HEALTH RISK ASSESSMENT OF INHALATION EXPOSURE TO PAHs ADSORBED ON PM$_{2.5}$ AT RESIDENTIAL AREAS LOCATED IN THE INNER CITY OF BANGKOK

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การประเมินความเสี่ยงต่อสุขภาพในการรับสัมผัสสารพอลิไซคลิกอะโรมาติกไฮโดรคาร์บอน (PAHs) ที่ดูดซับบนฝุ่นละอองขนาดเล็กกว่า 2.5 ไมครอน ($PM_{2.5}$) บริเวณที่พักอาศัยในเขตเมืองชั้นในของกรุงเทพมหานคร

นางสาวขณัฏฐาพรรณ ปานณรงค์

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิทยาศาสตรมหาบัณฑิต
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Thesis Title	HEALTH RISK ASSESSMENT OF INHALATION EXPOSURE TO PAHs ADSORBED ON $PM_{2.5}$ AT RESIDENTIAL AREAS LOCATED IN THE INNER CITY OF BANGKOK
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ขณัฏฐาพรรณ ปานณรงค์ : การประเมินความเสี่ยงต่อสุขภาพในการรับสัมผัสสารพอลิไซคลิกอะโรมาติกไฮโดรคาร์บอน (PAHs) ที่ดูดซับบนฝุ่นละอองขนาดเล็กกว่า 2.5 ไมครอน ($PM_{2.5}$) บริเวณที่พักอาศัยในเขตเมืองชั้นในของกรุงเทพมหานคร (HEALTH RISK ASSESSMENT OF INHALATION EXPOSURE TO PAHs ADSORBED ON $PM_{2.5}$ AT RESIDENTIAL AREAS LOCATED IN THE INNER CITY OF BANGKOK) อ.ที่ปรึกษาวิทยานิพนธ์หลัก: ผศ. ดร. ทรรศนีย์ พฤกษาสิทธิ์, 171 หน้า.

งานวิจัยนี้เป็นการศึกษาการประเมินความเสี่ยงต่อสุขภาพของผู้พักอาศัยจากการรับสัมผัสสารพอลิไซคลิกอะโรมาติกไฮโดรคาร์บอน (PAHs) ที่ดูดซับบนฝุ่นละอองขนาดเล็กกว่า 2.5 ไมครอน ($PM_{2.5}$) บริเวณที่พักอาศัยในเขตเมืองชั้นในของกรุงเทพมหานคร โดยทำการเก็บตัวอย่างฝุ่นละอองขนาดเล็กกว่า 2.5 ไมครอน ($PM_{2.5}$) และ ฝุ่นละอองขนาดใหญ่กว่า 2.5 ไมครอน แต่เล็กกว่า 10 ไมครอน ($PM_{2.5-10}$) บริเวณ 5 ชุมชนในเขตปทุมวัน เป็นเวลา 24 ชั่วโมง ในวันอาทิตย์ วันอังคาร และวันศุกร์ ในช่วงฤดูร้อน (เมษายน – พฤษภาคม 2556) และฤดูฝน (กันยายน – ตุลาคม 2556) ทำการเก็บตัวอย่างอากาศด้วยเครื่องเก็บตัวอย่างอากาศชนิดบุคคลที่ต่อกับ personal modular impactor (PMI) ด้วยอัตราการไหลของอากาศเท่ากับ 3 ลิตรต่อนาที วิเคราะห์สาร PAHs ในตัวอย่างฝุ่นด้วยเครื่อง HPLC Fluorescence และ UV detector ผลการศึกษาพบว่า ความเข้มข้นของ $PM_{2.5}$ และ PM_{10} ($PM_{2.5}$+$PM_{2.5-10}$) ที่พบภายในบ้านอยู่ในช่วง 7.52 - 92.85 ไมโครกรัมต่อลูกบาศก์เมตร และ 13.64 - 123.82 ไมโครกรัมต่อลูกบาศก์เมตร ตามลำดับ ในขณะที่ค่าความเข้มข้นของ $PM_{2.5}$ และ PM_{10} ที่ตรวจวัดภายนอกบ้านมีค่าอยู่ในช่วง 9.44 - 68.60 ไมโครกรัมต่อลูกบาศก์เมตร และ 17.72 to 134.37 ไมโครกรัมต่อลูกบาศก์เมตร ปริมาณความเข้มข้นเฉลี่ยของสาร PAHs รวมใน $PM_{2.5}$ (t-$PAHs_{2.5}$) ที่ตรวจวัดภายในและภายนอกบ้าน มีค่าอยู่ในช่วง 0.04 - 4.92 นาโนกรัมต่อลูกบาศก์เมตร และ 0.09 – 4.22 นาโนกรัมต่อลูกบาศก์เมตร ตามลำดับ ปริมาณ $PM_{2.5}$ มีความสัมพันธ์กับปริมาณ t-$PAHs_{2.5}$ อย่างมีนัยสำคัญทางสถิติ โดยมีค่า r เท่ากับ 0.660 ที่ระดับความเชื่อมั่น 95% (*p*<0.05)

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KHANUDTHAPARN PARNNARONG: HEALTH RISK ASSESSMENT OF INHALATION EXPOSURE TO PAHs ADSORBED ON $PM_{2.5}$ AT RESIDENTIAL AREAS LOCATED IN THE INNER CITY OF BANGKOK. ADVISOR: ASST. PROF. TASSANEE PRUEKSASIT, Ph.D., 171 pp.

This research studied on health risk assessment of the residents exposed to polycyclic aromatic hydrocarbons (PAHs) adsorbed on particles smaller than 2.5 µm ($PM_{2.5}$) via inhalation at the residential areas in the inner city of Bangkok. Particulate matters ($PM_{2.5}$ and $PM_{2.5-10}$) were collected on Sunday, Tuesday, and Friday for 24 hours in dry season (April to May 2013) and wet season (September to October 2013) at five representative communities in Pathumwan district. The air sampling was performed by using a personal modular impactor (PMI) connected to personal air pump with the flow rate of 3 L/min. PAHs adsorbed on particles were analyzed by HPLC with fluorescence and UV detectors. The indoor concentrations of $PM_{2.5}$ and PM_{10} ($PM_{2.5}$+$PM_{2.5-10}$) ranged from 7.52 to 92.85 $\mu g/m^3$ and from 13.64 to 123.82 $\mu g/m^3$, respectively. Whereas, the outdoor concentrations of $PM_{2.5}$ and PM_{10} ranged from 9.44 to 68.60 $\mu g/m^3$ and from 17.72 to 134.37 $\mu g/m^3$, respectively. The indoor and outdoor concentrations of total PAHs adsorbed on $PM_{2.5}$ (t-$PAHs_{2.5}$) ranged from 0.04 to 4.92 ng/m^3 and from 0.09 to 4.22 ng/m^3, respectively. The significant correlation between $PM_{2.5}$ concentrations and the concentrations of t-$PAHs_{2.5}$ could be obtained with the Pearson correlation (r) of 0.660 at 95% confidence ($p<0.05$).

Field of Study:	Environmental Management	Student's Signature	....
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CHAPTER I

INTRODUCTION

1.1 Rationale background and problem addressed

Presently, many countries are confronted with environmental problems, especially developing countries. Thailand is one of them as well which air pollution problems are the major concern in most urban areas due to the rapid economic and population growth. Urban areas, such as Bangkok, the capital city of Thailand with over 6 million populations, is a center of government, education, transportation, commerce, business, communication, and the prosperity of the country. As a result they are demanded for travelling and transportation. Moreover, the number of vehicles are increased every year. These are directly relevant to traffic problems in a crisis and also contribute to air pollution problems.

Air pollution problems, especially fine particles smaller than 2.5 μm ($PM_{2.5}$) should be considered. It is because its human health effects with deeply accumulate in respiratory system more than coarse particles lead to cardiovascular and respiratory disease include mortality. $PM_{2.5}$ can be found from many different outdoor sources, such as motor vehicle exhaust, production processes from industries and power plants, smoke from biomass burning and also indoor sources, such as cooking and smoking. In addition, it is formed in the air from the chemical reaction of gases such as SO_2, NO_x, and VOCs (PCD, 2009). Trends of particulate matters in Bangkok presented in the study of Wimolwattanapun et al. (2011) wich studied $PM_{2.5}$ and PM_{10} at urban Bangkok site (Chatuchak district) and a suburban site (Klongha district, Pathumthani) in Thailand. The result indicated that the annual average concentrations of $PM_{2.5}$ in Bangkok from 2003 to 2007 were 19.1, 26.6, 23.3, 24.3, and 23.2 μg/m^3, respectively. The annual average concentrations of $PM_{2.5}$ in Pathumthani from 2003 to 2007 were 14.4, 25.2, 20.2, 17.7, and 19.8 μg/m^3, respectively. Both sites would also exceed the U.S. annual average standard for $PM_{2.5}$, 15 μg/m^3. In addition, the relationship between personal PM_{10} exposure and indoor and outdoor PM_{10} concentrations were investigated in 14 shop houses on Sukhumvit Road, Bangkok. The averages of personal exposure, and indoor and outdoor PM_{10} concentrations were 81.6, 74.6 and 130.7 μg/m^3 respectively (Watchalayann et al., 2005).

Polycyclic aromatic hydrocarbons (PAHs) are the major compounds of $PM_{2.5}$. Thus, atmospheric pollution of PAHs contained in $PM_{2.5}$ is a serious environment issue. Most of PAHs existing in the environment are mainly emitted into air from many natural sources, such as forest fires and volcanic eruptions and also anthropogenic sources, such as cooking, heating, and smoking in household, production processes in industry, and combustion processes from motor vehicle exhaust. The indoor and outdoor concentrations of PAHs in 3 residential buildings were estimated at urban area of Guangzhou, China. The total PAHs concentrations ranged from 14.18 to 77.89 ng/m^3 and 15.83 to 84.83 ng/m^3 in the indoor and outdoor samples, respectively. High positive correlations between indoor and outdoor concentrations of $PM_{2.5}$ and PAHs, which were due to the high efficiency of indoor ventilation, indicated that concentrations of these indoor air pollutants were dominated by outdoor sources (Li et al., 2005). Furthermore, in the north central part of India, PAHs were measured in indoor and outdoor environment of 10 homes at urban and roadside areas during the winter season. The average concentration of total PAHs was 1946.84 ng/m^3 in kitchen, 1666.78 ng/m^3 in living room and 1212.57 ng/m^3 in outdoors at urban site, whereas at roadside site it was 2824.87 ng/m^3, 2161.26 ng/m^3, and 3294.28 ng/m^3 in kitchen, living room and outdoors respectively (Masih et al., 2010)

PAHs are also classified as one of the most hazardous air pollutants, causing serious health problems including skin or eye irritation and immunogenic-toxicity. They are also known as carcinogen, mutagen and toxic compounds not only for human but also for animals and plants. Moreover, PAHs compounds has been widely regarded as contaminants spreading and causing mutations in the environment with low acute toxicity but in the living things are found with chronic toxicity (WHO, 2010).

In this case, occupants who spend most of their time indoors, could be one of the high-risk groups with regards to $PM_{2.5}$ air pollution. As a results, they are likely exposure to PAHs in indoor environments such as homes or workplaces as well. Thus, it should be interesting to study this issue.

As mentioned above, many researches were conducted widely in residential areas in several countries. However, the information is still quite limited for a city like Bangkok. In addition, most of the previous studies of particulate matters in Bangkok always present in term of coarse particles – PM_{10}. And the studies of PAHs related to $PM_{2.5}$ in residential areas in Bangkok are limited. Thus, the purpose of this study was to investigate the concentrations of PAHs adsorbed on $PM_{2.5}$ at residential areas located in the inner city of Bangkok, and also evaluate the potential risk of occupants exposure to PAHs adsorbed on $PM_{2.5}$ via inhalation.

1.2 Objectives of this study

1) To analyze the concentration of fine particles and polycyclic aromatic hydrocarbons (PAHs) adsorbed on particles smaller than 2.5 μm ($PM_{2.5}$) at residential areas located in the inner city of Bangkok

2) To compare the concentration of fine particles and PAHs adsorbed on $PM_{2.5}$ at residential areas located in the inner city of Bangkok with seasonal variation

3) To evaluate health risk of the occupants due to inhalation exposure to PAHs adsorbed on $PM_{2.5}$ at residential areas located in the inner city of Bangkok

1.3 Hypotheses

1) The occupants in the inner city of Bangkok tend to be at risk from inhalation exposure to PAHs adsorbed on $PM_{2.5}$ at their residential areas

2) The concentration of PAHs adsorbed on $PM_{2.5}$ at residential areas of five communities located in the inner city of Bangkok in dry season will be higher than in wet season

1.4 Scopes of the study

1.4.1 Study areas

Five representative communities in the inner city of Bangkok were chosen for this study to collect the indoor and outdoor air sample - Salak Hin, Lang Wat Pathumwanaram, Phatthana Bonkai, Soi Pra Chen, and Chao Choocheep community.

1.4.2 Indoor air sampling technique

All samples were obtained using personal modular impactor (PMI) contained 2 types of filters connected to personal air pump with the flow rate of 3 L/min. For indoor air sampling, the sampling equipment was placed approximately 1.5-2 m height above the ground in the main living area where the residents spent most of their time.

1.4.3 Outdoor air sampling technique

For the outdoor air sampling, the same equipment as indoor air sampling were placed out of windows from the outside wall along the sampling period.

1.4.4 Sampling duration

In this study, the sampling were carried out in 2 seasons, dry season (April-May 2013) and wet season (September-October 2013). $PM_{2.5}$ and $PM_{2.5-10}$ were collected by using personal air pump at five study areas. The sampling of each community was conducted 3 times (Sunday, Tuesday, and Friday) for 1 week. These 3 days represent weekend, work day, and end of work day in a week, respectively. A total of 15 houses in 5 communities (3 houses of each community) were selected on the basis of their same patterns. One of three houses was selected for both of indoor and outdoor sampling and two others houses for only indoor sampling. The indoor and outdoor air samples of 24-h duration were collected simultaneously from morning to morning (7 AM-7 AM).

1.4.5 Analytical technique

The concentrations and species of PAHs were analyzed by High Performance Liquid Chromatography (HPLC) with fluorescence and UV detector.

1.5 Expected outcomes

1) The investigation of concentrations of PAHs adsorbed on PM2.5 at residential areas located in the inner city of Bangkok

2) The essential database of inhalation exposure to PAHs adsorbed on PM2.5 at residential areas located in the inner city of Bangkok

3) The health risk information of occupants which can be applied for risk management from inhalation exposure to PAHs adsorbed on PM2.5 at residential areas located in the inner city of Bangkok

4) The essential results would be applied as a guideline for the estimation of air pollution's profile at residential areas located in the inner city of Bangkok

CHAPTER II

LITERATURE REVIEWS

2.1 $PM_{2.5}$

2.1.1 Definition of $PM_{2.5}$

US.EPA. (United State Environmental Protection Agency) has provided the definition of $PM_{2.5}$ that $PM_{2.5}$ is fine particles with aerodynamic diameter less than 2.5 µm. Generally, these fine particles come from all types of combustion activities, for example, motor vehicle, power plants, industrial processes, and wood burning. In addition, the fine particles are formed in the air from the chemical reaction of gases such as SO_2, NO_x, and VOCs (Panich et al., 2004).

2.1.2 Sources of $PM_{2.5}$

$PM_{2.5}$ can be found in smoke. These fine particles may be come from main sources (primary particles) such as combustion. Moreover, they may result from the combination of gas emissions from power plants or from vehicle exhaust react with the air to form the secondary particles. In most cases, $PM_{2.5}$ is secondary particles.

$PM_{2.5}$ can remain in the atmosphere for several days to several weeks. The major components of $PM_{2.5}$ are sulfate ion, nitrate ion, ammonium, elemental carbon, organic carbon, and metal. The main sources of $PM_{2.5}$ are burning coal, oil, and woods, and are also the transformations of nitrogen oxides, sulfur dioxides, and organic compounds in atmosphere, processes with high heat, blast furnace, and steel mill. Sources of $PM_{2.5}$ vary by regions, for example, Bangkok and roadsides are motor vehicle, common areas are combustion and motor vehicle, and Samutprakan province are industries and transportation (PCD, 2009).

2.1.3 Air quality standard of $PM_{2.5}$

Presently, many countries recommended the air quality standard for $PM_{2.5}$ to protect health effects from long-term and short-term exposure to $PM_{2.5}$ such as USA, Canada, UK, EU, Australia, and New Zealand. Furthermore, WHO stipulated the Air

Quality Guideline (AQG) for $PM_{2.5}$ in short term (24 hours.) and long term (1 year) and provide the Interim Targets (IT) into 3 levels in case of cannot reach to guideline. Other countries can use Interim Targets for measurement the progress of implementation of solving the problem continuously. Some standards and guidelines for $PM_{2.5}$ announced by international organizations and some countries are summarized in Table 2.1.

In addition, Pollution Control Department (PCD) considered that setting the air quality standard for $PM_{2.5}$ of Thailand is the one of preventive measures and solving air pollution problems. In addition, it can be general criteria for promoting and preserving the environmental quality to increase the health effects protection of general public, both in short and long term (PCD, 2009). Thus, PCD set the annual average standard for $PM_{2.5}$ do not exceed 25 $\mu g/m^3$ and the daily average standard do not exceed 50 $\mu g/m^3$ because they are the non-harmful level for health (PCD, 2010).

Table 2.1 Standards and guidelines of $PM_{2.5}$

Organizations/Countries	Standard of $PM_{2.5}$ ($\mu g/m^3$)	
	Average 24 hrs	Average 1 yr
WHO (WHO Air Quality Guidelines Global Update 2005)		
Interim Target (IT-1)	75	35
Interim Target (IT-2)	50	25
Interim Target (IT-3)	37.5	15
Air Quality Guideline (AQG)	25	10
US.EPA. (National Ambient Air Quality Standards; NAAQS promulgated in December, 2006)	35	15
California State (State standard)	-	12
UK (Except Scotland)	-	25
Scotland	-	12
European Union (EU)	-	25
Canada (Canada-wide standards; CWS)	30	-
Newfoundland (Provincial standard)	25	-
Metro Vancouver	25	12
Australia	25	8
New Zealand	25	-

Source: Modified from PCD (2009)

2.1.4 Health effects of $PM_{2.5}$

$PM_{2.5}$ can deeply accumulate in respiratory system more than coarse particles. The previous epidemiological studies indicated that the relation between exposure to $PM_{2.5}$ and adverse health effects are premature death and increased hospital admissions for respiratory effects. Long-term period of exposure to $PM_{2.5}$ is more serious health effects than its short term (PCD, 2009). People who might be a group at high risk of exposure to $PM_{2.5}$ are patients with heart or lung disease, older adults and children. Moreover, pregnant women, newborns and people with health conditions are more susceptible affection from $PM_{2.5}$.

In 2004, PCD assigned Thammasat University the project to set draft of air quality standard for $PM_{2.5}$. Two epidemiological studies were analyzed as follow: time series analyses of the death and admission to hospital in Bangkok, and panel studied of acute effects of respiratory system exposure to $PM_{2.5}$. The results of these studies are exposure to $PM_{2.5}$ every 10 $\mu g/m^3$ in Bangkok (for 10,000,000 peoples) increased the risk of short term effects of daily mortality, cardiovascular mortality, and respiratory mortality 1.3%, 3.6%, and 1.7%, respectively, and increased lower and upper respiratory condition 9% and 11%, respectively. Moreover, epidemiological study in USA found that exposure to $PM_{2.5}$ every 25 $\mu g/m^3$ increased the risk of long term effects of daily mortality, cardiovascular mortality, and respiratory mortality 10-39%, 16-54%, and 3-61%, respectively (PCD, 2009).

2.1.5 Situation of $PM_{2.5}$ in other big cities

The indoor and outdoor concentrations of $PM_{2.5}$ in 3 residential buildings measured at urban area of Guangzhou, China were in range of 82.12-170.97 $\mu g/m^3$ and 83.33-176.04 $\mu g/m^3$, respectively which exceeded the daily average concentration of 65 $\mu g/m^3$ proposed by US EPA (Li et al., 2005). In addition, Massey, Kulshrestha, Masih, and Taneja (2012) studied the concentration of PM_{10}, $PM_{5.0}$, $PM_{2.5}$, and $PM_{1.0}$ in indoor and outdoor environments of roadside and urban homes located in North-Central India. For fine particles ($PM_{2.5}$) the annual mean concentrations in indoor and outdoor were 161 $\mu g/m^3$ and 160 $\mu g/m^3$ at roadside houses and 109 $\mu g/m^3$ and 123 $\mu g/m^3$ at urban houses. Nevertheless, the previous study found that the indoor and outdoor $PM_{2.5}$ average concentrations (67.7 and 74.5 $\mu g/m^3$) at residential homes located in generic urban, roadside, and industrial plant area in Guangzhou City, China, were about two times higher than the new guideline of WHO (Huang et al., 2007).

2.1.6 Situation of $PM_{2.5}$ in Bangkok

The PCD's measurement of air quality from 2002 to 2007 showed that Bangkok is continuously faced air pollution problems. The investigation of $PM_{2.5}$ at Baansomdet Chaopraya Rajabhat University (generic area) and Pollution Control Department's Dindang air quality monitoring station (roadside) demonstrated that the concentrations of $PM_{2.5}$ at roadside were higher than generic area as shown in Table 2.2.

Table 2.2 The annual average concentrations of $PM_{2.5}$ in Bangkok from 2002-2007

Year	Concentration of $PM_{2.5}$ for 24 hours (µg/m^3)	
	Generic area	Roadside
	Baansomdet Chaopraya Rajabhat University	Dindang
2002	32.87	56.61
2003	31.70	52.63
2004	37.28	54.85
2005	26.86	52.19
2006	23.91	36.53
2007	21.64	63.81

Source: Modified from PCD (2008)

In addition, the measurement at Dindang Road in 2012 indicated that the annual average concentrations of $PM_{2.5}$ were 34 µg/m^3 and the maximum daily average concentrations were 86 µg/m^3 which exceeded the new standard in Thailand (25 µg/m^3 for annual and 50 µg/m^3 for daily average concentrations) about 46 days (PCD, 2012).

2.2 PAHs

2.2.1 Chemical properties of PAHs

PAHs are compounds with macro molecular structure. They are semi-volatile organic compounds which contain 2 or more fused aromatic rings. In the atmosphere, PAHs present in both gaseous and particulate phases. PAHs with 2 and 3 rings are mostly found in the gaseous phase, while PAHs with 5 or more aromatic rings exist in the particles (WHO, 2010). Although, PAHs in gaseous phase (low-molecular-weight PAHs) are the great form of the total PAHs in the atmosphere, they are mentioned less mutagenic and/or carcinogenic than PAHs with high molecular weight that are adsorbed on fine particles (Wu, J. et al., 2012).

Generally, PAHs at normal temperature are solid with high boiling and melting point, low vapor pressure, and very low solubility in water. PAHs are inert compounds and can break down by photodecomposition and can also react with nitrogen oxide, nitric oxide, sulfur dioxide, sulfuric acid, ozone, and hydroxy radical (Wannavichit, 2005).

PAHs are released into the environment and can exist for long periods. Most of PAHs existing in the environment are mainly emitted into air from many sources. In addition, they can enter surface water, and can also be released to soils. However, the action of PAHs in the environment have to rely on their properties such as how they evaporate into the air or how they dissolve in water (ATSDR, 1995)

PAHs is known as carcinogen, mutagen, and toxic not only for human but also for animals and plants. The 16 PAHs listed by U.S. EPA as priority pollutants are showed in Figure 2.1.

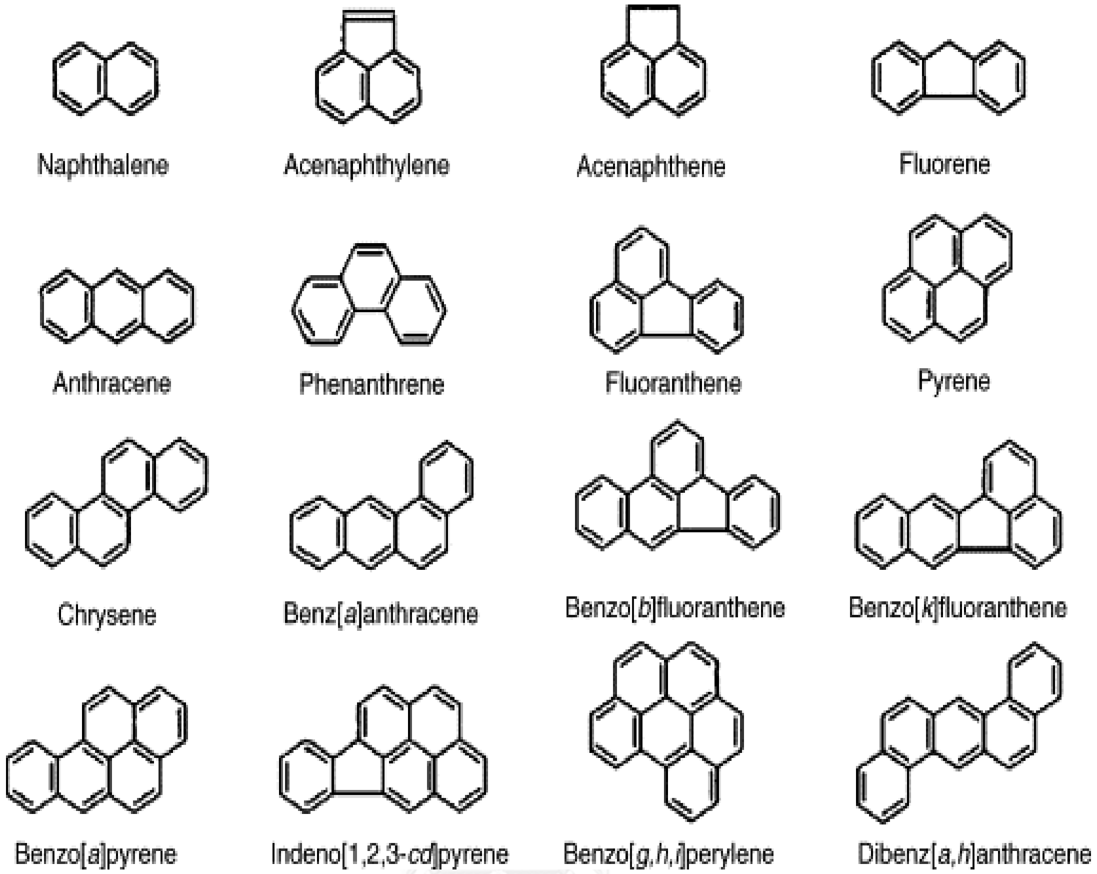


Figure 2.1 The structures of 16 priority PAHs, listed by the USEPA

Source: Anyakora et al. (2005)

2.2.2 Sources of PAHs

PAHs directly emit into the air from forest fires, volcanic eruptions, and human activities, such as, incomplete combustions. Therefore, sources of PAHs in atmosphere can divided into 2 main sources.

2.2.2.1 Natural sources

Forest fires and volcanic eruptions are mainly natural sources of PAHs. In Canada, PAHs in atmosphere result from forest fires are about 2,000 tons per year. Moreover, Benzo(a)pyrene is found from volcanic eruptions about 1.2-1.4 tons per year (Wannavichit, 2005).

2.2.2.2 Anthropogenic Sources

1) Household

PAHs from indoor sources and residential areas are result from heating including smoking. In countries with a winter season, PAHs are usually from burning in fireplaces with woods, coals, and cokes. Almost 90% of the rural population in developing countries and 50% of the world population use biomass as energy source (Torres-Dosal et al., 2008). In the USA, the residential burning of wood is now mentioned as the largest source of PAHs (WHO, 2000).

In India, people used woods and coals as a main heating sources in household that showed the concentration of Benzo(a)pyrene more than 120 ng/m^3 and the concentrations of individual species PAHs are 1.3-200 ng/m^3. Benzo(e)pyrene, Benzo(g,h,i)pyrene, and Benzo(b)fluoranthene are the individual species PAHs with high concentrations (Wannavichit, 2005).

In Christchurch, New Zealand, the average concentrations of individual species PAHs from heater in household were 1-210 ng/m^3, while the highest concentrations were Benzo(g,h,i)pyrene and Coronene with more than 43 ng/m^3. In Germany, the high concentration of PAHs was showed in residential areas from heating with coals and Benzo(a)anthracene, Benzo(b)fluoranthene, and Chrysene present with more than 260 ng/m^3 (Wannavichit, 2005).

2) Industry

PAHs have been found in coal tar production plants, coking plants, bitumen and asphalt production plants, coal-gasification sites, smoke houses, aluminum production plants, coal tarring facilities, and municipal trash incinerators. Workers may be exposed to PAHs by inhaling engine exhaust and using products that contain PAHs in a variety of industries such as mining, oil refining, metalworking, chemical production, transportation, and the electrical industry. PAHs have also been found in other facilities where petroleum, petroleum products, or coal are used or where wood, cellulose, corn, or oil are burned (ATSDR, 1995).

3) Motor vehicle

Emissions from traffic have been found to be the main outdoor source for the indoor PAH concentration at urban and suburban locations in many industrialized countries (WHO, 2010). PAHs emitted from the vehicles exhaust using diesel and benzene. PAHs from benzene cars are mostly low-molecular-weight PAHs, so they are formed in gaseous phase. For diesel cars, PAHs are burned within the engine at high temperature and emitted to external engines with lower temperature, so they would condense on particles.

Saiwan (1998) studied PAHs from motor vehicle exhaust at 3 roadsides located in Pratu Nam, Yaowarat, and Bang Yikhan, Bangkok. The results demonstrate that only 3 PAHs could be found, Phenanthrene, Fluoranthene, and Pyrene. The total PAHs were in range with 1.14 - 91.78 $\mu g/m^3$. The average concentration of PAHs found at roadside was higher than found at generic area. In addition, the distribution of PAHs in the air was similar to emission of motor vehicle exhaust. This may suggest that PAHs in the atmosphere of Bangkok originated from the motor vehicle exhaust.

2.3 PAHs adsorbed in $PM_{2.5}$

Generally, most of PAHs with low vapour pressure in the air are adsorbed on particles (particle-bound PAHs, pPAHs) (WHO, 2000). The carcinogenic PAHs (e.g. benzo(a)pyrene and benzo(a)anthrene) are mostly associated with the particulate matter and particle-bound PAHs are mentioned to be hazardous to human health.. Thus, many studies on PAHs in the air have been focused on PAHs bound to PM, particularly $PM_{2.5}$ (Zheng, 2009)

2.3.1 Size distribution of PAHs

The comparison of amount, surface areas, and concentrations of PM with diameter 0.001-100 µm showed that fine particles are greater than coarse particles. The high concentrations particles may have diameter of 0.5 and 10 µm due to fine particles have more amounts and surface areas than coarse particles, so PAHs are plentifully adsorbed on fine particles (Thongyen, 2009). Furthermore, Environmental Research and Training Centre studied the levels of 6 PAHs adsorbed on PM_{11} in Bangkok ambient air from residential areas, industrial zones, and roadsides. The results showed that benzo(ghi)perylene was found at the highest concentrations and noted that most of PAHs were adsorbed on particles because fine particles have more surface areas and PAHs are negligible evaporated in vapour phase (Thongyen, 2009).

In addition, Guo, Lee, Ho, Wang, and Zou (2003) investigated 16 PAHs in $PM_{2.5}$ and PM_{10} in Hong Kong from high traffic jam and general areas, found that PAHs ratio in $PM_{2.5}$ and PM_{10} at high traffic jam and general areas are 0.76-0.84 and 0.72-0.79, respectively. As a result, PAHs are adsorbed on $PM_{2.5}$ more than $PM_{2.5\text{-}10}$. Thongsanit, Jinsart, Hooper, Limpaseni, and Hooper (2002) studied PAHs in PM_{10} divided into 5 sizes: <0.95, 0.95-1.5, 1.5-3.0, 3.0-7.2, and >7.2 μm in Bangkok, found that 97.55% of PAHs were adsorbed on particles with <0.95 μm. And 1.02 %, 0.52 %, 0.50 %, and 0.41% of PAHs were adsorbed on particles with 0.95-1.5, 1.5-3.0, 3.0-7.2, and >7.2 μm, respectively. This result related to the study of Zhou, Wang, Huang, Mao, and Zhong (2005) about 17 PAHs in 5-stage size particles in Beijing, China which indicated that the total concentrations of 17 PAHs ranged between 0.84-152 ng/m^3. The highest concentration of PAHs (152 ng/m^3) were adsorbed on particles size less than 1.1 μm, while the lowest concentration of PAHs (0.84 ng/m^3) presented in particles size with 3.3-7.0 μm that showed in Table 2.3. Size distribution of cumulative percent for total-PAHs was shown in Figure 2.2.

Table 2.3 Size distribution of PAHs concentrations

Sampling	Season	≥ 7.0 μm	3.3 – 7.0 μm	2.0 – 3.3 μm	1.1 – 2.0 μm	≤ 1.1 μm
Suburban	Spring	0.91	3.7	5.6	16	26
Urban	Spring	6.0	3.2	8.2	5.7	49
Suburban	Summer	1.0	0.84	1.0	1.8	6.1
Urban	Summer	2.0	1.4	1.7	2.3	9.3
Suburban	Autumn	6.5	8.1	5.4	26	50
Urban	Autumn	7.0	7.3	8.2	41	65
Suburban	Winter	7.6	44	17	30	118
Urban	Winter	16	15	21	134	152

Source: Zhou et al. (2005)

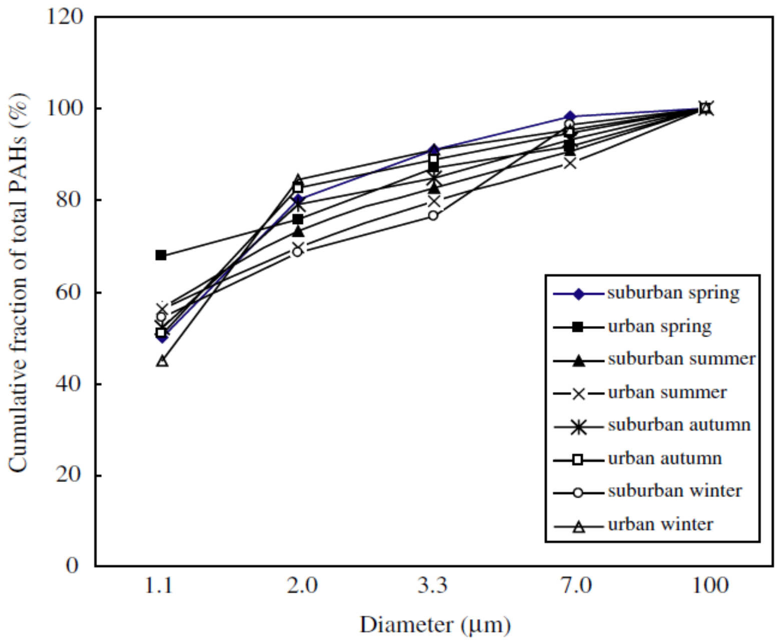
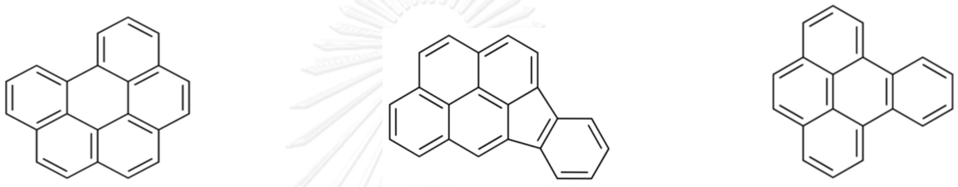


Figure 2.2 Size distribution of cumulative percent for total-PAHs

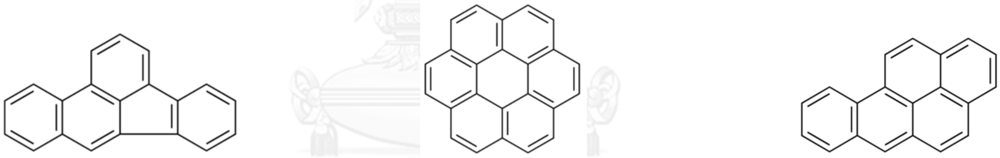
Source: Zhou et al. (2005)

2.3.2 Species of PAHs adsorbed on $PM_{2.5}$

The study of Thongsanit et al. (2002) about the concentrations of PAHs in 5-size stage PM_{10} in Bangkok from 6 locations: Chulalongkorn University, Chulalongkorn Hospital, Din Dang, Office of Environmental Policy and Planning, Singharat School, and Bangkok University found that the 6 high concentrations of PAHs were Benzo(g,h,i)perylene, Indeno(1,2,3-cd)pyrene, Benzo(e)pyrene, Benzo(b)fluoranthene, Coronene, and Benzo(a)pyrene as shown in Table 2.4 and the structure of them as shown in Figure 2.3.



Benzo[*ghi*]perylene Indeno[1,2,3-*cd*]pyrene Benzo[*e*]pyrene



Benzo[*b*]fluoranthene Coronene Benzo[*a*]pyrene

Figure 2.3 The structure of 6 high concentration of PAHs

Source: Anyakora et al. (2005)

Table 2.4 The 6 high concentrations and species of PAHs

Species of PAHs	The annual concentrations of PAHs (ng/m^3)					
	University	Roadside	Roadside	Background	Background	Background
	CU	Chulalongkorn Hospital	Dindang	Office of Environmental Policy and Planning	Singharat School	Bangkok University
BghiP						
average	12	15	13	12	17	10
range	2.5-27.6	3.8-40.1	3.1-25.3	0.5-29.2	2.3-38.8	1.2-19.6
Ind						
average	10	10	7	10	14	9
range	1.7-30.6	2.5-27.5	1.4-17.6	1.5-23.8	2.5-35.3	1.2-20.7
BeP						
average	10	10	9	7	7	5
range	1.6-28.4	1.9-22.9	1.3-17.7	0.9-25.0	0.7-24.8	0.5-17.5
BbF						
average	8	6	5	4	4	3
range	0.2-25.3	1.2-13.0	0.6-13.4	0.31-11.6	0.3-15.0	0.3-11.6
Cor						
average	4	5	3	5	8	4
range	1.2-12.8	1.0-14.2	1.2-7.0	1.5-11.2	1.6-19.1	0.5-8.3
Bap						
average	4	5	4	3	3	3
range	1.6-12.6	1.2-3.0	0.3-10.7	0.6-10.0	0.4-10.8	0.3-6.2

Source: Thongsanit et al. (2002)

2.3.3 Distribution of pPAHs in different environments

2.3.3.1 Roadside

Emissions from traffic have been found to be the main outdoor source for the indoor PAH concentration at urban and suburban locations in many industrialized countries.

Zhigang et al. (2009) studied the occurrence and sources of PAHs and *n*-alkanes in $PM_{2.5}$ in the roadside environment of the heaviest traffic road in Qingdao, China. For PAHs, the significant increase in winter was observed with average PAH level of 32.3, 11.5, 48.9 and 263 ng/m^3 for spring, summer, autumn and winter, respectively. The pyrogenic PAHs were mainly from the coal burning, and the liquid fossil fuel combustion was their second contribution even at the roadside of a busy street with heavy traffic in Qingdao. In addition, Cheng et al. (2012) also studied real-time characterization of particle-bound PAHs (pPAHs) at a heavily trafficked roadside site in Hong Kong. The average concentration of corrected pPAHs was 5.3 ± 3.7 ng/m^3, ranging from 0.2 to 22.0 ng/m^3. The pPAHs concentrations increased in the daytime in accordance with the heavy amount of road traffic, and decreased in the nighttime due to less traffic. Hourly pPAHs concentrations had high correlation coefficients with all goods vehicles (> 0.9) and large buses (~0.8), showing that diesel vehicle emissions are the primary source of pPAHs.

2.3.3.2 Indoor and outdoor air environments

Ohura et al. (2004) studied the characteristics of particle matter and associated PAHs in indoor and outdoor air in two cities in Shizuoka, Japan. Indoor and outdoor concentrations of particle matter (PM) and associated PAHs in summer and winter were determined. Ratios of indoor to outdoor PAHs concentrations showed that the indoor PAHs were mostly from outdoor sources. Moreover, Masih et al. (2010) studied characteristics of PAHs in indoor and outdoor atmosphere in the North central part of India. The spatial trend of total PAHs concentrations in the house located at urban sites, was kitchen > living room > outdoors whereas at roadside site, the trend was outdoors > kitchen > living room. The kitchen/outdoor, living room/outdoor ratios were higher than one for all PAHs compound at urban site homes indicating the additional indoor sources, whereas at roadside homes I/O ratio were found to be less than 1, which suggested that indoor concentrations of these PAHs may also be attributed to outdoors sources. In addition, Li et al. (2005) studied the vertical distribution of PAHs in the indoor and outdoor $PM_{2.5}$ in Guangzhou, China. Mass concentrations of $PM_{2.5}$ and 20 PAHs were measured in 15 non-smoking residences in 3 residential buildings located in urban area. High positive correlations between indoor and outdoor concentrations of $PM_{2.5}$ and PAHs, which were due to the high efficiency of indoor ventilation, indicated that concentrations of these indoor air pollutants were dominated by outdoor sources.

2.4 Sources of PAHs at residential areas

2.4.1 Cooking

Wood, crop residues, agricultural wastes, and animal dung are the most commonly used as biomass fuels for domestic Torres-Dosal et al. (2008). In developing countries, the indoor air pollution are mainly from cooking with solid fuels such as dung, wood, agricultural residues or coal, especially in unvented or flue less stoves, due to the highly usage of these fuels. As well as cooking fuel being a source of PAHs, generated particularly in unvented stoves, cooking practice (e.g. charring meat, deep frying) is another source of PAHs. The increase in cooking temperature generally increases the production of most PAHs since the evaporation of PAHs firstly increase from heated oils into the air. The burning of fossil fuels and biofuel for cooking, generally in unvented stoves causing high concentrations of particulate PAH compounds in indoor environments and also found that exposure during the cooking period is 2–10 times higher than ambient exposure (WHO, 2010).

2.4.2 Heating

The main source of heating in developing countries and a secondary heating source in countries with a cold winter climate are wood burning in fireplaces and wood fuel stoves. Fifty percent of the world population and approximately 90% of the rural population in developing countries are using biomass as energy source. Latin America represents 12% of the global consumption of biomass; in Mexico, 27 million people use wood as an energy source (Torres-Dosal et al., 2008). In India, people used woods and coals as a main heating sources in household that showed the concentration of Benzo(a)pyrene more than 120 ng/m^3 and the concentrations of individual species PAHs are 1.3-200 ng/m^3. Benzo(e)pyrene, Benzo(g,h,i)pyrene, and Benzo(b)fluoranthene are the individual species PAHs with high concentrations (Wannavichit, 2005)

2.4.3 Smoking

PAHs from smoking can be divided into 2 conditions as follow: from main stream and side stream. PAHs from side stream presented Pyrene 39-101 µg/100 cigarettes and Fluoranthene 126 µg/100 cigarettes, whereas, PAHs from mainstream presented Pyrene and Fluoranthene 5-27 and 1-27.2 µg/100 cigarettes, respectively (Wannavichit, 2005). The high concentration of B(a)P in indoor environment from cigarette smoke could still be presented as 22 ng/m^3 , even the reductions in the emission of PAHs from cigarette smoke have been reported. More than 87% of the total PAHs may be attributed to smokers' homes. On the other hand, background sources are the largest contributor to PAHs in non-smokers' homes (WHO, 2010).

2.4.4 Furniture and renovation

The age of a house or building, as it reflects its condition, affects indoor concentrations of PAHs. For example, the older house provide the higher PAHs concentrations, as outdoor sources have a higher effect due to higher air exchange through poorly fitting windows. Creosote provide varying amounts of PAHs, which has been traditionally used as a wood preservative in the foundations of buildings, in fences and in the manufacture of garden furniture and outdoor recreational facilities in parks. Creosote-impregnated wood products presented B(a)P levels of 58–749 µg/g (WHO, 2010).

2.5 Exposure to PAHs by inhalation and health effects

2.5.1 Exposure to PAHs by inhalation

PAHs are released into the environment from the incomplete combustion adsorbed on fine particles, which is the most dangerous because the particles are small, can be inserted into the lung and has a surface area results in a toxic elements.

PAHs can enter the body via many routes, such as inhalation, dermal, and oral. People who live in near hazardous waste site where PAHs are disposed, are liable to inhale PAHs. While people who eat or drink food and water contaminated with PAHs, could be exposed. Moreover, exposure to PAHs can also occur if skin contacts PAHs-contaminated soil or products like heavy oils or coal tar. However, soil contact normally occurs outdoors but food and water consumption is usually indoors, inhalation leads to exposure both indoors and outdoors. One of the most common way PAHs can enter the human body is through the respiratory system and lungs by breathing gas, smoke or particles in the air via inhalation. The inhalation route of exposure to PAHs most probably contaminated with smoke or particles in the air (USEPA, 2008)

An important contributor to the inhalation source of PAHs is environmental tobacco smoke (ETS). In ETS-polluted, the daily inhalation of B(a)P in indoor environments ranged from 4 to 15 ng/day compared with 1.3–6.7 ng/day in homes not exposed to ETS. The highly daily inhalation can be present as 26–62 ng/day in pubs and discotheques. In ETS-exposed children, children's daily exposures expressed as urinary cotinine levels (a biomarker of tobacco smoke) were 8.1 µg/l urine compared to 2.7 µg/l in children not exposed to ETS (WHO, 2010).

The average inhalation rate of the general population for women and men as 11.3 m^3/ day and 15.2 m^3/day, respectively, are recommended. Considering the different B(a)P indoor air concentrations reported, and using the adult male inhalation rate as a worst-case scenario, the daily intake dose due to inhalation spans the range of 0.15–32 ng/day (WHO, 2010).

2.5.2 Distribution and accumulation

PAHs can spread and target fat tissues in the body. Target organs include the liver and kidneys (USEPA, 2008). PAHs tend to be accumulated mostly in the kidneys, liver, and fat. Smaller accumulation being in the spleen, adrenal glands, and ovaries. PAHs are changed into many different substances by all tissues in the body. Some of these substances are more harmful and some are less harmful than the original PAHs. The results from studies on animal demonstrated that PAHs are not likely to be accumulated in the body for long periods. Most of PAHs entered the body leave within a few days, primarily in the feces and urine (ATSDR, 1995).

2.5.3 Health effects

PAHs are classified as one of the most hazardous air pollutants, causing serious health effects. Air with high concentrations of PAHs causes many adverse effects on human. The effects on human health depend on the concentration of PAHs, duration time of exposure, route of exposure, and the toxicity of PAHs. The other factors can affect human health from exposure including pre-existing health status and age.

2.5.3.1 Carcinogenicity

B(a)P known carcinogenic PAHs have induced tumors through dermal, oral, and respiratory tract routes. Mice, rats, rabbits, hamsters and monkeys are the species that have developed tumors after exposure to PAHs (WHO, 2010). The laboratory studies found that animals exposed to some PAHs over long periods have developed lung cancer from inhalation, stomach cancer from PAHs ingestion in food and skin cancer from skin contact. In addition, studies of people indicated that individuals exposed to mixtures that contain PAHs and other compounds by inhalation or dermal for long periods can also develop cancer (ATSDR, 1995).

2.5.3.2 Mutagenicity

Carcinogenic PAHs are also presented the mutagenicity. Some PAHs probably cause mutations in a number of genes which contribute to cancer development. From the experiment on animals, tumors induced by a series of PAHs have harbored mutations in K-*ras* (lung tumors) and H-*ras* oncogenes (skin, liver and mammary tumors). From studies of people, lung tumors from non-smokers exposed to PAHs from coal combustion emissions had mutations at guanine in K-*ras* codon 12 and *p53* genes. Ambient air particulate matters have variably caused genotoxicity in vitro and DNA adduct formation. The major active components are PAHs, particularly B(a)P and nitro- and oxy- PAHs. In addition, the presence of B(a)P levels in ambient air causing DNA adducts (WHO, 2010).

2.5.3.3 Neurotoxicity

No data of neurotoxicity from exposure to PAHs except naphthalene which has been reported to cause neurological symptoms in infants with such as drowsiness, crying down, and jaundice in the brain (kernicterus). These data showed that the symptoms are caused by lack of oxygen in the brain. As a result of anemia caused by hemolysis (hemolytic anemia) (Nonthakanok, 2013)

2.5.3.4 Potentiation and antagonism

Generally, PAHs which caused by various sources, are formed in mixture more than single form and may contain other substances, such as nicotine mixed with PAHs in cigarette smoke, and asbestos fibers are mixed with PAHs in soot, etc.

The reaction between PAHs themselves and interactions between PAHs and other compounds, can occur in both before and after enter into the body of humans and animals. Due to the carcinogenic and mutagenic PAHs will be metabolized to change into metabolites that are toxic, and can be combined with the large biomolecules, such as DNA, RNA and proteins. Thus, inhibit or stimulate enzymes that are involved with metabolism of PAHs themselves or from other compounds would be effective in enhancing or against the toxic effects of PAHs (Nonthakanok, 2013)

2.5.3.5 Primary irritation

Mixtures of PAHs are known to cause skin effects in animals and human such as irritation and inflammation. Anthracene, benzo(a)pyrene and naphthalene are direct skin irritants while anthracene and benzo(a)pyrene are reported to be skin sensitisers, i.e. cause an allergic skin response in animals and human. Repeated contact with skin may induce redness and skin inflammation (Nonthakanok, 2013)

2.6 Human health risk assessment

At the present, the public is aware of the presence of harmful chemicals in the environment. Many people concern about pesticides and other chemical substances in food, contaminants in drinking water, and toxic pollutants in the air. Health risk assessment is a scientific tool designed to help these problems and determine which potential hazards are the most significant. A human health risk assessment is the process to estimate the nature and probability of adverse health effects on humans who may be exposed to chemicals in contaminated environmental media, now or in the future.

Risk assessment is the process of analyzing and characterizing information about risk of exposure to environmental hazard. The process of risk assessment consists of 4 steps as shown in Figure 2.4.

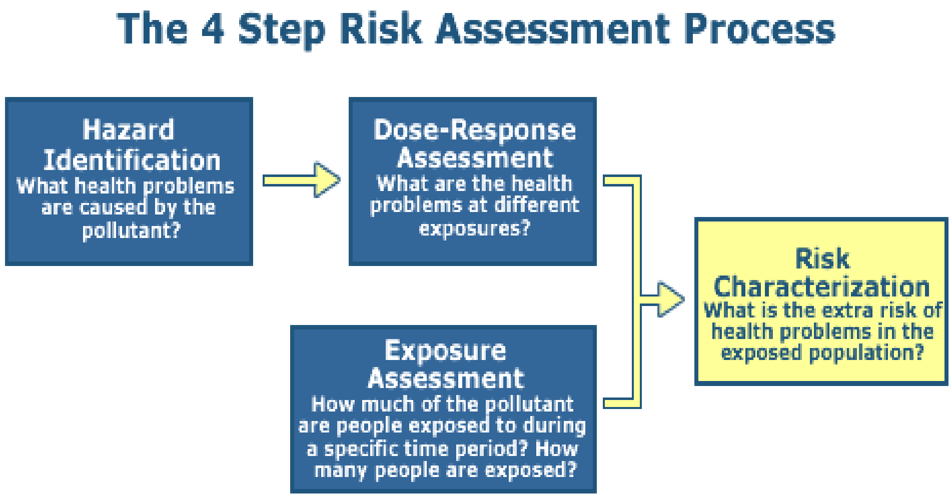


Figure 2.4 The 4 step risk assessment process

Source: USEPA (2011)

2.6.1 Hazard identification

The first step of risk assessment is hazard identification. This step aims to identify and determine the types of potential health problems that a chemical can cause. Depending on the chemical, these health effects may include short-term illness such as headaches, nausea, and eye, nose, and throat irritation; or chronic diseases such as cancer. Effects on sensitive populations such as pregnant women and the elderly or the people with health problems must also be considered. The data for hazard identification will come from a range of toxicological and epidemiological studies.

2.6.2 Dose-response assessment

The second step is dose-response assessment. This step aims to estimate how different levels of exposure to a chemical can impact the possibility of adverse health effects. Some factors are considered in this step which influences dose-response relationships such as age, gender, diet, lifestyle, histories of smoking, and other variables that could directly affect to susceptible groups.

2.6.3 Exposure assessment

The third step is exposure assessment. This step aims to determine the relationship between how long people were exposed to a chemical, how much of the chemical they were exposed to and how people were exposed. Briefly, the determination of the intensity, frequency, and duration of actual or hypothetical exposure of humans to the substances. To calculate the potential dose over the body weight and the average period of exposure was done by following generic equation:

$$\text{Intake} = \frac{CA \times IR \times ET \times EF \times ED}{BW \times AT} \qquad \text{(Eq. 2.1)}$$

where;

Intake (mg/kg/day) = Chronic Daily Intake (CDI) for cancer;

= Average Daily Dose (ADD) for non-cancer

CA (mg/m^3) = Contaminant concentration in air

IR (m^3/hr) = Intake rate

BW (kg) = Body weight

ET (hours/day) = Exposure time

EF (days/year) = Exposure frequency

ED (years) = Exposure duration

AT (days) = Averaging time

2.6.4 Risk characterization

The last step is risk characterization. This step aims to bring together the information developed in the previous three steps to estimate the risk of health effects in an exposed population. Risk characterization is a tool which synthesizes an overall conclusion about risk using for decision makers. The equations for calculating risk level are as follows:

$$\text{Cancer risk} = \text{CDI} \times \text{Slope factor} \qquad \text{(Eq. 2.2)}$$

where;

Cancer risk $> 10^{-6}$ means Carcinogenic effects of concern

Cancer risk $\leq 10^{-6}$ means Acceptable level

Hazard Quotient (HQ) = ADD/Reference dose (Eq. 2.3)

where;

HQ > 1 means Adverse non-carcinogenic effects of concern

HQ ≤ 1 means Acceptable level (of no concern)

A summation of the hazard quotients for all chemicals to which an individual is exposed, called a hazard index as shown in equation 2.4.

Hazard Index (HI) = $\sum (HQ_i)$ (Eq. 2.4)

where;

HI > 1 means Adverse non-carcinogenic effects of concern

HI ≤ 1 means Acceptable level (of no concern)

2.7 Related research articles

Li et al. (2005) studied the vertical distribution of PAHs in the indoor and outdoor $PM_{2.5}$ in Guangzhou, China. Mass concentrations of $PM_{2.5}$ and 20 PAHs were measured in 15 non-smoking residences in 3 residential buildings located in urban area during the 15 continued clear days. The indoor and outdoor concentrations of $PM_{2.5}$ significantly exceeded the daily average concentration of 65 μg/m^3 proposed by USEPA, with ranges of 82.12–170.97 μg/m^3 and 83.33–176.04 μg/m^3, respectively. The total PAH concentrations ranged from 14.18 to 77.89 ng/m^3 and 15.83 to 84.83 ng/m^3 in the indoor and outdoor samples, respectively, with 5–7-ring PAHs (from benzo[b]fluoranthene to coronene, MW = 252–300) as the predominant contributors (79–90%). High positive correlations between indoor and outdoor concentrations of $PM_{2.5}$ and PAHs, which were due to the high efficiency of indoor ventilation, indicated that concentrations of these indoor air pollutants were dominated by outdoor sources.

Ohura et al. (2004) studied the indoor and outdoor concentrations of particles and associated PAHs in two seasons (summer and winter) in two industrial cities (Fuji and Shimizu) in Shizuoka, Japan. A total of 88 houses in industrial, commercial, and residential areas were sampled for 24 hours. $PM_{2.5}$ was found in range with 44-56% of the total suspended PM. The indoor $PM_{2.5}$ concentrations measured in four campaigns ranged from 4.2 to 77 $\mu g/m^3$. In outdoors, the $PM_{2.5}$ concentrations ranged from 14 to 97 $\mu g/m^3$. The concentrations of indoor PAHs associated with $PM_{2.5}$ measured in four campaigns ranged from 1.6 to 23.7 ng/m^3. In outdoors, the concentrations of outdoor PAHs associated with $PM_{2.5}$ ranged from 1.1 to 29.5 ng/m^3. Most of the PAHs associated with the particles were in the $PM_{2.5}$ fraction. Ratios of indoor to outdoor PAHs concentrations showed that the indoor PAHs were mostly from outdoor sources, and the trends were especially noticeable in winter. In spite of the high contribution of PAHs to $PM_{2.5}$, no significant correlation was found between the concentration of $PM_{2.5}$ and the associated PAH concentration either indoors or outdoors. Carcinogenic risks associated with the inhalation of indoor PAHs were assessed, and Benzo(a)Pyrene showed the greatest contribution (51–64%) to the total carcinogenic risk.

Huang et al. (2007) studied spatial variation and relationship of indoor/outdoor $PM_{2.5}$ at residential homes in Guangzhou City, China. $PM_{2.5}$ were measured inside and outside 9 homes located in generic urban area, roadside area and industrial plant area. The indoor and outdoor $PM_{2.5}$ average concentrations (67.7 and 74.5 $\mu g/m^3$) were about two times higher than the new guideline of WHO. Both indoor and outdoor average $PM_{2.5}$ concentrations in roadside area (73.5 and 79.4 $\mu g/m^3$) and in industrial plant area (73.4 and 92.9 $\mu g/m^3$) were higher than those in generic urban area (56.2 and 51.2 $\mu g/m^3$). The average I/O ratio in generic urban area, roadside area and industrial plant area were 1.10, 0.93 and 0.79, respectively. Strong indoor/outdoor $PM_{2.5}$ correlation with I/O > 1 in generic urban area indicated excellent ventilation condition at there, good indoor/outdoor $PM_{2.5}$ correlation with I/O < 1 in roadside area suggested that the indoor $PM_{2.5}$ were mainly from the outdoor air, and poor indoor/outdoor $PM_{2.5}$ correlation in industrial plant area was ascribed to seldom ventilation in one home.

Martuzevicius et al. (2008) studied the traffic-related $PM_{2.5}$ aerosol in residential houses in the Greater Cincinnati and Northern Kentucky area. The samples were collected inside and outside of 6 houses located at a distance of approximately 30–300 m from major highways during spring and fall season. The outdoor $PM_{2.5}$ concentrations ranged from 7.3±0.7 µg/m^3 to 23.2±9.5 µg/m^3 in spring and from 14.1±4.4 µg/m^3 to 22.1±11.8 µg/m^3 in fall. The indoor $PM_{2.5}$ concentrations ranged from 9.1±3.3 µg/m^3 to 29.0±16.6 µg/m^3 in spring and from 10.4±2.6 µg/m^3 to 30.8±5.1 µg/m^3 in fall. The $PM_{2.5}$ I/O ratio ranged from 0.5±0.2 to 2.9±1.2 in spring and from 0.7±0.1 to 4.7±6.9 in fall. The traffic component was very pronounced in the ambient air of the six houses. Although the distance from the highway and traffic intensity are generally important for assessing the indoor concentration of traffic-related aerosols, the data collected in this study suggest that – specifically for houses located in a close proximity to major highways – these two factors may not necessarily play the most important role in differentiating exposure levels between houses.

Massey et al. (2009) studied Indoor/outdoor relationship of fine particles less than 2.5 µm ($PM_{2.5}$) in 14 residential homes in Agra located in central Indian region. The sample were collected for 24 hours inside and outside the homes located in roadside, rural and urban area, along with the field survey study done in the same region. The indoor average concentrations recorded for $PM_{2.5}$ were maximum for the rural homes (173.03 µg/m^3), and then by urban homes (135.55 µg/m^3). Indoor $PM_{2.5}$ monthly concentration ranged from 79.46 to 198.66 µg/m^3 in all the three microenvironments with six-month average concentration of 137.93 µg/m^3, 173.03 µg/m^3, and 135.55 µg/m^3 for roadside, rural and urban sites respectively. The average I/O ratios for $PM_{2.5}$ in roadside and rural areas were close to or above 1.00 and less than 1.00 for urban areas. The I/O ratios obtained were linked to the indoor activities using occupant's diary entries. The positive values of correlation coefficient (r) also indicated the indoor concentrations of particulate matter were correlated with the corresponding outdoor concentrations.

Zhu et al. (2009) studied pollution level, phase distribution and source analysis of PAHs in residential air in Hangzhou, China. The samples were collected from indoor and outdoor environments during both summer and winter and analyzed for the level of 16 PAHs. The results showed total PAH contents ranging from 0.425 to 36.2 ng/m^3 with highest concentrations in the kitchen areas generally. Particulate PAHs were predominantly absorbed on PM$_{2.5}$ with proportion of 59–97% to total particulate phase. PAH concentrations in indoor air of smoking residences tended to be higher than those of nonsmoking residences. Outdoor environment, Chinese conventional cooking practice, mothball emission and unknown source accounted for 10.5%, 32.8%, 71.5% and 6.2% of total PAHs in indoor air of nonsmoking residences, respectively. Outdoor environment was the fate for indoor PAHs in general, and consumed 10.5% of total PAHs. Finally, health risks associated with the inhalation of PAHs were assessed, and the results indicated that health-based guideline levels for lung cancer risk were exceeded. The largest contribution to total health risks in summer and winter was NA (72.9%) and BaP (45.2%), respectively.

Masih et al. (2010) studied the 23 PAHs in indoor and outdoor atmosphere of 10 houses at urban and roadside sites in the North central part of India during winter season. The average concentration of total PAH was 1,946.84 ng/m^3 in kitchen, 1,666.78 ng/m^3 in living room and 1,212.57 ng/m^3 in outdoors at urban site, whereas at roadside site it was 2,824.87 ng/m^3, 2,161.26 ng/m^3, and 3,294.28 ng/m^3 in kitchen, living room and outdoors respectively.

Vu et al. (2011) studied the assessment of carcinogenic risk due to inhalation of PAHs in PM$_{10}$ from an industrial city, Ulsan, Korea. Daily PM$_{10}$ samples were collected in a downtown area, a residential area and an industrial area during spring and summer. The average total PAH concentrations from the 3 representative sampling sites of Ulsan ranged from 16.15 to 57.12 ng/m^3 in spring and from 11.11 to 34.56 ng/m^3 in summer. The toxicity equivalent concentrations (TEQs) of the PAHs in PM$_{10}$ ranged from 1.82 to 13.1 ng/m^3, with an average level of 4.17 ng/m^3. The highest TEQs were found in the downtown area, which had an average value of 6.30 ng/m^3 in spring and 5.52 ng/m^3 in summer. BaP and DahA were identified as the major carcinogenic PAHs that contributed to 34.8 and 59.4% of the total carcinogenic potency of PAHs in PM$_{10}$ in Ulsan.

Wimolwattanapun et al. (2011) studied source apportionment and potential source locations of $PM_{2.5}$ and $PM_{2.5-10}$ at urban Bangkok sites (Chatuchak district) and a suburban site (Klongha district, Pathumthani) in Thailand. The annual average PM_{10} values in Bangkok during 2003-2007 were higher than the national ambient air quality standard (NAAQS) for annual average PM_{10} standard, 50 µg/m^3. The annual average $PM_{2.5}$ values in Bangkok during 2003-2007 were 19.1, 26.6, 23.3, 24.3, and 23.2, respectively, while in Phathumthani were 14.4, 25.2, 20.3, 17.7, and 19.8, respectively. Both sites would also violate the U.S. annual average standard for $PM_{2.5}$, 15 µg/m^3 and the new $PM_{2.5}$ standard of Thailand, 25 µg/m^3. The ratios of $PM_{2.5}$ to PM_{10} range from 0.3 to 0.5 indicating that there was generally higher in coarse PM ($PM_{2.5-10}$) than the fine PM ($PM_{2.5}$) at both sites.

CHAPTER III

RESEARCH METHODOLOGY

3.1 Study areas

This study selected Bangkok as the study area because this cities is an urban area where the number of populations over 6 million, also a center of government, education, transportation, commerce, business, communication, and the prosperity of the country. Bangkok has a complex environment including a mix of commercial, residential, and some industrial areas. Moreover, the number of vehicles is increased every year. As a result, these are relevant to traffic problems in a crisis and also contribute to air pollution problems. Five representative communities in Pathumwan, Bangkok were chosen for this study to collect the indoor and outdoor air sample as follow:

Community 1: Salak Hin (SLH)

Community 2: Lang Wat Pathumwanaram (LWP)

Community 3: Phatthana Bonkai (PBK)

Community 4: Soi Pra Chen (SPC)

Community 5: Chao Choocheep (CCC)

The location of these five communities is shown in Figure 3.1 and the detail of each site is summarized in Table 3.1.

A total of 15 houses in 5 communities (3 houses of each community) were selected on the basis of their same patterns. One of three houses is selected for both of indoor and outdoor sampling and two others houses for only indoor sampling. The location of selected houses in each community are shown in Figure 3.2-3.11.

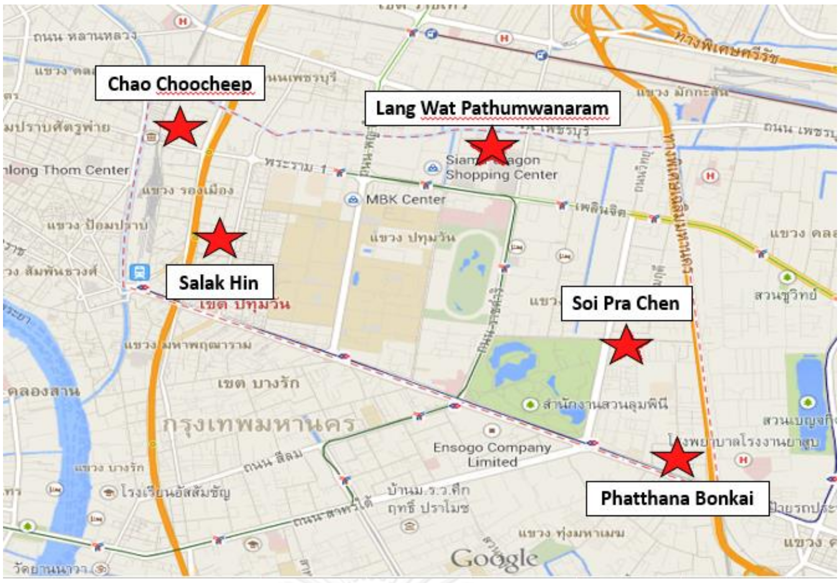


Figure 3.1 The location of five communities

Table 3.1 Details of five communities located in Pathumwan, Bangkok

Communities	Site Description
SLH	Located in King Rama VI Road, closed to express way, playground and activity yard were renovated.
LWP	Located in King Rama I Road, closed to Wat Pathumwanaram, Siam Paragon, Central World and Sansab Canal.
PBK	Located in King Rama IV Road
SPC	Located in Vitthayu Road, closed to Lumphini Park
CCC	Located in King Rama I Road, closed to overpass and railroad

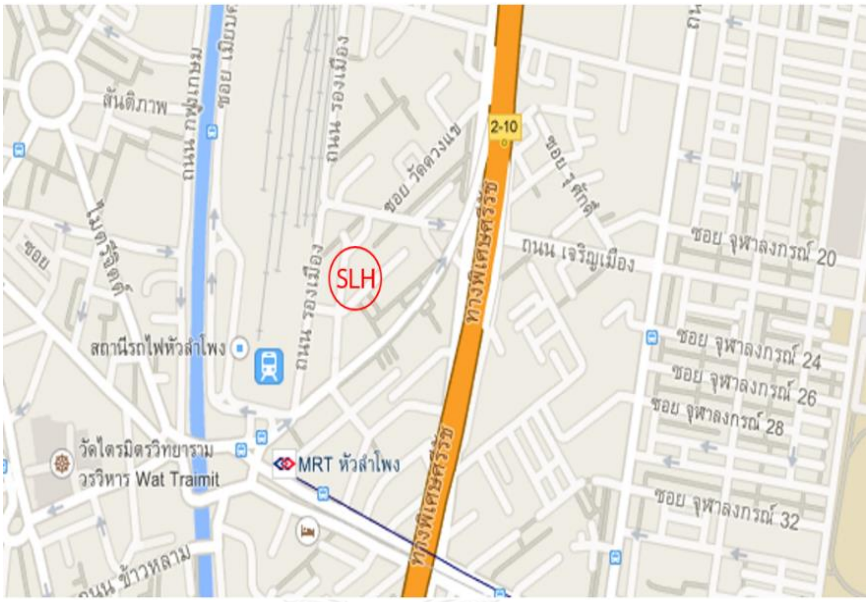


Figure 3.2 The location of Salak Hin community

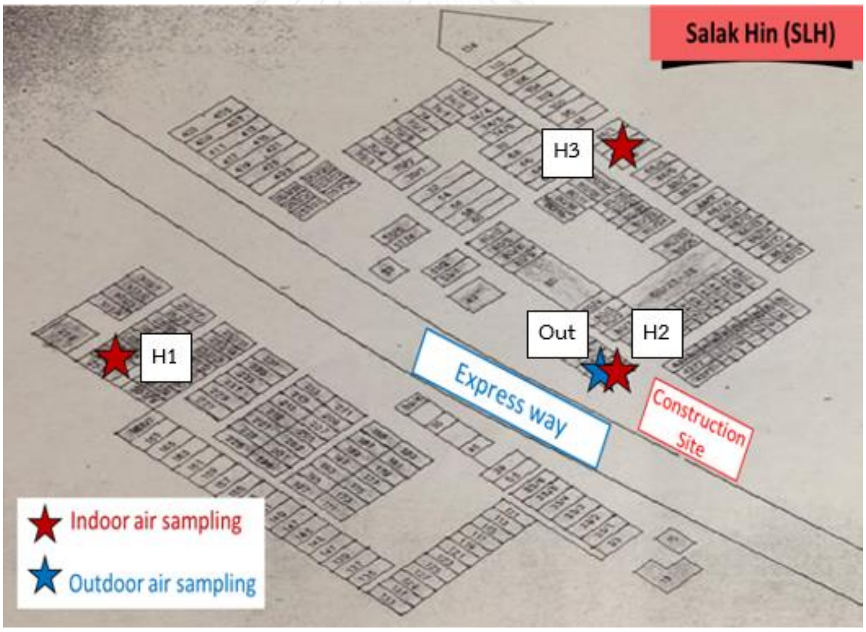


Figure 3.3 Map of sampling points at Salak Hin community

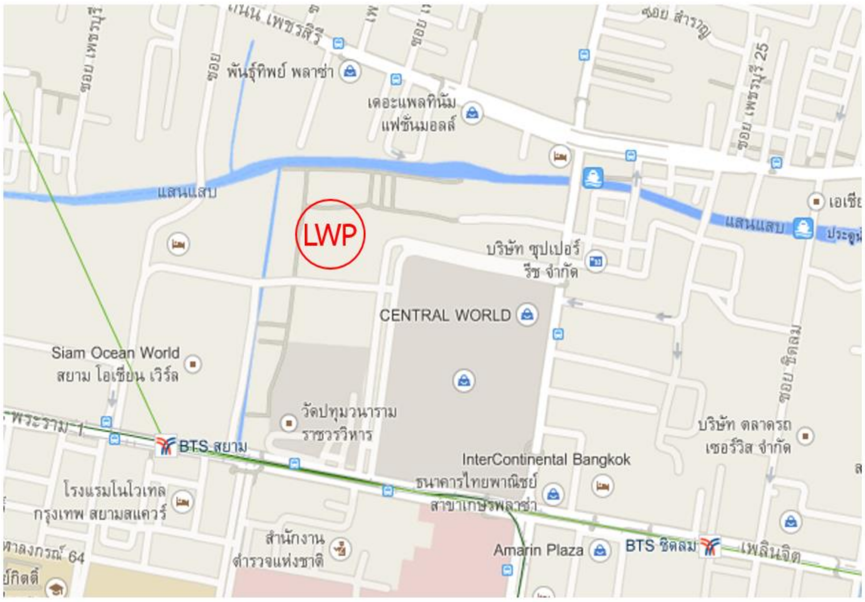


Figure 3.4 The location of Lang Wat Pathumwanaram community

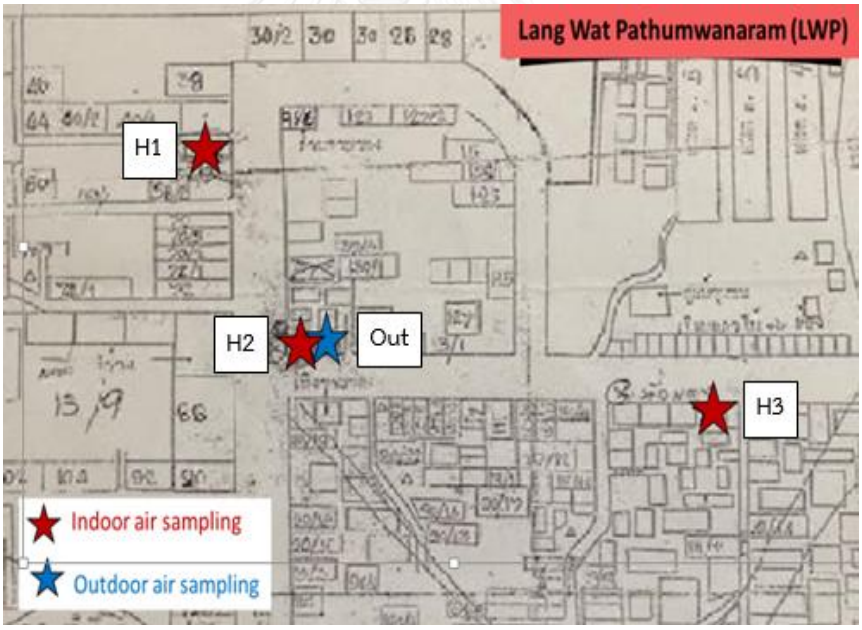


Figure 3.5 Map of sampling points at Lang Wat Pathumwanaram community

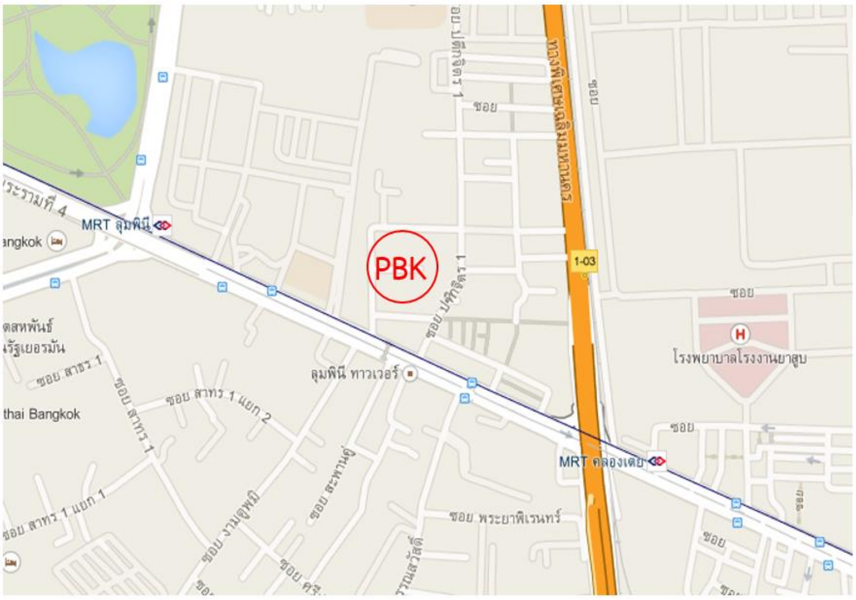


Figure 3.6 The location of Phatthana Bonkai

Figure 3.7 Map of sampling points at Phatthana Bonkai community

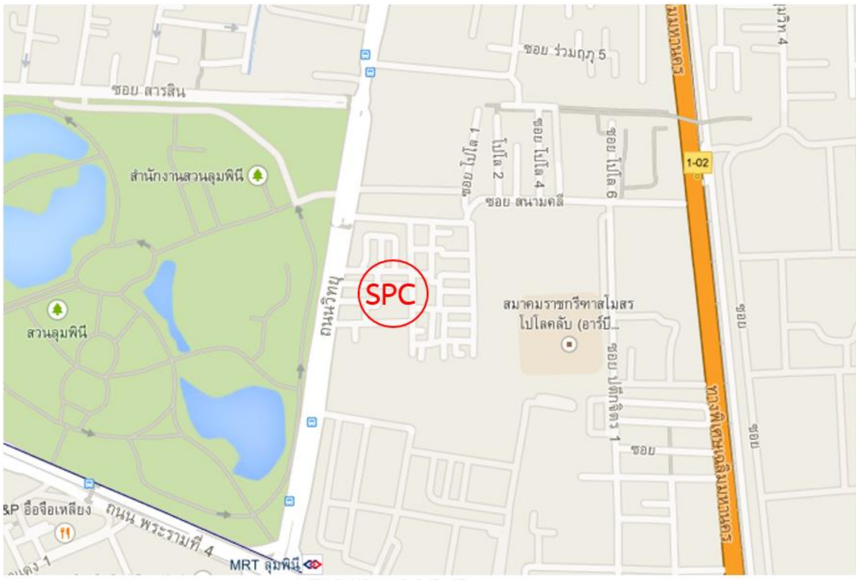


Figure 3.8 The location of Soi Pra Chen

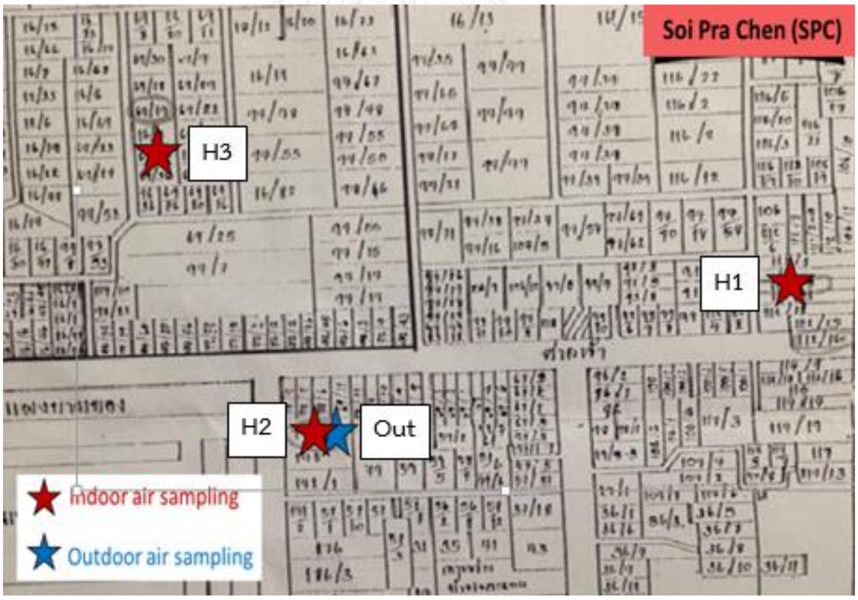


Figure 3.9 Map of sampling points at Soi Pra Chen community

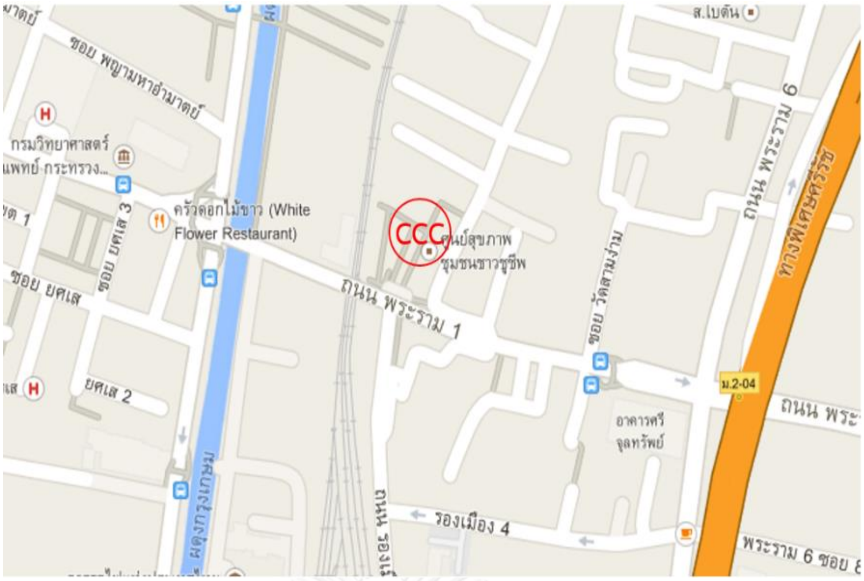


Figure 3.10 The location of Chao Choocheep

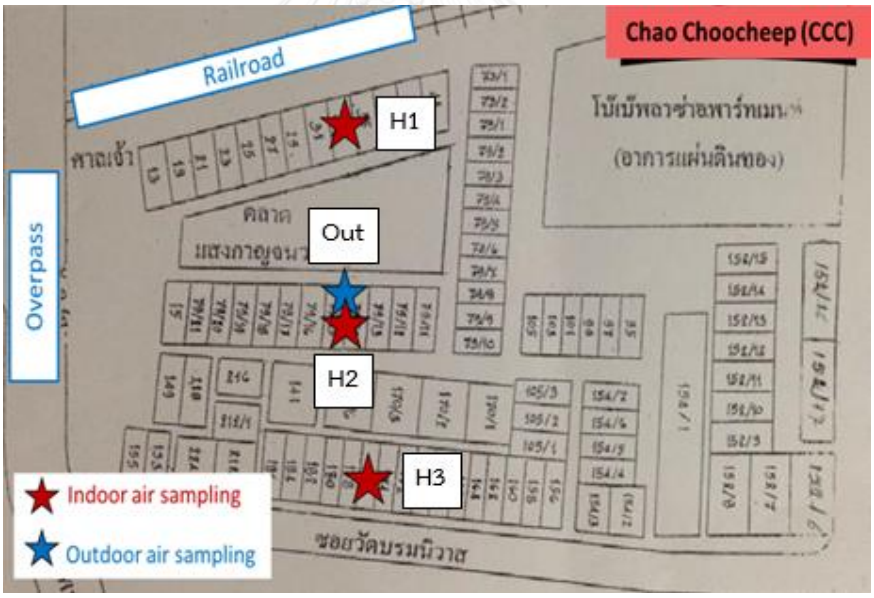


Figure 3.11 Map of sampling points at Chao Choocheep community

3.2 Sampling duration

In this study, the sampling would be carried out in 2 seasons, dry season (April-May 2013) and wet season (September-October 2013). $PM_{2.5}$ and $PM_{2.5-10}$ were collected by using personal air pump at five study areas. The sampling of each community was conducted 3 times (Sunday, Tuesday, and Friday) for 1 week. These 3 days represent weekend, work day, and end of work day in a week, respectively. A total of 15 houses in 5 communities (3 houses of each community) were selected on the basis of their same patterns. One of three houses was selected for both of indoor and outdoor sampling and two others houses for only indoor sampling. The indoor and outdoor air samples of 24-h duration were collected simultaneously from morning to morning (7 AM-7 AM).

3.3 Experimental preparation of $PM_{2.5}$ analysis

3.3.1 Filter preparation

$PM_{2.5}$ and $PM_{2.5-10}$ samples would be collected on 37 mm PTFE filters, 2.0 μm pore size and 25 mm PTFE filters, 0.2 μm pore size, respectively. All filters were soaked with acetone for about 15 minutes and dried for 5 minutes before keeping in desiccator for at least 24 hours. Then, the Microbalance (METLER UMX 2) with accuracy of 0.001 mg was used to weigh the filters before sampling (The figure of experiments were illustrated in Appendix A).

3.3.2 Gravimetric analysis

Gravimetric analysis is the most common way to calculate the mass of fine particles from net weight of filter. Before and after each sampling, the filter was weighed three times by an ultra-microbalance with 0.001 mg sensitivity (Mettler Toledo: METLER UMX 2); besides, standard pendulum 200 and 100 mg were weighed before and after each filter weighing for the quality control. In order to quality control, Shewhat control chart was used to verify the weighing of each sample set that the X-axis was categorical and represent sample sequence by the date of pendulum weighting, and the Y-axis was scaled in the weight unit (mg). The chart included center line (the average of the summary statistic, $y = \mu_k$), upper and lower warning lines ($y = \mu_k \pm 2SD$), and upper and lower action lines ($y = \mu_k \pm 3SD$). Weighting data points of standard pendulum above the upper action line or below the lower action line were out-of-acceptable criteria, while the points inside the upper action line and lower action line were in acceptable.

3.3.3 Personal Air Sampler preparation

All samples were obtained using Personal Modular Impactor (PMI) contained 2 types of filters connected to Personal Air Sampler with the flow rate of 3 L/min. The flow rate was calibrated before and after the sampling in order to calculate the volume of the air.

3.4 $PM_{2.5}$ analysis

3.4.1 Sampling of $PM_{2.5}$ and $PM_{2.5-10}$

$PM_{2.5}$ and $PM_{2.5-10}$ were collected by using Personal Air Sampler at the 5 study areas in Pathumwan, Bangkok – Salak Hin, Lang Wat Pathumwanaram, Phatthana Bonkai, Soi Pra Chen, and Chao Choocheep community. The sampling of each community was conducted 3 times (Sunday, Tuesday, and Friday) for 1 week. These 3 days represent weekend, work day, and end of work day in a week, respectively.

For indoor air sampling, the sampling equipment was placed in the main living area where the occupants spent most of their time. For the outdoor sampling, the equipment was placed out of windows from the outside wall. The indoor and outdoor air samples of 24-h duration were collected simultaneously from morning to morning (7 AM-7 AM). During sampling, all occupants stay normal daily activities. (All figure of indoor and outdoor air sampling were illustrated in Appendix B).

In addition, The questionnaires was made to fill by the occupants to know the information including the number of occupants, age and gender of each occupant, surrounding of the house, house age, the recent year of renovating the house, daily indoor and outdoor activities especially smoking activities, burning incense, cooking, and health information. All of this information is relate with exposure to PAHs. After sampling, Personal Air Sampler was calibrated and all filters were kept in plastic case before keeping in desiccator for at least 24 hours. Then, the filters were weighed in order to calculate the concentration of PM.

3.4.2 The calculation of PM

The calculation of PM is shown in the equation 3.1 and 3.2

$$\text{The total of air volume } (m^3) = \text{Air flow rate} \times \text{Duration time of sampling} \quad \text{(Eq. 3.1)}$$

$$\text{The concentration of PM } (\mu g/m^3) = \frac{\text{Final weight of filter} - \text{Initial weight of filter}}{\text{The total of air volume}} \quad \text{(Eq. 3.2)}$$

3.4.3 Sample Storage

The filters were kept in plastic case and stored at lower 0 ^{o}C until the further step of PAHs analysis.

3.5 Experimental preparation of PAHs analysis

3.5.1 The optimum conditions of High Performance Liquid Chromatography (HPLC)

The concentrations and species of PAHs were analyzed by High Performance Liquid Chromatography (HPLC), Shimadzu, SPD 20A and the detectors were fluorescence and UV detector, at Environmental Research and Training Centre (ERTC). The mobile phase that used in this analysis were acetonitrile (HPLC grade) and water (HPLC grade) and pumped into the system by using Shimadzu LC pumps AB20. By the way, these mobile phases were prepared and filtered with nylon filters (Advantec, USA), 0.22 µm pore size. The standard solution was PAHs mix standard manufactured by Supelco Company, which composed of Napthalene (Nap), Acenapthylene (Acpy), Acenapthene (Ace), Fluorene (Fl), Phenanthrene (Phe), Anthracene (Ant), Fluoranthene (Flu), Pyrene (Pyr), Benzo(a)anthracene (BaA), Chrysene (Chry), Benzo(b)fluoranthene (BbF), Benzo(k)fluoranthene (BkF), Benzo(a)pyrene (BaP), Dibenz(a,h)anthracene (DahA), Benzo(g,h,i)pyrylene (BghiP), and Indeno(1,2,3-cd)pyrene (Ind). The optimum conditions of HPLC used for PAHs analysis was presented in Table 3.2

3.5.2 Preparation of the PAHs Standard Curve

The calibration curves of PAHs were established from seven concentrations of 16-PAHs Mix Standard including 0.001, 0.005, 0.01, 0.05, 0.1, 0.5 and 1.0 ppm (µg/ml) diluted in acetronitrile (ACN) and then analyzed by using HPLC in the optimum conditions as mention above. The concentrations of PAHs Mix Standard were plotted in X-axis, while peak area of those were plotted in Y-axis as presented in Appendix A.

3.5.3 Limits of detection (LOD) and Limits of quantification (LOQ)

For the quality assurance and the quality control of HPLC, the limits of detection (LOD) and the limits of quantification (LOQ) were implement in this case. In order to determine those values, 0.05 ppm of PAHs mix standard was prepared and analyzed for ten replicates by using HPLC. Therefore, the calculations of average value, standard deviation (SD), and % RSD were obtained from this step. Multiplication of standard deviation could offer the values of LOD, LOQ and %RSD as presented in Eq. 3.3 - 3.5.

$$\text{LOD} = 3\text{SD} \qquad \text{(Eq.3.3)}$$

$$\text{LOQ} = 10\text{SD} \qquad \text{(Eq.3.4)}$$

$$\%\ \text{RSD} = (\text{SD} \times 100)/\text{average value} \qquad \text{(Eq.3.5)}$$

3.5.4 Recovery Test

In order to determine the efficiency of extraction, the recovery test of 0.1 ppm PAHs mix standard was performed. Firstly, the standard solution was injected into 2 types of filters, 37 mm PTFE filter, 2.0 µm pore size ($PM_{2.5}$) and 25 mm PTFE filter, 0.2

µm pore size ($PM_{2.5\text{-}10}$). Then, all of recovery samples were extracted and analyzed by HPLC as shown the method in Figure 3.12. The results was used to calculation % recovery test of 16 PAHs.

Table 3.2 The optimum conditions of HPLC

<table>
<tr><td>Main Column</td><td colspan="4">Supelcosil LC-PAH C16 25 cm x 4.6 mm ID, 5.0 µm particles</td></tr>
<tr><td>Pre Column</td><td colspan="4">Supelguard LC-18 Replacement Cartridges 4.5 cm x 4.0 mm ID, 5.0 µm</td></tr>
<tr><td>Mobile Phase</td><td colspan="4">A: Acetonitrile : Water (60 : 40) B: Acetonitrile : Water (88 : 12)</td></tr>
<tr><td>Column Temperature</td><td colspan="4">40 °C</td></tr>
<tr><td>Flow rate</td><td colspan="4">1.6 ml/min</td></tr>
<tr><td>Detector</td><td colspan="4">A : UV detector B: Fluorescence detector</td></tr>
<tr><td>Wavelength</td><td colspan="4">UV = 254 nm</td></tr>
<tr><td>Injection volume</td><td colspan="4">20 µl</td></tr>
<tr><td rowspan="11">Gradient Program</td><td>Time (min)</td><td>Mobile Phase (A:B)</td><td>Excitation (nm)</td><td>Emission (nm)</td></tr>
<tr><td>5.00</td><td>100:0</td><td>270</td><td>330</td></tr>
<tr><td>8.40</td><td></td><td>250</td><td>370</td></tr>
<tr><td>10.05</td><td></td><td>330</td><td>430</td></tr>
<tr><td>13.00</td><td>20:80</td><td></td><td></td></tr>
<tr><td>14.00</td><td></td><td>270</td><td>390</td></tr>
<tr><td>16.50</td><td></td><td>290</td><td>430</td></tr>
<tr><td>22.00</td><td></td><td>370</td><td>460</td></tr>
<tr><td>25.00</td><td>20:80</td><td></td><td></td></tr>
<tr><td>26.00</td><td>100:0</td><td></td><td></td></tr>
<tr><td>31.00 (stop)</td><td></td><td></td><td></td></tr>
</table>

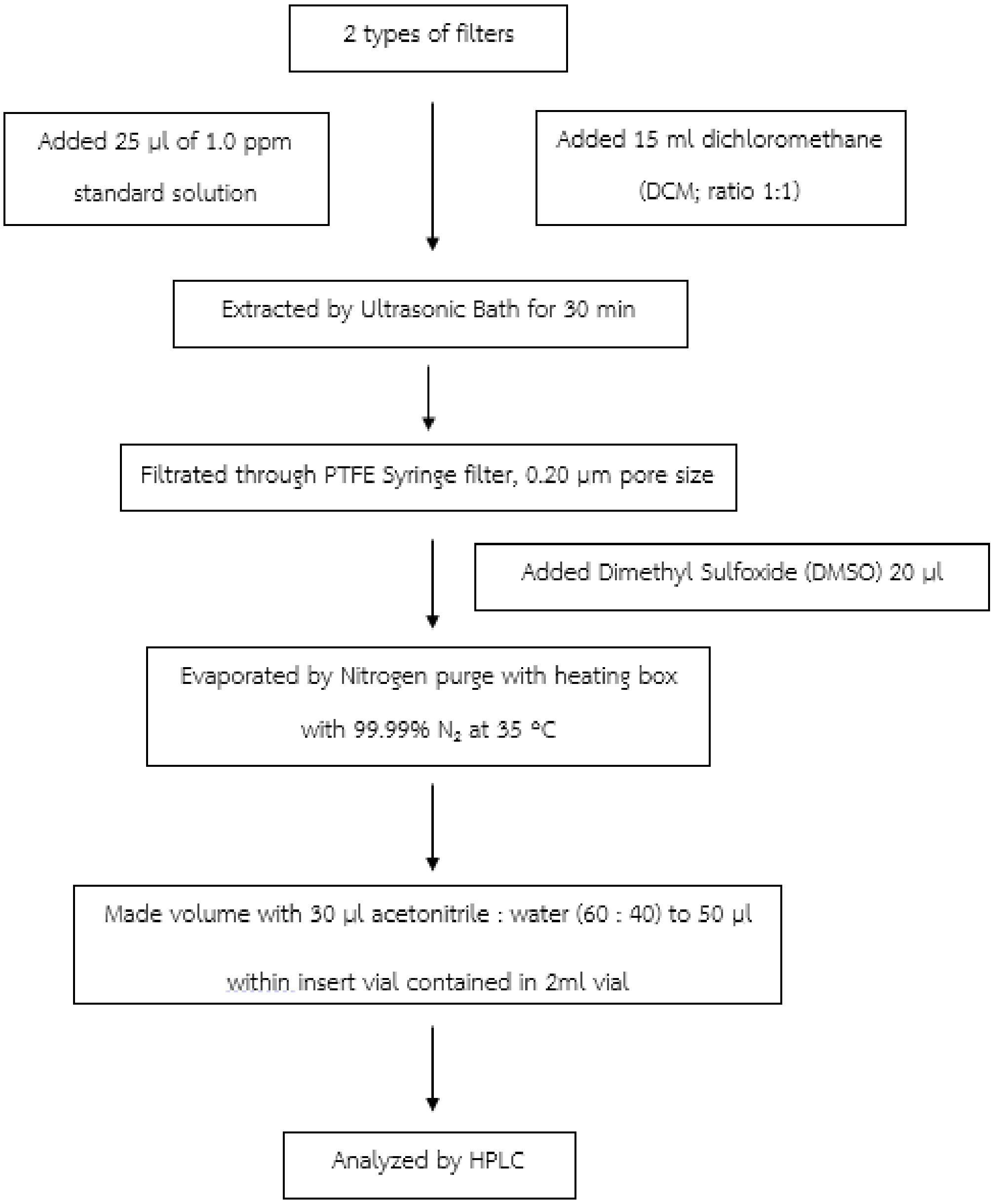


Figure 3.12 The method of recovery extraction

3.6 PAHs analysis

3.6.1 PAHs extraction

The method of PAHs extraction was presented in Figure 3.13. Firstly, 2 types of air sample filters, 37 mm PTFE filter, 2.0 µm pore size ($PM_{2.5}$) and 25 mm PTFE filter, 0.2 µm pore size ($PM_{2.5-10}$) were placed separately in 40 mL vials. After that, they were added 15 mL dichloromethane (DCM) and extracted by Ultrasonic Bath for 30 minutes. The extracted solvent were filtrated through PTFE syringe filters, 0.2 µm pore size into the new 40 mL vials and added 20 µl of Dimethyl Sulfoxide (DMSO) before purged by Nitrogen purge with heating box, Drythermo, DTU-1B with 99.99% nitrogen gas at 35°C. The solution was made volume with 30 µl of acetronitrile : water (60 : 40) to 50 µl. All sample vials will be kept under low temperature and then analyzed by HPLC (Modified from Nonthakanok (2013))

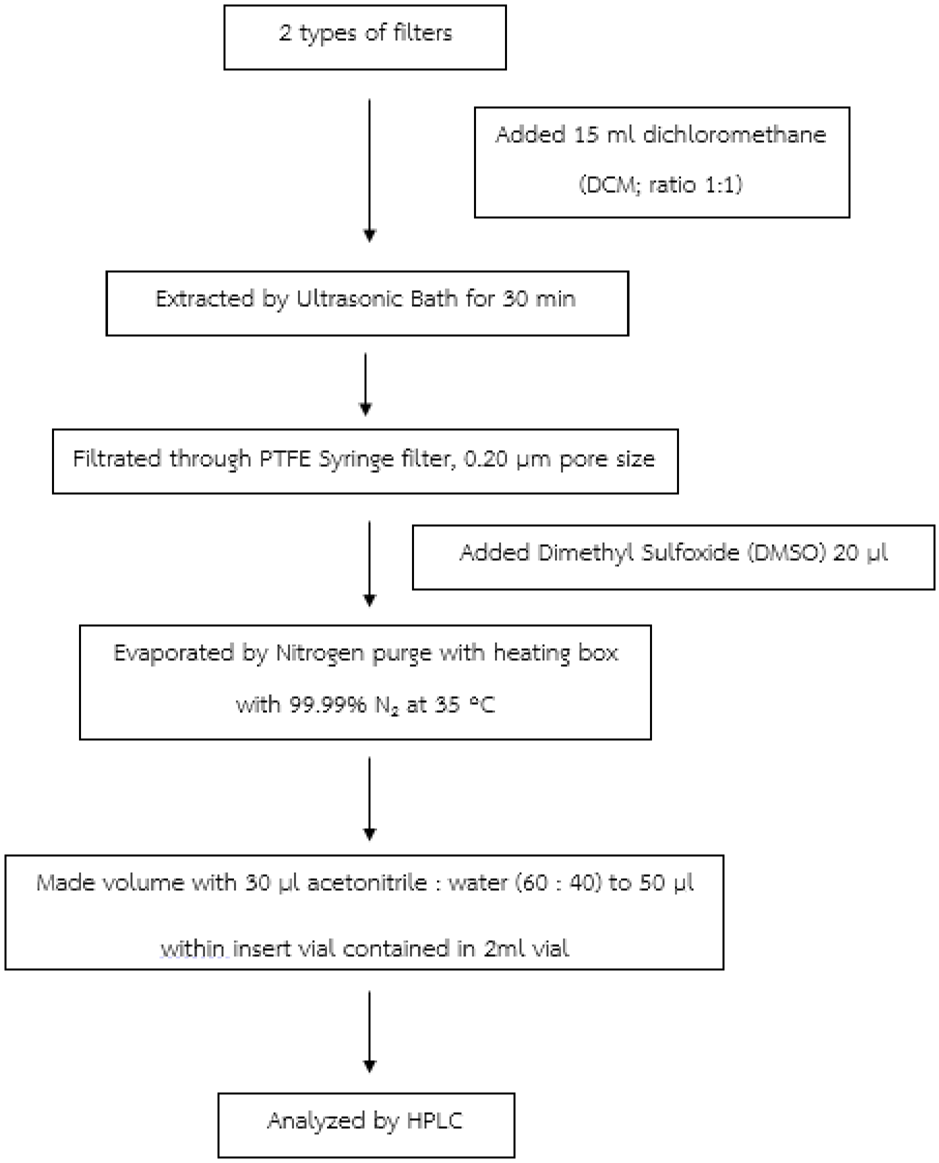


Figure 3.13 The method of PAHs extraction

3.6.2 The calculation of PAHs concentrations

In order to calculate the concentrations of PAHs, the results were compared with 16 PAHs mix standard solution. Peak area will be found by integration abundance of each species of PAHs. The result of peak integration as indicated in peak area will be used for the calculation of PAHs in dimension of mg/l as shown in the Eq.3.6 – 3.7.

$$\text{Peak area}_{\text{PAHs}} = \text{Peak area}_{\text{sample}} - \text{Peak area}_{\text{blank}} \qquad (\text{Eq.3.6})$$

$$[\text{PAHs}_i]\,(\text{mg/l}) = \text{Peak area}_{\text{PAHs}} / \text{standard curve slpoe} \qquad (\text{Eq.3.7})$$

For the calculation of PAHs in dimension of ng/m^3 was presented in Eq.3.8

$$\text{PAHs conc. (ng/m}^3) = \frac{(C_A - C_B) \times V_s}{V_{air}} \qquad (\text{Eq.3.8})$$

where;

PAHs conc. = Concentration of PAHs (ng/m^3)

C_A = Concentration of PAHs in samples (mg/l)

C_B = Concentration of PAHs in blank (mg/l)

V_s = Sample solution volume (50 µl)

V_{air} = Air volume (m^3)

3.7 Health risk assessment

This study focused on exposure to PAHs adsorbed on PM$_{2.5}$ of residents which the chemicals will be predominantly exposed by inhalation route. In this study, the risk assessment for inhalation exposure is then used to estimate the nature and possibility of adverse health effects in occupants. According to Environmental Protection Agency (EPA) approach, four steps: (1) Hazard Identification; (2) Dose-Respond Assessment; (3) Exposure Assessment; and (4) Risk Characterization will be conducted to obtain the risk level. US EPA guideline for risk assessment in Risk Assessment Guidance for Superfund (RAGS) Volume 1: Human Health Evaluation Manual used in this study for 2 parts. Part A, the baseline risk assessment and part F, Supplement Guidance for Inhalation Risk Assessment as shown in Table 3.3.

3.7.1 Hazard identification

In this study, PAHs have been demonstrated to be carcinogenic in humans and experimental animals, and they are classified as carcinogenic materials by many organizations, including the United States Agency for Toxic Substances and Disease Registry (ATSDR), the International Agency for Research on Cancer (IARC), the Department of Health and Human Services (DHHS), the National Occupation Safety and Health Administration (OSHA), and the US EPA (Lee & Vu, 2010). Table 3.4 shows the carcinogen classification of 17 priority PAHs by the IARC, compared to classifications by the DHHS and the US EPA.

Table 3.3 The four steps of risk assessment in RAGS part A and part F

RAGS Volume I: Human Health Evaluation Manual	Part A The baseline Risk Assessment		Part F Supplement Guidance for Inhalation Risk Assessment	
Step 1: Hazard Identification	Cancer	Non-cancer	Cancer	Non-cancer
Step 2 : Dose-response Assessment	Inhalation Cancer Slope Factor (CSF_i)	Inhalation Reference Dose (RFD_i)	Inhalation Unit Risk (IUR)	Reference Concentration (RFC)
Step 3 : Exposure Assessment	Chronic Daily Intake (CDI)	Average Daily Dose (ADD)	Exposure Concentration (EC)	Exposure Concentration (EC)
Step 4 : Risk Characterization	CDI x CSF_i	ADD x RFD_i	EC x IUR	EC/RfC

Source: Kitwattanavong (2010)

Table 3.4 The carcinogen classification of 17 priority PAHs by the USEPA, IARC, and DHHS

PAHs	EPA	IARC	DHHS
Acenaphthene	-	-	-
Acenaphthylene	Not classifiable	-	-
Anthanthrene	Not classifiable	Not classifiable	-
Benz(a)anthracene	Probably Carcinogen	Probably Carcinogen	Animal Carcinogen
Benzo(a)pyrene	Probably Carcinogen	Probably Carcinogen	Animal Carcinogen
Benzo(b)fluoranthene	Probably Carcinogen	Probably Carcinogen	Animal Carcinogen
Benzo(e)pyrene	-	Not classifiable	-
Benzo(ghi)perylene	Not classifiable	Not classifiable	-
Benzo(j)fluoranthene	Not included	Possibly Carcinogen	Animal Carcinogen
Benzo(k)fluoranthene	Probably Carcinogen	Possibly Carcinogen	-
Chrysene	Probably Carcinogen	Not classifiable	-
Dibenz(ah)anthracene	Probably Carcinogen	-	Animal Carcinogen
Fluoranthene	Not classifiable	Not classifiable	-
Fluorene	Not classifiable	Not classifiable	-
Ideno(1,2,3-cd)pyrene	Probably Carcinogen	Probably Carcinogen	Animal Carcinogen
Phenanthrene	Not classifiable	-	-
Pyrene	Not classifiable	Not classifiable	-

Source: Lee and Vu (2010)

Note: - mean no data

3.7.2 Dose-Response assessment

The second step is dose-response assessment that qualifies the relationship between adverse effects and amount of dose. Some agencies such as IRIS and RAIS provided the reference values of dose-response relationship which were able to use for calculating the risk level in further step. However, the data of dose-response assessment for non-carcinogenic substances were still limited. For carcinogenic, the inhalation cancer slope factor (CSF_i) used for estimation the cancer risk of inhalation exposure in this study were summarized in Table 3.5.

Table 3.5 Inhalation Cancer Slope Factor (CSFi) value for carcinogenic effect

PAHs	CSFi[1] (mg/kg-day$^{)-1}$	CSFi[2] (mg/kg-day)$^{-1}$
Benzo(a)anthracene	3.9E-1	-
Chrysene	3.9E-2	-
Benzo(b)fluoranthene	3.9E-1	-
Benzo(k)fluoranthene	3.9E-1	-
Benzo(a)pyrene	3.9E+1	3.1
Indeno(1,2,3-cd)pyrene	3.9E-1	-
Dibenz(a,h)anthracene	4.1E+0	-

Source: [1]OEHHA (2001)
[2]USEPA (2008)

Health risk assessment followed the four steps was based on the methods of U.S. EPA. PAHs are constituents of complex mixtures that should be assessed the individual species of them but the data of dose-response assessment were limited .Thus, the cancer potency of each PAHs was assessed on the basis of its benzo(a)pyrene equivalent concentration (BaP_{eq}). Calculation of the BaP_{eq} concentration for a given PAHs compound requires the use of its toxic equivalent factor (TEF), which represents the relative cancer potency of the given PAH compound. Then, Total-BaP_{eq} (t-BaP_{eq} or TEQ) was calculated by summing up of BaP_{eq}. Total-BaP_{eq} or TEQ was used for calculation as contaminant concentration in air (CA) for exposure assessment as shown in Eq.3.9 and 3.10 and TEF value were presented in Table 3.6.

$$BaP_{eq} = [PAHs_i] \times TEF \qquad (Eq.3.9)$$

$$Total\text{-}BaP_{eq} \, (t\text{-}BaP_{eq} \text{ or } TEQ) = \sum BaP_{eq} \qquad (Eq.3.10)$$

Table 3.6 Toxicity Equivalency Factors for Carcinogenic PAHs

PAHs	TEF
Napthalene	0.001
Acenaphthene	0.001
Acenaphthylene	0.001
Anthracene	0.01
Benz(a)anthracene	0.1
Benzo(a)pyrene	1
Benzo(b)fluoranthene	0.1
Benzo(ghi)perylene	0.01
Benzo(k)fluoranthene	0.1
Chrysene	0.01
Dibenz(ah)anthracene	1
Fluoranthene	0.001
Fluorene	0.001
Ideno(1,2,3-cd)pyrene	0.1
Phenanthrene	0.001
Pyrene	0.001

Source: USEPA (2012)

3.7.3 Exposure assessment

3.7.3.1 General scenario

The third step of human health risk assessment is exposure assessment which aims to find out with a numerical estimate of exposure or dose that human may expose from contaminated media and the number of people who possibly exposed with the pollutants at specific period of time. Based on the RAG Volume 1 Part A (US EPA, 1989), Human Health Evaluation Manual, a Chronic Daily Intake (CDI) was commonly used for general approach. The amount of intake was derived from the calculation of the atmospheric concentration of pollutant (CA), inhalation rate (IR), body weight (BW) and the function of time and exposure. In this study, the CDI was used for determination of carcinogenic compounds as shown in Eq.3.11.

$$\text{CDI (mg/kg/day)} = (\text{CA} \times \text{IR} \times \text{EF} \times \text{ED}) / (\text{BW} \times \text{AT}) \qquad \text{(Eq.3.11)}$$

where;

CDI (mg/kg/day) = Chronic daily intake
CA (mg/m^3) = Contaminant concentration in air (TEQ)
IR (m^3/day) = Inhalation rate (0.875 x 24 = 21 m^3/day assumed for adult)
BW (kg) = Body weight (derived from questionnaires)
EF (days/year) = Exposure frequency (350 days/year assumed for residential)
ED (years) = Exposure duration (derived from questionnaires)
AT (days) = Averaging time (70 × 365 = 25,550 days)

3.7.3.2 Age interval scenario

According to Handbook for Implementing the Supplemental Cancer Guidance at Waste and Clean-up Sites, the exposure factors handbook age-specific exposure parameters grouped by supplemental guidance age bins for residential cancer risk assessment was provided (as presented in Table3.14) in sensitivity analysis of the effect of various age-specific exposure parameters and age bins on cancer risk estimates and preliminary remediation goals using EPA’s new supplemental guidance for early life exposure to carcinogens. The possible cancer risk for residents was calculated by using age interval (i) as shown in Eq.3.12

$$\text{Risk}_i = (C \times IR_i \times EF_i \times SF \times ED_i \times ADAF_i)/(BW_i \times AT) \qquad \text{(Eq. 3.12)}$$

where;

C (mg/m3) = Concentration of contaminant in the air

IR_i (m3/day) = Inhalation rate for age bin “i”

EF_i (days/year) = Exposure frequency for age bin “i” (350 days/year for residents)

BW_i (kg) = Body weight of the exposed person for age bin “i” (based on Thai body weight)

AT (days) = Averaging time (70 years x 365 days = 25,550 days for long term exposure)

ED_i (years) = Exposure duration for age bin “i”

ADAF (unitless) = Age-dependent adjustment factor for age bin “i”

SF $(\text{mg/kg-day})^{-1}$= Cancer slope factor

Even though USEPA (2012) provide 30-year exposure scenario which calculate the possibility of developing cancer from birth to 30 years, in this study, after 30-age exposure were included for more realistic potential of an individual who exposed for the entire life. Moreover, the cancer risk to an individual exposed for the whole life starting at birth is calculated for inhalation exposure as provided in Eq.3.14–3.17. In order to find the total risk of individual, the sum of risks across all four age intervals were performed as illustrated in Eq. 3.17.

$$\text{Risk}_{0\text{-}2} = (C \times IR_{child} \times EF_{child} \times SF \times 2 \times 10) / (BW_{child} \times 25{,}550) \qquad \text{(Eq. 3.13)}$$

$$\text{Risk}_{2\text{-}16} = (C \times IR_{child} \times EF_{child} \times SF \times 14 \times 3) / (BW_{child} \times 25{,}550) \qquad \text{(Eq. 3.14)}$$

$$\text{Risk}_{16\text{-}30} = (C \times IR_{adult} \times EF_{adult} \times SF \times 14 \times 1) / (BW_{adult} \times 25{,}550) \qquad \text{(Eq. 3.15)}$$

$$\text{Risk}_{30\text{-}now} = (C \times IR_{adult} \times EF_{adult} \times SF \times ED \times 1) / (BW_{adult} \times 25{,}550) \qquad \text{(Eq. 3.16)}$$

$$\text{Total Risk} = \text{Risk}_{0\text{-}2} + \text{Risk}_{2\text{-}16} + \text{Risk}_{16\text{-}30} + \text{Risk}_{30\text{-}now} \qquad \text{(Eq. 3.17)}$$

Table 3.7 Parameters for calculation of cancer risk using age-dependent adjustment factor

Parameter	Unit	Age (Years)			
		0-2	2-16	16-30	30-present
IR[1]	m^3/day	6.8	11.8	13.4	13.4
ADAF[1]	unitless	10	3	1	1
BW[2]	kg	7.2	27.2	60.9	64.5
ED[1]	Years	2	14	14	Base on questionnaires
C[1]	mg/m^3	Vary among communities in minimum, maximum, and average values			
AT[1]	Days	70 × 365 = 25,550			
EF[1]	Days/year	350 for residents			

Source: [1]USEPA (2012)

[2]Raungdakanon (1996)

3.7.4 Risk characterization

Inhalation toxicity values will be "converted" into similar units for the risk quantification step. Cancer risk will be estimated by multiplying the chronic daily intake of the chemical from the air by the "inhalation cancer slope factor" (CSFi); the Hazard Quotient (HQ) for non-cancer effects will be estimated by dividing the intake of the chemical by an "inhalation reference dose" (RfDi). The risk level can be calculated as shown in Eq.3.18.

$$\text{Cancer risk} = \text{CDI} \times \text{CSFi} \qquad \text{(Eq. 3.18)}$$

where;

Cancer risk $>10^{-6}$	means carcinogenic effects of concern
Cancer risk $\leq 10^{-6}$	means acceptable level

CHAPTER IV

RESULTS AND DISCUSSION

4.1 Preliminary study

4.1.1 Quality control of fine particles weighing

Before and after each sampling, the filter was weighed three times by an ultra-microbalance with 0.001 mg sensitivity (Mettler Toledo: METLER UMX 2); besides, standard pendulum 200 and 100 mg were weighed before and after each filter weighing for the quality control. Shewhart control chart (Fig. 4.1 and 4.2 as example) was used to verify the weighing of each sample set that the X-axis was categorical and represent sample sequence by the date of pendulum weighting, and the Y-axis was scaled in the weight unit (mg). The chart included center line (the average of the summary statistic, $y=\mu_k$), upper and lower warning lines ($y = \mu_k \pm 2SD$), and upper and lower action lines ($y = \mu_k \pm 3SD$). Weighting data points of standard pendulum above the upper action line or below the lower action line were out-of-acceptable criteria, while the points inside the upper action line and lower action line were acceptable.

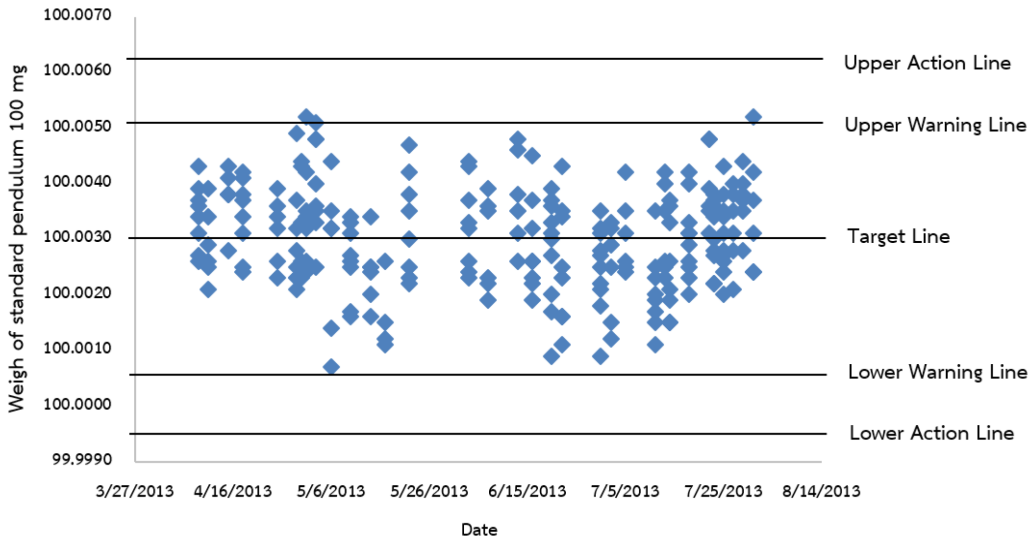


Figure 4.1 Control chart of standard pendulum 100 mg in dry season

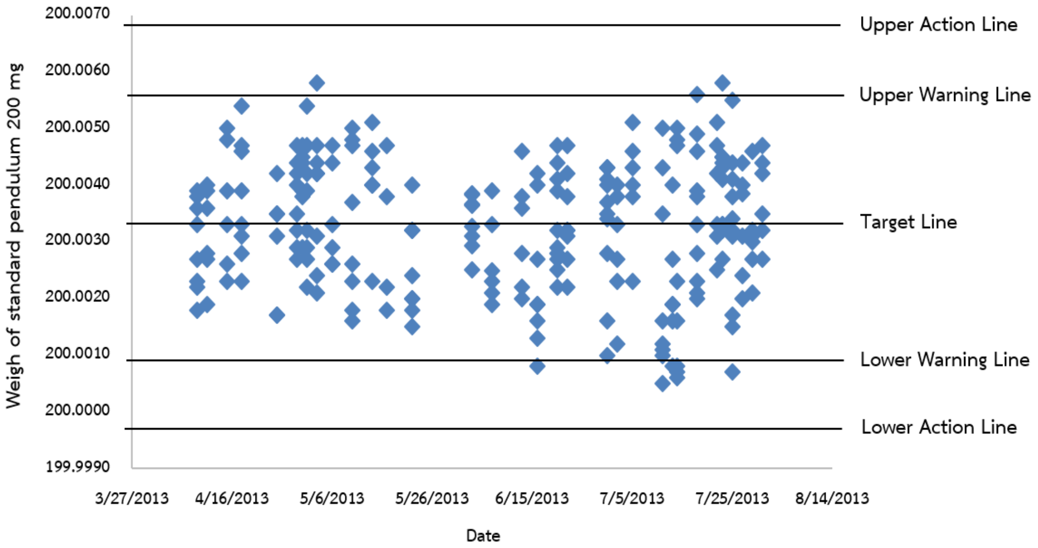


Figure 4.2 Control chart of standard pendulum 200 mg in dry season

Figure 4.1 and 4.2 showed the data of standard pendulum 100 and 200 mg in dry season (All data of standard pendulum were detailed in Appendix C). According to the weighting in dry season, the results demonstrated that the average weight of standard pendulum was 100.0030 and 200.0033 mg, respectively. For 100 mg standard pendulum, all of 240 points (100%) were in the range of action line ($\mu_k \pm 3SD$), 0.83% were out of range warning line ($\mu_k \pm 2SD$) but in range of action line, and none was out of the action line. Similarly, 240 points (100%) of 200 mg standard pendulum weight were in range of action line, 3.75% were out of range warning line but in range of action line, and zero point was out of the action line.

The summary result of standard pendulum weighting is shown in Table 4.1. These results reveal that the weighing data of 100 and 200 mg standard pendulum in two seasons ranged from 85.28 – 100% and 90.37 – 100%, respectively. Some out of action line observed might be caused by variation of weighting room condition including unstable room temperature and humidity condition. However, these results were statistically in acceptable range and the weighing of fine particles was considerable accuracy and reliability. The quality control of fine particles weighing in this study was similar to the result of Nonthakanok (2013) that found the acceptable amount of 100 and 200 mg standard pendulum were 91.37 and 94.24%, respectively.

Table 4.1 Quality control of the Microbalance

Season	Standard weight (mg)	Average of standard weight (mg)	The amount of standard weight within an acceptable range (%)
Dry season	100	100.0030	100
	200	200.0033	100
Wet season	100	100.0030	87.08
	200	200.0032	92.50

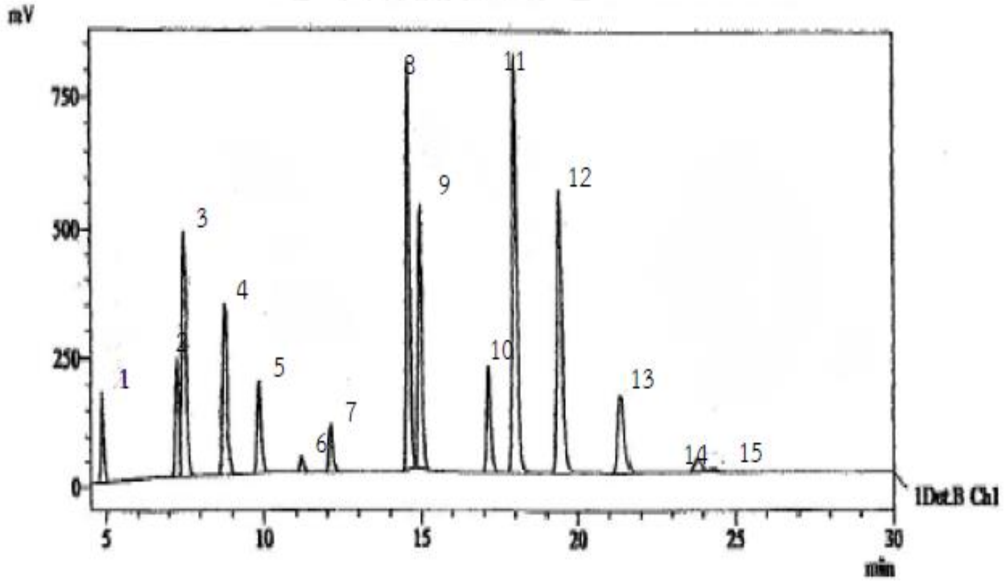
4.1.2 Quality control of PAHs analysis

4.1.2.1 Retention time of PAHs

The retention time of mixed 16 PAHs standard analyzed by HPLC was presented in Table 4.2, and Figure 4.3 showed the chromatogram of PAHs analyzed by using fluorescence detector including Napthalene, Acenapthene, Fluorene, Phenanthrene, Anthracene, Fluoranthene, Pyrene, Benzo(a)anthracene, Chrysene, Benzo(b)fluoranthene, Benzo(k)fluoranthene, Benzo(a)pyrene, Indeno(1,2,3-cd)pyrene, Dibenz(a,h)anthracene, Benzo(g,h,i)pyrylene, while the chromatogram of Acenapthylene was analyzed by using UV detector.

Table 4.2 Retention time of PAHs

PAHs	Retention time (min)	PAHs	Retention time (min)
Napthalene	4.898	Benzo(a)anthracene	14.633
Acenapthylene	5.639	Chrysene	14.971
Acenapthene	7.283	Benzo(b)fluoranthene	17.147
Fluorene	7.501	Benzo(k)fluoranthene	18.050
Phenanthrene	8.782	Benzo(a)pyrene	19.425
Anthracene	9.866	Dibenz(a,h)anthracene	21.371
Fluoranthene	11.189	Benzo(g,h,i)pyrylene	23.796
Pyrene	12.130	Indeno(1,2,3-cd)pyrene	24.280



1. Naphthalene
2. Acenapthene
3. Fluorine
4. Phenanthrene
5. Anthracene
6. Fluoranthene
7. Pyrene
8. Benzo(a)anthracene
9. Chrysene
10. Benzo(b)fluoranthene
11. Benzo(k)fluoranthene
12. Benzo(a)pyrene
13.Dibenz(a,h)anthracene
14. Benzo(g,h,i)pyrylene
15. Indeno(1,2,3-cd)pyrene

Figure 4.3 Chromatogram of mixed PAHs standard at the concentration of 0.05 ppm

4.1.2.2 Calibration curves

The calibration curves of PAHs were established from seven concentrations of 16-PAHs Mix Standard including 0.001, 0.005, 0.01, 0.05, 0.1, 0.5 and 1.0 ppm (µg/ml) which analyzed by HPLC. The concentrations of PAHs Mix Standard were plotted in X-axis, while peak areas of those were plotted in Y-axis as presented in Appendix C. The R^2 of the calibration curves of PAHs were identified in range of 0.9975-1.000 as provided in Table 4.3

Table 4.3 The R2 of PAHs standard from calibration curves

PAHs Mix Standard	R^2	PAHs Mix Standard	R^2
Napthalene	0.9993	Benzo(a)anthracene	1.0000
Acenapthylene	0.9995	Chrysene	0.9992
Acenapthene	0.9996	Benzo(b)fluoranthene	0.9991
Fluorene	0.9997	Benzo(k)fluoranthene	0.9988
Phenanthrene	0.9992	Benzo(a)pyrene	0.9988
Anthracene	1.0000	Dibenz(a,h)anthracene	0.9991
Fluoranthene	0.9992	Benzo(g,h,i)pyrylene	0.9978
Pyrene	0.9975	Indeno(1,2,3-cd)pyrene	0.9998

4.1.2.3 Limits of detection (LOD) and Limits of quantification (LOQ)

For quality assurance and quality control of HPLC, limits of detection (LOD) and limits of quantification (LOQ) were then implemented. In order to determine those values, 0.05 ppm of PAHs mix standard was prepared and analyzed for ten replicates by using HPLC. The values of LOD and LOQ were presented in Table 4.4. Therefore, the calculations of average value, standard deviation (SD), and % RSD were obtained from this step. Multiplication of standard deviation could offer the values of LOD, LOQ and %RSD as presented in Eq. 3.3 - 3.5.

Table 4.4 Results of LOD and LOQ for PAHs analysis

PAHs	LOD (mg/L)	LOQ (mg/L)	% RSD
Napthalene	0.0012	0.0042	0.86
Acenapthylene	0.0062	0.0208	4.23
Acenapthene	0.0019	0.0063	1.29
Fluorene	0.0015	0.0052	1.04
Phenanthrene	0.0013	0.0042	0.85
Anthracene	0.0009	0.0032	0.61
Fluoranthene	0.0018	0.0063	1.33
Pyrene	0.0018	0.0063	1.33
Benzo(a)anthracene	0.0020	0.0067	1.33
Chrysene	0.0032	0.0108	2.22
Benzo(b)fluoranthene	0.0013	0.0042	0.86
Benzo(k)fluoranthene	0.0020	0.0067	1.32
Benzo(a)pyrene	0.0013	0.0042	0.86
Dibenz(a,h)anthracene	0.0017	0.0056	1.18
Benzo(g,h,i)pyrylene	0.0020	0.0067	1.38
Indeno(1,2,3-cd)pyrene	0.0015	0.0052	1.02

4.1.2.4 Recovery test

In order to determine the efficiency of samples extraction, the recovery test of 0.1 ppm PAHs mix standard was performed for three replicates. According to the recovery test of 16 PAHs, the outcome presented the values between 74±9.4 - 123±4.0 as summarized in Table 4.5.

Table 4.5 % Recovery of PAHs

PAHs	% Recovery (mean±SD)	
	$PM_{2.5}$	$PM_{2.5-10}$
Napthalene	78±4.2	81±3.57
Acenapthylene	88±7.1	89±7.6
Acenapthene	83±3.9	91±3.1
Fluorene	92±3.0	93±2.5
Phenanthrene	105±4.1	99±5.6
Anthracene	93±1.8	87±2.2
Fluoranthene	91±3.1	85±1.7
Pyrene	74±9.4	98±6.3
Benzo(a)anthracene	115±2.7	102±3.4
Chrysene	115±4.3	104±4.0
Benzo(b)fluoranthene	90±3.6	108±1.9
Benzo(k)fluoranthene	112±7.0	113±6.3
Benzo(a)pyrene	111±6.1	111±5.7
Dibenz(a,h)anthracene	88±3.7	114±4.2
Benzo(g,h,i)pyrylene	94±7.9	123±4.0
Indeno(1,2,3-cd)pyrene	99±5.1	115±5.9

Note: $PM_{2.5}$ = PTFE filter for $PM_{2.5}$

$PM_{2.5-10}$ = PTFE filter for $PM_{2.5-10}$

4.2 Fine particulate matters at five communities in the inner city of Bangkok

4.2.1 Comparison of PM concentrations at five communities

Indoor and outdoor concentrations of fine particulate matters (PM) including $PM_{2.5}$ and PM_{10} ($PM_{2.5}$ + $PM_{2.5-10}$) at five communities in the inner city of Bangkok, were determined (All data of $PM_{2.5}$, $PM_{2.5-10}$, and PM_{10} concentrations were detailed in Appendix E). The sampling was carried out in 2 seasons, dry season (April to May 2013) and wet season (September to October 2013). For both seasons, the samples were taken from five communities in the inner city of Bangkok, as described previously in Chapter 3. In each community, three houses were selected for indoor air sampling, and one of these three houses was selected for outdoor air sampling additionally.

The sampling of each community was collected three times (Sunday, Tuesday, and Friday) for one week. These three days represent weekend, work day, and end of work day in a week, respectively. All samples were collected simultaneously for 24 hours starting from 7:00 a.m. until 7:00 a.m. of the next day by using Personal Modular Impactor (PMI) connected to a personal air pump.

Figure 4.4 – 4.7 presented the concentrations of $PM_{2.5}$ and PM_{10} measured at all sampling points of five communities in dry and wet season. The results indicated that PM concentrations at some study areas presented the similar trend among their sampling points whereas, some study areas showed the inconsistent of PM concentrations owing to the specific sources of PM found at their sampling points.

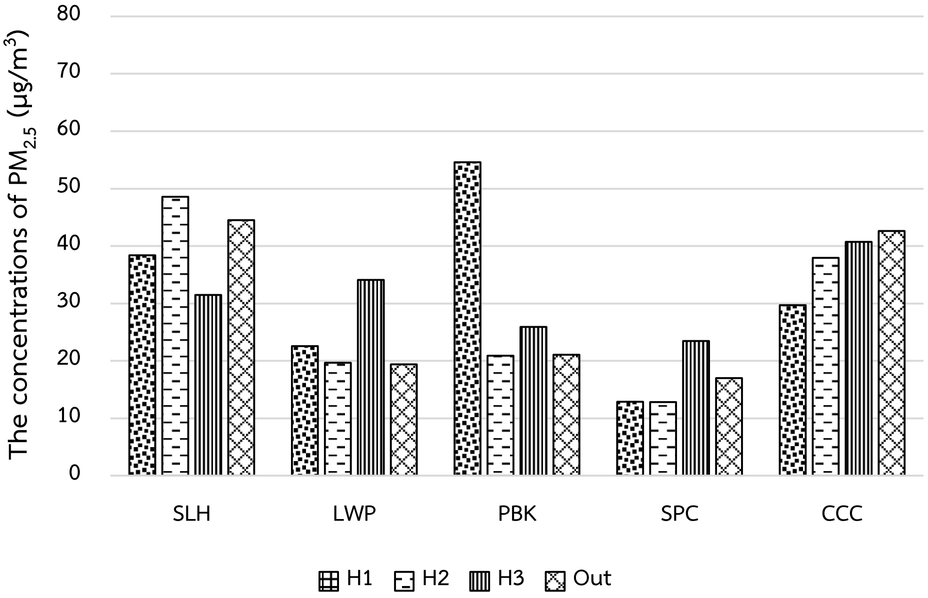


Figure 4.4 The average concentrations of $PM_{2.5}$ in dry season at five communities

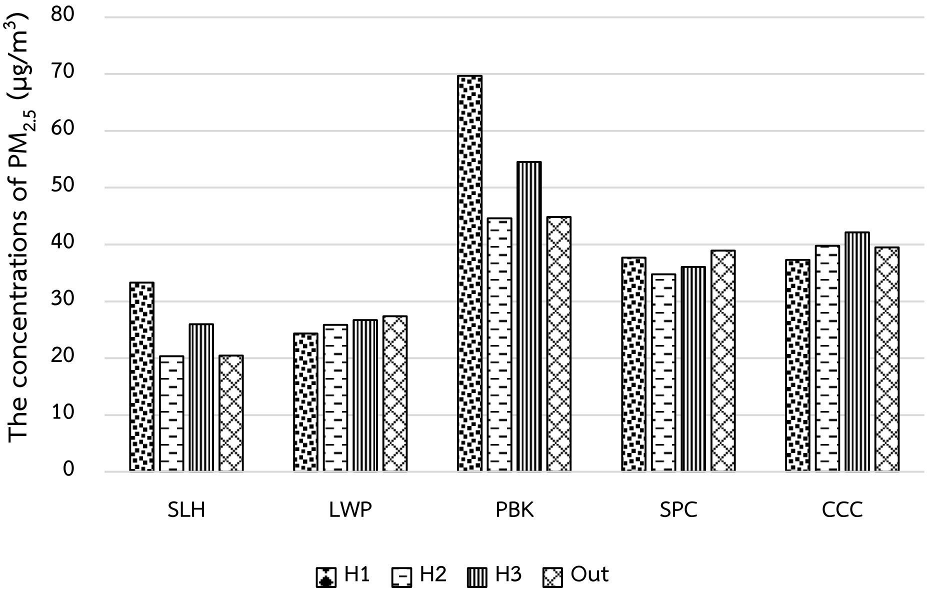


Figure 4.5 The average concentrations of PM$_{2.5}$ in wet season at five communities

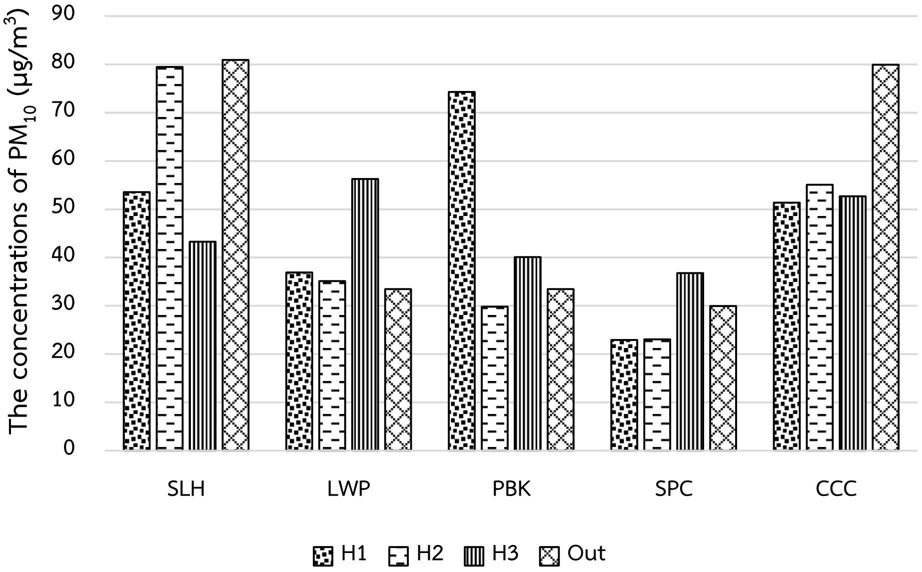


Figure 4.6 The average concentrations of PM$_{10}$ in dry season at five communities

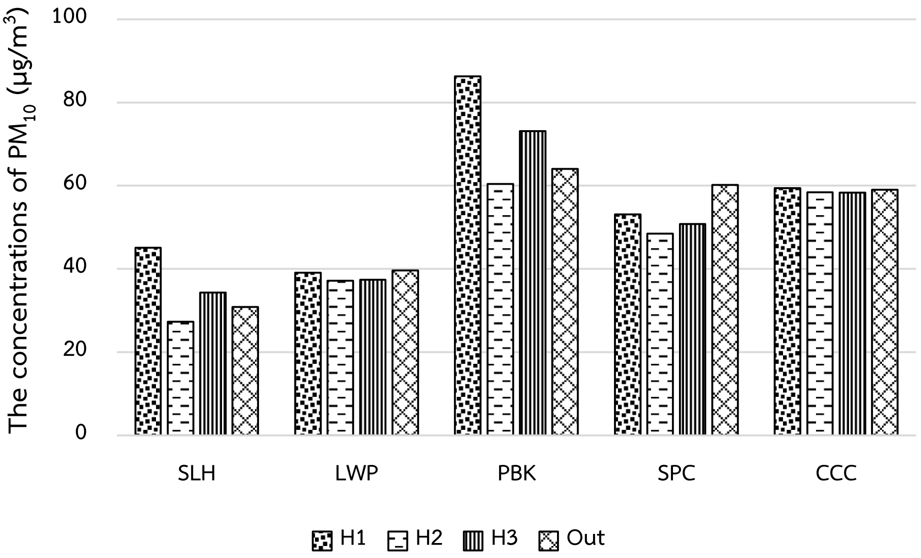


Figure 4.7 The average concentrations of PM_{10} in wet season at five communities

According to the results in dry season, the average concentrations of PM at H2 and outdoor of SLH were higher than those at the other houses. This is considerable that the playground and activity yard of this community were being renovated, thus construction activities and construction machine might additionally contributed the fine particles rather than the background concentration as usual. Whilst, the average concentrations of PM at H3 of LWP were higher than those at the other houses which had been affected from garbage burning closed to their house. At PBK, the average concentrations of PM at H1 were found the highest and higher than those at the other study areas. There was a specific daily activities at this house such as, cooking inside the house and using charcoal for their grilled meat selling which could contribute much of PM. The average concentrations of PM at H3 of SPC were higher than those at the other houses resulting from using more incense with five points in their house. Whereas, the average concentrations of PM at outdoor of CCC were higher than those at the other sampling points. These results might be caused by its location closed to railroad and overpass which mainly contributed from high traffic volume on roads nearby.

With respect to the results in wet season, the average concentrations of PM at H2 and outdoor of SLH were not the same trend as those in dry season due to the renovation of their playground and activity yard were completed. Thus, the average concentrations of PM presented in normal condition which H1 provided the higher concentrations of PM since there was incense burning and cooking inside the house. Whilst, the average concentrations of PM at LWP were presented the same trend at all sampling points. This is considerable that there was not specific activities in each house. At PBK, the average concentrations of PM at H1 were also found the highest and higher than those at the other study areas as same as in dry season which already mentioned above. Additionally, H3 were presented the higher concentrations of PM due to more vehicles passing from the market nearby. At SPC, the average concentrations of PM at outdoor were higher than those at the other sampling points which has been affected from vehicle passing. Whereas, the average concentrations of PM at CCC were presented the same trend at all sampling points. These results might be caused by its specific location nearby roadside and the indoor activities were not presented.

The 24-h indoor and outdoor average concentrations of $PM_{2.5}$ and PM_{10} measured at five communities Salak Hin (SLH), Lang Wat Pathumwanaram (LWP), Phatthana Bonkai (PBK), Soi Pra Chen (SPC), and Chao Choocheep (CCC) in dry and wet season is presented in Figure 4.8 - 4.11 and Table 4.6 – 4.7. The indoor concentrations of $PM_{2.5}$ and PM_{10} ranged from 7.52 to 92.85 $\mu g/m^3$ and from 13.64 to 123.82 $\mu g/m^3$, respectively. Whereas, the outdoor concentrations of $PM_{2.5}$ and PM_{10} ranged from 9.44 to 68.60 $\mu g/m^3$ and from 17.72 to 134.37 $\mu g/m^3$, respectively. The indoor average $PM_{2.5}$ concentrations at PBK (45.04±23.25 $\mu g/m^3$) was significantly higher than those at CCC (37.76±7.99 $\mu g/m^3$), SLH (33.00±12.73 $\mu g/m^3$), SPC (26.28±13.49 $\mu g/m^3$), and LWP (25.61±7.93 $\mu g/m^3$), respectively ($p<0.05$), using compare mean one way ANOVA, SPSS 20.0 for Window as the same trend of PM_{10} that found the indoor average concentrations at PBK (60.67±28.20 $\mu g/m^3$) was found the highest and significant higher than those ($p<0.05$) followed by those at CCC (56.07±7.24 $\mu g/m^3$), SLH (47.17±20.50 $\mu g/m^3$), LWP (40.40±10.12 $\mu g/m^3$), and SPC (39.19±16.47 $\mu g/m^3$), respectively.

The average outdoor $PM_{2.5}$ concentrations at CCC can be found the highest (41.05±12.15 $\mu g/m^3$), followed by PBK (32.95±18.88 $\mu g/m^3$), SLH (32.49±16.17 $\mu g/m^3$), SPC (27.98±15.55 $\mu g/m^3$), and LWP (23.41±6.97 $\mu g/m^3$), respectively. The significant difference could not be found ($p>0.05$) at all five communities, except at LWP. Whilst, the average outdoor concentration of PM_{10} at CCC provided the highest concentrations (69.47±34.43 $\mu g/m^3$), followed by SLH (55.86±32.34 $\mu g/m^3$), PBK (48.76±26.98 $\mu g/m^3$), SPC (45.07±21.87 $\mu g/m^3$), and LWP (36.56±8.35 $\mu g/m^3$), respectively, and the significant difference could be found at all five study areas, except at LWP.

Regarding to the results, the highest outdoor concentrations of $PM_{2.5}$ and PM_{10} at CCC might be caused by its location. This location closed to railway road and overpass which traffic emissions could contribute much of PM concentration. Whilst, the average indoor concentrations of $PM_{2.5}$ and PM_{10} at PBK was much higher than those at the other areas which not consistent with the outdoor PM concentrations. This is considerable that there were high intensive activities at representative houses of PBK. From observation, the highest concentrations of PM at PBK affected from the daily indoor activities of H1 which highly used charcoal to grill meat for sale.

Table 4.6 The indoor average concentrations of PM at five communities

	PM concentrations ($\mu g/m^3$) (mean±SD)				
	SLH	LWP	PBK	SPC	CCC
$PM_{2.5}$	$33.00\pm12.73_{bc}$	$25.61\pm7.93_{c}$	$45.04\pm23.25_{a}$	$26.28\pm13.49_{c}$	$37.76\pm7.99_{ab}$
PM_{10}	$47.17\pm20.50_{bc}$	$40.40\pm10.12_{c}$	$60.67\pm28.20_{a}$	$39.19\pm16.47_{c}$	$56.07\pm7.24_{ab}$

a,b,c,d = Statistical different between sampling positions analyzed by one way ANOVA at 95% confidence

Table 4.7 The outdoor average concentrations of PM at five communities

	PM concentrations ($\mu g/m^3$) (mean±SD)				
	SLH	LWP	PBK	SPC	CCC
$PM_{2.5}$	$32.49\pm4.92_{ab}$	$23.41\pm6.97_{b}$	$32.95\pm18.88_{ab}$	$27.98\pm15.56_{ab}$	$41.05\pm12.15_{a}$
PM_{10}	$55.86\pm32.34_{ab}$	$36.56\pm8.35_{b}$	$48.76\pm26.98_{ab}$	$45.07\pm21.87_{ab}$	$69.47\pm34.43_{a}$

a,b,c,d = Statistical different between sampling positions analyzed by one way ANOVA at 95% confidence

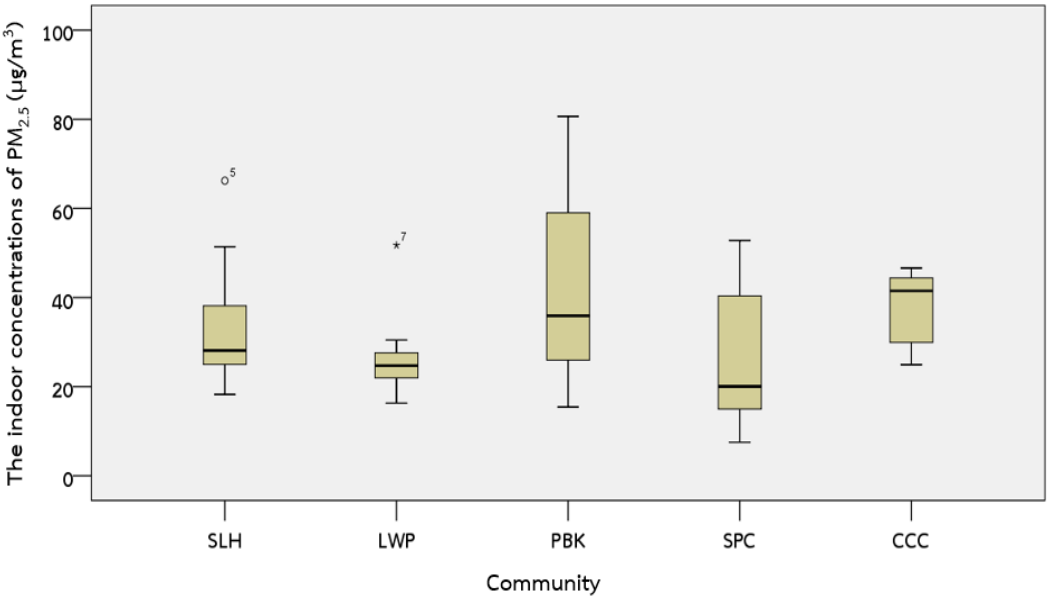


Figure 4.8 The indoor average concentrations of $PM_{2.5}$ in both dry and wet season at five communities

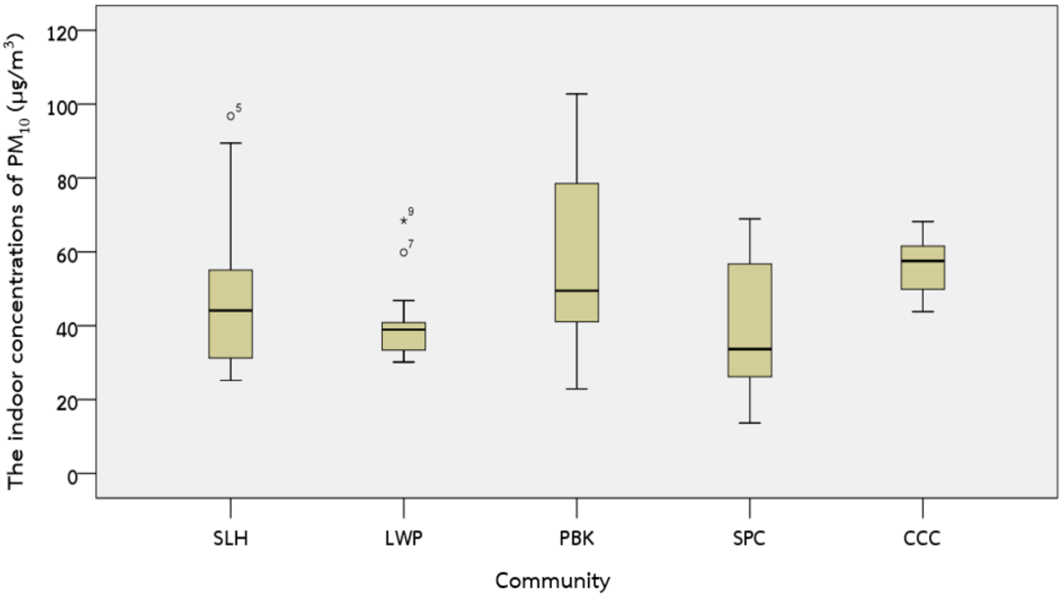


Figure 4.9 The indoor average concentrations of PM_{10} in both dry and wet season at five communities

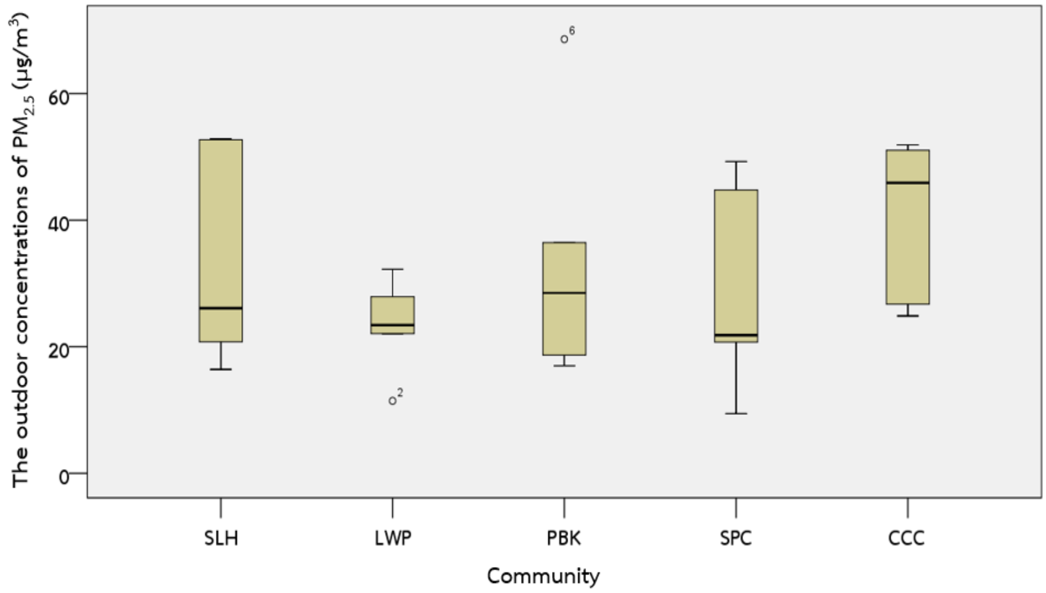


Figure 4.10 The outdoor average concentrations of $PM_{2.5}$ in both dry and wet season at five communities

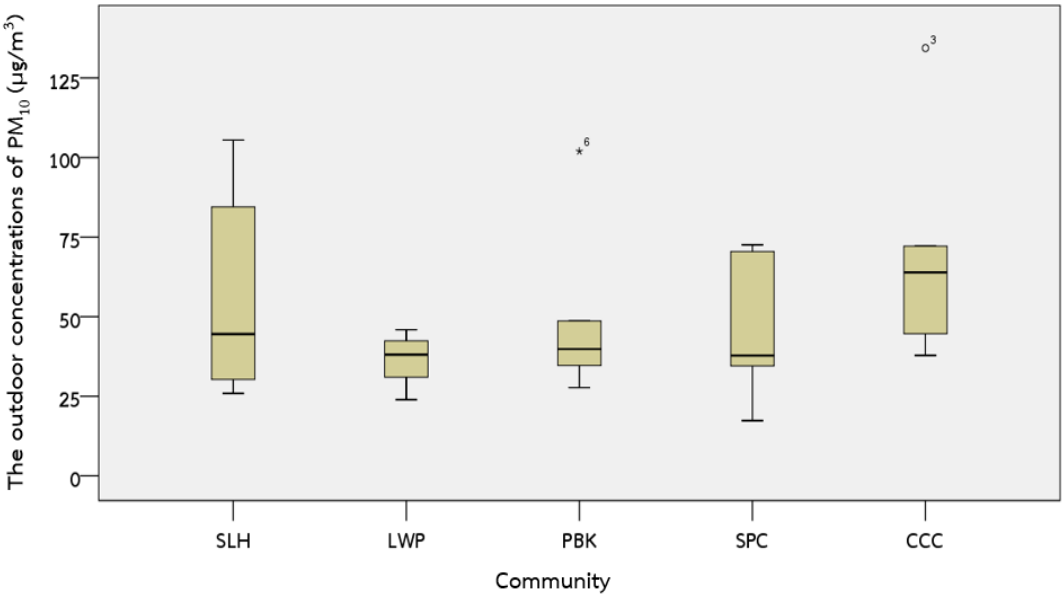


Figure 4.11 The outdoor average concentrations of PM_{10} in both dry and wet season at five communities

The concentrations of PM in this study were compared with some previous studies as provided in Table 4.8. The indoor concentrations of $PM_{2.5}$ in this study was lower than those found in Guangzhou, China, whereas it had the same trend as those report in Shizuoka, Japan. However, the previous study in Urumqi, China which performed the ambient $PM_{2.5}$ levels was higher than recorded in this study which only determined the indoor and outdoor levels.

Table 4.8 Comparison of PM concentrations in different cities

Location	Environment	Condition	PM Concentrations ($\mu g/m^3$)	Reference
Bangkok, Thailand	Indoor and outdoor air	Indoor $PM_{2.5}$ Outdoor $PM_{2.5}$ Indoor PM_{10} Outdoor PM_{10}	7.52 – 92.85 9.44 – 68.60 13.64 – 123.82 17.32 – 134.37	This study
Urumqi, China	24 h Ambient air	$PM_{2.5}$ $PM_{2.5-10}$	263.77 139.05	Limu et al. (2013)
Agra, India	Indoor and outdoor air	$PM_{2.5}$	79.46 – 198.66	Massey et al. (2009)
Guangzhou, China	Indoor and outdoor air	Indoor $PM_{2.5}$ Outdoor $PM_{2.5}$	67.7 74.5	Huang et al. (2007)
Guangzhou, China	Indoor and outdoor air	Indoor $PM_{2.5}$ Outdoor $PM_{2.5}$	82.12 – 170.97 83.33 – 176.04	Li et al. (2005)
Shizuoka, Japan	Indoor and outdoor air	Indoor $PM_{2.5}$ Outdoor $PM_{2.5}$	4.2 – 77 14 - 97	Ohura et al. (2004)

4.2.2 Seasonal variation of PM concentration

The air sampling of this study was performed in two seasons, dry (April to May 2013) and wet season (September to October 2013). For both seasons, the samples were taken from five communities. In order to analyze the seasonal variation, only the outdoor concentrations of PM were considered, as a results of the indoor concentrations of PM were not directly affected by the weather outside. This study reported the seasonal variation of PM concentration in term of the overview of the inner city due to all of study areas were a representative of the inner city (Pathumwan, Bangkok). Figure 4.12 - 4.13 showed the outdoor concentrations of $PM_{2.5}$ and PM_{10} in dry and wet season at all study areas. The outdoor $PM_{2.5}$ concentrations ranged from 9.44 to 52.84 µg/m^3 in dry and from 16.42 to 68.60 µg/m^3 in wet season. The average outdoor concentrations of $PM_{2.5}$ were 28.92±15.36 and 34.23±14.15 µg/m^3 in dry and wet season, respectively. While, the outdoor PM_{10} concentrations in dry and wet season ranged from 17.32 to 134.37 µg/m^3 and 25.87 to 101.97 µg/m^3 respectively. The average outdoor concentrations of PM_{10} were 50.74±20.84 and 51.55±32.88 µg/m^3 in dry and wet season, respectively.

Regarding to the overview of the inner city of Bangkok, the outdoor concentration of $PM_{2.5}$ and PM_{10} in wet season were higher than those in dry season. Moreover, the significant difference of the outdoor $PM_{2.5}$ and PM_{10} concentrations could not be found between dry and wet season ($p>0.05$), using compare mean paired-sample T-Test, SPSS 20.0 for Window as shown in Table 4.9. This study result indicated that seasonal variation was not effected on the concentrations of PM in the inner city of Bangkok.

On comparing among all study areas, the outdoor concentrations of $PM_{2.5}$ at SLH and CCC (44.51±14.32 and 42.60±15.36 µg/m^3, respectively) in dry season were higher than those in wet season (20.47±3.90 and 39.50±11.21 µg/m^3, respectively), but the results of those at the other communities found in wet season higher than in dry season.

Whilst, the outdoor concentrations of PM_{10} were found the same trend as those of $PM_{2.5}$ which SLH and CCC (58.75±22.72 and 42.77±13.32 µg/m^3, respectively) showed the concentrations in dry season higher than in wet season, but the other study areas found the outdoor concentrations in wet season higher than in dry season.

Normally, most of outdoor PM concentrations in dry season were found higher than those in wet season. The results of the outdoor $PM_{2.5}$ and PM_{10} concentrations at

SLH and CCC in dry season presented higher than those in wet season. This results were agreed with the study in India indicated that lower aerosol concentrations were recorded in rainy season because of the washout effect of particles from the atmosphere. The outdoor concentrations of $PM_{2.5}$ at urban homes averaged 100±45 μg/m^3 in summer, which was higher than in rainy season (91±34 μg/m^3) (Massey et al., 2012). Nevertheless, the results of the outdoor $PM_{2.5}$ and PM_{10} concentrations in wet season were higher than those in dry season at the other three communities and not consistent with the results of SLH and CCC. This might be caused by no rain during the sampling of PM at PBK, LWP, and SPC.

Table 4.9 The outdoor PM concentrations and the independent t-test

Type of PM	Outdoor		
	Dry	Wet	*p*-value
$PM_{2.5}$	28.92	34.23	0.386
PM_{10}	51.55	50.74	0.942

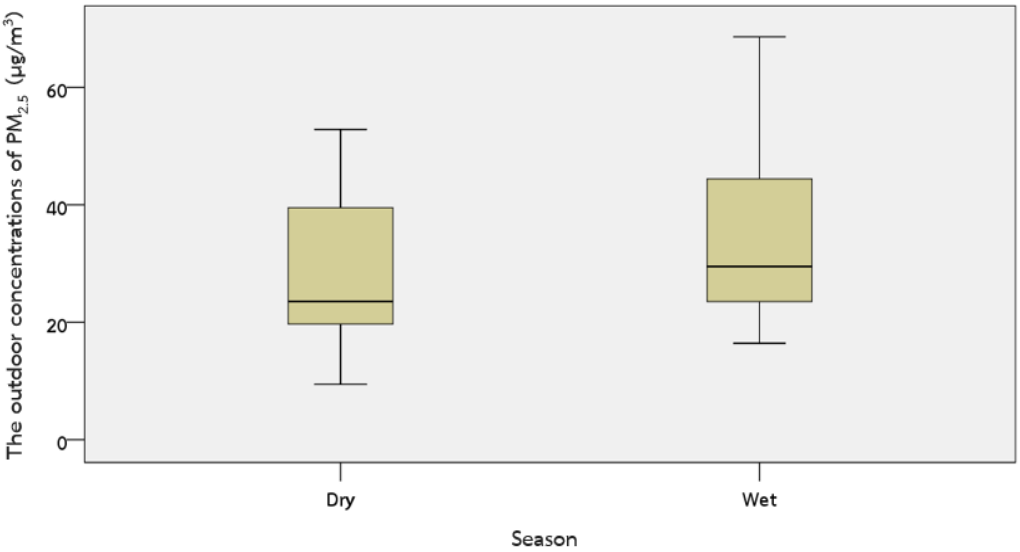


Figure 4.12 The outdoor concentrations of $PM_{2.5}$ in dry and wet season measured at five communities

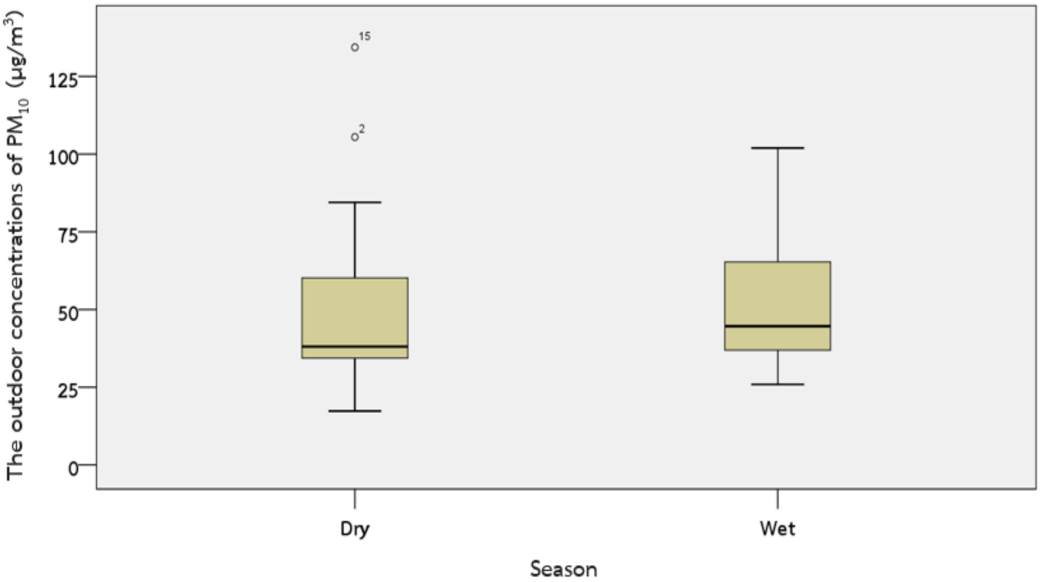


Figure 4.13 The outdoor concentrations of PM_{10} in dry and wet season measured at five communities

4.2.3 $PM_{2.5}/PM_{10}$

Table 4.10 presented the average ratios of $PM_{2.5}/PM_{10}$ indoors and outdoors at five communities. According to the results, the indoor $PM_{2.5}/PM_{10}$ ratios were ranged from 0.50-0.86, while the average indoor $PM_{2.5}/PM_{10}$ ratios provided 0.68±0.09. The outdoor $PM_{2.5}/PM_{10}$ ratios were ranged from 0.47-0.79 while the average indoor $PM_{2.5}/PM_{10}$ ratios provided 0.63±0.08. According to the results, $PM_{2.5}$ was a dominant fine particles and contributed for 60-70% approximately.

The major sources of $PM_{2.5}$ and PM_{10} at urban area are generally from the city background (traffic, construction, anthropogenic activities) and road traffic (motor emissions), at rural area are from vehicle exhausts, natural dust and agricultural burning, and industrial area were from high heat processes.

Table 4.10 The average ratios of $PM_{2.5}/PM_{10}$ indoors and outdoors at five communities

	$PM_{2.5}/PM_{10}$ ratios				
	SLH	LWP	PBK	SPC	CCC
Indoor	0.71±0.07	0.64±0.10	0.73±0.07	0.65±0.09	0.66±0.09
Outdoor	0.67±0.08	0.63±0.10	0.67±0.08	0.60±0.06	0.63±0.14

There were the previous researches study on $PM_{2.5}/PM_{10}$ ratios such as the study about inhalation exposure to particle-bound PAHs and health risk assessment of workers at religion place in Bangkok found that the average ratios of $PM_{2.5}/PM_{10}$ were 0.81±0.11 (approximately 80%) (Nonthakanok, 2013) which showed higher proportion of $PM_{2.5}$ due to incense burning in such study area. Similarly to this study, the study on speciation and origin of PM_{10} and $PM_{2.5}$ in Spain demonstrated that the $PM_{2.5}/PM_{10}$ ratios reached 0.4 – 0.7 in urban area, and 0.7 in rural area (Querol et al., 2004). In addition, the study on characterizing seasonal variations and spatial distribution of ambient PM_{10} and $PM_{2.5}$ concentrations based on long-term Swiss monitoring data found that the long-term averages of $PM_{2.5}/PM_{10}$ ratios of the daily values were 0.74 – 0.75 at urban area, with the exception of the traffic exposed site (0.59), 0.74 – 0.75 at suburban area, and 0.75 at rural area (Gehrig & Buchmann, 2003).

4.2.4 Correlation between indoor and outdoor concentrations of PM

The indoor (n=3) and outdoor (n=3) air samples were collected from the only one house (H2) at each community in dry and wet season. Indoor/outdoor (I/O) ratios can vary primarily resulting from many factors including locations, building pattern, and different activities (Massey et al., 2012). If I/O ratio is less than 1, the particles in indoor air are considerably arisen from the outdoor air, while the ratio greater than 1 indicated that indoor sources make a significant contribution to outdoor air concentrations (Ohura et al., 2004). To identify the impact of outdoor air and indoor sources on indoor air quality, I/O ratios were calculated.

Figure 4.14 – 4.15 presented the I/O ratios of $PM_{2.5}$ and PM_{10} in dry and wet season at all study areas. The average I/O ratios of $PM_{2.5}$ and PM_{10} at all five communities and Pearson's correlation were shown in Table 4.11. The average I/O ratios for $PM_{2.5}$ were in the range of 0.82±0.08 - 1.04±0.13. Moreover, there was a significant correlation between indoor and outdoor of $PM_{2.5}$ concentrations at five communities ($p<0.05$), using Pearson correlation, SPSS 20.0 for Window. Whereas, the average I/O ratios for PM_{10} were in the range of 0.79±0.03 - 1.01±0.14 as the same trend of those for $PM_{2.5}$ and the significant correlation could be found between indoor and outdoor ($p<0.05$).

The results of I/O ratios of $PM_{2.5}$ and PM_{10} at SPC which lower than 1 indicated that the indoor concentrations of $PM_{2.5}$ and PM_{10} were dominated from the outdoor sources which mainly contributed from vehicle passing the house. However, the I/O ratios of $PM_{2.5}$ and PM_{10} at some study areas which showed approximately 1 indicated that the concentrations of indoor air were similar to the outdoor concentrations. These results were supported with a good air ventilation from the opened door and windows therefore, the indoor and outdoor air were homogeneous. On the other hand, the I/O ratios of $PM_{2.5}$ and PM_{10} at some study areas were also greater than 1 demonstrated that indoor sources make a significant contribution to outdoor air concentrations. These results were supported with the specific indoor sources such as incense burning and cooking at the representative houses in some days, i.e. at SLH, LWP, and PBK on Tuesday. The I/O ratios obtained from this study were measured in the inner city which mostly found the dominant sources from the traffic emission outside in case of the specific indoor sources as cooking or incense burning could not found. The I/O ratios observed in this study were similar to those found at the residential building located in urban area of Guangzhou, China which found at the range of 0.88 - 1.11 (Li et al., 2005).

Table 4.11 Pearson's correlation of $PM_{2.5}$ and PM_{10} between indoor and outdoor

Community	Type of PM	Pearson's correlation		I/O ratios
		Pearson's coefficient (r)	*P* value	
SLH	$PM_{2.5}$	0.966**	0.002	1.04±0.13
	PM_{10}	0.987**	0.000	0.94±0.10
LWP	$PM_{2.5}$	0.891*	0.017	1.01±0.24
	PM_{10}	0.947**	0.004	1.01±0.14
PBK	$PM_{2.5}$	0.994**	0.000	1.01±0.09
	PM_{10}	0.993**	0.000	0.93±0.07
SPC	$PM_{2.5}$	0.996**	0.000	0.82±0.08
	PM_{10}	0.998**	0.000	0.79±0.03
CCC	$PM_{2.5}$	0.945**	0.004	0.96±0.10
	PM_{10}	0.998**	0.000	1.01±0.09

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

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

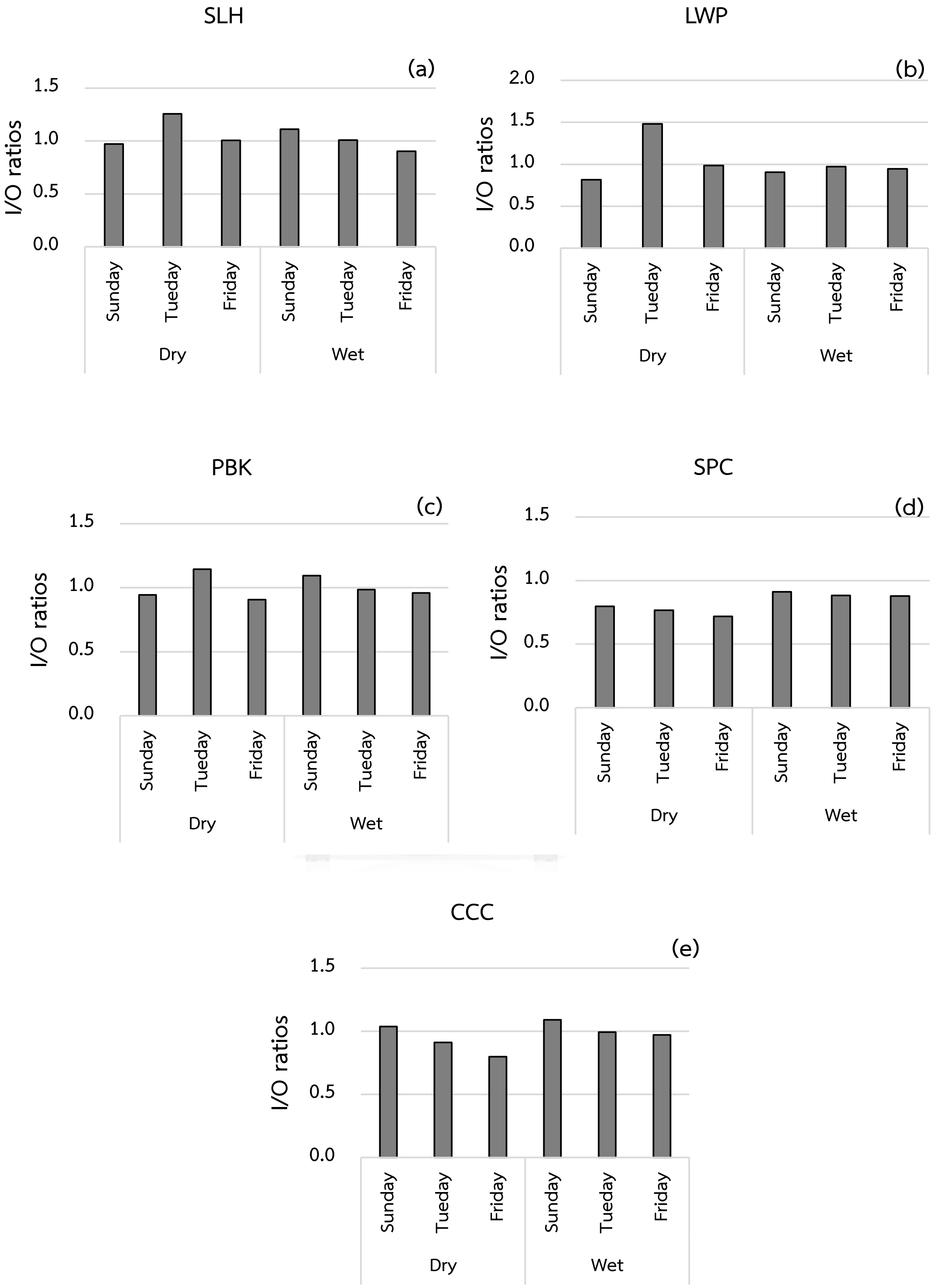


Figure 4.14 The I/O ratios of $PM_{2.5}$ at SLH (a), LWP (b), PBK (c), SPC (d), and CCC (e)

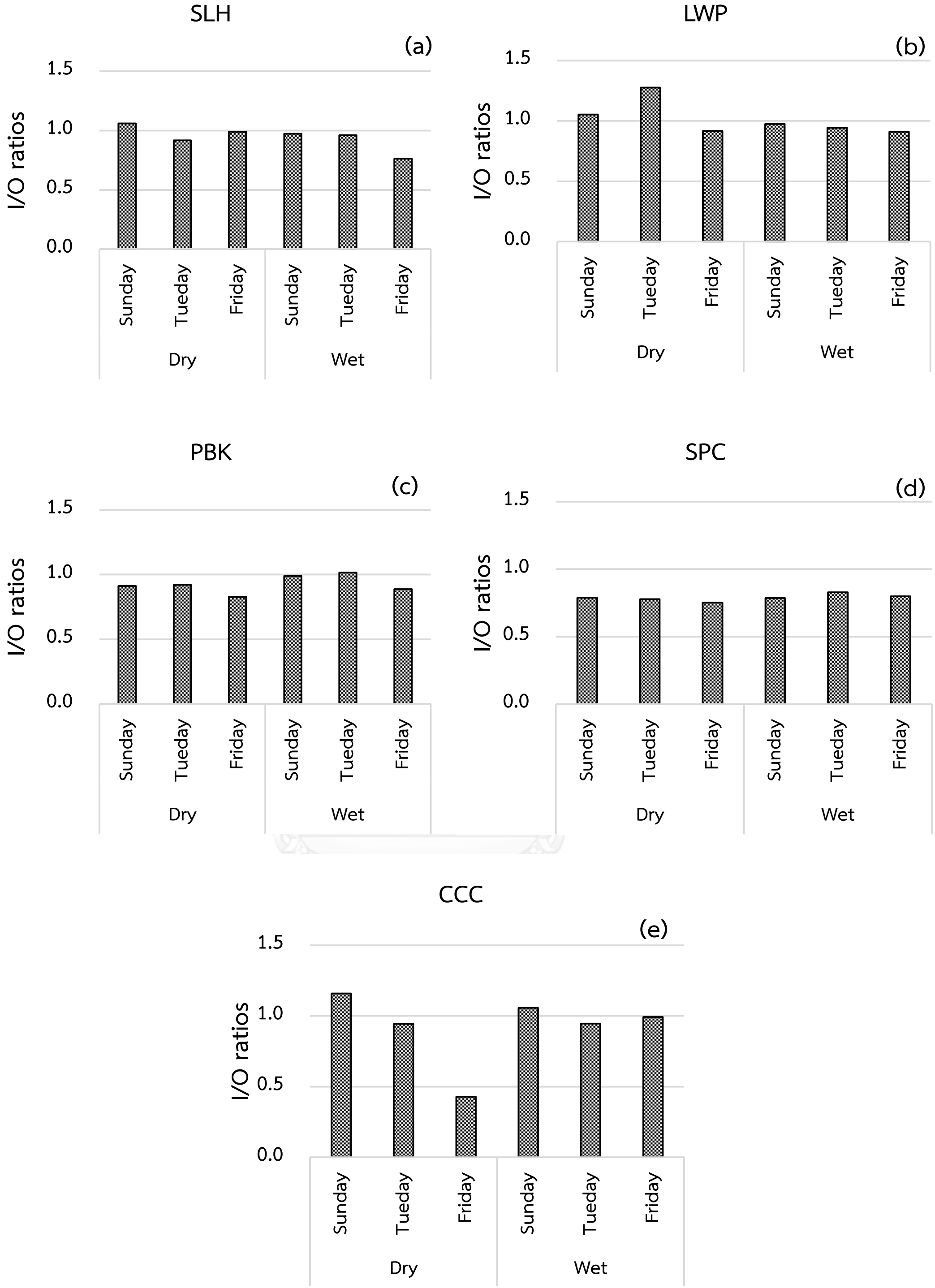


Figure 4.15 The I/O ratios of PM_{10} at SLH (a), LWP (b), PBK (c), SPC (d), and CCC (e)

4.2.5 Comparison of PM concentration with air quality standard

The comparison $PM_{2.5}$ and PM_{10} concentrations with air quality standard were provided in Table 4.12. On comparing the daily average of $PM_{2.5}$ and PM_{10} concentrations with the daily standard for $PM_{2.5}$ and PM_{10} in ambient air announced by PCD, Thailand (50 $\mu g/m^3$ for $PM_{2.5}$ and 120 $\mu g/m^3$ for PM_{10}), they were not exceeded the standard, but the maximum of those concentrations found to be 1.37 and 1.12 times, respectively higher than the air quality standard.

Figure 4.16 – 4.17 presented the outdoor concentrations of $PM_{2.5}$ and PM_{10} in dry and wet season at five communities. The outdoor concentrations of $PM_{2.5}$ in dry season at SLH and CCC were higher than Thailand's $PM_{2.5}$ standard. Surprisingly, the outdoor concentrations of $PM_{2.5}$ at PBK in wet season and the outdoor concentrations of PM_{10} at CCC in dry season were found the highest and higher than Thailand's $PM_{2.5}$ standard indicated that the residents of SLH, PBK, and CCC were likely to be at risk from inhalation exposure to PM for long period.

However, the PM concentrations only obtained from five communities and did not represent for all residents of all communities in Bangkok. Particularly, most of residential areas are located at some specific configuration, i.e. closed to express way, overpass, railway, cement plant, and construction site. The $PM_{2.5}$ and PM_{10} concentration might come from these additional outdoor sources not only from their own indoor activities.

Table 4.12 Comparison $PM_{2.5}$ and PM_{10} concentrations with air quality standard

PM	24-h PM Concentrations ($\mu g/m^3$)			Standard ($\mu g/m^3$)	Agency	References
	Min	Max	Average			
$PM_{2.5}$	9.44	68.60	31.58	50 25	PCD, Thailand WHO	PCD (2010) PCD (2009)
PM_{10}	17.32	134.37	51.14	120 50	PCD, Thailand WHO	PCD (2010) PCD (2009)

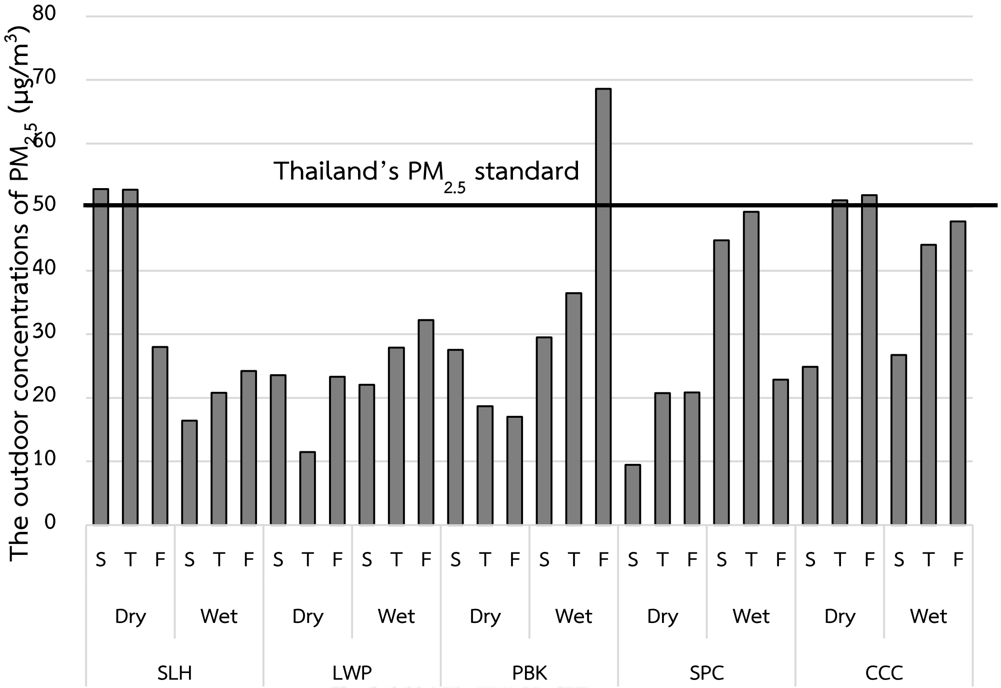


Figure 4.16 The outdoor concentrations of $PM_{2.5}$ in dry and wet season at five communities

Note: S = Sunday, T = Tuesday, F = Friday

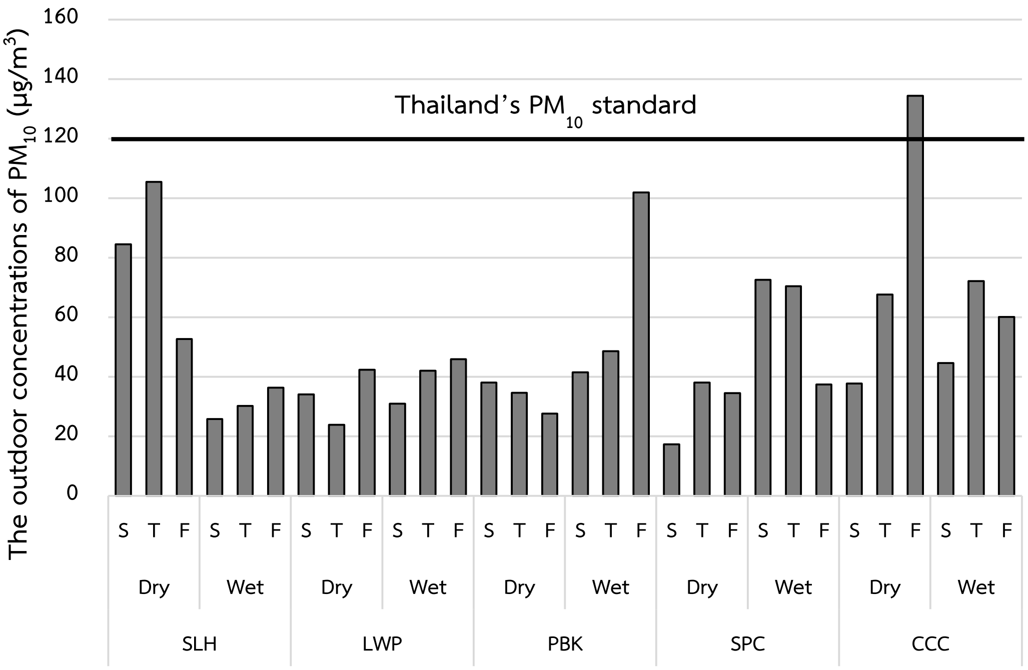


Figure 4.17 The outdoor concentrations of PM_{10} in dry and wet season at five communities

Note: S = Sunday, T = Tuesday, F = Friday

4.3 Correlation between $PM_{2.5}$ concentrations and $PAHs_{2.5}$ absorbed on $PM_{2.5}$

The correlation between $PM_{2.5}$ concentrations and the concentrations of t-$PAHs_{2.5}$ measured 24 hours at five communities as shown in Figure 4.18. The correlation between $PM_{2.5}$, and t-$PAHs_{2.5}$ could be statistically analyzed by Pearson correlation. The results demonstrated that the concentrations of $PM_{2.5}$ and t-$PAHs_{2.5}$ from all communities were significantly related at 95% confidence with the r value of 0.660 (*p*-value = 0.000).

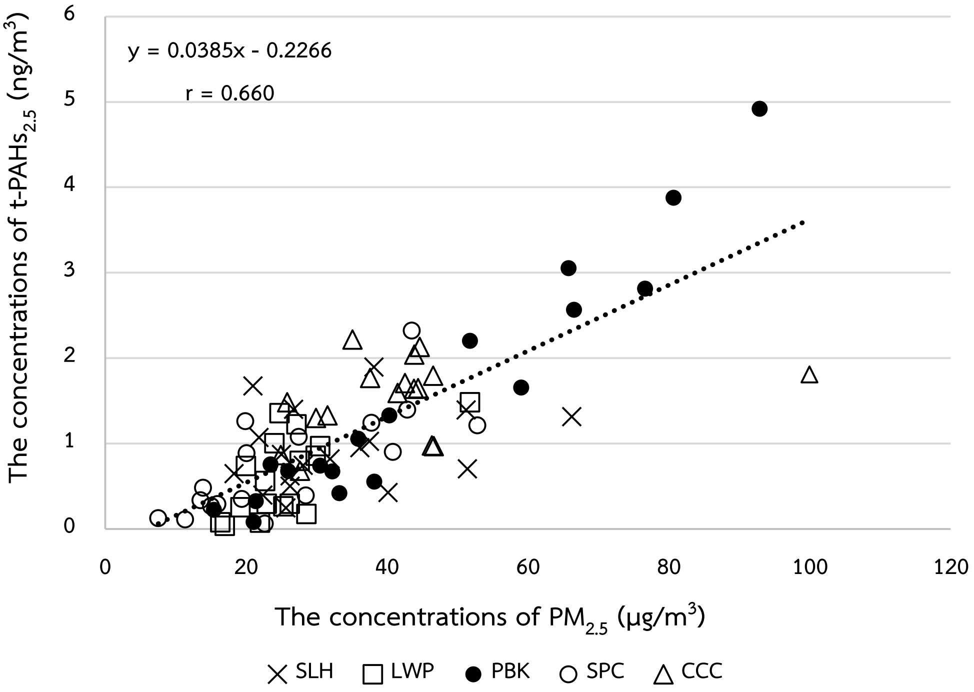


Figure 4.18 Correlation between the concentrations of $PM_{2.5}$ and t-$PAHs_{2.5}$

4.4 PAHs adsorbed on fine particles at five communities in the inner city of Bangkok

4.4.1 Comparison of PAHs concentrations at five communities

This research studied on PAHs adsorbed on $PM_{2.5}$ ($PAHs_{2.5}$) and $PM_{2.5-10}$ ($PAHs_{2.5-10}$) measured at five communities which were analyzed from the same particulate matters sample. However, only the concentration of $PAHs_{2.5}$ could be analyzed, because more than 80% of $PAHs_{2.5-10}$ was non-detectable (ND). With respect to the results, the concentrations of $PAHs_{2.5-10}$ showed ND levels might be caused by PAHs which produced from incombustion processes are mainly adsorbed on ultrafine particles (< 2.5 micron) not for coarse particles. In addition, the HPLC used for this analysis could not detect the concentrations of PAHs as low as picogram per cubic meter (10^{-12}). However, not all of $PAHs_{2.5-10}$ was presented in ND levels.

Figure 4.19 – 4.20 presented the total concentration of 16 PAHs adsorbed on $PM_{2.5}$ (t-$PAHs_{2.5}$) measured at all sampling points of five communities in dry and wet

season (All data of t-PAHs$_{2.5}$ and t-PAHs$_{2.5\text{-}10}$ concentrations were detailed in Appendix F). The results indicated that some study areas presented t-PAHs$_{2.5}$ concentrations in similar trend among their sampling points whereas, some study areas showed the inconsistent of t-PAHs$_{2.5}$ concentrations owing to the specific sources of t-PAHs$_{2.5}$ found at their sampling points. However, the t-PAHs$_{2.5}$ concentrations provided the results as similar as the concentrations of PM$_{2.5}$.

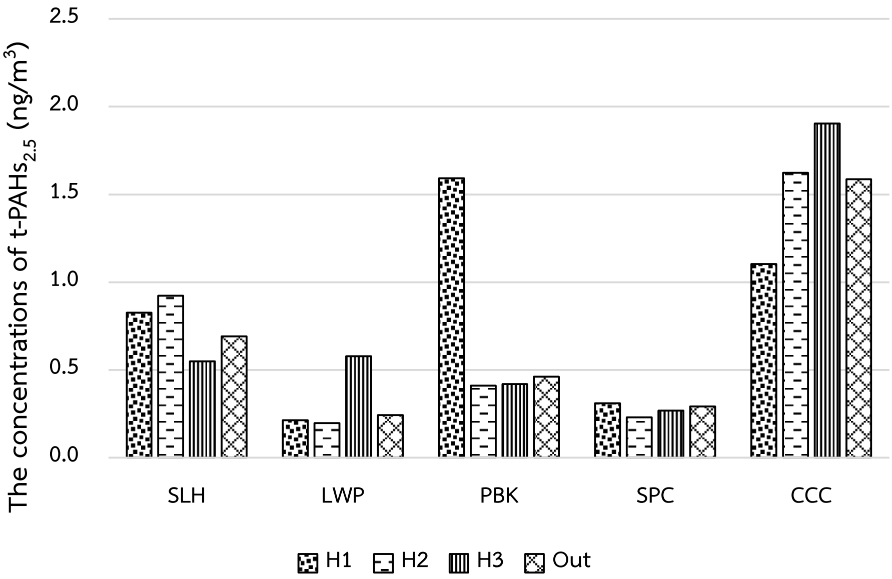


Figure 4.19 The average concentrations of t-PAHs$_{2.5}$ in dry season at five communities

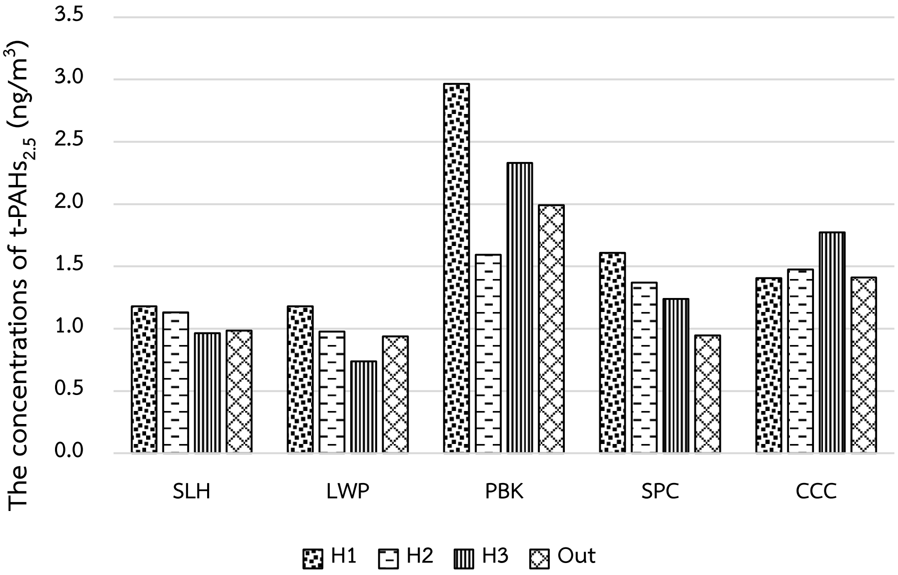


Figure 4.20 The average concentrations of t-PAHs$_{2.5}$ in wet season at five communities

The average concentrations of t-PAHs$_{2.5}$ in dry season mostly presented the similar trend as the average concentrations of PM$_{2.5}$ in dry season. H2 of SLH provided the average concentrations of t-PAHs$_{2.5}$ higher than those at the other houses due to construction activities and construction machine from the renovation of their playground and activity yard. Whereas, the average concentrations of t-PAHs$_{2.5}$ at H1 were higher than those at the other houses which had been affected from using charcoal for grilled meat selling and cooking inside the house.

As same as the average concentrations of t-PAHs$_{2.5}$ in wet season which mostly found the similar trend as the average concentrations of PM$_{2.5}$ in wet season. At SLH, the construction activities were stopped, thus the average concentrations of t-PAHs$_{2.5}$ presented normally which H1 provided the higher concentrations of t-PAHs$_{2.5}$ than the other houses from incense burning and cooking inside the house. Whilst, the average concentrations of t-PAHs$_{2.5}$ at PBK were also found the highest and higher than those at the other study areas by reason of the specific daily activities such as, cooking inside the house and using charcoal to grilled meat for sale which could contribute much of PM. Additionally, the higher concentrations of t-PAHs$_{2.5}$ at H3 has been affected from vehicle passing.

4.4.2 Indoor and outdoor PAHs concentrations at five communities

Generally, most of PAHs with low vapor pressure in the air are adsorbed on fine particles. More concentrations particulate matters presented are also provided more concentrations of PAHs. As if the significant correlation between PM and PAHs concentrations were found in this study, It can be concluded that PM was an important media which PAHs can be adsorbed on.

This study determined t-PAHs$_{2.5}$ at five communities, SLH, SPC, LWP, PBK, and CCC. In each community, one of three houses was selected for both of indoor and outdoor air sampling, and others two houses for indoor air sampling only. The indoor and outdoor concentrations of t-PAHs$_{2.5}$ were presented in Figure 4.21 - 4.22 and Table 4.13. The indoor concentrations of t-PAHs$_{2.5}$ ranged from 0.04 to 4.92 ng/m^3. Whereas, the outdoor concentrations of t-PAHs$_{2.5}$ ranged from 0.09 to 4.22 ng/m^3. The average indoor concentrations of t-PAHs$_{2.5}$ at PBK were found the maximum (1.55±1.39 ng/m^3) and significant greater than those at SLH (0.93±0.46 ng/m^3), SPC (0.84±0.70 ng/m^3), and LWP (0.62±0.48 ng/m^3), while not different from CCC (1.53±0.45 ng/m^3), at 95% confidence ($p<0.05$).

For outdoors, the average outdoor concentrations of t-PAHs$_{2.5}$ at CCC can be found the highest (1.51±0.54 ng/m^3), followed by those at PBK (1.23±1.50 ng/m^3), SLH (0.85±0.24 ng/m^3), SPC (0.62±0.38 ng/m^3), and LWP (0.59±0.43 ng/m^3), respectively. According to the outdoor concentrations of t-PAHs$_{2.5}$, they can be found the highest at CCC with the traffic emissions from railway road and overpass contribute much of t-PAHs$_{2.5}$ concentrations.

Whereas, the highest indoor average concentration of t-PAHs$_{2.5}$ at PBK caused by the highly indoor activities as cooking inside the house and using charcoals for their grilled meat selling at H1 that were a dominant indoor sources of t-PAHs$_{2.5}$ as well as PM$_{2.5}$. Some study areas presented the specific activities like incense burning and cooking inside the house result in higher indoor concentrations of t-PAHs$_{2.5}$. Whilst, the indoor concentrations of t-PAHs$_{2.5}$ at the other study areas which not presented the specific activities might got the effects from the vehicle passing. The indoor and outdoor concentrations of t-PAHs$_{2.5}$ presented the same trend as the average indoor and outdoor concentrations of PM$_{2.5}$ that found the highest at PBK and CCC, respectively. These results can be supported that PAHs directly adsorbed on PM$_{2.5}$.

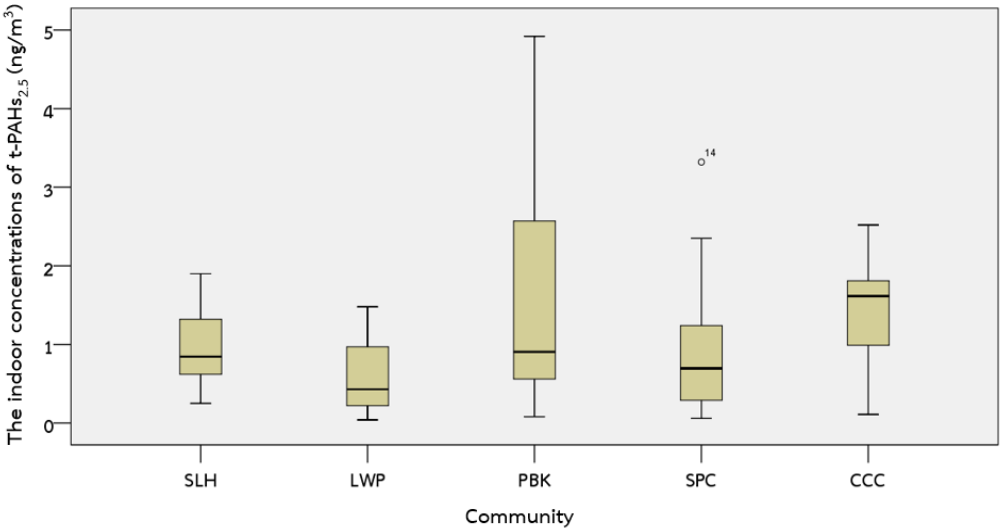


Figure 4.21 The indoor concentrations of t-PAHs$_{2.5}$ in dry and wet season measured at five communities

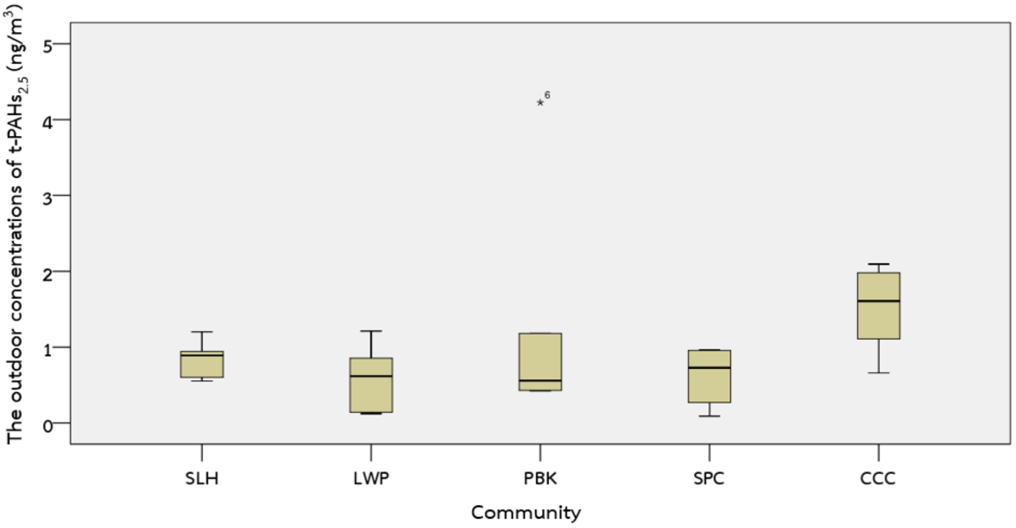


Figure 4.22 The outdoor concentrations of t-PAHs$_{2.5}$ in dry and wet season measured at five communities

Table 4.13 The indoor and outdoor average concentrations of t-PAHs$_{2.5}$ at five communities

	t-PAHs$_{2.5}$ concentrations (μg/m^3) (mean±SD)				
	SLH	LWP	PBK	SPC	CCC
Indoor	$0.93\pm0.46_{bc}$	$0.62\pm0.48_{c}$	$1.55\pm1.39_{ab}$	$0.84\pm0.70_{bc}$	$1.53\pm0.45_{a}$
Outdoor	$0.85\pm0.24_{ab}$	$0.59\pm0.43_{b}$	$1.23\pm1.50_{ab}$	$0.62\pm0.38_{ab}$	$1.51\pm0.54_{a}$

a,b,c,d = Statistical different between sampling positions analyzed by one way ANOVA at 95% confidence

The concentrations of t-PAHs$_{2.5}$ in this study were compared with some previous studies as provided in Table 4.14. The indoor and outdoor concentrations of t-PAHs$_{2.5}$ in this study was lower than those found in all previous studies. According to the higher concentrations of PAHs found in other studies, these might be due to the residents increased the daily activities relating to incombustion process like biomass burning for heating in winter.

Table 4.14 Comparison of PAHs in other studies

Location	Environment	Condition	t-PAHs Concentrations (ng/m^3)	Reference
Bangkok, Thailand	Indoor and outdoor air	Indoor PAHs$_{2.5}$ Outdoor PAHs$_{2.5}$	0.04 – 4.92 0.09 – 4.22	This study
Urumqi, China	Ambient air	PAHs$_{2.5}$ PAHs$_{2.5-10}$	0.11 – 1058.08 0.01 – 90.89	Limu et al. (2013)
Hangzhou, China	Indoor and outdoor air	Indoor PAHs$_{2.5}$	0.425 – 36.2	Zhu et al. (2009)
Guangzhou, China	Indoor and outdoor air	Indoor PAHs Outdoor PAHs	14.18 -77.89 15.83 – 84.83	Li et al. (2005)
Shizuoka, Japan	Indoor and outdoor air	Indoor PAHs$_{2.5}$ Outdoor PAHs$_{2.5}$ Indoor PAHs$_{2.5-10}$ Outdoor PAHs$_{2.5-10}$	1.6 – 23.7 1.1 – 29.5 0.18 – 2.05 0.17 – 2.48	Ohura et al. (2004)

4.4.3 Seasonal variation of PAHs concentrations

Since the indoor concentrations of t-PAHs$_{2.5}$ were not strongly depend on seasonal variation, therefore only those outdoor concentrations would be considered for seasonal variation analysis. The outdoor concentrations of t-PAHs$_{2.5}$ in dry (April to May 2013) and wet season (September to October 2013) were shown in Figure 4.23. The outdoor concentrations of t-PAHs$_{2.5}$ ranged from 0.09 to 2.10 ng/m^3 in dry season and from 0.59 to 4.22 ng/m^3 in wet season.

Most of study areas found the outdoor concentrations of t-PAHs$_{2.5}$ in wet season higher than those in dry season demonstrated that the outdoor concentrations of t-PAHs$_{2.5}$ were not depend on seasonal variation due to the rainy did not occurs normally when the sampling of PM was performed as same as the results of PM outdoor concentrations. Whereas, the outdoor concentrations of t-PAHs$_{2.5}$ at CCC were found in dry season (1.60±0.49 ng/m^3) higher than those in wet season (1.42±0.68 ng/m^3), but the significant difference could not be found between dry and wet season obtained from outdoors at all 5 communities ($p>0.05$) as shown in Table 4.15, using compare mean paired-sample T-Test, SPSS 20.0 for Window. These results considerable that seasonal variation was not the key affecting factor for outdoor concentrations of t-PAHs$_{2.5}$ in this study. As same as the results of the outdoor concentrations of PM that were not found the significantly different between dry and wet season.

According to the result of dry season, the outdoor concentrations of t-PAHs$_{2.5}$ in this study were compared with the result of Jung et al. (2010) which studied effects of heating season on residential indoor and outdoor PAHs black carbon, and PM$_{2.5}$. The results indicated that the heating compared to the non-heating season was associated significantly with elevated levels of $\sum 8\text{PAHs}_{\text{nonvolatile}}$ ($p<0.001$), but not the same trend as this study. On the other hand, the study of Hien et al. (2007) about distribution characteristics of polycyclic aromatic hydrocarbons with particle size in urban aerosols at the roadside in Ho Chi Minh City, Vietnam found that total PAHs measured were higher in the rainy season than in the dry season as same trend as this study which the concentrations of t-PAHs$_{2.5}$ in wet season higher than those in dry season at most of study areas.

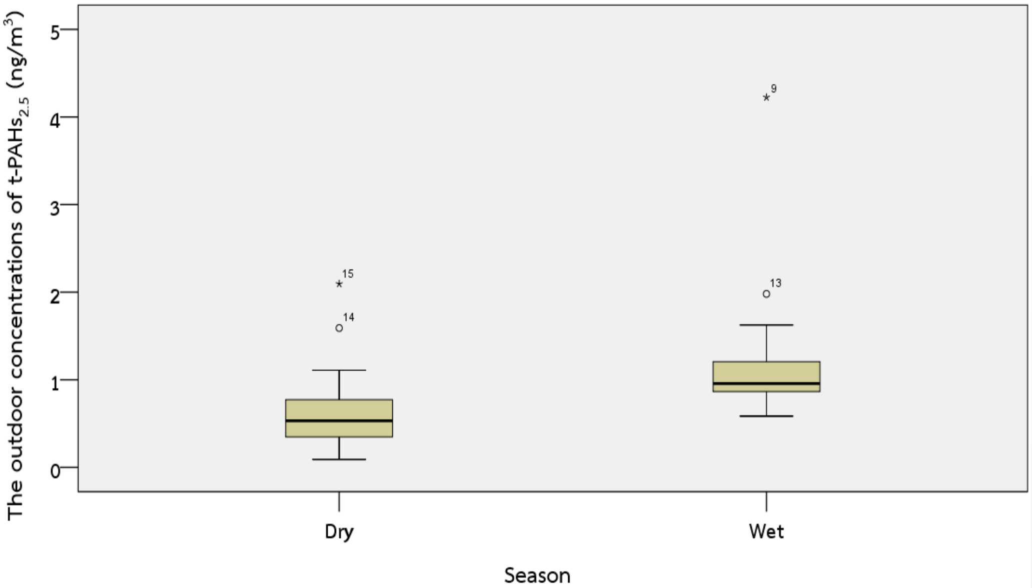


Figure 4.23 The outdoor concentrations of t-PAHs$_{2.5}$ in dry and wet season measured at five communities

Table 4.15 The outdoor t-PAHs$_{2.5}$ concentrations and independent t-test between dry and wet season

Community	Outdoor concentrations (ng/m^3)		*p*-value
	Dry	Wet	
SLH	0.70±0.21	1.00±0.18	0.276
LWP	0.24±0.19	0.95±0.23	0.089
PBK	0.46±0.06	1.99±1.95	0.310
SPC	0.03±0.23	0.94±0.03	0.050
CCC	1.60±0.49	1.42±0.68	0.951

4.4.4 Species of PAHs adsorbed on $PM_{2.5}$

According to the sampling of PAHs adsorbed on $PM_{2.5}$ ($PAHs_{2.5}$) and $PM_{2.5-10}$ ($PAHs_{2.5-10}$) at five communities, the predominant species of $PAHs_{2.5}$ in indoors and outdoors were presented in Figure 4.24 – 4.25 and Table 4.16. The results demonstrated that the predominant species of $PAHs_{2.5}$ at all five communities were B(ghi)P, B(a)P, B(b)F, Ind, and B(k)F.

However, there were some previous studies for examples, the study of PAHs associated with $PM_{2.5}$ in indoor and outdoor air at Shizuoka, Japan provided the major species of PAHs as BbF Fluor Cry BghiP and Ind (Ohura et al., 2004). While, the study of PAHs in the indoor and outdoor $PM_{2.5}$ in Guangzhou, China found Bghi BbF Ind BkF and BaP as the predominant species (Li et al., 2005). Moreover, the study of residential indoor and outdoor PAHs in Northern Manhattan and the South Bronx presented BaA BaP Ind DahA and BghiP (Jung et al., 2010). On comparing the predominant species of $PAHs_{2.5}$ and $PAHs_{2.5-10}$ found in this study with the previous study, they were found the similar results which presented the four predominant species as BghiP, BaP, BbF, and Ind.

The study on distribution characteristics of polycyclic aromatic hydrocarbons with particle size in urban aerosols at the roadside in Ho Chi Minh City, Vietnam found that among 10 PAHs investigated BghiP was the most abundant in both seasons (Hien et al., 2007). The abundance of BghiP found in this study is consistent with the previous study which BghiP was considered as a vehicular emission indicator.

Table 4.16 Dominant species of $PAHs_{2.5}$

Location	Environment	Predominant species of $PAHs_{2.5}$				
		1	2	3	4	5
SLH	Indoor	B(ghi)P	B(a)P	B(b)F	Ind	B(k)F
	Outdoor	B(ghi)P	B(a)P	B(b)F	Ind	B(k)F
LWP	Indoor	B(ghi)P	B(a)P	Ind	B(b)F	B(k)F
	Outdoor	B(ghi)P	B(a)P	B(b)F	B(k)F	Ind
PBK	Indoor	B(ghi)P	B(b)F	B(a)P	Ind	Pyr
	Outdoor	B(ghi)P	B(b)F	B(a)P	Ant	Ind
SPC	Indoor	B(ghi)P	B(a)P	Ind	B(b)F	B(k)F
	Outdoor	B(ghi)P	B(a)P	Ind	B(b)F	Flu
CCC	Indoor	B(ghi)P	B(a)P	B(b)F	B(k)F	Flu
	Outdoor	B(ghi)P	B(a)P	B(b)F	B(k)F	Flu

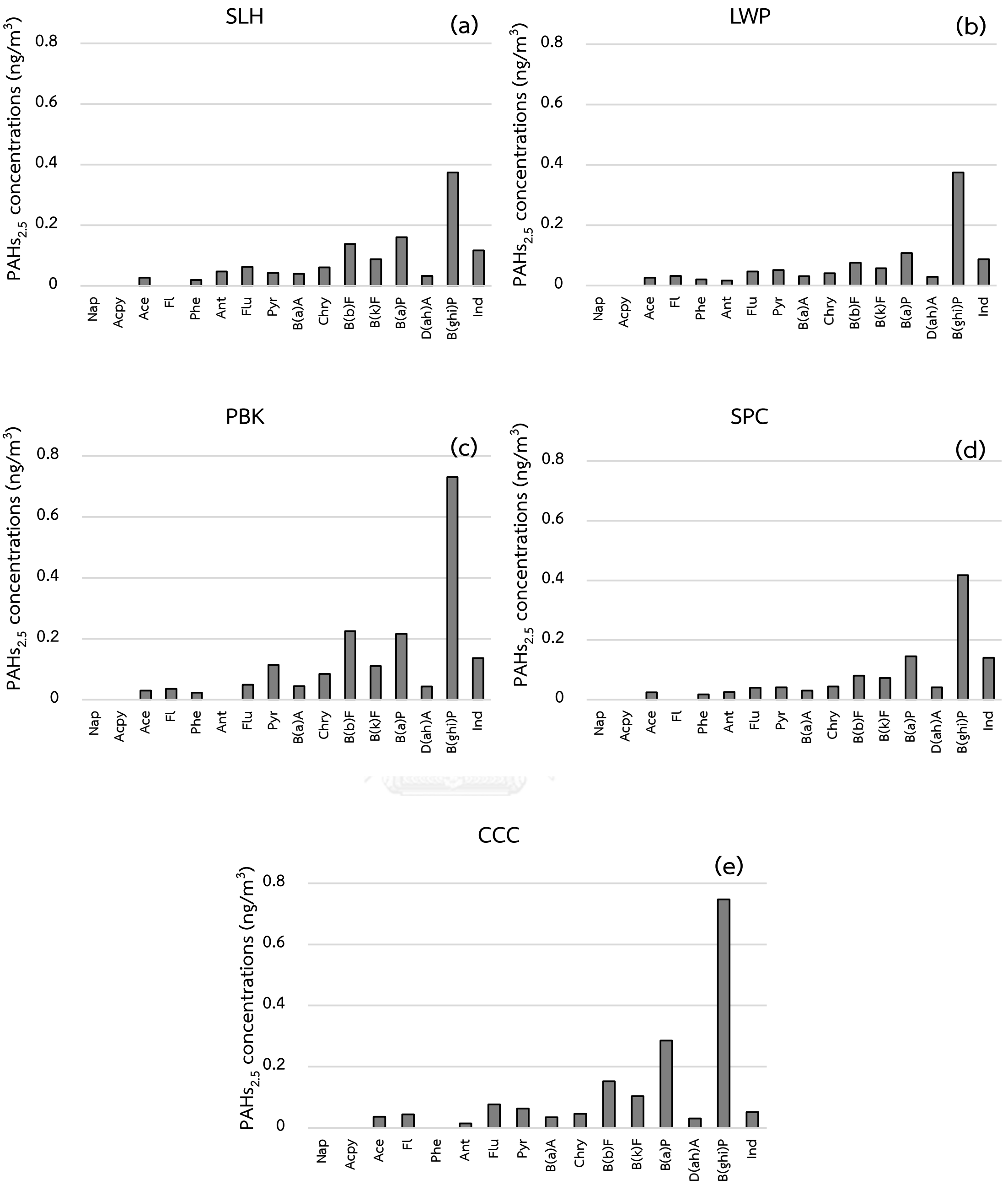


Figure 4.24 The indoor concentrations of PAHs$_{2.5}$ measured at SLH (a), LWP (b), PBK (c), SPC (d), and CCC (e)

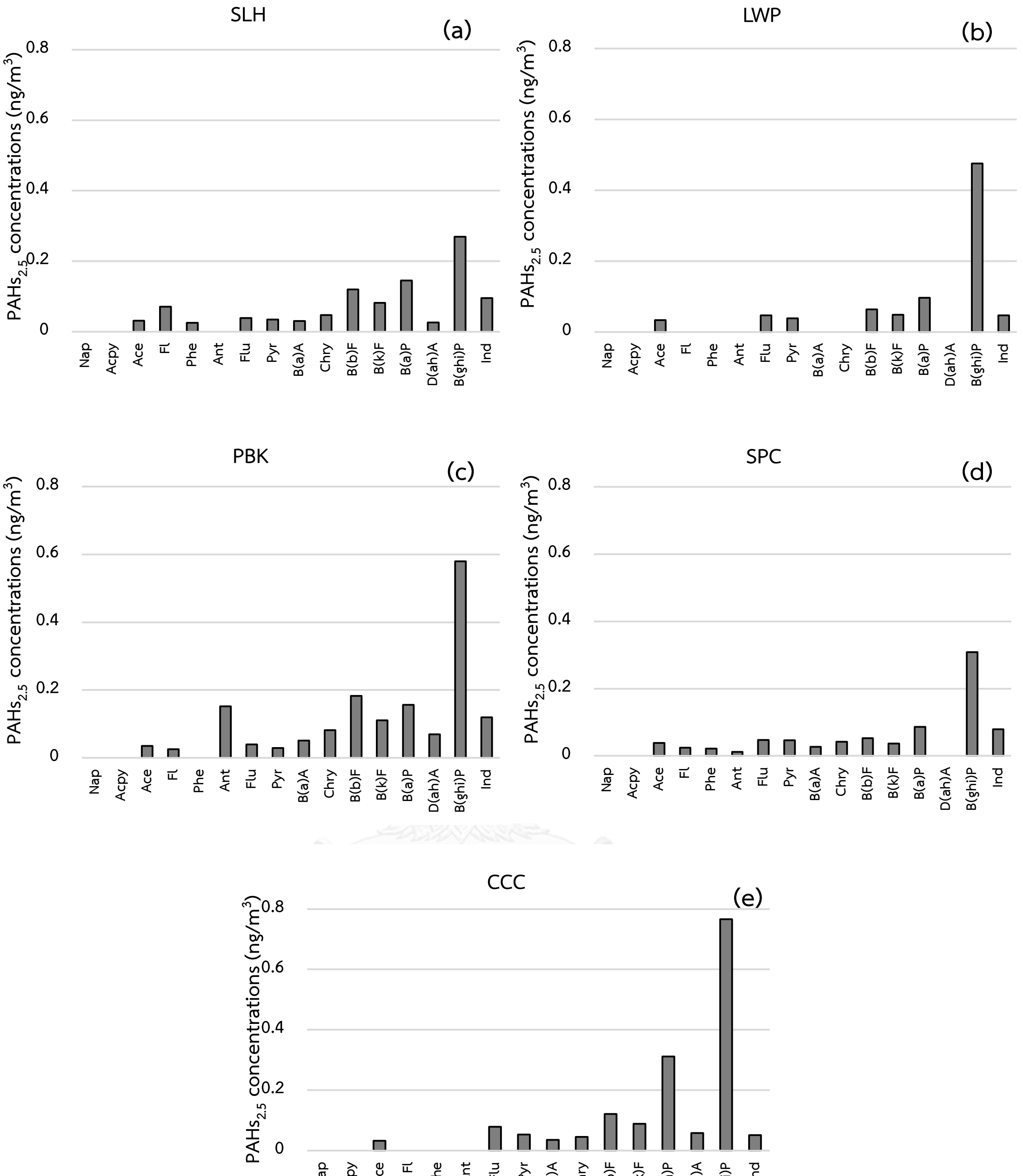


Figure 4.25 The outdoor concentrations of $PAHs_{2.5}$ measured at SLH (a), LWP (b), PBK (c), SPC (d), and CCC (e)

4.4.5 Correlation between indoor and outdoor concentrations of t-PAHs$_{2.5}$

In order to verify the correlation between indoor and outdoor concentrations of t-PAHs$_{2.5}$, the I/O ratios of t-PAHs$_{2.5}$ were determined. However, PAHs are constituents of complex mixtures which the individual species of PAHs were also influenced on t-PAHs, therefore the results of higher I/O ratios might be caused by the specific sources.

The I/O ratios of t-PAHs$_{2.5}$ at all five communities were shown in Figure 4.26. The I/O ratios of t-PAHs$_{2.5}$ obtained from five communities were 0.29 – 2.43, while the average I/O ratios for t-PAHs$_{2.5}$ were 1.09. Some days of the sampling period presented the remarkable I/O ratios resulting from the specific indoor activities. From the observation, there were specific sources of PAHs at some representative houses (H2) measured both indoor and outdoor PAHs such as incense burning, cooking inside the house at H2 of SLH, LWP, PBK, and SPC. In addition, the conditions of the house were also related. The indoor PAHs could not be distributed or diluted at representative house which low air ventilation by closed the door and windows result in the high accumulation of PAHs in indoors.

In addition, Table 4.17 also provided the Pearson's correlation of t-PAHs$_{2.5}$ between indoor and outdoor. The average I/O ratios of t-PAHs$_{2.5}$ at LWP and PBK were smaller than 1 (0.98±0.51 and 0.88±0.46, respectively). These results indicated that the indoor concentrations of t-PAHs$_{2.5\text{-}10}$ were dominated from the outdoor sources. The I/O ratios obtained from this study were measured in the inner city which mostly found the dominant sources from the traffic emission outside in case of the specific indoor sources as cooking or incense burning could not found in the representative house.

Whilst, the average I/O ratios of t-PAHs$_{2.5}$ at SLH, SPC, and CCC were more than 1 (1.23±0.39, 1.39±1.06, and 1.15±0.29, respectively), and significant correlation could not be obtained. The high I/O ratios levels (above 1) at the other three communities meaning indoor sources make a significant contribution and might not be affected from the outdoor air concentrations. These results were supported with the high indoor activities at CCC which caused by incense burning at H2. Whereas, the representative house SLH and SPC had low air ventilation with the doors and windows were kept closed, as the results, the accumulation of air pollutants like PAHs can be occurred.

The I/O ratios of t-PAHs$_{2.5}$ results were not consistent with I/O ratios of PM$_{2.5}$ results since the specific sources contributed to high amount of some PAHs$_{2.5}$ species which influenced on t-PAHs$_{2.5}$ concentration. The I/O ratios of t-PAHs$_{2.5}$ observed in this study were similar to those found at Guangzhou, China which found at the range of 0.88 - 1.11 (Li et al., 2005), but different from the study at New York City's Northern Manhattan and the Bronx that the I/O ratios were close to or lower than 1 for nonvolatile PAHs (Jung et al. 2010).

Table 4.17 I/O ratios and Pearson's correlation of t-PAHs$_{2.5}$ in both of dry and wet season

Community	Pearson's correlation		I/O ratios
	Pearson's coefficient (r)	*P*-value	
SLH	0.480	0.336	1.23±0.39
LWP	0.953**	0.003	0.98±0.51
PBK	0.981**	0.001	0.88±0.46
SPC	0.648	0.164	1.39±1.06
CCC	0.666	0.148	1.15±0.29

*Correlation is significant at the 0.05 level (2-tailed); **Correlation is significant at the 0.01 level (2-tailed)

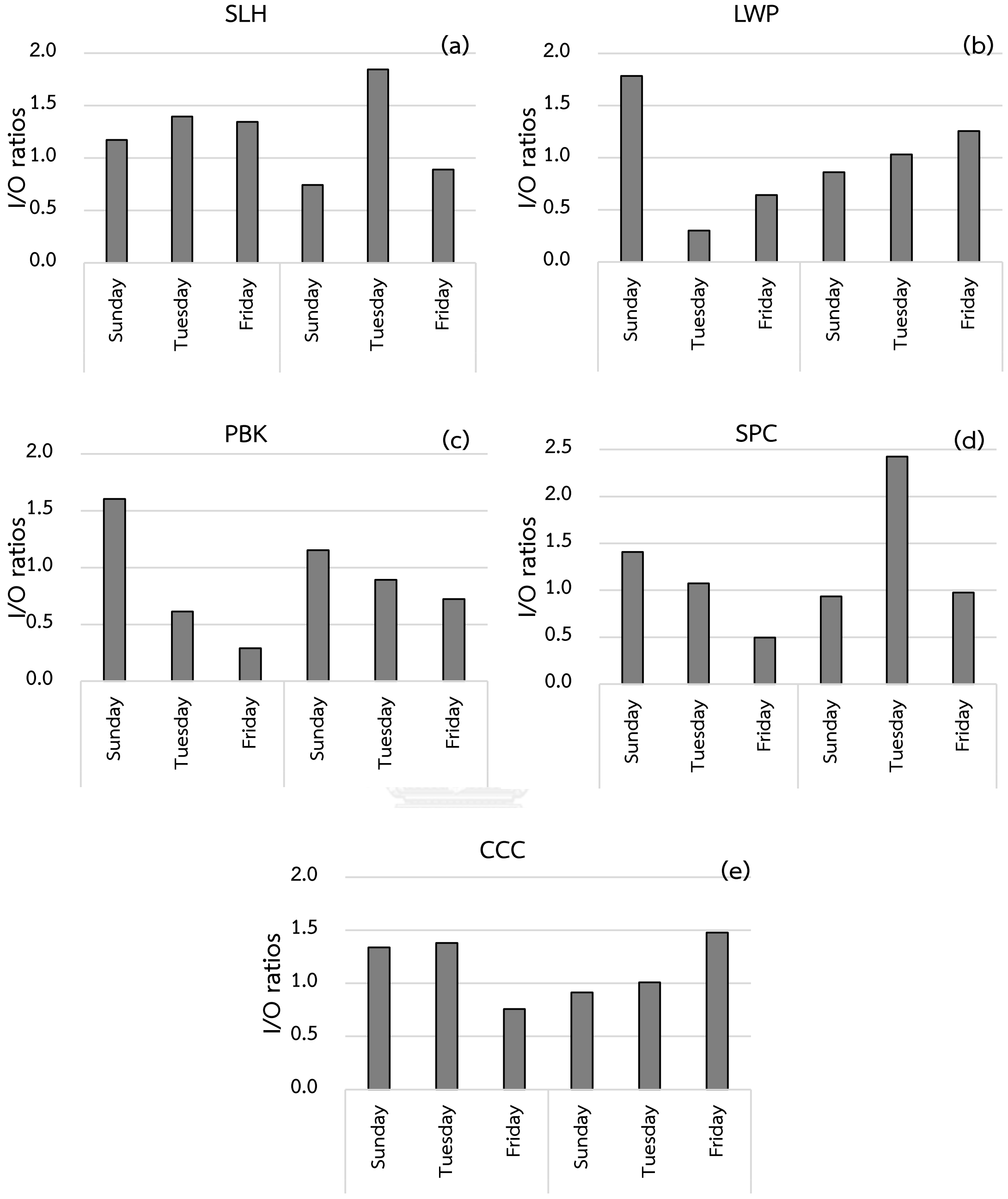


Figure 4.26 I/O ratios of t-PAHs$_{2.5}$ at SLH (a), LWP (b), PBK (c), SPC (d), and CCC (e)

4.4.6 Diagnostic ratios of PAHs$_{2.5}$

To characterize predominant source of PAHs found at the residential areas, diagnostic ratio of PAHs absorbed on PM$_{2.5}$ was investigated. Therefore, the diagnostic ratios of PAHs$_{2.5}$ were determined on the basis of related PAHs emitted from vehicles and fuel combustion, i.e. Ind/(Ind+BghiP) and B(a)P/B(ghi)P. . The diagnostic ratios of indoor and outdoor PAHs$_{2.5}$ measured at five communities were presented in Figure 4.27. The results found that Ind/(Ind+BghiP) ratios were totally lower than 0.4 and B(a)P/B(ghi)P ratios were also lower than 0.6, and these revealed that the indoor and outdoor sources of PAHs$_{2.5}$ were almost the same that contributed from vehicle emission and fuel combustion. These results were supported with the location of all five communities located in the inner city of Bangkok which mostly found the dominant sources from the traffic emission outside in case of the specific indoor sources as cooking or incense burning could not found in the representative house.

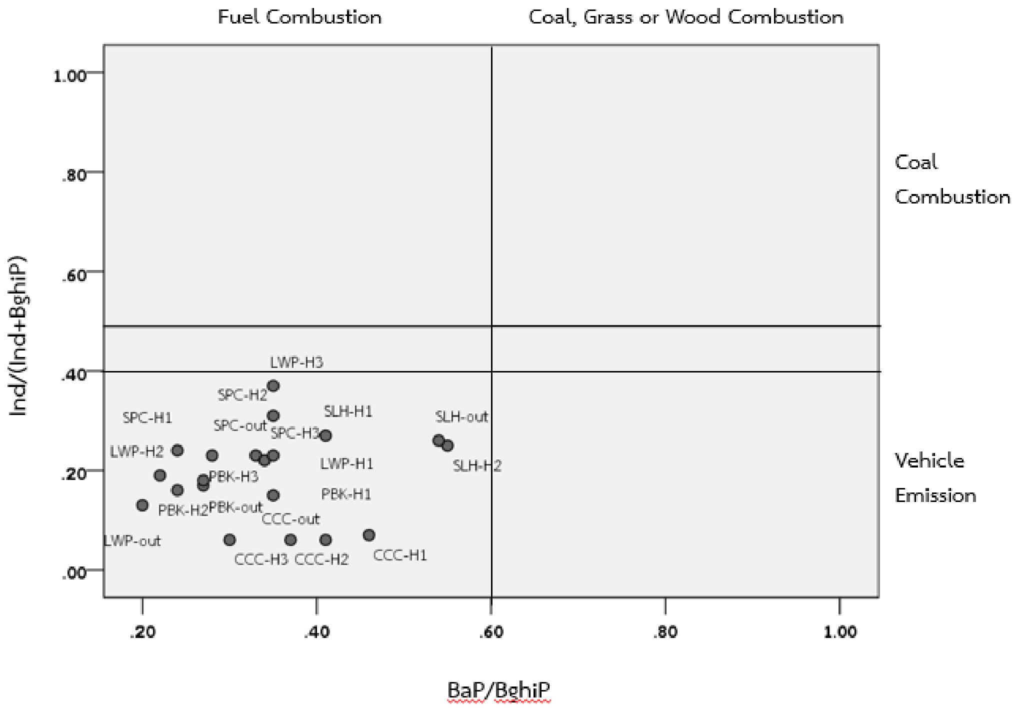


Figure 4.27 The diagnostic of indoor and outdoor PAHs$_{2.5}$ at five communities

4.4.7 Comparison of PAHs concentration with air quality standard

The specific guideline or air quality standard for individual PAHs have not been proposed by any agencies up till now as PAHs are constituents of complex mixtures. Thus, BaP was chosen as an indicator. The comparison of 24-h concentrations of PAHs and BaP with air quality standard was provided in Table 4.18. The results of this study presented the 24-h average concentrations of BaP which exceeded the standard of Ontario MOE (0.0011 ng/m^3) and New Hampshire DES (0.005 ng/m^3), but not over the standard of California EPA (0.18 ng/m^3). Noticeably, the maximum 24-h concentration was higher than the standard of all agencies. However, the standard of BaP was pronounced by international agencies. There were some specific factors which appropriate for their environments and may be not suitable condition for Thailand. The concentrations of BaP only obtained from five communities and did not represent for all residents of all communities in Bangkok. Particularly, most of residential areas are located at some specific conditions, i.e. closed to express way, overpass, railway road, and construction site. The BaP concentration might come from these additional outdoor sources.

Table 4.18 Comparison outdoor BaP concentrations with air quality standard

Compound	24-hr PAHs concentrations (ng/m^3)			Standard (ng/m^3)	Agency	References
	Max	Min	Average			
B(a)P	0.47	0.05	0.16	0.0011 0.18 0.005	Ontario MOE California EPA New Hampshire DES	AENV (2004)

4.5 Health situation of the residents exposed to fine particles via inhalation

Fine particles can deeply accumulate in respiratory system more than coarse particles. The previous epidemiological studies indicated that the relation between exposure to $PM_{2.5}$ and adverse health effects are premature death and increased hospital admissions for respiratory effects. Long-term period of exposure to $PM_{2.5}$ is more serious health effects than its short term (PCD, 2009). People who might be a group at high risk of exposure to $PM_{2.5}$ are patients with heart or lung disease, older adults and children. Moreover, pregnant women, newborns and people with health conditions are more susceptible affection from $PM_{2.5}$.

The symptom of residents asked in the questionnaires was assumed as acute effect (The questionnaire in English version were presented in Appendix G). The symptom related to long-term effect of PM such as asthma or allergy were not included. According to low PM concentration results, the symptom would be presented in chronic effect and not enough to be acute effect as irritation of eyes/nose/throat/skin. Therefore, the residents had rarely eyes/nose/throat/skin irritations only 5.56%. Whilst, general symptom frequently found in headache/drowsiness as 16.67%, followed by tired/fatigued (11.11%). Moreover, the rarely symptom presented the headache/drowsiness as 27.78%, followed by tired/fatigued (11.11%). Whereas, chest pain/ suffocation, bored with food/ temporary hearing and/or vision loss, faint/ unconscious were the symptom which the residents never had as shown in Table 4.19.

Table 4.19 Health information

	Never		Rarely		Frequently	
	n	%	n	%	n	%
Headache/ drowsiness	10	55.56	5	27.78	3	16.67
Irritations of eyes/ nose/ throat/ skin	17	94.44	1	5.56	0	0
Tired/ fatigued	14	77.78	2	11.11	2	11.11
Chest pain/ suffocation	18	100	0	0	0	0
Bored with food/ temporary hearing and/or vision loss	18	100	0	0	0	0
Faint/ unconscious	18	100	0	0	0	0

4.6 Health risk assessment via inhalation exposure to PAHs adsorbed on $PM_{2.5}$

Health risk assessment followed the four steps was based on the methods of U.S. EPA. PAHs are constituents of complex mixtures that should be assessed the individual species of them but the data of dose-response assessment was limited. Thus, the cancer potency of each PAHs was assessed on the basis of its benzo(a)pyrene equivalent concentration (BaP_{eq}). Calculation of the BaP_{eq} concentration for a given PAHs compound requires the use of its toxic equivalent factor (TEF), which represents the relative cancer potency of the given PAH compound. Then, Total-BaP_{eq} (t-BaP_{eq} or TEQ) was calculated by summing up of BaP_{eq} (equation 3.7-3.8). Total-BaP_{eq} or TEQ was used for calculation as contaminant concentration in air (CA) for exposure assessment.

4.6.1 General information used for risk calculation

According to the additional data collected by Tanasorn Tunsaringkarn, researcher at College of Public Health Science, Chulalongkorn University, she also shared the information gathered from her questionnaires specialized in particular elderly people living in the same five residential areas. The information was summarized in Table 4.20 that presented the information of age (year), body weight (kg), and exposure duration (year).

Table 4.20 The descriptive information of age (year), body weight (kg), and exposure duration (year) from the questionnaire

Criteria	Unit	N	Min	Max	Mean
Age	Year	434	60.0	97.0	69.3
Body weight	Kg	434	33.7	105.3	61.0
Exposure duration	Year	434	0.3	90.0	42.1

4.6.2 Health risk assessment based on general scenario

According to chronic daily intake (CDI) of t-BaP$_{eq2.5}$ calculated from general equation for residents due to inhalation exposure to PAHs adsorbed on PM$_{2.5}$ at five communities by using the data of Inhalation rate (IR) Exposure frequency (EF), Averaging time (AT), particularly, Exposure duration (ED), and Body Weight (BW) which derived from the questionnaires, the results were demonstrated in Table 4.21. Moreover, the minimum, maximum, and average of t-BaP$_{eq2.5}$ in 95% confidence interval were considered as representative of all t-BaP$_{eq2.5}$ levels for calculation CDI, cancer risk, and 95% confidence interval. The exposure of t-BaP$_{eq2.5}$ ranged from 3.96x10^{-11} – 3.50x10^{-7} mg/kg BW-day.

In addition, the minimum, maximum, and average of lifetime cancer risk with 95% CI, and % unacceptable risk were summarized in Table 4.22. The cancer risk in case of the residents were exposed to high t-BaP$_{eq2.5}$ levels (considered from the maximum of t-BaP$_{eq2.5}$), average t-BaP$_{eq2.5}$ levels (considered from the average of t-BaP$_{eq2.5}$), and low t-BaP$_{eq2.5}$ levels (considered from the minimum of t-BaP$_{eq2.5}$) ranged from 5.86x10^{-6} – 13.65x10^{-6}, 1.35x10^{-6} – 2.96x10^{-6}, and 0.002x10^{-6} – 0.02x10^{-6}, respectively. The average cancer risk were found the highest at CCC (2.96x10^{-6}), followed by those at SLH, PBK, SPC, and LWP, respectively. As the results, all of average and maximum cancer risk exceeded the acceptable level (1x10^{-6}) meaning that 1 of million people have a possibility to be at cancer risk. In addition, 95% confidence interval ranged from 1.14x10^{-6} – 2.71x10^{-6} result in all of five communities provided 100% of unacceptable risk. According to the results given in Figure 4.28 - 4.29, the range of lifetime cancer risk in box plot and 95% CI in error bar graph were over the acceptable risk (1x10^{-6}).

Table 4.21 Chronic daily intake of t-BaP$_{eq2.5}$ for residents based on general scenario

Community	CDI (mg/kg BW-day)		
	Min	Max	Average
SLH	4.27×10^{-10}	1.96×10^{-7}	5.16×10^{-8}
LWP	3.15×10^{-10}	1.50×10^{-7}	3.45×10^{-8}
PBK	3.96×10^{-11}	3.50×10^{-7}	5.10×10^{-8}
SPC	2.48×10^{-10}	2.02×10^{-7}	4.06×10^{-8}
CCC	2.22×10^{-10}	3.03×10^{-7}	7.59×10^{-8}

Table 4.22 The lifetime cancer risk of t-BaP$_{eq2.5}$ for residents based on general scenario

Community	Cancer risk ($\times10^{-6}$)			95% CI ($\times10^{-6}$)		% Unacceptable risk
	Min	Max	Average	Lower	Upper	
SLH	0.02	7.65	2.01	1.99	2.29	100
LWP	0.01	5.86	1.35	1.29	1.61	100
PBK	0.002	13.65	1.99	1.64	2.00	100
SPC	0.01	7.86	1.58	1.83	2.30	100
CCC	0.01	11.83	2.96	2.64	2.99	100

The CDI and cancer risk in this study were compared with some previous studies. The study at Guangzhou and Hong Kong of Wang et al. (2013) which study the risk assessment of non-dietary exposure to PAHs via house PM$_{2.5}$ found that the median lung cancer risk was determined to be 1.57×10^{-4} and 2.19×10^{-5} in Guangzhou and Hong Kong, respectively. These cancer risk results were higher than those found in this study and the health based guideline level (1×10^{-5}), indicating there is serious health risk associated with non-dietary exposure to PAHs in home environment. In addition, the study of Wu et al. (2010) about particle-bound PAHs at a traffic Site in Xiamen, China found that the CDI ranged from 0.20×10^{-6} – 1.64×10^{-6} mg/kg BW-day and the excess lifetime cancer risk ranged from 1.46×10^{-6} – 11.98×10^{-6} which similar to the results of this study. Not only for this research that studied health risk assessment of inhalation exposure to PAHs adsorbed on $PM_{2.5}$ at residential areas located in the inner city of Bangkok, but the research of Sawatsing (2013) also studied possible health risk and environmental concentration of carbonyl compounds and BTEX in residential areas of inner city of Bangkok, which the results provided the percent of unacceptable risk more than 75% based on general scenario. Therefore, the local residents living in inner city Bangkok seemed to face a potential risk for cancer development through inhalation of benzene, ethylbenzene, formaldehyde and acetaldehyde as well as PAHs absorbed on $PM_{2.5}$.

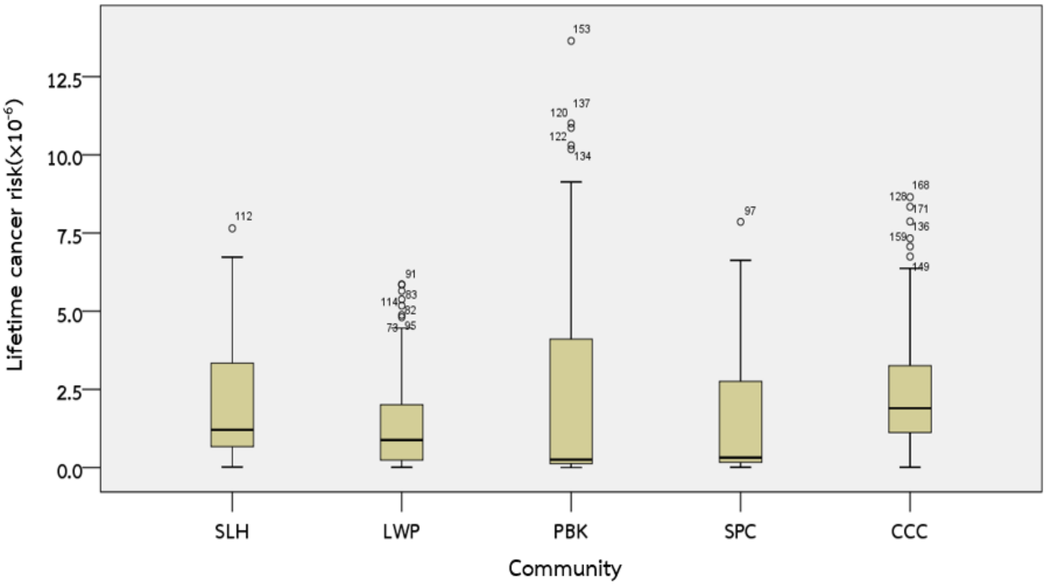


Figure 4.28 Lifetime cancer risk based on general scenario reported in box plot graph

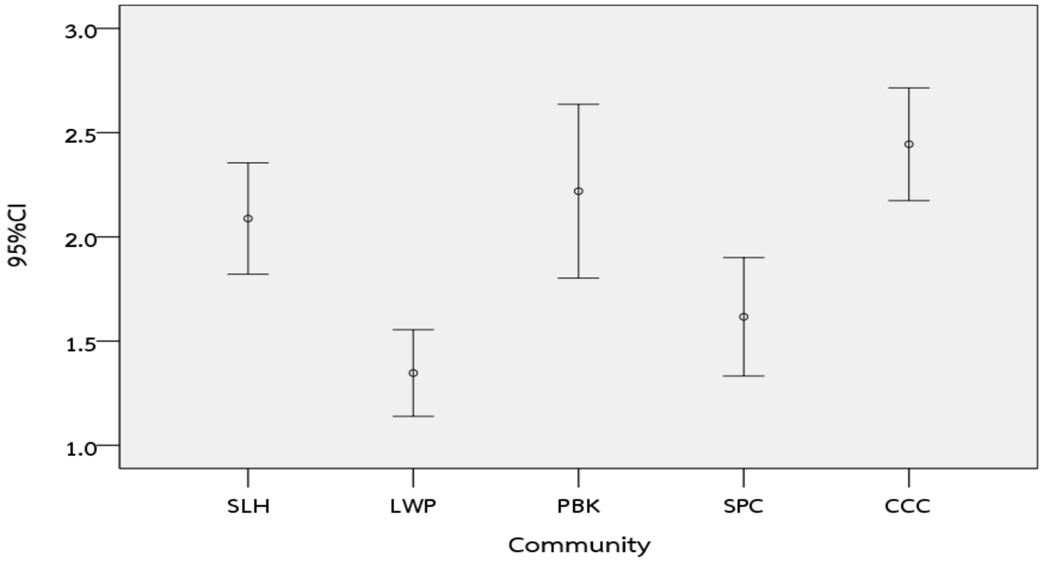


Figure 4.29 95% confidence interval of lifetime cancer risk based on general scenario reported in error bar graph

4.6.3 Health risk assessment based on age interval scenario

In order to estimate the possible health risk of cancer for the residents living in the inner city of Bangkok, the other scenarios were possibly considered. Particularly, exposure to pollutants in the different age provided differently sensitivity of effects to an individual in that age. Since birth or child was more sensitive on their incomplete developed organs, the age-dependent adjustment factor (ADAF) also presented in high levels (10). Whilst, adult or older person which have more mature physical development were related to lower age-dependent adjustment factor (ADAF = 3 or 1). Therefore, health risk assessment based on age interval scenario was performed in this study.

All residents were assumed to live in their residential areas since they were born until their own ages. The concentrations of pollutants used in this scenario were measured from indoor environment during dry and wet season. However, USEPA does not provide the parameter for the calculation of the age after 30 years old. This study considered that after age of 30 years, people also exposed to the hazard chemical. As a results, the cancer risk estimation for the individual overall lifetime should be determined.

Table 4.23 and 4.24 presented the CDI of t-BaP$_{eq2.5}$ and their lifetime cancer risk for residents based on age interval calculated by using age-dependent adjustment factor (ADAF). The CDI of t-BaP$_{eq2.5}$ ranged from 1.45x10^{-8} – 5.29x10^{-7} mg/kg BW-day. In addition, the minimum, maximum, and average of lifetime cancer risk with 95% CI, and % unacceptable risk were summarized. The cancer risk in case of the residents were exposed to high t-BaP$_{eq2.5}$ levels (considered from the maximum of t-BaP$_{eq2.5}$), average t-BaP$_{eq2.5}$ levels (considered from the average of t-BaP$_{eq2.5}$), and low t-BaP$_{eq2.5}$ levels (considered from the minimum of t-BaP$_{eq2.5}$) ranged from 8.89x10^{-6} – 20.62x10^{-6} and 4.21x10^{-6} – 9.37x10^{-6}, and 0.57x10^{-6} – 4.11x10^{-6}, respectively. Moreover, 95% CI ranged from 3.69x10^{-6} – 11.57x10^{-6}. In addition, 95% confidence interval ranged from 1.14x10^{-6} – 2.71x10^{-6} result in all of five communities provided 100% of unacceptable risk. According to the results given in Figure 4.30 and 4.31, the range of lifetime cancer risk in box plot and 95% CI in error bar graph were over the acceptable risk (1x10^{-6}).

Table 4.23 Chronic daily intake of t-BaP$_{eq2.5}$ for residents based on age interval scenario

Community	CDI (mg/kg BW-day)		
	Min	Max	Average
SLH	5.40x10^{-8}	2.59x10^{-7}	1.49x10^{-7}
LWP	1.68x10^{-8}	2.28x10^{-7}	1.08x10^{-7}
PBK	1.71x10^{-8}	5.29x10^{-7}	2.40x10^{-7}
SPC	1.45x10^{-8}	2.54x10^{-7}	1.22x10^{-7}
CCC	1.05x10^{-7}	3.34x10^{-7}	2.18x10^{-7}

Table 4.24 The lifetime cancer risk of t-BaP$_{eq2.5}$ for residents based on age interval scenario

Community	Cancer risk ($\times10^{-6}$)			95% CI ($\times10^{-6}$)		% Unacceptable risk
	Min	Max	Average	Upper	Lower	
SLH	2.11	10.12	5.82	5.42	6.62	100
LWP	0.66	8.89	4.21	3.69	4.73	100
PBK	0.67	20.62	9.37	8.58	11.57	100
SPC	0.57	9.90	4.74	4.27	5.66	100
CCC	4.11	13.02	8.51	7.09	8.40	100

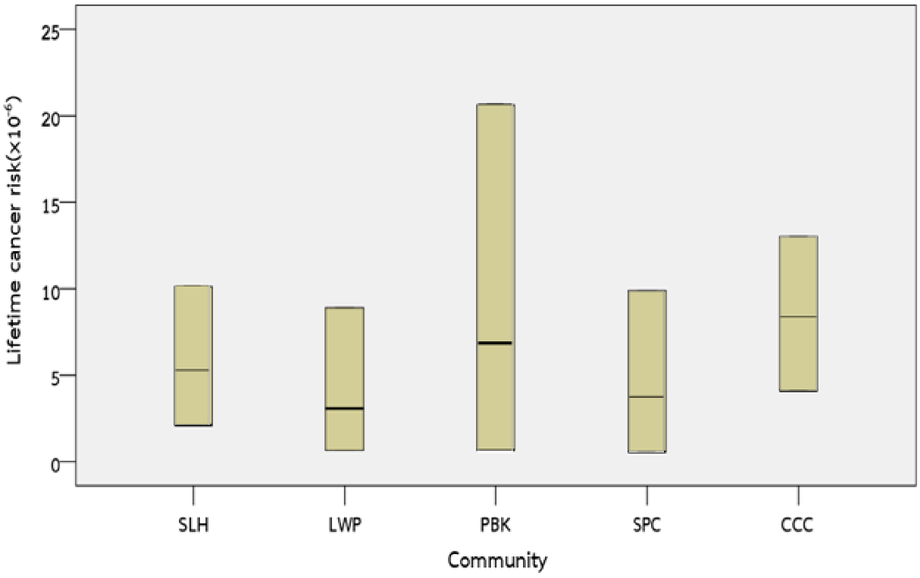


Figure 4.30 Lifetime cancer risk based on age interval scenario reported in box plot graph

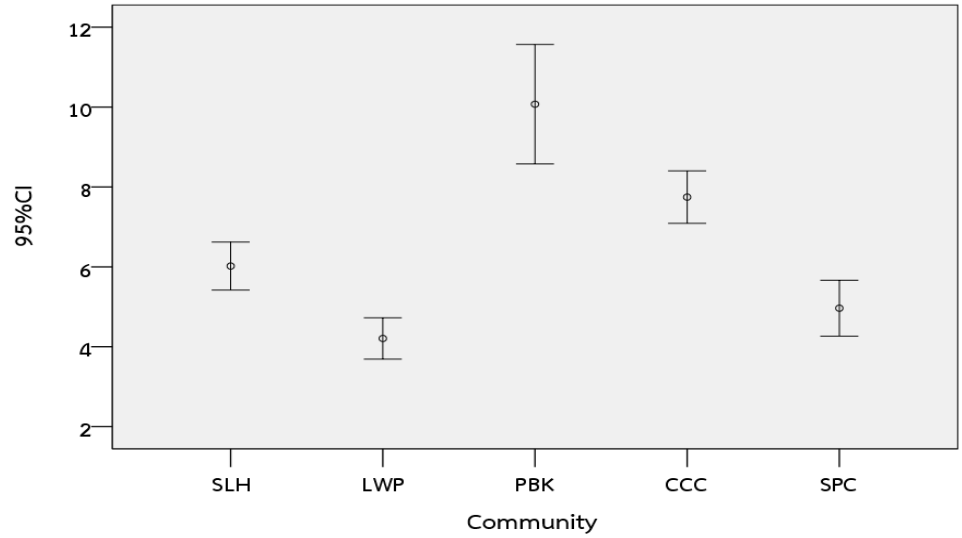


Figure 4.31 95% confidential interval of lifetime cancer risk based on age interval scenario reported in error bar graphs

These results revealed that the residents living in this community were clearly exposed to t-BaP$_{eq2.5}$ at the levels which could cause adverse health effect. Whereas, the cancer risk from exposure to t-BaP$_{eq2.5}$ for the residents of all study areas were in generally unacceptable level.

The previous research of Sawatsing (2013) studied possible health risk and environmental concentration of carbonyl compounds and BTEX in residential areas of inner city of Bangkok. Based on the age interval scenario, the results of this study showed the similar trend of Sawatsing's results with 100% of unacceptable risk for all carcinogenic pollutants. The residents living in the inner city of Bangkok posed to have a potential cancer risk due to inhalation exposure to not only PAHs adsorbed on PM$_{2.5}$ but also benzene, ethylbenzene, formaldehyde, and acetaldehyde.

The health risk assessment of residents evaluated by calculating the exposure duration (ED) found that the residents trend to be at cancer risk. Thus, the ways to reduce the cancer risk from exposure to PAHs should considered the key factors which caused the risk as follows: 1) the hazard from pollutants which is hard to control; 2) the exposure duration which can be considered to reduce the risk based on the cancer risk estimation equation as shown in equation 4.1 and 4.2.

$$\text{Risk} = \text{Hazard} \times \text{Exposure} \qquad \text{(Eq. 4.1)}$$

$$\text{CDI} = \text{CA} \times \text{IR} \times \text{EF} \times \text{ED}/ (\text{BW} \times \text{AT}) \qquad \text{(Eq. 4.2)}$$

From the equation as mentioned above, the key factors that reduce the cancer risk were reduction the exposure duration and avoidance the high concentrations of pollutants. In order to reduce the exposure duration, the residents should be suggested to do the outdoor activities instead of normally stay in the house. Particularly, the older residents who spend most of their times in the house are more likely to be exposed to high concentrations of pollutants than working age. They should be recommended to walking, joking, exercise, or breathing the fresh air outside. Regarding to avoidance the high concentrations of pollutants, using electric incense was suggested to the residents who almost burn incense daily and reducing biomass fuels used for domestic cooking in order to avoid high concentrations of pollutants. Moreover, increasing air ventilation and air circulation and using hood during inside-house cooking could decline the indoor levels which were expected to impact to health risk of the residents.

The classification of cancer risk level in term of the maximum based on general and age interval scenario were presented in Table 4.25 and 4.26 which were divided into three levels including unacceptable (high) level $>10\text{x}10^{-6}$), unacceptable (low) level ($1\text{-}9\text{x}10^{-6}$), and acceptable level ($<1\text{x}10^{-6}$). Most of selected houses had low air ventilation promoting the accumulation of atmospheric air pollutants. The suggestion is that the residents should not use or avoid to use incenses and charcoal and also increase air ventilation inside the house.

Table 4.25 Classification of cancer risk level based on general scenario

Group of level	Community
Unacceptable (high) level ($\geq 20 \times 10^{-6}$)	-
Unacceptable (medium) level ($10\text{-}19 \times 10^{-6}$)	PBK – H1 using charcoal for grilled meat selling and cooking inside the house, H2 using incense, H3 got effects from vehicle passing CCC – H2 using incense, H3 got effect from meat grilled shop nearby
Unacceptable (low) level ($1\text{-}9 \times 10^{-6}$)	SLH – H1 using incense, H2 got effects from construction site and traffic emission from expressway LWP – H1, H2 using incense and H3 got effects from garbage burning nearby SPC –H1 got effects from vehicle passing, H3 using incense
Acceptable level ($<1 \times 10^{-6}$)	-

Table 4.26 Classification of cancer risk level based on age interval scenario

Group of level	Community
Unacceptable (high) level ($\geq 20 \times 10^{-6}$)	PBK – H1 using charcoal for grilled meat selling and cooking inside the house, H2 using incense, H3 got effects from vehicle passing
Unacceptable (medium) level ($10\text{-}19 \times 10^{-6}$)	SLH – H2 got effects from construction site and traffic emission from expressway CCC – H2 using incense and H3 got effect from meat grilled shop nearby
Unacceptable (low) level ($1\text{-}9 \times 10^{-6}$)	LWP – H1, H2 using incense and H3 got effects from garbage burning nearby SPC – H1 got effects from vehicle passing, H3 using incense
Acceptable level ($<1 \times 10^{-6}$)	-

Although, all the cancer risk derived from general and age interval scenario, they also had the uncertainly estimation from the reference values. The variation of exposure levels in the reality which also change by time to time and the individual health profile. In this study, the exposure time (ET) was assumed for 24 hours per day, but some people did not spend their whole time in their house. Therefore, the ET value used could provide over estimation of the cancer risk. However, the cancer risk of residents only obtained from five communities and did not represent for all residents of all communities in Bangkok. The high concentration might come from these additional outdoor sources not only from their own indoor activities. Nevertheless, the residents in these study areas should have warning information of health effects, and recommendation of protecting themselves from inhalation exposure to fine particles and PAHs. They also should concern more health risk and how to protect their health while they are still staying in their house at the same area for a long time. Finally, this study results would be an important baseline data of the residents exposed to $PM_{2.5}$ and PAHs in Bangkok, Thailand.

CHAPTER V
CONCLUSION AND RECOMMENDATIONS

5.1 Conclusions

This research studied on health risk assessment of the residents exposed to PAHs adsorbed on $PM_{2.5}$ via inhalation at the residential areas in the inner city of Bangkok. All samples were collected on Sunday, Tuesday, and Friday for 24 hours in dry season (April to May 2013) and wet season (September to October 2013) at five representative communities. The statistical data analysis of this study were presented in Appendix H. All results could be summarized as follows:

1) The indoor average concentrations of $PM_{2.5}$ and PM_{10} in both dry and wet season at five communities were found the highest at PBK (45.04±23.25 and 60.67±28.20 $\mu g/m^3$, respectively). Whilst, the outdoor concentrations of $PM_{2.5}$ and PM_{10} in both dry and wet season presented the maximum at CCC (41.05±12.15 and 69.47±34.43 $\mu g/m^3$, respectively).

2) The outdoor concentrations of $PM_{2.5}$ at SLH and CCC (44.51±14.32 and 42.60±15.36 $\mu g/m^3$, respectively) in dry season were higher than those in wet season (20.47±3.90 and 39.50±11.21 $\mu g/m^3$, respectively), but the results of those at the other communities found in wet season higher than in dry season. The significant difference of the outdoor $PM_{2.5}$ and PM_{10} concentrations could not be found between dry and wet season at all 5 communities ($p>0.05$) indicated that the concentrations of PM in this study was not depend on seasonal variation.

3) The average indoor $PM_{2.5}/PM_{10}$ ratios provided 0.68±0.09 while, the average outdoor $PM_{2.5}/PM_{10}$ ratios provided 0.63±0.08. According to the results, $PM_{2.5}$ was a dominant fine particles and contributed for 60-70% approximately.

4) The results of I/O ratios of $PM_{2.5}$ and PM_{10} at SPC which lower than 1 indicated that the indoor concentrations of $PM_{2.5}$ and PM_{10} were dominated from the outdoor sources. However, the I/O ratios of $PM_{2.5}$ and PM_{10} at SLH, LWP, PBK, and CCC which

more than 1 in some days indicated that indoor sources make a significant contribution to outdoor air concentrations. The I/O ratios obtained from this study were measured in the inner city which mostly found the dominant sources from the traffic emission outside in case of the specific indoor sources as cooking or incense burning could not be found.

5) On comparing the daily average of $PM_{2.5}$ and PM_{10} concentrations with the daily standard for $PM_{2.5}$ and PM_{10} in ambient air announced by PCD, Thailand (50 $\mu g/m^3$ for $PM_{2.5}$ and 120 $\mu g/m^3$ for PM_{10}), they were not exceeded the standard.

6) The concentrations of $PM_{2.5}$ and t-$PAHs_{2.5}$ from all communities were significantly related at 95% confidence with the r value of 0.660 (*p*-value = 0.000).

7) The indoor average concentrations of t-$PAHs_{2.5}$ at PBK were found the maximum (1.55±1.39 ng/m^3) and greater than those at CCC, SLH, SPC, and LWP, respectively. For outdoors, the average concentrations of t-$PAHs_{2.5}$ at CCC can be found the highest (1.51±0.54 ng/m^3), followed by those at PBK, SLH, SPC, and LWP, respectively.

8) Most of study areas found the outdoor concentrations of t-$PAHs_{2.5}$ in wet season higher than those in dry season, but the significant difference could not be found between dry and wet season obtained from outdoors at all 5 communities ($p>0.05$). These results considerable that seasonal variation was not the key factor affecting to the outdoor concentrations of t-$PAHs_{2.5}$.

9) The average I/O ratios of t-$PAHs_{2.5}$ at LWP and PBK were smaller than 1 indicated that the indoor concentrations of t-$PAHs_{2.5}$ were dominated from the outdoor sources like vehicle emission. Whilst, the average I/O ratios of t-$PAHs_{2.5}$ at SLH, SPC, and CCC were more than 1 meaning indoor sources such as incense burning make a significant contribution to outdoor air concentrations.

10) The predominant species of $PAHs_{2.5}$ at all five communities were B(ghi)P, B(a)P, B(b)F, Ind, and B(k)F.

11) The diagnostic ratio of Ind/(Ind+BghiP) and B(a)P/B(ghi)P from indoors and outdoors indicated that the indoor and outdoor sources of $PAHs_{2.5}$ might be from vehicle emission and fuel combustion.

12) The results of the 24-h average concentrations of BaP which exceed the standard of Ontario MOE (0.0011 ng/m^3) and New Hampshire DES (0.005 ng/m^3), but not over the standard of California EPA (0.18 ng/m^3).

13) The CDI of $t\text{-}BaP_{eq2.5}$ based on general scenario ranged from $3.96 \times 10^{-11} - 3.50 \times 10^{-7}$ mg/kg BW-day. The 95% confidence interval ranged from $1.14 \times 10^{-6} - 2.71 \times 10^{-6}$ result in all of five communities provided 100% of unacceptable risk. Based on age interval scenario, The CDI of $t\text{-}BaP_{eq2.5}$ ranged from $1.45 \times 10^{-8} - 5.29 \times 10^{-7}$ mg/kg BW-day. The 95% confidence interval ranged from $3.69 \times 10^{-6} - 11.57 \times 10^{-6}$ which provided 100% of unacceptable risk at all study areas.

5.2 Recommendations and suggestions

5.2.1 Recommendations for the residents

1) The residents should reduce the high concentrations of pollutants, using electric incense was suggested to the residents who almost burn incense daily and reducing charcoal used for domestic cooking in order to avoid high concentrations of the pollutants.

2) The residents in these study areas should have warning information of health effects, and recommendation of protecting themselves from inhalation exposure to fine particles and PAHs.

3) They also should concern more health risk and how to protect their health while they are still staying in their house at the same area for a long time.

5.2.2 Recommendations for future study

1) Health risk assessment of inhalation exposure to PAHs adsorbed on $PM_{2.5}$ at the different environment in Bangkok should be performed.

2) The meteorological variables, such as daily temperature, daily relative humidity, daily precipitation, wind speed, and wind direction should be measured during the sampling in order to investigate more explicit effect of the seasons on PM and PAHs variation.

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APPENDIX

Appendix A: The experiments

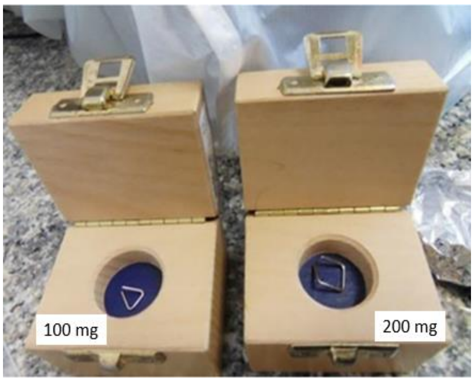


Figure A.1 Standard pendulum 100 and 200 mg

Figure A.2 The ultra-microbalance (Mettler Toledo: METLER UMX 2)

Figure A.3 Personal air pump connected to personal modular impactor (PMI)

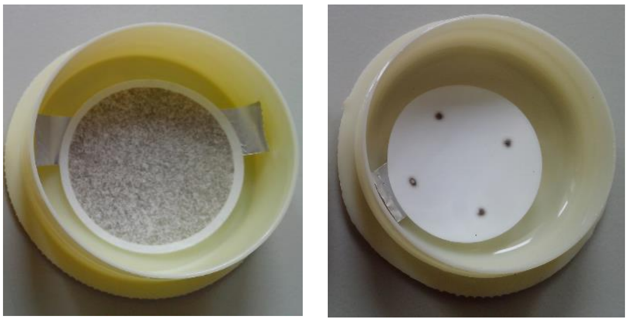


Figure A.4 Filter samples of $PM_{2.5}$ and $PM_{2.5\text{-}10}$

Figure A.5 Ultrasonic Bath

Figure A.6 Heating box, Drythermo, DTU-1B

Figure A.7 High Performance Liquid Chromatography (HPLC)

Fluorescence detector and UV detector

Appendix B: Indoor and outdoor air sampling

B.1 Salak Hin (SLH) community

Figure B.1 Indoor air sampling at H1

Figure B.2 Indoor and outdoor air sampling at H2

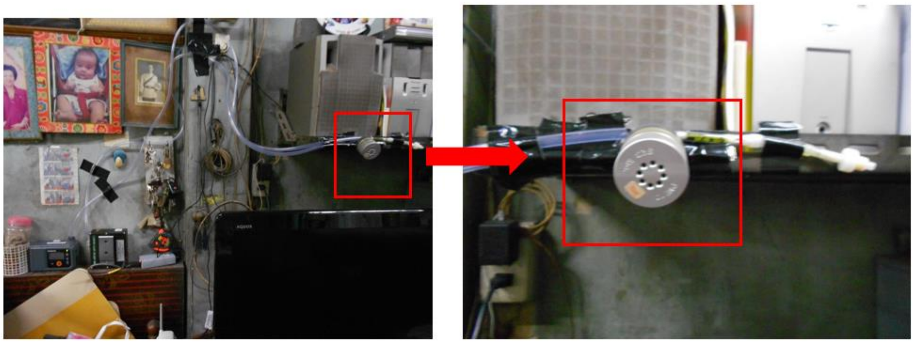


Figure B.3 Indoor air sampling at H3

B.2 Lang Wat Pathumwanaram (LWP) community

Figure B.4 Indoor air sampling at H1

Figure B.5 Indoor and outdoor air sampling at H2

Figure B.6 Indoor air sampling at H3

B.3 Phatthana Bonkai (PBK) community

Figure B.7 Indoor air sampling at H1

Figure B.8 Indoor and outdoor air sampling at H2

Figure B.9 Indoor air sampling at H3

B.4 Soi Pra Chen (SPC) community

Figure B.10 Indoor air sampling at H1

Figure B.11 Indoor and outdoor air sampling at H2

Figure B.12 Indoor air sampling at H3

B.5 Chao Choocheep (CCC) community

Figure B.13 Indoor air sampling at H1

Figure B.14 Indoor and outdoor air sampling at H2

Figure B.15 Indoor air sampling at H3

Appendix C: Standard pendulum 100 and 200 mg

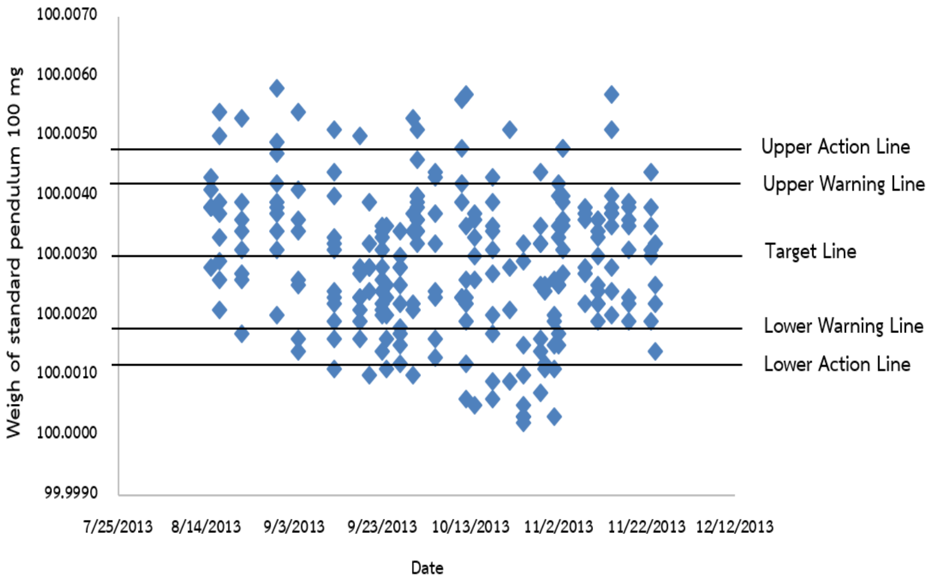


Figure C.1 Control chart of standard pendulum 100 mg in wet season

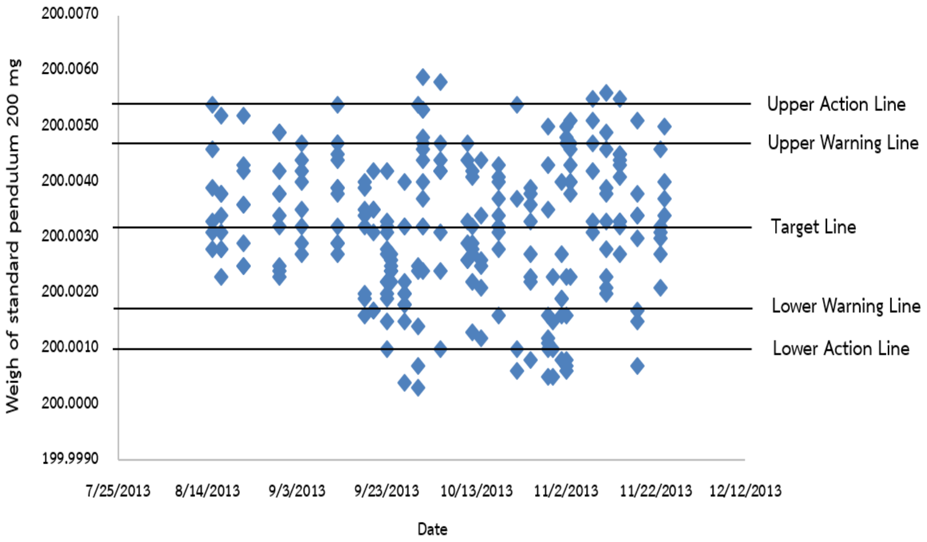


Figure C.2 Control chart of standard pendulum 200 mg in wet season

Table C.1 Standard pendulum 100 mg in dry season

Date	Standard pendulum 100 mg							
4/9/2013	100.0036	100.0039	100.0034	100.0031	100.0026	100.0043	100.0037	100.0027
4/11/2013	100.0021	100.0029	100.0039	100.0034	100.0025	100.0026		
4/15/2013	100.0038	100.0038	100.0043	100.0028	100.0038	100.0041		
4/18/2013	100.0037	100.0042	100.0031	100.0038	100.0034	100.0041	100.0025	100.0024
4/25/2013	100.0036	100.0034	100.0026	100.0023	100.0039	100.0032		
4/29/2013	100.0028	100.0023	100.0021	100.0025	100.0049	100.0023	100.0032	100.0037
4/30/2013	100.0043	100.0023	100.0024	100.0026	100.0033	100.0044		
5/1/2013	100.0032	100.0026	100.0033	100.0052	100.0034	100.0024	100.0035	100.0042
5/3/2013	100.004	100.0025	100.0033	100.0051	100.0048	100.0048	100.0035	100.0036
5/6/2013	100.0007	100.0032	100.0014	100.0044	100.0032	100.0035		
5/10/2013	100.0025	100.0016	100.0034	100.0031	100.0026	100.0033	100.0017	100.0027
5/14/2013	100.002	100.0034	100.0025	100.0016	100.0025	100.0024		
5/17/2013	100.0012	100.0011	100.0015	100.0026				
5/22/2013	100.0023	100.0025	100.0035	100.0047	100.0038	100.0042	100.0022	100.003
6/3/2013	100.0032	100.0037	100.0043	100.0023	100.0024	100.0026	100.0033	100.0044
6/7/2013	100.0023	100.0039	100.0022	100.0019	100.0035	100.0036		
6/13/2013	100.0038	100.0031	100.0046	100.0026	100.0048	100.0035		
6/16/2013	100.0022	100.0026	100.0037	100.0019	100.0032	100.0023	100.0045	100.0026
6/20/2013	100.0033 100.0031	100.0036 100.0027	100.0037	100.003	100.0009	100.0017	100.002	100.0039
6/22/2013	100.0016	100.0035	100.0043	100.0034	100.0016	100.0011	100.0025	100.0023
6/30/2013	100.0025 100.0021	100.0035 100.0009	100.0027	100.0018	100.0032	100.0022	100.0028	100.0031
7/2/2013	100.0033	100.0025	100.0032	100.0015	100.0012	100.0029		
7/5/2013	100.0025	100.0024	100.0042	100.0031	100.0035	100.0026		
7/11/2013	100.0019	100.0011	100.0023	100.002	100.0017	100.0035	100.0015	100.0025
7/13/2013	100.0042	100.004	100.0025	100.0026	100.0035	100.0023		
7/14/2013	100.0015	100.0026	100.0033	100.0036	100.0037	100.0019	100.0021	100.0015
7/18/2013	100.0026 100.0033	100.0029 100.0031	100.0031	100.0023	100.002	100.0042	100.004	100.0025
7/22/2013	100.0048	100.0048	100.0035	100.0036	100.0039	100.0031		
7/23/2013	100.0028 100.003	100.0022 100.0036	100.0027	100.0038	100.0037	100.0036	100.0034	100.0022

Table C.2 Standard pendulum 200 mg in dry season

Date	Standard pendulum 200 mg							
4/9/2013	200.0039	200.0023	200.0033	200.0038	200.0027	200.0018	200.0036	200.0022
4/11/2013	200.0039	200.004	200.0028	200.0019	200.0027	200.0036		
4/15/2013	200.0026	200.0039	200.0023	200.0033	200.0048	200.005		
4/18/2013	200.0023	200.0047	200.0033	200.0054	200.0046	200.0039	200.0028	200.0031
4/25/2013	200.0031	200.0035	200.0017	200.0042	200.0035	200.0017		
4/29/2013	200.0042	200.0047	200.0027	200.0035	200.0044	200.0032	200.0029	200.004
4/30/2013	200.0044	200.0039	200.0045	200.0038	200.0029	200.0047		
5/1/2013	200.0032	200.0054	200.0029	200.0039	200.0047	200.0027	200.0022	200.0042
5/3/2013	200.0047	200.0058	200.0042	200.0044	200.0042	200.0031	200.0021	200.0024
5/6/2013	200.0044	200.0026	200.0047	200.0026	200.0033	200.0029		
5/10/2013	200.0016	200.0018	200.0026	200.0037	200.0048	200.005	200.0023	200.0047
5/14/2013	200.004	200.004	200.0046	200.0043	200.0051	200.0023		
5/17/2013	200.0038	200.0047	200.0018	200.0022				
5/22/2013	200.0018	200.0032	200.0032	200.002	200.0015	200.004	200.002	200.0024
6/3/2013	200.0031	200.0039	200.0036	200.0033	200.0037	200.0038	200.0029	200.0025
6/7/2013	200.0025	200.0019	200.0021	200.0033	200.0023	200.0039		
6/13/2013	200.0038	200.0046	200.002	200.0028	200.0036	200.0022		
6/16/2013	200.0019	200.004	200.0008	200.0019	200.0027	200.0016	200.0042	200.0013
6/20/2013	200.0022 200.0039	200.0028 200.0047	200.0027	200.0041	200.0032	200.0029	200.0025	200.0044
6/22/2013	200.0027	200.0022	200.0042	200.0047	200.0038	200.0032	200.0032	200.0031
6/30/2013	200.0028 200.0035	200.0041 200.001	200.0037	200.0043	200.0034	200.0016	200.004	200.0043
7/2/2013	200.0012	200.0038	200.0027	200.0023	200.0033	200.004		
7/5/2013	200.004	200.0046	200.0043	200.0051	200.0023	200.0038		
7/11/2013	200.0043	200.0035	200.001	200.0012	200.0016	200.005	200.0005	200.0011
7/13/2013	200.0019	200.004	200.0008	200.0019	200.0027	200.0016		
7/14/2013	200.0016	200.0008	200.0006	200.0007	200.0048	200.005	200.0023	200.0047
7/18/2013	200.0049 200.0028	200.0021 200.0046	200.0033	200.0023	200.0039	200.0038	200.0056	200.002
7/22/2013	200.0047	200.0031	200.0025	200.0051	200.0033	200.0042		
7/23/2013	200.0043 200.0058	200.0045 200.0044	200.0033	200.0033	200.0027	200.0032	200.0045	200.0041
7/25/2013	200.0038 200.0007	200.0032 200.0034	200.0041	200.0055	200.0044	200.0031	200.0015	200.0017
7/27/2013	200.004	200.002	200.0024	200.0031	200.0039	200.0044		
7/29/2013	200.003	200.0021	200.0032	200.0027	200.0031	200.0046		
7/31/2013	200.0042	200.0047	200.0027	200.0035	200.0044	200.0032		

Table C.3 Standard pendulum 100 mg in wet season

Date	Standard pendulum 100 mg							
8/15/2013	100.0038	100.0038	100.0043	100.0028	100.0038	100.0041		
8/17/2013	100.0021	100.0029	100.0039	100.0054	100.0050	100.0026	100.0037	100.0033
8/22/2013	100.0036	100.0039	100.0034	100.0031	100.0026	100.0053	100.0017	100.0027
8/30/2013	100.002 100.0031	100.0034 100.0038	100.0039	100.0049	100.0042	100.0058	100.0037	100.0047
9/4/2013	100.0054	100.0041	100.0025	100.0014	100.0016	100.0036	100.0034	100.0026
9/12/2013	100.0023 100.0024	100.0019 100.0011	100.0032 100.0033	100.0022 100.0031	100.0051	100.004	100.0016	100.0044
9/18/2013	100.0016	100.0027	100.0028	100.0023	100.0021	100.005	100.0019	100.0023
9/20/2013	100.0028 100.001	100.0028 100.0032	100.0039	100.0024				
9/23/2013	100.0026 100.0031	100.0033 100.0021	100.0022 100.0014	100.0034 100.002	100.0024	100.0035	100.0028	100.0024
9/24/2013	100.0035	100.002	100.0016	100.0011	100.0025	100.0023		
9/27/2013	100.0025 100.0028	100.0015 100.0034	100.0017	100.0018	100.0012	100.0022	100.003	100.0028
9/30/2013	100.0021	100.0037	100.0034	100.0053	100.001	100.0022		
10/1/2013	100.004 100.0038	100.004 100.0051	100.0034 100.0046	100.0034 100.0036	100.0036	100.0032	100.0034	100.0039
10/5/2013	100.0032	100.0037	100.0043	100.0023	100.0024	100.0016	100.0013	100.0044
10/11/2013	100.0042	100.0039	100.0023	100.0023	100.0056	100.0048		
10/12/2013	100.0006	100.0035	100.0022	100.0026	100.0057	100.0019	100.0012	100.0023
10/14/2013	100.0005	100.0026	100.0033	100.0036	100.0037	100.003		
10/18/2013	100.0009 100.0043	100.0017 100.0034	100.0039	100.0027	100.0031	100.002	100.0006	100.0035
10/22/2013	100.0028	100.0051	100.0021	100.0009				
10/25/2013	100.0003	100.0005	100.0032	100.0015	100.0002	100.0029	100.000	100.001
10/29/2013	100.0007	100.0032	100.0014	100.0044	100.0032	100.0035	100.0025	100.0016
10/30/2013	100.0025	100.0024	100.0012	100.0011				
11/1/2013	100.0015	100.0026	100.0019	100.0011	100.0003	100.002		
11/2/2013	100.0017	100.0035	100.0015	100.0025	100.0042	100.004	100.0025	100.0033
11/3/2013	100.0031	100.0048	100.0048	100.0035	100.0036	100.0039	100.0027	100.004
11/8/2013	100.0028	100.0022	100.0027	100.0038	100.0037	100.0036		
11/11/2013	100.0034 100.0033	100.0022 100.0025	100.003	100.0036	100.0019	100.0036	100.0024	100.0022
11/14/2013	100.0028 100.002	100.0035 100.0051	100.004	100.0038	100.0037	100.0057	100.0037	100.0024
11/18/2013	100.0023	100.0039	100.0022	100.0019	100.0035	100.0036	100.0038	100.0031
11/23/2013	100.0019	100.0031	100.0044	100.003	100.0035	100.0038		
11/24/2013	100.0014	100.0022	100.0025	100.0032				

Table C.4 Standard pendulum 200 mg in wet season

Date	Standard pendulum 200 mg							
8/15/2013	200.0033	200.0054	200.0046	200.0039	200.0028	200.0031		
8/17/2013	200.0028	200.0038	200.0028	200.0038	200.0023	200.0031	200.0052	200.0034
8/22/2013	200.0043	200.0052	200.0029	200.0036	200.0042	200.0036	200.0025	200.0025
8/30/2013	200.0049 200.0042	200.0034 200.0038	200.0023	200.0049	200.0032	200.0024	200.0025	200.0038
9/4/2013	200.0042	200.0047	200.0027	200.0035	200.0044	200.0032	200.0029	200.004
9/12/2013	200.0044 200.0029	200.0039 200.0039	200.0045 200.0047	200.0038 200.0027	200.0029	200.0047	200.0032	200.0054
9/18/2013	200.0035	200.0032	200.0016	200.004	200.002	200.0034	200.0019	200.0039
9/20/2013	200.0031	200.0035	200.0017	200.0042	200.0035	200.0017		
9/23/2013	200.0022 200.0028	200.0042 200.0019	200.0033 200.001	200.0027 200.002	200.0032	200.0022	200.0015	200.0031
9/24/2013	200.0022	200.0025	200.0024	200.0024	200.0027	200.0026		
9/27/2013	200.0018 200.002	200.0022 200.0004	200.0018	200.0032	200.0032	200.002	200.0015	200.004
9/30/2013	200.0003	200.0024	200.0007	200.0025	200.0014	200.0054		
10/1/2013	200.0037 200.0053	200.0048 200.0059	200.0024 200.0046	200.004 200.0053	200.0032	200.0047	200.0032	200.0044
10/5/2013	200.0047	200.0058	200.0042	200.0044	200.0042	200.0031	200.001	200.0024
10/11/2013	200.0044	200.0026	200.0047	200.0026	200.0033	200.0029		
10/12/2013	200.0042	200.0013	200.0022	200.0028	200.0027	200.0041	200.0032	200.0029
10/14/2013	200.0025	200.0044	200.0026	200.0012	200.0021	200.0034		
10/18/2013	200.0032 200.0016	200.0032 200.004	200.0031	200.0028	200.0041	200.0037	200.0043	200.0034
10/22/2013	200.001	200.0006	200.0037	200.0054				
10/25/2013	200.0039	200.0023	200.0033	200.0038	200.0027	200.0008	200.0036	200.0022
10/29/2013	200.0043	200.0035	200.001	200.0012	200.0016	200.005	200.0005	200.0011
10/30/2013	200.0015	200.0005	200.001	200.0023				
11/1/2013	200.0019	200.004	200.0008	200.0019	200.0027	200.0016		
11/2/2013	200.0016	200.0008	200.0006	200.0007	200.0048	200.005	200.0023	200.0047
11/3/2013	200.004	200.004	200.0046	200.0043	200.0051	200.0023	200.0038	200.0047
11/8/2013	200.0047	200.0031	200.0055	200.0051	200.0033	200.0042		
11/11/2013	200.0049 200.0028	200.0021 200.0046	200.0033	200.0023	200.0039	200.0038	200.0056	200.002
11/14/2013	200.0043 200.0055	200.0045 200.0044	200.0033	200.0033	200.0027	200.0032	200.0045	200.0041

Appendix D: Standard curve of 16 PAHs mixed standard

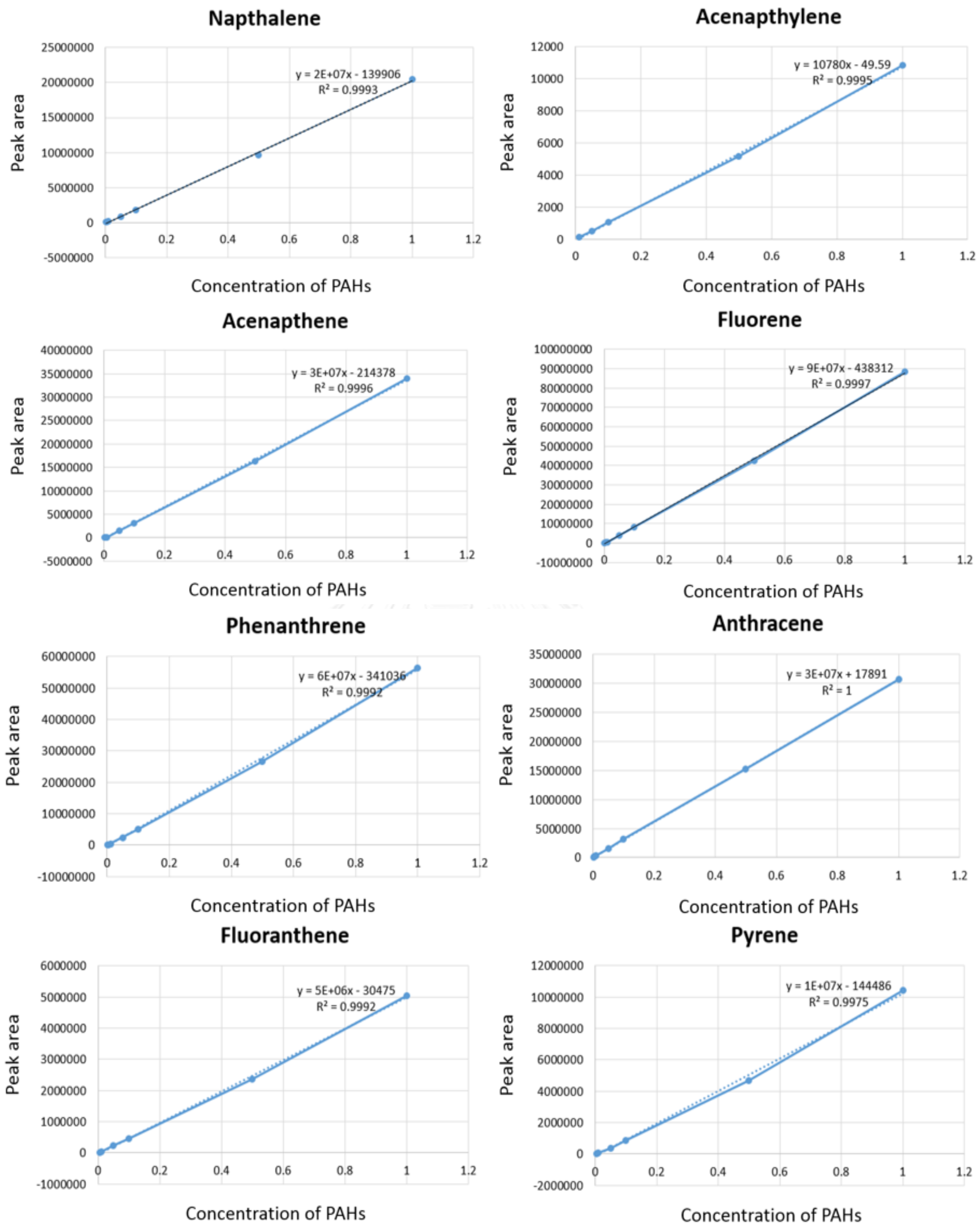


Figure D.1 Standard curve of 16 PAHs mixed standard analyzed by HPLC

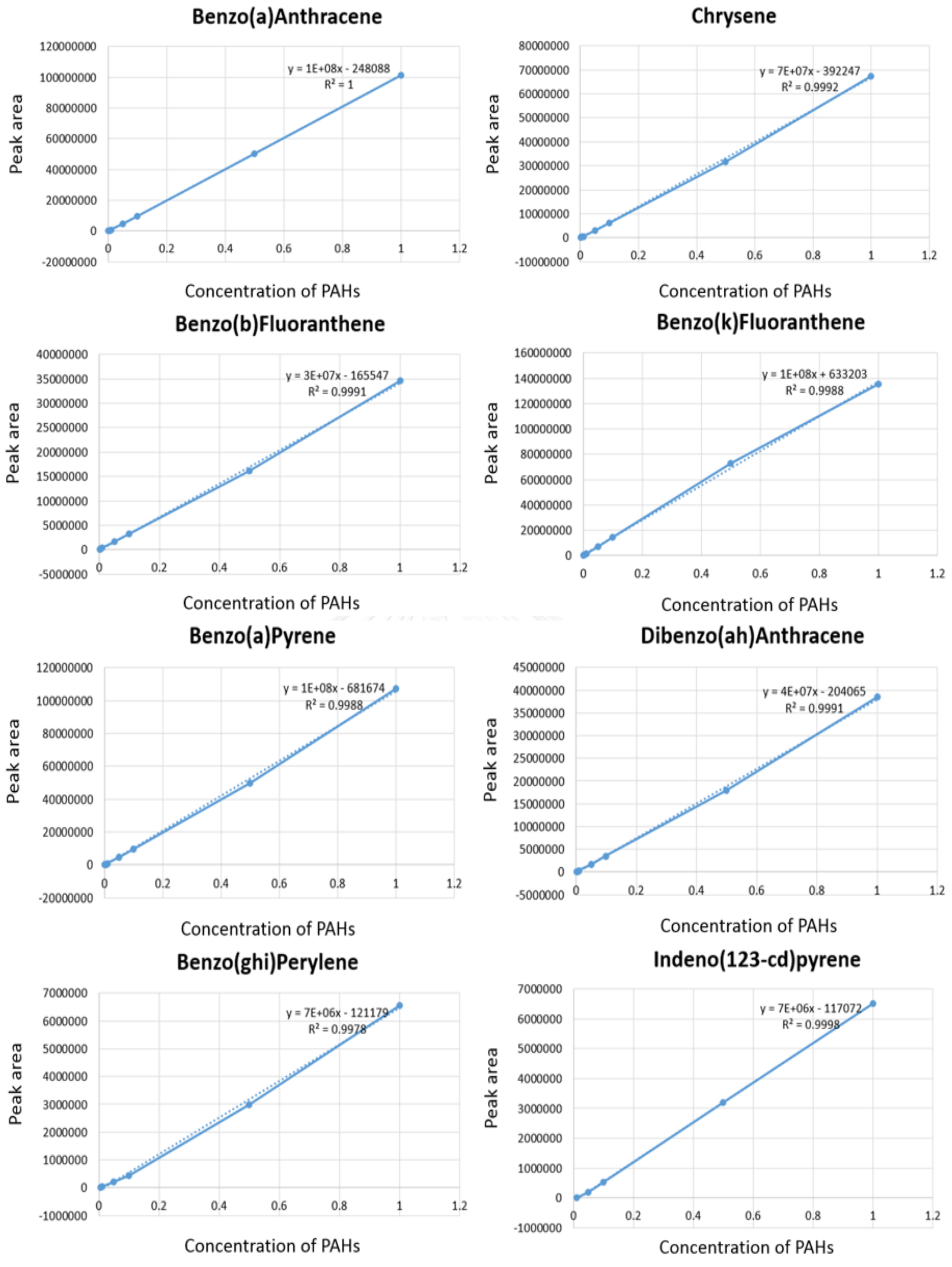


Figure D.2 Standard curve of 16 PAHs mixed standard analyzed by HPLC (continue)

Appendix E: The concentrations of $PM_{2.5}$, $PM_{2.5-10}$, and PM_{10}

Table E.1 The concentrations of $PM_{2.5}$ in dry and wet season at five communities

Community	Season	Day	$PM_{2.5}$ ($\mu g/m^3$)			
			H1	H2	H3	Out
SLH	Dry	Sun	51.22	51.40	40.11	52.84
		Tue	38.14	66.22	31.91	52.72
		Fri	25.66	28.10	22.36	27.97
	Wet	Sun	26.21	18.26	26.21	16.42
		Tue	36.14	20.96	24.99	20.77
		Fri	37.50	21.83	26.72	24.21
LWP	Dry	Sun	25.26	19.16	51.74	23.54
		Tue	16.31	16.97	21.96	11.44
		Fri	26.19	22.90	28.54	23.28
	Wet	Sun	24.00	19.96	29.84	22.07
		Tue	-	27.12	22.69	27.90
		Fri	24.71	30.47	27.57	32.23
PBK	Dry	Sun	66.51	25.97	33.23	27.52
		Tue	59.02	21.37	23.44	18.68
		Fri	38.18	15.42	21.05	16.99
	Wet	Sun	76.59	32.24	30.50	29.49
		Tue	51.75	35.91	40.31	36.45
		Fri	80.66	65.75	92.85	68.60
SPC	Dry	Sun	11.31	7.52	22.64	9.44
		Tue	13.49	15.92	19.35	20.73
		Fri	13.88	14.98	28.45	20.82
	Wet	Sun	40.35	40.79	37.77	44.77
		Tue	52.82	43.51	42.85	49.27
		Fri	19.86	20.05	27.47	22.83
CCC	Dry	Sun	31.53	25.83	37.57	24.87
		Tue	29.90	46.52	43.87	51.05
		Fri	27.65	41.49	-	51.89
	Wet	Sun	24.92	29.18	35.07	26.73
		Tue	42.54	43.80	44.65	44.05
		Fri	44.41	46.35	46.63	47.73

Note: - mean equipment error

Table E.2 The concentrations of $PM_{2.5-10}$ in dry and wet season at five communities

Community	Season	Day	$PM_{2.5-10}$ (μg/m^3)			
			H1	H2	H3	Out
SLH	Dry	Sun	18.32	38.05	15.68	31.64
		Tue	16.92	30.54	12.19	52.77
		Fri	10.36	24.05	7.57	24.75
	Wet	Sun	12.00	6.94	5.03	9.45
		Tue	9.99	8.08	8.38	9.48
		Fri	13.41	5.89	11.69	12.12
LWP	Dry	Sun	7.33	16.80	8.09	10.61
		Tue	14.96	13.58	18.61	12.48
		Fri	20.61	16.04	39.93	19.14
	Wet	Sun	13.85	10.18	11.01	8.90
		Tue	-	12.56	10.70	14.13
		Fri	15.64	11.26	10.32	13.67
PBK	Dry	Sun	12.01	8.70	14.05	10.54
		Tue	22.25	10.54	17.61	15.95
		Fri	24.97	7.48	10.95	10.70
	Wet	Sun	13.34	8.91	11.09	12.08
		Tue	14.42	13.55	13.61	12.20
		Fri	22.12	24.76	30.97	33.37
SPC	Dry	Sun	7.98	6.12	9.93	7.88
		Tue	9.77	13.67	18.70	17.33
		Fri	12.33	11.00	11.35	13.70
	Wet	Sun	16.37	16.30	18.47	27.82
		Tue	16.07	14.90	19.06	21.20
		Fri	13.81	9.85	6.66	14.65
CCC	Dry	Sun	19.33	18.01	10.09	12.94
		Tue	23.51	17.35	13.91	16.59
		Fri	22.23	16.05	-	82.49
	Wet	Sun	24.57	18.05	19.47	17.92
		Tue	19.06	24.40	17.56	28.13
		Fri	22.69	13.36	11.68	12.44

Note: - mean equipment error

Table E.3 The concentrations of PM_{10} in dry and wet season at five communities

Community	Season	Day	PM_{10} (μg/m^3)			
			H1	H2	H3	Out
SLH	Dry	Sun	69.54	89.45	55.79	84.48
		Tue	55.06	96.75	44.10	105.49
		Fri	36.01	52.14	29.93	52.72
	Wet	Sun	38.21	25.19	31.24	25.87
		Tue	46.13	29.04	33.36	30.25
		Fri	50.91	27.72	38.40	36.32
LWP	Dry	Sun	32.59	35.97	59.83	34.15
		Tue	31.27	30.54	40.57	23.92
		Fri	46.80	38.94	68.46	42.42
	Wet	Sun	37.84	30.14	40.85	30.97
		Tue	-	39.68	33.39	42.03
		Fri	40.36	41.73	37.89	45.90
PBK	Dry	Sun	78.52	34.67	47.28	38.06
		Tue	81.28	31.91	41.05	34.64
		Fri	63.14	22.90	32.00	27.69
	Wet	Sun	89.93	41.15	41.59	41.56
		Tue	66.17	49.46	53.92	48.65
		Fri	102.78	90.51	123.82	101.97
SPC	Dry	Sun	19.29	13.64	32.57	17.32
		Tue	23.26	29.59	38.06	38.06
		Fri	26.20	25.98	39.79	34.53
	Wet	Sun	56.72	57.10	56.24	72.59
		Tue	68.89	58.41	61.91	70.47
		Fri	33.67	29.90	34.14	37.48
CCC	Dry	Sun	50.86	43.84	47.66	37.81
		Tue	53.40	63.87	57.77	67.64
		Fri	49.89	57.54	-	134.37
	Wet	Sun	49.49	47.23	54.54	44.65
		Tue	61.59	68.20	62.21	72.18
		Fri	67.11	59.71	58.31	60.17

Note: - mean equipment error

Appendix F: The concentrations of t-PAHs$_{2.5}$ and t-PAHs$_{2.5\text{-}10}$

Table F.1 The concentrations of t-PAHs$_{2.5}$ in dry and wet season at five communities

Community	Season	Day	t-PAHs$_{2.5}$ (ng/m^3)			
			H1	H2	H3	Out
SLH	Dry	Sun	1.4078	0.70548	0.426494	0.60204
		Tue	1.8967	1.316574	0.820071	0.943635
		Fri	0.24818	0.743531	0.398302	0.553368
	Wet	Sun	0.501923	0.648749	0.622593	0.874018
		Tue	0.968478	1.672898	0.871592	0.906805
		Fri	1.064394	1.069951	1.39963	1.20197
LWP	Dry	Sun	0.265005	0.254684	1.483761	0.142571
		Tue	0.078175	0.036823	0.075023	0.122653
		Fri	0.296384	0.296503	0.175386	0.461909
	Wet	Sun	1.021249	0.737337	0.857776	0.855789
		Tue	-	1.250306	0.560797	1.211764
		Fri	1.356073	0.971787	0.799531	0.772567
PBK	Dry	Sun	2.566115	0.679189	0.419709	0.423395
		Tue	1.655679	0.327076	0.755497	0.532336
		Fri	0.556073	0.124765	0.083705	0.42997
	Wet	Sun	2.849297	0.7377	0.826986	0.585132
		Tue	2.261655	1.025147	1.301881	1.181452
		Fri	3.877743	3.020183	4.966258	4.224599
SPC	Dry	Sun	0.134825	0.127836	0.062001	0.090728
		Tue	0.338189	0.291228	0.432668	0.271254
		Fri	0.546821	0.334667	0.392616	0.545158
	Wet	Sun	2.351671	0.903186	1.321821	0.96659
		Tue	1.190403	3.295989	1.468461	0.957598
		Fri	1.262886	0.977506	1.146404	0.911164
CCC	Dry	Sun	1.354137	1.572253	1.800657	1.109106
		Tue	1.262039	2.194065	2.079735	1.590489
		Fri	0.737863	1.59063	-	2.095055
	Wet	Sun	0.863589	1.808331	2.611793	1.979983
		Tue	1.743415	1.713236	2.163739	1.625214
		Fri	1.648561	1.032306	0.968383	0.660876

Note: - mean equipment error

Table F.2 The concentrations of t-PAHs$_{2.5\text{-}10}$ in dry and wet season at five communities

Community	Season	Day	t-PAHs$_{2.5\text{-}10}$ (ng/m^3)			
			H1	H2	H3	Out
SLH	Dry	Sun	0.044119	ND	0.047206	ND
		Tue	ND	0.02087	0.025658	0.071778
		Fri	0.015788	0.012306	0.053166	0.013707
	Wet	Sun	ND	ND	ND	0.058348
		Tue	0.0753	0.029335	0.013807	ND
		Fri	0.028571	ND	0.066674	ND
LWP	Dry	Sun	0.042913	0.022684	ND	ND
		Tue	ND	ND	ND	ND
		Fri	0.119156	0.038632	0.11207	0.075531
	Wet	Sun	ND	ND	0.038889	ND
		Tue	0.075569	0.034687	0.091611	ND
		Fri	0.045992	ND	ND	ND
PBK	Dry	Sun	0.013638	ND	ND	0.015691
		Tue	0.023841	0.019325	ND	0.070802
		Fri	0.047483	0.028395	ND	0.034303
	Wet	Sun	0.234872	0.08559	0.05768	0.037239
		Tue	0.092172	ND	0.034346	0.016578
		Fri	0.04731	0.023787	0.170697	0.088707
SPC	Dry	Sun	0.032551	ND	ND	ND
		Tue	ND	ND	ND	ND
		Fri	ND	ND	ND	0.051068
	Wet	Sun	0.032077	0.083647	0.057859	0.071807
		Tue	0.028033	0.095677	0.031277	0.09457
		Fri	0.077558	ND	0.090438	ND
CCC	Dry	Sun	ND	0.053462	0.058758	0.07948
		Tue	0.194824	0.026379	ND	0.064119
		Fri	0.034352	0.074813	0.090543	0.242639
	Wet	Sun	ND	0.08129	ND	0.262015
		Tue	0.313004	0.268987	0.035806	0.388296
		Fri	ND	ND	ND	0.013228

Note: ND mean non-detectable level

Appendix G: Questionnaire

Questionnaire for the residents (English version)

Questionnaires for occupants

Date................/................../....................

Address..Community.....................................

Surrounding of home...

Gender ☐ Male ☐ Female

Age...................................years

Body weight.........................kg

Home age..................................years

Recent year of renovation...

Living time................................years

Expected time to live in this home.........................years

Living duration in home..hours/day

Time to leave home...

Time to go home..

Normal daily activities (work day) ....

Normal daily activities (weekend) ....

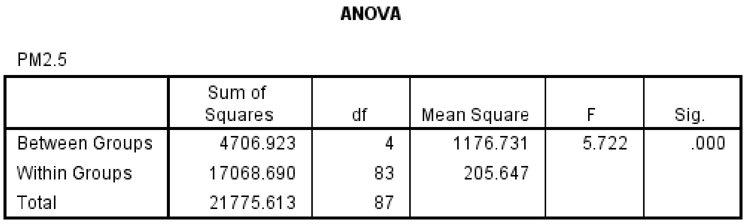
Cigarette smoking	☐ Yes	☐ No
Incense burning	☐ Yes	☐ No
Annual health check	☐ Yes	☐ No

Last health check ☐ Less than 3 months ☐ 3 months – 6 months
☐ 6 months – 1 year ☐ More than 1 year

Headache/ drowsiness	☐ Never	☐ Rarely	☐ Frequently
Irritations of eyes/ nose/ throat/ skin	☐ Never	☐ Rarely	☐ Frequently
Tired/ fatigued	☐ Never	☐ Rarely	☐ Frequently
Chest pain/ suffocation	☐ Never	☐ Rarely	☐ Frequently
Temporary hearing/ vision loss	☐ Never	☐ Rarely	☐ Frequently
Faint/ unconscious	☐ Never	☐ Rarely	☐ Frequently

Appendix H: Statistical analysis

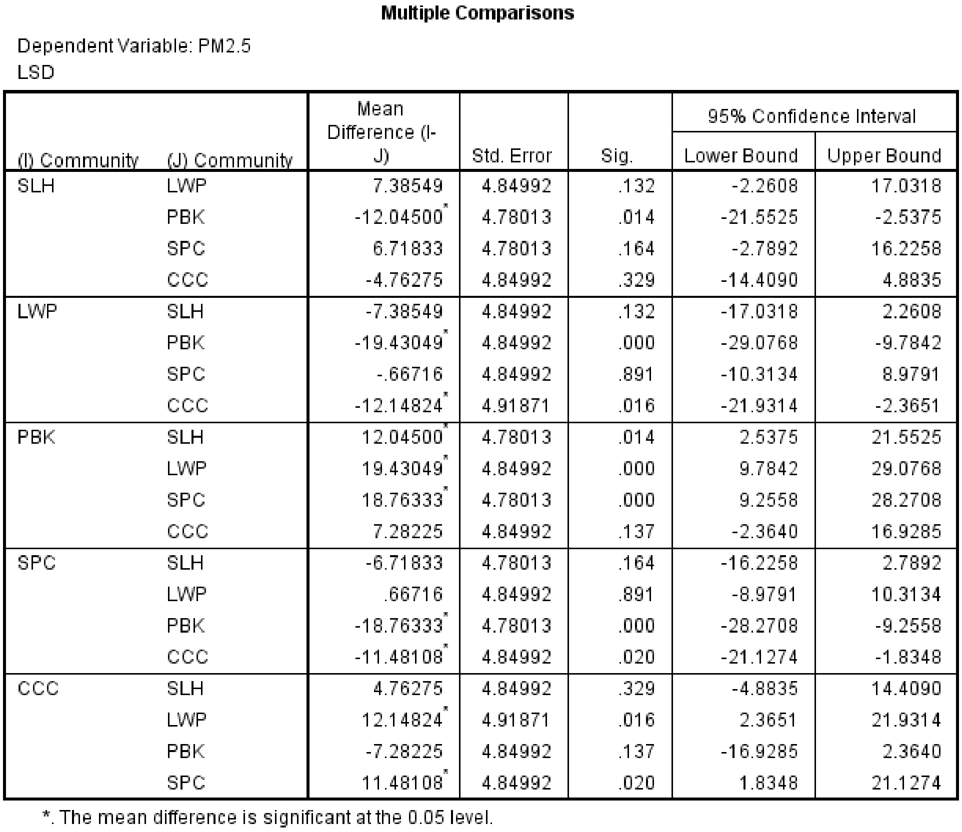
Table H.1 Statistical analysis using Oneway ANOVA of indoor concentrations of $PM_{2.5}$ among five communities



ANOVA

PM2.5

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	4706.923	4	1176.731	5.722	.000
Within Groups	17068.690	83	205.647		
Total	21775.613	87			



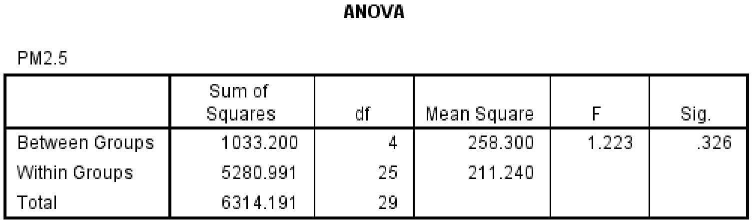
Multiple Comparisons

Dependent Variable: PM2.5
LSD

(I) Community	(J) Community	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
SLH	LWP	7.38549	4.84992	.132	-2.2608	17.0318
	PBK	-12.04500*	4.78013	.014	-21.5525	-2.5375
	SPC	6.71833	4.78013	.164	-2.7892	16.2258
	CCC	-4.76275	4.84992	.329	-14.4090	4.8835
LWP	SLH	-7.38549	4.84992	.132	-17.0318	2.2608
	PBK	-19.43049*	4.84992	.000	-29.0768	-9.7842
	SPC	-.66716	4.84992	.891	-10.3134	8.9791
	CCC	-12.14824*	4.91871	.016	-21.9314	-2.3651
PBK	SLH	12.04500*	4.78013	.014	2.5375	21.5525
	LWP	19.43049*	4.84992	.000	9.7842	29.0768
	SPC	18.76333*	4.78013	.000	9.2558	28.2708
	CCC	7.28225	4.84992	.137	-2.3640	16.9285
SPC	SLH	-6.71833	4.78013	.164	-16.2258	2.7892
	LWP	.66716	4.84992	.891	-8.9791	10.3134
	PBK	-18.76333*	4.78013	.000	-28.2708	-9.2558
	CCC	-11.48108*	4.84992	.020	-21.1274	-1.8348
CCC	SLH	4.76275	4.84992	.329	-4.8835	14.4090
	LWP	12.14824*	4.91871	.016	2.3651	21.9314
	PBK	-7.28225	4.84992	.137	-16.9285	2.3640
	SPC	11.48108*	4.84992	.020	1.8348	21.1274

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

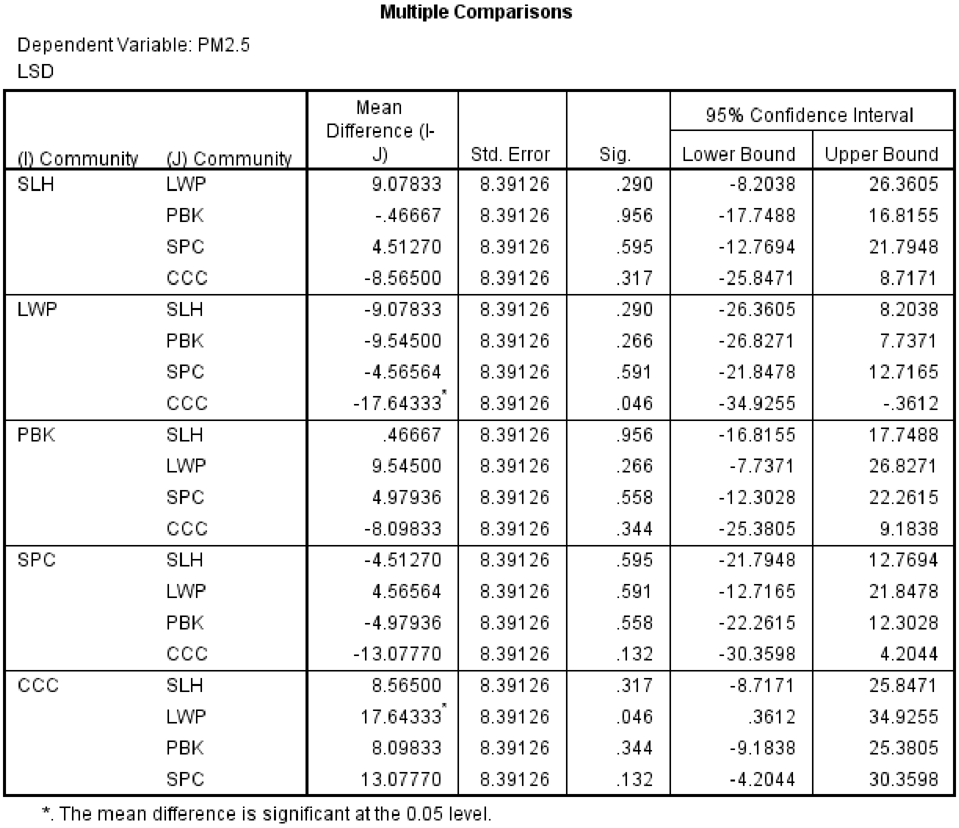
Table H.2 Statistical analysis using Oneway ANOVA of outdoor concentrations of $PM_{2.5}$ among five communities



ANOVA

PM2.5

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	1033.200	4	258.300	1.223	.326
Within Groups	5280.991	25	211.240		
Total	6314.191	29			



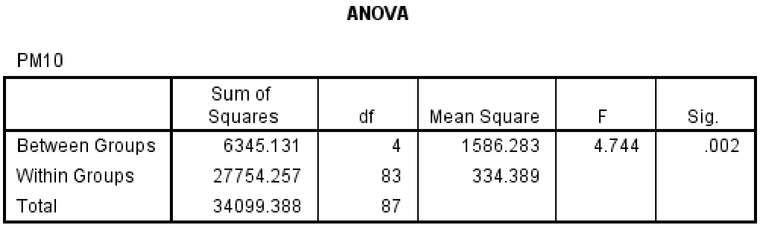
Multiple Comparisons

Dependent Variable: PM2.5
LSD

(I) Community	(J) Community	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
SLH	LWP	9.07833	8.39126	.290	-8.2038	26.3605
	PBK	-.46667	8.39126	.956	-17.7488	16.8155
	SPC	4.51270	8.39126	.595	-12.7694	21.7948
	CCC	-8.56500	8.39126	.317	-25.8471	8.7171
LWP	SLH	-9.07833	8.39126	.290	-26.3605	8.2038
	PBK	-9.54500	8.39126	.266	-26.8271	7.7371
	SPC	-4.56564	8.39126	.591	-21.8478	12.7165
	CCC	-17.64333*	8.39126	.046	-34.9255	-.3612
PBK	SLH	.46667	8.39126	.956	-16.8155	17.7488
	LWP	9.54500	8.39126	.266	-7.7371	26.8271
	SPC	4.97936	8.39126	.558	-12.3028	22.2615
	CCC	-8.09833	8.39126	.344	-25.3805	9.1838
SPC	SLH	-4.51270	8.39126	.595	-21.7948	12.7694
	LWP	4.56564	8.39126	.591	-12.7165	21.8478
	PBK	-4.97936	8.39126	.558	-22.2615	12.3028
	CCC	-13.07770	8.39126	.132	-30.3598	4.2044
CCC	SLH	8.56500	8.39126	.317	-8.7171	25.8471
	LWP	17.64333*	8.39126	.046	.3612	34.9255
	PBK	8.09833	8.39126	.344	-9.1838	25.3805
	SPC	13.07770	8.39126	.132	-4.2044	30.3598

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

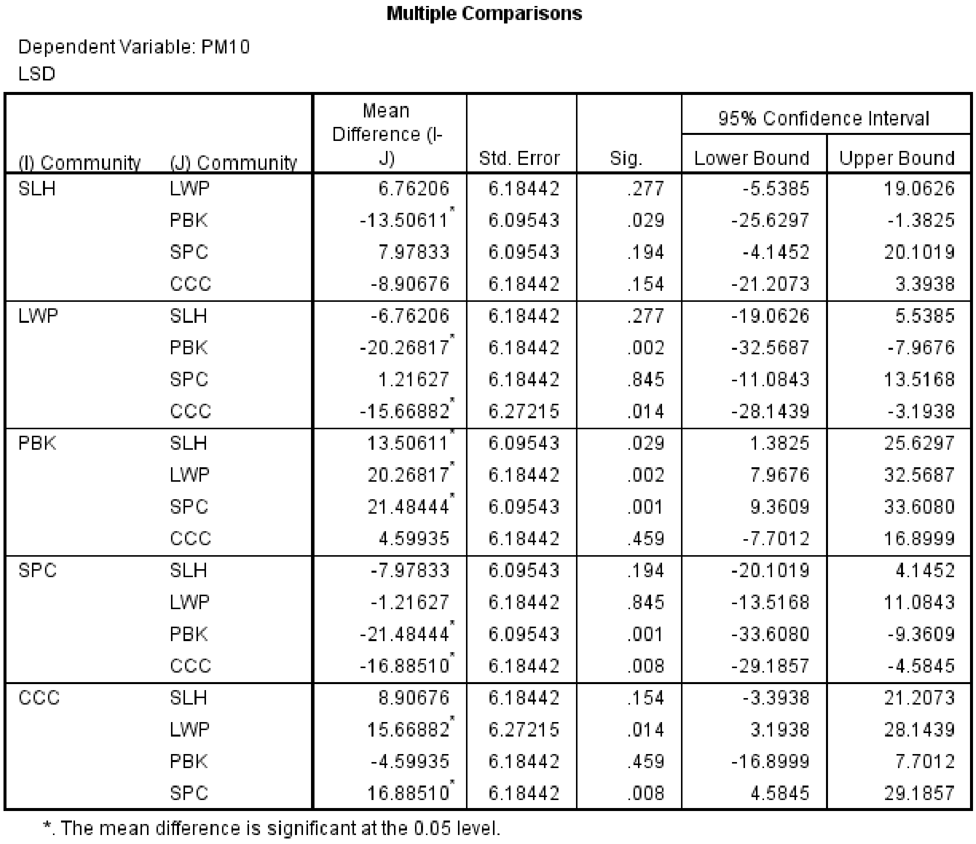
Table H.3 Statistical analysis using Oneway ANOVA of indoor concentrations of PM_{10} among five communities



ANOVA

PM10

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	6345.131	4	1586.283	4.744	.002
Within Groups	27754.257	83	334.389		
Total	34099.388	87			



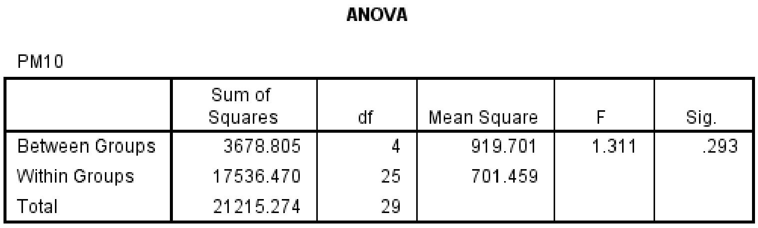
Multiple Comparisons

Dependent Variable: PM10
LSD

(I) Community	(J) Community	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
SLH	LWP	6.76206	6.18442	.277	-5.5385	19.0626
	PBK	-13.50611*	6.09543	.029	-25.6297	-1.3825
	SPC	7.97833	6.09543	.194	-4.1452	20.1019
	CCC	-8.90676	6.18442	.154	-21.2073	3.3938
LWP	SLH	-6.76206	6.18442	.277	-19.0626	5.5385
	PBK	-20.26817*	6.18442	.002	-32.5687	-7.9676
	SPC	1.21627	6.18442	.845	-11.0843	13.5168
	CCC	-15.66882*	6.27215	.014	-28.1439	-3.1938
PBK	SLH	13.50611*	6.09543	.029	1.3825	25.6297
	LWP	20.26817*	6.18442	.002	7.9676	32.5687
	SPC	21.48444*	6.09543	.001	9.3609	33.6080
	CCC	4.59935	6.18442	.459	-7.7012	16.8999
SPC	SLH	-7.97833	6.09543	.194	-20.1019	4.1452
	LWP	-1.21627	6.18442	.845	-13.5168	11.0843
	PBK	-21.48444*	6.09543	.001	-33.6080	-9.3609
	CCC	-16.88510*	6.18442	.008	-29.1857	-4.5845
CCC	SLH	8.90676	6.18442	.154	-3.3938	21.2073
	LWP	15.66882*	6.27215	.014	3.1938	28.1439
	PBK	-4.59935	6.18442	.459	-16.8999	7.7012
	SPC	16.88510*	6.18442	.008	4.5845	29.1857

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

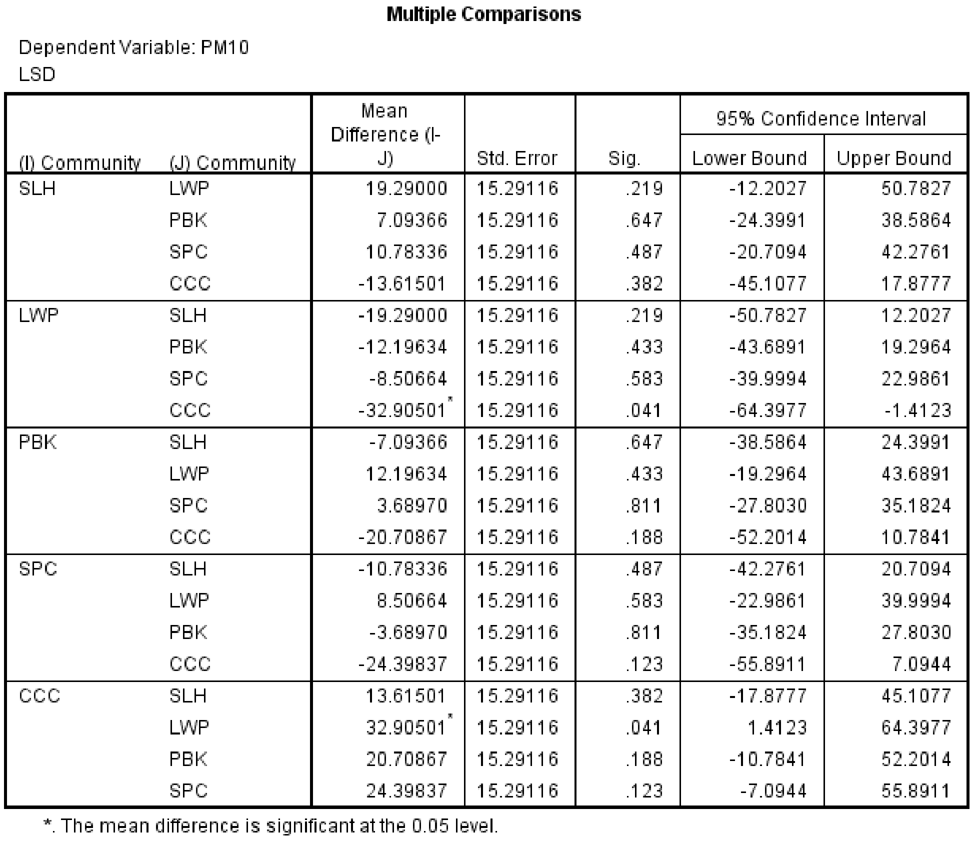
Table H.4 Statistical analysis using Oneway ANOVA of outdoor concentrations of PM_{10} among five communities



ANOVA

PM10

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	3678.805	4	919.701	1.311	.293
Within Groups	17536.470	25	701.459		
Total	21215.274	29			



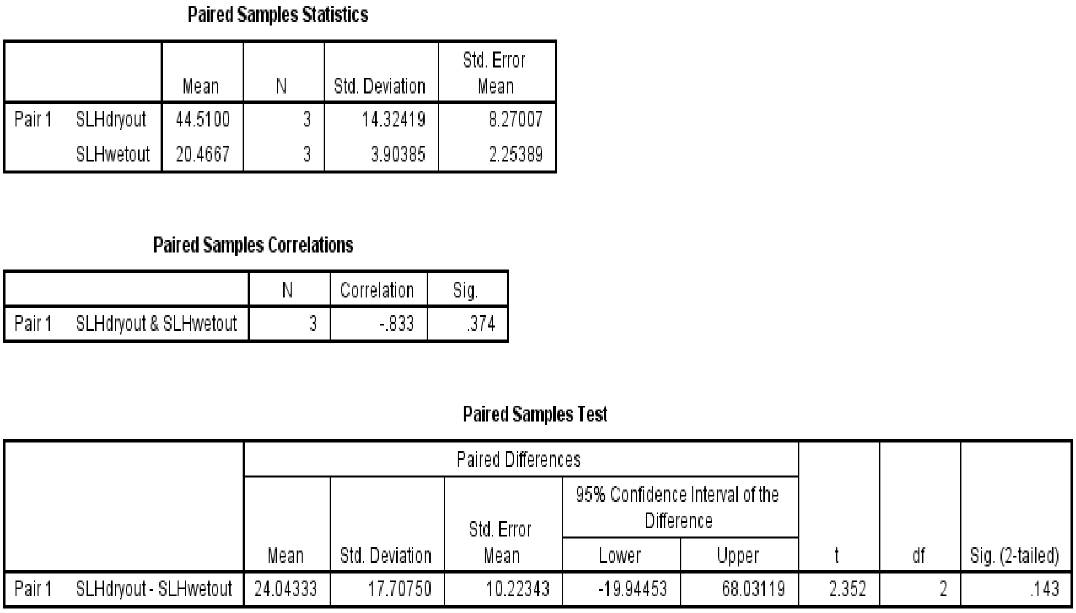
Multiple Comparisons

Dependent Variable: PM10
LSD

(I) Community	(J) Community	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
SLH	LWP	19.29000	15.29116	.219	-12.2027	50.7827
	PBK	7.09366	15.29116	.647	-24.3991	38.5864
	SPC	10.78336	15.29116	.487	-20.7094	42.2761
	CCC	-13.61501	15.29116	.382	-45.1077	17.8777
LWP	SLH	-19.29000	15.29116	.219	-50.7827	12.2027
	PBK	-12.19634	15.29116	.433	-43.6891	19.2964
	SPC	-8.50664	15.29116	.583	-39.9994	22.9861
	CCC	-32.90501*	15.29116	.041	-64.3977	-1.4123
PBK	SLH	-7.09366	15.29116	.647	-38.5864	24.3991
	LWP	12.19634	15.29116	.433	-19.2964	43.6891
	SPC	3.68970	15.29116	.811	-27.8030	35.1824
	CCC	-20.70867	15.29116	.188	-52.2014	10.7841
SPC	SLH	-10.78336	15.29116	.487	-42.2761	20.7094
	LWP	8.50664	15.29116	.583	-22.9861	39.9994
	PBK	-3.68970	15.29116	.811	-35.1824	27.8030
	CCC	-24.39837	15.29116	.123	-55.8911	7.0944
CCC	SLH	13.61501	15.29116	.382	-17.8777	45.1077
	LWP	32.90501*	15.29116	.041	1.4123	64.3977
	PBK	20.70867	15.29116	.188	-10.7841	52.2014
	SPC	24.39837	15.29116	.123	-7.0944	55.8911

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

Table H.5 Statistical analysis using Paired sample T-test of outdoor concentrations of $PM_{2.5}$ at SLH between dry and wet season



Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	SLHdryout	44.5100	3	14.32419	8.27007
	SLHwetout	20.4667	3	3.90385	2.25389

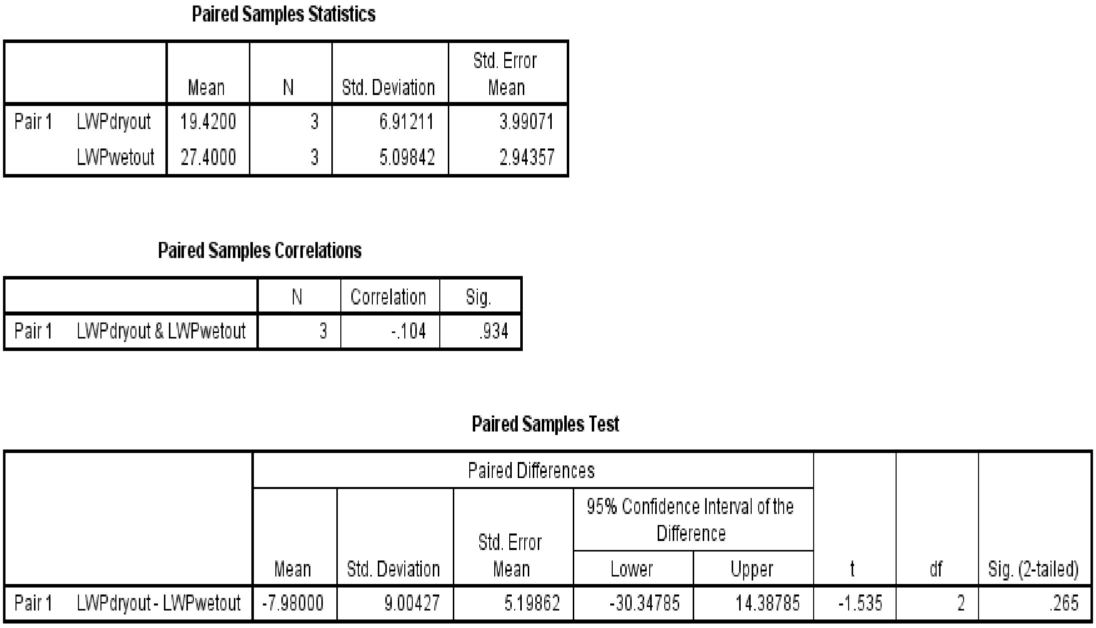
Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	SLHdryout & SLHwetout	3	-.833	.374

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	SLHdryout - SLHwetout	24.04333	17.70750	10.22343	-19.94453	68.03119	2.352	2	.143

Table H.6 Statistical analysis using Paired sample T-test of outdoor concentrations of $PM_{2.5}$ at LWP between dry and wet season



Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	LWPdryout	19.4200	3	6.91211	3.99071
	LWPwetout	27.4000	3	5.09842	2.94357

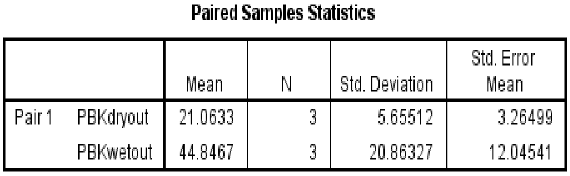
Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	LWPdryout & LWPwetout	3	-.104	.934

Paired Samples Test

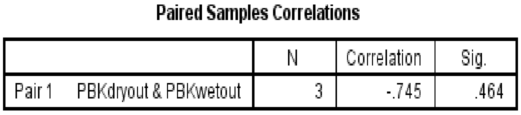
		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	LWPdryout - LWPwetout	-7.98000	9.00427	5.19862	-30.34785	14.38785	-1.535	2	.265

Table H.7 Statistical analysis using Paired sample T-test of outdoor concentrations of $PM_{2.5}$ at PBK between dry and wet season



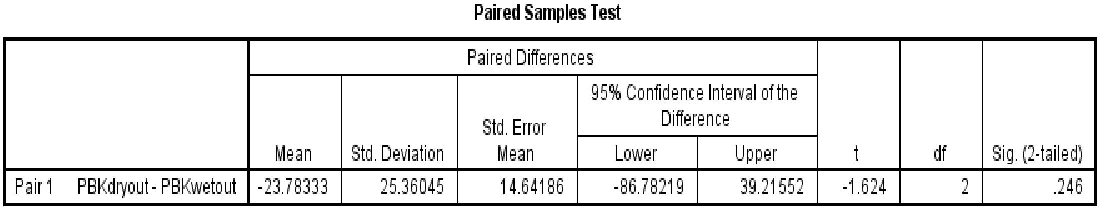
Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	PBKdryout	21.0633	3	5.65512	3.26499
	PBKwetout	44.8467	3	20.86327	12.04541



Paired Samples Correlations

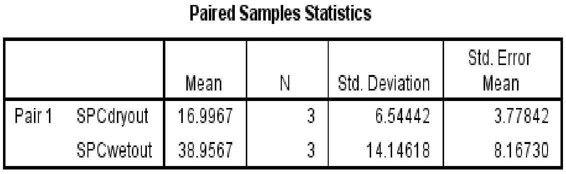
		N	Correlation	Sig.
Pair 1	PBKdryout & PBKwetout	3	-.745	.464



Paired Samples Test

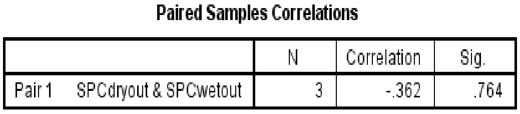
		Paired Differences					t	df	Sig. (2-tailed)
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1	PBKdryout - PBKwetout	-23.78333	25.36045	14.64186	-86.78219	39.21552	-1.624	2	.246

Table H.8 Statistical analysis using Paired sample T-test of outdoor concentrations of $PM_{2.5}$ at SPC between dry and wet season



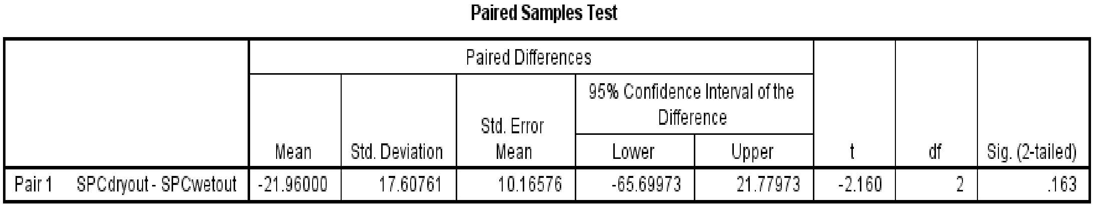
Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	SPCdryout	16.9967	3	6.54442	3.77842
	SPCwetout	38.9567	3	14.14618	8.16730



Paired Samples Correlations

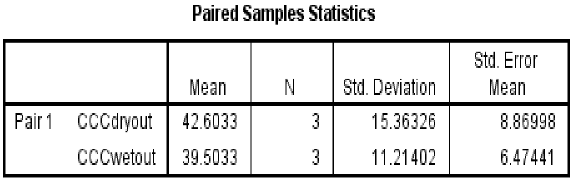
		N	Correlation	Sig.
Pair 1	SPCdryout & SPCwetout	3	-.362	.764



Paired Samples Test

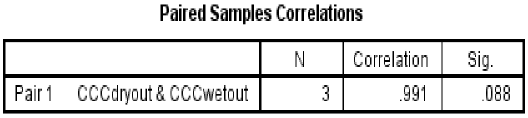
		Paired Differences					t	df	Sig. (2-tailed)
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1	SPCdryout - SPCwetout	-21.96000	17.60761	10.16576	-65.69973	21.77973	-2.160	2	.163

Table H.9 Statistical analysis using Paired sample T-test of outdoor concentrations of $PM_{2.5}$ at CCC between dry and wet season



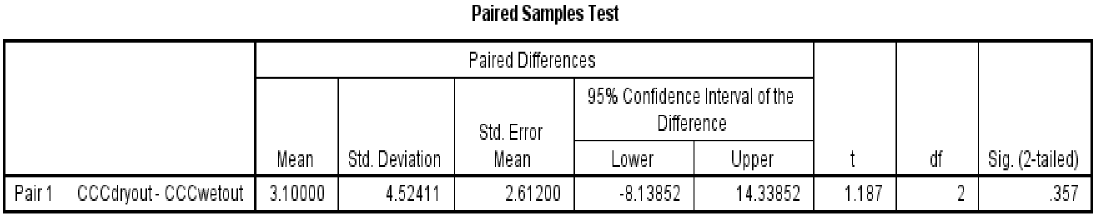
Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	CCCdryout	42.6033	3	15.36326	8.86998
	CCCwetout	39.5033	3	11.21402	6.47441



Paired Samples Correlations

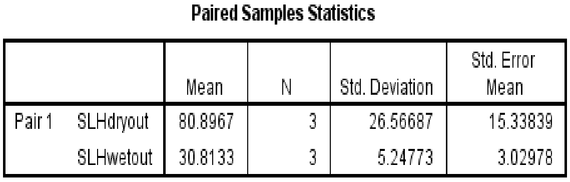
		N	Correlation	Sig.
Pair 1	CCCdryout & CCCwetout	3	.991	.088



Paired Samples Test

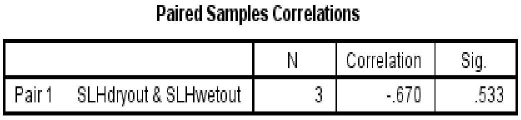
		Paired Differences					t	df	Sig. (2-tailed)
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1	CCCdryout - CCCwetout	3.10000	4.52411	2.61200	-8.13852	14.33852	1.187	2	.357

Table H.10 Statistical analysis using Paired sample T-test of outdoor concentrations of PM_{10} at SLH between dry and wet season



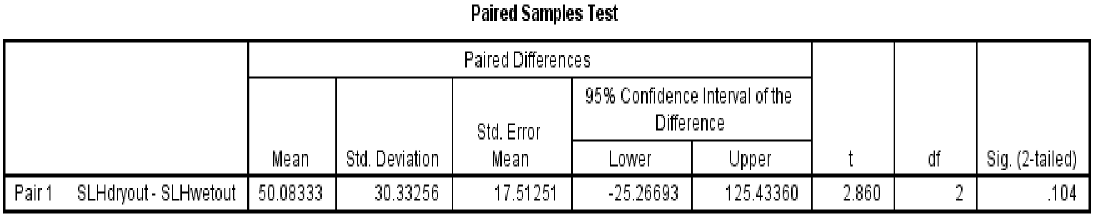
Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	SLHdryout	80.8967	3	26.56687	15.33839
	SLHwetout	30.8133	3	5.24773	3.02978



Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	SLHdryout & SLHwetout	3	-.670	.533



Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1	SLHdryout - SLHwetout	50.08333	30.33256	17.51251	-25.26693	125.43360	2.860	2	.104

Table H.11 Statistical analysis using Paired sample T-test of outdoor concentrations of PM_{10} at LWP between dry and wet season

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	LWPdryout	33.4967	3	9.26729	5.35047
	LWPwetout	39.6333	3	7.74818	4.47341

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	LWPdryout & LWPwetout	3	.190	.878

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1	LWPdryout - LWPwetout	-6.13667	10.89080	6.28780	-33.19090	20.91757	-.976	2	.432

Table H.12 Statistical analysis using Paired sample T-test of outdoor concentrations of PM_{10} at PBK between dry and wet season

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	PBKdryout	33.4633	3	5.28419	3.05083
	PBKwetout	64.0600	3	33.02186	19.06518

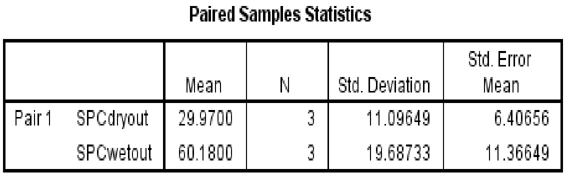
Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	PBKdryout & PBKwetout	3	-.975	.141

Paired Samples Test

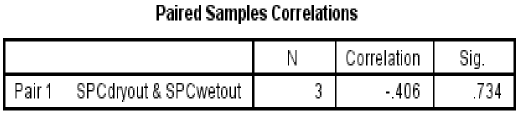
		Paired Differences					t	df	Sig. (2-tailed)
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1	PBKdryout - PBKwetout	-30.59667	38.19411	22.05138	-125.47610	64.28277	-1.388	2	.300

Table H.13 Statistical analysis using Paired sample T-test of outdoor concentrations of PM_{10} at SPC between dry and wet season



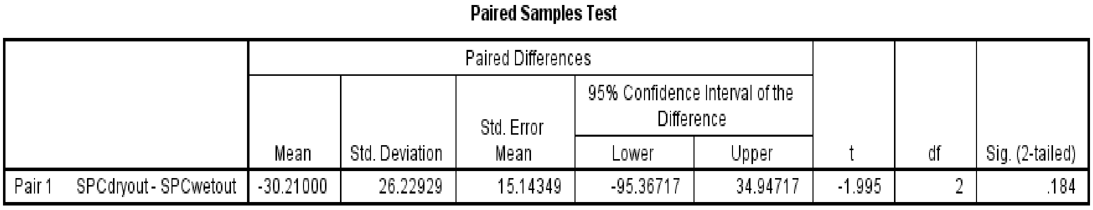
Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	SPCdryout	29.9700	3	11.09649	6.40656
	SPCwetout	60.1800	3	19.68733	11.36649



Paired Samples Correlations

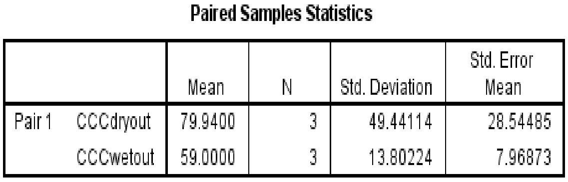
		N	Correlation	Sig.
Pair 1	SPCdryout & SPCwetout	3	-.406	.734



Paired Samples Test

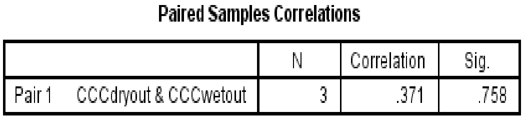
		Paired Differences					t	df	Sig. (2-tailed)
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1	SPCdryout - SPCwetout	-30.21000	26.22929	15.14349	-95.36717	34.94717	-1.995	2	.184

Table H.14 Statistical analysis using Paired sample T-test of outdoor concentrations of PM_{10} at CCC between dry and wet season



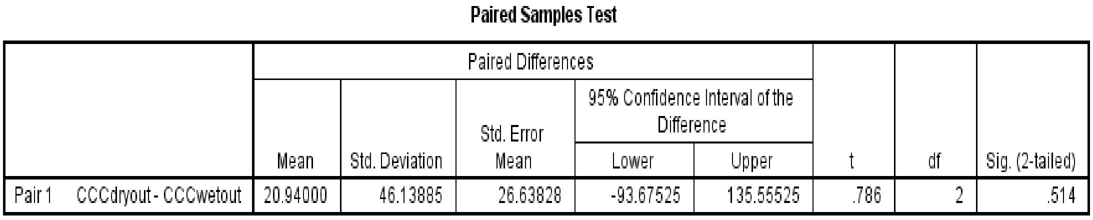
Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	CCCdryout	79.9400	3	49.44114	28.54485
	CCCwetout	59.0000	3	13.80224	7.96873



Paired Samples Correlations

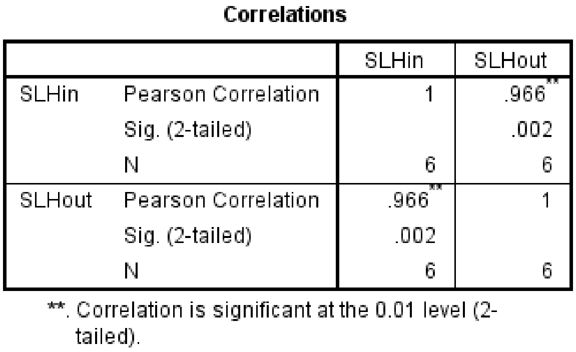
		N	Correlation	Sig.
Pair 1	CCCdryout & CCCwetout	3	.371	.758



Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1	CCCdryout - CCCwetout	20.94000	46.13885	26.63828	-93.67525	135.55525	.786	2	.514

Table H.15 Statistical analysis using Pearson correlation between indoor and outdoor concentrations of $PM_{2.5}$ at SLH

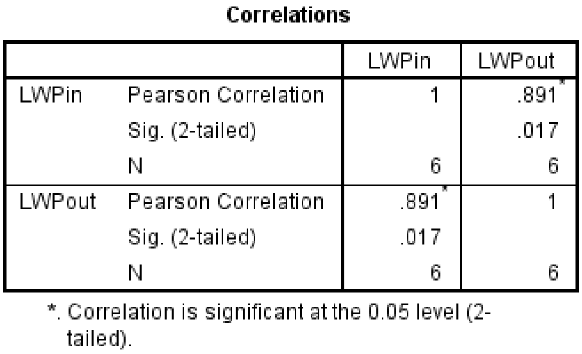


Correlations

		SLHin	SLHout
SLHin	Pearson Correlation	1	.966**
	Sig. (2-tailed)		.002
	N	6	6
SLHout	Pearson Correlation	.966**	1
	Sig. (2-tailed)	.002	
	N	6	6

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

Table H.16 Statistical analysis using Pearson correlation between indoor and outdoor concentrations of $PM_{2.5}$ at LWP

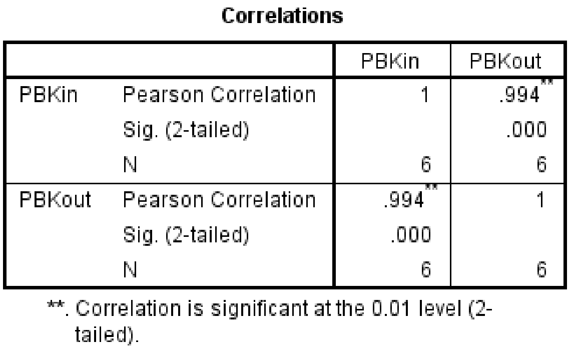


Correlations

		LWPin	LWPout
LWPin	Pearson Correlation	1	.891*
	Sig. (2-tailed)		.017
	N	6	6
LWPout	Pearson Correlation	.891*	1
	Sig. (2-tailed)	.017	
	N	6	6

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

Table H.17 Statistical analysis using Pearson correlation between indoor and outdoor concentrations of $PM_{2.5}$ at PBK

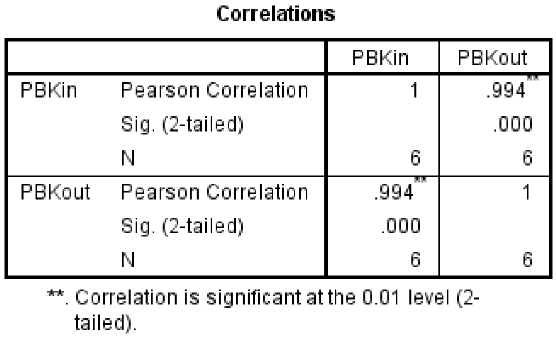


Correlations

		PBKin	PBKout
PBKin	Pearson Correlation	1	.994**
	Sig. (2-tailed)		.000
	N	6	6
PBKout	Pearson Correlation	.994**	1
	Sig. (2-tailed)	.000	
	N	6	6

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

Table H.18 Statistical analysis using Pearson correlation between indoor and outdoor concentrations of $PM_{2.5}$ at SPC

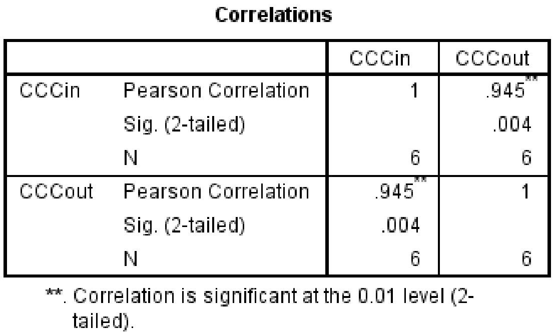


Correlations

		PBKin	PBKout
PBKin	Pearson Correlation	1	.994**
	Sig. (2-tailed)		.000
	N	6	6
PBKout	Pearson Correlation	.994**	1
	Sig. (2-tailed)	.000	
	N	6	6

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

Table H.19 Statistical analysis using Pearson correlation between indoor and outdoor concentrations of $PM_{2.5}$ at CCC

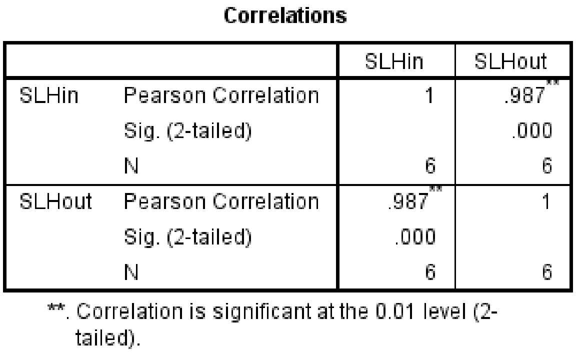


Correlations

		CCCin	CCCout
CCCin	Pearson Correlation	1	.945**
	Sig. (2-tailed)		.004
	N	6	6
CCCout	Pearson Correlation	.945**	1
	Sig. (2-tailed)	.004	
	N	6	6

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

Table H.20 Statistical analysis using Pearson correlation between indoor and outdoor concentrations of PM_{10} at SLH

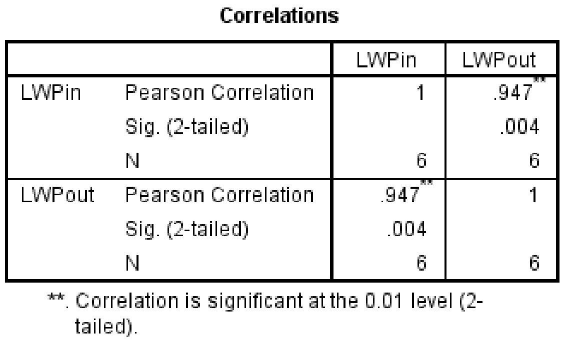


Correlations

		SLHin	SLHout
SLHin	Pearson Correlation	1	.987**
	Sig. (2-tailed)		.000
	N	6	6
SLHout	Pearson Correlation	.987**	1
	Sig. (2-tailed)	.000	
	N	6	6

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

Table H.21 Statistical analysis using Pearson correlation between indoor and outdoor concentrations of PM_{10} at LWP

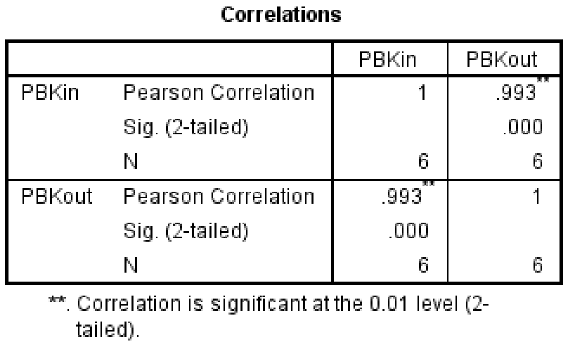


Correlations

		LWPin	LWPout
LWPin	Pearson Correlation	1	.947**
	Sig. (2-tailed)		.004
	N	6	6
LWPout	Pearson Correlation	.947**	1
	Sig. (2-tailed)	.004	
	N	6	6

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

Table H.22 Statistical analysis using Pearson correlation between indoor and outdoor concentrations of PM_{10} at PBK

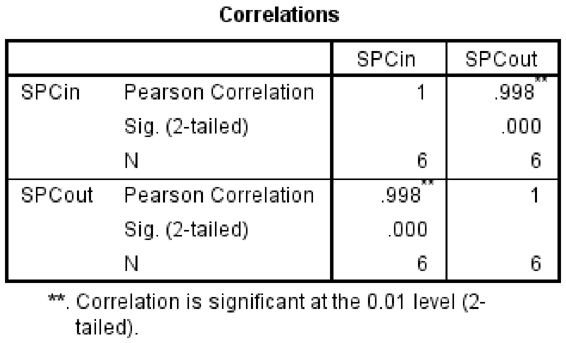


Correlations

		PBKin	PBKout
PBKin	Pearson Correlation	1	.993**
	Sig. (2-tailed)		.000
	N	6	6
PBKout	Pearson Correlation	.993**	1
	Sig. (2-tailed)	.000	
	N	6	6

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

Table H.23 Statistical analysis using Pearson correlation between indoor and outdoor concentrations of PM_{10} at SPC

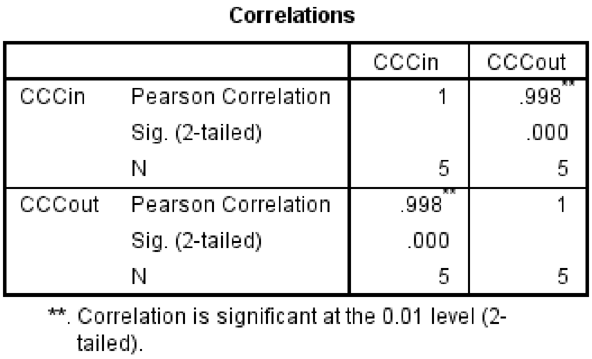


Correlations

		SPCin	SPCout
SPCin	Pearson Correlation	1	.998**
	Sig. (2-tailed)		.000
	N	6	6
SPCout	Pearson Correlation	.998**	1
	Sig. (2-tailed)	.000	
	N	6	6

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

Table H.24 Statistical analysis using Pearson correlation between indoor and outdoor concentrations of PM_{10} at CCC

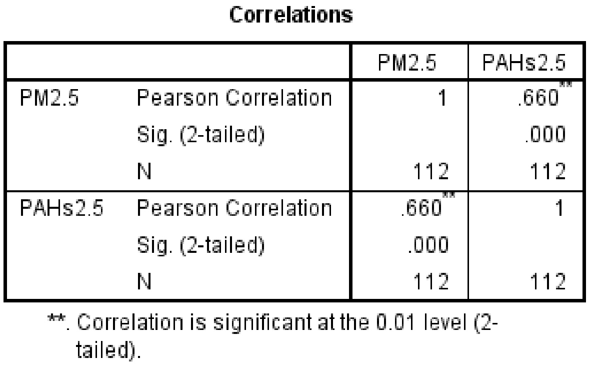


Correlations

		CCCin	CCCout
CCCin	Pearson Correlation	1	.998**
	Sig. (2-tailed)		.000
	N	5	5
CCCout	Pearson Correlation	.998**	1
	Sig. (2-tailed)	.000	
	N	5	5

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

Table H.25 Statistical analysis using Pearson correlation between $PM_{2.5}$ and t-$PAHs_{2.5}$ concentrations

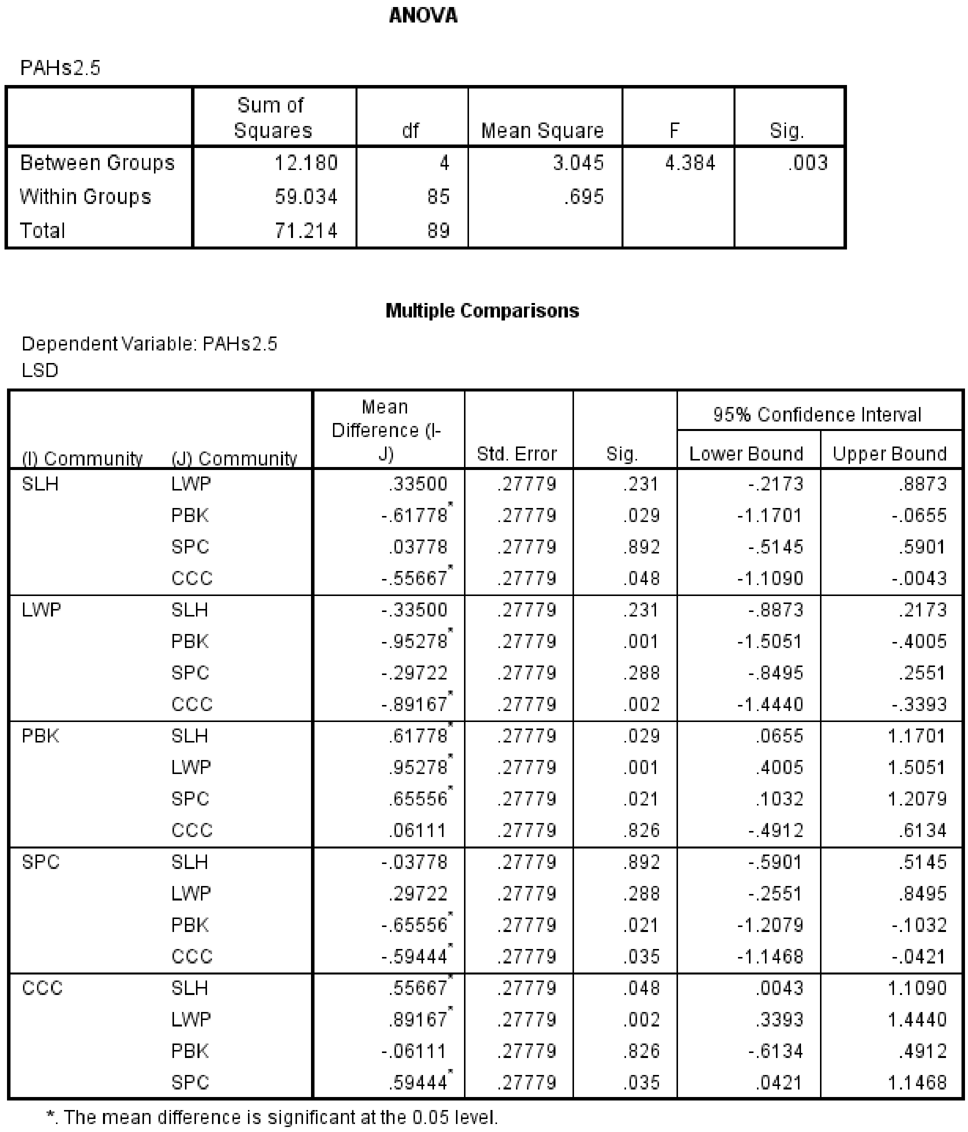


Correlations

		PM2.5	PAHs2.5
PM2.5	Pearson Correlation	1	.660**
	Sig. (2-tailed)		.000
	N	112	112
PAHs2.5	Pearson Correlation	.660**	1
	Sig. (2-tailed)	.000	
	N	112	112

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

Table H.26 Statistical analysis using Oneway ANOVA of indoor concentrations of t-PAHs$_{2.5}$ among five communities



ANOVA

PAHs2.5

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	12.180	4	3.045	4.384	.003
Within Groups	59.034	85	.695		
Total	71.214	89			

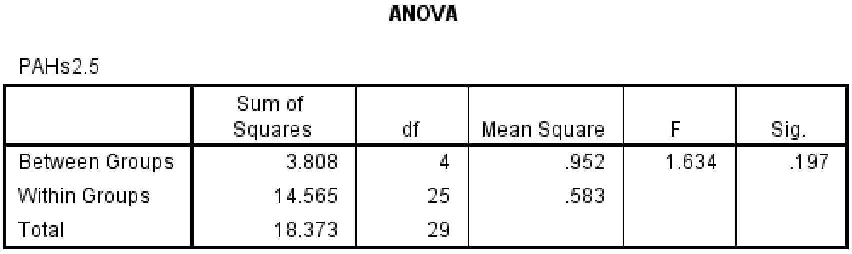
Multiple Comparisons

Dependent Variable: PAHs2.5
LSD

(I) Community	(J) Community	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
SLH	LWP	.33500	.27779	.231	-.2173	.8873
	PBK	-.61778*	.27779	.029	-1.1701	-.0655
	SPC	.03778	.27779	.892	-.5145	.5901
	CCC	-.55667*	.27779	.048	-1.1090	-.0043
LWP	SLH	-.33500	.27779	.231	-.8873	.2173
	PBK	-.95278*	.27779	.001	-1.5051	-.4005
	SPC	-.29722	.27779	.288	-.8495	.2551
	CCC	-.89167*	.27779	.002	-1.4440	-.3393
PBK	SLH	.61778*	.27779	.029	.0655	1.1701
	LWP	.95278*	.27779	.001	.4005	1.5051
	SPC	.65556*	.27779	.021	.1032	1.2079
	CCC	.06111	.27779	.826	-.4912	.6134
SPC	SLH	-.03778	.27779	.892	-.5901	.5145
	LWP	.29722	.27779	.288	-.2551	.8495
	PBK	-.65556*	.27779	.021	-1.2079	-.1032
	CCC	-.59444*	.27779	.035	-1.1468	-.0421
CCC	SLH	.55667*	.27779	.048	.0043	1.1090
	LWP	.89167*	.27779	.002	.3393	1.4440
	PBK	-.06111	.27779	.826	-.6134	.4912
	SPC	.59444*	.27779	.035	.0421	1.1468

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

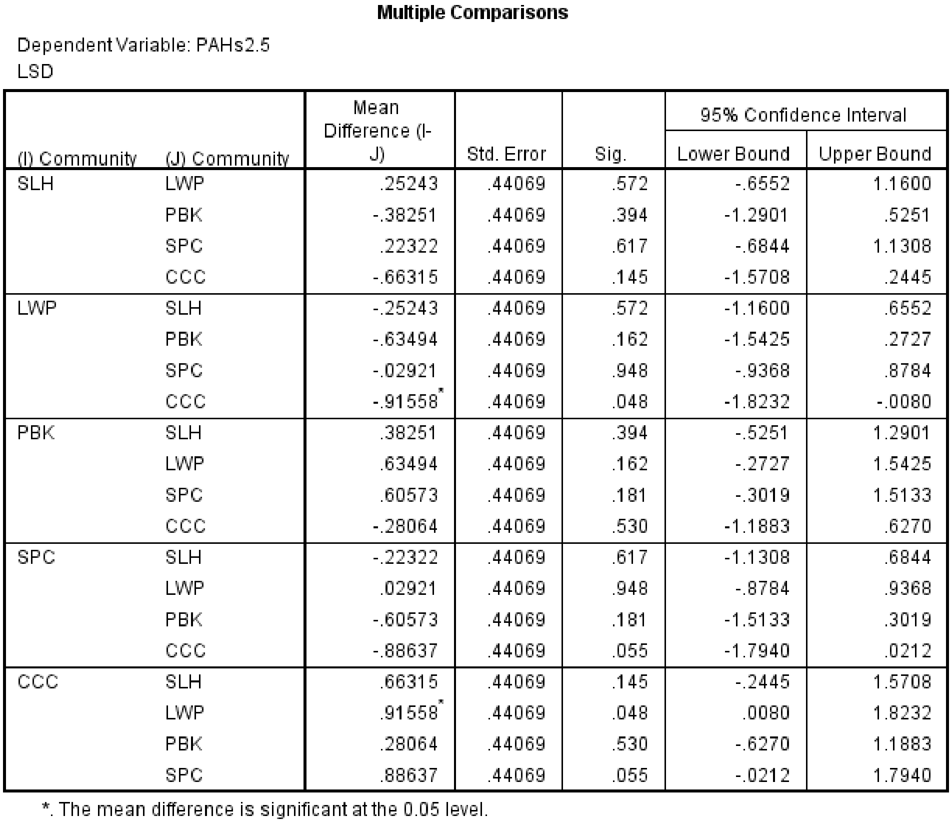
Table H.27 Statistical analysis using Oneway ANOVA of outdoor concentrations of t-PAHs$_{2.5}$ among five communities



ANOVA

PAHs2.5

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	3.808	4	.952	1.634	.197
Within Groups	14.565	25	.583		
Total	18.373	29			



Multiple Comparisons

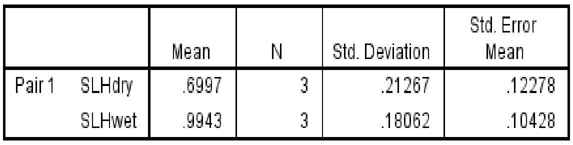
Dependent Variable: PAHs2.5
LSD

(I) Community	(J) Community	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
SLH	LWP	.25243	.44069	.572	-.6552	1.1600
	PBK	-.38251	.44069	.394	-1.2901	.5251
	SPC	.22322	.44069	.617	-.6844	1.1308
	CCC	-.66315	.44069	.145	-1.5708	.2445
LWP	SLH	-.25243	.44069	.572	-1.1600	.6552
	PBK	-.63494	.44069	.162	-1.5425	.2727
	SPC	-.02921	.44069	.948	-.9368	.8784
	CCC	-.91558*	.44069	.048	-1.8232	-.0080
PBK	SLH	.38251	.44069	.394	-.5251	1.2901
	LWP	.63494	.44069	.162	-.2727	1.5425
	SPC	.60573	.44069	.181	-.3019	1.5133
	CCC	-.28064	.44069	.530	-1.1883	.6270
SPC	SLH	-.22322	.44069	.617	-1.1308	.6844
	LWP	.02921	.44069	.948	-.8784	.9368
	PBK	-.60573	.44069	.181	-1.5133	.3019
	CCC	-.88637	.44069	.055	-1.7940	.0212
CCC	SLH	.66315	.44069	.145	-.2445	1.5708
	LWP	.91558*	.44069	.048	.0080	1.8232
	PBK	.28064	.44069	.530	-.6270	1.1883
	SPC	.88637	.44069	.055	-.0212	1.7940

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

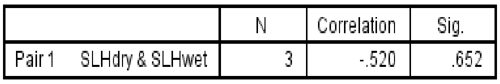
Table H.28 Statistical analysis using Paired sample T-test of outdoor concentrations of t-$PAHs_{2.5}$ at SLH between dry and wet season

Paired Samples Statistics



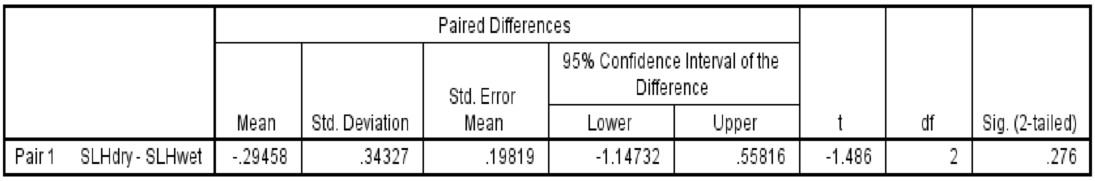
		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	SLHdry	.6997	3	.21267	.12278
	SLHwet	.9943	3	.18062	.10428

Paired Samples Correlations



		N	Correlation	Sig.
Pair 1	SLHdry & SLHwet	3	-.520	.652

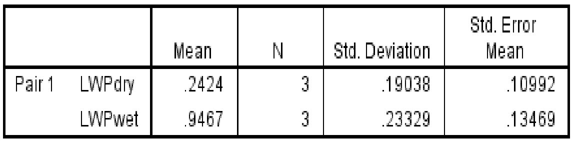
Paired Samples Test



		Paired Differences					t	df	Sig. (2-tailed)
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1	SLHdry - SLHwet	-.29458	.34327	.19819	-1.14732	.55816	-1.486	2	.276

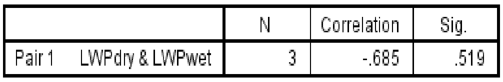
Table H.29 Statistical analysis using Paired sample T-test of outdoor concentrations of t-$PAHs_{2.5}$ at LWP between dry and wet season

Paired Samples Statistics



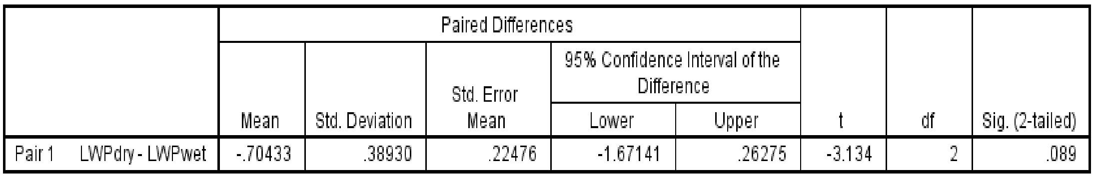
		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	LWPdry	.2424	3	.19038	.10992
	LWPwet	.9467	3	.23329	.13469

Paired Samples Correlations



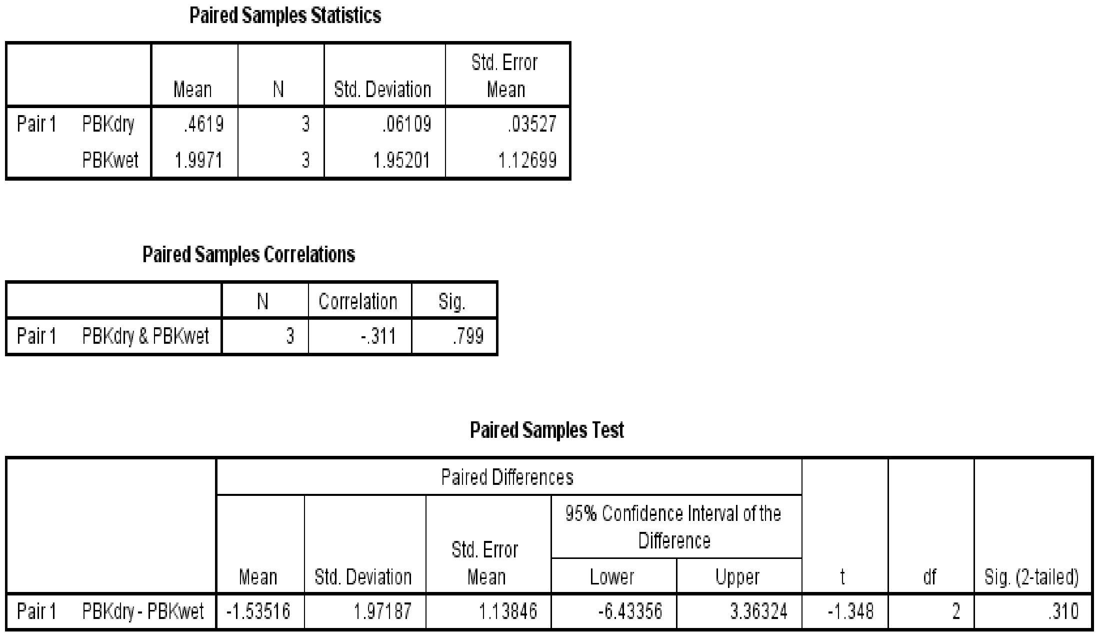
		N	Correlation	Sig.
Pair 1	LWPdry & LWPwet	3	-.685	.519

Paired Samples Test



		Paired Differences					t	df	Sig. (2-tailed)
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1	LWPdry - LWPwet	-.70433	.38930	.22476	-1.67141	.26275	-3.134	2	.089

Table H.30 Statistical analysis using Paired sample T-test of outdoor concentrations of t-PAHs$_{2.5}$ at PBK between dry and wet season



Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	PBKdry	.4619	3	.06109	.03527
	PBKwet	1.9971	3	1.95201	1.12699

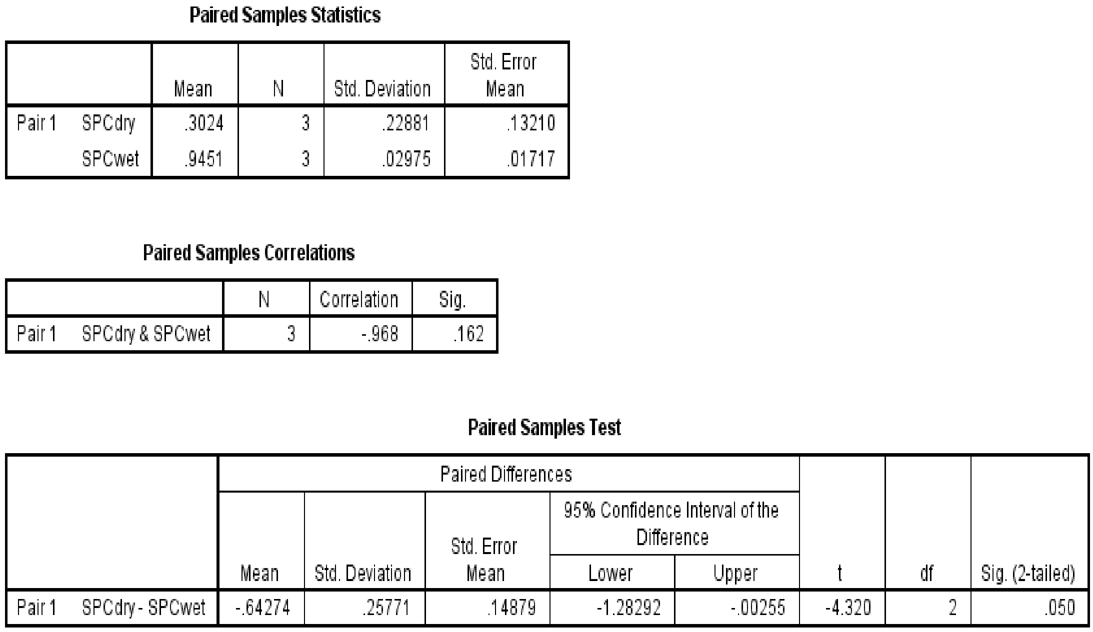
Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	PBKdry & PBKwet	3	-.311	.799

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1	PBKdry - PBKwet	-1.53516	1.97187	1.13846	-6.43356	3.36324	-1.348	2	.310

Table H.31 Statistical analysis using Paired sample T-test of outdoor concentrations of t-PAHs$_{2.5}$ at SPC between dry and wet season



Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	SPCdry	.3024	3	.22881	.13210
	SPCwet	.9451	3	.02975	.01717

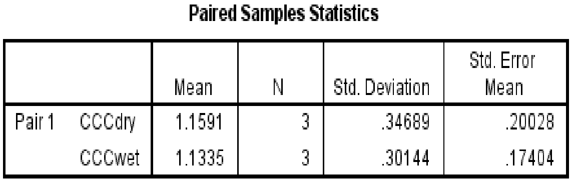
Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	SPCdry & SPCwet	3	-.968	.162

Paired Samples Test

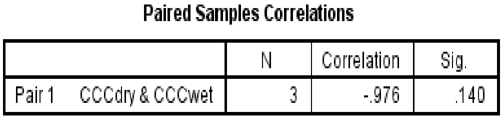
		Paired Differences					t	df	Sig. (2-tailed)
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1	SPCdry - SPCwet	-.64274	.25771	.14879	-1.28292	-.00255	-4.320	2	.050

Table H.32 Statistical analysis using Paired sample T-test of outdoor concentrations of t-PAHs$_{2.5}$ at CCC between dry and wet season



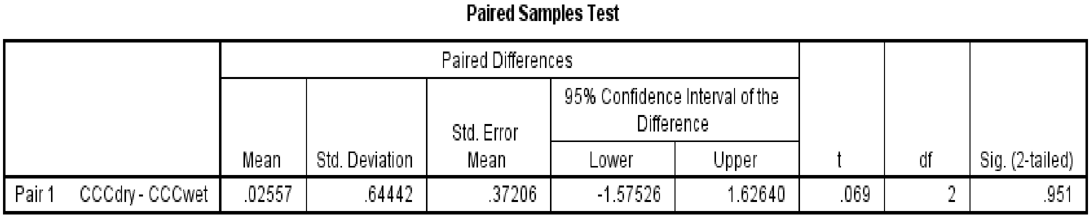
Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	CCCdry	1.1591	3	.34689	.20028
	CCCwet	1.1335	3	.30144	.17404



Paired Samples Correlations

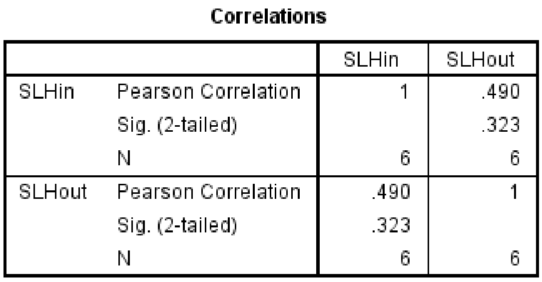
		N	Correlation	Sig.
Pair 1	CCCdry & CCCwet	3	-.976	.140



Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1	CCCdry - CCCwet	.02557	.64442	.37206	-1.57526	1.62640	.069	2	.951

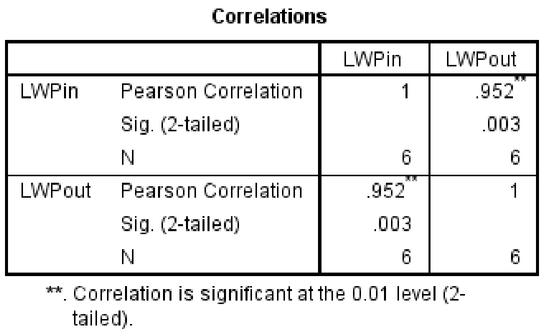
Table H.33 Statistical analysis using Pearson correlation between indoor and outdoor concentrations of t-PAHs$_{2.5}$ at SLH



Correlations

		SLHin	SLHout
SLHin	Pearson Correlation	1	.490
	Sig. (2-tailed)		.323
	N	6	6
SLHout	Pearson Correlation	.490	1
	Sig. (2-tailed)	.323	
	N	6	6

Table H.34 Statistical analysis using Pearson correlation between indoor and outdoor concentrations of t-PAHs$_{2.5}$ at LWP

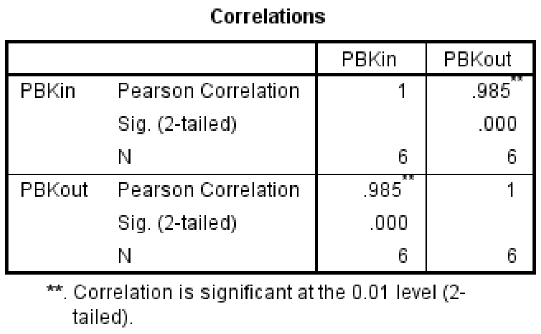


Correlations

		LWPin	LWPout
LWPin	Pearson Correlation	1	.952**
	Sig. (2-tailed)		.003
	N	6	6
LWPout	Pearson Correlation	.952**	1
	Sig. (2-tailed)	.003	
	N	6	6

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

Table H.35 Statistical analysis using Pearson correlation between indoor and outdoor concentrations of t-PAHs$_{2.5}$ at PBK

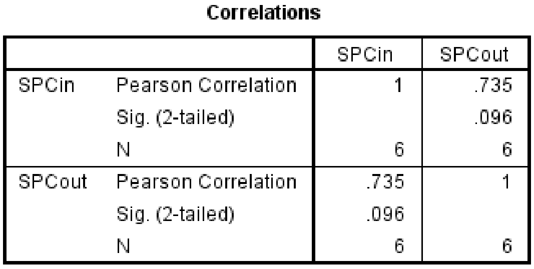


Correlations

		PBKin	PBKout
PBKin	Pearson Correlation	1	.985**
	Sig. (2-tailed)		.000
	N	6	6
PBKout	Pearson Correlation	.985**	1
	Sig. (2-tailed)	.000	
	N	6	6

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

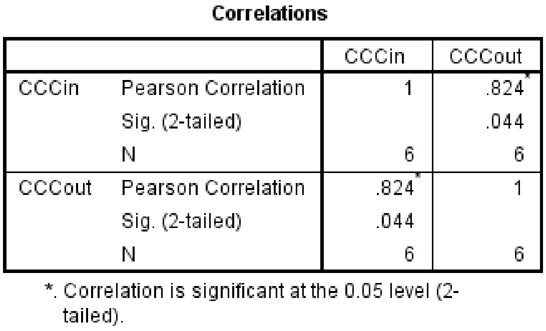
Table H.36 Statistical analysis using Pearson correlation between indoor and outdoor concentrations of t-PAHs$_{2.5}$ at SPC



Correlations

		SPCin	SPCout
SPCin	Pearson Correlation	1	.735
	Sig. (2-tailed)		.096
	N	6	6
SPCout	Pearson Correlation	.735	1
	Sig. (2-tailed)	.096	
	N	6	6

Table H.37 Statistical analysis using Pearson correlation between indoor and outdoor concentrations of t-PAHs$_{2.5}$ at CCC



Correlations

		CCCin	CCCout
CCCin	Pearson Correlation	1	.824*
	Sig. (2-tailed)		.044
	N	6	6
CCCout	Pearson Correlation	.824*	1
	Sig. (2-tailed)	.044	
	N	6	6

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

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