However, there was a significant difference only between the open dump area and reference area in September. From these results, it could summarize that the PM levels at non-e-waste dismantling house and open dump area were significant differences from those at e-waste dismantling house and reference area in both April and September. For the differences in open dump area with other areas, it might be due to the activities in this area, which was not only an area for dumping municipal waste but also unwanted e-waste compartments (refrigerator foams, LCD, and CRT monitors). Additionally, the open dump area in this community has been used for open burning of inseparable e-waste parts such as wires and small residues appliances to separate precious metals and to

sell to waste transfer dealer or a recycling plant (Bungadaeng et al., 2019; Thongkaow et al., 2017b).

The statistical analysis result could support that PM levels at non-e-waste dismantling house and open dump area were the two of the highest concentration in both sampling period. Also, $PM_{2.5}$ and PM_{10} concentrations at the reference area were significantly different compared with other sampling sites (e-waste dismantling house, non-e-waste dismantling house, and open dump area) especially the PM_{10} result. This could indicate that there was no influence from e-waste dismantling activities on PM levels at the reference area, which is far away and also has none of e-waste dismantling activities. While, levels of PM in e-waste dismantling house, non-e-waste dismantling house, and open dump area might have influenced from the e-waste dismantling activities at could disperse within their e-waste community.

The average $PM_{2.5}$ of both sampling period at e-waste dismantling house, non-e-waste dismantling house, open dump area, and reference area were 29.7 ±14.3, 33.8 ±18.8, 30.7 ±13.5, and 26.3 ±12.5 $\mu g/m^3$, respectively. Also, PM_{10} concentrations at those sampling sites were 49.6 ±17.7, 55.4 ±17.5, 57.6 ±17.5, and 38.0 ±13.7 $\mu g/m^3$, respectively. The mean concentration of PM_{10} at open dump area showed the highest level and were about 1.2 and 1.1 times higher than those of e-waste dismantling house and non-e-waste dismantling house, whereas only PM_{10} at reference area was statistically different ($p>0.05$) from those observed at e-waste, non-e-waste dismantling, and open dump area. While the highest concentration of $PM_{2.5}$ was detected at non-e-waste dismantling house, but there was no statistically significant difference between all sampling sites. The similarity of PM levels at each sampling point might occur due to the topography of this study area that was plain in rural habitation, so the distribution of PM could be greater than other areas such as located in a valley or surrounded by hills.

From some previous studies, there was an investigation of PM concentrations around the CRT recycling factory, and the average of $PM_{2.5}$ (256.6-290.8 $\mu g/m^3$) and PM_{10} (326.3-394.5 $\mu g/m^3$) were 8 times higher than the highest concentration of $PM_{2.5}$ and PM_{10} levels in this study (Wenxiong Fang, Yichen Yang, & Zhenming Xu, 2013). PM_{10} levels at the open burning site also lower than the average PM_{10} (200 ±3.05 and 195 ±5.50 $\mu g/m^3$) that was collected at the e-waste burning site in

Moradabad, India, about 5 and 3 times in April and monsoon, respectively (Gangwar et al., 2016a). Additionally, the result studied by Xue et al. (2012) was similar to this study, in which PM_{10} distribution in a typical (PCBs) manufacturing workshop was higher than the level observed in the off-site area (Xue et al., 2012). Thus, e-waste dismantling, as well as burning activities, could influence the distribution of $PM_{2.5}$ and PM_{10} to the ambient air around this study area.

4.1.2 Relationship of PM concentrations between the sampling sites in e-waste dismantling community

To investigate whether the dispersion of the PMs emitted from major sources could affect its presence at the surrounding area, the correlation of PMs between sampling sites was determined. The relationship of $PM_{2.5}$ and PM_{10} between sampling sites in the e-waste dismantling community consisting of e-waste dismantling house (ES), non-e-waste dismantling house (NS), open dump area (OD), and reference area (RF) in both April and September are shown in Figure 4.13 for $PM_{2.5}$ and Figure 4.14 for $PM_{10.}$ For the relationship of $PM_{2.5}$, the graph in Figure 4.13 shows higher $PM_{2.5}$ concentrations in April at open dumpsite at Daengyai (DY03OD) and Banpao (BP03OD) than other areas. The $PM_{2.5}$ at non-e-waste dismantling in Banpao (BP02NS) was inferior next to the dump site, while those in Daengyai (DY02NS) was similar to e-waste dismantling house. And only e-waste dismantling at Banpao that $PM_{2.5}$ was seen lower than other areas. In September, the same graph was found that $PM_{2.5}$ concentrations highest at NS of both Daengyai and Banpao, whereas ES and OD had shown a similar trend.

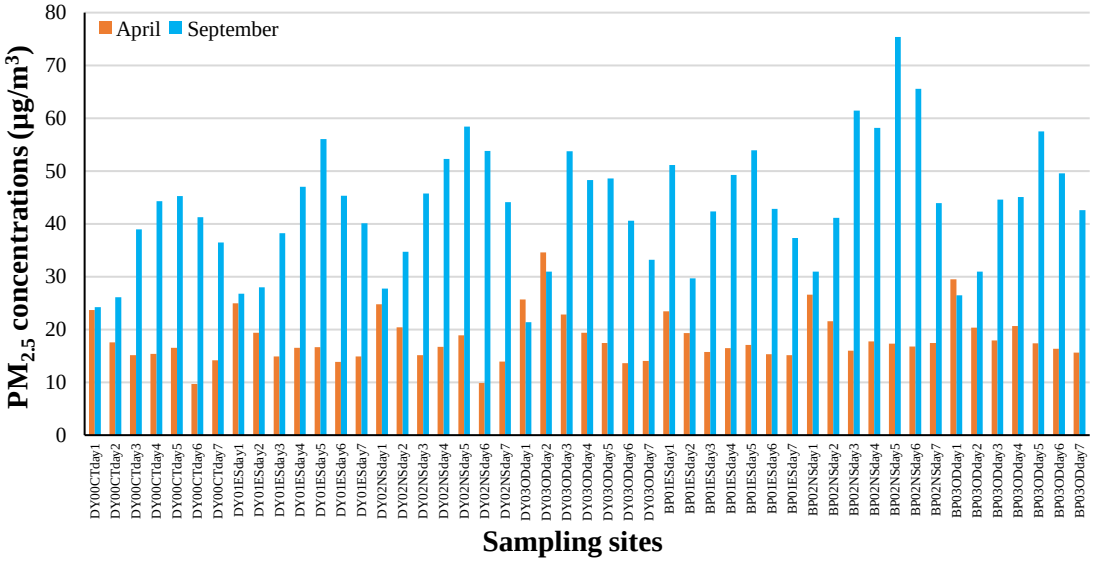


Figure 4.13 Comparison of $PM_{2.5}$ concentration between April and September.

For PM_{10}, the graph shows higher PM_{10} concentrations in April at OD both at Daengyai and Banpao than other areas, as shown in Figure 4.14. PM_{10} levels at NS in Banpao was inferior next to the OD but still higher than ES, while those in Daengyai was similar to ES. The PM_{10} levels in September, as shown in the same graph, were found that PM_{10} concentrations were highest at ES in Daengyai, but in Banpao has the highest at OD. Moreover, the levels of PM_{10} at NS and OD at Daengyai were similar, whereas NS in Banpao was higher than ES. From this result of $PM_{2.5}$ and PM_{10} could imply that in April has the highest PMs concentration at OD while NS and ES were a similar trend.

Furthermore, in September, PM_{10} also has the highest levels at OD, which was similar to PM_{10} and $PM_{2.5}$ in April. However, only the level of $PM_{2.5}$ was found highest at NS. It means there might be some other activities that could impact the contribution of $PM_{2.5}$ at NS in September.

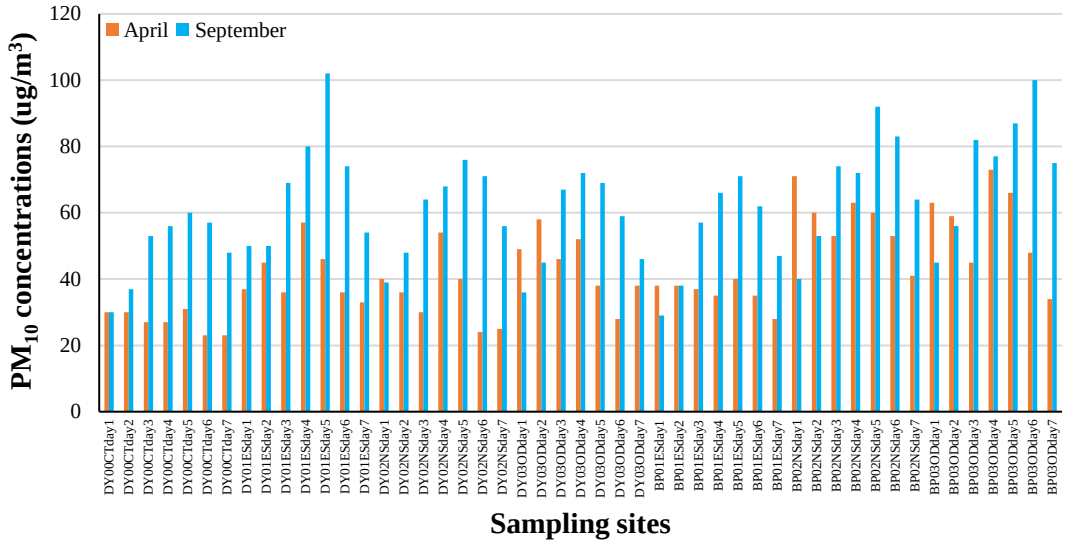


Figure 4.14 Comparison of PM_{10} concentration between April and September.

Next, the relationship of $PM_{2.5}$ and PM_{10} between ES (DY01ES and BP01ES), OD (DY03OD and BP03OD) compared with NS (DY02NS and BP02NS) and RF were examined by Pearson's correlation analysis. As in Table 4.10, Pearson's correlation of $PM_{2.5}$ measured in April gave high significant correlation at 99% confidence level between DY01ES and DY02NS (r = 0.923), BP02NS (r = 0976), and RF (r = 0.940). A similar trend was found at BP; the r-values of BP01ES with DY02NS, BP02NS, and RF were 0.904, 0.973, and 0911. The correlation between BP03OD also had strong significant correlation with BP02NS (r = 0.943) and RF (r = 0.880) and had inferior coefficient value with DY02NS (r = 0.832). However, at DY03OD has no significant correlation with NS and RF area. For September, the relationship of DY01ES with DY02NS has strong correlation (r = 0.968) along with RF (r = 0.952) and BP02NS (r = 0.897). While BP01ES has a nonsignificant correlation with those areas. However, BP03OD shows strong correlation at 99% confidence with DY02NS (r = 0.977), BP02NS (r = 0.951), and RF (r = 0.946). Meanwhile, DY03OD shows significant correlation at 95% with DY02NS (r = 0.806), BP02NS (r = 0.867), and RF (r = 0.854).

Table 4.10 Pearson correlation coefficient values of $PM_{2.5}$ and PM_{10} analyzed between e-waste dismantling, open dump with non-e-waste and reference area

Sampling sites		$PM_{2.5}$			PM_{10}		
		DY02NS	BP02NS	RF	DY02NS	BP02NS	RF
April	DY01ES	0.923**	0.976**	0.940**	0.892**	0.490	0.426
	BP01ES	0.904**	0.973**	0.911**	0.408	0.762*	0.834*
	DY03OD	0.689	0.640	0.613	0.608	0.510	0.601
	BP03OD	0.832*	0.943**	0.880**	0.908**	0.864**	0.708
September	DY01ES	0.968**	0.897**	0.952**	0.895**	0.884**	0.844**
	BP01ES	0.342	0.370	0.418	0.989**	0.956**	0.981**
	DY03OD	0.806*	0.867*	0.854*	0.901**	0.842**	0.987**
	BP03OD	0.977**	0.951**	0.946**	0.923**	0.930**	0.934**

** means the correlation is significant at the 0.01 level (99% confidence level).
* means the correlation is significant at the 0.05 level (95% confidence level).

For Pearson's correlation of PM_{10} results, there was only a highly significant correlation at 99% confidence level between DY01ES and DY02NS (r = 0.892). For high correlation at 99% confidence level, it was also found when compared BP03OD with DY02NS (r = 0.908) and between BP03OD and BP02NS. There also shows significant correlation at 95% confidence level when compared BP01ES with BP02NS (r = 0.762) and RF (r = 0.834). Even so, there was no significant correlation between DY03OD and other areas (NS and RF). In September, the relationship of PM_{10} at ES and OD with NS and RF had found a strong significant correlation at 99% confidence level. At DY01ES, the correlations with DY02NS, BP02NS, and RF were 0.895, 0.884, and 0.844, respectively. For BP01ES, the correlation with those sites were 0.989, 0.956, and 0.981, respectively. The correlation at DY03OD with those sites were 0.901, 0.842, and 0.987, respectively. Lastly, the correlations of BP03OD with DY02NS, BP02NS, and RF were 0.923, 0.930, and 0.934, respectively.

Pearson's correlation of $PM_{2.5}$ results could be summarized that the e-waste dismantling house has a better correlation with those non-e-waste dismantling house and reference areas in April, while the open dump area has more strong correlation with those areas in September. For correlation results of PM_{10} in September, it could indicate that both ES and OD at Dangeyai and Banpao were the significant contribution of PM_{10} to NS and RF. Nevertheless, OD at Banpao in April, along with ES at Daengyai, was the main part to support the similar trend of PM_{10} with NS and

RF. However, if compared correlation of $PM_{2.5}$ and PM_{10} results in April, $PM_{2.5}$ were found the correlations of ES with NS and RF, and OD with RF, while PM_{10} showed the correlation to that of RF only at BP01ES.

This could signify the more distribution of $PM_{2.5}$ than PM_{10} due to their long-lived property in ambient and disperse to hundreds of miles. Whilst, PM_{10} which had bigger particulate matter size so it could easily be deposited on to the ground in the short of time (Public Lab, 2017; United States Environmental Protection Agency (US-EPA), 2018; L. Wang, Liu, Sun, Ji, & Wang, 2015). There was a previous study about PM_{10} concentrations at the e-waste dismantling house in Dangeyai subdistrict; the result was also showed a good correlation (r = 0.825) between indoor and outdoor (Prueksasit, Chanthahong, & Kanghae, 2020). This result has implied that e-waste activities could enhance PMs concentrations in nearby areas and caused a similar trend to other areas as well.

PM concentration measured at the e-waste dismantling (EW), non-e-waste dismantling (NS), and open dump area (OD) was taken to compare with that of reference area (RF), as the ratios of the concentration given in Table 4.11. The average of EW/RF ratios were 1.14 and 1.33 for $PM_{2.5}$ and PM_{10}, respectively. For those of NS/RF ratios were 1.24 and 1.51, and for OD/RF ratios were 1.20 and 1.58. All the ratio which were higher than one indicated that the areas involving e-waste dismantling activity, including e-waste dismantling houses, non-e-waste dismantling houses, and open dump site could probably influence the higher contribution of $PM_{2.5}$ and PM_{10} levels in this e-waste communities. Nonetheless, correlation results of both $PM_{2.5}$ and PM_{10} in this study could indicate that activities related to e-waste dismantling have an influence on the contribution of PMs levels to their nearby areas.

Table 4.11 Ratios of the PM concentration at e-waste, non-e-waste dismantling, and open dump area compared with the reference area

Ratios	$PM_{2.5}$			PM_{10}		
	April	September	Average	April	September	Average
EW/RF	1.11	1.17	1.14	1.42	1.24	1.33
NS/RF	1.14	1.35	1.25	1.7	1.32	1.51
OD/RF	1.29	1.11	1.20	1.82	1.34	1.58

EW = E-waste dismantling house, NS = Non-e-waste dismantling house
OD = Open dump area, RF = Reference area

In addition, the relationship of PM levels at each sampling point was also investigated. $PM_{2.5}$ and PM_{10} ratios were calculated, as presented in Table 4.12, in order to characterize the spatial distribution of PM in this e-waste dismantling community. The result showed that the proportion of $PM_{2.5}$ and PM_{10} in April were 0.46, 0.41, 0.42, and 0.58 at e-waste dismantling house, non-e-waste dismantling house, open dump area, and reference area, respectively. These proportions were also comparable with the $PM_{2.5}/PM_{10}$ ratio of resident site, traffic site, and industrial site in April at Beijing, which was the range from 0.45 to 0.48 (Y. Sun et al., 2004). For September, $PM_{2.5}$ and PM_{10} ratio at e-waste dismantling house, non-e-waste dismantling house, open dump area, and reference area were 0.74, 0.77, 0.63 and 0.75, respectively. Evidently, higher $PM_{2.5}$ and PM_{10} ratio in September at all sampling points were indicated that more contribution of $PM_{2.5}$ accounted for about half of April occurred in this , which might cause by more anthropogenic activities such as forest fire, agricultural waste burning in the surrounding the study area. $PM_{2.5}/PM_{10}$ ratio that higher than 0.6 could be explained to the contribution from combustion sources or secondary particulate matters whereas the lower ratio was signified an impact of mechanical activities resuspended soil or road dust (Akyuz & Cabuk, 2009; Pérez et al., 2008; Querol et al., 2004). Moreover, this high proportion in September could have an effect on human health in this study area (Y. Sun et al., 2004).

Additionally, PM ratios between e-waste dismantling house, non-e-waste dismantling house, open dump area, and reference area of April were similar to each

other as same as those ratios in September. This similarity ratio between each site also implied the spatial distribution in this study area. Both $PM_{2.5}$ and PM_{10} could distribute into the nearby areas around the e-waste community either at Daengyai or Banpao.

Table 4.12 $PM_{2.5}/PM_{10}$ ratios at all sampling points in April and September

Sampling sites	$PM_{2.5}/PM_{10}$	
	April	September
E-waste dismantling house	0.46	0.74
Non-e-waste dismantling house	0.42	0.77
Open dump area	0.42	0.63
Reference area	0.58	0.75

4.1.3 Meteorological data and their correlation to PM concentrations

The meteorological data during the PM sampling was also monitored, including temperature, relative humidity, precipitation, wind speed, and wind direction at the reference site and open dump areas of Daengyai and Banpao subdistrict was shown in Table 4.13, Figure 4.15 and Figure 4.16. The temperatures at each site in April were 32.42 ±1.12, 32.31 ±1.00, 32.10 ±1.14 °C, respectively, as shown in Table 4.13. For September, there were 27.56 ±0.78, 28.22 ±0.69 and 27.89 ±0.57 °C, respectively. The average temperature of this study area was 32.28 ±1.07 °C in April and 27.89 ±0.67 °C in September. The relative humidity at those areas were 63.44 ±5.44, 62.63 ±5.65 and 66.25 ±5.41%, respectively, in April and 64.00 ±1.19, 62.36 ±1.98 and 60.99 ±1.60% in September. The mean relative humidity in April and September was 64.10 ±5.39 and 62.45 ±1.41%, respectively. Next, precipitation, there were 0.01 ±0.03, 0.25 ±0.53 and 0.06 ±0.12 mm/hr at the reference area, open dump area in Daengyai and Banpao, respectively in April which was slight precipitation (less than 0.5 mm/hr defined by U.S. Geological Survey (U.S. Geological Survey (USGS), 2020) and the average of three sampling sites was 0.11 ±0.19 mm/hr. In contrast, there was no precipitation detected in the sampling area in September. For wind speed at the reference area, open dump area in Daengyai and Banpao were 1.04 ±0.18, 1.48

±0.32, 1.42 ±0.29 m/s in April and 1.04 ±0.37, 1.53 ±0.61 and 1.32 ±0.70 m/s, respectively. And the average of wind speed was 1.46 ±0.49 m/s in April and 1.30 ±0.52 m/s in September. Finally, the predominant wind direction in April at open dump sites of Daengyai and Banpao, and reference area were from the southeast (SE), southeast to west, west-southwest (WSW), respectively, as shown in Figure 4.15. The predominant wind direction in September at both open dump site in Banpao and reference area were from east-northeast (ENE) while at the open dump in Daengyai was from the northeast (NE) as shown in Figure 4.16.

The statistical analysis result shows a significant difference in the temperature between April and September at the open dump area in both Daengyai and Banpao subdistrict. Relative humidity was found significantly different between April and September only at the open dump area in Banpao. Only precipitation at reference area that was statistically different between both sampling period. Lastly, for windspeed, there was no significant difference between April and September at all meteorological monitoring sites. According to previous studies, the meteorological conditions, as mentioned above, can influence on increasing or decreasing the PM concentrations (Gangwar et al., 2016a; Outapa & Ivanovitch, 2019; G. Xu et al., 2017). However, in this study, there was only a slight difference and no significant difference in meteorological conditions between April and September.

Table 4.13 Meteorological conditions in April and September in the study area

Meteorological parameters		RF	DYOD	BPOD	Average
April	Temperature (°C)	32.42 ±1.12	32.31 ±1.00	32.10 ±1.14	32.28 ±1.07
	Relative humidity (%)	63.44 ±5.44	62.63 ±5.65	66.25 ±5.41	64.10 ±5.39
	Precipitation (mm/hr)	0.01 ±0.03	0.25 ±0.53	0.06 ±0.12	0.11 ±0.19
	Wind speed (m/s)	1.04 ±0.18	1.48 ±0.32	1.42 ±0.29	1.46 ±0.49
September	Temperature (°C)	27.56 ±0.78	28.22 ±0.69	27.89 ±0.57	27.89 ±0.67
	Relative humidity (%)	64.00 ±1.19	62.36 ±1.98	60.99 ±1.60	62.45 ±1.41
	Precipitation (mm/hr)	-	-	-	-
	Wind speed (m/s)	1.04 ±0.37	1.53 ±0.61	1.32 ±0.70	1.30 ±0.52

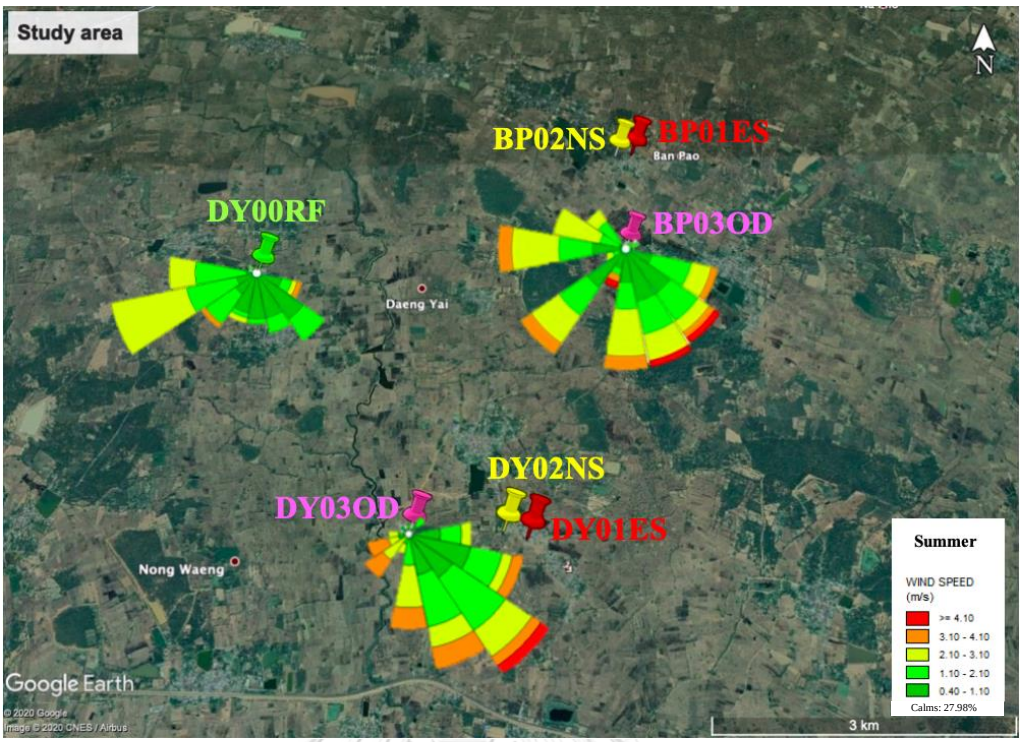


Figure 4.15 The predominant wind direction in April at three meteorological stations (DY00RF, DY03OD, and DY03OD)

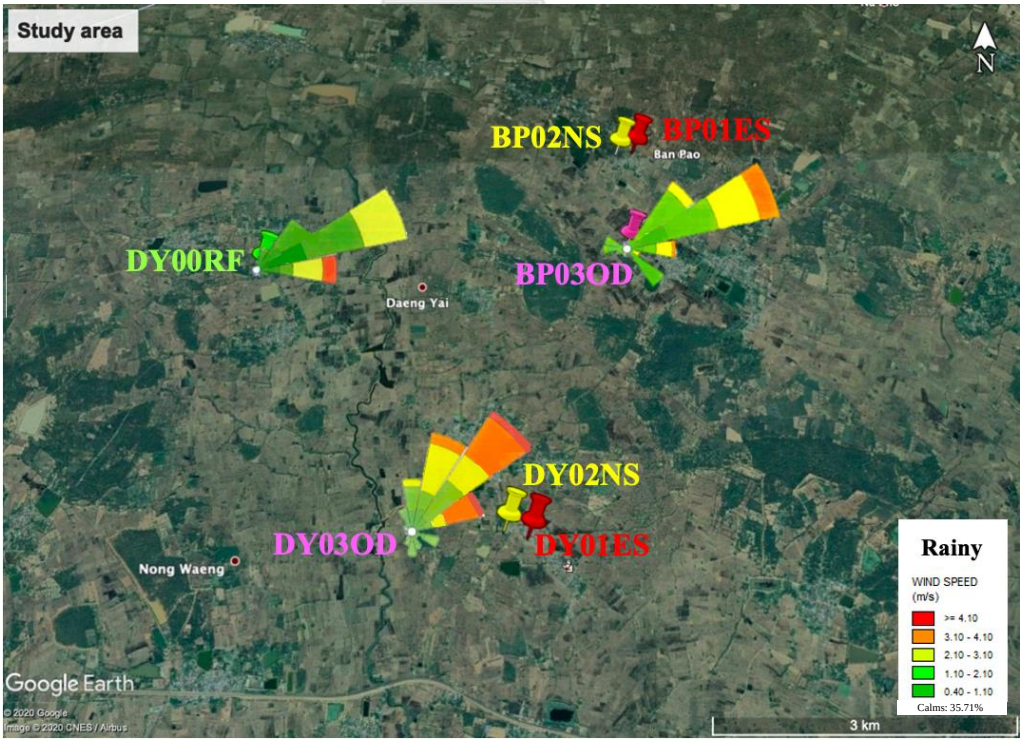


Figure 4.16 The predominant wind direction in September at three meteorological station (DY00RF, DY03OD, and DY03OD)

Pearson's correlation between PM concentrations and meteorological factors was examined, and the results are shown in Table 4.14. This correlation was compared the PMs concentrations data with their meteorological area, including $PM_{2.5}$ and PM_{10} levels at reference area with meteorological at reference area, $PM_{2.5}$ and PM_{10} levels at e-waste dismantling house, non-e-waste dismantling house, open dump area in Daengyai with meteorological at open dump area, and $PM_{2.5}$ and PM_{10} levels at e-waste dismantling house, non-e-waste dismantling house, open dump area in Banpao with meteorological at open dump area. For $PM_{2.5}$ concentrations, the correlation with meteorological parameters has shown only a significant negative correlation at 99% confidence level with the ambient temperature (r = -0.844). There also have similar correlation results at non-e-waste dismantling house, open dump area, and reference area that only has a significant correlation with the temperature factor (r = -0.813, 0.745, and 0.843, respectively). This could indicate that the ambient temperature factor had influenced on $PM_{2.5}$ concentrations in this study area.

For $PM_{10,}$ the results of Pearson's correlation between PM_{10} with meteorological parameters are shown in Table 4.14. There was only a significant correlation between PM_{10} levels and temperature at e-waste dismantling house (r = -0.552) at 99% confidence level. Similar to the correlation results between PM_{10} at the reference area and ambient temperature, which gave a correlation coefficient value of -0.759 at 99% confidence level. Meanwhile, PM_{10} level at non-e-waste dismantling house has a significant correlation with temperature (r = -0.479) at 99% confidence level and were correlated with precipitation (r = -0.458) and wind speed (r = -0.422) at 95% confidence level. Lastly, there was significant correlation at 99% confidence level between PM_{10} concentration at open dump area and wind speed (r = -0.496) and were correlated with precipitation (r = -0.434) and temperature (r = -0.404) at 95% confidence level. These results could point out that PM_{10} concentrations at e-waste dismantling house, non-e-waste dismantling house, and reference areas have major influenced by ambient temperature within their area while only at open dump area has major manipulated by wind speed.

Table 4.14 Pearson correlation of $PM_{2.5}$ and PM_{10} with meteorological parameters at e-waste dismantling, non-e-waste dismantling, open dump, and reference area

Sampling sites		Meteorological parameters			
		Temperature (°C)	Relative humidity (%)	Precipitation (mm/hr)	Wind speed (m/s)
		r	*r*	*r*	*r*
ES	$PM_{2.5}$	-0.844**	-0.222	-0.412	-0.168
	PM_{10}	-0.552**	-0.254	-0.249	-0.178
NS	$PM_{2.5}$	-0.813**	-0.206	-0.346	-306
	PM_{10}	-0.479**	-0.155	-0.458*	-0.422*
OD	$PM_{2.5}$	-0.745**	-0.269	-0.353	-0.343
	PM_{10}	-0.404*	-0.281	-0.434*	-0.496**
RF	$PM_{2.5}$	-0.843**	0.141	-0.281	-0.176
	PM_{10}	-0.759**	0.037	-0.316	0.302

ES = e-waste dismantling house, NS = non-e-waste dismantling, OD = open dump area, RF = reference area

** means the correlation is significant at the 0.01 level (99% confidence level).
* means the correlation is significant at the 0.05 level (95% confidence level).

For more understanding of the influences of meteorological factors (temperature, relative humidity, precipitation, and wind speed) on PMs concentration in this study area, the multiple regression analysis with the stepwise method was used regarding the analysis method used in the previous study (Goharnejad, Goharnejad, Asadi, & Zakeri Niri, 2018). The results of multiple regression between PMs concentration and meteorological data are shown in Table 4.15. The regression results show that only temperature has statistically significant on decreasing $PM_{2.5}$ at the reference area (β_1 = -3.912) at 95% confidence levels. While the temperature at e-waste dismantling and non-e-waste dismantling has significantly influenced on reducing $PM_{2.5}$ (β_1 = -5.393 and -6.920, respectively) and wind speed (β_2 = -6.561 and -13.226, respectively). For the regression result at open dump area, it was found that temperature, wind speed, and relative humidity could decrease $PM_{2.5}$ concentration (β_1 = -4.495, β_2 = -10.927, and β_3 = -0.686, respectively) significantly ($p < 0.05$).

Next, the regression analysis result of PM_{10} was found that only temperature has statistically significant effect on reducing PM_{10} at the e-waste dismantling house (β_1 = -4.301) at 95% confidence level. Meanwhile, regression results were found

temperature and wind speed was statistically significant influence on decreasing PM_{10} levels at non-e-waste dismantling (β_1 = -3.909 and β_2 = -16.308, respectively) and open dump area (β_1 = -18.868 and β_2 = -3.382, respectively) at 95% confidence levels. Meanwhile, there was no regression result between meteorological factors and PM_{10} levels in the reference area. However, the meteorological factors, as mention before, have lower influenced on PM_{10} concentration variation, which was about 30.50%, 43.60%, and 43.70%.

When integrated multiple regression analysis results with the Pearson's correlation result, it was found that the precipitation did not influence both $PM_{2.5}$ and PM_{10}, which might respond to the almost absent precipitation during the sampling period in September. In comparison, not only temperature that has an effect on both $PM_{2.5}$ and PM_{10}, but also comes along with wind speed and relative humidity, which all these factors had negative relationships with PMs. Moreover, it means PMs concentrations, especially $PM_{2.5}$, would be decreased if the sampling area had a high temperature, wind speed, and relative humidity. Similar to other studies that indicated the higher wind speed causes the lower PM concentration (Giri, Krishna Murthy, & and Adhikary, 2008; Papatsara et al., 2019; Peter, Nagendra, et al., 2018; Y. Sun et al., 2004). The negative relationship between PMs and relative humidity at the e-waste dismantling house was similar to the study of Lou et al. (2017) that high-humidity and extreme-humidity has an important role in decreasing PMs concentration (Lou et al., 2017). Although less influence of some meteorological factors on PM_{10} could be observed in the reference area, this might have other factors that also affect on PM_{10} variation. The deposition of larger particles like PM_{10} would be easier than small particles responding to the gravity force. Meanwhile, small particles like $PM_{2.5}$ would be continuously suspended in ambient air unless they had adequate mass from attachment to each other, aggregation, and hygroscopic growth (D'Angelo et al., 2016; Langner, Kull, & Endlicher, 2011; Lou et al., 2017).

Table 4.15 Multiple regression of $PM_{2.5}$ and PM_{10} with meteorological parameters at e-waste dismantling, non-e-waste dismantling, open dump, and reference area

Sampling sites		Regression equations	R^2	Sig
ES	$PM_{2.5}$	$PM_{2.5}$ = 201.636 - 5.393T - 6.561WS	0.762	<0.05
	PM_{10}	PM_{10} = 179.226 - 4.301T	0.305	<0.05
NS	$PM_{2.5}$	$PM_{2.5}$ = 261.440 - 6.920T - 13.226WS	0.779	<0.05
	PM_{10}	PM_{10} = 196.597 - 3.909T - 16.308WS	0.436	<0.05
OD	$PM_{2.5}$	$PM_{2.5}$ = 225.078 - 4.495T - 10.927WS - 0.686RH	0.757	<0.05
	PM_{10}	PM_{10} = 186.650 - 18.868WS - 3.382T	0.437	<0.05
RF	$PM_{2.5}$	$PM_{2.5}$ = 143.674 - 3.912T	0.711	<0.05
	PM_{10}	-	-	-

The influence of meteorological factors on PMs levels in this study area might be primarily affected by wind speed and followed by temperature. However, PM concentrations could also be induced by other factors as well, such as the anthropogenic sources nearby, the distance between sampling sites and possible sources, atmospheric pressure in the sampling period, the topographical factors of each study area, and the temperature inversion condition.

4.2 Spatial variation of heavy metals contamination in PM

Heavy metals contamination in $PM_{2.5}$ and PM_{10} including Arsenic (As), Cadmium (Cd), Chromium (Cr), Copper (Cu), Manganese (Mn), Nickel (Ni), Lead (Pb), Zinc (Zn) and Iron (Fe) at e-waste dismantling house, non-e-waste dismantling house, open dump area in Daengyai and Banpao Subdistrict, Banmaichaiyaphot and Phutthaisong District, and reference area in Daengyai, Buriram province, was examined. The PMs were collected for 24 hours and then digested by a microwave digestion oven (CEM MARS-5). The concentrations of heavy metals were analyzed by an inductive coupled plasma mass spectrometer (ICP-MS).

4.2.1 Quality assessment and quality control (QA/QC) of laboratory

For QA/QC of instrumental analysis, the results are shown in Table 4.16. For R^2 of the standard calibration curve for As, Cd, Cr, Cu, Mn, Ni, Pb, Zn, and Fe were all higher than 0.9990 at both times of heavy metals analyzed by ICP-MS. The lowest concentrations of all heavy metals mentioned that could be determined by ICP-MS, the limit of detection (LOD), which was statically analyzed by the blank. The LOD those heavy metals were 0.033, 0.379, 0.317, 1.349, 0.348, 5.871, 0.102, 0.745, and 5.675 µg/L, respectively. For a limit of quantification (LOQ), the quantitative concentration results obtained which were 0.110, 1.262, 1.056, 4.497, 1.160, 19.571, 0.339, 2.483, and 18.917 µg/L for As, Cd, Cr, Cu, Mn, Ni, Pb, Zn, and Fe, respectively. Further, the relative standard deviation or %RSD was used to determine the accuracy of ICP-MS in this study, which was 4.4, 11.0, 10.0, 12.9, 13.0, 11.6, 3.4, 17.5, and 13.8% for those heavy metals, respectively. Finally, the %recovery of the method used for digesting heavy metals in $PM_{2.5}$ and PM_{10} was examined by using SRM (1648a-Urban Particulate Matter). The %recovery of all heavy metals in both $PM_{2.5}$ and PM except Cr was in an accepted range, which was between 80 – 120% (see Table 4.16). For acceptable and accuracy of Cr levels in PM, the concentration had been corrected using their recovery factor (R), while R is equal to 100% divided by actual mean recovery which were 50.0% and 33.3% for $PM_{2.5}$ and PM_{10}, respectively.

Table 4.16 The QA/QC result of the metals analyzed by ICP-MS

Heavy metals	R^2 of a calibration curve		LOD (µg/L)	LOQ (µg/L)	%RSD	%Recovery	
	1st	2nd				$PM_{2.5}$	PM_{10}
						min-max	min-max
As	0.9999	0.9999	0.033	0.110	4.4	91.2 – 118.1	112.6 – 131.2
Cd	0.9998	0.9994	0.379	1.262	11.0	84.6 – 111.7	80.9 – 117.9
Cr	0.9999	0.9994	0.317	1.056	10.0	41.3 – 59.7	21.1 – 72.5
Cu	0.9999	0.9996	1.349	4.497	12.9	82.5 – 110.3	89.4 – 119.9
Mn	0.9996	0.9995	0.348	1.160	13.0	85.6 – 118.2	71.4 – 118.0
Ni	0.9992	0.9993	5.871	19.571	11.6	80.5 – 114.7	94.7 – 114.1
Pb	0.9995	0.9999	0.102	0.339	3.4	68.8 – 97.9	67.8 – 108.8
Zn	0.9998	0.9993	0.745	2.483	6.7	83.8 – 129.9	85.4 – 107.0
Fe	0.9993	0.9993	5.675	18.917	3.7	83.4 – 118.1	62.8 – 112.5

The spatial and temporal variation of heavy metals concentration in $PM_{2.5}$ and PM_{10} observed in April and September were investigated. The heavy metals concentration in $PM_{2.5}$ and PM_{10} was taken to analyze the differences among four different sampling sites, including e-waste dismantling house, non-e-waste dismantling house, open dump, and reference area by using ANOVA, and among two sampling period using independent samples t-test statistical analysis. Moreover, meteorological data was analyzed against heavy metals concentrations at each sampling site for both $PM_{2.5}$ and PM_{10} to find the correlation. In accordance with the above information, the results of heavy metals in $PM_{2.5}$ and PM_{10} are revealed as follows.

4.2.2 Spatial variation of heavy metals concentration in $PM_{2.5}$

The average concentration of heavy metals in $PM_{2.5}$ in both April and September is shown in Figure 4.17 and Figure 4.18, respectively (all heavy metals concentrations in $PM_{2.5}$ are shown in appendix A-1 and A-2 for April and September, respectively). The mean heavy metal levels contaminated in $PM_{2.5}$ at e-waste dismantling of both Daengyai (DY01ES) and Banpao (BP01ES), non-e-waste dismantling house of both Daengyai (DY02NS) and Banpao (BP02NS), open dump

area of both Daengyai (DY03OD) and Banpao (BP03OD), and reference area (DY00RF) of both sampling period were shown in Table 4.17.

Table 4.17 Heavy metals concentration in $PM_{2.5}$ at all sampling sites (ng/m^3)

Heavy metals	Sampling period	Sampling sites (Mean ±SD)						
		DY00RF	DY01ES	BP01ES	DY02NS	BP02NS	DY03OD	BP03OD
As	April	0.027 ±0.012	0.028 ±0.023	0.010 ±0.005	0.013 ±0.009	0.028 ±0.010	0.025 ±0.012	0.009 ±0.006
	September	0.056 ±0.040	0.086 ±0.045	0.298 ±0.061	0.091 ±0.043	0.100 ±0.047	0.230 ±0.093	0.332 ±0.130
Cd	April	0.155 ±0.059	0.079 ±0.001	0.080 ±0.003	0.124 ±0.059	0.106 ±0.037	0.234 ±0.139	0.169 ±0.057
	September	0.519 ±0.207	0.751 ±0.429	1.816 ±0.364	0.595 ±0.284	0.581 ±0.237	1.323 ±0.603	1.426 ±0.736
Cr	April	0.759 ±1.018	3.752 ±4.079	2.811 ±5.252	0.419 ±0.732	6.342 ±11.474	1.381 ±1.518	0.235 ±0.374
	September	19.263 ±16.841	1.472 ±0.712	12.371 ±14.689	2.752 ±2.655	7.794 ±12.449	17.537 ±25.844	19.263 ±16.841
Cu	April	5.641 ±3.747	4.694 ±3.668	2.199 ±1.372	7.993 ±2.819	11.840 ±3.435	6.665 ±6.062	1.891 ±2.980
	September	3.943 ±2.895	4.654 ±1.782	21.499 ±7.306	9.676 ±2.764	46.655 ±20.339	16.386 ±14.445	17.740 ±7.378
Mn	April	4.929 ±4.325	1.442 ±0.709	1.280 ±0.965	1.592 ±1.028	2.011 ±1.278	1.302 ±0.482	1.426 ±0.699
	September	4.687 ±0.722	7.515 ±1.758	13.750 ±4.019	4.857 ±1.239	6.911 ±1.641	11.555 ±5.080	16.083 ±4.924
Ni	April	4.392 ±3.930	2.601 ±1.644	1.574 ±0.413	3.105 ±0.999	6.365 ±6.069	1.725 ±0.627	1.486 ±0.333
	September	1.493 ±0.600	7.289 ±3.972	22.540 ±21.114	1.254 ±0.080	4.121 ±4.801	10.142 ±3.215	6.636 ±2.220
Pb	April	1.585 ±1.829	2.119 ±1.227	1.364 ±0.468	1.541 ±1.115	0.471 ±0.866	19.766 ±16.644	19.767 ±26.811
	September	18.153 ±8.516	29.167 ±15.360	61.631 ±16.749	20.217 ±4.422	25.501 ±9.200	50.659 ±21.190	56.021 ±28.563
Zn	April	30.177 ±20.985	104.324 ±36.691	30.880 ±45.737	54.233 ±52.497	156.579 ±49.555	44.498 ±5.212	33.890 ±16.791
	September	58.975 ±22.989	81.379 ±16.845	137.434 ±70.882	67.364 ±15.600	64.161 ±10.288	101.277 ±51.753	278.118 ±31.945
Fe	April	49.033 ±23.000	90.920 ±39.513	72.692 ±41.229	83.282 ±82.513	127.312 ±72.554	91.746 ±38.667	34.979 ±19.767
	September	66.390 ±19.869	72.041 ±23.134	217.714 ±86.750	42.140 ±18.077	93.859 ±72.821	169.405 ±83.968	264.858 ±69.649

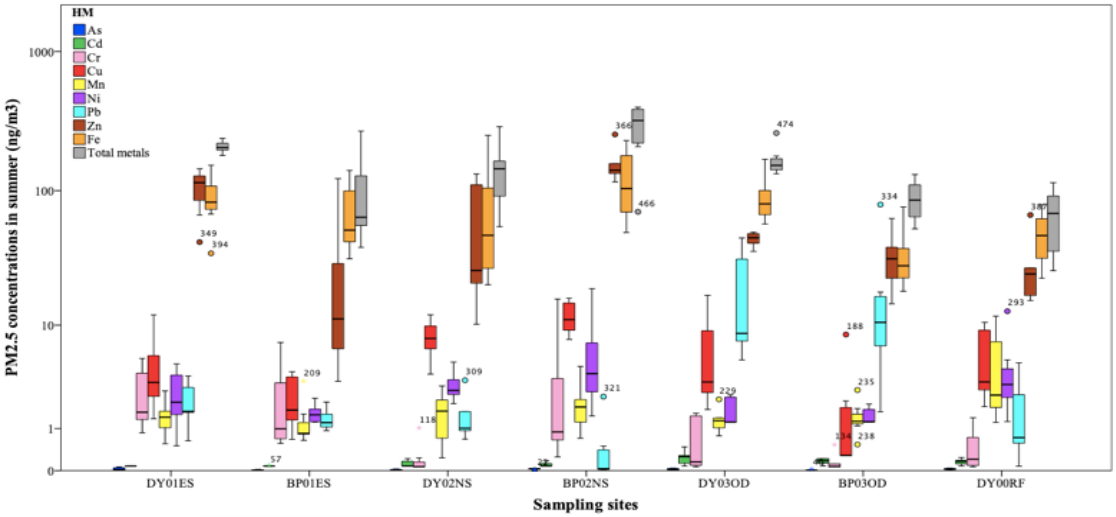


Figure 4.17 Heavy metals concentrations in $PM_{2.5}$ at e-waste dismantling (DY01ES and BP01ES), non-e-waste (DY02NS and BP02NS), open dump area (DY03OD and BP03OD) and reference area (DY00RF) in April

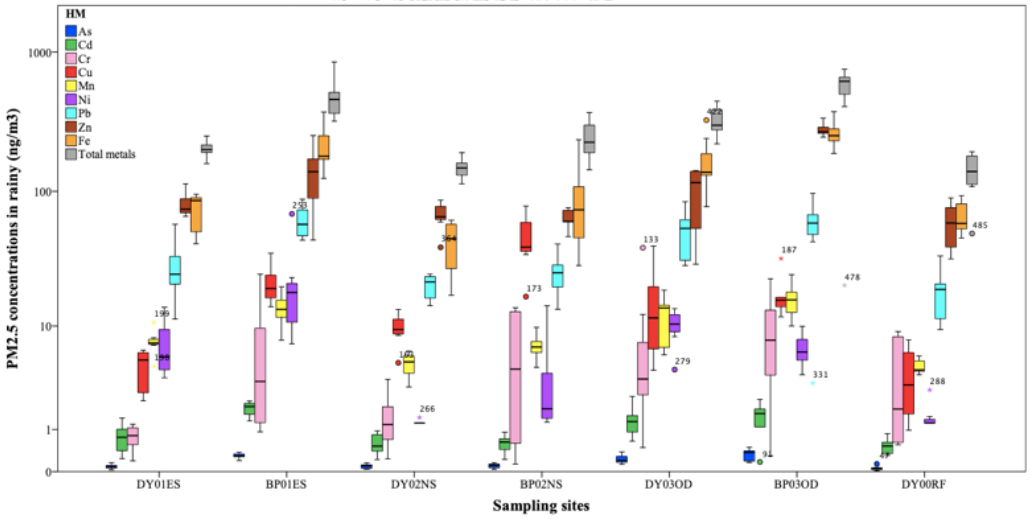
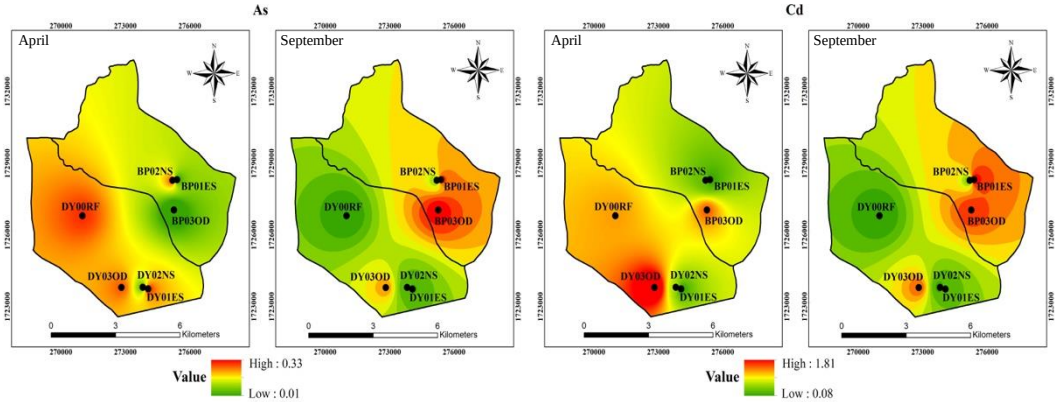


Figure 4.18 Heavy metals concentrations in $PM_{2.5}$ at e-waste dismantling (DY01ES and BP01ES), non-e-waste (DY02NS and BP02NS), open dump area (DY03OD and BP03OD) and reference area (DY00RF) in September

The spatial distribution map of all studied heavy metals, i.e., As, Cd, Cr, Cu, Mn, Ni, Pb, Zn, Fe, and total metals contaminated in $PM_{2.5}$ in April and September are shown in Figure 4.19. It shows high As levels at reference area (RF) and open dump area (OD) in April and September, respectively. For Cd levels, there were high at OD

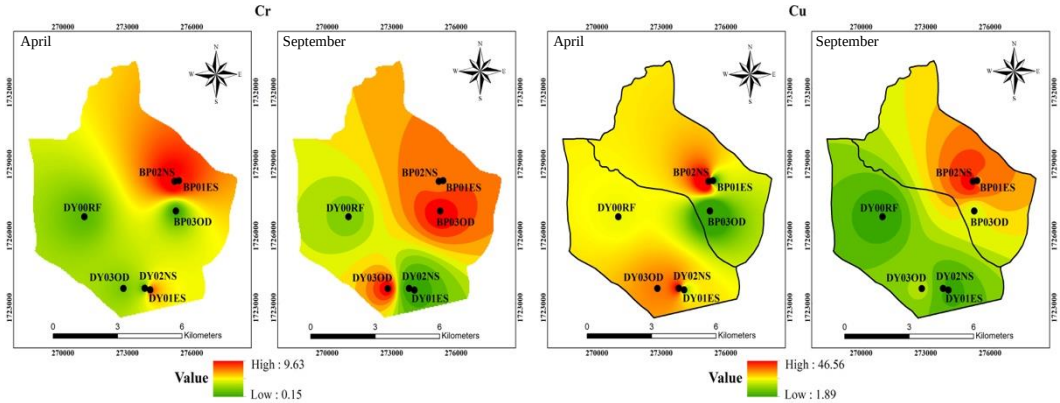
in both April and September. This result showed that the Cr level was high at ES in April and at OD in September. In comparison, Cu showed high concentration at NS both in April and September.

When compared Mn levels between all sampling sites, the results showed a high level at RF in April and at OD in September. Figure 4.19 has shown high concentrations of Ni at NS and RF in April while also shows a high level at ES in September. For Pb, it was shown that high Pb concentration was presented at OD in both April and September. There was a high Zn concentration at NS and OD in April and September, respectively. The Fe concentration at NS shows higher than other areas, whereas that at the OD was higher than other areas in September. Finally, the distribution of total metals has shown the high levels at NS and ES in April, while in September, there was high concentration at OD.



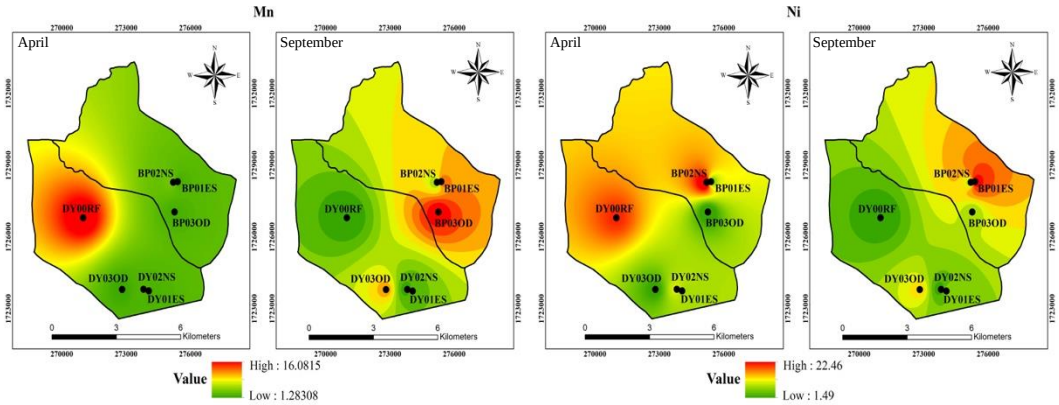
(a) As

(b) Cd

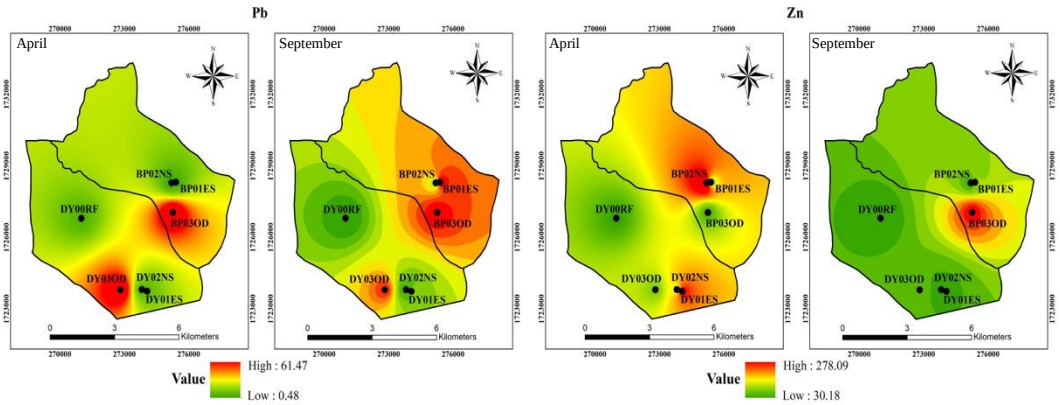


(c) Cr

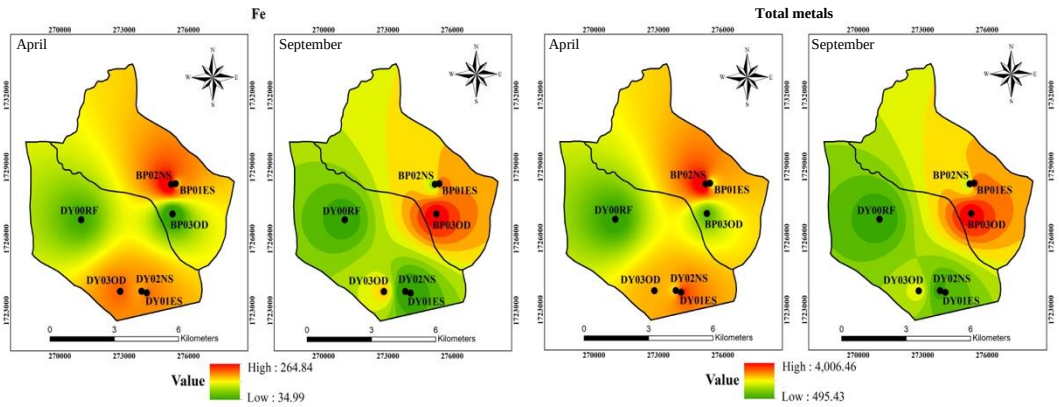
(d) Cu



(e) Mn (f) Ni



(g) Pb (h) Zn



(i) Fe (j) Total metals

Figure 4.19 Spatial variation of As (a), Cd (b), Cr (c), Cu (d), Mn (e), Ni (f), Pb (g), Zn (h), Fe (i), and total metals (j) in $PM_{2.5}$ (ng/m^3)

To better understanding the spatial distribution of heavy metals, including As, Cd, Cr, Cu, Mn, Ni, Pb, Zn, and Fe contaminated in $PM_{2.5}$ at this e-waste community, the differences of $PM_{2.5}$ between at e-waste dismantling house, non-e-waste dismantling house, open dump area, and reference area were analyzed by using ANOVA test, and the results are shown in Table 4.18. The result shows that there was no significant difference at 95% confidence level between As levels at the open dump (OD) and e-waste dismantling house (ES), but that of the OD was significantly different from non-e-waste dismantling and reference area. When Cd concentrations were compared, the result had shown that OD and ES were significant differences ($p < 0.05$) with NS and reference area (RF). While there was not significantly different between all sampling sites of Cr levels in $PM_{2.5}$. For Cu, it shows significant differences ($p < 0.05$) at NS with all sampling areas (ES, OD, and RF). The difference in Mn levels has shown significantly different between OD and NS at 95% confidence levels. There were significant differences in Ni levels at ES when compared with NS and RF. In comparison, Pb concentration at OD has shown significantly different ($p < 0.05$) with the rest areas (ES, NS, and RF). The difference of Zn levels between all sampling was found that there was a significantly different ($p < 0.05$) between OD and RF. Lastly, there were significant differences between Fe concentrations at OD with NS and RF at 95% confidence level.

Table 4.18 Descending order of heavy metals concentration in $PM_{2.5}$ and PM_{10}

Heavy metals	$PM_{2.5}$	PM_{10}
As	$Od^{a} > ES^{ab} > NS^{b} > RF^{b}$	$RF^{a} > OD^{a} > NS^{a} > ES^{a}$
Cd	$OD^{a} > ES^{ab} > NS^{c} > RF^{c}$	$OD^{a} > NS^{a} > ES^{a} > RF^{a}$
Cr	$RF^{a} > OD^{a} > ES^{a} > NS^{a}$	$RF^{a} > OD^{a} > NS^{a} > ES^{a}$
Cu	$NS^{a} > OD^{b} > ES^{b} > RF^{b}$	$NS^{a} > OD^{b} > ES^{b} > OD^{b}$
Mn	$OD^{a} > ES^{ab} > RF^{ab} > NS^{b}$	$OD^{a} > NS^{a} > ES^{a} > RF^{b}$
Ni	$ES^{a} > OD^{ab} > NS^{b} > RF^{b}$	$NS^{a} > RF^{ab} > ES^{ab} > OD^{b}$
Pb	$OD^{a} > ES^{b} > NS^{b} > RF^{b}$	$NS^{a} > OD^{a} > WS^{a} > RF^{a}$

Heavy metals	$PM_{2.5}$	PM_{10}
Zn	$OD^{a}>ES^{ab}>NS^{ab}>RF^{b}$	$RF^{a}>NS^{ab}>OD^{b}>ES^{bc}$
Fe	$OD^{a}>ES^{ab}>NS^{b}>RF^{b}$	$NS^{a}>OD^{a}>ES^{a}>RF^{b}$

Notation: RF = Reference area, ES = E-waste dismantling house, NS = Non-e-waste dismantling house, OD = open dump area. If the right superscripts are different alphabet, it means heavy metal concentrations are statistically significant differences between sites.

The results mentioned above could be summarized that As, Cd, Cr, Mn, Pb, Zn, and Fe were highest at open dump area, while Cu and Ni were highest at non-e-waste dismantling and e-waste dismantling house, respectively. This could indicate that at the open dump area has activities that enhance the heavy metals concentrations in $PM_{2.5}$. As mentioned before in section 4.1.1, in this study, there were e-waste burning activities in which compiles of electric wires were burned for collecting precious copper. Plus, there were some studies found that the open burning has an influence on heavy metals increasing in e-waste dismantling house (Gangwar et al., 2019; Gangwar et al., 2016a; Gullett et al., 2007). The levels of almost heavy metals at OD were also similar to ES, and this could signify those e-waste activities at both open dump area and e-waste dismantling house on the contribution of heavy metals contaminated $PM_{2.5}$ in this area. Similarly to many studies at e-waste dismantling or recycling site and e-waste burning area, the informal e-waste dismantling activities involved with removing the external components made of steel, aluminum, or plastic and foam, separating the internal parts, burning wire and plastic products could release various types of heavy metals (Bi et al., 2010; Fujimori et al., 2012; Gangwar et al., 2019; Gangwar et al., 2016a; Gu et al., 2010; He et al., 2017; Oguri et al., 2018; Singh, Thind, & John, 2018; Vassanadumrongdee, 2015b; F. Xu et al., 2015).

Nevertheless, the high level of Cu at non-e-waste dismantling house might be influenced by other activities besides e-waste dismantling; it could be from a charcoal cooking that was normally used in this study area. There was a study found that BBQ charcoal and charcoal burning could emit the Cu and contaminated in PM, then it could disperse to other areas (Kabir, Kim, & Yoon, 2011; Susaya, Kim, Ahn, Jung, & Kang, 2010). At the same time, the highest of Ni at the e-waste dismantling house

could support the evaluation of Ni in consequence of e-waste dismantling directly. Further, Ni was the metal that usually found in PM that was collected from e-waste dismantling sites, especially disassembly of batteries, CD players, hard disks, LCD screens, and also circuit boards (Wenxiong Fang et al., 2013; Gangwar et al., 2019; Puangprasert & Prueksasit, 2019; Vassanadumrongdee, 2015b). For almost metals also found higher at e-waste dismantling, which could signify those e-waste activities at both open dump area and e-waste dismantling house on the contribution of heavy metals contaminated $PM_{2.5}$ in this area. Pointedly, only Pb at OD was presented different level from the rest areas. This result consistent with some previous studies those also found high Pb levels at e-waste open burning area, and Pb was also the main metals found in wires and PCB components (Bi et al., 2010; Deng et al., 2006; Gangwar et al., 2019; Oguri et al., 2018; Xue et al., 2012). Nonetheless, only Cr was found similar levels at all sampling sites, which suggests that Cr is not the major metals that were emitted from e-waste, but it might have already existed in this study area.

4.2.3 Spatial variation of heavy metals concentration in PM_{10}

For heavy metal in PM_{10}, the average heavy metal concentrations in April and September at all sampling sites has shown in Figure 4.20 and Figure 4.21. At both e-waste dismantling sites in Daengyai (DY01ES) and Banpao (BP01ES), both non-e-waste dismantling sites in Daengyai (DY02NS) and Banpao (BP02NS), both open dump sites in Daengyai (DY03OD) and Banpao (BP03OD), and reference area (DY00RF), the mean levels of all heavy metals are shown in Table 4.19.

Table 4.19Heavy metals concentration in PM_{10} at all sampling sites (ng/m^3)

Heavy metals	Sampling period	Sampling sites (Mean ±SD)						
		DY00RF	DY01ES	BP01ES	DY02NS	BP02NS	DY03OD	BP03OD
As (ng/m^3)	April	2.139 ±1.580	2.098 ±0.806	1.303 ±0.900	2.679 ±1.283	1.437 ±1.265	1.057 ±0.922	3.541 ±3.560
	September	6.070 ±1.941	2.195 ±1.884	4.056 ±4.183	3.954 ±4.112	4.258 ±4.571	5.214 ±4.591	4.065 ±3.516
Cd (ng/m^3)	April	0.079 ±0.038	0.080 ±0.028	0.098 ±0.025	0.095 ±0.048	0.147 ±0.060	0.111 ±0.083	0.058 ±0.021
	September	0.980 ±0.539	1.121 ±0.647	1.107 ±0.578	1.107 ±0.644	1.059 ±0.575	1.101 ±0.780	1.159 ±0.730
Cr (ng/m^3)	April	2.423 ±2.557	1.1481 ±1.518	0.406 ±0.763	0.554 ±0.927	1.130 ±1.423	0.188 ±0.341	0.184 ±0.444
	September	14.581 ±8.342	7.249 ±10.050	2.471 ±2.751	14.401 ±11.360	7.586 ±5.651	23.237 ±17.771	2.6533 ±2.786

Heavy metals	Sampling period	Sampling sites (Mean ±SD)						
		DY00RF	DY01ES	BP01ES	DY02NS	BP02NS	DY03OD	BP03OD
Cu (ng/m^3)	April	16.143 ±2.812	19.486 ±4.723	23.900 ±7.114	21.117 ±9.346	34.485 ±13.014	22.329 ±14.647	17.820 ±8.580
	September	24.501 ±12.096	26.877 ±9.185	29.456 ±11.116	103.233 ±22.825	103.233 ±22.825	38.971 ±15.509	20.943 ±7.711
Mn (ng/m^3)	April	8.571 ±3.034	15.730 ±7.942	12.200 ±3.705	11.488 ±6.129	23.785 ±7.292	22.741 ±9.634	22.741 ±9.634
	September	15.577 ±7.757	33.608 ±14.870	19.158 ±9.124	27.089 ±15.114	18.418 ±8.837	17.420 ±10.843	28.758 ±15.982
Ni (ng/m^3)	April	0.943 ±0.562	0.941 ±0.485	0.340 ±0.147	0.820 ±0.643	0.903 ±0.430	0.421 ±0.206	0.443 ±0.241
	September	1.216 ±0.782	1.849 ±0.842	1.131 ±0.378	1.972 ±1.062	0.933 ±0.630	1.158 ±0.660	0.814 ±0.217
Pb (ng/m^3)	April	2.475 ±1.473	4.151 ±2.749	2.112 ±1.008	2.972 ±1.734	3.127 ±2.377	3.698 ±6.220	1.387 ±1.039
	September	27.651 ±18.703	34.328 ±23.851	28.990 ±18.565	31.979 ±23.042	31.216 ±21.895	29.716 ±19.906	35.026 ±24.495
Zn ($\mu g/m^3$)	April	8.414 ±4.098	7.984 ±3.311	4.350 ±2.210	9.363 ±2.491	5.139 ±3.471	5.053 ±2.356	2.434 ±1.871
	September	5.914 ±1.630	1.272 ±1.539	1.369 ±1.007	4.674 ±2.516	4.130 ±2.822	2.969 ±3.132	5.545 ±4.332
Fe (ng/m^3)	April	156.409 ±110.219	275.304 ±129.695	259.688 ±116.349	191.166 ±59.226	301.028 ±152.191	114.613 ±72.854	236.864 ±241.688
	September	299.836 ±101.213	469.159 ±191.329	330.864 ±68.546	441.062 ±213.076	655.740 ±330.848	606.763 ±203.129	430.769 ±107.801

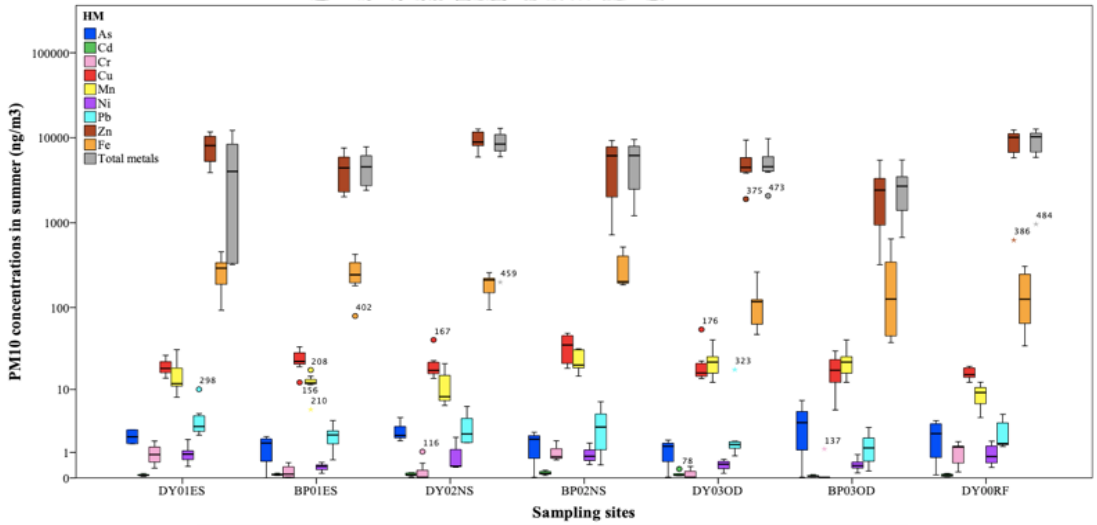


Figure 4.20 Heavy metals concentrations in PM_{10} at e-waste dismantling (DY01ES and BP01ES), non-e-waste (DY02NS and BP02NS), open dump area (DY03OD and BP03OD) and reference area (DY00RF) in April

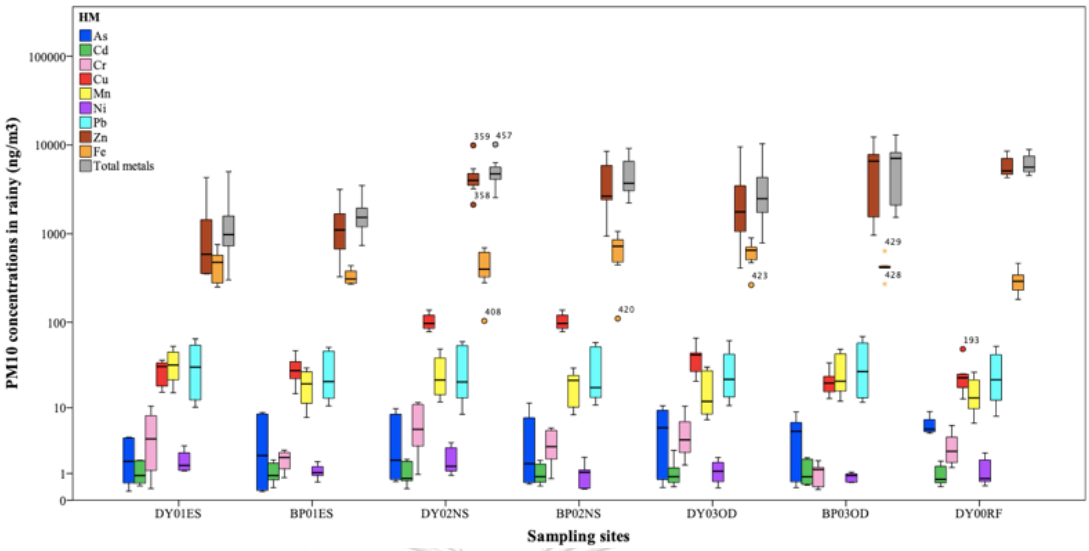
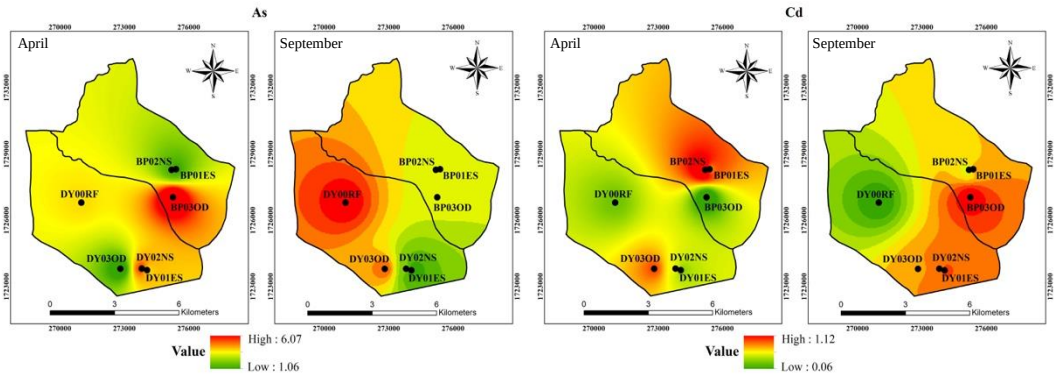


Figure 4.21 Heavy metals concentrations in PM_{10} at e-waste dismantling (DY01ES and BP01ES), non-e-waste (DY02NS and BP02NS), open dump area (DY03OD and BP03OD) and reference area (DY00RF) in September.

To have more explicit spatial distribution of As, Cd, Cr, Cu, Mn, Ni, Pb, Zn, Fe, and total metals contaminated in PM_{10} over the e-waste dismantling house in April and September, the distribution map at all sampling sites were provided in Figure 4.22. The result shows high As levels at reference area (RF) and open dump area (OD) in April and September, respectively. For Cd levels, there was high at NS and OD in April and September, respectively. This Cr distribution map result was revealed a higher level at RF in April; meanwhile, Cr levels in September were greater at NS. The map showed high Cu concentration at NS both in April and September. When compare Mn levels between all sampling sites, the results showed that OD and ES have higher level than others area in April and September, respectively. The high concentration of Ni was observed at RF and ES in April and September, respectively. There were also high Pb levels at ES and OD in both April and September.

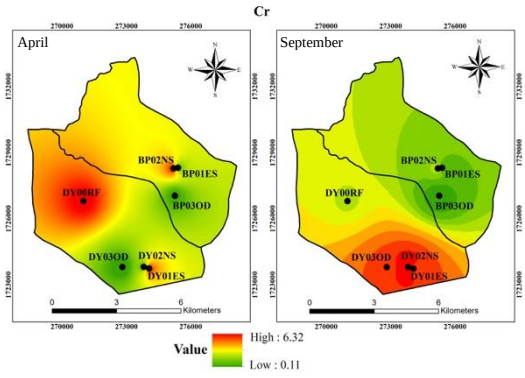
For Zn concentration in April, it was found higher at ES, NS, and RF at Daengyai, but in September, its high concentration was found at RF and OD at Banpao. The Fe concentration in April at NS was found higher than other areas, whereas at NS and OD was found higher than other areas in September. Lastly, the

distribution of total metals has shown higher levels at RF and NS in April, while in September was shown higher at RF and OD.

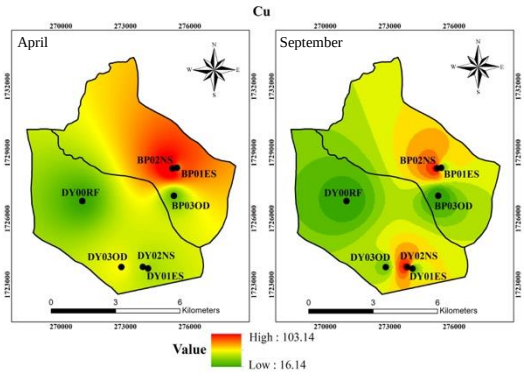


(a) As

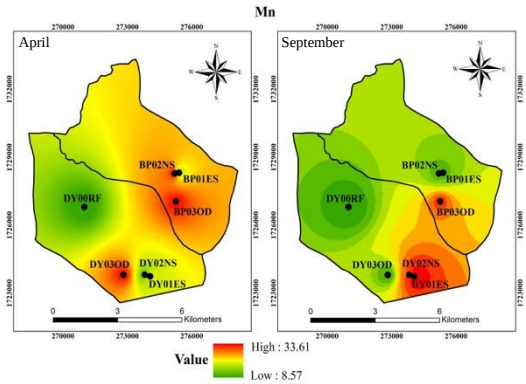
(b) Cd

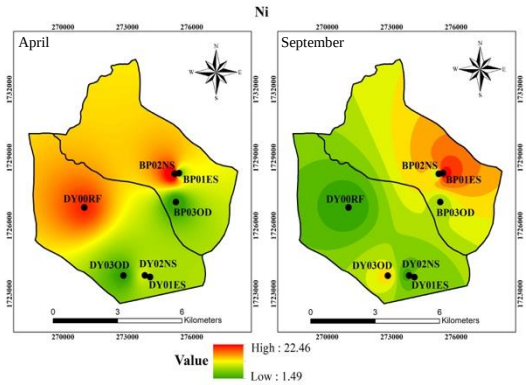


(c) Cr

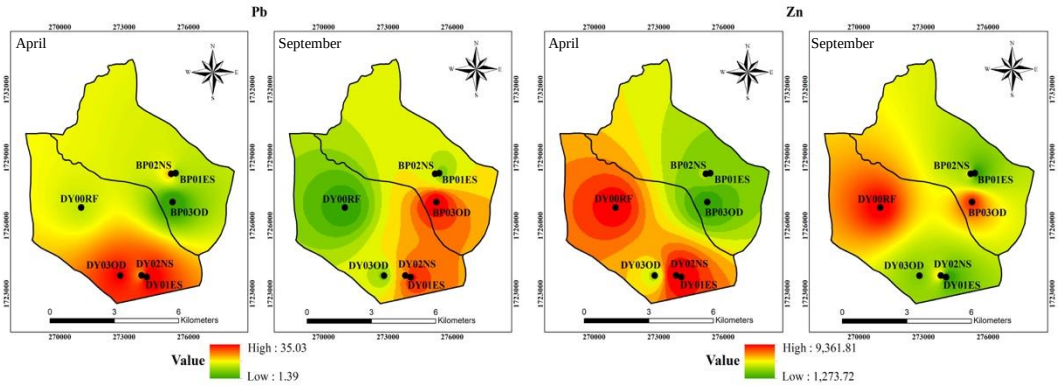


(d) Cu

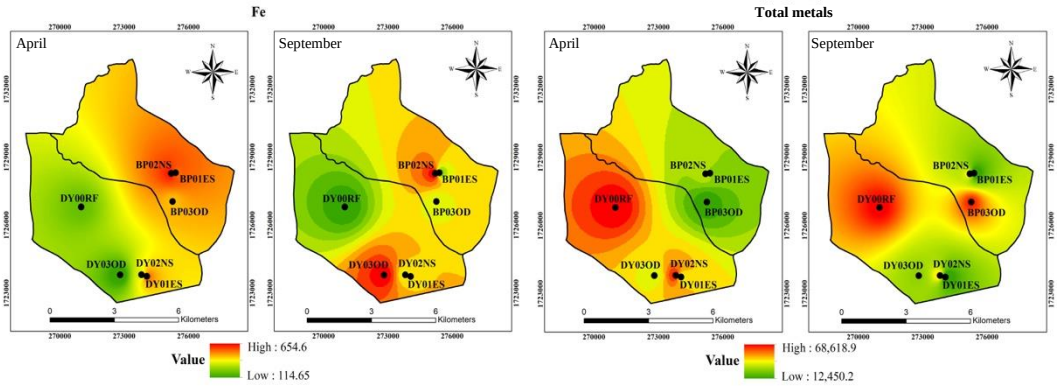




(e) Mn (f) Ni



(g) Pb (h) Zn



(i) Fe (j) Totals metal

Figure 4.22 Spatial variation of As (a), Cd (b), Cr (c), Cu (d), Mn (e), Ni (f), Pb (g), Zn (h), Fe (i), and total metals (j) in PM_{10} (ng/m^3)

From Table 4.18, the differences of PM_{10} between at e-waste dismantling house, non-e-waste dismantling house, open dump area, and reference area were analyzed by using the ANOVA test. The result shows that there was no statistically significant difference between e-waste dismantling (ES), non-e-waste dismantling (NS), open dump (OD), and reference area (RF) at 95% confidence levels for As in PM_{10}. Similar to Cd, Cr, and Pb results, which have no differences between all sampling sites. While Cu was shown significantly different ($p < 0.05$) between non-e-waste and the rest area. The result shows that there was significantly lower at RF when compared with

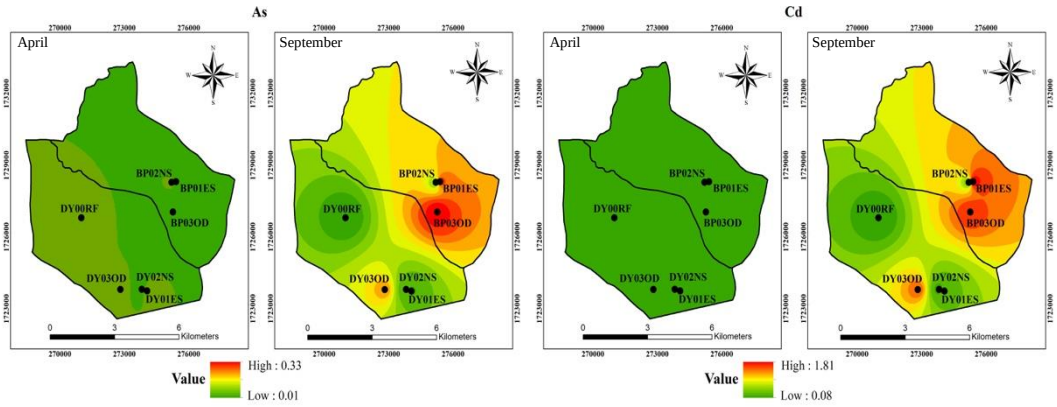
other areas (ES, NS, and OD) for Mn and Fe at 95% confidence levels. For Ni, there has found only a significant difference ($p < 0.05$) between NS and OD. Lastly, the result was showed significant differences at 95% confidence levels between RF and OD, RF and ES, and NS compared with ES.

Heavy metals including As, Cd, Cr, Cu, Mn, Ni, Pb, Zn, and Fe contaminated in PM_{10} in April and September as mentioned above were noticed that As and Zn were strongly distributed to all over the study area and might indicate that As and Zn were normally found in the ambient air over this e-waste dismantling community. This result was found similar to the previous study in the same e-waste dismantling community that As and Zn had also been found at every sampling point (Chanthahong & Kanghae, 2017). While Cr, Cu, Ni, Pb, and Fe were found highly at non-e-waste dismantling house, especially Cu, which similar to the higher Cu in $PM_{2.5}$ at NS. These metals were mostly found in e-waste dismantling activities, and the location of non-e-waste dismantling house was closed to the e-waste dismantling houses so this concentrated metals in this area might disperse and have influenced from e-waste dismantling activities nearby their area (He et al., 2017; W. Huang, Long, Wang, Huang, & Ma, 2015). While Cd and Mn were dominated at open dump areas which some studies have found Cd when burning of e-waste or plastic component (Deng et al., 2006; Gangwar et al., 2016a; Y. Wang et al., 2017). Nevertheless, for Mn, it normally contains in iron and steel or crustal soil, and some studies found Mn in soil and sediments at the e-waste recycling area (Cayumil et al., 2016; Quan et al., 2014). So, it is possible for Cd and Mn to found dominated metals in PM_{10} at the open dump area in this study.

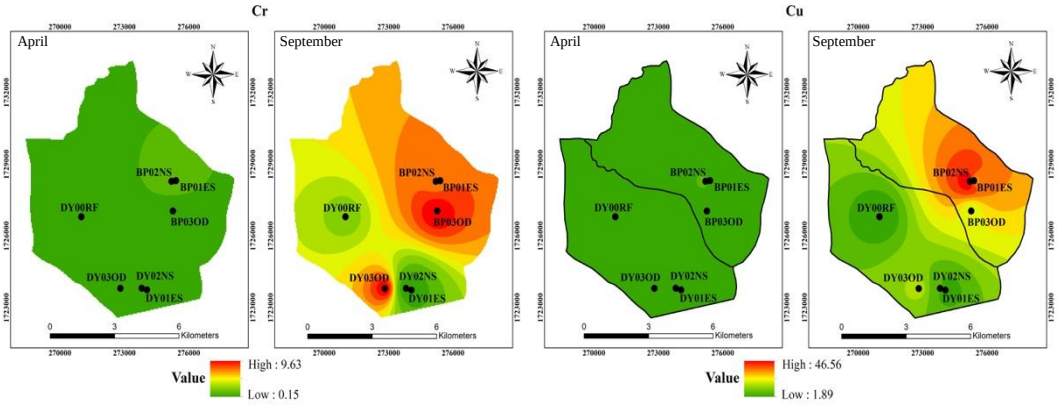
From both spatial variations of heavy metals in $PM_{2.5}$ and PM_{10}, these could indicate that heavy metals in $PM_{2.5}$ were found dominant in open dump and e-waste dismantling house, which mostly involved e-waste burning, CRT smashing, and e-waste recycling processes. Whilst heavy metals in PM_{10} were randomly distributed all over this e-waste community and signify to have heavy metals that were already existed in the background air environment.

4.3 Temporal variation of heavy metals concentration in $PM_{2.5}$ and PM_{10}

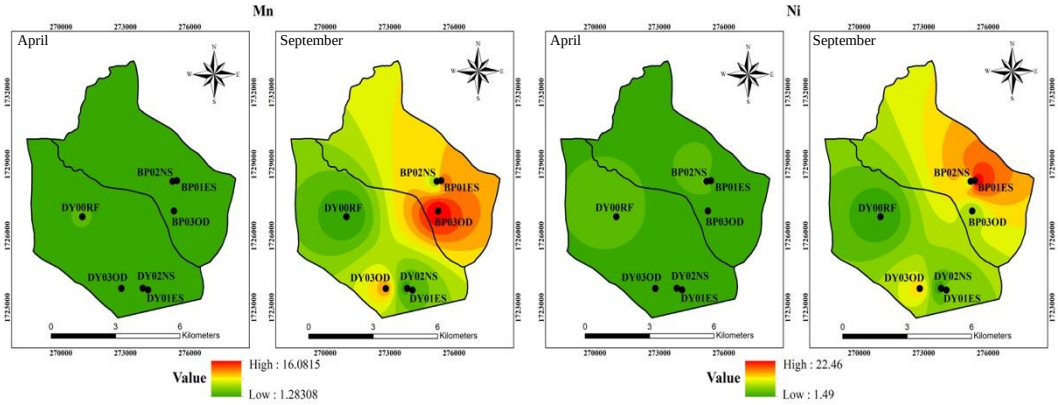
The investigation of temporal distribution helped to understand more about emission sources and the direction of the interested air pollutants with their concentration at different periods. Plus, this could assist in the background concentrations for the different time in this study area. The heavy metals concentration in detail has already been shown in section 4.2, so this section would be present in the map pattern to understand the differences between the two sampling periods. Figure 4.23 shows the temporal variation of heavy metals, including As, Cd, Cr, Ni, Mn, Pb, Zn, Fe, and total metals in $PM_{2.5}$ between April and September. This temporal distribution map was fixed at the same lowest and highest for both sampling periods, which made it easier to clearly classify the difference of each heavy metal concentrations between April and September. The difference of all heavy metals was clearly found in every area, and the concentration was found higher in September than in April. This higher concentration of these heavy metals in September suggests that there must be more intense activities, or there was more than one major source in September for this e-waste community.



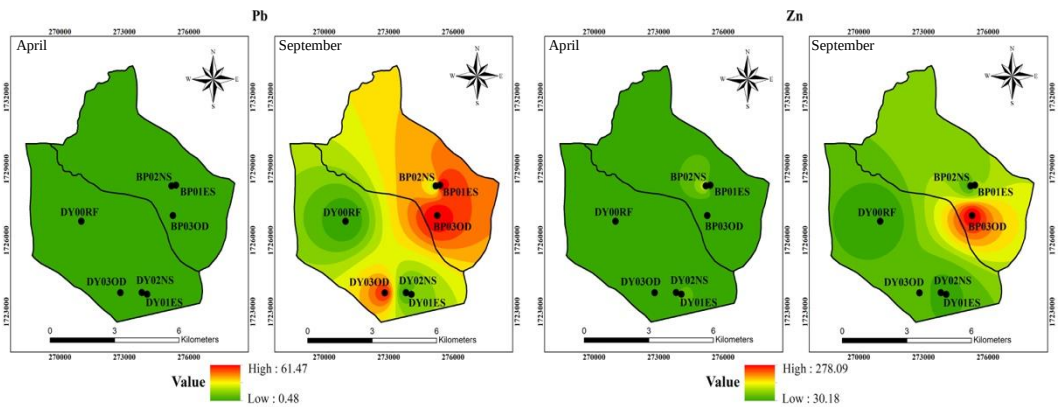
(a) As (b) Cd



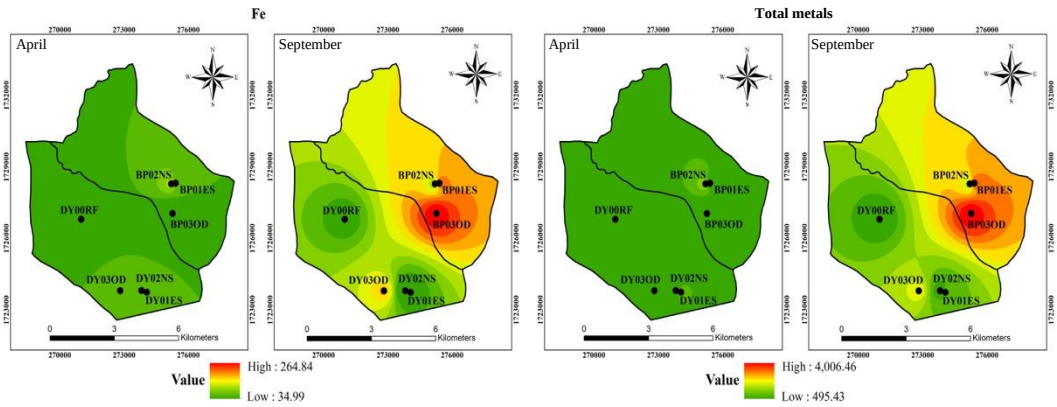
(c) Cr (d) Cu



(e) Mn (f) Ni



(g) Pb (h) Zn



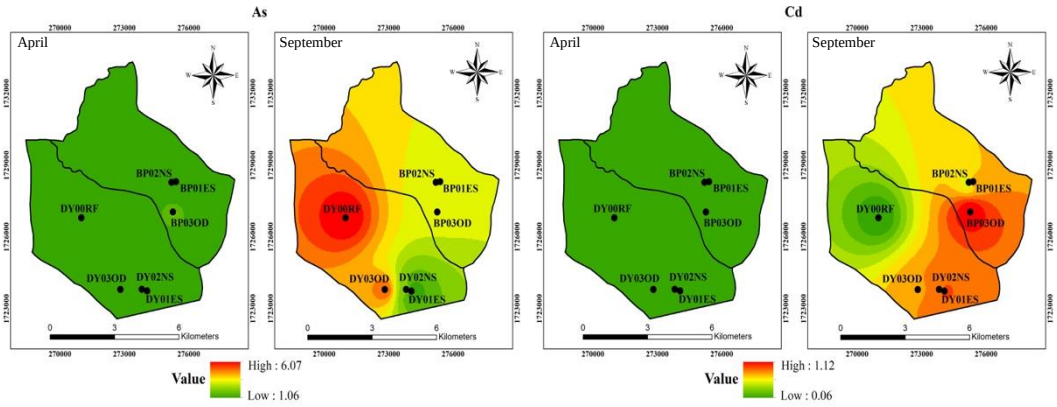
(i) Fe (j) Total metals

Figure 4.23 Temporal variation of As (a), Cd (b), Cr (c), Cu (d), Mn (e), Ni (f), Pb (g), Zn (h), Fe (i), and total metals (j) in $PM_{2.5}$

The temporal variation of heavy metals in PM_{10} between April and September can be seen in Figure 4.24. The results show that all heavy metals except Zn were clearly lower levels during April s, while Zn was the only metal that was higher in April than September but not significantly different. This pattern of temporal variation of PM_{10} was similar to $PM_{2.5}$, and it clearly shows that the meteorological condition in different within this sampling area might have an influence on heavy metals concentration in both $PM_{2.5}$ and PM_{10}. According to previous studies, the meteorological conditions, as mentioned above, can influence on increasing or decreasing the PM concentrations (Gangwar et al., 2016a; Outapa & Ivanovitch, 2019; G. Xu et al., 2017).

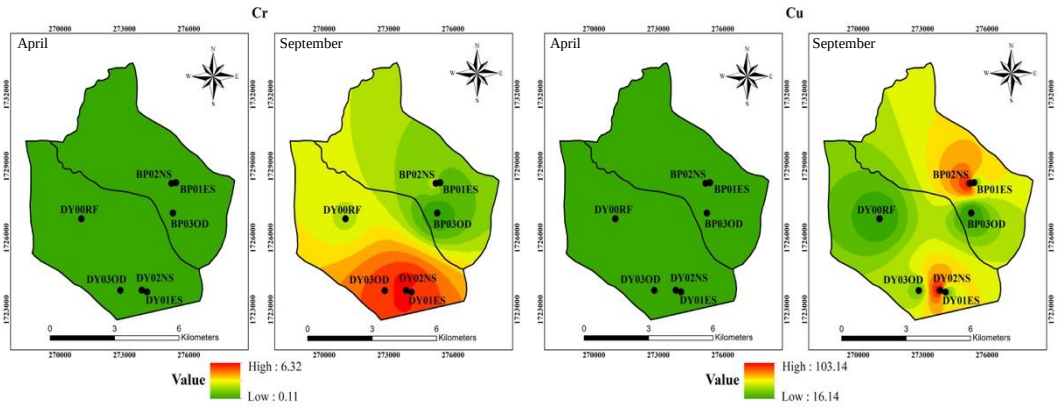
The multivariate linear regression analysis with the stepwise model was used to investigate their relationship, and the result for $PM_{2.5}$ and PM_{10} are shown in Table 4.20 and Table 4.21. The multiple regression result in Table 4.20 was shown that only temperature has statistically significant on decreasing Ni (β_1 = -0.975), Zn (β_1 = -9.114), and Fe (β_1 = -11.218) at 95% confidence level. However, it was low influenced, which cover about 7.80%, 8.50%, and 9.90% on those concentrations in

$PM_{2.5}$ variation, respectively. For As, Cd, Cu, and Pb, regression results show statistically significant of temperature (β_1 = -0.300, -0.177, -2.282, and -5.765, respectively) and relative humidity (β_2 = -0.006, -0.029, -0.804, and -0.346, respectively) on reducing those metals in $PM_{2.5}$. Meanwhile, wind speed and temperature were found statistically significant in decreasing Cr levels in $PM_{2.5}$ (β_1 = -3.480 and β_2 = -0.679, respectively), but it was about 12.40%, which considered as a low influenced. Lastly, wind speed, temperature and relative humidity were found statistically significant on diminishing Mn contaminated in $PM_{2.5}$ (β_1 = -2.493, β_2 = -1.469, and β_3 = -0.324, respectively). From this multiple regression could indicate that only As, Cd, and Mn have moderate influence of wind speed, temperature, and relative humidity on these levels in $PM_{2.5}$, which was about 41.30%, 47.20%, and 48.20%, respectively.



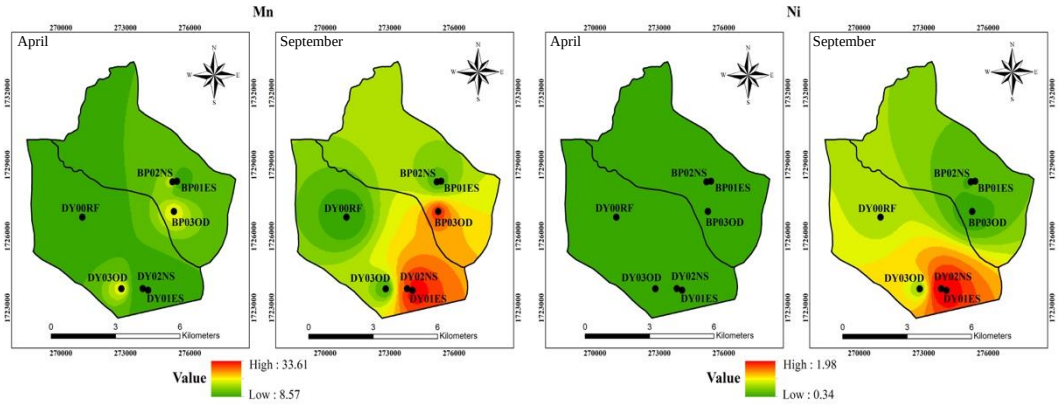
(a) As

(b) Cd

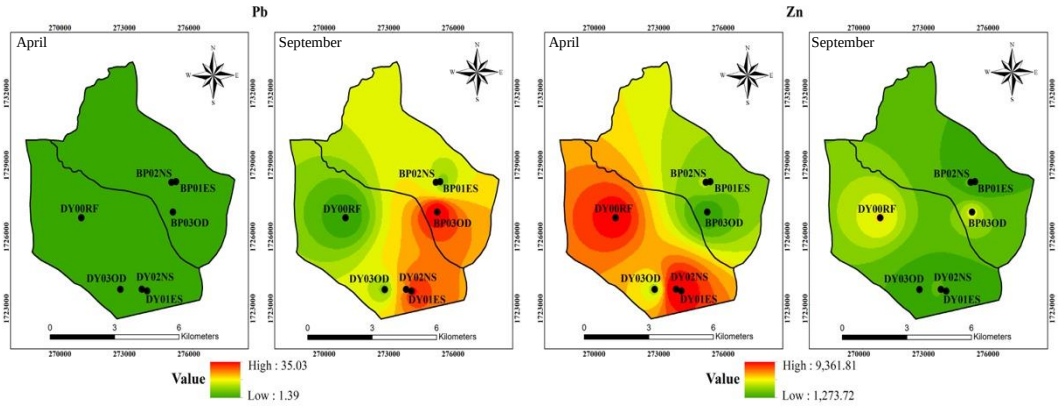


(c) Cr

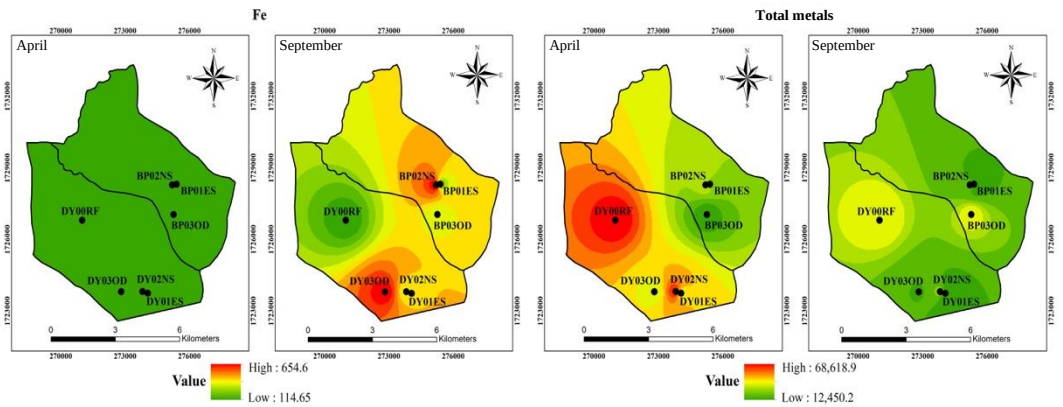
(d) Cu



(e) Mn (f) Ni



(g) Pb (h) Zn



(i) Fe (j) Total metals

Figure 4.24 Temporal variation of As (a), Cd (b), Cr (c), Cu (d), Mn (e), Ni (f), Pb (g), Zn (h), Fe (i), and total metals (j) in PM_{10}

The regression results of PM_{10} are shown in Table 4.21; it has been found statistically significant of temperature on decreasing As, Cr, Cu, Ni, and Fe concentration in PM_{10} (β_1 = -0.405, -0.681, -5.716, -0.122, and -50.187) but only Cr that has strong influence than the rest metals which about 55.00%. Conversely, the temperature was found statistically significant on increasing Zn in PM_{10} but had low influence, which was around 9.00%. Wind speed and temperature were statistically significant in reducing Pb in PM_{10} (β_1 = -10.451 and β_2 = -6.183). Meanwhile, wind speed, temperature, and relative humidity were found statistically significant influence on decreasing Cd contaminated in PM_{10}. But there was no regression result between Mn levels in PM_{10} and meteorological conditions. These multiple regression results of PM_{10} could signify that only Cd, Cr, and Pb have a moderate influence of wind speed, temperature, and relative humidity on these levels in PM_{10}, which was about 57.90%, 55.00%, and 49.60%, respectively.

Table 4.20 Multiple regression of heavy metals in $PM_{2.5}$ with meteorological parameters

Heavy metals	Equations	r^2	Sig
As	$PM_{2.5}$ = 1.381 - 0.300T - 0.006RH	0.413	<0.05
Cd	$PM_{2.5}$ = 7.747 - 0.177T - 0.029RH	0.472	<0.05
Cr	$PM_{2.5}$ = 28.651 - 3.480WS - 0.679T	0.124	<0.05
Cu	$PM_{2.5}$ = 131.346 - 2.282T - 0.804RH	0.208	<0.05
Mn	$PM_{2.5}$ = 73.792 - 1.469T - 0.324RH - 2.493WS	0.482	<0.05
Ni	$PM_{2.5}$ = 34.688 - 0.975T	0.078	<0.05
Pb	$PM_{2.5}$ = 286.554 - 5.765T - 1.434RH	0.346	<0.05
Zn	$PM_{2.5}$ = 362.214 - 9.114T	0.085	<0.05
Fe	$PM_{2.5}$ = 442.765 - 11.218T	0.099	<0.05

Table 4.21 Multiple regression of heavy metals in PM_{10} with meteorological parameters

Heavy metals	Equations	r^2	Sig
As	PM_{10} = 15.386 - 0.405T	0.067	<0.05
Cd	PM_{10} = 8.811 - 0.212T - 0.347WS - 0.021RH	0.579	<0.05
Cr	PM_{10} = 22.621 - 0.681T	0.550	<0.05
Cu	PM_{10} = 207.992 - 5.716T	0.183	<0.05
Mn	-	-	-
Ni	PM_{10} = 4.667 - 0.122T	0.156	<0.05
Pb	PM_{10} = 217.381 - 6.183T - 10.451WS	0.496	<0.05
Zn	PM_{10} = 456.746T - 8911.450	0.090	<0.05
Fe	PM_{10} = 1851.945 - 50.187T	0.270	<0.05

When integrated the results of the relationship between heavy metals and meteorological data and temporal variation of heavy metals in PMs, it was found that the precipitation did not influence the heavy metals, which similar to the regression results of PMs concentrations as mentioned in section 4.3.1. All these meteorological factors, including wind speed, temperature, and relative humidity, has a negative relationship with metals variation, especially As, Cd, Mn in $PM_{2.5}$ and Cd, Cr, Pb in PM_{10}. It was related to other studies which implied that the greater of wind speed, temperature, and relative humidity could cause the lower heavy metals concentrations (Aksu, 2015; Czernecki et al., 2016; X. Liu et al., 2017; Radzka, 2020; Vasilakos et al., 2006). This study area is a rural area that has e-waste dismantling activities operated almost every day, and the main possible sources of Zn might come from an e-waste dismantling processes, crop or agricultural combustion, or refuse incineration in April than September (Deng et al., 2006; johnson, 2011; Robinson, 2009; Vassanadumrongdee, 2015b). However, the influence of meteorological factors on metals levels in PMs in this study area could also be induced by other factors as mentioned before in section 4.1.3 for the PMs level, involving the amount of e-waste received to dismantling during that period or the occurrence of agricultural burning in that specific time.

These similar results of PM and heavy metals could also indicate that particulate matters act as media for heavy metals contaminated in ambient air. Thus, a meteorological condition that influences PM would have the same influence on heavy metals as well.

4.4 Composition of heavy metals in $PM_{2.5}$ and PM_{10}

For quantitative apportionment, the elemental compositions were also examined. Heavy metals content of As, Cd, Cr, Cu, Mn, Ni, Pb, Zn, and Fe in $PM_{2.5}$ and PM_{10} at reference, non-e-waste dismantling house, e-waste dismantling house, and open dump area were calculated and revealed in the unit of mg/g $PM_{2.5}$ and PM_{10} as shown in Table 4.22 and Table 4.23, respectively

Table 4.22 Heavy metals content in $PM_{2.5}$ (µg/g) collected from reference area, non-e-waste dismantling house, e-waste dismantling house, and open dump area.

Heavy metals (µg/g)	Reference area		Non-e-waste Dismantling house		E-waste Dismantling house		Open dump area	
	Mean ±SD	%	Mean ±SD	%	Mean ±SD	%	Mean ±SD	%
As	1.539 ±1.045	0.04	1.543 ±0.792	0.04	2.811 ±2.556	0.08	3.248 ±3.197	0.04
Cd	11.956 ±4.172	0.36	9.165 ±4.376	0.29	17.157 ±15.865	0.59	20.264 ±15.185	0.29
Cr	53.527 ±76.475	1.22	75.455 ±180.815	1.66	98.158 ±158.583	4.00	132.145 ±242.045	2.53
Cu	215.032 ±196.175	6.11	575.892 ±463.888	18.63	247.544 ±218.334	13.10	284.171 ±236.539	4.89
Mn	238.913 ±273.347	7.30	103.701 ±44.403	3.02	168.481 ±114.179	7.00	204.108 ±149.974	4.27
Ni	193.469 ±337.026	6.04	146.858 ±154.587	2.94	237.567 ±268.053	8.13	157.696 ±130.065	2.82
Pb	283.746 ±253.087	8.12	256.446 ±230.465	7.10	589.137 ±666.633	11.07	1159.918 ±885.620	18.39
Zn	1483.740 ±1121.289	36.89	3181.622 ±3341.224	22.38	3261.281 ±2528.051	24.65	2694.947 ±2726.748	27.92
Fe	1511.846 ±1607.527	33.92	3545.144 ±3518.657	43.95	4148.902 ±2381.408	31.39	4073.640 ±3086.206	38.86

The percent contribution of each heavy metal in $PM_{2.5}$ at all sampling sites, including reference area, non-e-waste dismantling house, e-waste dismantling house, and open dump in Table 4.22, shows that Zn had the highest compositions (36.89%)

along with Fe (33.92%) at reference area. While at non-e-waste dismantling house, e-waste dismantling house and open dump area had the highest composition of Fe (43.95%, 31.39%, and 38.86%, respectively). For reference area, the lower composition than Zn and Fe were Pb, Mn, Cu, and Ni with the content about 8.12%, 7.30%, 6.11%, and 6.04%, respectively. However, the other metals, including Cr, Cd, and As had a composition in $PM_{2.5}$ lower than 5%. Next, the component of Cu and Pb shows lower percentage than Zn and Fe, which were 18.63% and 7.10%, respectively, at non-e-waste area whereas the composition of Mn, Ni, Cr, Cd, and As shows lower than 5% (3.02%, 2.94%, 1.66%, 0.29%, and 0.04%, respectively). The composition of Cu, Pb, Ni, and Mn at e-waste dismantling house was 13.10%, 11.07%, 8.13%, and 7.00%, which lower than Zn and Fe. Whilst the composition of Cr, Cd, and As at those were 4.00%, 0.59%, and 0.08%, respectively, which lower than 5%. Lastly, the composition of heavy metals at open dump area shows only Pb compositions (18.39%) was lower than Zn and Fe while Cu, Mn, Ni, Cr, Cd, and As existed lower than 5% (4.89%, 4.27%, 2.82%, 2.53%, 0.29%, and 0.04%, respectively).

When compare the composition of each heavy metal in $PM_{2.5}$ between reference area, non-e-waste dismantling house, e-waste dismantling house, and open dump area as shown in Figure 4.25, the result shows all heavy metals except Zn and Fe were mostly higher at e-waste dismantling house than the others. This could indicate the impact of e-waste dismantling activities that might lead to the direct emission of those heavy metals within the e-waste dismantling house. When comparing the composition of Pb at those sampling sites, the results show a higher range more than other heavy metals at open dump area, which might reflect the open burning of e-waste component in that area. There were studies revealed that Pb was found commonly when heavy metals concentration in particulate matters were investigated at e-waste open burning site due to the burning of wires and PCBs (Deng et al., 2006; Gangwar et al., 2019; Gangwar et al., 2016a; Xue et al., 2012). Pb was also the main component that found in funnel glass of CRT monitor, so the higher content of Pb in this area could be a sequence of smashing activity of the funnel glass in CRT for separate the plastics and wires at the open dump area (Wenxiong Fang et al., 2013; johnson, 2011; Vassanadumrongdee, 2015b). For non-e-waste dismantling house, the major metals inferior to Zn and Fe was Cu. Usually in this study area, non-

e-waste dismantling house was located randomly nearby e-waste dismantling house so, the spreading of heavy metals could normally disperse around from e-waste dismantling house to non-e-waste area. But other heavy metal sources especially Cu was also come from cooking by using charcoal; there was found that BBQ charcoal and charcoal burning could emit the Cu and disperse to other areas (Kabir et al., 2011; Susaya et al., 2010).

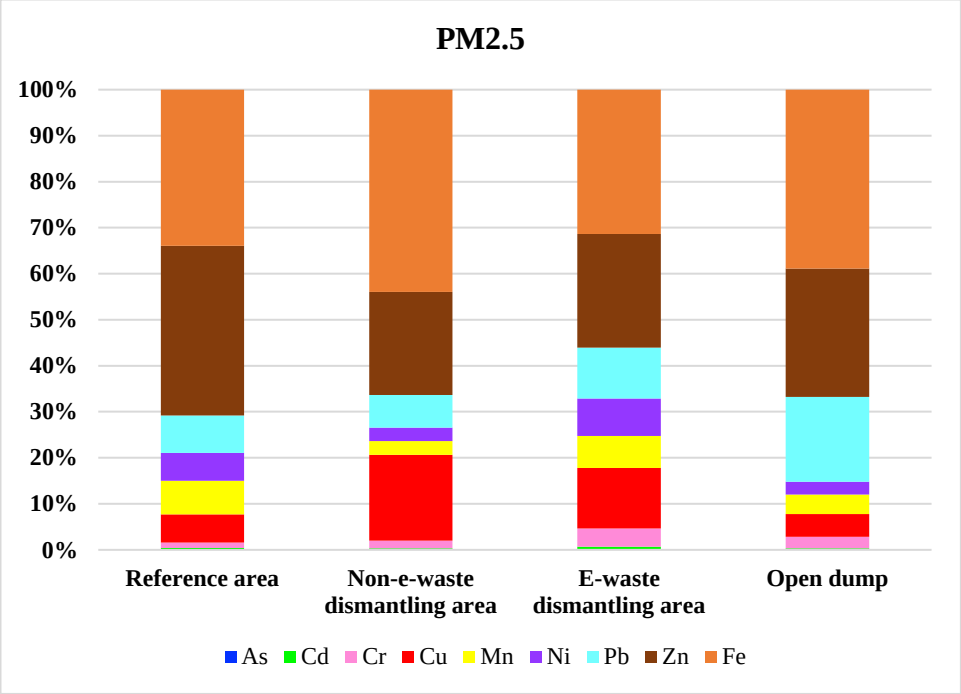


Figure 4.25 Composition of each heavy metals (%) in $PM_{2.5}$ at reference area, non-e-waste dismantling house, e-waste dismantling house, and open dump area

From Table 4.23, the content of Zn in PM_{10} shows the highest proportion at reference area, non-e-waste dismantling house, e-waste dismantling house, and open dump area, which accounted for 96.04%, 89.48%, 78.67%, and 91.14%, respectively. Only the reference area that all heavy metals except Zn had low composition (<5%). While the content of Fe at non-e-waste dismantling house (8.67%), e-waste dismantling house (18.04%), and open dump area (7.13%) had composition inferior the Zn content but higher than 5%. On the other hand, except Zn and Fe, the rest of heavy metals at e-waste dismantling, non-e-waste dismantling, and open dump area had composition lower than 5%.

Table 4.23 Heavy metals content in PM_{10} (µg/g) collected from reference area, non-e-waste dismantling house, e-waste dismantling house, and open dump area

Heavy metals	Reference area		Non-e-waste Dismantling house		E-waste Dismantling house		Open dump area	
	Mean ±SD	%	Mean SD	%	Mean SD	%	Mean SD	%
As	66.741 ±72.693	0.06	47.266 ±65.128	0.03	41.681 ±70.140	0.10	57.550 ±78.344	0.03
Cd	11.019 ±9.859	0.01	9.186 ±8.205	0.01	9.973 ±8.916	0.02	9.061 ±9.536	0.02
Cr	43.911 ±30.030	0.04	32.942 ±44.585	0.05	15.982 ±27.631	0.05	24.691 ±41.337	0.04
Cu	552.879 ±173.366	0.37	862.470 ±634.991	0.91	530.489 ±197.023	1.31	461.111 ±249.711	0.59
Mn	307.750 ±94.054	0.22	350.449 ±124.696	0.45	379.915 ±110.334	1.07	342.195 ±112.542	0.56
Ni	28.328 ±14.990	0.02	20.151 ±11.173	0.03	19.767 ±8.032	0.06	12.615 ±7.254	0.02
Pb	296.291 ±308.781	0.32	259.098 ±263.122	0.36	282.674 ±262.951	0.67	235.401 ±263.110	0.46
Zn	265890.646 ±164464.192	96.04	174934.565 ±125993.167	89.48	139211.937 ±115332.411	78.67	114571.741 ±74478.347	91.14
Fe	4238.976 ±2607.560	2.92	5843.833 ±3031.569	8.67	5575.270 ±3630.592	18.04	4373.764 ±2925.486	7.13

When the composition of heavy metals in PM_{10} at all sampling sites were compared, the result shows similar content as displayed in Figure 4.26. Nevertheless, if the composition of all metals was fixed at 5% maximum as shown in Figure 4.27, the contributions of all heavy metals (e.g., As, Cd, Cr, Cu, Mn, Ni, Pb, Zn, and Fe) were shown clearly highest at e-waste dismantling house and lowest at reference area. From this result, a greater proportion of such metals might also correspond to the e-waste dismantling activities such as smashing e-waste component to separate the precious part (motors, wires, plastics). However, Cu and Mn composition were found the highest at e-waste dismantling house, which could be affected by the dispersion of heavy metals from e-waste dismantling activities, including the separating of PCBs,

CD players, hard disks, and iron and steel, which usually contain Mn (Wenxiong Fang et al., 2013; Oguri et al., 2018; Singh et al., 2018; Vassanadumrongdee, 2015b; Zeng et al., 2016). There was also Cu contented in PM_{10} at non-e-waste and open dump area that has higher composition than other metals but inferior Zn and Fe. Similar to Cu content, Pb composition was also found high content inferior to the Cu, but it was still the highest composition at e-waste dismantling house. The PCBs contain Cu and Pb, and it is used as a component for almost every electrical appliances (Bi et al., 2010; Olubanjo et al., 2015; Vassanadumrongdee, 2015b; Xue et al., 2012). This high Cu and Pb contribution in PM_{10} was similar to the contribution at those workers who were exposed in the study of airborne Cd, Cu, Ni and Pb that e-waste dismantling workers exposed in Buriram, Thailand. Thus, the higher composition of all heavy metals at non-e-waste dismantling and open dump area might be due to the e-waste dismantling activities near its location (Puangprasert & Prueksasit, 2019).

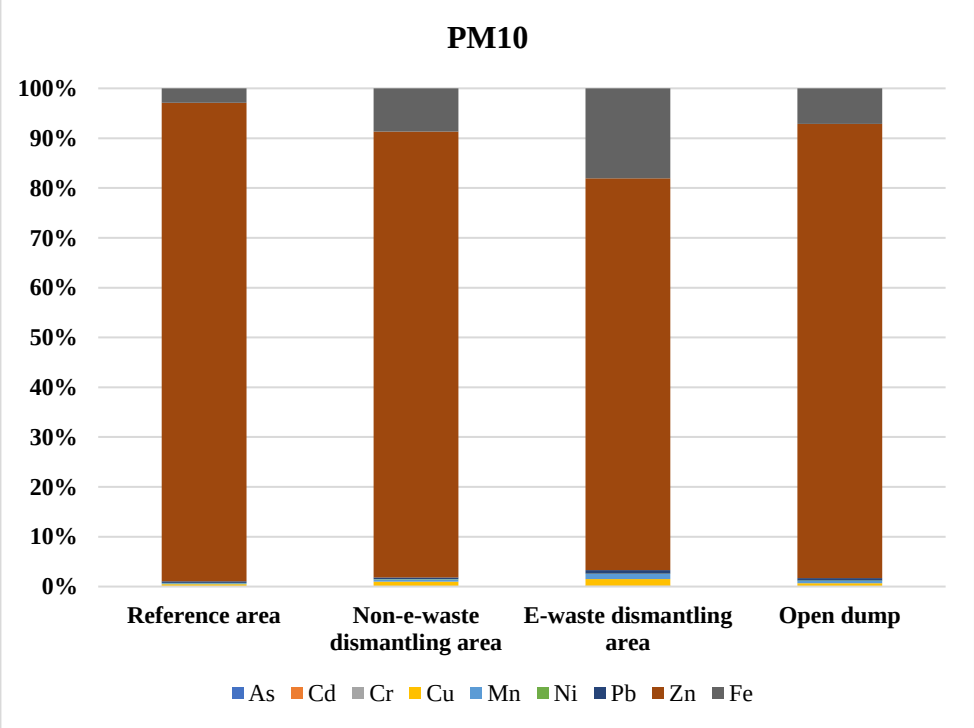


Figure 4.26 Composition of each heavy metals (%) in PM_{10} at reference area, non-e-waste dismantling house, e-waste dismantling house, and open dump area

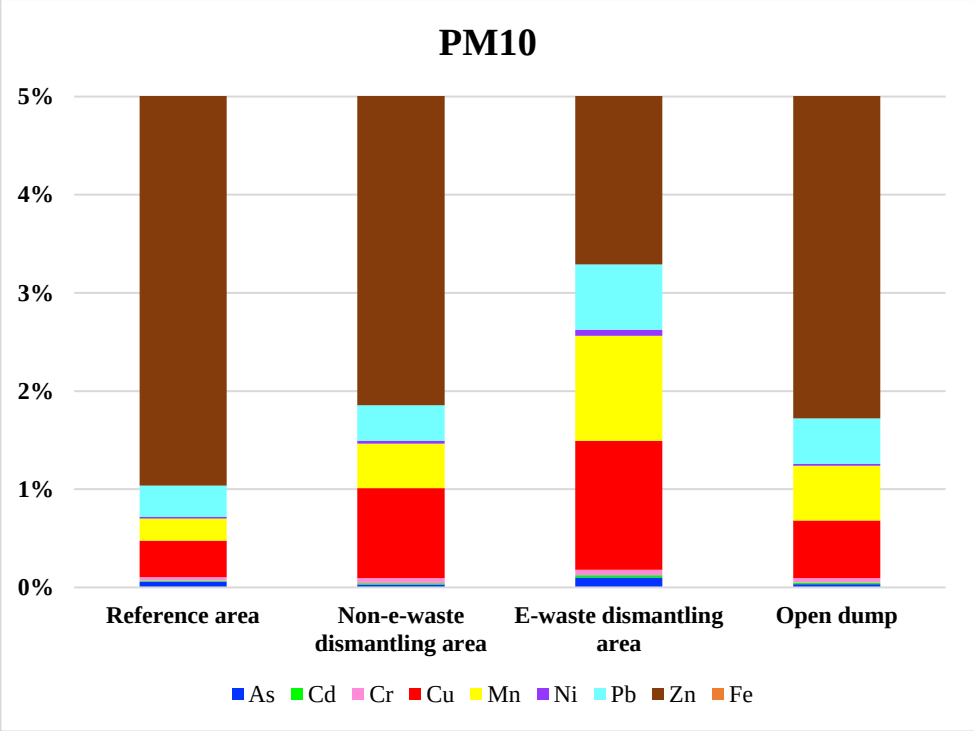


Figure 4.27 Composition of each heavy metals (%) in PM_{10} at reference area, non-e-waste dismantling, e-waste dismantling, and open dump (5% maximum fixed)

From the overall results of heavy metals content in both $PM_{2.5}$ and PM_{10}, it indicates that e-waste dismantling activities were deliberated an important heavy metals source in this study area. The difference between heavy metal content in $PM_{2.5}$ and PM_{10} might be due to the different sizes of PMs, which $PM_{2.5}$ has fined size than PM_{10}, so the major source of heavy metals content in $PM_{2.5}$ probably comes from burning activity. Whilst PM_{10} major source might come from soil dust and smashing e-waste components activities. Additionally, this result showed that heavy metals from e-waste dismantling activities could disperse to non-e-waste dismantling houses and open dump area as well.

4.5 Potential source identification of heavy metals in $PM_{2.5}$ and PM_{10}

The principal component analysis (PCA) is a multivariate statistical approach that can be used to identify possible sources of airborne metals. The complexity in high-dimensional of heavy metal data would be simplified while retaining trends and patterns by transforming the data into fewer dimensions or new significant variables called principal component (PC), and each common factor represents different sources (Chang et al., 2009; Lever et al., 2017). The PCA would then be implemented to identify profiles of heavy metals in $PM_{2.5}$ and PM_{10}. In this study, the SPSS program (version 22) was used to analyze PCA with varimax rotation.

The PCA result of heavy metals in $PM_{2.5}$ is shown in Table 4.24, and there was only one principal component (PC). There was explained 60.87% of the total variance, and their factor loadings were As (0.945), Mn (0.916), Cd (0.900), Pb (0.0.862), and Fe (0.775), Zn (0.708), Ni (0.654), Cu (0.594), and Cr (0.555). Within these metals in PC1, if the difference of factor loading between metals was less than 0.100, it could be considered as co-metals derived from the same source. From Table 4.24, the co-metals could be grouped as As-Mn, Cd-Pb, Fe-Zn, Ni-Cu-Cr.

For the PCA analysis of PM_{10}, the factor loading scores are summarized in Table 4.25 and shown in Figure 4.28. There were two principal components; PC1 was explained 57.71% of total variance, including Pb (0.901), Ni (0.887), Mm (0.885), Cd (0.857), Cr (0.788), As (-0.629), and Zn (-0.451), while PC2 contained Fe (0.857) and Cu (0.720). The co-metal found in PM_{10} for PC1 was Pb-Ni-Mn-Cd, while Cr, As, and Zn was isolated metals, and Fe-Cu was a co-metal in PC2.

Table 4.24 Principal components analysis of heavy metals in $PM_{2.5}$

Metals	PC1
	% Variance = 60.87
	Factor loading
As	0.945
Mn	0.916
Cd	0.900
Pb	0.862

Metals	PC1
	% Variance = 60.87
	Factor loading
Fe	0.775
Zn	0.708
Ni	0.654
Cu	0.594
Cr	0.555

Table 4.25 Principal components analysis of heavy metals in PM_{10}

Metals	PC1	PC2
	% Variance = 57.71	% Variance = 17.77
	Factor loading	Factor loading
Pb	**0.901**	0.309
Ni	**0.887**	0.094
Mn	**0.885**	0.035
Cd	**0.857**	0.343
Cr	**0.788**	0.375
As	**-0.629**	0.622
Zn	**-0.451**	-0.138
Fe	0.287	**0.857**
Cu	0.288	**0.720**

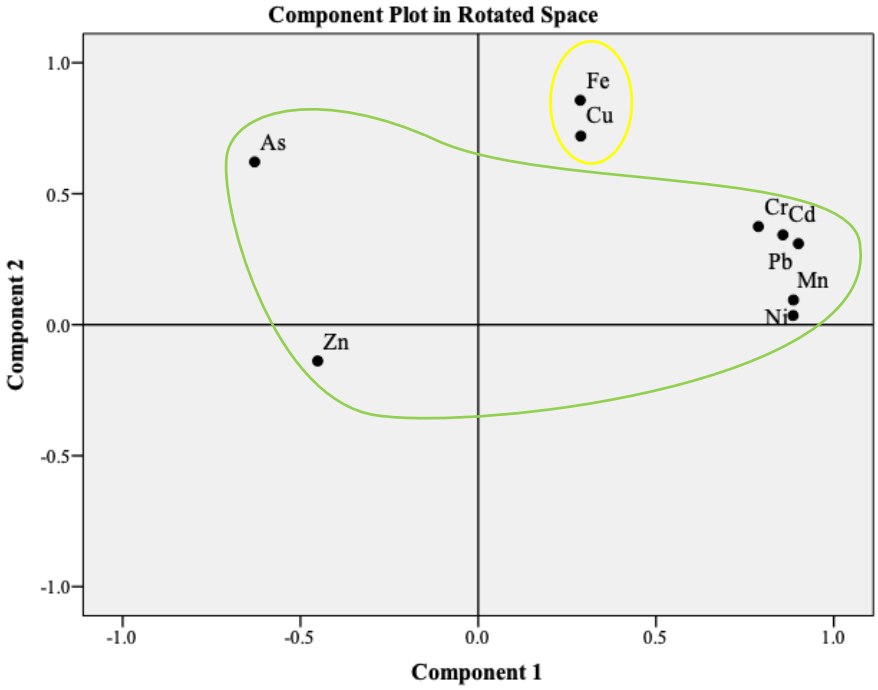


Figure 4.28 Principal component analysis of heavy metals in PM_{10} at the e-waste dismantling house

Table 4.26 Classification of heavy metals sources in $PM_{2.5}$ and PM_{10} based on the data of previous studies.

Sampling sites	Natural	Anthropogenic			
		E-waste dismantling activities	Open burning of e-waste	Refuse incineration	Automobile
Previous studies*	Cd, Ni, Cr, Al, Zn, Fe, Mn, As, V, Co	Sb, As, Ba, Be, Cd, Cr, Cu, Pb, Ni, Zn, Fe, Li	Zn, Cu, Pb, Cr, Ni	K, Zn, Pb, Sb, Cr, Co	Br, Ce, La, Pt, Cd, Cu, Pb, Ni, Cr, Mn, Co
$PM_{2.5}$ -PC1	As-Mn, Fe-Zn	Cd-Pb, Fe-Zn, Ni-Cu-Cr	Ni-Cu-Cr	-	Cd-Pb, Ni-Cu-Cr
PM_{10} - PC1 - PC2	Cr, As, Zn -	Pb-Ni-Mn-Cd, Cr, As, Zn Fe-Cu	-	-	Pb-Ni-Mn-Cd

*(Bi et al., 2010; Deng et al., 2006; Gangwar et al., 2019; Oguri et al., 2018; Singh et al., 2018; Vassanadumrongdee, 2015b; Xue et al., 2012; Zeng et al., 2016)

The classification of heavy metal in $PM_{2.5}$ and PM_{10} in this study area corresponding to possible sources was examined by comparing with source identification of the metals reported by some previous studies, as shown in Table 4.26. For the result of $PM_{2.5}$, the metals in PC1 mainly came from e-waste dismantling activities, including Cd-Pb, Fe-Zn, and Ni-Cu-Cr. Cd and Pb were also

found together in dust from the e-waste recycling area in Qinyuan village, Guangzhou city, China. This study showed PCA analysis, which has found Cd and Pb loadings were similar to the loading of octa- brominated diphenyl ethers (BDE) and deca-BDE, which have found in circuit boards and electricity meter, indicating that Cd-Pb in PC1 was also released from e-waste dismantling activities (He et al., 2017). Whilst not only Ni-Cu-Cr has found at e-waste dismantling activities but also from open burning of e-waste and automobile sources. There were some studies also indicated the contamination of these metals including Ni-Cu-Cr was from e-waste dismantling activities, but only Ni and Cu that has found the higher level at e-waste burning activities (Deng et al., 2006; Gangwar et al., 2016a; Vassanadumrongdee, 2015b; Wu et al., 2016). The possible sources of Fe and Zn could be either natural or e-waste dismantling activities, in which those levels were found relatively high in ambient air as the background and also additionally emitted from the disassembly of e-waste components such as hard disk, circuit boards, CRT screen (Chanthahong & Kanghae, 2017; B. Thongriw, 2015; V. Tyagi, Gurjar, B. R., Joshi, N., & Kumar, P.,, 2012). Lastly, As-Mn could be identified as the co-metals from a natural source similar to previous studies that reveal the Mn was the primary metal in soil (Fujimori et al., 2012; Lee & Hieu, 2011; K. Liu et al., 2017).

The possible sources of the heavy metals in PM_{10} were also identified based on the data of previous studies, as shown in Table 4.26. It could be explained that the metals in PC1 largely came from e-waste dismantling activities, including Pb-Ni-Mn-Cd, Cr, As, and Zn. The co-metals of Pb-Ni-Mn-Cd were found similar to that of $PM_{2.5,}$ especially Pb and Cd. Moreover, these metals have possibility originated from automobile source as well. There was a study about PCA analysis of heavy metals in indoor and outdoor dust at a family-run e-waste workshop in Wenling City, China, that gave similar heavy metals loading in component 1. The result has shown that component 1 had high loadings on Cr, Mn, Ni, Zn, and Cd, which indicates a common source in this group originating from e-waste dismantling activities (F. Xu et al., 2015). Meanwhile, Cr, As, and Zn might also be initiated from natural sources, especially Zn that is found plentiful in crustal soil (Kong et al., 2012; Wuana & Okieimen, 2011). While in PC2, Fe-Cu was identified to come from e-waste dismantling activities only which responding to other studies results that were found

higher Fe and Cu in PM at e-waste recycling; in particular, Cu was highly found in electronic wires (Adaramodu A. A., Osuntogun A. O., & Ehi-Eromosele C. O., 2012; Gangwar et al., 2016a; Wu et al., 2016).

With respect to the result explained above, the potential sources of heavy metals in $PM_{2.5}$ and PM_{10} collected in ambient air at the e-waste dismantling community (e-waste dismantling house, non-e-waste dismantling house, and open dump area) and reference area could be classified in two major sources, including e-waste dismantling activities (anthropogenic source) and natural sources. This finding could be implied that even though the non-e-waste dismantling house did not have any e-waste dismantling activities, but it might be affected by the dispersion of some heavy metals from e-waste dismantling activities nearby. In addition, there were some other sources like from open burning of e-waste and automobile sources that could influence the contribution of heavy metals in the surrounding area as well.

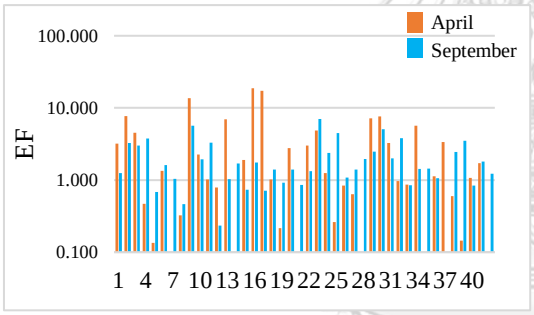
4.6 Enrichment factor (EF) analysis of heavy metals in $PM_{2.5}$ and PM_{10}

Enrichment factor (EF) was used in this study to identify whether anthropogenic sources possibly cause the elevation of heavy metal. EF was calculated for each elemental species based on the actual concentration in the environment using the reference element. In this study, Manganese (Mn) was applied in the EF calculation as a reference metal, which was often used to evaluate the source of metals that initiated from crustal or anthropogenic sources (Deely & Fergusson, 1994; Pant et al., 2015; Srithawirat et al., 2016). The average Mn concentration in particulate matters for this analysis was obtained from the concentrations measured at the reference area, Wat E Sarn primary school in Daengyai. The interpretation of EF at the value of higher than 1 (> 1) would then be considered as an identifying criterion of the significant contribution of target elements to the ambient air from additional anthropogenic sources.

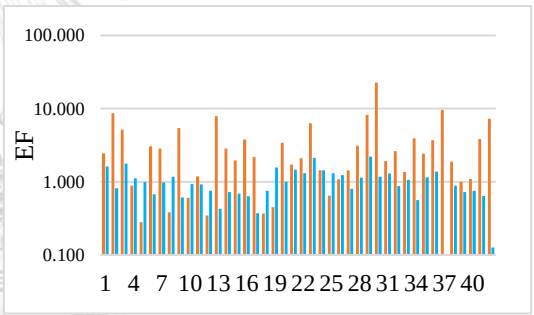
The EF analysis results of heavy metal in $PM_{2.5}$ at all sampling sites (e-waste dismantling, non-e-waste dismantling, and open dump area) by using Mn as a reference element is shown in Figure 4.29 (Enrichment factors of all heavy metals in $PM_{2.5}$ are shown in Appendix G-1). The EF of the metals in $PM_{2.5}$ was shown mostly higher than one, including As (66.67% of total), Cd (61.90%), Cu (66.67%), Ni (69.05%), Pb (55.95%), and Zn (50.00%) (EF > 1), which indicate the contribution possibility of such metals from e-waste dismantling activities. Interestingly, As, Cd, Ni, and Cu were enriched in the ambient air of the study areas higher than other metals. E-waste dismantling could be considered as an additional contribution source of Cd, Ni, and Cu because they are contained in e-waste components such as batteries, circuit boards, plastics, electric wires, CRT screens, and motor (Olubanjo et al., 2015; M. D. J. Uddin, 2012; Vassanadumrongdee, 2015b). For high enrichment of Cu as displayed in Figure 4.29, this result was similar to that of high EF found in another study at the e-waste community area, indicating this heavy metal was elevated from humans activities (F. Xu et al., 2015). For As, it was usually detected in the e-waste dismantling house in this studied community, but it was also found in coal and oil burning, circuit boards, plasma screen, and there are e-waste activities such as smashing CRT screen, plasma screen before separating the inner parts which could penetrate into the ambient air within this area (Chanthahong & Kanghae, 2017).

Although Pb and Zn were low enrichment, they were still considered to come from an anthropogenic source. There were some studies found Zn and Pb at e-waste burning site, which indicated the opportunity of Pb and Zn contributed to the surrounding environment (Gangwar et al., 2019; Gangwar et al., 2016a; Gullett et al., 2007; Y. Wang et al., 2017).

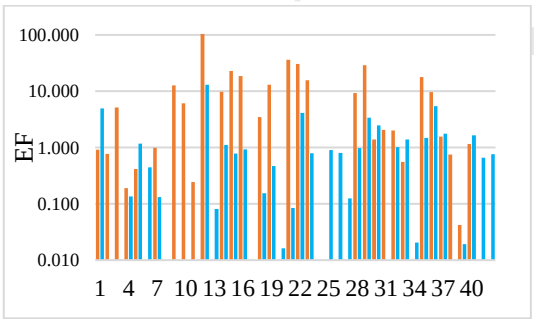
Whereas the elements with EF < 1, such as Cr (40.48% of total) and Fe (38.10%), were possibly donated from a crustal source. Cr and Fe can be generally found in natural ambient air in the rural area (Jampahom, 2016; K. Liu et al., 2017; B. Thongriw, 2015). Nonetheless, both metals still have the possibility of releasing from other anthropogenic sources such as oil burning and road dust (johnson, 2011; V. Tyagi, Gurjar, B. R., Joshi, N., & Kumar, P.,, 2012).



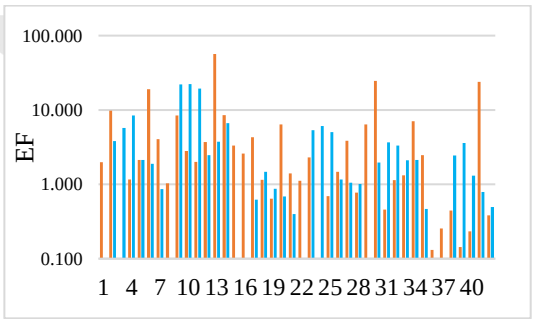
As



Cd



Cr



Cu

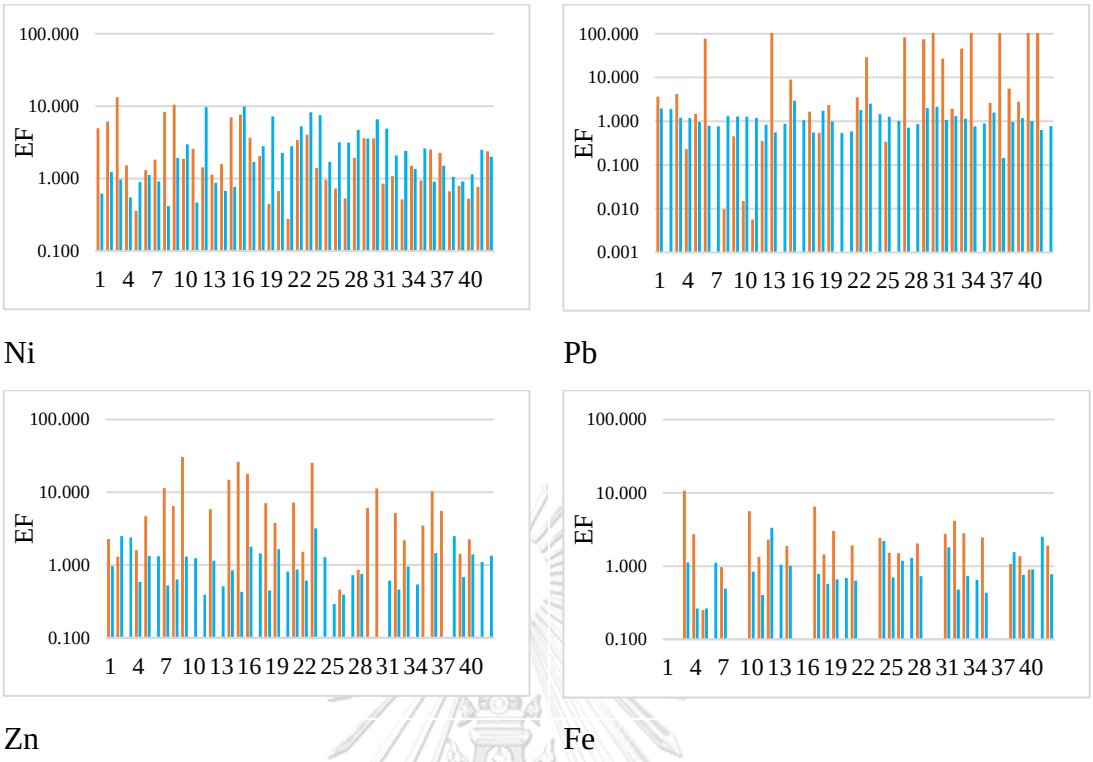
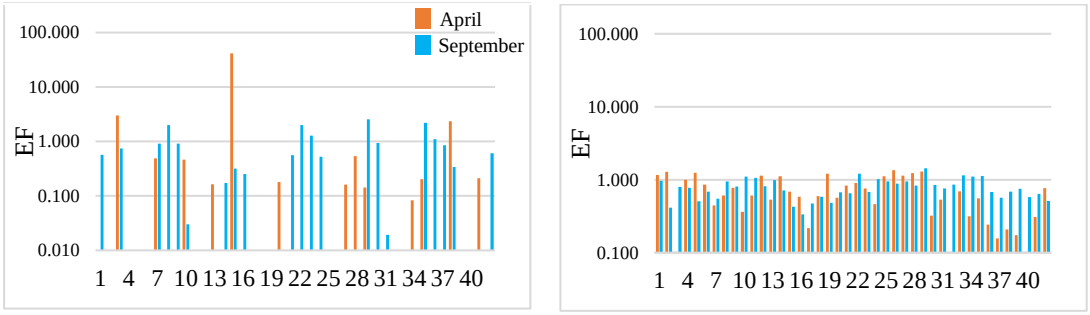


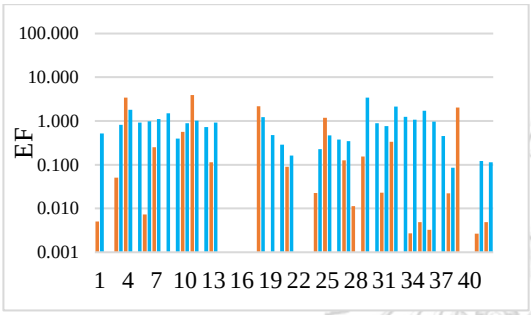
Figure 4.29 Enrichment factors of As, Cd, Cr, Cu, Mn, Ni, Pb, Zn, and Fe in $PM_{2.5}$

Enrichment factors of heavy metals in PM_{10} at all sampling sites are shown in Figure 4.30 (Enrichment factors of all heavy metals in PM_{10} are shown in Appendix G-2). The EFs of Fe and Cu in PM_{10} were presented higher than 1 (EF > 1) much more frequency than those of other metals, which suggests their contribution from some additional anthropogenic sources. With respect to the results of PCA as mentioned before, Fe-Cu could be identified to derive from e-waste dismantling activities. However, As, Cd, Cr, Ni, Pb, and Zn in PM_{10} could not clearly remark that they have totally come from natural sources because the calculation of EF in this study was based on the metals determined in the reference area, which might have other distribution sources of heavy metals, e.g., refuse open burning and automobiles. Responding to the information mentioned, these heavy metals in PM_{10} (As, Cd, Cr, Ni, Pb, and Zn) could initiate from both natural and other sources within this area.

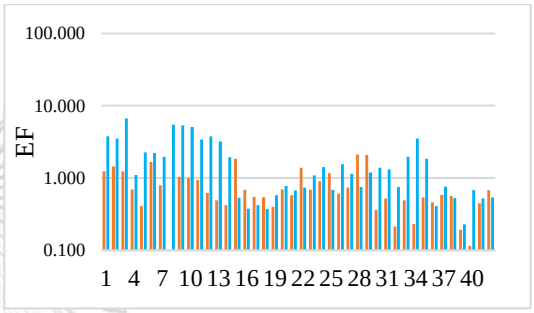


As

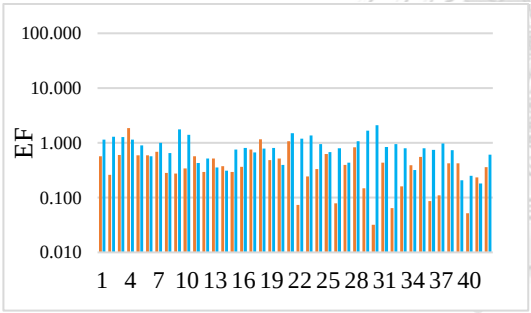
Cd



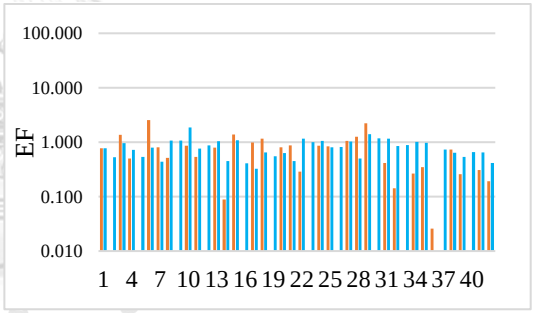
Cr



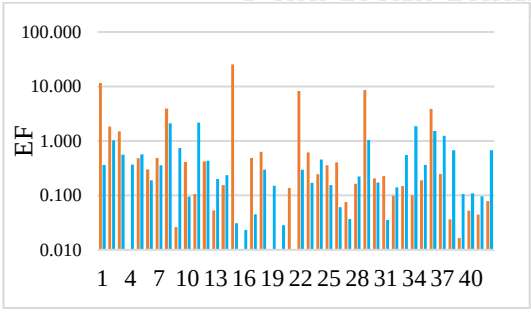
Cu



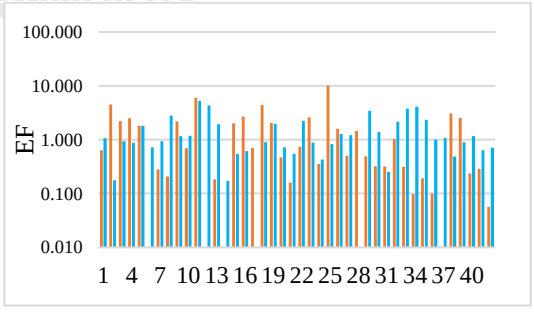
Ni



Pb



Zn



Fe

Figure 4.30 Enrichment factors of As, Cd, Cr, Cu, Mn, Ni, Pb, Zn, and Fe in PM_{10}

Furthermore, both analysis results of PCA, as seen in Table 4.26. in section 4.5, and of EF, as shown in Figure 4.29 and Figure 4.30, were integrated to identify

and summarize the potential sources of all studied metals. On the basis of the EF value higher than one combined with the PCA identified as anthropogenic sources, the possible sources of target metals would then be originated from additional human-made activities like the activities related to e-waste dismantling and open burning of e-waste in this study area. The integrated results (Table 4.27) show that Fe and Cr in $PM_{2.5}$ were originated from a natural source, while those of As, Cd, Cu, Ni, Pb, and Zn could be initiated from e-waste dismantling and open burning activities, and automobile source in this area. However, the results of PCA have shown that Cr in PC1 cannot be ignored, so Cr was considered as a metal that existed in this background environment. For PM_{10}, Cr, As, Zn, Pb, Ni, and Cd were originated from natural due to the previous study of heavy metal in PM_{10} was also found these heavy metal both non- and e-waste dismantling houses (Chanthahong & Kanghae, 2017). At the same time, Fe and Cu were elevated from e-waste dismantling activities. Anywise, Pb, Ni, and Cd, which has EF lower than 1 but they have contained in PC1 of PCA result, could not be negligible. Thus, Pb, Ni, and Cd in PM_{10} were speculated that they already had existed in the background environment in this study area.

Table 4.27 Identification of potential sources of heavy metals in $PM_{2.5}$ by comparison PCA and EF results.

Sampling sites	Natural sources	Existing metal in the background environment	Additional anthropogenic sources		
			E-waste dismantling activities	Open burning of e-waste	Automobile
$PM_{2.5}$	Fe	Cr	As, Cd, Cu, Ni, Pb, and Zn	Ni, Cu	Cd, Pb, Ni, Cu
PM_{10}	Cr, As, Zn	Pb, Ni, Cd	Fe, Cu	-	-

Consequently, various heavy metals in $PM_{2.5}$ had been elevated in the ambient air from activities related to e-waste disassembly and automobile combustion. Whilst those appeared in PM_{10} were considerable to come from natural or soil resuspension and other background activities than e-waste dismantling activities.

All the results in this study could indicate that e-waste dismantling activities were the main anthropogenic source of heavy metals in PMs in this e-waste community area. $PM_{2.5}$ was found the greater contribution of heavy metals than $PM_{10.}$ Due to their fine particle size, the e-waste dismantling workers should be recommended to use the personal protective equipment such as particulate respirators mask, which helps to reduce the exposure to heavy metals via inhalation. From the spatial variation of heavy metals in PM, heavy metals had been found not only at the e-waste dismantling house but also at non-e-waste dismantling and reference areas. Further, there is one more critical area, which is an open dump area that the e-waste dismantling and e-waste burning still be implemented, so not only e-waste workers but also all residents within this study area should concern about exposure to heavy metals contaminated in PM as well. Moreover, the local administrative office of the community should provide an e-waste dismantling and e-waste residue storage areas located far away from the residential area to prevent emission possibility of heavy metals to the ambient air around the community.

CHAPTER V
CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

$PM_{2.5}$ and PM_{10} concentrations in the ambient air at e-waste dismantling communities, Banmaichaiyaphot and Phutthaisong District, Buriram province were investigated during April (28 April - 4 May 2019) and September (25 September - 2 October 2019). E-waste dismantling and the surrounding area, including non-e-waste dismantling, open dumping area in Daengyai and Banpao Subdistrict, and reference area in Daengyai, Buriram province. The collection of PM had been performed for 24 hours at each sampling site for 7 days consecutively. Heavy metals contamination in $PM_{2.5}$ and PM_{10}, including As, Cr, Cu, Cd, Ni, Mn, Pb, Fe, and Zn, were analyzed to compare between each site and s. The spatial and temporal variation of heavy metals concentration in $PM_{2.5}$ and PM_{10} observed in April and September were also investigated. Moreover, enrichment factors and PCA analysis were used to identify potential sources of these heavy metals. The overall results could be concluded as follows:

5.1.1. Spatial and temporal variation of $PM_{2.5}$ and PM_{10}

(1) Average $PM_{2.5}$ level at the open dump (20.4 ±6.0 μg/m^3) area was highest in April and followed by those of non-e-waste dismantling house, e-waste dismantling house. While in September, $PM_{2.5}$ was highest at non-e-waste dismantling (49.5 ±13.7 μg/m^3) area and followed by e-waste dismantling house, open dump area, respectively. The results showed a significant difference ($p<0.05$) only between $PM_{2.5}$ level at the open dump area and references area in April. While in September, $PM_{2.5}$ levels were found a significant difference between non-e-waste dismantling house and open dump area, and between non-e-waste dismantling house and reference area.

(2) For PM_{10} levels, the results showed the highest concentrations at open dump area in April (49.8 ±12.9μg/m^3) and September (65.4 ±18.4 μg/m^3), and followed by non-e-waste dismantling house, e-waste dismantling house and reference area. In April, there was a statistically significant difference in open dump area with e-waste dismantling house, non-e-waste dismantling house and reference area.

However, there was a significant difference only between the open dump area and reference area in September.

(3) Pearson's correlation results show significant correlations between $PM_{2.5}$ at e-waste dismantling house and non-e-waste dismantling house, e-waste dismantling and reference areas in April, while that of the open dump had a strong correlation with those areas in September. For the correlation results of PM_{10}, the PM_{10} at both e-waste dismantling and open dump areas gave a significant contribution to non-e-waste and reference areas in April and September.

(4) The ambient temperature had influenced on $PM_{2.5}$ concentrations (r = -0.745 to -0.843) in this study area. For PM_{10} concentrations at e-waste dismantling house, non-e-waste dismantling house, and reference areas had major influenced by ambient temperature (r = -0.404 to -0.795) while only that at the open dump area had major manipulated by wind speed (r = -0.422 to -0.496). When integrating the analysis with multiple regression, the result indicated that meteorological factors on PMs levels in this study area might be primarily affected by wind speed (β_1 = -3.382 to -6.920) and followed by temperature (β_2 = -6.561 to -18.868).

5.1.2. Spatial and temporal variation of heavy metals in $PM_{2.5}$ and PM_{10}

(1) For $PM_{2.5}$, As, Cd, Cr, Mn, Pb, Zn, and Fe were highest at open dump area (0.230 ±0.093, 1.426 ±0.736, 9.632 ±8.421, 16.083 ±4.924, 56.021 ±28.563, 278.118 ±31.945, and 264.858 ±69.649 ng/m^3, respectively) while Cu and Ni were highest at non-e-waste dismantling (46.655 ±20.339 ng/m^3) and e-waste dismantling house (22.540 ±21.114 ng/m^3), respectively. Heavy metals contaminated in PM_{10} shows the similarity of As (2.195 - 6.070 ng/m^3) and Zn concentration (1,272.275 - 8,418.981 ng/m^3) at all sampling sites. While Cr, Cu, Ni, Pb, and Fe were found highly at non-e-waste dismantling house (6.323 ±4.469, 103.233 ±22.825, 1.972 ±1.062, 31.979 ±23.042, and 655.740 ±330.848, respectively) And for Cd and Mn were highest at open dump area.

(2) The investigation of the temporal distribution of heavy metals in $PM_{2.5}$ was clearly found in every area, and the concentration was found higher in September than April. Meanwhile, all heavy metals except Zn in PM_{10} were clearly

lower levels during April, while Zn was the only metal that was higher in April than September.

(3) All meteorological factors, including wind speed, temperature, and relative humidity, had negative relationships with metals, especially As, Cd, and Mn in $PM_{2.5}$, and Cd, Cr, and Pb in PM_{10}.

5.1.3. The composition of heavy metals in $PM_{2.5}$ and PM_{10}

(1) The percent contribution of each heavy metal in $PM_{2.5}$ at all sampling sites shows that Zn had the highest compositions (22.38% - 36.89% of the total) along with Fe (31.39% - 33.92%) at all sampling sites. For all heavy metals except Zn and Fe were mostly higher at the e-waste dismantling house than the others. While Cu has found most contribution (18.63%) inferior to Zn and Fe at non-e-waste dismantling house. Lastly, the composition at the open dump area shows only Pb compositions (18.39%) was lower than Zn and Fe. Additionally, As and Cd has found the lowest composition at all sampling sites (< 1%).

(2) For the composition in PM_{10}, the content of Zn shows the highest proportion at all sampling sites (78.67% - 96.04%). While the content of Fe at non-e-waste dismantling house (8.67%), e-waste dismantling house (18.04%), and open dump area (7.13%) had composition inferior the Zn content but higher than 5%. The contributions of all heavy metals (As, Cd, Cr, Cu, Mn, Ni, Pb, Zn, and Fe) were shown clearly highest at e-waste dismantling house and lowest at reference area.

5.1.4. Potential sources of heavy metals in $PM_{2.5}$ and PM_{10}

(1) For the PCA result of $PM_{2.5}$, the metals were mainly coming from e-waste dismantling activities, including Cd-Pb, Fe-Zn, and Ni-Cu-Cr, while As-Mn could be identified as the co-metals from a natural source. The possible sources of the heavy metals in PM_{10} were coming from e-waste dismantling activities, including Pb-Ni-Mn-Cd, Cr, As, Zn and Fe-Cu. Meanwhile, Cr, As, and Zn might be initiated from natural sources or crustal soil.

(2) The EF of the metals in $PM_{2.5}$ was shown mostly higher than one, including As (66.67% of total), Cd (61.90%), Cu (66.67%), Ni (69.05%), Pb (55.95%), and Zn (50.00%) (EF > 1) whereas the elements with EF < 1, such as Cr

(40.48% of total) and Fe (38.10%), were possibly donated from crustal. The EFs of Fe (45.24%) and Cu (41.67%) in PM_{10} were presented higher than 1 (EF > 1). However, As, Cd, Cr, Ni, Pb, and Zn in PM_{10} were presented the EF < 1, which had frequency lower than 50% of total data.

(3) The integrated results between PCA and EF analysis show that Fe and Cr in $PM_{2.5}$ were originated from a natural and background environment source, respectively, while those of Cd, Cu, Ni, Pb, Zn, and As could be initiated from e-waste dismantling, open burning activities, and automobile sources in this area. For PM_{10}, Cr, As, and Zn was originated from natural, and Pb, Ni, and Cd had existed in the background environment. In comparison, Fe and Cu were originated from e-waste dismantling activities.

5.2 Recommendations and suggestions

Based on the findings and conclusions as presented above, some recommendations for further study are as follows;

1) More sampling sites located far away from the e-waste dismantling community, which is defined as a major source, should be assigned to have better widespread mapping on spatial and temporal distribution over the study area.

2) More data points of heavy metal concentration in PM should be observed as much as possible to get more precise identifying their possible sources by principal component analysis.

3) The sampling should be set more frequently regarding significant different meteorological conditions and also e-waste dismantling activities in this area to have a more explicit temporal variation of heavy metal concentration in the PM.

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APPENDIX

Appendix A The concentration of $PM_{2.5}$ and heavy metals

Table A-1. $PM_{2.5}$ and heavy metals concentrations in April

Sampling sites		Day	Air volume of $PM_{2.5}$ (m^3)	$PM_{2.5}$ ($\mu g/m^3$)	Heavy metals (ng/m^3)								
					As	Cd	Cr	Cu	Mn	Ni	Pb	Zn	Fe
E-waste dismantling house	DY01ES	1	23.907	24.9	0.008	ND	1.730	4.870	0.894	3.145	3.757	108.279	82.430
		2	23.990	19.4	0.045	ND	3.232	3.285	1.413	4.804	MD	143.903	34.951
		3	23.907	14.9	0.063	ND	MD	6.513	0.557	2.088	0.637	123.549	67.697
		4	23.990	16.5	0.048	ND	10.701	12.023	2.724	4.594	2.935	131.558	78.861
		5	23.657	16.7	0.008	ND	2.635	1.353	1.899	1.830	1.657	66.473	152.456
		6	23.657	13.9	0.013	ND	MD	2.585	1.439	ND	MD	42.254	131.950
		7	23.990	14.9	0.015	ND	7.967	2.231	1.167	0.507	1.609	114.249	88.094
	BP01ES	1	23.990	23.4	0.013	0.087	2.362	1.677	0.914	1.560	1.532	6.456	89.071
		2	23.990	19.3	ND	ND	1.645	1.754	0.847	1.510	1.206	122.248	139.965
		3	23.907	15.7	ND	ND	MD	MD	0.850	ND	MD	16.339	38.512
		4	23.907	16.5	ND	ND	MD	4.109	1.542	ND	1.051	MD	46.832
		5	23.657	17.1	0.013	ND	MD	1.305	0.791	ND	MD	3.360	31.871
		6	23.990	15.3	ND	ND	14.534	3.672	3.370	2.297	2.098	29.309	110.908
		7	23.990	15.1	0.020	ND	1.136	0.675	0.645	1.957	0.932	7.565	51.685
Non-e-waste dismantling house	DY02NS	1	23.907	24.8	0.030	0.220	0.154	6.455	1.991	4.984	3.433	20.969	250.251
		2	23.990	20.4	0.018	0.176	ND	12.040	1.379	3.733	MD	10.183	27.209
		3	23.907	15.1	ND	ND	ND	MD	0.236	3.223	0.683	28.360	47.386

Sampling sites		Day	Air volume of $PM_{2.5}$ (m^3)	$PM_{2.5}$ ($\mu g/m^3$)	Heavy metals (ng/m^3)								
					As	Cd	Cr	Cu	Mn	Ni	Pb	Zn	Fe
		4	23.990	16.7	0.018	0.154	0.470	9.833	2.203	2.754	1.011	23.952	120.158
		5	23.657	18.9	0.008	ND	ND	7.204	3.036	2.359	1.644	131.908	20.437
		6	23.657	9.8	ND	ND	2.046	8.524	MD	2.661	0.932	MD	90.612
		7	23.990	13.9	ND	ND	ND	3.905	0.706	2.020	MD	110.027	26.922
	BP02NS	1	23.990	26.6	ND	ND	MD	7.694	4.575	19.093	ND	137.525	229.638
		2	15.994	21.6	0.034	ND	2.298	11.048	1.463	6.838	ND	253.965	103.559
		3	23.907	16.0	0.030	ND	1.333	15.324	2.008	3.871	ND	156.579	212.338
		4	23.907	17.8	0.033	0.174	0.510	14.306	1.856	3.945	ND	MD	49.674
		5	23.657	17.3	0.038	ND	31.807	10.195	2.456	7.578	0.317	132.794	150.230
		6	23.990	16.8	0.023	0.130	7.130	16.147	1.009	1.464	2.387	115.555	93.372
		7	23.990	17.5	0.033	ND	1.317	8.164	0.706	1.762	0.500	143.056	52.375
Open dump area	DY03OD	1	23.990	25.7	0.043	0.477	3.148	13.391	1.278	2.318	45.354	36.086	61.648
		2	23.990	34.6	0.010	0.260	ND	16.988	0.774	ND	8.315	49.811	57.310
		3	23.990	22.8	0.030	0.174	0.312	1.743	1.396	ND	26.407	43.907	72.560
		4	23.990	19.4	0.023	0.282	3.067	5.979	1.362	ND	5.204	48.124	113.906
		5	23.824	17.5	0.038	0.284	ND	3.308	2.235	2.481	37.782	45.413	168.389
		6	23.657	13.6	0.023	ND	0.234	2.484	1.245	2.383	8.606	49.040	88.203
		7	23.990	14.0	0.013	ND	2.775	2.760	0.824	ND	6.691	39.109	80.207
	BP03OD	1	23.907	29.5	ND	0.220	1.066	ND	1.316	1.675	1.634	62.826	28.299
		2	23.990	20.4	ND	0.176	0.237	ND	1.228	ND	17.965	38.646	18.238

Sampling sites		Day	Air volume of $PM_{2.5}$ (m^3)	$PM_{2.5}$ ($\mu g/m^3$)	Heavy metals (ng/m^3)								
					As	Cd	Cr	Cu	Mn	Ni	Pb	Zn	Fe
		3	23.990	17.9	ND	0.219	0.147	2.151	1.783	ND	6.840	37.248	35.920
		4	23.990	20.6	ND	0.219	ND	1.527	2.775	1.808	15.363	27.157	76.170
		5	23.657	17.4	0.023	0.112	ND	ND	1.091	ND	79.267	22.821	25.860
		6	23.824	16.3	ND	ND	ND	8.427	1.253	ND	6.793	14.638	20.363
		7	23.990	15.6	ND	0.154	MD	ND	0.538	1.999	10.507	MD	40.005
Reference area	DY00RF	1	23.907	23.7	0.025	0.240	0.449	8.680	5.299	2.665	2.495	24.589	MD
		2	23.990	17.6	0.020	0.174	1.453	10.525	11.756	5.200	0.570	66.654	MD
		3	23.907	15.1	0.008	ND	ND	3.311	1.215	1.245	0.837	MD	22.879
		4	23.990	15.4	0.043	0.195	2.786	9.533	2.472	2.039	4.915	16.909	49.659
		5	23.574	16.5	0.033	0.157	0.179	1.874	1.677	3.615	0.616	15.521	44.816
		6	23.740	9.7	0.033	0.165	MD	2.841	10.079	12.843	0.076	MD	MD
		7	23.990	14.2	MD	ND	0.379	2.720	2.001	3.137	MD	27.210	78.779

Non-detection limit (ND) of As is < 0.009, Cd < 0.077, Cr < 0.071, Cu < 0.259, Mn < 0.084, Ni < 1.611, Pb < 0.020, Zn < 0.141, Fe < 1.459

MD is missing data

Table A-2. $PM_{2.5}$ and heavy metals concentrations in September

Sampling sites		Day	Air volume of $PM_{2.5}$ (m^3)	$PM_{2.5}$ ($\mu g/m^3$)	Heavy metals (ng/m^3)								
					As	Cd	Cr	Cu	Mn	Ni	Pb	Zn	Fe
E-waste dismantling house	DY01ES	1	23.990	26.8	0.082	0.391	1.616	6.074	8.056	4.049	57.690	70.780	51.940
		2	23.990	28.0	0.030	0.239	1.317	MD	4.692	13.961	11.357	65.956	85.659
		3	23.990	38.2	0.080	0.434	2.362	2.213	10.663	4.655	24.767	113.026	93.176
		4	23.990	47.0	0.060	0.759	1.966	2.672	7.316	7.665	39.918	69.182	86.636
		5	23.990	56.1	0.160	1.413	0.793	6.388	7.265	11.387	28.187	93.560	49.853
		6	24.000	45.3	0.130	1.152	0.332	5.580	7.599	3.685	24.262	74.214	41.636
		7	24.000	40.1	0.058	0.870	1.916	4.997	7.010	5.620	17.991	82.937	95.386
	BP01ES	1	23.400	51.2	0.365	1.849	17.748	35.418	19.968	68.650	87.702	251.900	371.656
		2	23.400	29.7	0.198	1.315	1.575	16.074	7.707	19.003	44.471	192.403	123.993
		3	23.400	42.3	0.303	1.916	1.575	24.444	12.105	23.387	73.589	113.630	298.130
		4	23.400	49.3	0.295	2.049	15.000	14.095	11.277	7.193	44.180	69.759	162.253
		5	23.300	53.9	0.377	2.192	2.710	16.846	14.477	9.917	57.600	44.309	177.890
		6	23.200	42.8	0.295	2.089	5.801	19.382	17.253	11.544	73.005	151.628	178.998
		7	23.200	37.3	0.256	1.304	42.191	24.233	13.462	18.088	50.868	138.409	211.076
Non-e-waste dismantling house	DY02NS	1	23.990	27.7	0.052	0.347	4.194	8.875	3.027	ND	14.566	59.989	23.223
		2	23.990	34.7	0.040	0.217	MD	4.999	3.330	ND	14.397	65.461	57.633
		3	24.000	45.7	0.155	0.954	0.517	9.367	4.892	ND	24.827	86.309	61.728

Sampling sites		Day	Air volume of $PM_{2.5}$ (m^3)	$PM_{2.5}$ ($\mu g/m^3$)	Heavy metals (ng/m^3)								
					As	Cd	Cr	Cu	Mn	Ni	Pb	Zn	Fe
		4	23.990	52.3	0.130	0.911	1.536	12.344	5.920	ND	21.712	73.720	32.031
		5	24.000	58.4	0.102	0.759	2.194	13.448	6.254	ND	23.562	65.316	17.211
		6	24.000	53.8	0.100	0.521	7.833	10.268	5.094	ND	23.945	81.601	45.356
		7	24.000	44.1	0.055	0.455	2.989	8.434	5.480	1.435	18.508	39.152	57.797
	BP02NS	1	23.400	31.0	0.036	0.467	MD	61.005	5.638	1.537	18.018	73.731	28.802
		2	23.300	41.1	0.095	0.223	MD	39.337	4.571	2.636	13.497	46.974	35.422
		3	23.400	61.4	0.159	0.801	0.261	57.771	7.828	6.004	41.417	71.763	73.520
		4	23.300	58.2	0.139	0.916	MD	34.643	7.204	ND	26.335	60.031	59.661
		5	23.300	75.4	0.038	0.625	24.076	16.843	6.771	14.331	21.942	60.449	235.449
		6	23.100	65.6	0.122	0.631	2.488	38.676	9.746	1.811	31.907	60.067	81.459
		7	23.100	44.0	0.109	0.406	27.736	78.314	6.620	ND	25.393	76.109	142.701
Open dump area	DY03OD	1	24.000	21.4	0.200	0.911	4.769	4.315	5.834	13.605	28.789	MD	239.982
		2	24.000	31.0	0.128	0.651	4.898	5.325	6.909	13.636	33.797	MD	325.055
		3	24.000	53.8	0.138	0.933	8.117	7.997	6.556	8.235	29.267	29.403	133.051
		4	24.000	48.3	0.310	1.692	23.370	11.555	13.988	10.968	56.587	136.866	137.221
		5	24.000	48.6	0.383	2.451	6.829	39.993	18.830	9.841	84.133	141.148	144.803
		6	24.000	40.6	0.260	1.280	0.927	33.975	14.963	4.366	68.211	97.691	77.592
		7	24.000	33.2	0.193	1.345	73.852	11.544	13.803	10.340	53.831	MD	128.133
	BP03OD	1	23.990	26.5	0.163	1.087	15.412	16.599	11.151	6.633	42.966	336.479	187.402
		2	23.990	30.9	MD	MD	5.317	MD	9.990	4.527	3.298	MD	MD

Sampling sites		Day	Air volume of $PM_{2.5}$ (m^3)	$PM_{2.5}$ ($\mu g/m^3$)	Heavy metals (ng/m^3)								
					As	Cd	Cr	Cu	Mn	Ni	Pb	Zn	Fe
		3	23.990	44.6	0.373	1.413	18.130	11.790	14.515	3.935	58.839	265.900	251.576
		4	16.790	45.1	0.369	1.802	0.597	16.048	17.951	6.164	65.790	261.084	281.049
		5	23.990	57.5	0.493	2.281	11.076	32.381	24.591	6.091	96.694	270.905	230.761
		6	23.990	49.6	0.406	1.803	38.440	15.540	18.468	9.946	69.656	245.201	373.502
		7	23.990	42.6	0.188	0.171	45.870	14.081	15.911	9.158	54.907	289.140	MD
Reference area	DY00RF	1	23.990	24.2	0.060	0.306	15.412	MD	4.339	2.836	10.623	89.576	MD
		2	23.990	26.1	0.015	0.328	5.317	1.600	4.087	ND	9.360	32.188	MD
		3	24.000	39.0	0.050	0.523	18.130	1.582	4.758	ND	19.901	35.023	53.404
		4	23.990	44.3	0.023	0.545	0.597	0.977	3.935	1.478	12.194	83.845	81.087
		5	24.000	45.2	0.135	0.694	11.076	5.667	5.632	ND	22.065	44.124	58.569
		6	23.990	41.3	0.070	0.868	38.440	6.085	5.718	ND	33.850	69.182	45.838
		7	24.000	36.5	0.042	0.369	45.870	7.749	4.337	1.241	19.077	58.890	93.053

Non-detection limit (ND) of As is < 0.009, Cd < 0.077, Cr < 0.071, Cu < 0.259, Mn < 0.084, Ni < 1.611, Pb < 0.020, Zn < 0.141, Fe < 1.459

MD is missing data

Appendix B The concentration of PM_{10} and heavy metals

Table B-1. PM_{10} and heavy metals concentrations in April

Sampling sites		Day	Air volume of PM_{10} (m^3)	PM_{10} ($\mu g/m^3$)	Heavy metals (ng/m^3)								
					As	Cd	Cr	Cu	Mn	Ni	Pb	Zn	Fe
E-waste dismantling house	DY01ES	1	1750.700	37	2.668	0.061	MD	20.353	7.884	0.372	4.717	11726.286	454.357
		2	1517.250	45	MD	0.099	1.128	18.382	17.943	1.162	4.059	MD	279.512
		3	1621.550	36	MD	0.041	MD	14.585	11.861	0.857	2.179	7130.771	126.546
		4	1725.500	57	MD	0.125	1.354	26.637	31.220	1.829	10.027	9183.697	388.317
		5	1576.200	46	MD	0.078	4.281	13.931	19.200	1.012	2.387	MD	294.268
		6	1604.600	36	1.529	0.065	MD	24.387	11.416	0.452	2.662	MD	291.384
		7	1751.600	33	MD	0.089	1.274	18.129	10.588	0.906	3.028	3895.393	92.746
	BP01ES	1	1742.400	38	MD	0.117	MD	22.439	11.488	ND	1.416	5553.790	244.173
		2	1624.600	38	MD	0.086	MD	12.277	11.976	0.524	0.634	6276.022	181.467
		3	1578.500	37	MD	0.109	ND	29.690	14.668	0.465	2.348	4425.766	79.257
		4	1578.500	35	1.694	0.091	0.801	22.358	12.100	0.382	2.811	2022.645	345.844
		5	1562.200	40	0.005	0.080	MD	19.319	17.599	ND	1.630	7568.869	210.461
		6	1584.200	35	1.456	0.140	2.002	27.486	12.188	ND	3.739	2258.730	331.825
		7	1650.000	28	2.057	0.067	ND	33.732	5.379	ND	2.206	2346.905	424.790
Non-e-waste dismantling house	DY02NS	1	1635.900	40	MD	0.158	ND	20.817	12.035	1.093	4.005	8175.811	221.194
		2	1575.050	36	1.739	0.097	ND	17.332	8.025	ND	1.757	12655.065	212.219
		3	1635.900	30	4.141	MD	ND	17.432	6.293	ND	1.609	11669.010	212.060

Sampling sites		Day	Air volume of PM_{10} (m^3)	PM_{10} ($\mu g/m^3$)	Heavy metals (ng/m^3)								
					As	Cd	Cr	Cu	Mn	Ni	Pb	Zn	Fe
		4	1653.000	54	MD	0.141	2.079	22.951	21.051	2.000	2.929	MD	149.236
		5	1618.800	40	MD	0.078	ND	13.831	18.839	1.217	MD	9669.541	258.446
		6	1618.800	24	MD	0.069	ND	40.998	8.038	ND	5.931	5938.589	MD
		7	1749.900	25	2.158	0.027	1.727	14.457	6.132	ND	1.603	8074.890	93.840
	BP02NS	1	1828.800	71	MD	0.214	MD	MD	31.126	1.407	6.888	7166.927	186.118
		2	684.450	60	MD	0.234	MD	49.306	32.000	1.575	0.925	721.076	404.971
		3	1598.400	53	1.853	0.107	2.459	41.313	18.406	0.597	2.979	9267.247	193.404
		4	1406.300	63	0.016	0.127	2.430	46.007	30.972	0.896	4.594	1528.979	518.478
		5	1576.200	60	MD	0.073	MD	21.158	18.951	0.609	1.390	8502.433	MD
		6	1555.200	53	2.443	0.109	3.024	30.616	20.281	0.801	4.685	2634.907	202.170
		7	1675.800	41	MD	0.165	MD	18.511	14.762	0.438	0.427	6151.623	MD
Open dump area	DY03OD	1	1551.500	49	0.022	0.275	0.919	54.710	18.687	0.443	17.786	9405.000	262.617
		2	1612.800	58	MD	0.077	MD	13.740	25.555	ND	0.824	4478.519	47.682
		3	1661.750	46	MD	0.118	ND	16.137	13.837	0.579	1.077	3841.203	66.859
		4	1756.800	52	MD	MD	0.315	13.745	41.052	ND	1.627	1899.332	119.482
		5	1601.600	38	MD	0.060	ND	22.746	25.695	0.452	1.469	4049.806	60.169
		6	1590.400	28	1.362	0.070	ND	15.576	22.049	0.657	1.701	5423.193	117.220
		7	1668.800	38	1.789	0.069	ND	19.646	12.313	0.540	1.400	6276.348	128.264
	BP03OD	1	1635.900	63	MD	0.051	ND	12.090	18.687	0.257	0.208	4200.053	53.579
		2	1647.300	59	MD	0.038	ND	22.156	25.555	0.505	0.575	5445.846	MD

Sampling sites		Day	Air volume of PM_{10} (m^3)	PM_{10} ($\mu g/m^3$)	Heavy metals (ng/m^3)								
					As	Cd	Cr	Cu	Mn	Ni	Pb	Zn	Fe
		3	1702.350	45	7.137	0.046	ND	17.493	13.837	0.559	1.882	620.095	646.412
		4	1684.800	73	0.019	0.048	1.191	12.465	41.052	0.887	2.937	320.562	293.687
		5	1618.800	66	MD	MD	ND	5.319	25.695	ND	MD	1414.931	45.694
		6	1630.200	48	3.467	0.069	ND	30.190	22.049	0.395	1.955	2421.891	343.785
		7	1658.700	34	MD	0.095	ND	25.028	12.313	ND	0.768	2617.105	38.030
Reference area	DY00RF	1	1722.000	30	0.087	0.121	2.728	14.966	10.690	1.705	4.609	624.394	306.432
		2	1650.250	30	MD	0.086	MD	13.529	9.097	1.627	MD	7781.748	52.900
		3	1607.200	27	1.797	0.132	1.932	18.356	8.228	0.787	1.537	10112.325	125.451
		4	1827.000	27	MD	0.084	0.690	19.545	12.374	0.629	3.433	5810.300	34.792
		5	1457.450	31	MD	0.035	MD	18.900	10.461	1.139	MD	11100.641	78.755
		6	1596.000	23	3.717	0.051	6.531	15.382	5.016	0.384	1.450	12335.059	270.779
		7	1782.500	23	2.957	0.041	5.118	12.326	4.135	ND	1.347	11140.402	225.755

Non-detection limit (ND) of As is < 0.0001, Cd < 0.0011, Cr < 0.0010, Cu < 0.0038, Mn < 0.0012, Ni < 0.0236, Pb < 0.0003, Zn < 0.0021, Fe < 0.0214

MD is missing data

Table B-2. PM_{10} and heavy metals concentrations in September

Sampling sites		Day	Air volume of PM_{10} (m^3)	PM_{10} ($\mu g/m^3$)	Heavy metals (ng/m^3)								
					As	Cd	Cr	Cu	Mn	Ni	Pb	Zn	Fe
E-waste dismantling house	DY01ES	1	1645.280	50	4.020	0.567	MD	32.603	23.008	1.158	30.551	352.488	278.983
		2	1678.520	50	4.118	0.451	MD	15.427	20.337	1.174	10.169	355.967	571.701
		3	1627.200	69	MD	0.895	MD	17.257	32.249	1.463	13.834	670.901	MD
		4	1690.120	80	0.638	1.817	26.130	36.759	53.072	2.885	64.399	4304.283	536.496
		5	1675.040	102	0.558	1.787	14.939	31.042	49.485	3.106	62.096	1437.177	755.048
		6	1627.200	74	0.265	1.788	8.090	35.710	41.864	2.009	48.007	512.832	422.431
		7	1844.040	54	3.573	0.543	1.585	19.343	15.243	1.145	11.242	MD	250.296
	BP01ES	1	1604.480	29	8.318	0.531	MD	14.857	7.553	0.606	10.675	1104.344	379.781
		2	1706.460	38	8.715	0.385	MD	18.623	8.548	0.832	10.507	1098.545	345.221
		3	1572.870	57	6.388	0.894	3.180	26.866	14.980	0.966	20.680	3152.755	270.407
		4	1577.230	66	0.252	1.657	7.393	37.999	29.796	1.401	44.717	1257.061	275.869
		5	1573.960	71	0.290	1.842	3.986	47.242	27.805	1.708	51.604	326.766	276.787
		6	1571.780	62	0.375	1.567	2.740	32.898	25.995	1.360	48.809	411.983	437.119
		7	1674.240	47	MD	0.877	MD	27.711	19.429	1.043	15.938	2233.413	MD
Non-e-waste dismantling house	DY02NS	1	1686.640	39	3.646	0.658	3.137	118.406	11.748	0.905	11.082	2127.831	280.348
		2	1637.370	48	MD	0.349	MD	90.552	12.809	1.182	8.311	9917.676	103.506
		3	1664.600	64	9.752	0.755	10.117	137.321	16.157	1.409	20.441	4211.688	636.176
		4	1652.060	68	0.712	1.733	27.426	77.819	38.253	3.058	51.516	3863.130	376.368
		5	1628.330	76	0.713	1.880	29.042	121.824	49.468	3.446	60.074	5397.050	693.745

Sampling sites		Day	Air volume of PM_{10} (m^3)	PM_{10} ($\mu g/m^3$)	Heavy metals (ng/m^3)								
					As	Cd	Cr	Cu	Mn	Ni	Pb	Zn	Fe
		6	1585.100	71	0.623	1.727	19.727	96.676	39.591	2.717	56.814	3200.152	398.895
		7	1666.500	56	8.280	0.643	11.356	80.032	21.597	1.088	15.613	4000.730	598.396
	BP02NS	1	1637.250	40	8.993	0.450	8.984	118.406	8.178	ND	10.778	8499.756	515.306
		2	1465.200	53	6.143	0.448	3.548	90.552	8.388	1.059	11.047	4703.437	445.376
		3	1624.940	74	0.523	1.377	6.581	137.321	21.342	2.041	52.611	941.442	1063.639
		4	1600.620	72	11.410	0.766	9.329	77.819	12.304	ND	17.538	7306.082	722.955
		5	1631.700	92	0.612	1.809	6.550	121.824	29.694	1.198	58.601	2492.246	999.345
		6	1573.980	83	0.546	1.722	18.108	96.676	27.318	1.174	51.885	2323.969	733.504
		7	1746.030	64	1.576	0.842	MD	80.032	21.701	ND	16.055	2649.134	110.053
Open dump area	DY03OD	1	1647.300	36	9.929	0.587	16.601	22.454	7.068	0.794	12.160	3677.940	548.750
		2	1654.140	45	5.545	0.414	6.543	20.810	7.407	1.121	10.654	969.180	471.129
		3	1674.270	67	0.391	1.110	21.447	42.134	25.012	1.438	38.193	410.487	264.489
		4	1681.500	72	0.687	1.535	50.160	42.416	30.483	2.024	48.399	1162.439	734.990
		5	1684.800	69	0.733	2.645	46.330	65.856	30.649	1.897	61.521	3275.953	898.425
		6	1684.800	59	10.540	0.841	11.501	46.462	11.948	0.459	21.980	9528.533	679.152
		7	1680.000	46	8.670	0.575	10.080	32.662	9.375	0.375	15.104	1765.313	650.403
	BP03OD	1	1664.490	45	7.241	0.474	7.335	12.980	12.020	0.599	MD	9029.135	271.545
		2	1578.320	56	8.858	0.485	5.453	19.919	13.043	0.913	11.686	12290.643	639.363
		3	1651.400	82	5.787	0.837	1.693	14.046	20.884	1.047	17.694	6584.132	429.538
		4	999.000	77	0.387	1.792	MD	17.325	40.842	ND	41.239	1179.280	414.533

Sampling sites		Day	Air volume of PM_{10} (m^3)	PM_{10} ($\mu g/m^3$)	Heavy metals (ng/m^3)								
					As	Cd	Cr	Cu	Mn	Ni	Pb	Zn	Fe
		5	1820.320	87	0.591	1.999	MD	34.224	46.026	0.897	68.541	962.709	415.966
		6	1514.100	100	0.636	1.987	2.785	28.292	49.063	1.067	57.775	2021.528	432.997
		7	1657.430	75	4.957	0.541	1.307	19.812	19.430	0.589	13.220	6749.447	411.443
Reference area	DY00RF	1	1689.350	30	4.719	0.501	6.273	22.944	8.631	0.579	10.581	4290.933	193.838
		2	1666.350	37	5.075	0.420	6.771	12.812	6.358	0.457	7.822	4827.646	290.990
		3	1612.800	53	8.936	0.644	11.993	13.973	10.993	0.749	14.481	5110.709	464.606
		4	1703.150	56	MD	1.559	20.375	49.402	26.606	1.852	49.807	7275.236	298.991
		5	1636.450	60	MD	1.756	28.451	25.481	23.381	1.816	53.008	4529.694	182.027
		6	1703.920	57	MD	1.265	19.321	21.916	19.880	2.399	36.128	8534.422	276.058
		7	1722.800	48	5.551	0.719	8.883	24.976	13.189	0.662	21.730	6834.509	392.338

Appendix C Statistical test

Table C-1 One-way ANOVA test of $PM_{2.5}$ between all sampling sites

Multiple Comparisons

LSD

Dependent Variable	(I) SamplingPoints	(J) SamplingPoints	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
PM2.5April	E-waste dismantling	Non-e-waste dismantling	-.40284	1.78110	.822	-3.9924	3.1867
		Open dump area	-2.98114	1.74781	.095	-6.5036	.5413
		Reference area	1.38979	2.14062	.520	-2.9244	5.7039
	Non-e-waste dismantling	E-waste dismantling	.40284	1.78110	.822	-3.1867	3.9924
		Open dump area	-2.57830	1.78110	.155	-6.1679	1.0113
		Reference area	1.79263	2.16789	.413	-2.5765	6.1617
	Open dump area	E-waste dismantling	2.98114	1.74781	.095	-.5413	6.5036
		Non-e-waste dismantling	2.57830	1.78110	.155	-1.0113	6.1679
		Reference area	4.37093*	2.14062	.047	.0568	8.6851
	Reference area	E-waste dismantling	-1.38979	2.14062	.520	-5.7039	2.9244
		Non-e-waste dismantling	-1.79263	2.16789	.413	-6.1617	2.5765
		Open dump area	-4.37093*	2.14062	.047	-8.6851	-.0568
PM2.5Rainny	E-waste dismantling	Non-e-waste dismantling	-7.53450	4.17947	.078	-15.9524	.8834
		Open dump area	1.03371	4.17947	.806	-7.3842	9.4516
		Reference area	5.34029	5.11878	.302	-4.9695	15.6500
	Non-e-waste dismantling	E-waste dismantling	7.53450	4.17947	.078	-.8834	15.9524
		Open dump area	8.56821*	4.17947	.046	.1503	16.9861
		Reference area	12.87479*	5.11878	.016	2.5650	23.1845
	Open dump area	E-waste dismantling	-1.03371	4.17947	.806	-9.4516	7.3842

		Non-e-waste dismantling	-8.56821*	4.17947	.046	-16.9861	-.1503
		Reference area	4.30657	5.11878	.405	-6.0032	14.6163
	Reference area	E-waste dismantling	-5.34029	5.11878	.302	-15.6500	4.9695
		Non-e-waste dismantling	-12.87479*	5.11878	.016	-23.1845	-2.5650
		Open dump area	-4.30657	5.11878	.405	-14.6163	6.0032

*. The mean difference is significant at the 0.05 level.

Table C-2 One-way ANOVA test of PM_{10} between all sampling sites

Multiple Comparisons

LSD

Dependent Variable	(I) SamplingPoints	(J) SamplingPoints	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
PM10.April	E-waste dismantling	Non-e-waste dismantling	-7.78571	4.25774	.074	-16.3612	.7898
		Open dump area	-11.14286*	4.25774	.012	-19.7184	-2.5673
		Reference area	11.35714*	5.21464	.035	.8543	21.8600
	Non-e-waste dismantling	E-waste dismantling	7.78571	4.25774	.074	-.7898	16.3612
		Open dump area	-3.35714	4.25774	.435	-11.9327	5.2184
		Reference area	19.14286*	5.21464	.001	8.6400	29.6457
	Open dump area	E-waste dismantling	11.14286*	4.25774	.012	2.5673	19.7184
		Non-e-waste dismantling	3.35714	4.25774	.435	-5.2184	11.9327
		Reference area	22.50000*	5.21464	.000	11.9972	33.0028
	Reference area	E-waste dismantling	-11.35714*	5.21464	.035	-21.8600	-.8543
		Non-e-waste dismantling	-19.14286*	5.21464	.001	-29.6457	-8.6400

		Open dump area	-22.50000*	5.21464	.000	-33.0028	-11.9972
PM10.Rainny	E-waste dismantling	Non-e-waste dismantling	-3.64286	6.37379	.570	-16.4803	9.1946
		Open dump area	-4.78571	6.37379	.457	-17.6232	8.0518
		Reference area	11.92857	7.80626	.133	-3.7941	27.6512
	Non-e-waste dismantling	E-waste dismantling	3.64286	6.37379	.570	-9.1946	16.4803
		Open dump area	-1.14286	6.37379	.859	-13.9803	11.6946
		Reference area	15.57143	7.80626	.052	-.1512	31.2941
	Open dump area	E-waste dismantling	4.78571	6.37379	.457	-8.0518	17.6232
		Non-e-waste dismantling	1.14286	6.37379	.859	-11.6946	13.9803
		Reference area	16.71429*	7.80626	.038	.9917	32.4369
	Reference area	E-waste dismantling	-11.92857	7.80626	.133	-27.6512	3.7941
		Non-e-waste dismantling	-15.57143	7.80626	.052	-31.2941	.1512
		Open dump area	-16.71429*	7.80626	.038	-32.4369	-.9917

*. The mean difference is significant at the 0.05 level.

Appendix D Statistical test

Table D-1 Pearson's correlation test of $PM_{2.5}$ between all sampling sites of $PM_{2.5}$

Correlations

		PM2.5.DYes.S	PM2.5BPes.S	PM2.5.DYns.S	PM2.5.BPns.S	PM2.5.DYod.S	PM2.5.BPod.S	PM2.5.RF.S	PM2.5.DYes.R	PM2.5.BPes.R	PM2.5.DYns.R	PM2.5.BPns.R	PM2.5.DYod.R	PM2.5.BPod.R	PM2.5.RF.R
PM2.5.DYes.S	Pearson Correlation	1	.993**	.923**	.976**	.621	.952**	.940**	-.652	.202	-.791*	-.710	-.724	-.773*	-.776*
	Sig. (2-tailed)		.000	.003	.001	.137	.001	.002	.113	.665	.034	.074	.066	.042	.040
	N	7	7	7	6	7	7	7	7	7	7	7	7	7	7
PM2.5BPes.S	Pearson Correlation	.993**	1	.904**	.973**	.645	.943**	.911**	-.660	.183	-.784*	-.676	-.719	-.764*	-.788*
	Sig. (2-tailed)	.000		.005	.001	.118	.001	.004	.107	.694	.037	.095	.069	.046	.035
	N	7	7	7	6	7	7	7	7	7	7	7	7	7	7
PM2.5.DYns.S	Pearson Correlation	.923**	.904**	1	.820*	.689	.832*	.974**	-.497	.229	-.657	-.551	-.507	-.621	-.637
	Sig. (2-tailed)	.003	.005		.045	.087	.020	.000	.256	.621	.109	.200	.245	.136	.124
	N	7	7	7	6	7	7	7	7	7	7	7	7	7	7
PM2.5.BPns.S	Pearson Correlation	.976**	.973**	.820*	1	.640	.943**	.862*	-.713	.431	-.839*	-.779	-.831*	-.836*	-.870*
	Sig. (2-tailed)	.001	.001	.045		.171	.005	.027	.112	.394	.037	.068	.040	.038	.024
	N	6	6	6	6	6	6	6	6	6	6	6	6	6	6
PM2.5.DYod.S	Pearson Correlation	.621	.645	.689	.640	1	.534	.613	-.726	-.405	-.697	-.530	-.360	-.719	-.731
	Sig. (2-tailed)	.137	.118	.087	.171		.217	.143	.065	.368	.082	.221	.427	.069	.062
	N	7	7	7	6	7	7	7	7	7	7	7	7	7	7
PM2.5.BPod.S	Pearson Correlation	.952**	.943**	.832*	.943**	.534	1	.880**	-.619	.319	-.736	-.659	-.608	-.749	-.675
	Sig. (2-tailed)	.001	.001	.020	.005	.217		.009	.138	.485	.059	.107	.148	.053	.096
	N	7	7	7	6	7	7	7	7	7	7	7	7	7	7
PM2.5.RF.S	Pearson Correlation	.940**	.911**	.974**	.862*	.613	.880**	1	-.564	.259	-.729	-.635	-.551	-.679	-.675
	Sig. (2-tailed)	.002	.004	.000	.027	.143	.009		.187	.574	.063	.125	.199	.094	.096
	N	7	7	7	6	7	7	7	7	7	7	7	7	7	7
PM2.5.DYes.R	Pearson Correlation	-.652	-.660	-.497	-.713	-.726	-.619	-.564	1	.507	.968**	.897**	.727	.966**	.952**
	Sig. (2-tailed)	.113	.107	.256	.112	.065	.138	.187		.246	.000	.006	.064	.000	.001
	N	7	7	7	6	7	7	7	7	7	7	7	7	7	7
PM2.5.BPes.R	Pearson Correlation	.202	.183	.229	.431	-.405	.319	.259	.507	1	.342	.370	.248	.371	.418
	Sig. (2-tailed)	.665	.694	.621	.394	.368	.485	.574	.246		.453	.414	.592	.413	.350
	N	7	7	7	6	7	7	7	7	7	7	7	7	7	7
PM2.5.DYns.R	Pearson Correlation	-.791*	-.784*	-.657	-.839*	-.697	-.736	-.729	.968**	.342	1	.943**	.806*	.977**	.974**
	Sig. (2-tailed)	.034	.037	.109	.037	.082	.059	.063	.000	.453		.001	.028	.000	.000
	N	7	7	7	6	7	7	7	7	7	7	7	7	7	7
PM2.5.BPns.R	Pearson Correlation	-.710	-.676	-.551	-.779	-.530	-.659	-.635	.897**	.370	.943**	1	.867*	.951**	.901**
	Sig. (2-tailed)	.074	.095	.200	.068	.221	.107	.125	.006	.414	.001		.012	.001	.006
	N	7	7	7	6	7	7	7	7	7	7	7	7	7	7
PM2.5.DYod.R	Pearson Correlation	-.724	-.719	-.507	-.831*	-.360	-.608	-.551	.727	.248	.806*	.867*	1	.792*	.854*
	Sig. (2-tailed)	.066	.069	.245	.040	.427	.148	.199	.064	.592	.028	.012		.034	.014
	N	7	7	7	6	7	7	7	7	7	7	7	7	7	7
PM2.5.BPod.R	Pearson Correlation	-.773*	-.764*	-.621	-.836*	-.719	-.749	-.679	.966**	.371	.977**	.951**	.792*	1	.946**
	Sig. (2-tailed)	.042	.046	.136	.038	.069	.053	.094	.000	.413	.000	.001	.034		.001
	N	7	7	7	6	7	7	7	7	7	7	7	7	7	7
PM2.5.RF.R	Pearson Correlation	-.776*	-.788*	-.637	-.870*	-.731	-.675	-.675	.952**	.418	.974**	.901**	.854*	.946**	1
	Sig. (2-tailed)	.040	.035	.124	.024	.062	.096	.096	.001	.350	.000	.006	.014	.001	
	N	7	7	7	6	7	7	7	7	7	7	7	7	7	7

**. Correlation is significant at the 0.01 level (2-tailed).

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

Table D-2 Pearson's correlation test of $PM_{2.5}$ between all sampling sites of PM_{10}

Correlations

		PM10.Dyes.S	PM10.BPes.S	PM10.Dyns.S	PM10.BPns.S	PM10.DYod.S	PM10.BPod.S	PM10.RF.S	PM10.Dyes.R	PM10.BPes.R	PM10.Dyns.R	PM10.BPns.R	PM10.DYod.R	PM10.BPod.R	PM10.RF.R
PM10.Dyes.S	Pearson Correlation	1	.348	.892**	.490	.491	.840*	.426	.454	.407	.298	.181	.518	-.024	.254
	Sig. (2-tailed)		.444	.007	.265	.263	.018	.340	.306	.364	.516	.697	.234	.959	.583
	N	7	7	7	7	7	7	7	7	7	7	7	7	7	7
PM10.BPes.S	Pearson Correlation	.348	1	.408	.762*	.305	.677	.834*	.358	.066	.049	.071	.191	-.162	-.081
	Sig. (2-tailed)	.444		.364	.047	.506	.095	.020	.430	.888	.916	.880	.682	.729	.863
	N	7	7	7	7	7	7	7	7	7	7	7	7	7	7
PM10.Dyns.S	Pearson Correlation	.892**	.408	1	.716	.608	.908**	.583	.299	.148	.015	-.104	.306	-.325	-.023
	Sig. (2-tailed)	.007	.364		.071	.148	.005	.169	.515	.751	.974	.825	.504	.477	.962
	N	7	7	7	7	7	7	7	7	7	7	7	7	7	7
PM10.BPns.S	Pearson Correlation	.490	.762*	.716	1	.510	.864*	.760*	.058	-.234	-.306	-.360	-.094	-.526	-.406
	Sig. (2-tailed)	.265	.047	.071		.242	.012	.048	.901	.614	.505	.428	.841	.225	.367
	N	7	7	7	7	7	7	7	7	7	7	7	7	7	7
PM10.DYod.S	Pearson Correlation	.491	.305	.608	.510	1	.472	.601	-.397	-.462	-.556	-.619	-.200	-.757*	-.567
	Sig. (2-tailed)	.263	.506	.148	.242		.284	.154	.378	.296	.195	.138	.667	.049	.185
	N	7	7	7	7	7	7	7	7	7	7	7	7	7	7
PM10.BPod.S	Pearson Correlation	.840*	.677	.908**	.864*	.472	1	.708	.395	.161	.065	-.021	.267	-.257	-.030
	Sig. (2-tailed)	.018	.095	.005	.012	.284		.075	.381	.730	.891	.965	.563	.578	.950
	N	7	7	7	7	7	7	7	7	7	7	7	7	7	7
PM10.RF.S	Pearson Correlation	.426	.834*	.583	.760*	.601	.708	1	.157	-.186	-.242	-.221	-.049	-.537	-.344
	Sig. (2-tailed)	.340	.020	.169	.048	.154	.075		.737	.690	.602	.633	.917	.214	.450
	N	7	7	7	7	7	7	7	7	7	7	7	7	7	7
PM10.Dyes.R	Pearson Correlation	.454	.358	.299	.058	-.397	.395	.157	1	.914**	.895**	.884**	.850*	.691	.844*
	Sig. (2-tailed)	.306	.430	.515	.901	.378	.381	.737		.004	.006	.008	.015	.085	.017
	N	7	7	7	7	7	7	7	7	7	7	7	7	7	7
PM10.BPes.R	Pearson Correlation	.407	.066	.148	-.234	-.462	.161	-.186	.914**	1	.989**	.956**	.941**	.870*	.981**
	Sig. (2-tailed)	.364	.888	.751	.614	.296	.730	.690	.004		.000	.001	.002	.011	.000
	N	7	7	7	7	7	7	7	7	7	7	7	7	7	7
PM10.Dyns.R	Pearson Correlation	.298	.049	.015	-.306	-.556	.065	-.242	.895**	.989**	1	.985**	.901**	.923**	.989**
	Sig. (2-tailed)	.516	.916	.974	.505	.195	.891	.602	.006	.000		.000	.006	.003	.000
	N	7	7	7	7	7	7	7	7	7	7	7	7	7	7
PM10.BPns.R	Pearson Correlation	.181	.071	-.104	-.360	-.619	-.021	-.221	.884**	.956**	.985**	1	.842*	.930**	.968**
	Sig. (2-tailed)	.697	.880	.825	.428	.138	.965	.633	.008	.001	.000		.017	.002	.000
	N	7	7	7	7	7	7	7	7	7	7	7	7	7	7
PM10.DYod.R	Pearson Correlation	.518	.191	.306	-.094	-.200	.267	-.049	.850*	.941**	.901**	.842*	1	.735	.897**
	Sig. (2-tailed)	.234	.682	.504	.841	.667	.563	.917	.015	.002	.006	.017		.060	.006
	N	7	7	7	7	7	7	7	7	7	7	7	7	7	7
PM10.BPod.R	Pearson Correlation	-.024	-.162	-.325	-.526	-.757*	-.257	-.537	.691	.870*	.923**	.930**	.735	1	.934**
	Sig. (2-tailed)	.959	.729	.477	.225	.049	.578	.214	.085	.011	.003	.002	.060		.002
	N	7	7	7	7	7	7	7	7	7	7	7	7	7	7
PM10.RF.R	Pearson Correlation	.254	-.081	-.023	-.406	-.567	-.030	-.344	.844*	.981**	.989**	.968**	.897**	.934**	1
	Sig. (2-tailed)	.583	.863	.962	.367	.185	.950	.450	.017	.000	.000	.000	.006	.002	
	N	7	7	7	7	7	7	7	7	7	7	7	7	7	7

**. Correlation is significant at the 0.01 level (2-tailed).

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

Appendix G Enrichment factors of heavy metals

Table G-1 Enrichment factors of heavy metals in $PM_{2.5}$ between e-waste dismantling, non-e-waste dismantling, and open dump area.

Heavy metals	day	DY02NS		BP02NS		DY01ES		BP01ES		DY03OD		BP03OD	
		April	September	April	September	April	September	April	September	April	September	April	September
As	1	3.194	1.242	0.324	0.462	1.897	0.736	3.015	1.322	7.132	2.479	1.127	1.057
	2	7.673	3.273	13.660	5.663	18.720	1.742	4.858	7.000	7.594	5.048	3.351	0.000
	3	4.505	3.015	2.269	1.933	17.178	0.714	1.251	2.382	3.264	2.003	0.596	2.445
	4	0.470	3.757	1.022	3.301	1.013	1.403	0.261	4.476	0.971	3.792	0.145	3.517
	5	0.134	0.680	0.786	0.234	0.214	0.919	0.835	1.086	0.864	0.849	1.071	0.836
	6	1.343	1.604	6.962	1.023	2.759	1.397	0.634	1.397	5.642	1.419	1.706	1.796
	7	0.000	1.036	0.000	1.700	0.000	0.854	0.000	1.964	0.000	1.444	0.000	1.220
Cd	1	2.440	1.625	0.381	1.175	1.951	0.688	2.102	1.313	8.241	2.214	3.691	1.382
	2	8.623	0.812	5.449	0.608	3.777	0.635	6.302	2.126	22.696	1.174	9.683	0.000
	3	5.148	1.774	0.605	0.931	2.181	0.370	1.429	1.440	1.917	1.295	1.889	0.886
	4	0.886	1.111	1.188	0.918	0.368	0.749	0.649	1.312	2.625	0.873	1.000	0.725
	5	0.281	0.985	0.348	0.749	0.450	1.578	1.080	1.229	1.357	1.056	1.097	0.753
	6	3.070	0.674	7.870	0.427	3.396	0.999	1.432	0.798	3.925	0.564	3.851	0.643
	7	2.834	0.976	2.834	0.721	1.715	1.459	3.102	1.138	2.428	1.145	7.250	0.126
Cr	1	0.915	4.934	0.000	0.000	22.889	0.786	30.567	4.095	29.135	3.370	9.581	5.412
	2	0.775	0.000	12.717	0.000	18.519	0.927	15.715	0.794	1.381	2.464	1.569	1.757
	3	5.148	0.000	6.106	0.000	0.000	0.000	0.000	0.000	2.057	0.000	0.754	0.000
	4	0.189	0.135	0.244	0.000	3.486	0.154	0.000	0.898	1.999	1.009	0.042	0.019
	5	0.416	1.165	122.017	12.987	13.078	0.469	0.000	0.804	0.556	1.394	1.157	1.645
	6	0.000	0.442	0.000	0.081	0.000	0.016	0.000	0.125	0.000	0.021	0.000	0.658

Heavy metals	day	DY02NS		BP02NS		DY01ES		BP01ES		DY03OD		BP03OD	
		April	September	April	September	April	September	April	September	April	September	April	September
	7	0.985	0.131	9.830	1.107	35.945	0.085	9.274	0.974	17.727	1.488	0.000	0.762
Cu	1	1.979	0.000	1.027	0.000	3.326	0.000	1.120	0.000	6.397	0.000	0.131	0.000
	2	9.752	3.835	8.435	21.982	2.597	0.000	2.313	5.327	24.515	1.969	0.256	0.000
	3	0.000	5.759	2.800	22.196	4.291	0.624	0.000	6.073	0.458	3.669	0.443	2.443
	4	1.157	8.398	1.999	19.368	1.145	1.471	0.691	5.034	1.138	3.327	0.143	3.601
	5	2.123	2.137	3.715	2.472	0.638	0.874	1.476	1.156	1.324	2.111	0.234	1.309
	6	18.997	1.894	56.774	3.729	6.373	0.690	3.866	1.056	7.078	2.134	23.860	0.791
	7	4.069	0.861	8.507	6.621	1.406	0.399	0.770	1.007	2.464	0.468	0.384	0.495
Ni	1	4.977	0.619	8.298	0.417	6.995	0.769	3.394	5.260	3.606	3.568	2.531	0.910
	2	6.120	1.227	10.567	1.926	7.686	9.935	4.030	8.233	3.575	6.590	2.253	1.513
	3	13.328	0.973	1.881	2.984	3.658	1.698	1.410	7.516	0.856	4.887	0.670	1.055
	4	1.516	0.550	2.577	0.466	2.045	2.789	0.965	1.698	1.090	2.088	0.790	0.914
	5	0.360	0.901	1.431	9.747	0.447	7.218	0.728	3.155	0.515	2.407	0.528	1.141
	6	1.312	1.122	1.139	0.868	0.677	2.265	0.535	3.126	1.502	1.363	0.772	2.516
	7	1.825	0.915	1.592	0.671	0.277	2.802	1.935	4.696	0.948	2.618	2.370	2.012
Pb	1	3.662	1.965	0.010	1.305	8.925	2.925	3.560	1.794	75.372	2.016	2.637	1.574
	2	0.000	1.888	0.451	1.289	0.000	1.057	29.366	2.520	221.567	2.136	301.727	0.144
	3	4.201	1.213	0.015	1.265	1.660	0.555	0.000	1.453	27.459	1.067	5.569	0.969
	4	0.231	1.184	0.006	1.180	0.542	1.761	0.343	1.264	1.922	1.305	2.784	1.183
	5	1.474	0.962	0.351	0.827	2.375	0.990	0.000	1.016	46.021	1.140	197.797	1.004
	6	77.647	0.794	313.737	0.553	0.000	0.539	82.562	0.715	916.718	0.770	718.976	0.637
	7	0.000	0.768	0.000	0.872	0.000	0.583	0.000	0.859	0.000	0.887	0.000	0.785
Zn	1	2.270	0.960	6.478	0.633	26.101	0.426	1.522	0.611	6.085	0.000	10.288	1.462

Heavy metals	day	DY02NS		BP02NS		DY01ES		BP01ES		DY03OD		BP03OD	
		April	September	April	September	April	September	April	September	April	September	April	September
	2	1.302	2.496	30.617	1.305	17.962	1.785	25.456	3.170	11.351	0.000	5.551	0.000
	3	0.000	2.397	0.000	1.245	0.000	1.440	0.000	1.275	0.000	0.609	0.000	2.489
	4	1.589	0.584	0.000	0.391	7.061	0.444	0.000	0.290	5.166	0.459	1.431	0.683
	5	4.694	1.333	5.842	1.140	3.782	1.644	0.459	0.391	2.195	0.957	2.260	1.406
	6	0.000	1.324	0.000	0.509	0.000	0.807	0.000	0.726	0.000	0.540	0.000	1.097
	7	11.461	0.526	14.901	0.847	7.199	0.871	0.863	0.757	3.490	0.000	0.000	1.338
Fe	1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	2	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	3	10.663	1.124	5.616	0.837	6.454	0.779	2.406	2.194	2.760	1.808	1.070	1.544
	4	2.715	0.263	1.332	0.402	1.441	0.575	1.512	0.698	4.163	0.476	1.366	0.760
	5	0.252	0.265	2.289	3.344	3.004	0.660	1.508	1.182	2.819	0.739	0.887	0.902
	6	0.000	1.111	0.000	1.043	0.000	0.683	0.000	1.294	0.000	0.647	0.000	2.523
	7	0.969	0.492	1.884	1.005	1.917	0.634	2.035	0.731	2.472	0.433	1.889	0.776

Table G-2 Enrichment factors of heavy metals in PM_{10} between e-waste dismantling, non-e-waste dismantling, and open dump area.

Heavy metals	day	DY02NS		BP02NS		DY01ES		BP01ES		DY03OD		BP03OD	
		April	September	April	September	April	September	April	September	April	September	April	September
As	1	0.000	0.568	0.000	2.011	41.799	0.320	0.000	2.014	0.143	2.570	0.000	1.102
	2	0.000	0.000	0.000	0.918	0.000	0.254	0.000	1.277	0.000	0.938	0.000	0.851
	3	3.012	0.743	0.461	0.030	0.000	0.000	0.000	0.525	0.000	0.019	2.361	0.341
	4	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	5	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	6	0.000	0.000	0.163	0.000	0.181	0.000	0.161	0.000	0.083	0.000	0.212	0.000
	7	0.492	0.911	0.000	0.173	0.000	0.557	0.535	0.000	0.203	2.197	0.000	0.606
Cd	1	1.159	0.965	0.608	0.948	0.688	0.424	0.901	1.210	1.302	1.429	0.241	0.679
	2	1.281	0.413	0.776	0.809	0.584	0.336	0.760	0.682	0.321	0.847	0.156	0.564
	3	0.000	0.798	0.364	1.102	0.216	0.474	0.462	1.019	0.530	0.758	0.208	0.684
	4	0.992	0.773	0.609	1.063	0.595	0.584	1.110	0.949	0.000	0.860	0.174	0.749
	5	1.238	0.506	1.138	0.811	1.207	0.481	1.351	0.882	0.689	1.149	0.000	0.578
	6	0.852	0.686	0.531	0.991	0.567	0.671	1.136	0.947	0.316	1.107	0.308	0.637
	7	0.442	0.547	1.115	0.712	0.833	0.654	1.232	0.828	0.555	1.126	0.768	0.511
Cr	1	0.005	0.523	0.000	1.511	0.000	0.000	0.000	0.000	0.154	3.452	0.003	0.963
	2	0.000	0.000	0.000	0.397	0.000	0.000	0.000	0.000	0.000	0.886	0.000	0.450
	3	0.051	0.817	0.569	0.886	0.000	0.000	0.023	0.229	0.023	0.770	0.022	0.085
	4	3.452	1.798	3.918	1.011	2.166	1.234	1.186	0.471	0.335	2.149	2.029	0.000
	5	0.000	0.926	0.000	0.729	0.000	0.476	0.000	0.377	0.000	1.242	0.000	0.000
	6	0.007	0.984	0.115	0.921	0.000	0.289	0.126	0.347	0.003	1.080	0.003	0.122
	7	0.254	1.112	0.000	0.000	0.090	0.161	0.011	0.000	0.005	1.705	0.005	0.115

Heavy metals	day	DY02NS		BP02NS		DY01ES		BP01ES		DY03OD		BP03OD	
		April	September	April	September	April	September	April	September	April	September	April	September
Cu	1	1.236	3.791	0.000	5.446	1.844	0.533	1.395	0.740	2.091	1.195	0.462	0.406
	2	1.452	3.508	1.036	5.357	0.689	0.376	0.689	1.081	0.362	1.394	0.583	0.758
	3	1.242	6.686	1.006	5.062	0.551	0.421	0.907	1.411	0.523	1.325	0.567	0.529
	4	0.690	1.096	0.940	3.406	0.540	0.373	1.170	0.687	0.212	0.749	0.192	0.228
	5	0.406	2.260	0.618	3.764	0.402	0.576	0.608	1.559	0.490	1.972	0.115	0.682
	6	1.663	2.215	0.492	3.210	0.697	0.774	0.735	1.148	0.230	3.527	0.447	0.523
	7	0.791	1.957	0.421	1.947	0.574	0.670	2.104	0.753	0.535	1.840	0.682	0.538
Ni	1	0.569	1.148	0.283	0.653	0.296	0.750	0.074	1.196	0.149	1.675	0.086	0.742
	2	0.260	1.285	0.275	1.758	0.362	0.804	0.245	1.356	0.032	2.106	0.111	0.975
	3	0.596	1.281	0.339	1.404	0.755	0.666	0.332	0.946	0.437	0.844	0.422	0.736
	4	1.870	1.149	0.570	0.428	1.153	0.781	0.621	0.676	0.064	0.954	0.425	0.207
	5	0.593	0.897	0.295	0.519	0.484	0.808	0.078	0.791	0.161	0.797	0.052	0.251
	6	0.589	0.569	0.515	0.356	0.516	0.398	0.397	0.434	0.389	0.318	0.233	0.180
	7	0.687	1.004	0.373	0.309	1.074	1.497	0.830	1.070	0.551	0.796	0.361	0.605
Pb	1	0.772	0.770	0.513	1.075	1.388	1.083	0.286	1.153	2.207	1.403	0.026	0.000
	2	0.000	0.527	0.000	1.071	0.000	0.406	0.000	0.999	0.000	1.169	0.000	0.728
	3	1.369	0.960	0.866	1.871	0.983	0.326	0.857	1.048	0.417	1.159	0.728	0.643
	4	0.502	0.719	0.535	0.761	1.158	0.648	0.837	0.802	0.143	0.848	0.258	0.539
	5	0.000	0.536	0.000	0.870	0.000	0.553	0.000	0.819	0.000	0.885	0.000	0.657
	6	2.552	0.790	0.799	1.045	0.807	0.631	1.061	1.033	0.267	1.012	0.307	0.648
	7	0.803	0.439	0.089	0.449	0.878	0.448	1.259	0.498	0.349	0.978	0.192	0.413
Zn	1	11.631	0.364	3.942	2.091	25.464	0.031	8.277	0.294	8.617	1.047	3.848	1.511
	2	1.843	1.020	0.026	0.738	0.000	0.023	0.613	0.169	0.205	0.172	0.249	1.241

Heavy metals	day	DY02NS		BP02NS		DY01ES		BP01ES		DY03OD		BP03OD	
		April	September	April	September	April	September	April	September	April	September	April	September
	3	1.509	0.561	0.410	0.095	0.489	0.045	0.246	0.453	0.226	0.035	0.036	0.678
	4	0.000	0.369	0.105	2.172	0.626	0.297	0.356	0.154	0.099	0.139	0.017	0.106
	5	0.484	0.563	0.423	0.433	0.000	0.150	0.405	0.061	0.149	0.552	0.052	0.108
	6	0.300	0.188	0.053	0.198	0.000	0.029	0.075	0.037	0.100	1.858	0.045	0.096
	7	0.489	0.357	0.155	0.236	0.137	0.000	0.162	0.222	0.189	0.363	0.079	0.670
Fe	1	0.641	1.063	0.209	2.806	2.010	0.540	0.741	2.239	0.490	3.457	0.100	1.006
	2	4.548	0.177	2.176	1.160	2.679	0.614	2.606	0.882	0.321	1.390	0.000	1.071
	3	2.210	0.932	0.689	1.179	0.700	0.000	0.354	0.427	0.317	0.250	3.064	0.487
	4	2.521	0.876	5.954	5.229	4.424	0.900	10.165	0.824	1.035	2.146	2.544	0.903
	5	1.822	1.801	0.000	4.323	2.036	1.960	1.588	1.279	0.311	3.765	0.236	1.161
	6	0.000	0.726	0.185	1.934	0.473	0.727	0.504	1.211	0.098	4.093	0.289	0.636
	7	0.280	0.931	0.000	0.170	0.160	0.552	1.446	0.000	0.191	2.332	0.057	0.712

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