ENVIRONMENTAL CONCENTRATION OF CARBONYL COMPOUNDS AND BTEX IN RESIDENTIAL AREAS OF INNER CITY OF BANGKOK AND THEIR POSSIBLE HEALTH RISK

Miss Rajitpitch Sawatsing

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ปริมาณสารคาร์บอนิลและบีเทคบริเวณที่พักอาศัยในเขตกรุงเทพมหานครชั้นใน และความเสี่ยงต่อสุขภาพ

นางสาวรจิตพิชญ์ สวัสดิ์สิงห์

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิทยาศาสตรมหาบัณฑิต
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Thesis Title	ENVIRONMENTAL CONCENTRATION OF CARBONYL COMPOUNDS AND BTEX IN RESIDENTIAL AREAS OF INNER CITY OF BANGKOK AND THEIR POSSIBLE HEALTH RISK
By	Miss Rajitpitch Sawatsing
Field of Study	Environmental Management
Thesis Advisor	Tassanee Prueksasit, Ph.D.
Thesis Co-Advisor	Daisy Morknoy, Ph.D.

Accepted by the Graduate School, Chulalongkorn University in Partial Fulfillment of the Requirements for the Master's Degree

....Dean of the Graduate School
(Associate Professor Amorn Petsom, Ph.D.)

THESIS COMMITTEE

....Chairman
(Assistant Professor Chantra Tongcumpou, Ph.D.)

....Thesis Advisor
(Tassanee Prueksasit, Ph.D.)

....Thesis Co-Advisor
(Daisy Morknoy, Ph.D.)

....Examiner
(Assistant Professor Ekawan Luepromchai, Ph.D.)

....External Examiner
(Assistant Professor Chalongkwan Tangbanluekal, Ph.D.)

จิตพิชญ์ สวัสดิ์สิงห์ : ปริมาณสารคาร์บอนิลและบีเทคบริเวณที่พักอาศัยในเขตกรุงเทพมหานครชั้นใน และความเสี่ยงต่อสุขภาพ. (ENVIRONMENTAL CONCENTRATION OF CARBONYL COMPOUNDS AND BTEX IN RESIDENTIAL AREAS OF INNER CITY OF BANGKOK AND THEIR POSSIBLE HEALTH RISK) อ.ที่ปรึกษาวิทยานิพนธ์หลัก: ดร. ทรรศนีย์ พฤกษาสิทธิ์, อ.ที่ปรึกษาวิทยานิพนธ์ร่วม: ดร. เดชี่ หมอกน้อย, 234 หน้า.

งานวิจัยนี้มีวัตถุประสงค์เพื่อหาความเข้มข้นของสารประกอบคาร์บอนิลและบีเทคภายในและภายนอกอาคาร และประเมินความเสี่ยงต่อสุขภาพของผู้พักอาศัยจากการรับสัมผัสสารผ่านการหายใจ ทำการเก็บตัวอย่างอากาศที่บริเวณชุมชนที่พักอาศัยในเขตปทุมวันซึ่งเป็นตัวแทนกรุงเทพมหานครชั้นในจำนวน 5 ชุมชน ในช่วงฤดูร้อนระหว่างวันที่ 21 เมษายน ถึง 24 พฤษภาคม 2556 และฤดูฝนระหว่างวันที่ 22 กันยายน ถึง 25 ตุลาคม 2556 ใช้ 2,4 dinitrophenylhydrazine (DNPH) cartridge และ charcoal glass tube เชื่อมต่อกับเครื่องดูดอากาศขนาดพกพาที่อัตราการไหลของอากาศเท่ากับ 100 มิลลิลิตรต่อนาที สำหรับเก็บตัวอย่างสารประกอบคาร์บอนิลและบีเทคในอากาศ ตามลำดับ ติดตั้งชุดเก็บตัวอย่างภายในบ้านและภายนอกบ้านที่ความสูงจากพื้นดินประมาณ 1.5 ถึง 2.0 เมตร และเก็บตัวอย่างอากาศตลอด 24 ชั่วโมง สกัดสารประกอบคาร์บอนิลด้วยสารอะซิโตรไนไตรล์และสารบีเทคด้วยคาร์บอนไดซัลไฟด์ และนำมาวิเคราะห์ด้วยเครื่อง HPLC/UV และ GC/FID ตามลำดับ ผลการศึกษาพบว่า ปริมาณสารประกอบคาร์บอนิล 4 ชนิดหลักที่พบในบ้านของผู้พักอาศัย ได้แก่ ฟอร์มัลดีไฮด์ อะเซตัลดีไฮด์ โพพิโอนัลดีไฮด์ และเฮกซานัลดีไฮด์ อยู่ในช่วงความเข้มข้นเท่ากับ 0.14-38.73 0.10-11.02 0.03-2.08 และ 0.03-6.28 ไมโครกรัมต่อลูกบาศก์เมตร ตามลำดับ และสารเบนซีน โทลูอีน เอทธิลเบนซีน เอ็มพีไซลีน และโอไซลีนอยู่ในช่วง 0.21-510.07 0.25-1069.78 0.12-132.16 0.51-167.18 และ 1.22-59.75 ไมโครกรัมต่อลูกบาศก์เมตร ตามลำดับ ผลการประเมินความเสี่ยงการก่อเกิดมะเร็งที่มีต่อผู้พักอาศัยในเขตกรุงเทพชั้นในโดยใช้สมการมาตรฐานทั่วไป พบว่า ค่า 95% CI ของ lifetime cancer risk ของการรับสัมผัสสารฟอร์มัลดีไฮด์ อะเซทัลดีไฮด์ เบนซีนและเอททิลเบนซีนอยู่ในช่วง 5.99×10^{-5}-4.72×10^{-5}, 1.09×10^{-5}-9.93×10^{-6}, 1.03×10^{-4}-8.83×10^{-5}, และ 1.45×10^{-5}-1.10×10^{-5} ตามลำดับ ในกรณีที่คำนวณโดยใช้สมการที่ประเมินความเสี่ยงโดยแบ่งตามช่วงอายุ ค่า 95% CI ของ lifetime cancer risk ของสารดังกล่าวอยู่ในช่วง 1.94×10^{-4}-1.79×10^{-4}, 3.20×10^{-5}-3.00×10^{-5}, 2.72×10^{-3}-2.40×10^{-3}, และ 5.78×10^{-5}-5.38×10^{-5} ตามลำดับ ซึ่งผลการประเมินโดยส่วนใหญ่จากทั้งสองวิธีมีค่าเกินระดับความเสี่ยงที่ยอมรับได้ที่กำหนดให้ประชากรหนึ่งล้านคนมีโอกาสเสี่ยงต่อการเกิดมะเร็งเพียงหนึ่งคน (หรือ 10^{-6}) การคาดประมาณอาจสูงเกินความเป็นจริงอยู่บ้าง เนื่องจากค่าจำนวนชั่วโมงที่คาดว่าผู้อาศัยน่าจะอยู่ภายในบ้านคิดเป็นเวลา 24 ชั่วโมงและค่าความถี่การรับสารของผู้อาศัยกำหนดให้ 350 วันต่อปี ในขณะที่ผลการประเมินความเสี่ยงที่ไม่ก่อมะเร็งที่แสดงด้วยค่า hazard quotient (HQ) ของสารโทลูอีน เอ็มพีไซลีน โอไซลีน และ โพรพิโอนัลดีไฮด์ ส่วนใหญ่อยู่ในเกณฑ์ที่ยอมรับได้

สาขาวิชา การจัดการสิ่งแวดล้อม	ลายมือชื่อนิสิต ....
ปีการศึกษา 2556	ลายมือชื่อ อ.ที่ปรึกษาวิทยานิพนธ์หลัก ....
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KEYWORDS: BTEX / CARBONYL COMPOUNDS / INDOOR AND OUTDOOR AIR / RESIDENTIAL AREA / HEALTH RISK ASSESSMENT

RAJITPITCH SAWATSING: ENVIRONMENTAL CONCENTRATION OF CARBONYL COMPOUNDS AND BTEX IN RESIDENTIAL AREAS OF INNER CITY OF BANGKOK AND THEIR POSSIBLE HEALTH RISK. ADVISOR: TASSANEE PRUEKSASIT, Ph.D., CO-ADVISOR: DAISY MORKNOY, Ph.D., 234 pp.

This study aimed to determine the concentrations of carbonyl compounds and BTEX in indoor and outdoor environments and estimate the potential health risk of the residents via inhalation exposure. All samples were taken from 5 communities during dry season (21st April to 24th May, 2013) and wet season (22nd September to 25th October, 2013) by using 2, 4 dinitrophenylhydrazine (DNPH) cartridge and charcoal glass tube connected with personal air pump with air flow rate equaled 100 mL/min for carbonyl compounds and BTEX collections, respectively. The equipments were installed at indoor and outdoor environments at 1.5-2.0 meter height above the ground during 24 hours. Carbonyl compounds extracted by using acetonitrile and BTEX extracted by using carbon disulfide were analyzed by using HPLC/UV and GC/FID, respectively. The results shew the indoor concentrations of four main carbonyl compounds which were formaldehyde, acetaldehyde, propionaldehye, and hexanaldehyde were ranked in 0.14-38.73, 0.10-11.02, 0.03-2.08, and 0.03-6.28 $\mu g/m^3$, respectively. And benzene, toluene, m-, p-xylene, and o-xlyene were ranked in 0.21-510.07, 0.25-1069.78, 0.12-132.16, 0.51-167.18, and 1.22-59.75 $\mu g/m^3$, respectively. According to lifetime cancer risk from indoor concentrations based on general scenario, the results revealed that 95% CI of formaldehyde, acetaldehyde, benzene, and ethylbenzene were in the ranges of $5.99x10^{-5}$-$4.72x10^{-5}$, $1.09x10^{-5}$-$9.93x10^{-6}$, $1.03x10^{-4}$-$8.83x10^{-5}$, and $1.45x10^{-5}$-$1.10x10^{-5}$ $\mu g/m^3$, respectively. In case of age interval scenario, the 95% CI of lifetime cancer risk of these chemicals were in the ranges of $1.94x10^{-4}$-$1.79x10^{-4}$, $3.20x10^{-5}$-$3.00x10^{-5}$, $2.72x10^{-3}$-$2.40x10^{-3}$, and $5.78x10^{-5}$-$5.38x10^{-5}$. Most cancer risk from both scenarios were above the acceptable criteria which one people from one million people had possibility of developing cancer (or 10^{-6}). There were some overestimated risk due to exposure during equaled to 24 hours and the exposure frequency equaled to 350 days/year, while the most non-cancer risks were in the acceptable range.

Field of Study: Environmental Management	Student's Signature ....
Academic Year: 2013	Advisor's Signature ....
	Co-Advisor's Signature ....

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LIST OF ABBREVIATIONS

AALs	Allowable ambient limit
AAQC	Ambient air quality criterion
AAQG	Ambient air quality guideline
ACGIH	The American Conference of Government Industrial Hygienists
ADAF	Age-dependent Adjustment Factor
ADD	Average daily dose
AEGLs	Acute exposure guideline level
ANOVA	The analysis of variance
AT	Average time
ATSDR	The Agency for Toxic Substances and Disease Registry
BTEX	Benzene, Toluene, Ethylbenzene, and Xylenes
BW	Body weight
C	Celling limit
CA	Contaminant concentration in air
CDI	Chronic daily intake
CI	Confidence interval
CNS	Central nervous system
NGV	Natural gas vehicle
CSF_i	Inhalation cancer slope factor
DHHS	The Department of Health and Human Services
EC	Exposure concentration
ED	Exposure duration
EF	Exposure frequency
ERTC	Environmental Research and Training Centre
GC/FID	Gas Chromatography with Flame Ionize Detector
HEC	Human equivalent concentration
HI	Hazard index
HPLC/UV	High Performance Liquid Chromatography with UV Detector

HQ	Hazard quotient
HSDB	Hazard Substance Data Bank
IARC	The International Agency for Research on Cancer
IDHL	Immediately Dangerous to Life and Health concentration
IDL	The instrument detection limit
IQL	The instrument quantification limit
IR	Inhalation rate
IRIS	Integrated Risk Information System
IUPAC	InternationalUnion of Pure and Applied Chemistry
LOA	Level of odor awareness
LOD	The limit of detection
LOQ	The limit of quantification
LEL	Lower explosive limit
MfE	Ministry for the Environment
MRL	Inhalation minimum risk level
MTBE	Methyl tertiary butyl ether
MOE	Ontario Ministry of the Environment
NAC/NRC	National Academic of Science/National Research Council
NIOSH	National Institute for Occupational Safety and HealthCare
NRC	National Research Center
OEHHA	The Office of Environmental Health Hazard Assessment
OSHA	The Occupational Safety & Health Administration
PACs	Protective action criteria
PCD	Pollution Control Department
PEL	Permissible exposure limit
RAGS	The original Risk Assessment Guidance for Superfund
RAIS	The Risk Assessment Information System
REL	Recommended exposure limit
RfC	Reference concentration
RfD_i	Inhalation reference dose

RSD	Relative standard deviation
SAAAQO	Short-term Alberta ambient air quality objective
SCAPA	Subcommittee on Consequence Assessment and Protective Action
STEL	Short term exposure limit
TCEQ	Texas Commission on Environmental Quality Environmental Health Perspective
TELs	Threshold effects exposure limit
TLV-C	Threshold limit value ceiling
TWA	Time-weight average
UF	Uncertainty factor
VOCs	Volatile organic compounds
WEEL	Workplace environmental exposure level

CHAPTER I

INTRODUCTION

1.1 Rationale background and problem addressed

Since Thailand is one of well-known country in South East Asia, this country attracts a lot of foreigners and also Thai people to travel around. The transportation is expected to be the main sources of air pollution rise, especially in the big cities (e.g., Bangkok, Chiang Mai, Pattaya). Land Transport Department, Ministry of Transport and Communications (2000) claimed that there were 4.5 million registered vehicles which increasing of 113% from 1991. These high rates of transportations and traffic congestions provides air pollutants in atmosphere such CO_2, CO, NO_2, SO_2, PM, VOCs and others. The accumulation of these air pollutants trends to increase because the plenty of buildings and sky train may interrupt the dispersion of chemical plumes.

Carbonyl compounds are ubiquitous in the atmospheric environment (Granby, Christensen, & Lohse, 1997; J. Zhang & Smith, 1999). Formaldehyde, arcrolein, and acetaldehyde were classified to be carcinogenic substances to human (Armando Báez et al., 2003; J. Zhang, Lioy, & He, 1994). In urban areas, formaldehyde and acetaldehyde are the two most abundant carbonyl compounds in the atmosphere (Granby et al., 1997; E. Grosjean, Williams, & Grosjean, 1993; J. Zhang & Smith, 1999). Hence, the study of carbonyls concentrations is very important that they can affect to human health and their roles in the atmospheric chemistry. Carbonyl compounds were determined in many cities and rural area around the world; for example, Rome, Italy (Massimiliano Possanzini, Palo, & Cecinato, 2002), Osaka, Japan (Nguyen et al., 2001), Beirut, Lebanon (Moussa, El-Fadel, & Saliba, 2006), Xalapa, Mexico (AP Báez et al., 2001). For indoor air, (Armando Báez et al., 2003) suggested that the concentrations of carbonyl compounds in indoor air were higher than outdoor air in all sampling sites. Moreover, the result in the study of (Corrêa et al., 2010) indicated that the total carbonyl compounds produced by biodiesel-based fuel engines were greater than those found from diesel fuel engines.

Benzene, toluene, ethylbenzene, and xylene (BTEX) are mainly produced by anthropogenic activities. Vehicle exhaust had been concerned to be the main sources or atmospheric BTEX, followed by gasoline evaporation, emissions from solvents and paintings, leakage of natural gas and liquefied petroleum gas, and so forth (Y. Liu, Shao, Zhang, Fu, & Lu, 2005; Lu, Liu, Shao, & Huang, 2007; Song et al., 2007). BTEX can cause variety of adverse health effects such as fatigue, asthma, dizziness, and irritation of eye, nose, and throat (US EPA, 1987, 1991). In addition, (Mehlman, 1990) suggested that Benzene is characterized as human carcinogen, while other BTEX compounds also damage neurological properties and can develop some symptoms such as confusion, weakness, tiredness, nausea, memory loss (Baker, Smith, & Landrigan, 1985; Mehlman, 1990). BTEX also had been examined in several places worldwide such as Delhi and Kolkata, India (Dutta et al., 2009; Hoque, Khillare, Agarwal, Shridhar, & Balachandran, 2008). MongKok, Causeway Bay, Kuai Chung, Yuen Long, and HokTsui, Hongkong (Lee, Chiu, Ho, Zou, & Wang, 2002), Algiers, Algeria (Kerchich & Kerbachi, 2012), Bangkok, Thailand (Prechthai et al., 2013). Beijing, China (J. Liu et al., 2009).

Urban air pollution is one of top issue in environmental topic since metropolitan areas usually provide high levels of atmospheric pollution due to the combination of huge numbers of inhabitants, high density of population, intense vehicle traffic (Iovino, Polverino, Salvestrini, & Capasso, 2009). Furthermore, lots of height buildings obstruct air ventilation in some area of metropolitan cities, including Bangkok. These supported the accumulation of air pollution, especially indoor environment. (Ruchirawat, Settachan, Navasumrit, Tuntawiroon, & Autrup, 2007) claimed that the children living in big city like Bangkok may have an increased health risk of develop certain diseases due to exposure to genotoxic substances in air pollution compared to children living in suburban or rural areas. Many studies indicated that the major sources of air pollution in downtown, especially in Bangkok was the exhaust emission from vehicles (Han & Naeher, 2006; Leong, Muttamara, & Laortanakul, 2002; Muttamara, Leong, & Lertvisansak, 1999; Tamura, Jinsart, Yano, Karita, & Boudoung, 2003).

There were some researches that studied the concentration of the same chemicals in residential areas in Bangkok. (Daisy Morknoy, Khummongkol, & Prueaksasit, 2011) investigated 10 carbonyls at five roadside sites and five residential areas during July 2007 to April 2008. The results indicated that formaldehyde and acetaldehyde were the most abundant in Bangkok ambient air. Moreover, the concentrations of formaldehyde in residential areas were 3.06 to 10.9 µg m^{-3}, whereas its ambient concentration ranged from 5.14 to 17.2 µg m^{-3}. In case of acetaldehyde, the concentrations at residential sites were around 1.07 to 8.05 µg m^{-3}, while the concentration at roadside areas ranged from 1.59 to 7.95 µg m^{-3}. Since formaldehyde and acetaldehyde were water-dissolved carbonyls, their atmospheric concentrations were low during the rainy season. In contrast, their concentrations were quite high in cold season due to stable condition. Unlike cold season, summertime provided the promoted condition for photochemical reactions and also photolysis which caused declined concentrations of formaldehyde and acetaldehyde. Likewise, the concentrations of these two carbonyls were low during diurnal periods.

Even through the study of air pollution in Bangkok are available, the concentration of atmospheric toxic substances in residential areas still rare. Most studies were determined in working places such as gas stations, express roads for occupational health risk (Wiwanitkit, Suwansaksri, & Nasuan, 2001; Yimrungruang, Cheevaporn, Boonphakdee, Watchalayann, & Helander, 2008) and roadside (Jinsart et al., 2002; Daisy Morknoy et al., 2011; Muttamara & Leong, 2000). The most studies of carbonyl compounds and BTEX in Bangkok were taken at working places (Kitwattanavong, 2010; Tanasorn Tunsaringkarn et al., 2012; Tunsaringkarn, Siriwong, Rungsiyothin, & Nopparatbundit, 2012). For air pollution studied in residential areas in Bangkok, the study of carbonyl compounds and BTEX is still limited; although, there are some research in residential areas involved particulate maters (Chueinta, Hopke, & Paatero, 2000), health problems (Karita, Yano, Tamura, & Jinsart, 2004), carbonyl compounds (Daisy Morknoy et al., 2011). This information inspires the idea of this study aiming to investigate the concentration of carbonyl compounds and BTEX in residential areas, and evaluate current health risk situation of the residents in Pathumwan District, Bangkok where represented the central area of the city.

1.2 Objectives of the study

1) To determine indoor and outdoor concentration of carbonyl and BTEX in residential areas of inner city of Bangkok.
2) To investigate the relationship between indoor and outdoor concentration of carbonyl and BTEX in residential areas.
3) To compare concentration of carbonyl and BTEX between dry and wet seasons in residential areas of inner city of Bangkok.
4) To estimate potential health risk of inhalation exposure to carbonyl and BTEX of the residents in this living places.

1.3 Hypotheses

1) The atmospheric concentrations of carbonyl compounds and BTEX from indoor air can provide health effects to the residents for long term of exposure.
2) The outdoor concentrations of carbonyl compounds and BTEX have correlation with the indoor concentration of those compounds found in inner city of Bangkok.

1.4 Scopes of the study

1.4.1 Study areas

Five communities in Pathumwan district, Bangkok consist of SalakHin, LhungWatPathumwan, PattanaBonkai, SoiPrachen, and Chaw Chucheep communities have been selected as the sampling sites, since these communities are located in different zone of the district where have crowded population, and closed to the roads or highways in some cases. At each community, three houses were selected for sampling indoor air sample and one of these three houses was chosen for outdoor air sampling either.

1.4.2 Sampling technique for outdoor air concentration

In order to taking samples at the selected sites, 2,4 dinitrophenylhydrazine (DNPH) cartridge and a charcoal glass tube was used to collect carbonyl compounds and BTEX, respectively. DNPH cartridge and charcoal glass tube was connected to personal air pumps, using a flow rate of 100 mL/min. These devices were installed outside the sampling houses for 24 hours in each community.

1.4.3 Sampling technique for indoor concentration

For measurement of carbonyl compounds and BTEX along the daily exposure, the same sampling devices as outdoor were used for indoor air environment during the same sampling period (24 hours). The cartridge and charcoal glass tube was attached on the house wall for capturing the representative indoor air which would be used to calculate exposure inhalation of the residents.

1.4.4 Sampling program and duration

This research was divided into two parts: (1) to investigate the concentration of carbonyl compounds and BTEX at five communities in Pathumwan district, Bangkok, Thailand, comparison between dry and wet seasons, and (2) to determine the correlation between the indoor and outdoor concentrations of carbonyl compounds and BTEX at the communities.

Two phases of sampling were (1) dry (summer) season during 21st April to 24th May 2013, and (2) wet (rainy) season during 22nd September to 25th October 2013. Practically, 24-h sampling of both indoor and outdoor will be conducted three days a week (Sunday, Tuesday, and Friday) at each community for each season. These sampling days have been considered to cover weekday and weekend, which are reliable and good representative of air in those communities.

1.4.5 Analytical techniques

Since carbonyl compounds and BTEX have different chemical properties, HPLC/UV will be used for quantitative and qualitative analysis of carbonyl compounds collected by 2, 4 dinitrophenylhydrazine (DNPH) cartridges and extracted by using acetonitrile. The standard method 8315A (US EPA, 1996b) was followed for the analytical technique for determination of carbonyl compounds. Nonetheless, GC/FID will be used for analysis of BTEX absorbed in charcoal glass tubes and extracted by using carbon disulfide. The method analyzed BTEX followed the standard method 5030B suggested by (US EPA, 1996a).

1.4.6 Health risk assessment

Based on United States Environmental Agency (US EPA), the four steps which were (1) Hazard Identification; (2) Does-Respond Assessment; (3) Exposure Assessment; and (4) Risk Characterization would be performed in two scenario, general scenario and age interval scenario, in this study. Based on general scenario the health risk assessment process applied for this study following Risk Assessment Guidance for Superfund (RAGS): Volume I for Human Health Evaluation Manual created by the U.S. Environmental Protection Agency (EPA) with several parts (i.e., part A, vol.3 A, B, C, D, E, and F). Due to the related information about inhalation exposure guidelines, part A and F would be referred in this study. Part A is the Baseline Risk Assessment (US EPA, 1989), while part F is Supplemental Guidance for Inhalation Risk Assessment (US EPA, 2009). For the risk assessment of carcinogenic substances, the RAG Volume 1 Part A (1989), Human Health Evaluation Manual, a Chronic Daily Intake (CDI) will be considered for general guideline. While, the risk assessment of non-carcinogenic substance will follow the RAGS part F developed by US EPA (2009) in order to serve RfC values for risk estimation via inhalation partway. For age interval scenario, the lifetime cancer risk is calculated from each level of exposure period of time with age-specific parameters provided by Handbook for Implementing the Supplemental Cancer Guidance at Waste and Clean-up Sites (US EPA, 2012c).

The indoor concentrations of carbonyl compounds and BTEX determined from those five communities will be taken to calculate the health risk of cancer and non-cancer from inhalation exposure. Moreover, the essential information taken from questionnaire such as age, weight, gender, hours living in house, behavior related to air pollution, health problems will be also utilized for health risk assessment.

1.4.7 Ethical Consideration

The experimental protocol was approved by the committee on human rights related to human experimentation of Chulalongkorn University with the certified code no. 068/2013.

1.5 Expected outcomes

The outcomes expected to gain from this study are as follows:

1) The baseline information on indoor and outdoor air concentration of carbonyl compounds and BTEX in five communities of inner city of Bangkok, Thailand , which can be compared with air quality in other big cities in Asian Economy Community (AEC),
2) The health risk information of the residents who definitely living in the communities located in downtown of Bangkok, Thailand. This information might be used for further risk management and risk communication in order to set a precaution and reduce the risk from inhalation exposure of carbonyl compounds and BTEX in the society.

CHAPTER II

LITERATURE REVIEWS

2.1 Communities in Bangkok, Thailand

According to the (Report of Community in Bangkok, 2005) as the latest official version, Bangkok covered 1,568.737 km^2 with 50 districts within 6 groups of area (i.e., Center-Bangkok, South-Bangkok, North-Bangkok, West-Bangkok, East-Bangkok, North-Thon, South-Thon). The number of total population in 2005 was 5,658,953 people. Moreover, there were 1,809 communities (now almost 1,976 communities) consisted of 729 crowded communities, 299 housing developed communities, 348 suburban communities, 357 urbanized communities, and 76 flat communities within 374,428 houses or 458,157 families. The total population in all communities was around 1,843,089 people or 32.57% of all population in Bangkok. The amount and type of each administrative group of area is demonstrated in Table 2.1. Additionally, Bangkok can be categorized to 12 groups of administration (i.e., Rattanakosin, Lumpini, Vibhavadi, Chaophya, Krung Tonburei, Taksin, PranakonNeour, Burapha, Suwintawong, Srinagarind, Mahasawat, Sanamchai)

Pathumwan district has been considered to be the area for sample collection in this study, because it has many crowded communities which have quite similar characteristic such as lots of vehicle, their location near shopping malls. The approximate number of population in this area is 28,697 people within 4,911 houses, and 7,783 families. In Pathumwan district, there are 16 communities that can be categorized (i.e., WatDaung-Kae, Flat Police Station NakornbanPathumwan, Flat Train Station WatDaung-Kae, Patthana Bon-Kai, SalukHin, Baan Krua Tai, JarustMeaung, Chaw ChuCheep, Soi Polo, SoiPrachen, LhungWat-Pathumwanaram, SoiRaum-Rudee, Wat Chai-Mongkol, KanKaha Bon-Kai, Wat Sham-Ngham, WatBalom-Niwas).

Only five communities (i.g., SalukHin community: S, Patthana Bon-Kai community: B, LhungWatPathum community: P, SoiPrachen community: J, and Chaw Chucheepcommunity:C) that are selected to be sampling sites in this study. These five areas are crowed community in South-Bangkok group, Pathumwan district. The useful information of each community is provided in Table 2.2.

Table 2. 1 The amount and type of community in Bangkok

Administrative group of area	Community	Type of community				
		Crowded	Housing developed	Suburban	Urbanized	Flat
Bangkok	1,809	729	299	348	357	76
Rattanakosin	98	36	-	-	62	-
Lumpini	74	41	7	-	24	2
Vibhavadi	175	131	12	-	23	9
Chaophya	173	105	20	1	41	6
Krung Tonburei	209	188	3	-	17	1
Taksin	126	70	8	11	37	-
PranakonNeour	275	47	138	14	41	35
Burapha	177	60	48	22	45	2
Suwintawong	135	-	14	121	-	-
Srinagarind	138	5	22	65	30	16
Mahasawat	141	34	21	85	1	-
Sanamchai	88	12	6	29	36	5

(Report of Community in Bangkok, 2005)

Table 2. 2 The information of five residential areas for sample collection.

Community	Population			Number of family	Number of house	Number of committee
	Men	Women	Total			
S	426	449	875	115	80	8
B	2,897	3,053	5,950	1,190	441	25
P	2,892	3,208	6,100	1,260	516	16
J	2,982	3,003	5,985	1,175	470	25
C	473	508	981	198	91	8

Remark: For P (LhungWat-Pathumwanaram community), the actual number of population and houses are decline, since that area has been chosen for several shopping malls. The information of other communities quite the same. (Report of Community in Bangkok, 1995)

2.2 Chemical properties and toxicity of carbonyl compounds and BTEX

2.2.1 Carbonyl compounds

Carbonyl compounds have a similar functional group which is double bond between oxygen atom and carbon atom (C=O) in their molecular structure. This double bond of carbon atom and oxygen atom is polar bond because of the difference of electronegativity. Carbonyls can be both aldehydes or ketones as presented their chemical structure in Figure 2.1. For aldehydes, carbonyl functional group is located at the end of the molecular structure, while it is the central part of a carbon chain of ketone. Typically, the double bond of carbonyl group can react with other chemical easily.

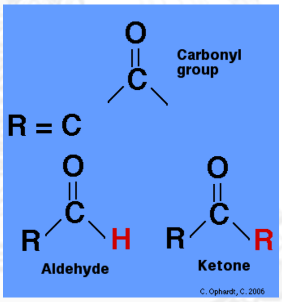


Figure 2. 1 Chemical structures of carbonyl functional group, aldehydes, and ketone (Ophardt, 2006)

Turning to consider about the formation of carbonyl compounds, aldehydes can be generated from the oxidation of primary (1°) alcohols such as reaction 2.1.

$$CH_3CH_2OH\ (l) + [O] \rightarrow CH_3CHO\ (l) + H_2O\ (l) \qquad (2.1)$$

Ethanol Ethanal

Nonetheless, other chemical can possible be occurred further as in reaction 2.2.

$$CH_3CHO\ (l) + [O] \rightarrow CH_3COOH\ (l) \qquad (2.2)$$

Ethanal Ethanoic acid

In addition, ketones can be formed by the oxidation of secondary (2°) alcohols such as reaction 2.3.

$$CH_3CHOHCH_3\,(l) + [O] \rightarrow CH_3COCH_3\,(l) + H_2O\,(l) \qquad (2.3)$$

Propan-2-ol Propanone

This way, aldehydes are readily oxidized to acids, whereas ketones can only be oxidized to acids under strong conditions.For the identification of carbonyl compounds, there are two general methods: (1) the characteristically strong peak at 1,400-1,600 cm^{-1} in the infrared spectrum and (2) the formation of orange crystalline precipitate with 2, 4-dinitrophenylhydrazine. These manners cannot differentiate aldehydes and ketones. Moreover, there are some chemicals that can reduce amount of carbonyl group such as hydride reagents (e.g., $NaBH_4$, $LiAlH_4$), hydrogen, catalyst (e.g., Raney nickel, copper chromite, radium, rhenium, ruthenium).

Since carbonyl compounds are classified to be Volatile Organic Compounds (VOCs), these compounds have been considered to be the major critical substances of the photochemical reactions in lower stratosphere and also troposphere (Lary & Shallcross, 2000). Atmospheric free radicals have been expected to be the significant results of the photolysis of carbonyl compounds. To illustrate, peroxyacetyl nitrate (PAN) which is one of a temporary reservoir for reactive nitrogen and also aerosols formation is generated from the reaction of acetone in the atmosphere (Arnold, Knop, & Ziereis, 1986). Furthermore, (Hinckley J.M., 2008) claimed that the carbonyl group plays an important role in benzophenone photochemical reaction. The photoreduction of benzophenone in isopropyl alcohol is shown in Figure 2.2. These reactions are stimulated by sunlight, then generated a lot of radicals and also form acetone as by-product.

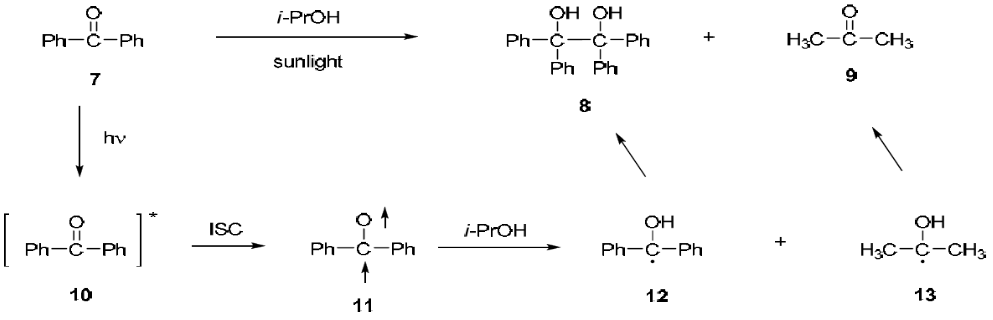


Figure 2. 2 Photoreduction of benzophenone in isopropyl alcohol

(^{7}Benzophenone; ^{8}Benzopinacol; ^{9}Acetone; ^{10}A photoexcited state of benzophenone; ^{11}Triplet; ^{12}Radical; ^{13}The 2-hydroxypropyl radical) (Hinckley J.M., 2008)

Based on the study of (Tanner, Miguel, De Andrade, Gaffney, & Streit, 1988) they suggested that formaldehyde and acetaldehyde had significantly impact to the formation of secondary pollutants, increasing of ozone maxima, and also the photochemical reaction. For instant, there were two reactions that the net formation of one or two hydroperoxyl (HO_2) radicals could be generated from the gas-phase photochemical reaction of HCHO: (1) reaction with OH as presented in reaction 2.4 and (2) photolysis as described in reaction 2.5.

$$HCHO + OH + O_2 \rightarrow HO_2 + CO + H_2O \qquad (2.4)$$

$$HCHO + h\nu \text{ (wavelength < 360 nm)} \rightarrow HCO + H \qquad (2.5)$$

$$HCO + O_2 \rightarrow HO_2 + CO \qquad (2.6)$$

$$H + O_2 \rightarrow HO_2 \qquad (2.7)$$

Additionally, nitric oxide (NO) may be oxidized by these hydroperoxyl radicals and converted to NO_2 and OH or assemble as shown in reaction 2.8. This chemical reaction promoted the level of atmospheric hydrogen peroxide which was an important oxidant of dissolved sulfur dioxide in cloud water and precipitation.

$$2HO_2 \rightarrow H_2O_2 + O_2 \qquad (2.8)$$

The formation of HO_2 radicals, CO, and methylperoxyl radicals could be performed by the photolysis of acetaldehyde in the atmospheric condition (reaction 2.9), while the peroxyacetyl radical and peroxyacetyl nitrate (PAN) might be the by-product from the reaction between OH and acetaldehyde as demonstrated in reaction 2.10-2.12. However, acetylperoxyl radicals that were produced as illustrated in reaction 11 could oxidize NO to NO_2 when the abundant of NO concentration has been found. This way, the formation of PAN has been interrupted.

$$CH_3CHO \rightarrow CH_3 + CHO + 2O_2 \rightarrow CH_3O_2 + HO_2 + CO \qquad (2.9)$$

$$CH_3CHO + OH \rightarrow CH_3CO\cdot + H_2O \qquad (2.10)$$

$$CH_3CO\cdot + O_2 \rightarrow CH_3C(O)O_2\cdot \qquad (2.11)$$

$$CH_3C(O)O_2\cdot + NO_2 \leftrightarrow CH_3C(O)OONO_2 \text{ (PAN)} \qquad (2.12)$$

During the daytime in polluted urban atmosphere, the important reaction which generated high concentration of PAN was the degradation of CH_3CHO by reaction with OH, especially the concentration of NO was very low. This situation provided ozone level rise in urban atmosphere. After PAN, higher alkyl homologues, and aromatic homologues (e.g., peroxybenzoyl nitrate) were expected to be photochemical toxins and strong lachrymators. In addition, PAN which had long lifetime, especially in cold temperature was considered to be the important chemical involved the transportation of NO_x within regional and global environment. Proportionately, this study mainly focused on some aldehydes and ketone (e.g., formaldehyde, acetaldehyde, acetone, propionaldehyde, and crotonaldehyde) which are considered to be secondary atmospheric pollutants. The description of characteristics, physicochemical properties, potential sources, and human health effects of these carbonyl compounds are briefly summarized as follows:

1) Formaldehyde

Formaldehyde has many scientific names such as methyl aldehyde, methylene glycol, methylene oxide, formalin, formol, formic aldehyde, oxomethane, or oxymethylene. Normally, this chemical is colorless gas and has a strong, suffocating, pungent, and highly irritating odor at ambient condition. Its molecular structure is demonstrated in Figure 2.3. In addition, it can dissolve in alcohol, ether, acetone, benzene, water, and other polar solvents (HSDB, 2011f). Typically, formaldehyde can be broke down easily in environment by sunlight or microorganism activities in soil and water media. If human intake this compound inside of the body, the metabolism can convert it to formic acid readily. A synopsis of its physicochemical properties is provided in Table 2.3.

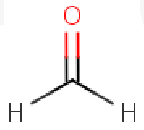


Figure 2. 3 Chemical structure of formaldehyde (HSDB, 2011f)

Table 2. 3 Physicochemical properties of formaldehyde

Property	Information	Reference
Formula	CH_2O	U.S. EPA, 2007
CAS registry no.	50-00-0	(HSDB, 2011f)
Molecular weight	30.03	
Density	0.816 g/cm^3 at 20 °C	
Vapor density	1.067 (Air= 1)	
Vapor pressure	3,890 mmHg at 25 °C 10 mmHg at -88 °C	(HSDB, 2011f) U.S. EPA, 2007
Log K_{ow}	0.35 -0.65	
Henry's law constant at 25 °C	$3.37\text{x}10^{-7}$ atm-m^3/mol at 25 °C	(HSDB, 2011f)
Conversion factors in air (25 °C, 760 mmHg)	1 ppm = 1.23 mg/m^3	U.S. EPA, 2007
Boiling point	-19.5 °C	(HSDB, 2011f)
Melting point	-92 °C	
Solubility in water	$4.00 \text{ x } 10^5$ mg/L at 20 °C	

Since formaldehyde is widely used in manufacture of building materials and numerous household products, it has been considered to be the atmospheric toxic substance both indoors and outdoors. Besides, this substance is also a by-product of combustion and other natural processes. Smoking and the use of un-vented, fuel-burning appliances (e.g., gas stoves, kerosene space heaters) can generate formaldehyde as well. Inside the building, pressed wood products; for example, particle board, hardwood, plywood paneling are the most significant sources of formaldehyde as well as glues, adhesives, paints, and coating products. Nonetheless, automobile exhaust fumes, power plants, and other anthropogenic activities are also the important sources of formaldehyde (US EPA, 2012b).

According to the National Cancer Institute (2011), formaldehyde can cause adverse health effects (e.g., watery eyes, burning sensations in the eyes, nose, and throat, coughing, wheezing, nausea, and skin irritation) at level exceeding 0.1 ppm in the atmospheric condition.

People who drink water contaminated with high concentration of formaldehyde can get vomiting, coma, severe pain, and possible death. In 1980, the findings of nasal cancer in rats had been found after testing with formaldehyde. Since that time, some studies of humans have suggested that the exposure of this chemical has correlation with certain types of cancer. Based on the International Agency for Research on Cancer (IARC), this substance has been classified to be human carcinogenic chemical. Moreover, the National Toxicology Program, an interagency program of the Department of Health and Human Services (DHHS) described formaldehyde as human carcinogen. Based on the Hazardous Substances Data Bank (HSDB), there is sufficient evidence that formaldehyde has the carcinogenicity susceptible with human as in group 1, likewise in experimental animals.

2) Acetaldehyde

Acetaldehyde is also known as acetic aldehyde, ethyl aldehyde, or ethanal (IUPAC name). Generally, it is a colorless volatile liquid with a pungent, fruity odor at the normal condition. It is a highly flammable and reactive substance. The chemical structure of this compound is illustrated in Figure 2.4. Acetaldehyde is miscible in ethanol, ether, benzene, gasoline, solvent naphtha, toluene, xylene, turpentine, acetone, water, and slightly soluble in chloroform (HSDB, 2011a). Commonly, acetaldehyde exists in coffee, bread, and ripe fruits. It can be produced by metabolism of plants, oxidation of ethylene. The possible routes of exposure for this chemical are air, water, groundwater or land, as well as drink and smoke. A synopsis of its physicochemical properties is provided in Table 2.4.

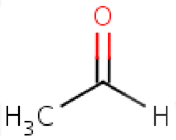


Figure 2. 4 Chemical structure of acetaldehyde (HSDB, 2011a)

Table 2. 4 Physicochemical properties of acetaldehyde

Property	Information	Reference
Formula	C_2H_4O	(HSDB, 2011a)
CAS registry no.	75-07-0	
Molecular weight	44.05	

Property	Information	Reference
Density	0.7834 g/cm^3 at 18 ℃ 0.788 g/cm^3	(HSDB, 2011a) U.S. EPA, 1994
Vapor density	1.52 (Air = 1)	(HSDB, 2011a)
Vapor pressure	902 mmHg at 25 ℃	
Log K_{ow}	-0.34	
Henry's law constant at 25 ℃	6.67×10^{-5} atm-m^3/mol at 25 ℃	
Conversion factors in air (25 ℃, 760 mmHg)	1 ppm = 1.83 mg/m^3 1 mg/m^3 = 0.55 ppm	U.S. EPA, 1994
Boiling point	20.1 ℃	(HSDB, 2011a)
Melting point	-123.37 ℃	
Solubility in water	1×10^6 mg/L at 25 ℃ (miscible)	

According to U.S. EPA (2000), acetaldehyde is commonly used as an intermediate in the synthesis of other chemicals (e.g., acetic acid, pyridine and pyridine bases, and peracetic acid). This substance is also commonly used in the productions of perfumes, polyester resins, basic dyes, and also be used as a fruit and fish preservative, a flavoring agent, fuel compositions, solvent in rubber, tanning, and paper industries. Naturally, acetaldehyde is ubiquitous in the ambient environment. It can be generated by higher plant respiration, incomplete wood combustion in fireplaces and wood stoves, vehicle exhaust fumes, burning of tobacco, coffee roasting, coal refining, and waste processing. Additionally, our bodies can form acetaldehyde after the degradation of ethanol, especially people who drink alcohol beverage.

Human who exposed with acetaldehyde can get irritation of the eyes, skin, and respiratory tract via inhalation pathway of exposure. Other human health effects (e.g., erythema, coughing, pulmonary edema, and necrosis) may present when human expose at higher levels. Some studies claimed that experimental animals showed a depressed respiratory rate and elevated blood pressure when they exposed acetaldehyde via inhalation. Based on (HSDB, 2011a), this compound is considered to be human carcinogenic substance with inadequate evidence. Since there is sufficient evidence for carcinogenicity of acetaldehyde in experimental animals, this chemical has been classified to be possibly carcinogenic chemical to human as in group 2B.

3) Acetone

Acetone is also known as propanone (IUPAC name), propan-2-one, dimethyl ketone, β-ketopropane, 2-propanone, dimethyl formaldehyde, or pyroacetic spirit. Its molecular structure is presented in Figure 2.5. Acetone is colorless, mobile, flammable liquid with pungent, irritating, and floral smell. This substrate is miscible with benzene, water, alcohol, dimethylformamide, ether, chloroform, and other oils (HSDB, 2011b). Other relevant chemical and physical properties are provided in Table 2.5. Typically, it is used for cleaning purposes in laboratory and solvent. Nonetheless, acetone can be generated and removed out from human body via normal metabolism. This chemical can be formed in blood and urine. In case of diabetes patients, acetone can be detected in large amounts.

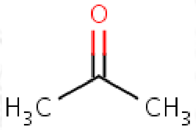


Figure 2. 5 Chemical structure of acetone (HSDB, 2011b)

Since acetone is the simplest structure of ketone, it is commonly used as solvent for fats, oils, waxes, resins, rubbers, plastics, pharmaceuticals and rubber cements. These performances may release acetone into the environment via many waste streams. Additionally, this chemical is an important agent for extracting and starting or intermediate agent for the manufacture of other chemicals. Moreover, acetone is one of the by-product gas from wood-burning fireplaces (Lipari, Dasch, & Scruggs, 1984). In nature, acetone is expected to be component of oxidation of humus substances. Moreover, formation of west coast kelp can also produce acetone. In plants and animals, acetone is a natural by-product of their metabolism. Furthermore, volcanoes and forest fires can also emit acetone into the atmospheric environment (Graedel, Hawkins, & Claxton, 1986).

Table 2. 5 Physicochemical properties of acetone

Property	Information	Reference
Formula	C_3H_6O	(HSDB, 2011b)
CAS registry no.	67-64-1	
Molecular weight	58.08	
Density	0.7845 g/cm^3 at 20 °C	
Vapor density	2 (Air = 1)	(DHHS, 1988)
Vapor pressure	231 mmHg at 25 °C	(HSDB, 2011b)
Log K_{ow}	-0.24	
Henry's law constant at 25 °C	3.97×10^{-5} atm-m^3/mole at 25 °C	
Conversion factors in air (25 °C, 760 mmHg)	1 ppm = 0.42 (mg/m^3) 1 mg/m^3 = 2.38 (ppm) 1 ppm = 2.374 mg/m3	The National Academic Press, 1984; (ATSDR, 1994)
Boiling point	56.05 °C at 760 mm Hg	(HSDB, 2011b)
Melting point	-94.7 °C	
Solubility in water	Miscible with water	(O'Neil, 2001)

Although there are no rigid evidences of chronic health effects at low level of exposure, acetone may cause severe irritation with eyes, depress the central and nervous system, and potential pulmonary as respiration risk at very high atmospheric concentration. According to (IRIS, 2000), acetone has been classified to be non-human carcinogenic substance due to lacking of carcinogenic evidences in humans and animals. Likewise IRIS (2000), American Conference of Governmental Industrial Hygienists TLVs and BEIs (2010) claimed that acetone is considered to be chemical group A4 with no carcinogenic activity susceptible with human.

4) Propionaldehyde

Propionaldehyde also has many scientific name such as propanal (IUPAC name), methylacetaldehyde, propionic aldehyde, and propaldehyde. This compound is a colorless liquid with a slightly irritating, fruity odor. The molecular structure of propionaldehyde is illustrated in Figure 2.6. Propionaldehyde is soluble in water, chloroform, and miscible with ethanol, ethyl ether (HSDB, 2011g). Since this chemical is a saturated 3-carbon aldehyde, propionaldehyde is a structural isomer of acetone. A synopsis of its physicochemical properties is provided in Table 2.6.

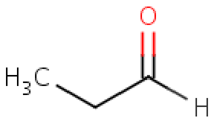


Figure 2. 6 **Chemical structure of propionaldehyde** (HSDB, 2011g)

Table 2. 6 **Physicochemical properties of propionaldehyde**

Property	Information	Reference
Formula	C_3H_6O	(HSDB, 2011g)
CAS registry no.	123-38-6	
Molecular weight	58.079	
Density	0.8657 g/cm^3 at 25 °C	
Vapor density	1.8 at 100 °F (Air = 1)	
Vapor pressure	317 mmHg at 25 °C	
Log K_{ow}	0.59	
Henry's law constant at 25 °C	7.34x10^{-5} atm-m^3/mole at 25 °C	
Conversion factors in air (25 °C, 760 mmHg)	1 ppm = 2.38 mg/m^3 1 mg/m^3 = 0.42 ppm	IRIS, 2008
Boiling point	48 °C	(HSDB, 2011g)
Melting point	-80 °C	
Solubility in water	3.06x10^5 mg/L at 25 °C	

Normally, propionaldehyde is an important chemical in the manufacture of propionic acid, polyvinyl and other plastic materials, rubber chemicals, disinfectant, and also preservatives (Lewis, 1997). In term of the production, propionaldehyde is mainly generated in industrial process through hydroformylation via combination of synthesis gas (carbon monoxide and hydrogen) with ethylene using rhodium as a metallic catalyst. Furthermore, the reaction between oxidizing propanol with a mixture of sulfuric acid and potassium dichromate can also produce propionaldehyde as well. In nature, this substance can be emitted as a volatile form arboreous plants (Isidorov, Zenkevich, & Ioffe, 1985).

The vapor of propionaldehyde can cause irritation of eyes and skin, burning sensation, nosebleeds, sore throat, cough, phlegm, and rash after expose via respiratory tract. Higher level of exposure can develop pulmonary edema or even the death. Additionally, the irritation of the lungs, which related to bronchitis, may possibly occur when human exposed with propionaldehyde for long period of time.

5) Crotonaldehyde

Crotonaldehyde is also known as 2E-but-2-enal (IUPAC name), crotoinicaldehdye, crotonal, aldehyde crotonique, or β-methacrolein. The chemical structure of crotonaldehyde is demonstrated in Figure 2.7. This substrate is a colorless liquid with pungent and suffocating smell. Crotonaldehyde is soluble in chloroform, ethanol, ethyl ether, acetone, water, and miscible with benzene, alcohol, ether, toluene, kerosene, gasoline, and solvent naphtha (HSDB, 2011d). The information of physicochemical properties of crotonaldehyde is provided in Table 2.7.

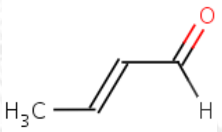


Figure 2. 7 Chemical structure of crotonaldehyde (HSDB, 2011d)

Crotonaldehyde are generated from the arboreous plant Chinese arborvitae(Isidorov et al., 1985) and also in ground musty sorghum (Seitz, Ram, & Rengarajan, 1999). For man-made source of this chemical, the exhaust gases from gasoline and methanol powered engines comprises of crotonaldehyde (Konopczynski et al., 1980). Mostly, crotonaldehyde is used as an intermediate for n-butyl alcohol and 2-ethylhexyl alcohol, a solvent, or used in a preparation of rubber accelerators, purification of lubricating oils, insecticides, tear gases, fuel-gas warning agents, organic synthesis, leather tanning, and also alcohol denaturants (Lewis et al., 2007). These sources can release this substance into the environmental atmosphere. Additionally, the combustion of wood, tobacco, cigarette, polymer, and turbin exhaust also generate atmospheric crotonaldehyde (Graedel et al., 1986; Hampton, Pierson, Harvey, & Schuetzle, 1983; Lipari et al., 1984). In addition, crotonaldehyde can be produced by the crotonic condensation of acetaldehyde. Commonly, crotonaldehyde is used as a precursor to other fine chemical such as sorbic acid, trimethyl hydroquinone, and vitamin E.

Table 2. 7 Physicochemical properties of crotonaldehyde

Property	Information	Reference
Formula	C_4H_6O	(HSDB, 2011d)
CAS registry no.	4170-30-3	
Molecular weight	70.09	
Density	0.8516 g/cm^3 at 20 °C	
Vapor density	2.41 (Air = 1)	
Vapor pressure	30 mmHg at 25 °C	
Log K_{ow}	0.60	
Henry's law constant at 25 °C	9.68x10^{-6} atm-m^3/mol at 25 °C	
Conversion factors in air (25 °C, 760 mmHg)	1 mg/L= 349 ppm 1 ppm = 2.8 mg/m^3	
Boiling point	102.2 °C	
Melting point	-76 °C	
Solubility in water	1.81x10^5 mg/L at 20 °C	

In term of toxicity, this compound is considered to be irritant agent. Crotonaldehyde is highly toxic via the dermal route of exposure. Crotonaldehyde in liquid phase can cause rapid and severe eye and skin irritation or burns. Moreover, exposure with vapor of this compound promotes inflammation of mucous membranes. Since crotonaldehyde is very irritating agent, ingestion of this substance would probably cause burns of the lips, mouth, throat, esophagus, and stomach (ATSDR, 2009). Vapor of crotonaldehyde can develop pulmonary edema at high concentrations (Sullivan, 1992). According to U.S. Environmental Protection Agency's Integrated Risk Information System (IRIS), crotonaldehyde has been classified to be group C which is possible human carcinogenic substance, while World Health Organization, International Agency for

Research on Cancer (IARC, 1995) suggested that crotonaldehdye is not classifiable as human carcinogen as in group 3.

2.2.2 Reaction between carbonyl compounds and DNPH cartridge

(Uchiyama, Inaba, & Kunugita, 2011) described the reaction of carbonyl compounds with 2,4-dinitrophenylhydrazine forming the corresponding 2,4-DNP hydrazones as presented in Figure 2.8. In the beginning of hydrazone formation, the amine attacked the carbonyl carbon. While alkoxide ion provided a proton, ammonium ion took a proton and formed a neutral tetrahedral intermediate. The neutral tetrahedral intermediate or called a carbinolamine was in equilibrium with two protonated forms. Protonation could occur either the nitrogen or the oxygen atom. Elimination of water from the oxygen-protonated intermediate produced a protonated hydrazone that lost a proton to yield the hydrazone. The main advantage of the DNPH derivatization method was the ability to analyze various aldehydes and ketones simultaneously in a complex mixture. Sampling could be performed using acidic solutions of DNPH in impingers or with acidic solid sorbents coated with DNPH in a cartridge. In this study, a cartridge containing acidic solid sorbents coated with DNPH which was provided for sampling aldehydes had been selected for air sampling collection.

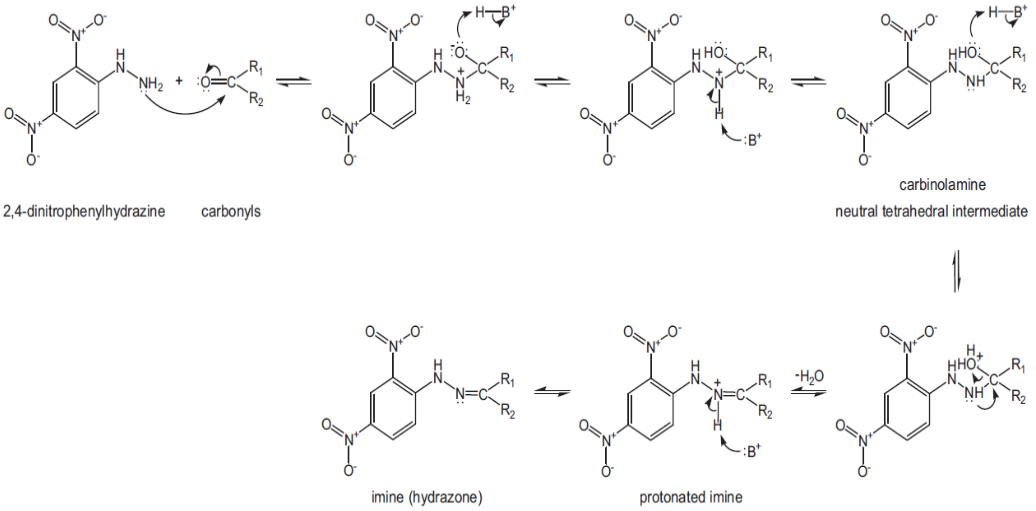


Figure 2. 8 Scheme of the derivatization reaction of DNPH with carbonyls (Uchiyama et al., 2011)

2.2.3 BTEX

BTEX is in the term used for benzene, toluene, ethylbenzene, and xylene. These compounds are considered to be the Volatile Organic Compounds (VOCs) that commonly found in petroleum product (e.g., gasoline, diesel fuel) (US EPA, 2010a). Generally, BTEX are components in crude oil, crude petroleum, and exist in seawater (IPCS, 1993). The volcanoes, and forest fires have been concerned to be the natural sources of BTEX compounds, since their emission increases the atmospheric concentration of BTEX in the environment (IPCS 1985, 1993, 1996, ATSDR 2007a). Turning to consider the human-made sources of BTEX, automobile and aircraft exhaust fume, oil spill, leakage of petroleum fuel, cigarette smoke, and other anthropogenic performances can also release BTEX to the atmospheric condition.

Understanding fate and transportation of BTEX are necessary, since it has several mechanisms involved (e.g., volatilization, dispersion, sorption, dissolution, precipitation, degradation). Due to their high value of Henry’s constant, BTEX compounds can readily volatile to the atmospheric media. This way, the exposure of atmospheric BTEX have to be evaluated in order to prevent the appearance of any adverse human health effects both indoors and outdoors, especially around the residential areas where people expected to have long period of exposure.

There are various types of technology for the remediation of BTEX such as biodegradation, vapor phase extraction, air stripping (Christensen and Elton, 1996), photochemical reaction (Jeong, Sekiguchi, & Sakamoto, 2004).

Jeong et al. (2004), OH radicals could be generated when molecules of water absorbed a continuous UV spectrum between 175 and 190 nm as shown the mechanism in reaction 2.13. They also suggested that the reaction in a nitrogen stream was not recommended, since the complete oxidation to CO_2 could not be success under the absence of oxygen.

$$H_2O + h\nu \rightarrow H + O\cdot \qquad (2.13)$$

Even through, there was not TiO_2catalyst, toluene was drastically degraded in humid stream. Hence, the complete conversion of toluene had been found when TiO_2 was available at that condition. Since the dried air stream was served as condition, reactive species of O_3 (e.g., $O(^1D)$, $O(^3P)$) had been obtained from the reactor upon 254+185 nm irradiation as depicted in reactions 2.14-2.16; while formation of OH radicals was limited. Based on these reactions, the reactive species of oxygen had substantially influent to the decomposition of toluene.

$$O_2 + hv\ (< 243\ nm) \rightarrow O(^1D) + O(^3P) \quad (2.14)$$

$$O(^1D) + M \rightarrow O(^3P) + M\ (M=O_2\ or\ N_2) \quad (2.15)$$

$$O(^3P) + O_2 + M \rightarrow O_3 + M \quad (2.16)$$

$$O_3 + hv\ (< 310\ nm) \rightarrow O(^1D) + O2 \quad (2.17)$$

$$O(^1D) + H_2O \rightarrow 2OH\cdot \quad (2.18)$$

Furthermore, the electronically excited reactive species of oxygen atoms ($O(^1D)$) that was formed by the photolysis of ozone might react with OH radicals after adding water vapor in an air stream as provided in reaction 17-18. In this condition, abundant reactive species including OH radicals could exist. In briefly conclusion, the findings supported that the humid air stream promoted the abundant reactive species in gas phase which enhanced the effectiveness of toluene decomposition without TiO_2 catalyst. The description of characteristics, physicochemical properties, potential sources, and human health effects of BTEX are briefly summarized as follows:

1) Benzene

Benzene has several names such as cyclohexa-1,3,5-triene, 1,3,5-cyclohexatriene, benzol, or phene. This compound is a colorless and highly flammable liquid with a sweet smell. Generally, benzene occurs naturally, but mostly come from petroleum production. Its molecular structure is presented in Figure 2.9. Benzene is soluble in water and miscible with alcohol, chloroform, ether, carbon disulfide, acetone, oils, carbon tetrachloride, glacial acetic acid, and most organic solvents (HSDB, 2011c). Basically, benzene is a natural composition of crude oil and cigarette smoke. Due to its high octane number, it plays an important role in gasoline. A synopsis of its physicochemical properties is provided in Table 2.8.

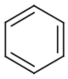


Figure 2. 9 Chemical structure of benzene (HSDB, 2011c)

Practically, this chemical has been used as an intermediate in the production of other chemicals including ethylbenzene, cumene, cyclohexane, nitrobenzene, and so forth. Furthermore, benzene is also used as precursor in the manufacture of pesticides, plastics, resins, lubricants, rubbers, dyes, and detergents. Artificial pollution sources of benzene are the production, storaging, transportation, venting, combustion of gasoline, oil spills, and so on. Nevertheless, benzene can also be generated from nature (e.g., volcano activities, forest fires, plant volatilization). This substance also is the gradient of fruits, vegetables, meats, and daily products as well (HSDB, 2011c).

Table 2. 8 Physicochemical properties of benzene

Property	Information	Reference
Formula	C_6H_6	(HSDB, 2011c)
CAS registry no.	71-43-2	
Molecular weight	78.11	
Density	0.8787 at 15 °C	
Vapor density	2.8 (air= 1)	
Vapor pressure	94.8 mmHg at 25 °C	
Log K_{ow}	2.13	
Henry's law constant at 25 °C	5.56×10^{-3} atm-m^3/mol at 25 °C	
Conversion factors in air (25 °C, 760 mmHg)	1 ppm = 3.26 mg/m^3	
Boiling point	80.1 °C	
Melting point	5.5 °C	
Solubility in water	1.79×10^{3} mg/L at 25 °C	

High concentrations of benzene in the atmosphere provide neurological toxicity and may sensitize the myocardium to endogenous catecholamines, while gastrointestinal and neurological toxicity can occur after exposed via intestinal route. The chronic human health effects of benzene are hemato toxicity, aplastic anemia, pancytopenia, leukemia, dizziness, drowsiness, confusion, and loss of consciousness. According to (HSDB, 2011c), benzene has been classified to be human carcinogen as group 1 with sufficient evidences in humans and experimental animals.

2) Toluene

Toluene is also known as methylbenzene (IUPAC name), phenyl methane, toluol, or anisen. It is a colorless, water-insoluble liquid with paint thinner smell. Its chemical structure is depicted in Figure 2.10. Toluene is soluble in water, ethanol, benzene, diethyl ether, acetone, chloroform, glacial acetic acid, carbon disulfide and miscible with alcohol, chloroform, ether, acetone, glacial acetic acid, and carbon disulfide. This substance is popular utilized as an industrial feedstock, a solvent, an inhalant drug, and so on. A synopsis of its physicochemical properties is provided in Table 2.9.

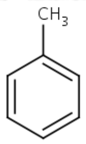


Figure 2. 10 Chemical structure of toluene (HSDB, 2011h)

In nature, toluene can be found in natural gas deposits, crude oil, and also can be generated from volcanoes and forest fires. However, smoke of cigarettes, volatilization of petroleum fuels, toluene-based solvents, thinners, vehicle exhaust fumes, and other man-made sources can emit toluene to the atmospheric environment.

Tiredness, weakness, confusion, drunken type actions, memory loss, nausea, loss of appetite and hearing, and color vision loss can occur to people who exposed with low or moderate levels of toluene. Nonetheless, high concentration of toluene can cause light-headness, nausea, or sleepiness after exposed via inhalation with a short period of time. Additionally, unconsciousness and death can possibly happen after exposed with this substance. In case of cancer, there are still inadequate evidences in humans and experimental animals. Hence, toluene which is classified as a group 3, does not be considered to be human carcinogenic substance (IARC, 1999). In contrast, (US EPA, 2006b) and IRIS (2000) suggested that toluene does not have carcinogenicity susceptible with human as group D. Likewise, American Conference of Governmental Industrial Hygienists TLVs and BEIs claimed toluene as non-carcinogenic substance to human as group A4.

Table 2. 9 Physicochemical properties of toluene

Property	Information	Reference
Formula	C_7H_8	(HSDB, 2011h)
CAS registry no.	108-88-3	
Molecular weight	92.14	
Density	0.8636 at 20 °C	
Vapor density	3.1 (Air=1)	
Vapor pressure	28.4 mmHg at 25 °C	
Log K_{ow}	2.73	
Henry's law constant at 25 °C	6.64×10^{-3} atm-m^3/mole at 25 °C	
Conversion factors in air (25 °C, 760 mmHg)	1 ppm = 3.76/m^3 1 mg/L= 226 ppm	
Boiling point	110.6 °C	
Melting point	-94.9 °C	
Solubility in water	526 mg/L at 25 °C	

3) Ethylbenzene

Ethylbenzene also has various scientific names (i.g., ethylbenzol, phenyl ethane, alpha-methyl toluene) which are a highly flammable, colorless liquid with a gasoline-like odor. Its chemical structure is presented in Figure 2.11. Ethylbenzene is soluble in ethyl alcohol, ethyl ether, water, alcohol, benzene, carbon tetrachloride, ether, and miscible with the normal organic solvents. This compound is very important in the petrochemical industries. It is commonly used as intermediate and precursor of the manufacture of other chemicals (e.g., styrene, plastics). A synopsis of its physicochemical properties is given in Table 2.10.

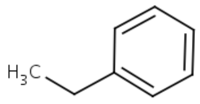


Figure 2. 11 Chemical structure of ethylbenzene (HSDB, 2011e)

This chemical can be generated naturally from biomass combustion and is component of crude oil. By the way, ethylbenzene is used as a resin solvent, component of automotive and aviation fuels, and intermediate for the production of styrene. These ways, this chemical can be released to the environment from several waste streams (HSDB, 2011e).

The acute toxicity of this substance trends to be low. However, the high atmospheric concentration of ethylbenzene can cause eyes and throat sensitivities and dizziness. Nonetheless, our bodies can degrade this compound to 1-phenyl ethanol, acetophenone, phenyl glyoxylic acid, mandelic acid, benzoic acid, hippuric acid. This chemical is classified as a group D which does not have human carcinogenic activity (IRIS, 2000).

Table 2. 10 Physicochemical properties of ethylbenzene

Property	Information	Reference
Formula	C_8H_{10}	(HSDB, 2011e)
CAS registry no.	100-41-4	
Molecular weight	106.16	
Density	0.8670 at 20 ℃	
Vapor density	3.66 (Air= 1)	
Vapor pressure	9.6 mmHg at 25 ℃	
Log K_{ow}	3.15	
Henry's law constant at 25 ℃	7.88×10^{-3} atm-m^3/mol at 25 ℃	
Conversion factors in air (25 ℃, 760 mmHg)	1 mg/L = 230 ppm 1 ppm = 4.35 mg/m^3 at 25 ℃	
Boiling point	136.1 ℃	
Melting point	-94.9 ℃	
Solubility in water	169 mg/L at 25 ℃	

4) Xylenes

There are three isomeric xylenes comprise of meta-, ortho-, and para-xylene (m-, o-, p-xylene). The property of their mixture is a colorless, slightly greasy, and flammable liquid. The molecular structures of these compounds are demonstrated in Figure 2.12. These isomeric xylenes are soluble in water and miscible with absolute alcohol, ether, and many other organic liquids. These chemicals can be produced by catalytic reforming and coal carbonization in the production of coke fuel. A synopsis of their physicochemical properties is given in Table 2.11. Xylenes play an important role in petrochemicals.

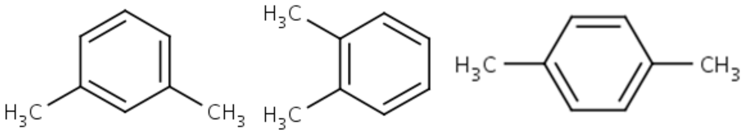


Figure 2. 12 Chemical structure of m-, o-, p-xylene (HSDB, 2011i)

Table 2. 11 Physicochemical properties of xylenes

Property	Mixed xylene	m-xylene	o-xylene	p-xylene
Formula	C_8H_{10} ^{a}			
CAS registry no.	1330-20-7^a	108-38-3^a	95-47-6^a	106-42-3^a
Molecular weight	106.17^a	106.16^a	106.16^a	106.16^a
Density	0.86 at 20 ℃^{a}	0.8684 at 15 ℃^{a}	0.880 at 20 ℃^{a}	0.861 at 20 ℃^{a}
Vapor density	No data	3.66 (Air = 1)^a	3.7 (Air = 1)^a	3.7 (Air= 1)^a
Vapor pressure	No data	8.29 mmHg at 25 ℃^{a}	6.61 mmHg at 25 ℃ ^{a}	8.84 mmHg at 25 ℃^{a}
Log K_{ow}	No data	3.20^a	3.12^a	3.15^a
Henry's law constant at 25 ℃	No data	6.91x 10^{-3} atm-m^3/mol^c	5.18x10^{-3} atm-m^3/mol^a	6.90x10^{-3} atm-m^3/mol^a
Conversion factors in air (25 ℃, 760 mmHg)	1 ppb = 4.34 mg/m^{3b}			
Boiling point	Grade dependent^a	139.07 ℃^{a}	144.5 ℃^{a}	138.23 ℃^{a}
Melting point	No data	-47.4 ℃^{a}	-25.2 ℃^{a}	13.25 ℃^{a}
Solubility in water	106 mg/L at 25 ℃^{a}	1.61x10^2 mg/L at 25 deg C^a	1.78x10^2 mg/L at 25 ℃^{a}	1.62x10^2 mg/L at 25 ℃^{a}

^{a}(HSDB, 2011i); ^{b}(ATSDR, 1995b), HSDB (1995), CRC (1994); ^{c}(US EPA, 2013a)

Petroleum, forest fires, and volatiles of plants are expected to be the natural source of xylene. Small quantities of mixed xylenes can be found in the petroleum stocks. However, there are several anthropogenic sources of xylenes such as agricultural spraying, petroleum product, chemical solvent, chemical intermediate, an aquatic herbicide, gasoline, petroleum refining, coal tar and coal gas distillation, transportation, loss of leakage and evaporation during transportation and storage of fuels.

Since xylene has flammable property, it is suggested to be toxic chemical. High concentration of xylene can cause central nervous system damage and irritation in humans for acute exposure. Nonetheless, the chronic exposure shows low effects with experimental animals. Even through xylene does not expected to be a mutagen or carcinogenic substance, the mixed of xylenes present the moderate to low harmfulness to aquatic wildlife (IPCS, 1997).

2.3 Carbonyl compounds and BTEX concentrations in mega cities

2.3.1 Carbonyl compounds concentration in mega cities

In the atmosphere, carbonyl compounds can be generated by primary emission such as natural vegetation, industrial plants, incinerators, and vehicles, likewise secondary emissions from photo-oxidation of biogenic and anthropogenic hydrocarbons (Graedel et al., 1986; D. Grosjean, Grosjean, & Moreira, 2002). The atmospheric concentration of carbonyl compounds should be concerned since they are considered to be toxic and carcinogenic substances with regard to their adverse effects to public health and vegetation (California EPA, 1993; WHO, 1987). In troposphere, carbonyl compounds are critical importance in the complex group of chemical reactions (Williams, Revitt, & Hamilton, 1996). This group of atmospheric chemicals is main contributors to urban photochemical smog, and also be significant precursors of free radicals, ozone, peroxy acetyl nitrate, nitric acid, organic aerosols, and peroxyradicals produced by photolysis or OH radical reaction (Altshuller, 1993; Carlier, Hannachi, & Mouvier, 1986; E. Grosjean, Rasmussen, & Grosjean, 1998; Lary & Shallcross, 2000).

Primary emissions of carbonyl compounds from gasoline and diesel automobile were identified in several studies. In the study of (Lee, Ho, Chan, Zielinska, & Chow, 2001), the most abundant carbonyl compounds found at the PolyU roadside station were formaldehyde and acetaldehyde. In this case vehicular exhaust was the main important source of carbonyl compounds in urban areas and their key compounds of photochemically generated air pollution (Carlier et al., 1986). Figure 2.13 presented the measured concentrations of formaldehyde and acetaldehyde along with the summary statistics in Table 2.12. Interestingly, an annual and seasonal formaldehyde concentrations, which was 4.6 μg/m^3 ranging from 0.82-11.3 μg/m^3, were higher than acetaldehyde, which was 2.1 μg/m^3, ranging from 0.16-6.8 μg/m^3 for 2-10 times. Moreover, the formaldehyde/acetaldehyde ratio measured in this study (n=41) was 2.03, which was quite similar to the study of (Baez, Belmont, & Padilla, 1995) with 2.33 as a ratio. The comparison of formaldehyde, acetaldehyde, and acetone concentrations in many cities worldwide was illustrated in Table 2.13.

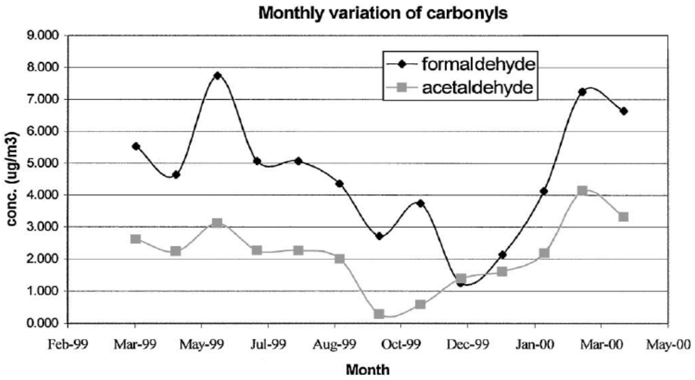


Figure 2. 13 **The monthly variation of formaldehyde and acetaldehyde in Hong Kong, China** (Lee et al., 2001)

Table 2. 12 **Summary of carbonyls concentrations and general weather conditions at PolyU station for samples acquired between April 1999 to April 2000 (n=41) (Concentration in μg/m^3)**

	Formaldehyde	Acetaldehyde
Maximum	11.34	6.75
Minimum	0.82	0.16
Medium	4.53	2.05
Annual average	4.65±2.46	2.11±1.36
Summer (May-August)	5.64±1.42	2.46±0.43
Winter (November-February)	2.82±1.35	1.44±0.66

	Summer	Winter
Global solar radiation (MJ/m^2)	14.4	10.5
Monthly average temperature (°C)	27.8	17.9

(Lee et al., 2001)

Table 2. 13 Comparison of the concentration of carbonyl compounds

Location	Carbonyl compounds (μg/m^3)			Environment
	Formaldehyde	Acetaldehyde	Acetone	
Fortaleza, Brazil[1]	0.9-5.1	0.1-3.4	0.1-9.0	Suburb
Bahia, Brazil[2]	0.24-3.1	0.7-4.1	-	Rural
Sao Paulo, Brazil[3]	4.0-27.7	9.3-178.0	-	Urban
Xalapa, Mexico[4]	6.0-38.0	5.0-32.0	1.0-28.0	Urban
Athens, Greece[5]	0.05-33.3	2.7-21.3	1.0-136.0	Urban
Schauinsland, Germany[6]	0.5-2.8	0.2-3.2	0.5-11.4	Rural
Kuopio, Finland[7]	1.3-2.8	1.1-3.2	-	Highway
Shanghai, China[8]	2.6-49.5	4.3-100.4	3.3-38.8	Urban
Rio de Janeiro, Brazil[9]	0.9-5.1	0.1-3.4	0.1-9.0	Urban
Kolkata, India[10]	3.6-61.8	6.5-24.8	1.5-17.7	Urban
Tsuen Wan, Hong Kong[11]	1.9-11.0	0.3-7.7	0.1-3.8	Urban
Isesaki, Japan[12]	3.3-5.4	-	-	Urban
Bangkok, Thailand[13]	22.0-24.0	9.0-12.0	-	Urban
Beirut, Lebanon[14]	0.0006-0.0122	0.0004-0.0051	0.0001-0.0117	Urban

Reference: 1, (Cavalcante et al., 2006); 2, (Andrade, Andrade, & Pinheiro, 1998); 3, (Miguel et al., 1995); 4, (Armando Báez et al., 2003); 5, (Bakeas, Argyris, & Siskos, 2003); 6, (Slemr, Junkermann, & Volz-Thomas, 1996); 7, (Viskari, Vartiainen, & Pasanen, 2000); 8, (Huang et al., 2008); 9, (D. Grosjean et al., 2002); 10; (Dutta et al., 2009); 11, (Sin, Wong, & Louie, 2001); 12, (Tago, Kimura, Kozawa, & Fujie, 2005); 13, (Daisy Morknoy et al., 2011); 14, (Moussa et al., 2006).

2.3.2 BTEX concentration in mega cities

Benzene, toluene, ethylbenzene, and xylene (BTEX) were mainly produced by anthropogenic activities, especially automobile exhaust that was expected to be the abundant source. This group of chemicals can cause variety of adverse health effects such as fatigue, irritation of eye, nose, and throat, dizziness, asthma, tiredness, confusion, memory loss and so forth. Additionally, nausea and similar nonspecific symptoms had been involved with BTEX. Benzene was also considered to have carcinogenic property to human (Mehlman, 1990; US EPA, 1987, 1991). Among BTEX compounds, xylenes were highly reactive and contribute to ozone formation and hence to climate change (Finlayson-Pitts & Pitts Jr, 1993).

In the study of (Iovino et al., 2009), the concentrations of all BTEX were dominant during autumn, especially toluene and ethylbenzene. However, there was not different significantly among spring, summer, and winter seasons as illustrated in Figure 2.14. Figure 2.15 demonstrated the concentrations of BTEX in three areas in Itary (i.e., Naples metropolitan, near suburban, and far suburban) which were interpreted during the months with higher solar intensity (May, June, and July) and the rest of the year. This notice could be implied that increasing distance far from the metropolitan provided the reduction of BTEX levels.

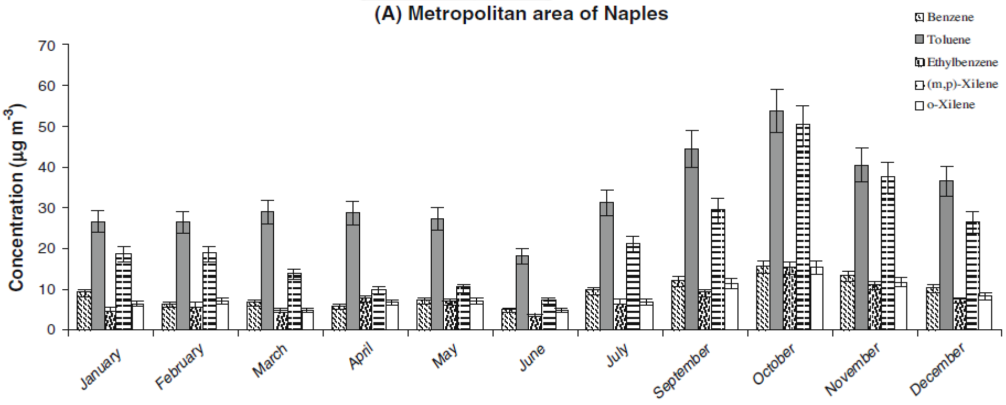


Figure 2. 14 Monthly fluctuations of average BTEX concentrations in Naples metropolitan area (a) (Iovino et al., 2009)

Components of BTEX mean concentrations at three sites, roadside, urban, and semi-rural, in Algiers, Algeria for the whole measurements were concluded in Table 2.14. (Kerbachi, Boughedaoui, Bounoua, & Keddam, 2006) found that the concentrations were wide variation both between the sites and the chemicals. The VOC compounds determined from roadside were normally associated with the vehicular emissions in urban areas and this result was quite similar to other studies (E. Grosjean et al., 1998; Lee et al., 2002; Löfgren & Petersson, 1992; Sexton & Westberg, 1984). Since the appropriated standard was not available, BTEX had been only quantitatively determined. In urban zones, BTEX constituted up to 60% of main non-methane VOCs (Lee et al., 2002) and also could be used as indicator of organic compound pollution from road traffic. For the overview, toluene was the most abundant species followed by benzene in all sampling areas. The concentrations of BTEX measured in many cities were given in Table 2.15.

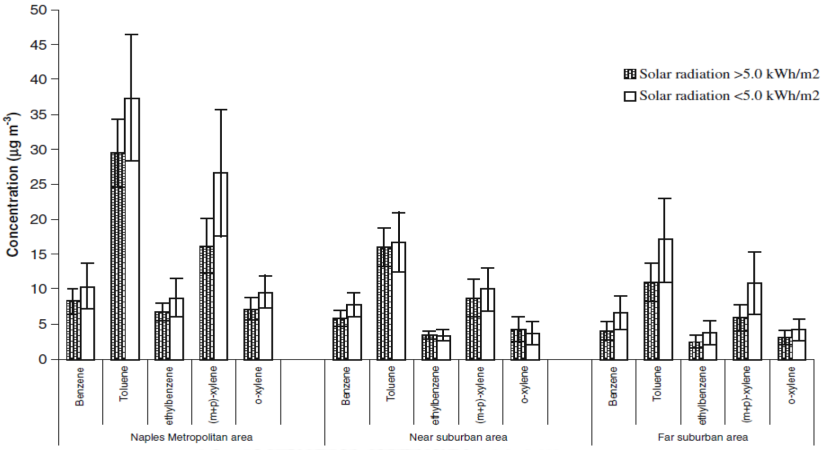


Figure 2. 15 BTEX average concentrations recorded in Naples Metropolitan area and two suburban areas, in the months with higher solar intensity (May, June, and July) and the rest of the year. (Iovino et al., 2009)

Table 2. 14 Ambient air mean, minimum and standard deviation of BTEX concentrations (µg/m^3) measured in Algiers for the three sites

Sites	Parameters	Benzene	Toluene	Ethylbenzene	(m,p)-Xylene	o-Xylene	BTEX
S1, Roadside	Average	27.1	39.2	6.3	19.2	7.6	99.4
	(SD)	(11.7)	(14.9)	(4.3)	(8.6)	(4.0)	(36.4)
	Minimum	9.6	12.4	0.8	3.5	0.7	38.6
	Maximum	57.2	76.9	16.2	31.7	17.7	181.8
S2, Urban	Average	9.6	15.2	0.9	3.2	n.d.	28.9
	(SD)	(4.3)	(5.3)		(2.9)		(13.2)
	Minimum	4.2	8.9	n.d.	0.7	n.d.	14.7
	Maximum	17.1	21.9	5.9	6.3	n.d.	52.8
S3,	Average	6.5	13.7	0.8	4.4	n.d.	25.4

Sites	Parameters	Benzene	Toluene	Ethylbenzene	(m,p)-Xylene	o-Xylene	BTEX
Semi-rural	(SD)	(0.9)	(2.6)	(0.5)	(2.8)		(5.7)
	Minimum	5.5	10.4	n.d.	0.8	n.d.	17.9
	Maximum	8.3	17.4	2.6	8.7	n.d.	35.3

n.d.: not detected; SD: standard deviation. (Kerbachi et al., 2006)

Table 2. 15 Comparison of the concentration of BTEX in ambient air

Location	The range of concentration of BTEX compounds (µg/m^{3})					Environment
	Benzene	Toluene	Ethylbenzene	m,p-Xylene	o-Xylene	
Kolkata, India1	13.5-35.8	34.1-183.0	2.2-56.5	10.7-141.1	4.3-77.0	Urban
Algiers, Algeria[2]	4.2-17.1	8.9-21.9	ND-5.9	0.7-6.3	ND	Urban
Algiers, Algeria[2]	5.5-8.3	10.4-17.4	ND-2.6	0.8-8.7	ND	Semi-rural
Beijing, China[3]	2.4-5.0	4.0-11.0	1.9-4.4	3.0-8.1	1.4-3.6	Urban
Naples, Italy[4]	4.4-17.2	15.8-57.7	2.8-15.3	2.9-16.1	6.6-47.7	Urban
Daegu, Korea[5]	4.0-6.7	24.6-85.2	1.7-5.6	1.4-8.7	0.8-4.4	Urban
Algiers, Algeria[6]	1.1-26.8	9.1-63.3	2.0-12.0	4.9-48.8	2.2-14.7	Urban/Roadside
Hanoi, Vietnam[7]	4.0-10,170.0	9.0-260.0	1.0-96.0	3.0-170.0	1.0-88.0	Roadside
Fujian, China[8]	1.2-153.6	5.6-115.2	0.6-13.9	0.7-85.4	0.4-58.7	Urban
Suzhou, China[9]	2.6^{m}-8.2	11.5^{m}-81.4	-	3.5^{m}-19.4		Urban
Montana, USA[10]	0.1-6.2	0.3-4.3	0.01-3.3	-	-	Rural
Gdynia, Poland[11]	0.1-2.4	0.5-2.0	0.1-0.6	0.5-2.1	0.2-1.3	Urban
Kocaeli, Turkey[12]	0.1-21.4	1.7-187.2	0.7-31.7	0.8-132.4	0.6-47.1	Industrial
Balikesir, Turkey[13]	0.3-14.8	1.4-85.9	0.1-16.7	0.1-38.0	0.1-3.3	Urban/rural
Delhi, India[14]	6.0-203.0	23.0-381.0	1.0-62.0	3.0-238.0	9.0-115.0	Urban

Reference: 1, (Dutta et al., 2009); 2, (Kerbachi et al., 2006); 3, (J. Liu et al., 2009); 4, (Iovino et al., 2009); 5, (Choi et al., 2009); 6, (Kerchich & Kerbachi, 2012); 7, (Truc & Kim Oanh, 2007); 8, (Tong et al., 2013); 9, (F. Wang et al., 2010); 10, Ward et al., 2009; 11, (Marć, Zabiegała, Simeonov, & NamieŚnik, 2014); 12, (Pekey & Yılmaz, 2011); 13, (Yalcin, 2013); 14, (Hoque et al., 2008). ND = Not detected; m= mean value

2.4 Seasonal variation of carbonyl compounds and BTEX

2.4.1 Seasonal variation of carbonyl compounds

(Cerón, Cerón, & Muriel, 2007) suggested that the carbonyl concentrations found in semi-urban area were higher than those found in rural areas, but lower than those found in urban areas. During winter, acetone had different correlate with the others due to its different sources. For the rest of carbonyl compounds excluding acetone, the substantial sources were anthropogenic activities, especially automobile exhaust. On the other hand, during the day time that provided high temperature could support secondary pollutants via photochemical processes generating carbonyl compounds as present in Figure 2.16 that carbonyl concentrations peaked during Summer time. According to the results comparing among winter, summer, and autumn, the levels of carbonyl compounds in winter were the highest since vehicular emissions were the only significant sources.

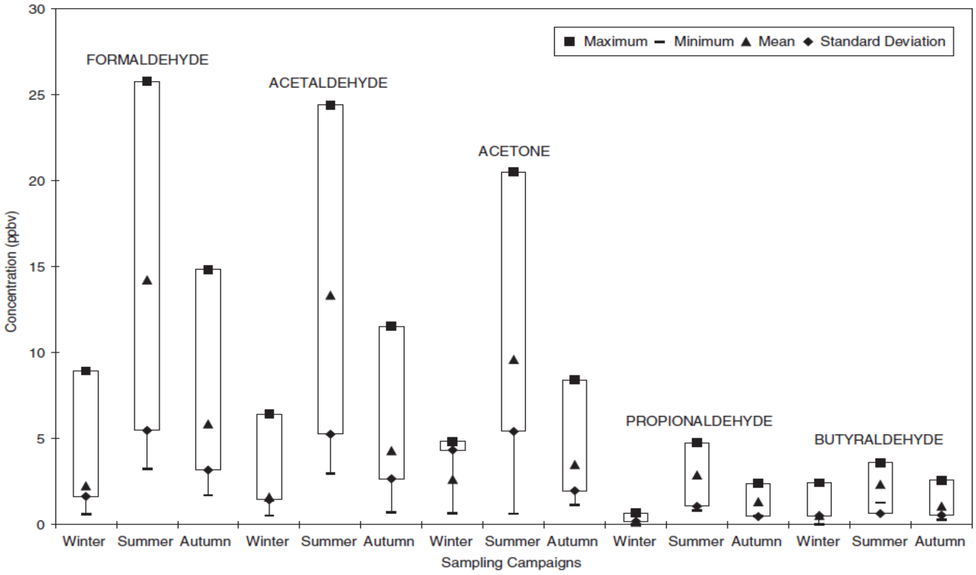


Figure 2. 16 Maximum, minimum, mean, and standard deviation of carbonyl ambient air concentrations in Carmen City (Cerón et al., 2007)

In case of rainy season, Morknoy et al. (2011) indicated that the concentrations of formaldehyde and acetaldehyde were declined during rainy season, which might cause by wet precipitation mechanism or rain washout. Even through other studied mentioned that wet precipitation might provide a little effect to the concentration of carbonyl compounds, the results of Morknoy et al. (2011) opposed with significant declined concentration of carbonyl compounds in Bangkok. According to Figure 2.17, the concentrations of soluble carbonyl compounds were removed substantially by wet precipitation. The concentrations of carbonyl compounds during winter were almost three times greater than those in rainy season because rain and the meteorological conditions offered more stable that trended to have high photochemical reactions creating more carbonyl compounds.

During summer season, Morknoy et al. (2011) claimed that the declined levels of formaldehyde and acetaldehyde might cause by photolysis under high temperature. Moreover, atmospheric lifetime (e.g., time of day, sunlight intensity, temperature, available hydroxyl radicals and nitrate radicals) could influent to the atmospheric concentrations of carbonyl compounds. During summer, the concentrations of carbonyl compounds were quite low in tropical country, while the concentrations of carbonyl compounds were high.

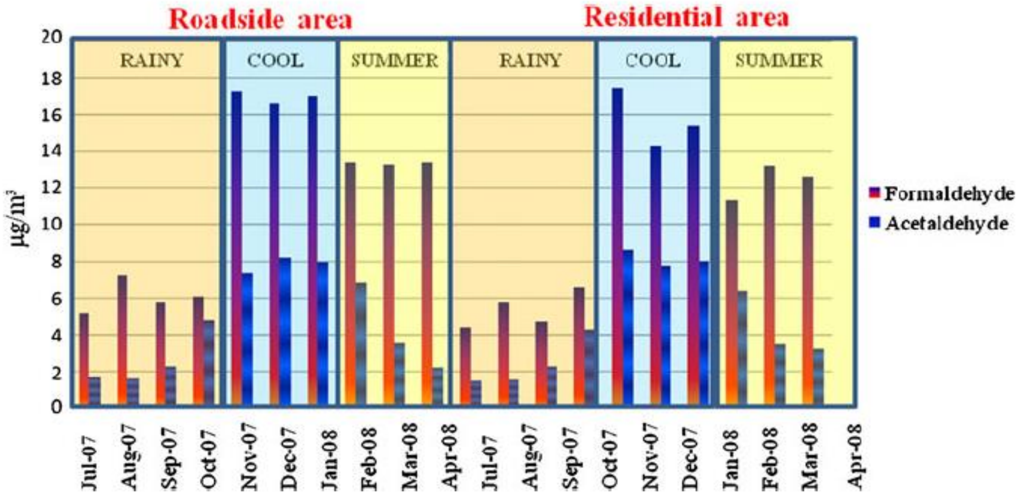


Figure 2. 17 Seasonal variation of formaldehyde and acetaldehyde concentrations in Bangkok (Morknoy et al., 2011)

Huang et al. (2008) studied the concentration of carbonyl compounds in ambient air of Shanghai. According to the Figure 2.18, they indicated that formaldehyde, acetaldehyde, and acetone, which were low molecular weight, had similar profiles with their peak concentration in the morning (8:00-10:00, traffic peak hours) or early afternoon (13:00-14:00) during the day except acetone in summer. The lowest concentrations of those three carbonyl compounds were noticed in the afternoon. If the peak concentration at 8:00-10:00 were related to the morning rush hour, increased concentrations should also be observed in afternoon traffic peak hours; however, no change was found even in winter. On weekends, the peak concentrations of low molecular carbonyl compounds also appeared often in the early morning when there were no rush hours. It was unexpected that the highest levels of formaldehyde, acetaldehyde, and acetone were seen during the nighttime in spring, summer, and autumn (no nighttime samples during winter), which was contrary to the outcomes of other studies (Moussa et al., 2006; Pang & Mu, 2006).

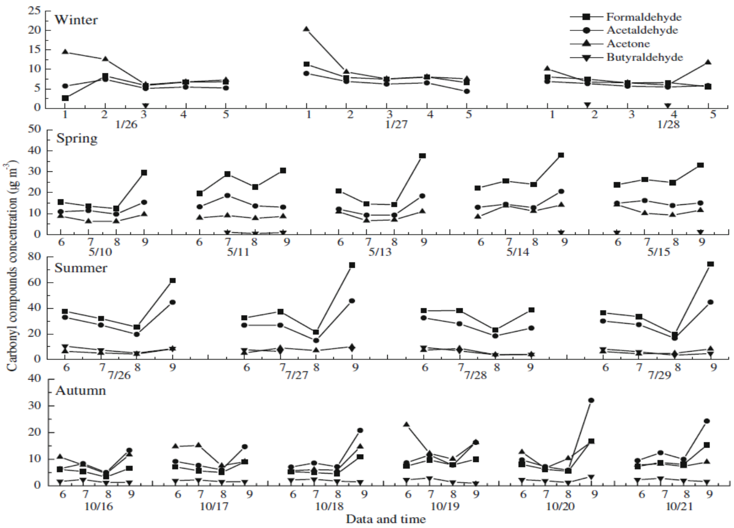


Figure 2. 18 Diurnal variations of low molecular weight (LMW) carbonyl compounds in selected days in different seasons in Shanghai urban ambient air. 1: 8:00-10:00, 2: 10:00-12:00, 3: 12:00-14:00, 4: 14:00-16:00, 5: 16:00-18:00, 6: (8:00-11:00), 7: (11:00-14:00), 8: (15:00-18:00), 9: (18:00-8:00) (Huang et al., 2008)

2.4.2 Seasonal variation of BTEX

(Ho, Lee, Guo, & Tsai, 2004) revealed that in Hong Kong, the concentrations of xylenes were slightly greater in summer than in winter, while toluene and ethylbenzene had similar levels. Nonetheless, benzene concentration was lower in summer than in winter as described in Table 2.16. Some VOCs had higher concentrations because there was more evaporation during the summer. Nevertheless, almost VOCs had greater concentrations during winter due to regional physical dispersion or transportation at HokTsui. Strong wind from the north-east area was one possible source of VOCs. During summer, the mixing depth and more rain could dilute or washout the pollutants with less accumulation of chemical than in winter. Furthermore, chemical removal by OH radical, dry and wet deposition, high temperature were also stimulate VOC removal faster in summer than in winter. Likewise other studies such as (Baek, Kim, & Perry, 1997; Hartwell et al., 1987; Wathne, 1983) that the winter VOC concentrations were greater than those in summer.

Table 2. 16 Concentrations of selected VOCs at three stations in Hong Kong (24-h average)

Unit: µg/m^3	PU winter	PU summer	KT winter	KT summer	HT winter	HT summer
Methyl chloride	2.38±0.70	1.84±0.46	2.84±0.45	1.70±0.31	2.25±0.24	1.27±0.12
Methylene chloride	2.12±1.58	3.06±2.01	1.94±1.19	2.41±1.14	1.56±1.27	1.08±2.00
Benzene	5.07±2.28	2.97±1.10	4.92±2.01	1.74±0.69	2.07±0.62	0.32±0.17
Carbon tetrachloride	1.00±0.25	0.80±0.14	0.99±0.22	0.89±0.09	0.78±0.05	0.58±0.06
Toluene	26.44±10.71	26.22±8.48	26.42±18.55	64.34±36.77	3.23±2.58	1.05±1.31
Tetrachloroethene	1.31±0.73	0.90±0.48	1.56±2.35	4.10±2.91	ND	0.27±0.33
Ethylbenzene	2.61±1.67	3.18±2.11	2.53±2.34	2.17±0.78	0.24±0.19	ND
m-, p-xylene	2.78±1.30	3.99±1.82	2.23±1.76	2.31±0.66	ND	ND
o-xylene	2.03±0.96	3.06±1.99	1.66±1.19	1.61±0.47	ND	ND
1, 3, 5-trimethylbenzene	0.79±0.49	1.39±2.75	0.40±0.21	0.44±0.10	ND	ND
1, 2, 4-trimethylbenzene	2.15±0.98	2.59±2.45	1.60±0.79	1.54±0.32	ND	ND

ND non-detectable (below detection limit); ±SD. (Ho et al., 2004)

Based on the study of (Majumdar, Mukherjee, Mukhopadhaya, & Sen, 2011) toluene was the most abundant species of BTEX found in Kolkata, India followed by benzene. Figure 2.19 supported that almost BTEX concentrations during winter seemed greater than those found during summer.

In the study of Kerbachi et al. (2006), the concentrations of BTEX were determined during winter (November-March), summer (July-September) in Algiers, Algeria. The results compared between two seasons were slightly different. Winter concentrations of BTEX were higher than those found during summer for approximately 10%. Exception of o-xylene should be performed when the difference was not statistically significant at the 95% confidence level. However, this profile could provide the common trend as presented in Figure 2.20.

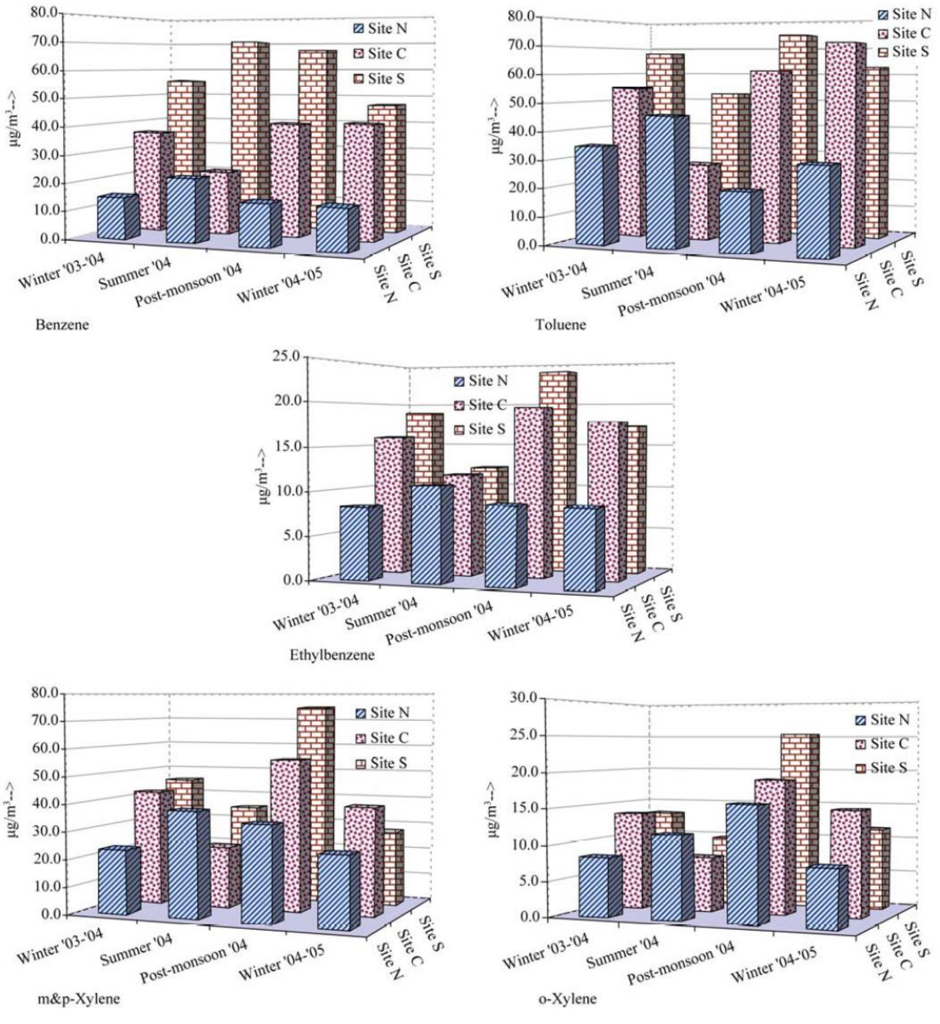


Figure 2. 19 Seasonal levels of BTEX in three monitoring sites in Kolkata City (Majumdar et al., 2011)

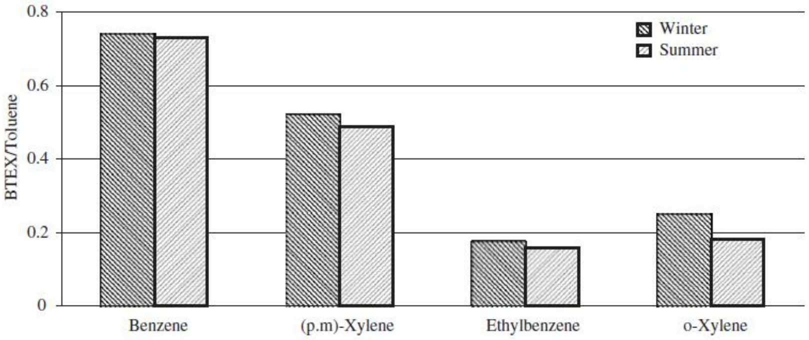


Figure 2. 20 **Winter versus summer normalized BTEX concentration (urban area). Normalization is done using the ratio of BTEX concentration to that of toluene** (Kerbachi et al., 2006)

2.5 Carbonyl compounds and BTEX concentrations found in Thailand

2.5.1 Carbonyl concentration found in Thailand

(Ongwandee, Moonrinta, Panyametheekul, Tangbanluekal, & Morrison, 2009) determined the indoor concentration of formaldehyde and acetaldehyde in offices in Bangkok, Thailand. In this study, the RH variations (45-70%) had little impact on formaldehyde collection efficiency (M Possanzini & Di Palo, 1999). The indoor and outdoor concentrations of formaldehyde and acetaldehyde collected from the 12 offices were demonstrated in Figure 2.21. The mean indoor concentrations of formaldehyde and acetaldehyde were 35.5 and 17.1 µg·m-3, respectively. Furniture made from pressed-wood materials could be substantial source of formaldehyde in indoor air, since urea-formaldehyde and melamine-formaldehyde resins were used as hot-press adhesives (S. Kim, 2009). Furthermore, office 9 was found to have significantly greater formaldehyde and acetaldehyde concentrations of 2.8 and 1.6 times the mean concentrations. It was found that the room had carpet, the interior walls that covered by plywood and one-fourth of the office space was occupied by the board shelves. The extensive use of plywood and board in this office could promote high levels of indoor formaldehyde concentration.

According to the study of (Nopparatbundit, 2010), the dominant species of carbonyl compounds found in gasoline workers and roadside were formaldehyde, acetaldehyde, and acetone. The concentrations of carbonyl compounds in urban and suburban areas were illustrated in Table 2.17. The mean concentrations of formaldehyde and acetaldehyde at dispensing area were 15.8 and 9.3 μg/m^3, respectively. For roadside, the mean concentrations of formaldehyde and acetaldehyde were 15.7 and 7.3 μg/m^3, respectively. In case of acetone, 18.5 and 13.0 μg/m^{3}were the mean concentrations found at dispensing area and roadside, respectively.

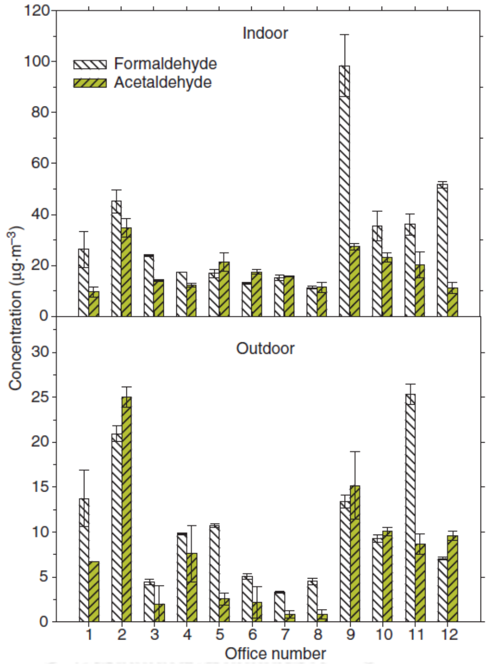


Figure 2. 21 Concentrations of indoor and outdoor formaldehyde and acetaldehyde for 12 office buildings. (Ongwandee et al., 2009)

Table 2. 17 Concentration of carbonyl compounds (±SD) (μg/m^3) and range according to gasoline workers and roadside in each area (urban areas and suburban areas)

Chemical's name	Urban site				Suburb site			
	Gasoline workers	Range	Roadside	Range	Gasoline workers	Range	Roadside	Range
Formaldehdye	14.61±3.38	7.78-19.81	16.76±8.07	7.88-31.24	15.64±6.52	11.65-35.78	14.70±5.27	8.83-23.82
Acetaldehyde	8.00±2.70	2.46-12.28	8.27±4.16	0.95-13.67	10.68±2.52	4.54-13.58	6.35±3.86	1.48-11.54
Acetone	18.04±5.60	9.22-30.45	13.53±4.06	5.82-17.38	19.00±13.86	10.48-59.99	12.50±5.78	6.65-22.02
Propionaldehyde	1.60±0.50	0.81-2.43	1.58±0.51	0.74-2.32	2.10±2.08	0.91-8.51	1.30±0.51	0.77-2.18
Crotonaldehyde	0.66±0.22	0.53-1.30	0.98±0.46	0.53-1.85	0.62±0.20	0.53-1.09	0.84±0.41	0.53-1.62
Butyraldehyde	5.22±2.46	0.47-7.88	5.70±1.91	3.54-9.18	3.62±2.20	0.81-8.73	2.79±0.88	2.01-4.50
Benzaldehyde	1.20±0.07	1.16-1.37	< 1.16*	NR	< 1.16*	NR	< 1.16*	NR

Chemical's name	Urban site				Suburb site			
	Gasoline workers	Range	Roadside	Range	Gasoline workers	Range	Roadside	Range
Isovaleraldehyde	1.00±0.10	0.95-1.23	1.36±0.30	0.95-1.79	0.98±0.10	0.95-1.32	< 0.94	0.94-0.94
Valeraldehyde	1.14±0.62	0.53-2.22	1.65±1.44	0.53-4.47	0.90±0.86	0.53-3.52	2.64±1.30	1.16-4.64
o-Tolualdehyde	<2.64*	2.64-2.64	< 2.64*	NR	< 2.64*	2.64-2.64	< 2.64*	2.64-2.64
Hexanaldehdye	2.40±1.08	1.48-5.38	2.28±0.74	1.48-3.13	2.72±1.18	1.72-6.16	1.91±0.60	1.48-2.99
2,5Dimethylbenz aldehyde	<2.84*	NR	<2.84*	NR	<2.84*	NR	< 2.84*	NR

*reported as the limit of detection (LOQ) of each CCs; NR not reported because of concentration less than LOQ (Nopparatbundit, 2010)

2.5.2 BTEX concentrations found in Thailand

(Pimpisut, 2003) revealed the background concentration of BTEX determined at estate and residential areas in Map Ta Put Petrochemical Complex, Rayong, Thailand. Mean, median, and range of BTEX concentrations measure at all sampling sites and background location were illustrated in Table 2.18. The highest level of benzene was 7.8 µg/m^3. Toluene was the most abundant compound found and highest mean concentration was 44.8 µg/m^3. Ethylbenzene was only occasionally detected but found at low concentration. Xylene was found with the highest concentration equaled 8.0 µg/m^3. All highest concentrations were found during the dry season. According to the survey of the potential impacts of the industrial sources, it could be claimed that the downwind sites had higher BTEX concentration than the background levels, where the concentrations at upwind sites had similar levels with the background.

Table 2. 18 **Statistic of daytime measurements of BTEX at nine monitoring stations in the study area and at the background sites (unit µg/m^3)**

Sites	B			T			E			X		
	mean	median	range	mean	median	range	mean	median	range	mean	median	range
SDC N=19	4.8	4.1	BDL-18.6	9.5	3.3	0.8-78.2	0.3	0.9	BDL-3.5	0.2	0.5	BDL-2.7
School N=19	5.1	3.8	BDL-26.5	7.4	4.9	2.1-28.3	0.2	1.0	BDL-3.1	0.5	1.1	BDL-5.6
THC	6.9	5.0	BDL-	27.2	7.4	2.8-	1.3	2.7	BDL-	3.8	3.2	BDL-

N=19			23.0			370.5			8.8			30.3
TSK N=19	7.7	6.1	BDL- 32.1	44.8	11.6	1.6- 220.8	1.0	0.7	BDL- 17.0	8.0	7.0	BDL- 41.9
IEAT N=19	3.8	4.1	BDL- 17.7	2.2	2.0	BDL- 8.6	0.7	7	BDL- 13.9	0.6	3.4	BDL- 7.4
NFC N=12	3.8	3.4	BDL- 20.9	3.1	3.3	BDL- 10.3	0.4	2.5	BDL- 5.0	2.4	2.4	BDL- 24.5
Padaeng N=13	1.7	3.7	BDL- 4.1	1.9	2.0	BDL- 5.1	BDL	BDL	BDL	0.2	1.6	BDL- 3.1
PAC N=12	2.8	4.7	BDL- 6.6	13.5	6.6	BDL- 98.5	0.1	0.5	BDL- 0.9	0.4	2.5	BDL- 4.9
Jetty N=14	7.8	4.3	BDL- 40.1	12.3	5.3	BDL- 65.4	1.3	3.2	BDL- 15.2	2.6	4.9	BDL- 19.3
N.F; N=5	5.1	4.6	BDL- 6.4	24.9	5.5	3.3- 98.8	0.6	1.4	BDL- 2.8	3.2	8.1	BDL- 16.2
B.G; N=6	1.2	3.2	BDL- 3.9	4.7	4.7	3.2- 6.2	1.4	4.2	BDL- 8.3	1.7	1.4	BDL- 7.2

Note: N=no. of samples and BDL =below detection limits

TSK=TSK's guardhouse, PIG=Padaeng industry factory's guardhouse, NFC=National Fertilizer Company, School=the old site of secondary school, THC= Ta Kuan Public Health Center, SDC=Rayong Skills Development Center, PAC=the Provincial Administrative Center, Jetty=Thai Tank Terminal (Pimpisut et al., 2003)

(Ongwandee & Chavalparit, 2010) examined BTEX concentration of commuter via five routes (A: Bus passing park business areas, B: Bus passing major business areas, C: Bus passing crowed shopping centers, D: sky train, E: boat). Based on Figure 2.22, the concentration of BTEX in non-A/C buses vary month-to-month was demonstrated. During the southwest monsoon (March-October), the weather was generally cold and rain. These types of conditions could interrupt the dispersion. On the other hand, the weather was clear and sunshine which could enhance the dispersion during the northeast monsoon. There was no statistical difference in concentration in non-A/C bus between seasonal monsoons. This might cause by the small number of samples. Little temporal variation in ambient and in-bus concentrations in Bangkok might due to its tropical location which the weather was fairly consistent.

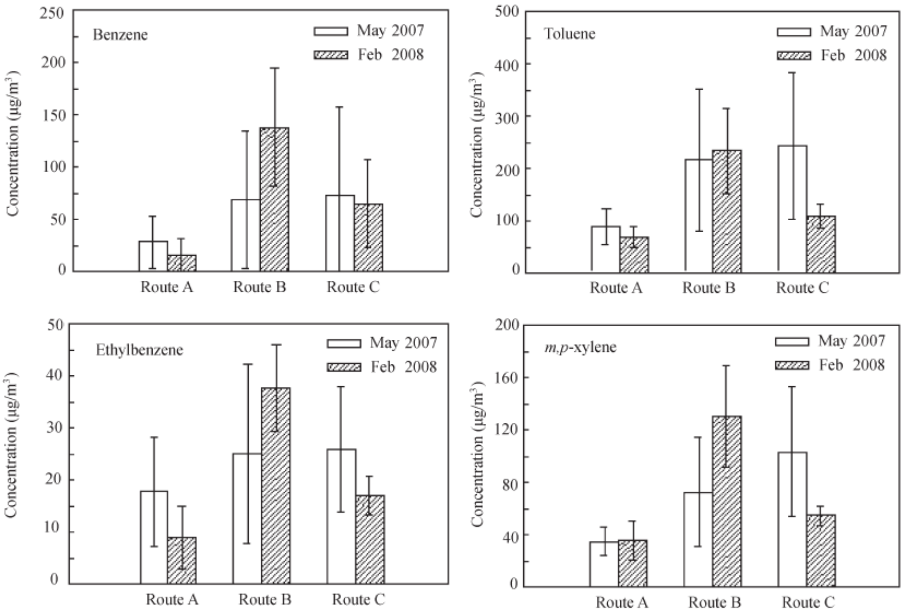


Figure 2. 22 Month-to-month variation of BTEX concentrations in non-A/C bus on each bus route. Uncertainty range shown is based on one standard deviation of measured samples. (Ongwandee and Chavalparit, 2010)

2.6 Health problems and risk assessment associated with carbonyl compounds and BTEX studied in Thailand

2.6.1 Health problems and risk assessment associated with carbonyl compounds studied in Thailand

Nopparatbundit (2010) calculated the cancer risk for inhalation exposure of gasoline workers in Bangkok, Thailand. He revealed that in urban area, cancer risk approximately range from 2 workers in 10 million to 2 workers in one hundred thousand. For suburban area, cancer risk range from 3 workers in 10 million to 2 workers in one hundred thousand. In term of average mean level, carcinogenic risk characterization for formaldehyde was 3 workers in million for all gasoline workers, while risk of acetaldehyde was 2, 3 and 4 workers in 10 million. The cancer risk of formaldehyde and acetaldehyde from exposure in urban and suburban along four sampling sites were presented in Table 2.19 and 2.20.

Table 2. 19 Results of cancer risk characterization in urban area

Chem	Location											
	Urban (P1)						Urban (P2)					
	AM^{b}	Intake^{a} (x10^{-5})	Cancer Risk (x10^{-6})	RME^{a}	RME Intake^{a} (x10^{-4})	Cancer Risk (x10^{-6})	AM^{b}	Intake^{a} (x10^{-5})	Cancer Risk (x10^{-6})	RME^{b}	RME Intake^{a} (x10^{-4})	Cancer Risk (x10^{-6})
Form	14.23	4.60	2.09	16.22	3.37	0.153	14.98	4.84	2.20	19.8	4.11	0.187
Acet	5.88	1.90	14.6	6.61	1.37	1.06	10.13	3.27	25.2	12.28	2.55	1.96

Chem.=Chemical; AM=Arithmetic mean; Form=Formaldehyde; Acet=Acetaldehyde; ^{a}(mg/kg/day); ^{b}(μg/m^{3}) (Nopparatbundit, 2010)

Table 2. 20 Results of cancer risk characterization in suburban area

Chem	Location											
	Suburb(P3)						Suburb (P4)					
	AM^{b}	Intake^{a} (x10^{-5})	Cancer Risk (x10^{-6})	RME^{a}	RME Intake^{a} (x10^{-4})	Cancer Risk (x10^{-6})	AM^{b}	Intake^{a} (x10^{-5})	Cancer Risk (x10^{-6})	RME^{b}	RME Intake^{a} (x10^{-4})	Cancer Risk (x10^{-6})
Form	17.68	5.75	2.62	35.78	3.64	16.6	13.8	4.49	2.04	15.3	1.56	7.08
Acet	9.17	2.98	0.230	13.58	1.38	1.06	12.2	3.97	0.306	12.88	1.31	1.01

Chem=Chemical; AM=Arithmetic mean; Form=Formaldehyde; Acet=Acetaldehyde; ^{a}(mg/kg/day); ^{b}(μg/m^{3}) (Nopparatbundit, 2010)

(Kitwattanavong, Prueksasit, Morknoy, Tunsaringkarn, & Siriwong, 2013) estimated the non-cancer risk of carbonyl compounds for petrol station workers in Bangkok. The ECs of main non-carcinogenic chemical of carbonyl compounds, which was propionaldehyde, was range between 75- to 104-fold from the highest in toluene down to low levels for propionaldehyde, with all the HQs, ranging from 0.004 to 0.351 as shown in Table 2.21. For carcinogenic risk of formaldehyde and acetaldehyde, the CDI values ranged from 6.05 x 10^{-2} to 5.28 x 10^{-4} mg/kg·day and 1.51 x 10^{-3} to 1.31 x 10^{-2} mg/kg·day, respectively. And 95% confidence interval of the mean 30 year (lifetime) cancer risks was totally significant higher than the acceptable risk level (1 x 10^{-6}) for formaldehyde and acetaldehyde.

Table 2. 21 Exposure concentrations (ECs) and hazard quotients (HQs) for non-carcinogenic substances, shown as the min-max range and 95% confidence interval

Pollutant	EC (µg/m^3)	HQs	95% Confidence interval for HQs
Toluene	21.64-111.96	0.004-0.022	0.012-0.015
m-,p-Xylene	9.31-35.19	0.093-0.351	0.157-0.215
o-Xylene	3.57-11.39	0.036-0.114	0.056-0.073
Propionaldehyde	0.10-1.09	0.013-0.136	0.026-0.047

(Kitwattanavong et al., 2013)

2.6.2 Health problems and risk assessment associated with BTEX studied in Thailand

(T Tunsaringkarn et al., 2012) reported that the most common symptom of gasoline station workers was headache followed by fatigue and throat irritation that was given in Table 2.22. There was no difference in the frequency of symptoms between men and women. Exposure of benzene and toluene was positively linked to fatigue as described in Table 2.23.

According to the Table 2.24, the mean lifetime cancer risks for exposure of gasoline station workers to benzene and ethylbenzene were estimated at 1.75×10^{-4} and 9.55×10^{-7}, respectively. Nonetheless, the cancer risk of benzene was more than acceptable limit of 10^{-6}. The cancer risk for workers in gasoline stations was slightly greater than the risk at the roadside where the mean lifetime risk for benzene was 8.71×10^{-5}, while the risk for ethylbenzene at roadside (1.26×10^{-6}) was slightly higher than that for gasoline station exposure (9.55×10^{-7}). For ethylbenzene, the cancer risk at gasoline station and roadside were within the acceptable limits. For non-cancer risks that estimated by using hazard index (HQ), the numbers found at gasoline station and roadside was 0.617 and 0.396 which were less than 1.

Table 2. 22 Frequency of symptoms among gasoline station workers.

Symptom	n (%)		
	Mean (n=38)	Women (n=11)	Total (%)
Headache	18 (47)	5 (45)	23 (47)

Fatigue	10 (26)	1 (9)	11 (22)
Throat irritation	2 (5)	2 (18)	4 (8)
Nose irritation	2 (5)	1 (9)	3 (6)
Nausea	0 (0)	2 (18)	2 (4)
Dizziness	0 (0)	1 (9)	1 (2)
Depression	0 (0)	1 (9)	1 (2)

(Tunsaringkarn et al., 2012)

Table 2. 23 Association between BTEX exposure and frequency of symptoms among gasoline station workers.

Independent parameter compound	Dependent Parameter Symptom	Unadjusted prevalence	Logistic regression analysis OR (95% CI)*
Benzene	Headache	61	0.996 (0.980-1.012)
	Fatique	29	0.964 (0.933-0.997)
	Throat irritation	11	0.980 (0.942-1.019)
Toluene	Headache	61	0.998 (0.991-1.005)
	Fatique	29	0.990 (0.980-0.999)
	Throat irritation	11	0.994 (0.981-1.007)

*Adjusted for sex, age, BMI, length of service, days of work per week, and hours of work per day at gasoline station (Tunsaringkarn et al., 2012)

Moreover, (Tunsaringkarn, Ketkaew, Zapuang, Rungsiyothin, & Taneepanichkul, 2011) studied the relation between BTEX concentrations and biological parameters of gasoline workers in Bangkok. Blood benzene level found in gasoline worker group showed no relationship to all biological parameters as shown in Table 2.25. In contrast, toluene concentrations were significantly inverse-related to blood urea nitrogen and creatinine and serum cholinesterase levels, whereas ethylbenzene levels were significantly inverse relation to blood urea nitrogen and creatinine. However, xylene levels were significantly inverse relation to blood urea nitrogen.

Furthermore, all blood urea nitrogen, creatinine, and serum cholinesterase in men were substantially greater than those found in women with p<0.001, p<0.001, p<0.01, respectively.

Table 2. 24 **The average BTEX exposure and the associated risks among gasoline station workers.**

Site	BTEX compound	CDI (mg/kg/day)	EC (mg/m^3)	Non-cancer risk (HQ)	Cancer risk
Gasoline station workers	Benzene	6.41x10^{-3}	1.81x10^{-2}	0.600	1.75x10^{-4}
	Toluene		3.82x10^{-2}	0.008	
	Ethylbenzene	2.48x10^{-4}	0.70x10^{-3}	0.007	9.55x10^{-7}
	Xylene		1.58x10^{-3}	0.002	
Total risk				0.617	1.76x10^{-4}
Roadside	Benzene	3.19x10^{-3}	1.15x10^{-2}	0.380	8.71x10^{-5}
	Toluene		2.48x10^{-2}	0.005	
	Ethylbenzene	3.24x10^{-4}	0.93x10^{-3}	0.009	1.26x10^{-6}
	Xylene		1.56x10^{-3}	0.002	
Total risk				0.396	8.84x10^{-6}

(Tunsaringkarn et al., 2012)

Kitwattanavong et al. (2013) estimated the cancer and non-cancer risks of BTEX for petrol station workers in Bangkok. For cancer risk assessment, the chronic diary intake of benzene and ethylbenzene were ranged from 1.51 x 10^{-3} to 1.31 x 10^{-2} mg/kg·day and 5.97 x 10^{-4} to 2.34 x 10^{-3} mg/kg·day, respectively. And 95% confidence interval of the mean 30 year (lifetime) cancer risks were totally significant higher than the acceptable risk level (1 x 10^{-6}) for benzene and ethylbenzene. In case of non-carcinogenic risk assessment, the hazard quotients (HQ) of toluene, m-, p-xylene, and o-xylene were in acceptable ranges (<1) which were 0.004-0.022, 0.093-0.351, 0.036-0.114, respectively.

Table 2. 25 **Relation between blood benzene, toluene, ethylbenzene, xylene, and blood biological parameters in gasoline workers.**

Compound	Linear regression model results*			
	Standardized Coefficients	95% CI	*p*-value	Relation to Blood Biological Parameters
Benzene	-	-	-	-
Toluene	-0.241	-0.011 to -0.001	0.015	BUN
	-0.016	-0.001 to 0.000	0.030	Creatinine
	-0.226	-2.695 to -0.515	0.023	Serum cholinesterase
Ethylbenzene	-0.236	-0.008 to -0.001	0.018	BUN
	-0.258	-0.001 to -0.000	0.010	Creatinine
Xylene	-0.232	-0.014 to -0.001	0.021	BUN
	-0.202	-0.001to 0.000	0.202	Creatinine

*Adjusted for gender, age, cigarette smoking, alcohol drinking (Tunsaringkarn et al., 2011)

2.7 Indoor sources of carbonyl compounds and BTEX

2.7.1 Indoor sources of carbonyl compounds

Carbonyl compounds can be found in the indoor air since some carbonyl compounds were used as components in solvents and household products such as pressed wood, vanish, wood stoves. Some studies reported that little was known about the influence of nonsmoking occupants on carbonyl concentrations in real or simulated indoor microenvironment (Jiang & Zhang, 2012). The possible indoor sources of formaldehyde, acetaldehyde, acetone, and propionaldehyde are summarized in Table 2.26.

Table 2. 26 **Common sources of carbonyl compounds in indoor air**

Compound	Type of product	Product
Formaldehyde[1]	Pressed wood	Particleboard, plywood, medium-density fiberboard (MDF), wall, floor materials
	Consumer	Fingernail hardeners, nail polish, wallpaper, paper

		goods, paint, coating
	Coatings and furniture	Acid-catalyzed urea-formaldehyde type finishes
	Permanent press fabrics	Clothing, lines, draperies
	Combustion appliance	Wood stoves, gas appliance, kerosene stoves
	Tobacco	Cigarettes, cigars
Acetaldehyde[2]	Foods and flavours	Cheese, heated milk, cooked chicken
	Combustion appliance	Wood stoves, fireplaces
	Smoke	Tobacco smoke, Cannabis smoke
	Cleaning household products	Disinfectants, lacquers, vanishes
	Fragrance	Room air deodorizers
	others	Pesticide, dyes, synthetic rubber
Acetone[3]	Smoke	Tobacco smoke, wood burning
	Household chemical	nail polish, paint
	Combustion appliance	Wood stoves
Propionaldehyde[4]	Wood products	Coated urea-formaldehyde wood products, Bare phenol-formaldehyde wood products
	Others	Paper products, Fiberglass products

Reference: 1, (California EPA, 2004); 2, (Canada EPA, 2000); 3, (ATSDR, 1995a); 4, http://www.eng.utoledo.edu/~akumar/IAQ/TEXT/INTROTOEMISSIONFACTORS.HTML [Online]

2.7.2 Indoor sources of BTEX

Benzene, toluene, ethylbenzene, m,p-xylenes and o-xylene (BTEX) are a group of Volatile Organic Compounds (VOCs). Indoor sources include paints, cigarette smoke and building materials as well as vehicle combustion gases and evaporative emission can migrate from attached settings with exposure 2 to 100 times higher indoors than outsides (Canada EPA, 2013). The possible indoor sources of benzene, toluene, ethylbenzene, and xylene are gathered in Table 2.27.

Table 2. 27 Common sources of BTEX in indoor air

Compounds	Type of product	Product
Benzene[1]	Smoke	Cigarette smoke, exhaust from automobile, smoke from wood burning fires
	Petroleum-based	Glues, paints, furniture wax, lubricants
	Water well	groundwater
	Others	Showering, dishwashing, laundry
Toluene[2]	Smoke	Tobacco smoke, exhaust from automobile
	Paint-based	Paints, paint thinners, Painting
	Other	Adhesives, synthetic fragrances, nail polish
Ethylbenzene[3]	Smoke	Automobile exhaust, cigarette
	Liquid-based	Vanishes, solvents, orienting ink, paint
	Others	Pesticide
Xylene[4]	Smoke	Automobile exhaust
	Others	synthetic fragrances and paints

Reference: 1, (US EPA, 2006a); 2, (US EPA, 2013b); 3, (ATSDR, 2005); 4, (US EPA, 2000)

2.8 Air quality standards related to carbonyl compounds and BTEX in outdoor and indoor air

Since most people stay in building (offices, homes, etc.) for long time in during a day, the quality of indoor air should be concerned. There are many sources of indoor air pollution in any home. These include combustion sources such as oil, gas, kerosene, coal, wood, and tobacco products; building materials and furnishings as diverse as deteriorated; products for household cleaning and maintenance, personal care, or hobbies; central heating and cooling systems and humidification devices; and outdoor air pollution. Even though the air quality guideline does not have specific value for residential places, some agencies provide public exposure limits for indoor and ambient air as present in Table 2.28 and 2.29 which relevant to BTEX and carbonyl compounds, respectively. However, the exposure limit for occupational places which described in Table 2.30 and 2.31 also can be implemented for indoor and outdoor air quality standard.

Table 2. 28 Air quality guidelines for public exposure to BTEX in indoor and ambient air

Compound	Agency	Public Exposure Limit	Concentration	
			ppm	µg/m^3
Benzene	U.S.EPA-Clean Air Act	ambient	0.0004	-
	TCEQ (2007)	indoor	0.0014	-
	EPA Region VI (2003)	ambient	0.00008	0.25
	EPA Region III (2003)	ambient	0.00007	0.23
	Austria	ambient (annual ave)	-	10
	Germany	ambient (annual ave)	-	15
	Great Britain	ambient (annual ave)	-	16
	DEFRA (2000, 2003)	ambient (annual ave)	-	16.25
	MfE (2002)	ambient (annual ave)	-	10
	EEA (2012)	TEL (24-hr)	0.00054	1.74
		AAL (annual ave)	0.00004	0.12
Toluene	CEPA (1999)	RMEL (STEL)	4.0	15,000
		RMEL (LTEL)	0.66	2,300
	SoQ (2008)	NEPM air toxic (annual ave)	0.100	-
		Queensland Air EPP (annual ave)	100 ppb	-
	MfE (2000)	ambient (annual ave)	-	190
	California EPA (2005)	ambient (annual ave)	-	300
	U.S. EPA (2004b)	ambient (annual ave)	-	400
	EEA (2012)	TEL (24-hr)	0.02123	80
		AAL (annual ave)	0.00531	20
Ethylbenzene	California EPA (2005)	ambient (annual ave)	-	2,000
	U.S. EPA (2004b)	ambient (annual ave)	-	1,000
	Danish EPA (2013)	ambient (C-value)	-	500
	WHO (1996)	ambient	-	22,000
Xylene	MfE (2000)	ambient (annual ave)	-	950
	California EPA (2005)	ambient (annual ave)	-	700
	U.S. EPA (2004b)	ambient (annual ave)	-	100
	Alberta (2005)	Ontario ambient (1-hr ave)	0.529	2,300
		California ambient (24-hr ave)	0.161	700
	EEA (2012)	TEL (24-hr)	0.00272	11.80
		AAL (annual ave)	0.00272	11.80

Table 2. 29 Air quality guidelines for public exposure: carbonyls in indoor and ambient air

Compound	Agency	Public Exposure Limit	Concentration	
			ppm	µg/m^3
Formaldehyde	NIOSH (1992)	IDLH	20	-
	EPA (1992c)	AZ (1-hr) (ambient ave)	-	20
		AZ (24-hr) (ambient ave)	-	1.2
		LA (annual ave)	-	7.69
		NY (1-year)	-	50
		OK (24-hr)	-	12
	EEA (2012)	TEL (24-hr)	0.002	2
		AAL (annual ave)	0.00006	0.08
Acetaldehyde	ACGIH (2007)	TLV-C	25	-
	NIOSH (1992)	IDLH	2,000	-
	EEA (2012)	TEL (24-hr)	1.11	2
		AAL (annual ave)	0.00028	0.5
	Alberta (2004)	ambient ave (1-hr)	-	90
Acetone	EEA (2012)	TEL (24-hr)	0.06803	160.54
		AAL (annual ave)	0.06803	160.54
	Alberta (2004)	SAAAQO	2.4	5,900
	Ontario MOE (1999)	AAQC (1-hr)	-	48,000
		AAQC (24-hr)	-	48,000
	ATSDR (2003)	MRL (24-hr)	-	62,000
		Chronic inhalation MRL (annual ave)	-	30,000
	Arizona DEQ (1999)	AAQG (1-hr)	-	20,000
		AAQG (24-hr)	-	14,000
Propionaldehyde	Ontario MOE (1999)	AAQC (10-min)	-	10
	NAC/NRC (2013)	AEGLs-1 (10-min)	45	-
		AEGLs-2 (10-min)	330	-
		AEGLs-3 (10-min)	1,100	-
		LOA	0.64	-
	SCAPA (2012)	PAC-1	45	-
		PAC-2	260	-
		PAC-3	840	-
		LEL	23,000	-
Crotonaldehyde	NRC (2007)	AEGLs-1 (10-min)	0.19	550
		AEGLs-2 (10-min)	27	77,000
		AEGLs-3 (10-min)	77	130,000

IDLH=Immediately dangerous to life and health limit; TLV-C=threshold limit value-ceiling; AALs=Allowable ambient limits; TELs=Threshold effects exposure limits; SAAAQO=Short-term Alberta ambient air quality objective; AAQC=Ambient air quality criterion; MRL=Inhalation minimum risk level; AAQG=Ambient air quality guideline; AEGLs=Acute exposure guideline levels; LOA=Level of odor awareness; PACs=Protective action criteria; LEL=Lower explosive limit. Meanings: AEGL-1=the airborne concentration of a substance above which is predicted that the general population, including susceptible individuals, could experience notable discomfort, irritation, or certain asymptomatic nonsensory effects.; AEGL-2=the airborne concentration of a substance above which is predicted that the general population, including susceptible individuals, could experience irreversible or other serious, long-lasting adverse health effects or an impaired ability to escape; AEGL-3= the airborne concentration of a substance above which is predicted that the general population, including susceptible individuals, could experience life-threatening health effects or death.

Table 2. 30 Acceptable limits for occupational exposure to BTEX and carbonyl compounds

Compound	Agency	Exposure Limit	Concentration	
			ppm	μg/m^3
Benzene	NIOSH (REL)	TWA (8-hr)	0.1	320
		C (15-min)	1	3,200
	OSHA (PEL)	TWA (8-hr)	10	30,000
		AccepTable C (10-min)	25	75,000
		Maximum C (10-min)	50	150,000
	ACGIH (TLV)	TWA (8-hr)	10	30,000
		STEL (15-min)	25	75,000
Toluene	NIOSH (REL)	TWA (8-hr)	100	375,000
		C (10-min)	200	750,000
	OSHA (PEL)	TWA (8-hr)	200	750,000
		AccepTable C (10-min)	300	1,125,000
		Maximum C (10-min)	500	1,875,000
	ACGIH (TLV)	TWA (8-hr)	100	375,000
		STEL (15-min)	150	560,000

Compound	Agency	Exposure Limit	Concentration	
			ppm	μg/m^3
Ehtylbenzene	NIOSH (REL)	TWA (8-hr)	100	435,000
		STEL (15-min)	125	545,000
	OSHA (PEL)	TWA (8-hr)	100	435,000
	ACGIH (TLV)	TWA (8-hr)	100	435,000
		STEL (15-min)	125	545,000
Xylenes	NIOSH (REL)	TWA (8-hr)	100	434,000
		C (10-min)	200	868,000
	OSHA (PEL)	TWA (8-hr)	100	435,000
	ACGIH (TLV)	TWA (8-hr)	100	435,000
		STEL (15-min)	150	655,000
Formaldehyde	NIOSH (REL)	TWA (8-hr)	0.016	20
		C (15-min)	0.1	130
	OSHA (PEL)	TWA (8-hr)	0.75	930
		STEL (15-min)	2	2,460
	ACGIH (TLV)	TWA (8-hr)	0.30	390
Acetaldehyde	NIOSH (REL)	none established	-	-
	OSHA (PEL)	TWA (8-hr)	200	360,000
	ACGIH (TLV)	C (15-min)	25	45,000
Acetone	NIOSH (REL)	TWA (10-hr)	250	590,000
	OSHA (PEL)	TWA (8-hr)	1,000	2,400,000
	ACGIH (TLV)	TWA (8-hr)	500	1,200,000
		STEL (15-min)	750	1,800,000
Propionaldehyde	ACGIH (TLV)	TWA (8-hr)	20	47,600
	AIHA (WEEL)	TWA (8-hr)	20	47,600
Crotonaldehyde	NIOSH (REL)	TWA (10-hr), supplementary exposure limit	2	6,000
	OSHA (PEL)	TWA (8-hr)	2	6,000
Benzaldehyde	AIHA (WEEL)	TWA (8-hr)	2	8,680
		STEL (15-min)	4	17,400
Valeraldehyde	NIOSH (REL)	TWA (10-hr), supplementary exposure limit	50	175,000
	ACGIH (TLV)	TWA (8-hr)	50	175,000

TWA=Time-weight average; TLV=Threshold Limit Value; STEL=Short-term Exposure Limit; C=Ceiling limit; PEL=Personal Exposure Limit; REL=Recommended Exposure Limit; and WEEL=Workplace Environmental Exposure Level (Kitwattanavong, 2010)

Table 2. 31 Occupational exposure limit of BTEX and carbonyl compounds in Thailand

Compound	Exposure Limit	Concentration	
		ppm	µg/m^3
Benzene	TWA (8-hr)	10	30,000
	STEL (10-min)	50	75,000
	Acceptable C (10-min)	25	150,000
Toluene	TWA (8-hr)	200	750,000
	STEL (10-min)	500	1,875,000
	Acceptable C (10-min)	300	1,125,000
Xylenes	TWA (8-hr)	100	435,000
Formaldehyde	TWA (8-hr)	3	1,300
	STEL (30-min)	10	13,000
	Acceptable C (10-min)	5	6,500

(Kitwattanavong, 2010)

2.9 Human health risk assessment

Generally, EPA claims that the way in order to investigate the nature and probability of health effects in humans exposed to chemicals in contaminated areas now and in the future is the human health risk assessment.

There are four main steps of human health risk assessment consist of hazard identification, dose-response assessment or toxicity assessment, exposure assessment, and risk characterization as described in Figure 2.23. Moreover, the further approaches of risk assessment can be risk communication and risk management which focusing on the protection, prevention, and reduction of the risk at the contaminated sites.

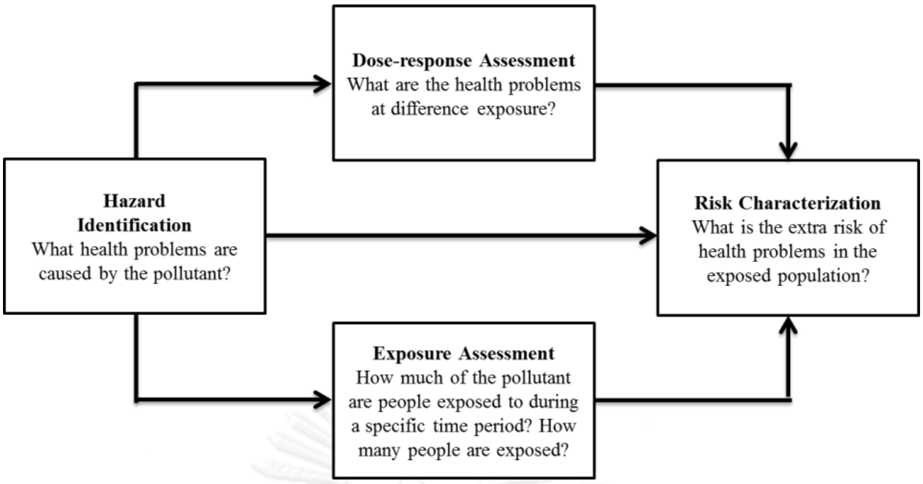


Figure 2. 23 Four steps of risk assessment. (Modified from (US EPA, 2012b))

2.9.1 Hazard Identification

Principle, hazard identification is the most important step in risk assessment which is the process of the investigation of human health risk and human health effects comprise of adverse health effects and chronic effects (e.g., cancer, birth defects). The possible harmful effects from each anthropogenic activity which may let human expose to the toxic substances need to be identified in order to prevent and clarify the human risk. Additionally, chemical stressors have been determined whether they can cause an increase adverse health effects. The available scientific information both clinical and epidemiological evidences are utilized to evaluate and classify hazardous compounds. This way, many kinds of animals (e.g., rabbits, mice, horses, monkeys) have been used in laboratory for studying the toxicity of hazardous substances. This approach can be utilized as the useful information for predicted human health effects after expose to the chemical and also for human health risk assessment, especially the chemical that lack of epidemiological studies. To sum up, the key point of this step is to identify the types of adverse health effects that can possibly be caused by exposure of some substance, and to characterize the quality and weight of evidence supporting this investigation.

2.9.2 Dose-response assessment or toxicity assessment

The following step is dose-response assessment or toxicity assessment which is the process of examination of the relationship between dose and response collected from animal tests. In principle, there are two steps of dose-response assessment. The first step is an assessment of all available information such as the experiments. This step tries to gather the dose-response relationship over the range of observed dose which may not be used to identify the dose that causes the adverse health effects. The other is the examination of the effects beyond the lower range of available observed data in order to indicate the threshold value which is initial dose causes human health effects. Moreover, the dose-response relationship is vary due to several factors such as age, gender, diet, behavior, personal immunity, nationality, heritage diseases, and so on which have to be considered for uncertainty factor when animal responses were used to predict the human health effects. Briefly, the main purpose of this approach is to know the health effects at different exposure level or dose. The reference values used for risk assessment of inhalation exposure were described as presented in Table 2.32 and 2.33 for the calculation forward. Furthermore, the dose-response relationship is variety due to several criteria (e.g., age, gender, behavior, diet, personal health, nationality) which have to be considered for uncertainty factor when animal responses were used to predict the human responses.

Table 2. 32 Toxicity values for carcinogenic compounds

Compound	Inhalation Slope Factor $(mg/kg\text{-}day)^{-1}$	
	RAIS' s CSF_i [a]	OEHHA' s CFS_i [b]
Formaldehyde	-	2.1×10^{-2}
Acetaldehyde	-	1.0×10^{-2}
Benzene	2.73×10^{-2}	1.0×10^{-1}
Ethylbenzene	3.85×10^{-3}	8.7×10^{-3}

(a) (RAIS, 2013); (b) (OEHHA, 2009)

Table 2. 33 Toxicity values for non-carcinogenic compounds

Compound	Inhalation R_fCs (mg/m^3)		
	RAIS' s R_fC [a]	IRIS' s R_fC [b]	ATSDR' s R_fC [c]
Propionaldehyde	8×10^{-3}	8×10^{-3}	-
Toluene	5	5	3.01×10^{-1}

Xylene	0.1	0.1	-

[a](RAIS, 2013); [b](US EPA, 2003, 2005, 2008); [c](ATSDR, 2012)

2.9.3 Exposure assessment

The third step of human health risk assessment is exposure assessment which aims to come up with a numerical estimate of exposure or dose that human may expose from contaminated media such water, air, dust, dirt, food, and so forth through all exposure routes (e.g., dermal, inhalation, and oral routes). There are a lot of important words involved. To illustrate, while a no-observed-adverse-effect level (NOAEL) is the highest adverse effect between exposed group and control group, the lowest-observed-adverse-effect level (LOAEL) is the lowest exposure level or dose that can cause the adverse health effect. Besides, mathematical modeling has been recently designed for incorporation more than one effect (single NOAEL or LOAEL) by implementing a NOAEL to a Benchmark Dose (BMD) or Benchmark Dose Lower-confidence Limit (BMDL). In case of the reference dose (RfD), it is an oral or dermal dose derived from NOAEL, LOAEL or BMDL, and uncertainty factors (UFs). The uncertainty factors (UFs) in possible difference between humans and tested animals have been concerned. Nonetheless, reference concentration (RfC) has been used to estimate human health risk from inhalation route of exposure by determination of chemical concentration in the atmospheric media. The important point of this assessment is to identify the level of exposure during the exposure period of time and the number of people who exposed.

Based on the RAG Volume 1 Part A (US EPA, 1989) which is the general used equation, 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. 2.1.

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

where;

CDI (mg/kg·day) = Chronic daily intake

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

IR (m^3/hr) = Inhalation rate (0.875 m^3/hr assumed for adult)

BW (kg) = Body weight (derived from questionnaires)

ET (hours/day) = Exposure time (24 hours/day for resident)

EF (days/year) = Exposure frequency (350 days/year assumed for resident)

ED (years) = Exposure duration (derived from questionnaire)

AT (days) = Averaged time (70 x 365 = 25,550 days)

However, the general equation illustrated previously does not cover the temporary exposure that cannot use IR and BW because of the amount of the toxic compound. Recently, the RAGS part F was developed by (US EPA, 2009) in order to serve RfC values for estimation of the risk after expose with non-carcinogenic substances via inhalation partway as provided in Eq. 2.2.

$$EC = (CA \times ET \times EF \times ED)/AT \qquad \text{(Eq.2.2)}$$

where;

EC ($\mu g/m^3$) = Exposure concentration

CA ($\mu g/m^3$) = Contaminant concentration in the air

ET (hours/day) = Exposure time (24 hours/day for resident)

EF (days/year) = Exposure frequency (350 days/year assumed for resident)

ED (years) = Exposure duration (derived from questionnaire)

AT (hours) = Averaged time (ED x 365 x 24 = 613,200 hours)

2.9.4 Risk Characterization

The final step of risk assessment is risk characterization which integrates all of individual components comprise of hazard identification, dose-response assessment, and exposure assessment in order to provide an integrative analysis. This data analysis of all findings, assumptions, limitations, and also uncertainties are assessed by environmental managers, enterprise executives, governmental authorities, and other stakeholders in order to figure out the solution, judgment, or other decision making. The concrete point of this step is to conclude the number of people who may possibly have risk and the suggestion of risk reduction for further approaches. Cancer risk can also estimate from inhalation toxicity values. Cancer risk can be implemented by multiplying the Chronic Daily Intake (CDI) of the atmospheric contaminant with the inhalation Cancer Slope Factor (CSF_i) as shown in Eq. 2.3.

$$\text{Cancer risk} = \text{CDI} \times CSF_i \qquad \text{(Eq.2.3)}$$

where;

Cancer risk $> 10^{-6}$ means that the carcinogenic effects have possibility to occur

Cancer risk $\leq 10^{-6}$ means that the carcinogenic risk is in an acceptable level

Moreover, the Hazard Quatient (HQ), which was used as a critical parameter of the acceptable risk of non-carcinogenic substances, substantially can be calculated by dividing Exposure Concentration (EC) of the toxic compound with the Reference Concentration (RfC) as demonstrated in Eq. 2.4.

$$\text{HQ} = \text{EC}/(\text{RfC} \times 1000\mu\text{g/mg}) \qquad \text{(Eq.2.4)}$$

where;

HQ > 1 means that the adverse non-carcinogenic health effects may occur

HQ ≤ 1 means that the non-carcinogenic risk is in an acceptable level

For total cancer risk and total non-cancer risk, the summation of cancer risk and summation of hazard quotient were used as described in Eq. 2.5 and 2.6.

$$\text{Total cancer risk} = \sum (\text{Cancer risk}_i) \qquad \text{(Eq. 2.5)}$$

where;

Total cancer risk $> 10^{-6}$ means that the carcinogenic effects have possibility to occur

Total cancer risk $\leq 10^{-6}$ means that the carcinogenic risk is in an acceptable level

$$\text{Hazard Index (HI)} = \sum (HQ_i) \qquad \text{(Eq. 2.6)}$$

where;

HI $>$ 1 means that the adverse non-carcinogenic health effects may occur

HI $\leq$ 1 means that the non-carcinogenic risk is in an acceptable level

According to Handbook for Implementing the Supplemental Cancer Guidance at Waste and Cleanup Sites (US EPA, 2012c), the exposure factors handbook age-specific exposure parameters grouped by supplemental guidance age bins for residential cancer risk assessment was provided (as presented in Table 2.34) 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. 2.7.

$$\text{Risk}_i = (C \times IR_i \times EF_i \times SF \times ED_i \times ADAF_i)/(BW_i \times AT) \qquad \text{(Eq. 2.7)}$$

where C (mg/m^3) is concentration of contaminant in the air, IR$_i$ (m3/day) is the inhalation rate for age bin "i", EF$_i$ (days/year) is exposure frequency for age bin "i" (350 days/year for residents), BW$_i$ (kg) is body weight of the exposed person for age bin "i" (based on Thai body weight), AT (days) is averaging time (70 years x 365 days = 25,550 days for long term exposure of cancer), ED$_i$ (years) is exposure duration for age bin "i", ADAF (unitless) is age-dependent adjustment factor for age bin "i", SF (mg/kg-day)$^{-1}$ is cancer slop factor.

Even though US EPA (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. (2.12).In order to find the total risk of individual, the sum of risks across all four age intervals were performed as illustrated in Eq. (2.8 - 2.11).

$$\text{Risk}_{0\text{-}2} = (C \times IR_{child} \times EF_{child} \times SF \times 2 \times 10)/(BW_{child} \times 25{,}550) \qquad \text{(Eq. 2.8)}$$

$$\text{Risk}_{2\text{-}16} = (C \times IR_{child} \times EF_{child} \times SF \times 14 \times 3)/(BW_{child} \times 25{,}550) \qquad \text{(Eq. 2.9)}$$

$$\text{Risk}_{16\text{-}30} = (C \times IR_{adult} \times EF_{adult} \times SF \times 14 \times 1)/(BW_{adult} \times 25{,}550) \qquad \text{(Eq. 2.10)}$$

$$\mathrm{Risk}_{30\text{-now}} = (C \times IR_{adult} \times EF_{adult} \times SF \times ED \times 1)/(BW_{adult} \times 25{,}550) \quad \text{(Eq. 2.11)}$$

$$\mathrm{Total\ Risk} = \mathrm{Risk}_{0\text{-}2} + \mathrm{Risk}_{2\text{-}16} + \mathrm{Risk}_{16\text{-}30} + \mathrm{Risk}_{30\text{-now}} \quad \text{(Eq. 2.12)}$$

Table 2. 34 Parameters for calculation of cancer risk using age-dependent adjustment factor

Parameter	Unit	Age (Years)			
		0-2	2-16	16-30	30-now
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 x 365 = 25,550			
EF[1]	Days/year	350 for residents			

[1](US EPA, 2012c) ; [2](Nichra Raungdakanon, 1996) and Department of Health, 1999

2.10 Related research articles

(Sin et al., 2001), the concentration of C_1-C_8 carbonyl compounds at two urban areas in Hong Kong were examined. According to the findings, the daily total carbonyl concentration were around 2.4-37 μg m^{-3}. In this study, formaldehyde was the most abundant one (36-43%) followed by acetaldehyde (18-21%), and acetone (8-20%). By the way, the mean formaldehyde/acetaldehyde molar ratios at two areas in winter (1.9±0.6 and 2.0±0.6) were significantly less ($p \leq 0.01$) than those in summer (2.8±1.1 and 2.5±1.2). Furthermore, the correlations among formaldehyde, acetaldehyde, and NO_X had been found clearly during the winter periods when vehicles were expected to be the priority of sources. In conclusion, the ambient formaldehyde and acetaldehyde concentrations in urban areas of Hong Kong did not statically different to other countries.

(K.-H. Kim & Kim, 2002) had conducted the measurements of aromatic VOCs at the Nan-Ji-Do (NJD) landfill site during spring and fall seasons. Based on the outcomes, the concentration of benzene, toluene, m-xylene, p-xylene, o-xylene, and ethylbenzene were 1.65, 9.62, 1.84, 0.83, and 1.17, respectively. After correlation analysis had been performed, the results illustrated that toluene was the most abundant VOCs. They assumed that this landfill site may probably distribute BTEX to the urbanized zones.

Báez et al. (2003) examined the concentration of carbonyl compounds at two houses, two offices, and three museums for indoor and outdoor air assessment. According to the results, indoor air trended to have higher concentration of carbonyl compounds when compared to outdoor air samples. In case of outdoor air, acetone had been found that it was the most abundant one (12-60 µg m^{-3}). Practically, acetaldehyde and formaldehyde had similar profiles which were 17 to 89 µg m^{-3} and 11 to 97 µg m^{-3}, respectively, followed by acetaldehyde with 5 to 47 µg m^{-3}. They claimed that formaldehyde and acetaldehyde provided higher risks, especially in smoking places.

Cavalcante et al. (2006) determined the cancer risk assessment of carbonyl compounds in outdoor and indoor air of libraries, laboratories, classrooms, and offices at the Universidade Federal do Ceará, Fortaleza, Brazil. The samples were collected from 7,000 students and 950 employees (officers, technicians, and researchers) during normal activities in this campus. The outcomes demonstrated that acetone was the most abundant carbonyl compounds both in indoor air and outdoor air followed by formaldehyde and acrolein. While acetone had the highest concentration in offices and laboratories, formaldehyde was the main carbonyl compound in classrooms, student laboratories, and libraries. In the fact, the concentration of carbonyl compounds in indoor air seemed higher than outdoor air. Employees, technicians, and researchers trended to have more cancer risk than the students.

(W. Liu et al., 2006) estimated indoor source strengths of 10 carbonyls and also measured indoor concentration of carbonyl compounds that affected by outdoor contributions. Based on all findings, formaldehyde and acetaldehyde had the strongest indoor source strengths with 3.9 and 2.6 mg h-1, respectively, followed by hexaldehyde with 0.59 mg h^{-1}. However, acetone had the widest variation in indoor sources ranging from undetected to 14 mg h^{-1}. In case of formaldehyde, the outdoor contributions to indoor concentrations were low. In contrast, indoor concentrations of acrolein and crotonaldehyde were detected by outdoor contribution more than 90%. For acetone, propionaldehyde, benzaldehyde, glyoxal, and methylglyoxal, the outdoor contributions to indoor concentrations ranged from 10 to 90%. They summarized that both indoor and outdoor sources also had contributions to indoor concentrations of carbonyl compounds

Hoque et al. (2008) investigated the concentration of benzene, toluene, ethylbenzene, and xylene (BTEX) in the ambient air of Delhi for studying their temporal and spatial distributions. The correlation coefficient among inter-species concentration was obtained at all sampling spots. Furthermore, Pearson's correlations of different chemicals indicated that gasoline vehicular exhaust might be the main source of BTEX in Delhi. In addition, the largest contributor would be xylene and followed by toluene in the atmosphere.

Huang et al. (2008) studied the level of carbonyl compounds in Shanghai ambient air during five periods (e.g., covering winter, high-air-pollution days, spring, summer, and autumn). They demonstrated that formaldehyde, acetaldehyde, and acetone were the most abundant carbonyl compounds which were 19.40±12.00, 15.92±12.07, and 11.86±7.04 µg m^{-3}, respectively. Additionally, formaldehyde and acetaldehyde had similar diurnal patterns in all periods and had the highest concentration in early morning or early afternoon. During summer, formaldehyde and acetaldehyde played an important role, whereas acetone had been found in the highest concentration in winter. The researchers claimed that automobile exhaust and industrial sector could be the main sources of carbonyl compounds in China.

(Caselli, de Gennaro, Marzocca, Trizio, & Tutino, 2010) assessed the quality of air in Bari that got impacts from vehicular traffic. After investigated the major meteorological factors (ambient temperature, wind, atmospheric pressure, and natural radioactivity), they claimed that buildings, barriers, traffic conditions, and local meteorological conditions could affect to the pollution dispersion which enhanced the accumulation of BTEX at those traffic areas.

(Corrêa et al., 2010), 183 samples were collected in order to observe the atmospheric pollutants during 2004-2009 in the Rio de Janeiro. They found the reduction of formaldehyde from 135.8 µg m^{-3} in 2004 to 49.3 µg m^{-3} in 2009. Likewise, acetaldehyde also had a slightly decline from 34.9 µg m^{-3} in 2004 to 26.8 µg m^{-3} in 2009. These reductions may occur due to the alternative energy usages which reduced the usages of compressed natural gas (CNG) and ethanol-based fuels.

(Esplugues et al., 2010) determined the concentrations of BTEX both inside and outside the houses of 352 one-year old children in Spain. The outcomes illustrated that the average concentrations of benzene, toluene, ethylbenzene, ortho-xylene, and meta-, para-xylene were

0.9, 3.6, 0.6, 0.6, and 1.0 µg m^{-3}, respectively. In the fact, almost data supported that indoor concentrations of all species were approximately 2.5 times higher than those in outdoor areas. The concentrations of BTEX inside the houses may possibly come from less one-year painting inside the houses, while a great frequency of traffic in urban areas were considered to be the major sources of BTEX outside the houses.

(Majumdar, Mukherjeea, & Sen, 2011) provided the study of BTEX concentration in Kolkata, India at three different areas during different period of time. According to the study, the seasonal benzene and toluene varied between 13.8 to 72.0 µg m^{-3} and 21.0 to 83.2 µg m^{-3}, respectively at all sampling points. BTEX were calculated into the total environmental load which was $9.7x10^4$ kg converted to approximately $1.9x10^5$ tons of carbon dioxide equivalent per year for global warming impact comparison. In case of human health risk assessment, benzene and ethylbenzene had the higher cumulative lifetime cancer risk than acceptable value between $3.0x10^5$ and $8.9x10^6$ in all sampling spots, whereas the non-cancer health risk value were acceptable.

(Y. Zhang et al., 2012) observed the atmospheric concentration of carbonyls and BTEX during summers of Beijing between 2008 and 2010. The total concentration of formaldehyde, acetaldehyde, and acetone were 33.4, 36.7, and 48.6 µg m^{-3}, respectively. Besides, the maximal contributions of photochemical reactions of formaldehyde and acetaldehyde were 47.6 – 60.3%. In case of the average ozone formation potential (OFPs) of carbonyls, BTEX, and carbon dioxide, they were approximately 166.1, 65.4, and 100.8 µg m^{-3}, respectively. In conclusion, they claimed that the concentration profiles of BTEX and carbonyls were significantly different due to their different sources; even through, vehicle emission was expected to be the sources of both carbonyls and BTEX. Nonetheless, carbonyls were mainly generated from photochemical reaction of VOCs from automobiles.

(Lan & Minh, 2013) monitored the concentration of each BTEX species at 17 roadside spots in urban zones of Ho Chi Minh city, Vietnam. Based on the outcomes, toluene was considered to be the most abundant species among BTEX, while observed hour-average benzene concentration was maximum with 254 µg m^{-3}. The daily profiles of these compounds presented that the concentrations of benzene, toluene, ethylbenzene, p, m-xylene, and o-xylene were 56, 121, 21, 64, and 23 µg m^{-3}, respectively. Furthermore, p, m-xylene provided the highest ozone formation potential among other BTEX species. Since motorcycles were the most popular used vehicles in Vietnam (91%), they were indicated to be the main source of BTEX in HoChiMinh city.

(Q. Liu, Liu, & Zhang, 2013) monitored the ambient levels of carbonyls and BTEXs at 210 residential houses in Xicheng district, Beijing. The concentration of formaldehyde, acetaldehyde, acrolein, acetone, benzene, toluene, and xylene were in the ranges of 0.2-213.4, 0.7-140.9, 0.1-25.2, 0.3-102.1, 1.0-47.5, 1.3-552.6, and 0.2-150.6 µg m^{-3}, respectively. Furthermore, the I/O (indoor concentration/ outdoor concentration) ratio demonstrated that organic solvents which used in adhesives and decorations were the major sources of formaldehyde, acetaldehyde, benzene, and toluene in houses with renovation age less than five years. Additionally, they found that the indoor concentration of acetone, acrolein, and xylene were affected by outdoor distribution. According to all findings, formaldehyde, acetaldehyde, and benzene posed the higher risks to human than previous studies.

CHAPTER III

RESEARCH METHODOLOGY

3.1 Overall framework of the study

Figure 3.1 presents the sequential overall steps of methodology that started with contacting heads of each community, surveying the areas, selecting houses for sampling sites, collecting samples during summer and rainy seasons, collecting data from questionnaires, analysis of samples, analysis of data, and calculating health risk would be performed step-by-step.

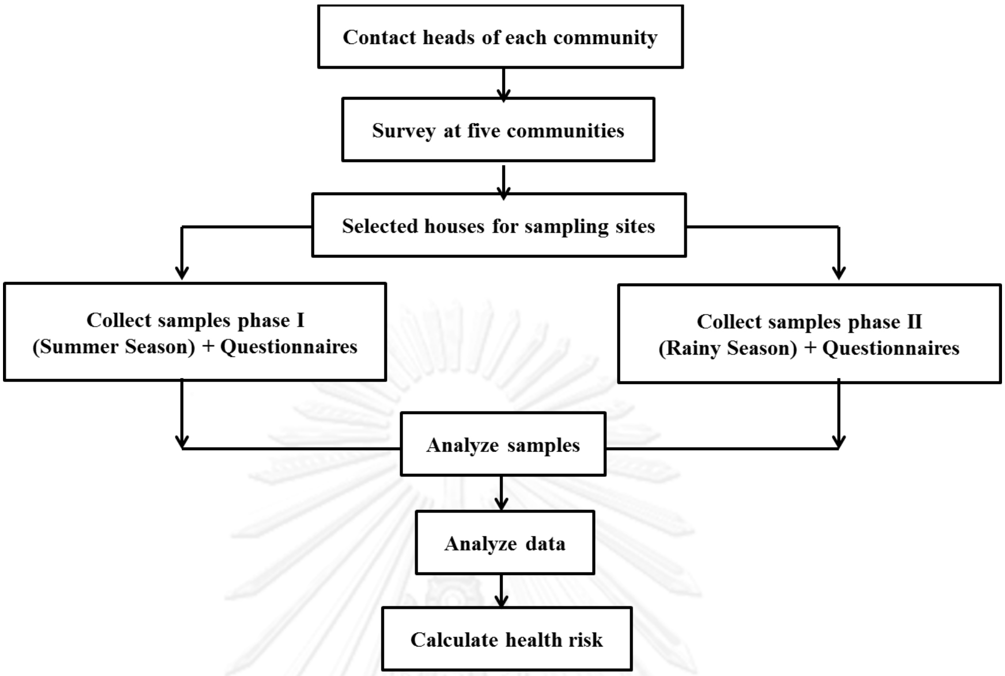


Figure 3. 1 The overall framework of this study

3.2 Study area

Bangkok city is the first range of the crowed population in Thailand with 3,634 persons/ km^2 which contains 5,701,394 people within 1568.7 km^2. According to (BMA Data Center, 2012), Bangkok is located the south of middle part of Thailand with latitude 13.45 °North and longitude 100.28 °East. This metropolitan comprises of 50 districts within 6 zones (i.e., Center-Bangkok, South-Bangkok, North-Bangkok, West-Bangkok, East-Bangkok, North-Thonburi, South-Thonburi). Pathumwan district is the selected area for sample collection in this study as the representative inner city of Bangkok as shown in Figure 3.2. The description of sampling sites is given in Table 3.1, and the location of each spot is presented in Figure 3.3. The collection of indoor and outdoor samples was performed at five communities consists of Saluk Hin, Lhung Wat-Pathum, Patthana Bon-Kai, Soi Pra-Chen, and Chaw Chu-Cheep, as presented in Figure 3.4 to 3.13, respectively.

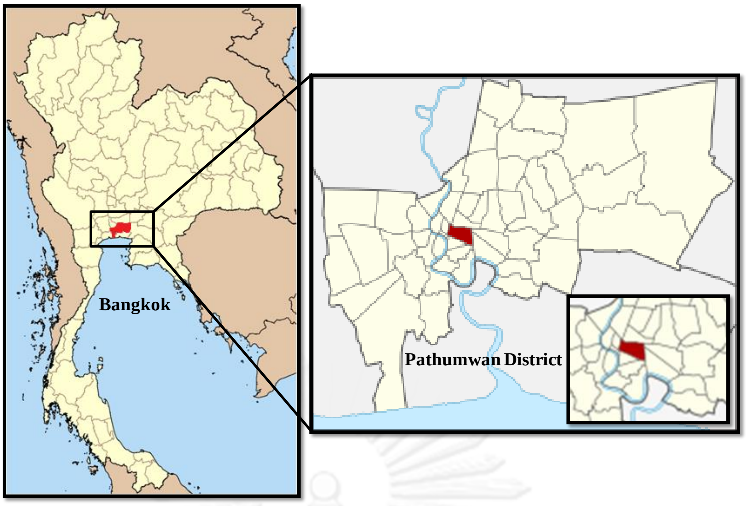
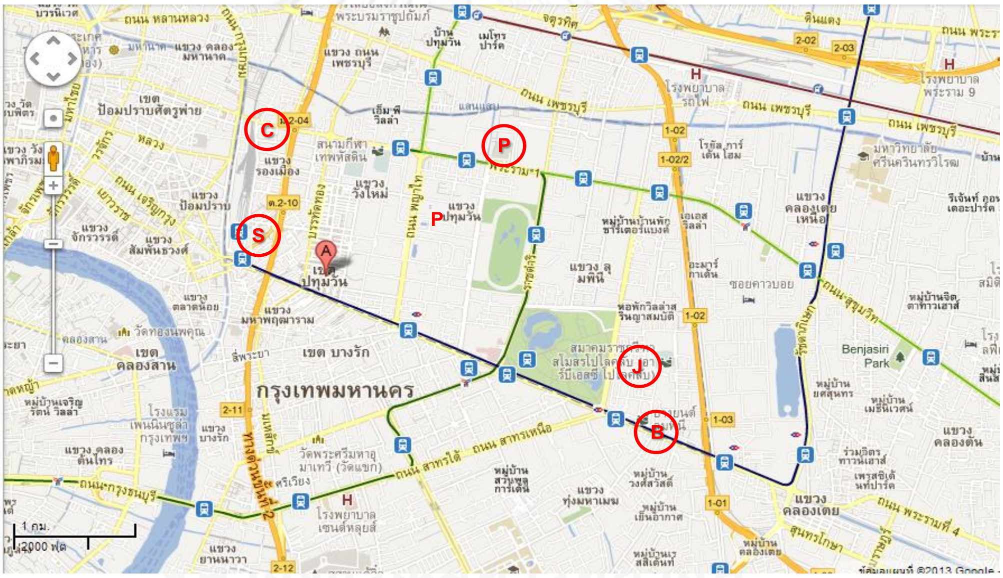


Figure 3. 2 Map of Pathumwan district in Bangkok, Thailand



Saluk Hin (S); Lhung Wat-Pathum (P); Patthana Bon-Kai (B); Soi Pra-Chen (J); Chaw Chu-Cheep (C)

Figure 3. 3 The location of each residential area for sample collection

Table 3. 1 Detail information of five residential areas for sampling collection

Community	Population*	Number of houses*	Area Description
SalukHin	875	80	Medium size; closed to CharuMuang Rd. (4-lan road), LuangMuang Rd. (8-lan road), under Sri Rut express way (6-lan

			road), and the 2nd express way (6-lan road); has express way passed the central area of this community; improve the yard for children playground
Lhung Wat-Pathum	6,100	516	Medium size; closed to Rama I Rd. (6-lane road); located near Siam Paragon, Central World, PathumwanWanaram temple, BTS Siam and WatPathum school; mostly has mismanagement of waste collection; found some activities related to cement usage
Patthana Bon-Kai	5,950	441	Large size; closed to Rama IV Rd. (8-lane road); located near MRT Lumpini station, Tobacco industry and across Thai Alliance Building; is smoking area and a lot of motorcycle usage
SoiPra-chen	5,985	470	Large size; closed to Witthayu Rd. (6-lan road) ;located near Lumpini park, Lumpini police station; plant a lot of trees; not too close to the road nearby; no industry around this area
Chaw Chu-Cheep	981	91	Small size; closed to Rama I Rd. (4-lan road); located near Ministry of Energy, railway (4 lines), across Sa Bua Temple; has two-floor houses of all residence

Remark: For P (Lhung Wat-Pathum community), the actual number of population and houses are decline, since that area has been chosen for several shopping malls. The information of other communities is quite the same. *(Personnel Classification Division, 2012)

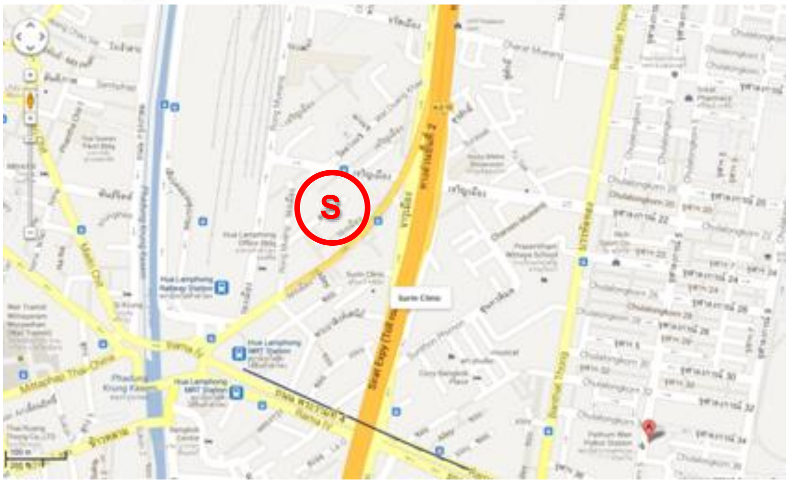


Figure 3. 4 The location of Saluk Hin Community, Pathumwan district

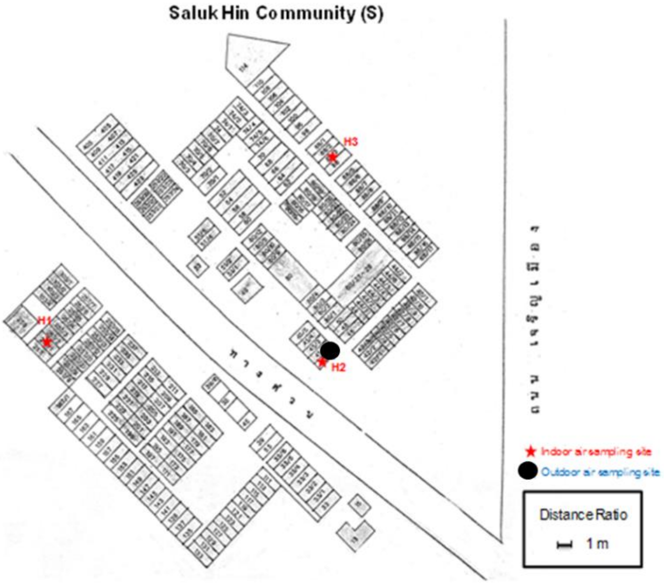


Figure 3. 5 Map of sampling points at Saluk Hin Community, Pathumwan district

Figure 3. 6 The location of Lhung Wat-Pathum, Pathumwan district

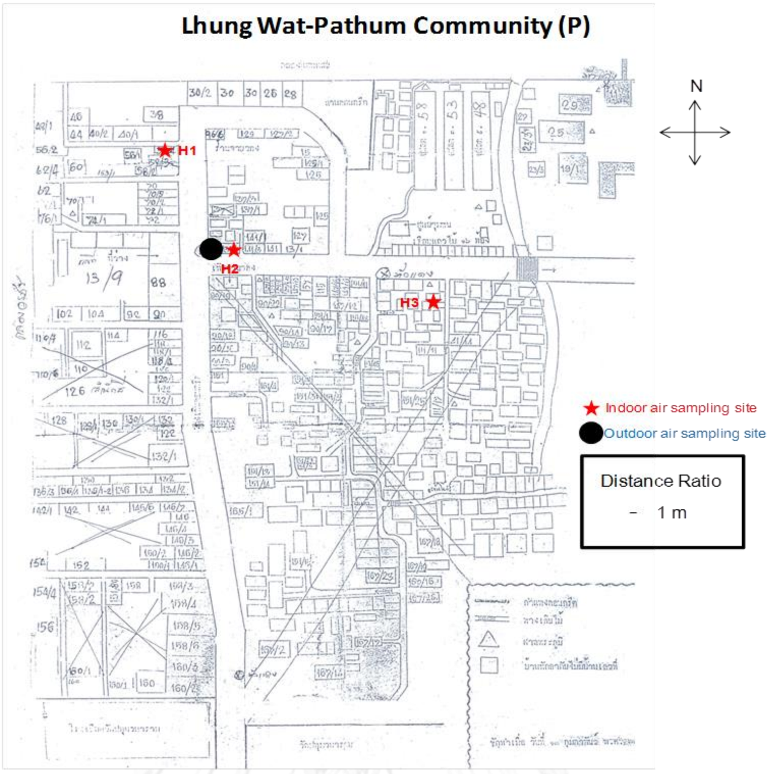


Figure 3. 7 Map of sampling points at Lhung Wat-Pathum Community, Pathumwan district

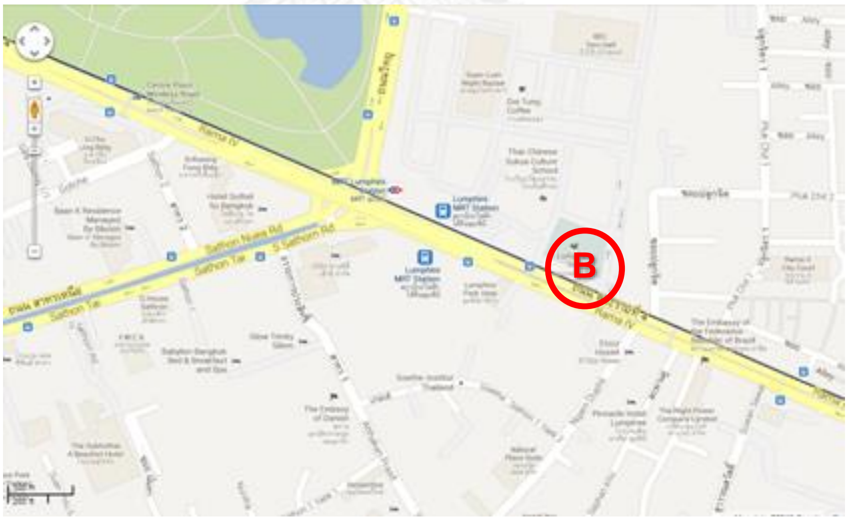


Figure 3. 8 The location of Patthana Bon-Kai Community, Pathumwan district

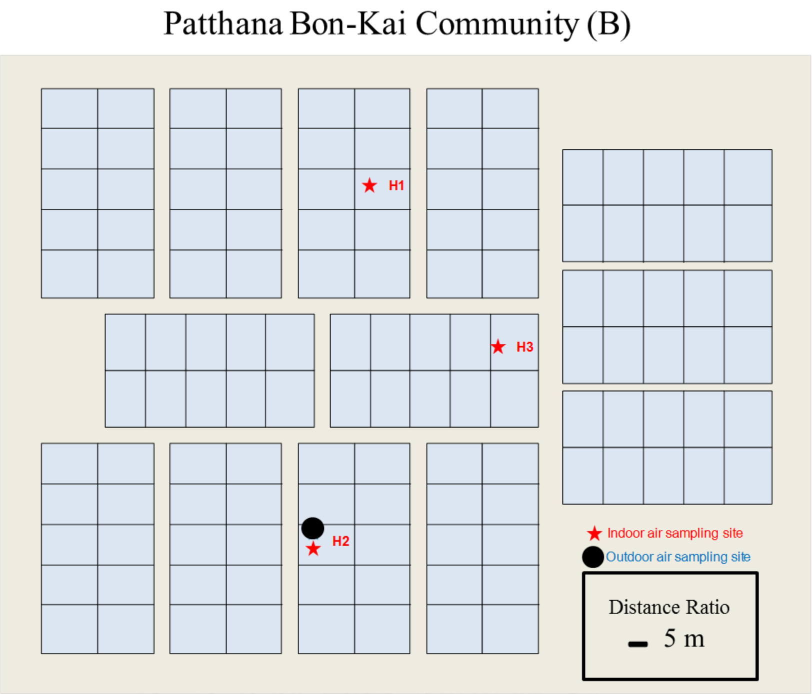


Figure 3. 9 Map of sampling points at Patthana Bon-Kai Community, Pathumwan district

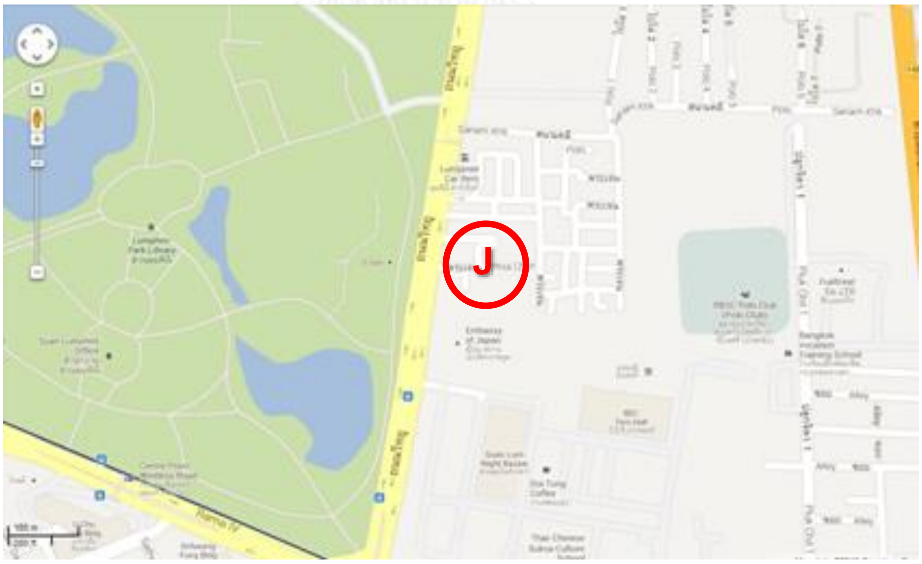


Figure 3. 10 The location of Soi Pra-Chen Community, Pathumwan district

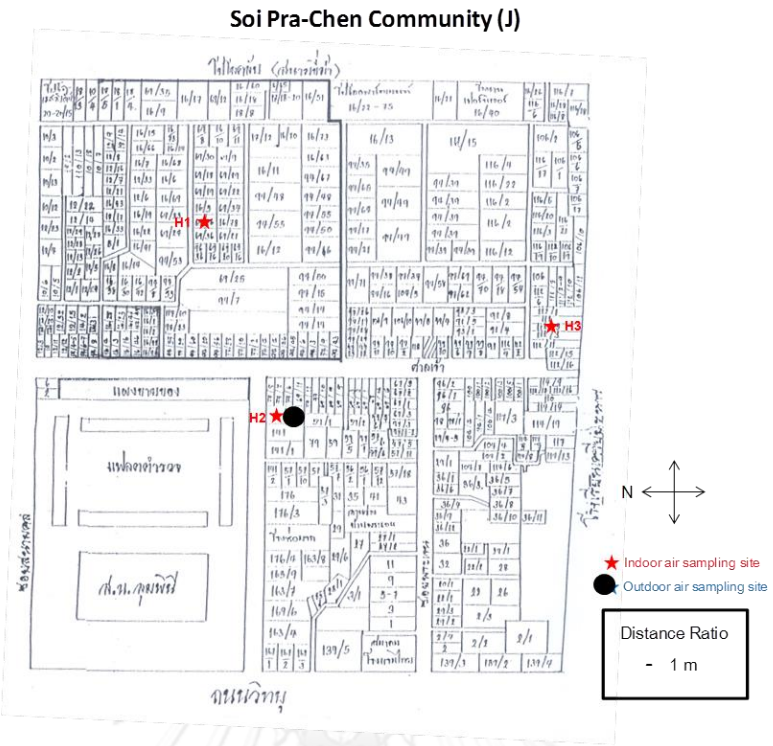

Soi Pra-Chen Community (J)

Figure 3. 11 Map of sampling points at Soi Pra-Chen Community, Pathumwan district

Figure 3. 12 The location Chaw Chu-Cheep Community, Pathumwan district

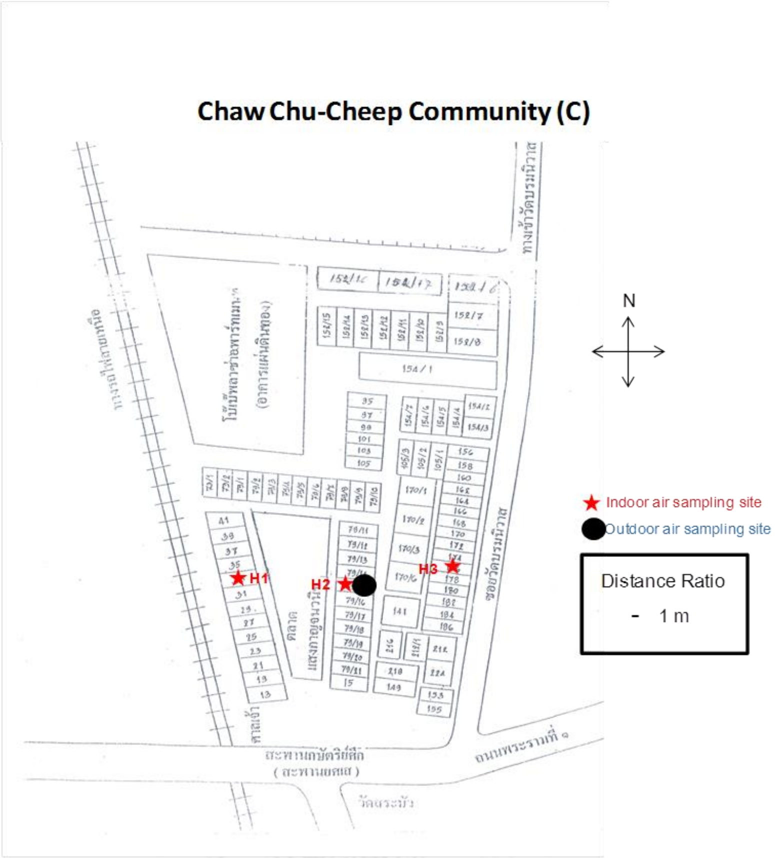


Figure 3. 13 Map of sampling points at Chaw Chu-Cheep Community, Pathumwan district

3.3 Analytical Instruments

3.3.1 High Performance Liquid Chromatography (HPLC)

A High Performance Liquid Chromatography with UV-VIS detector, model Shimadzu SPD 20A, and the integrator of Shimadzu CBM 20A (See Figure 3.14), at Environmental Research and Training Centre (ERTC) were used for analysis of carbonyl compounds. The mobile phases that used in this analysis were acetonitrile (HPLC grade) and water (HPLC grade) manufactured by Fisher Company, Canada 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.

In term of oven, the temperature was set at 40 °C during the performance. A column RP Amide Discovery C16 250 cm x 4.6 mm i.d. with 0.5 µm packed by Supelco Company, USA, was used for analysis of carbonyl compounds. The samples were pumped into the system with a linear gradient program. The standard solution of mixed carbonyl compounds (i.e., formaldehyde, acetaldehyde, acetone, acrolein, propionaldehyde, crotonaldehyde, butyraldehyde, benzaldehyde, isovaleraldehyde, valeraldehyde, o-tolualdehyde, m,p-tolualdehyde, hexanaldehyde, and 2,5-dimethylbenzaldehyde) was TOII/IP-6A Aldehyde/Ketone-DNPH Mix (Supelco, USA). The analysis condition of carbonyl compounds followed the study of (D. Morknoy, 2008) is provided in Table 3.2.

Figure 3. 14 A High Performance Liquid Chromatography with UV-VIS detector, model Shimadzu SPD 20A, Japan

Table 3. 2 The condition for analysis of carbonyl compounds

Main Column	RP Amide Discovery C 16 250 cm x 4.6 mm i.d. with 0.5 μm packing
Pre-Column	RP Amide C 16 2 cm x 4.0 mm i.d. with 0.5 μm packing
Mobile Phase	A: Water HPLC grade (45%) B: Acetonitrile HPLC grade (55%)
Column Temperature	40 °C
Flow rate	1.0 mL/min
Detector	UV detector
Wavelength	360 nm
Injection Volume	25 μL
Gradient Program	Time (min)
Acetonitrile: 55%	20

Acetonitrile: 65%	5
Acetonitrile: 55%	5

(Morknoy, 2008)

3.3.2 Gas Chromatography (GC)

Gas Chromatography, Agilent Technology model HP 6890N, detected signals with Flame Ionization Detector (GC/FID) was used to qualitative and qualitative analysis of benzene, toluene, ethylbenzene, m-xylene, p-xylene, and o-xylene. The samples of dry season were analyzed at Central Laboratory on 4^{th} floor of 4 Departments Laboratory Building, Faculty of Engineer, Chulalongkorn University, while those of rainy season were performed at Hazardous Substance and Waste Management Laboratory on 10^{th} floor of Research Building, Chulalongkorn University.

The 6890N Model G1530N with capillary column, Hp-5 Size 30 m x 0.32 mm x 0.25 µm (19091J-413) produced by Agilent, USA (see Figure 3.15), was used for BTEX analysis. In addition, Nitrogen (N_2), Helium (He), Hydrogen (H_2) and Air zero were used as carrier gases. The initial temperature in the oven was set at 45 °C and was held for 5 minutes. Then, the program increased temperature from 45 °C to 80 °C at 3 °C/min as the ramp 1. Next, temperature was extended from 80 °C to 85 °C at 5 °C/min as the ramp 2. However, after running a lot samples, cleaning column should be required. The standard solution of BTEX, HC BTEX Mix (Supelco, USA), was used for finding an optimum condition. The optimum condition was gained as shown in Table 3.3.

Figure 3. 15 Gas Chromatography with flame ionization detector, Agilent Technology model HP 6890N, USA

Table 3. 3 The condition for analysis of BTEX

Capillary Column	HP-5 size 30 m x 0.32 mm x 0.25 µm (19091J-413)			
Carrier Gas	Air Zero Helium (He) Hydrogen (H_2) Nitrogen (N_2)			
Flow Rate of He	1.0 mL/min			
Type of Injection	Spiltless			
Injection Volume	1 µL			
Injector Temperature	300 °C			
Detector	Flame Ionization Detector (FID)			
Detector Temperature	300 °C			
Oven Ramp	°C/min	Next °C	Hold (min)	Run Time (min)
Initial		45	5.00	5.00
Ramp 1	3.00	80	0.00	16.67
Ramp 2	5.00	85	0.00	17.67

3.4 Preliminary experiments

3.4.1 Standard curves

The calibration curves were performed by using mixed standard solution of 14 carbonyl compounds, which comprised of formaldehyde, acetaldehyde, acetone, acrolein, propionaldehyde, crotonaldehyde, butyraldehyde, benzaldehyde, isovaleraldehyde, valeraldehyde, o-tolualdehyde, m,p-tolualdehyde, hexanaldehyde, and 2,5-dimethylbenzaldehyde. The concentration of 0.005, 0.010, 0.050, 0.100 and 1.000 µg/mL (1 µg/mL = 1 ppm) were prepared for standard curves. For each carbonyl compound, the quantity of reliability was identified with $R^2 \geq 0.99$ and the % RSD was not over than 10%. All standard curves of calbonyl compounds were provided in Appendix C.

In case of BTEX, the mixed standard solution, HC BTEX Mix (Supelco, USA) containing benzene, toluene, ethylbenzene, m-, p-xylene, and o-xylene were used. The mixed standard of BTEX was prepared at the concentrations of 125, 250, 500, 1,000, 2,000, 4,000, and 8,000 ng/mL (1,000 ng/mL = 1 ppm). In each standard BTEX concentration, 4-bromofluorobenzene (Supelco, USA) was added with 20,000 ng/mL as final concentration of internal standard. All reliabilities of BTEX was examined with $R^2 \geq 0.99$ and the %RSD was less than 10%. All standard curves of BTEX were provided in Appendix C.

3.4.2 Limitations of analytical instruments

The Instrument Detection Limit (IDL) and Instrument Quantification Limit (IQL) of HPLC-UV were examined. The standard of mixed carbonyl compounds at the lowest concentration of each component was determined for 7 times in order to check the limitation of HPLC-UV. 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 IDL and IQL as presented in Eq. 3.1 and 3.2. The limitation of HPLC-UV of carbonyl compounds detection was shown in Table 3.4.

$$\text{IDL} = 3\text{SD} \qquad \text{(Eq.3.1)}$$

$$\text{IQL} = 10\text{SD} \qquad \text{(Eq.3.2)}$$

Nonetheless, GC/FID also had to be determined the Limit of Detection (LOD) and Limit of Quantification (LOQ) via the measurement of the lowest concentration of mixed standard BTEX. The signal to noise ratio could be defined in order to find the limitation of the instrument. Eq. 3.3 and 3.4 showed the calculation of LOD and LOQ, while Eq. 3.5 provided the calculation of standard deviation. If the concentration of sample was lower than LOQ, not detected (ND) would be reported. However, if the concentration of sample was between LOD and LOQ, not detected (ND) would be optional for report. In these cases, the identification of LOD or LOQ was required nearby the results. The limitation of GC/FID for determination of BTEX was given in Table 3.5.

$$\text{LOD} = (3 \times \text{the lowest concentration used} \times \delta)/\bar{x} \qquad \text{(Eq.3.3)}$$

$$\text{LOQ} = (10 \times \text{the lowest concentration used} \times \delta)/\bar{x} \qquad \text{(Eq.3.4)}$$

$$\delta = \sqrt{\sum_{i=1}^{n} (\mathrm{Xi} - \bar{x})^2/(\mathrm{n}-1)} \qquad \text{(Eq.3.5)}$$

where;

δ = Standard deviation

Xi = Peak area of target compound observed

$\bar{x}$ = Average peak area of these observations

n = Number of observations

Table 3. 4 The limitation of HPLC/UV-VIS for the quantification of carbonyl compounds presented in IDL and IQL values

Compound	Phase 1		Phase 2	
	IDL (ppm)	IQL (ppm)	IDL (ppm)	IQL (ppm)
Formaldehyde	0.002	0.005	0.001	0.004
Acetaldehyde	0.001	0.005	0.001	0.003
Acetone	0.002	0.008	0.002	0.005
Propionaldehyde	0.002	0.005	0.001	0.004
Crotonaldehyde	0.001	0.004	0.004	0.014
Butylaldehyde	0.002	0.006	0.002	0.005
Benzaldehyde	0.003	0.011	0.002	0.005
Isovalualdehyde	0.002	0.008	0.002	0.006
Valualdehyde	0.003	0.009	0.005	0.015
o-Tolualdehyde	0.003	0.010	0.004	0.013
m-, p-Tolualdehyde	0.002	0.007	0.003	0.011
Hexaldehyde	0.003	0.008	0.005	0.018
2,5-Dimethylbenzaldehyde	0.003	0.012	0.006	0.019

Table 3. 5 The limitation of GC/FID for the quantification of BTEX presented in LOD and LOQ values

Compound	Phase 1		Phase 2	
	LOD (ng/mL)	LOQ (ng/mL)	LOD (ng/mL)	LOQ (ng/mL)
Benzene	5.75	19.16	4.45	14.85
Toluene	5.32	17.74	0.39	1.31
Ethylbenzene	1.60	5.34	8.83	29.43
m-,p-Xylene	2.67	8.90	3.51	11.71
o-Xylene	11.08	36.93	33.37	111.25

3.4.3 Recovery test

In this study, the personal technique was assumed to have acceptable accuracy when all tests were done by the same person. Hence, only the instrument's accuracy was defined in this case. In term of carbonyl compounds, the recovery test was performed in previous study (Morknoy,

2008) by injection of 100 µL of mix standard solution of carbonyl compounds with the concentration of 0.1 ppm (final concentration = 0.05 ppm) into active 2,4-dinitrophenylhydrazine cartridges (Wako Pure Chemical Industries Ltd., Japan) and then extracted the samples followed the same procedure. All extracted solutions were analyzed by using HPLC/UV (see Figure 3.16). According to the recovery test of 14 carbonyl compounds, the outcome presented the values between 63.8 - 92% as demonstrated in Table 3.6.

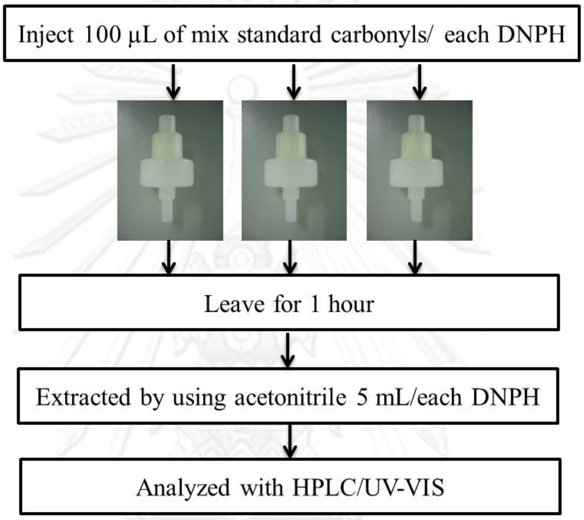


Figure 3. 16 The recovery test divided into two types: personal technique check and the instrument check

For the recovery test of BTEX, the standard solution of BTEX, HC BTEX Mix (Supelco, USA) at the concentration of 8,000 ng/mL was spiked into active activated charcoal glass tubes (SKC Inc., USA) and then injected extracted solution into GC/FID for quantitative and qualitative analysis. The result of the recovery test of BTEX were in range of 95.3 -100.6% which were illustrated in Table 3.7.

Table 3. 6 The result of % recovery of carbonyl compounds

Compounds	% Recovery
Formaldehyde	92.0
Acetaldehyde	87.6
Propionaldehyde	82.7
Crotonaldehyde	81.3
Butyraldehyde	63.8
Benzaldehyde	88.9
Isovaleraldehyde	83.2
Valeraldehyde	80.2
o-Tolualdehyde	85.8
m-,p-Tolualdehyde	90.7
Hexaldehyde	84.9
2,5-Dimethylbenzaldehyde	87.1

Remark: Acetone could not be quantified since it had abnormal peak.

Table 3. 7 The result of % recovery of BTEX

Compounds	% Recovery
Benzene	95.9
Toluene	96.5
Ethylbenzene	100.6
m-,p-Xylene	96.5
o-Xylene	95.3

3.4.4 Relative Standard Deviation (%RSD)

Standard Deviation is the measurement of deviation of various terms from their average in an observation. It tells how the different numbers in a data are scattered around the mean, while relative standard deviation is measured in percentage. It is also called percent relative standard deviation. It reflects spread of the data in percent. A higher relative standard deviation means that the numbers are widely spread from its average, while a lower relative standard deviation means the numbers are closer to its average. Relative standard deviation is often termed as coefficient of variation. It is the absolute value of coefficient of variation. The abbreviation used for relative standard deviation is RSD or %RSD. Formula for relative standard deviation is given below shown in Eq. 3.6.

$$\% \text{ RSD} = (\text{SD} \times 100)/\bar{X} \qquad \text{(Eq. 3.6)}$$

where,

% RSD = Relative standard deviation

SD = Standard deviation

$\bar{x}$ = Average peak area of these observations

In order to find the %RSD, injection of mix standard TO-11A as the standard solution of carbonyl compounds with the concentration of 0.1 ppm was performed. Whilst the mix standard BTEX with the concentration of 8,000 ng/mL was analyzed several timed for identification of %RSD. The relative standard deviations of carbonyl compounds and BTEX were summarized in Table 3.8 and 3.9, respectively.

Table 3. 8 The relative standard deviation of carbonyl compounds

Compound	%RSD	
	Dry season	Wet season
Formaldehyde	0.484	0.864
Acetaldehyde	0.454	0.657
Acetone	0.764	1.087
Propionaldehyde	0.495	0.847
Crotonaldehyde	0.397	3.017
Butyraldehyde	0.535	1.045
Benzaldehyde	1.047	1.158
Isovaleraldehyde	0.743	1.323
Valeraldehyde	0.860	2.918
o-Tolualdehyde	0.973	2.992
m-, p-Tolualdehyde	0.639	2.212
Hexaldehyde	0.806	3.600
2,5-Dimethylbenzaldehyde	1.097	4.259

Table 3. 9 The relative standard deviation of BTEX

Compound	%RSD	
	Dry season	Wet season
Benzene	6.563	3.616
Toluene	4.798	1.707
Ethylbenzene	2.621	1.389
m-,p-Xylene	1.836	1.252
o-Xylene	4.319	1.252

3.4.5 Sampling train design of carbonyl and BTEX collection

Typically, sampling train suggested by (US EPA, 1983) was one popular used technique for air sampling train design. The contaminated air with interested pollutant was pumped into the system where the specific pollutant would be captured by a sample collection device. Then the rest would pass through the sampling train. In this situation, the air coming out was measured the flow rate and duration of air sampling. The instrument for air sample collection could be either physical or chemical mechanism in order to separate the pollutant from the air stream for further analysis.

Kitwattanavong et al. (2013) studied the sampling train design for the collection of carbonyl compounds and BTEX. They claimed that the results were similar between the sampling train type A (2, 4-DNPH cartridge and charcoal glass tube connecting to personal air device) and type B (only charcoal glass tube joining with personal pump). This result supported that 2, 4-DNPH cartridge did not have much impact to the efficiency of charcoal glass tube when they were combined together.

Because of two main groups of atmospheric pollutants, carbonyl compounds and BTEX had been considered to be the target pollutants in this study. Two different sample collection devices were required for effective air sample collection. 2, 4-dinitrophenylhydrazine (2, 4-DNPH) active cartridge produced by Wako Pure Chemical Industries, Ltd., Japan, (see Figure 3.17) which followed the Method TO-IIA were used for carbonyl compounds collection. In this study, carbonyl compounds contaminated in the air stream that coming into the air sampling device reacted with the acidified 2, 4-dinitrophenylhydrazine (2, 4-DNPH) contained in the cartridge and formed the corresponding hydrazones derivative based on the reaction that was demonstrated in Figure 3.18.

Figure 3. 17 2, 4-Dinitrophenylhydrazine active cartridge

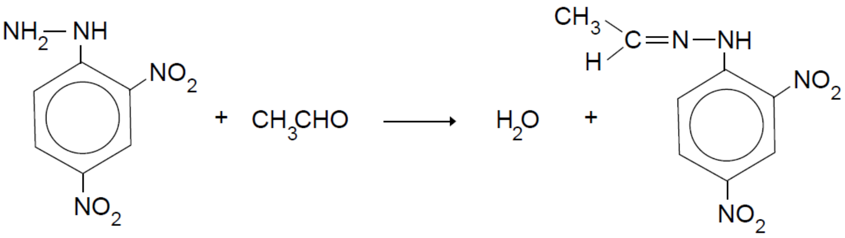


Figure 3. 18 Reaction of aldehydes with 2, 4-DNPH

For sample collection of BTEX, the activated charcoal (SKC Inc., USA) has been used for removal of these chemicals from the actual air stream via physical adsorption. Figure 3.19 illustrated the activated charcoal with size of 20-40 mesh contained in glass tube or called a charcoal glass tube. The charcoal in glass tube could be divided into two parts as sorbent materials which were the front part containing 400 mg of activated charcoal and the back part containing 200 mg of activated charcoal.

Figure 3. 19 Charcoal glass tube

Since all target hazard chemicals should be captured from the same air stream, the connection of 2, 4 DNPH active cartridge and a charcoal glass tube should be installed and joined with a personal air pump (See Figure 3.20) (Sibata mini pump MP E30, Japan) as a sampling train that was shown in Figure 3.21. The actual sampling device which consisted both 2, 4 DNPH active cartridge and a charcoal glass tube connected with a personal air device was demonstrated in Figure 3.22. During sample collection, personal air devices should be calibrated before and after sampling. Bubble gas calibrator, Gilibrator-2 Standard Flow Kit, 20CC-6LPM (USA), was used in this study as illustrated in Figure 3.23.

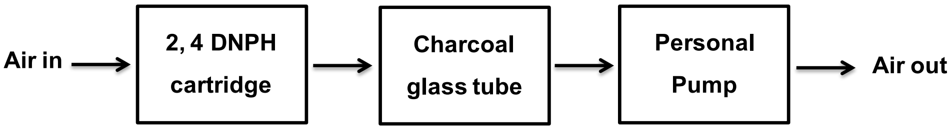


Figure 3. 20 Schematic diagram of sample collection system

Figure 3. 21 The personal air pump

Figure 3. 22 An actual sample collection

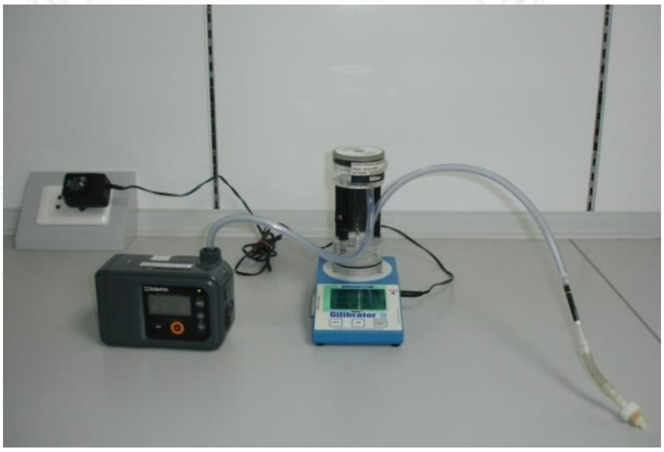


Figure 3. 23 Calibration of person air pump by using bubble gas calibrator

3.5 Indoor and outdoor air sampling at the residential areas

3.5.1 Indoor and outdoor air sampling

In order to collect the samples, the sampling trains of 2, 4 DNPH cartridge and charcoal glass tube attached with low-flow personal air pump were installed at indoor and outdoor places of five residential areas during 24 hours, began and finished at 7:00 AM during dry season (21st April-24th May) and wet season (July-August).

The air flow rate of personal air devices were set at 100 mL/min. Figure 3.24 and 3.25 demonstrated the indoor and outdoor sampling at the sites. After finishing the sample collection, DNPH cartridges were extracted immediately at laboratory by using acetonitrile as a solvent and kept in amber colored screwed vials. For all samples, both charcoal glass tubes and amber vials contained carbonyl compounds were stored in freezer or refrigerator (<-4 ℃). Moreover, all personal air pumps were calibrated by using Primary Standard Airflow type of bubble gas calibrator (Gilibrator-2 Standard Flow Kit, 20CC-6LPM) produced by Gilian (USA), before and after sample collections in order to check whether the air flow rate was the same range or not.

In case of indoor air sampling, three houses in five residential areas were chosen for indoor air sampling. However, only one house of each community was selected for outdoor air sampling. Most of houses for outdoor air samplings were located at the central area of each community. The height of installation of sampling train was around 2 meters above the ground. Likewise, outdoor air samplings were performed in the same condition as the indoor air sampling. Additionally, the sample collections were done at two different periods of time which were dry and wet season in order to compare the concentration of carbonyl compounds and BTEX in those five residential areas of study.

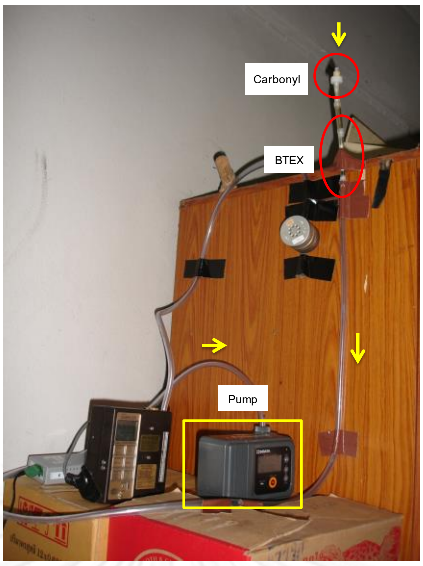


Figure 3. 24 Indoor air sampling at Patthana Bon-Kai community

Figure 3. 25 Outdoor air sampling at Patthana Bon-Kai community

3.5.2 Sample Preparation

3.5.2.1 Carbonyl compounds

The extraction procedure for DNPH active cartridges is shown in Figure 3.26. The immediate extraction was required after samples were collected in order to prevent the contamination in samples. The solvent used for extraction was acetonitrile, HPLC grade, produced by J.T. Baker, Inc., USA.

3.5.2.2 BTEX

The extraction procedure for charcoal gas tubes is illustrated in Figure 3.27. After samples were collected, a charcoal gas tube had to be closed with caps for avoiding the sample lost. Additionally, the front and back activated charcoal tubes were determined the concentration of BTEX separately. Whereas the front part of activated charcoal was representative of actual amount, the back part of activated charcoal was used as breakthrough checking. All samples were spiked with 100 µL (for front part) and 50 µL (for back part) of internal standard, 4-bromofluorobenzene (Supelco, USA) at the final concentration of 2,000 ng/mL. Moreover, carbon disulfide (CS_2) (ITALMAR Co., LTD., Thailand) was used as solvent for sample extraction.

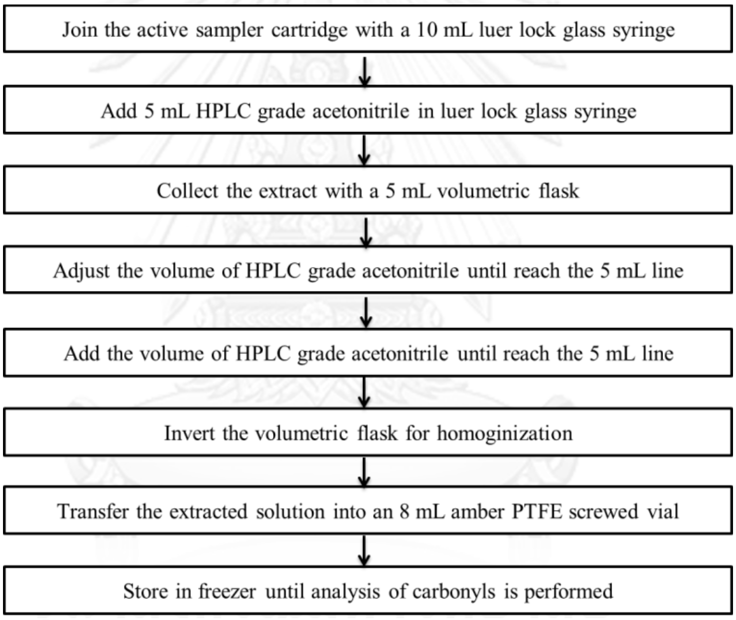


Figure 3. 26 Procedure of DNPH active sample extraction

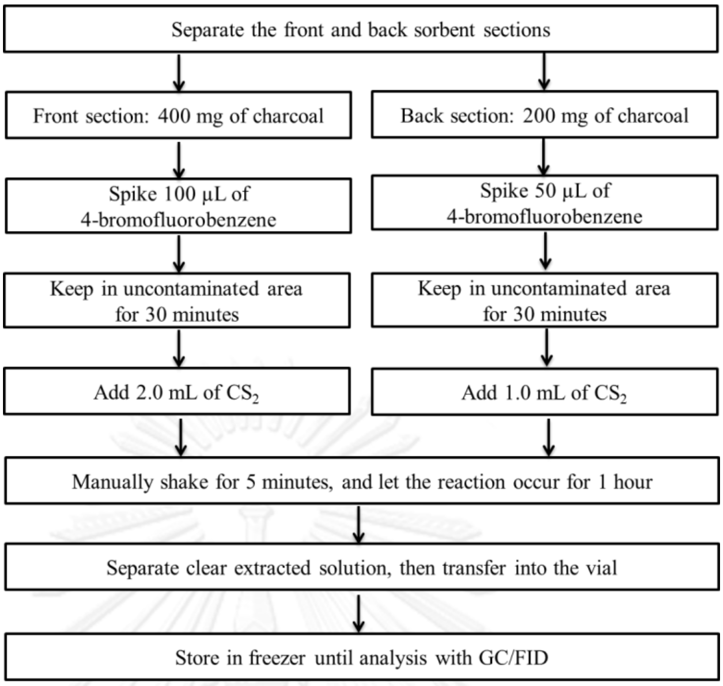


Figure 3. 27 Procedure of charcoal glass tube extraction

3.5.3 Calculation of carbonyl compounds and BTEX concentrations

3.5.3.1 Carbonyl compounds

In order to check the stability of HPLC instrument, the quantitative of carbonyl compounds in the samples could be determined for daily calibration curve. The concentration of the daily calibration was 0.1 mg/L which was the middle concentration of the actual calibration curve. The different percentage between the concentration of the daily calibration and the actual calibration should not exceed 10%. Hence, the calculation of the mass and the actual concentration of carbonyl compounds could be performed by using the detected concentrations of carbonyl compounds (ppm = µg/mL) analyzed by HPLC/UV (See Eq. 3.7 and 3.8).

$$M_S = (X_A - X_B) \times V_S \qquad \text{(Eq. 3.7)}$$

where;

M_S (µg/sample) = Mass of carbonyl compounds

X_A (µg/mL) = Concentration of carbonyl compounds in sample

X_B (µg/mL) = Concentration of carbonyl compounds in blank

V_S (mL) = Sample volume 5 mL

$$\text{Concentration of carbonyls } (\mu g/m^3) = \frac{\text{Mass of carbonyls } (\mu g)}{\text{Volume of air } (m^3)} \qquad \text{(Eq. 3.8)}$$

3.5.3.2 BTEX

The comparison between quantitative of BTEX in the samples and mixed standard solution containing internal standard, 4-bromofluorobenzene (Supelco, USA), at the final concentration of 2,000 ng/mL was performed. Eq. 3.9 and 3.10 presented the calculation for the mass of BTEX and the actual concentration of BTEX, respectively.

$$M_S = \frac{P_A - P_B \times C_S \times V_S}{P_S \times V_I} \qquad \text{(Eq. 3.9)}$$

where;

M_S (µg/sample) = Mass of BTEX

C_S (µg/mL) = Concentration of the mixed standard solution

P_A (unitless) = Peak area of BTEX per peak area of 4-bromofluorobenzene in sample

P_B (unitless) = Peak area of BTEX per peak area of 4-bromofluorobenzene in blank

P_S (unitless) = Peak area of BTEX per peak area of 4-bromofluorobenzene in mixed standard solution

V_S (µL) = Sample volume 2 mL

V_I (µL) = Injection volume 1 µL

$$\text{Concentration of BTEX } (\mu g/m^3) = \frac{\text{Mass of BTEX } (\mu g)}{\text{Volume of air } (m^3)} \qquad \text{(Eq. 3.10)}$$

3.5.4 Data Analysis

All obtained data were analyzed as follows:

1) The difference of the toxic chemicals among those five residential areas was statistically analyzed by using ANOVA with *SPSS 19.0 for Windows*.

2) Relationship between some factors associated with the concentration of carbonyl compounds and BTEX were determined by using Pearson’s correlation.

3) All cancer risk and non-cancer risk and also CDI and EC values were analyzed and reported in term of 95% Confidential Interval using *SPSS 19.0* for Windows.

3.6 Health Risk Assessment of the resident living in five communities

This study mainly emphasized on daily exposure of carbonyl compounds and BTEX at five residential areas during dry and wet season. The possible adverse health effects were considerably caused by exposure via inhalation as the main pathway, since carbonyl compounds and BTEX were atmospheric toxic substances. Therefore, the risk assessment of inhalation exposure was determined for the long term of exposure when people trended to live in their own houses for many years in order to estimate their health risk. Based on United States Environmental Agency (US EPA, 2012a), the four steps which were (1) Hazard Identification; (2) Does-Respond Assessment; (3) Exposure Assessment; and (4) Risk Characterization would be performed in this study. Risk Assessment Guidance for Superfund (RAGS): Volume I for Human Health Evaluation Manual was created by the U.S. Environmental Protection Agency (EPA) with several parts (i.e., part A, vol.3 A, B, C, D, E, and F). Due to the related information about inhalation exposure guidelines, part A and F were applied in this study. Part A was the Baseline Risk Assessment (US EPA, 1989), while part F was Supplemental Guidance for Inhalation Risk Assessment (US EPA, 2009). Some different parameters presented in Table 3.10 were used in part A and F within each step of risk assessment.

There were some different values for each step of risk assessment between part A and part F of RAGS volume I. This study would follow the calculation of part A and part F for the risk assessment.

Table 3. 10 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 Supplemental Guidance for Inhalation Risk Assessment	
Step1: Hazard Identification	Cancer	Non-cancer	Cancer	Non-cancer
Step 2: Dose-Respond 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	$CDI \times CSF_i$	ADD/RfD_i	EC x IUR	EC/RfC

(Kitwattanavong, 2010)

3.6.1 Hazard identification

Hazard identification which is the first step of risk assessment emphasizes on the health effects that possible caused by exposure of toxic substances. In this study, carbonyl compounds and BTEX were expected to be target chemicals that cause human health effects for the people living at the residential areas. Both carcinogenicity and non-carcinogenicity had been considered. The toxicity of some chemicals is given in Table 3.11.

3.6.2 Dose-respond assessment or toxicity assessment

For the second step of risk assessment, dose-respond assessment mainly focuses on the health effects at different level of exposure. After identification of health problems caused by hazardous substance, the process of examination of the relationship between dose and response collected from animal tests had been performed by United States Environmental Protection Agency. The reference values used for risk assessment of inhalation exposure were described as presented in Table 3.12 and 3.13.

Table 3. 11 The human health effects caused by exposure of carbonyl and BTEX in the atmosphere

Compound	Cancer Classification				Hazard Index Target(s)	Precursor Effect/ Tumor Type	Critical Effects
	(a)	(b)	(c)	(d)			
Formaldehyde	B1	B1	1	A2	Nasal cavity(e) Respiratory system; eyes(g)	Squamous cell carcinoma(f)	Irritation of upper and lower airway and eyes; degenerative; inflammatory and hyperplastic changes of the nasal mucosa(g)
Acetaldehyde	B2	B2	2B	-	Nasal(e); bronchi; eyes; nose; throat; respiratory system(k)	Nasal squamous cell carcinoma or adenocarcinoma (e)(f)	Degeneration of olfactory epithelium (e)(f); sensory irritation; broncoconstriction; eyes redness and swelling(k)
Acetone	D	D	-	A4	-	-	Nephropathy(f)
Propionaldehyde	-	-	-	-	-	-	Atrophy of olfactory epithelium(f)
Benzene	D	-	-	A3	Blood(e);Hematopoietic system; development; nervous system(h)	Leukemia(f)	Decreased lymphocyte count (e)(f);lowered red and white blood cell count(h)
Toluene	D	D	3	A4	Nervous system; respiratory system; teratogenicity(j)	-	Neurological effects in occupationally-exposed workers(e)(f); neurotoxic effects (decrease brain weight, altered dopamine receptor binding)(j)
Ethylbenzene	C	-	3	A3	Kidney(e); alimentary system (liver); endocrine system(i)	Tumors(e)	Developmental toxicity(e)(f); liver; kidney; pituitary gland(i)
Xylene	D	D	3	A4	-	-	Impaired motor coordination (decreased rotarod performance)(e)(f)

(a)(US EPA, 2012b);(b) (US EPA, 2006b);(c)(IARC, 2006); (d)(ACGIH, 2010);(e)(RAIS, 2013);(f)(US EPA, 2010b);(g)(OEHHA, 2012c);(h)(OEHHA, 2012a);(i)(OEHHA, 2012b);(j)(OEHHA, 1999);(k)(OEHHA, 2008)(a)(b)B1=probable human carcinogen; B2=probable human carcinogen; C=possible human carcinogen; D=not classifiable as to human carcinogenicity (c)2B=possibly carcinogenic to humans; 3 not classifiable as to its carcinogenicity to humans (d)A2=suspected human carcinogen; A3=confirmed animal carcinogen with unknown relevance to humans; A4=not classifiable as a human carcinogen

Table 3. 12 Toxicity values for carcinogenic compounds

Compound	Inhalation Slope Factor (mg/kg-day)$^{-1}$	
	RAIS’ s CSF$_i$(a)	OEHHA’ s CFS$_i$(b)
Formaldehyde	-	2.1 x 10^{-2}
Acetaldehyde	-	1.0 x 10^{-2}
Benzene	2.73 x 10^{-2}	1.0 x 10^{-1}
Ethylbenzene	3.85 x 10^{-3}	8.7 x 10^{-3}

(a) (RAIS, 2013); (b) (OEHHA, 2009)

Table 3. 13 Toxicity values for non-carcinogenic compounds

Compound	Inhalation R$_f$Cs (mg/m^3)		
	RAIS’ s R$_f$C(a)	IRIS’ s R$_f$C(b)	ATSDR’ s R$_f$C(c)
Propionaldehyde	8 x 10^{-3}	8 x 10^{-3}	-
Toluene	5	5	3.01 x 10^{-1}
Xylene	0.1	0.1	-

(a) (RAIS, 2013);(b)(US EPA, 2003, 2005, 2008); (c)(ATSDR, 2012)

3.6.3 Exposure assessment

3.6.3.1 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.

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

where;

CDI (mg/kg·day) = Chronic daily intake

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

IR (m^3/day) = Inhalation rate (21 m^3/day assumed for adult)

BW (kg) = Body weight (derived from questionnaires)

EF (days/year) = Exposure frequency (350 days/year assumed for resident)

ED (years) = Exposure duration (derived from questionnaire)

AT (days) = Averaged time (70 x 365 = 25,550 days)

The RAGS part F was then developed by US EPA (2009) in order to serve RfC values for estimation of the risk after expose with non-carcinogenic substances via inhalation pathway. In this approach, Exposure Concentrations (ECs) of each target organ was calculated from time-weighted average concentrations or modeled contaminant concentrations in atmospheric media. Additionally, the RAGS part F was considered to be used for calculation of non-carcinogenic chemicals which used EC values (See Eq. 3.12).

$$EC = (CA \times ET \times EF \times ED)/AT \qquad \text{(Eq. 3.12)}$$

where;

EC ($\mu g/m^3$) = Exposure concentration

CA ($\mu g/m^3$) = Contaminant concentration in the air

ET (hours/day) = Exposure time (24 hours/day for resident)

EF (days/year) = Exposure frequency (350 days/year assumed for resident)

ED (years) = Exposure duration (derived from questionnaire)

AT (hours) = Averaged time (70 x 365 x 24 = 613,200 hours)

3.6.3.2 Age interval scenario

According to Handbook for Implementing the Supplemental Cancer Guidance at Waste and Clean-up Sites (US EPA, 2012), 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. 3.13.

$$Risk_i = (C \times IR_i \times EF_i \times SF \times ED_i \times ADAF_i)/(BW_i \times AT) \qquad \text{(Eq. 3.13)}$$

where,

C (mg/m^3) = Concentration of contaminant in the air

IR_i (m^3/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 $(mg/kg\text{-}day)^{-1}$ = Cancer slop factor

Even though US EPA (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. 3.18.

$$Risk_{0\text{-}2} = (C \times IR_{child} \times EF_{child} \times SF \times 2 \times 10)/(BW_{child} \times 25{,}550) \quad \text{(Eq. 3.14)}$$

$$Risk_{2\text{-}16} = (C \times IR_{child} \times EF_{child} \times SF \times 14 \times 3)/(BW_{child} \times 25{,}550) \quad \text{(Eq. 3.15)}$$

$$Risk_{16\text{-}30} = (C \times IR_{adult} \times EF_{adult} \times SF \times 14 \times 1)/(BW_{adult} \times 25{,}550) \quad \text{(Eq. 3.16)}$$

$$Risk_{30\text{-}now} = (C \times IR_{adult} \times EF_{adult} \times SF \times ED \times 1)/(BW_{adult} \times 25{,}550) \quad \text{(Eq. 3.17)}$$

$$\text{Total Risk} = Risk_{0\text{-}2} + Risk_{2\text{-}16} + Risk_{16\text{-}30} + Risk_{30\text{-}now} \quad \text{(Eq. 3.18)}$$

Table 3. 14 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 x 365 = 25,550			
EF[1]	Days/year	350 for residents			

[1] US EPA, 2012; [2] Nichara, 1996 and Department of Health, 1999

3.6.4 Risk characterization and interpretation

EPA's Risk Assessment Guidance for Superfund (RAGS), part A outlined a previously recommended approach for conducting site-specific baseline risk assessments for inhaled contaminants. In addition, Inhalation Dosimetry Methodology described the Agency's refined recommended approach for interpreting inhalation toxicity studies in laboratory animals or humans to atmospheric hazard chemicals. Cancer risk can be also estimated from inhalation toxicity values. Cancer risk can be implemented by multiplying the Chronic Daily Intake (CDI) of the atmospheric contaminant with the inhalation Cancer Slope Factor (CSF_i) as shown in Eq. 3.19.

$$\text{Cancer risk} = \text{CDI} \times CSF_i \qquad \text{(Eq.3.19)}$$

where;

Cancer risk $> 10^{-6}$ means that the carcinogenic effects have possibility to occur

Cancer risk $\leq 10^{-6}$ means that the carcinogenic risk is in an acceptable level

According to the RAGS part F, a Human Equivalent Concentration (HEC) was normally gain from the experimental exposures, while a Reference Concentration (RfC) was estimated by dividing HEC with Uncertainty Factors (UFs). Moreover, the Hazard Quatient (HQ), which was used as a critical parameter of the acceptable risk of non-carcinogenic substances, substantially can be calculated by dividing Exposure Concentration (EC) of the toxic compound with the Reference Concentration (RfC) as demonstrated in Eq. 3.20.

$$\text{HQ} = (\text{EC})/(\text{RfC} \times 1000\ \mu\text{g/mg}) \qquad \text{(Eq.3.20)}$$

where;

HQ > 1 means that the adverse non-carcinogenic health effects may occur

HQ ≤ 1 means that the non-carcinogenic risk is in an acceptable level

For total cancer risk and total non-cancer risk, the summation of cancer risk and summation of hazard quotient were used as described in Eq.3.21and 3.22.

$$\text{Total cancer risk} = \sum (\text{Cancer risk}_i) \qquad \text{(Eq. 3.21)}$$

$$\text{Hazard Index (HI)} = \sum (HQ_i) \quad \text{(Eq. 3.22)}$$

The interpretation of total cancer risk and hazard index were the same as mentioned in the interpretation of cancer risk and hazard quotient, respectively.

3.6.5 Questionnaire

Furthermore, the owners of the selected houses were asked to complete questionnaires in face to face interviews. The questions included general information, house information, resident activities, and also health problems related to respiratory diseases. Some information was used for calculating risk level such as bodyweight, age, and hour living in the house. The form and information gained from questionnaires were shown in Appendix A. The related information such as characteristic, noticeable activity of each house that might support the concentrations of carbonyl compounds and BTEX measured in indoor environment in Appendix F.

CHAPTER IV

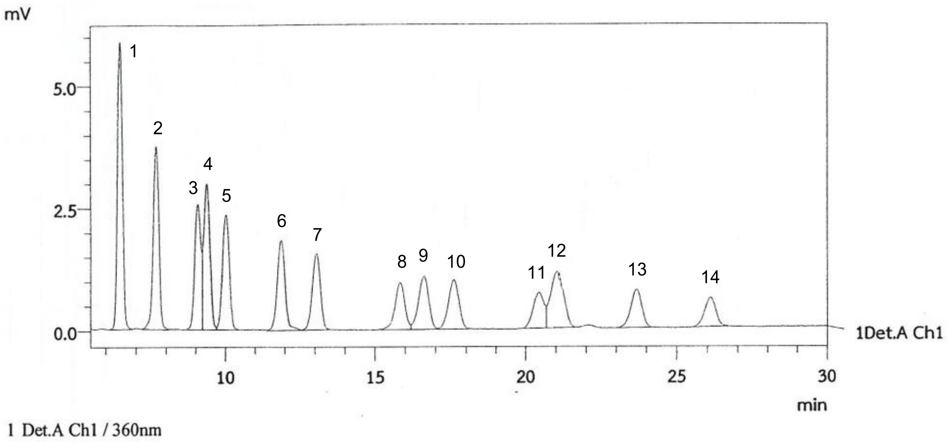
RESULTS AND DISCUSSION

4.1 Preliminary study

4.1.1 Optimum condition of instruments for carbonyl compounds and BTEX analysis

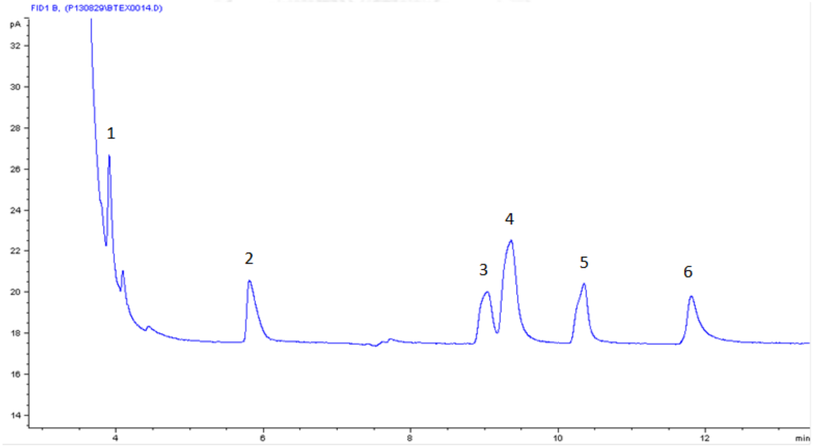
In this study, high performance liquid chromatography with the ultra violet detector (HPLC-UV) was used for qualitative and quantitative determination of carbonyl compounds. The instrument condition was set following the study of Morknoy (2008). The total runtime of this condition was 30.00 minutes. Figure 4.1 presented the chromatogram of mixed fourteen standard carbonyl compounds with the retention time of each compound. Fourteen isolated peaks could be identified i.e. formaldehyde, acetaldehyde, acetone, acrolein, propionaldehyde, crotonaldehyde, butyraldehyde, benzaldehyde, isovaleraldehyde, valeraldehyde, o-tolualdehyde, m-, p-tolualdehyde, hexanaldehyde, and 2, 5-dimethylbenzaldehyde.

In case of BTEX, gas chromatography with flame ionization detector (GC-FID) was chosen to analyze BTEX in the activated charcoal glass tubes. The optimum condition has been found by using mixed standard solution of BTEX dissolved in 4-fluorobenzene solution with the concentration of 20,000 ng/mL as an internal standard. The total runtime was 17.67 minutes per sample. The chromatogram of mixed standard BTEX was illustrated in Figure 4.2 with the retention time of each compound.



1. Formaldehyde (6.4)
2. Acetaldehyde (7.5-7.7)
3. Acetone (8.9-9.1)
4. Acrolein (9.71)
5. Propionaldehyde (9.8-10.0)
6. Crotonaldehyde (11.1-12.2)
7. Butyraldehyde (12.7-13.1)
8. Benzaldehyde (15.8-16.0)
9. Isovaleraldehyde (16.5-16.8)
10. Valeraldehyde(17.2-17.6)
11. o-Tolualdehyde (20.0-20.6)
12. m-,p-Tolualdehyde (21.0-21.6)
13. Hexanaldehyde (23.3-23.6)
14. 2,5-Dimethylbenzaldehyde (26.0-26.7)

Figure 4. 1 Chromatogram of standard 14 carbonyl compounds at the concentration of 0.05 ppm (The number in bracket represented retention time)



1. Benzene (3.85)
2. Toluene (5.75)
3. Ethylbenzene (8.90)
4. m-, p-Xylene (9.20)
5. o-Xylene (10.20)
6. 4-bromofluorobenzene (11.80)*

The number in the blanket is the retention time of the compounds and * means an internal standard

Figure 4. 2 Chromatogram of mixed standard BTEX at the concentration of 8,000 ng/mL dissolved in 4-bromofluorobenzene solution as the internal standard with 20,000 ng/mL

4.1.2 Calibration curves

For carbonyl compounds, six concentrations of mixed carbonyl compounds standard which comprised of 0.005, 0.010, 0.050, 0.100, 0.500, and 1.000 mg/L were prepared for the standard curve. Each compound has an individual calibration curve. The concentrations of mixed standard carbonyl compounds were plotted in Y-axis, while peak areas of those were plotted in X-axis as presented in Appendix A. The calibration curves of 14 mixed standard carbonyl compounds have the R^2 in the range of 0.9988-0.9998.

In case of BTEX, the calibration curves of mixed BTEX standard were established from seven concentrations including 125, 250, 500, 1,000, 2,000, 4,000, and 8,000 ng/mL. Likewise the calibration curves of carbonyl compounds, the calibration curves of BTEX were demonstrated in Appendix A. The R^2 of the calibration curves of BTEX were identified in range of 0.9859-0.9996.

The standard concentrations of carbonyl compounds and BTEX in the units of mg/mL and ng/mL, respectively, were converted in the unit of µg/m^3 which was mass of substance in the atmosphere per volume of air as provide in Table 4.1.

Table 4. 1 Concentrations of carbonyl compounds and BTEX standards in calibration curves

Standard solution	Concentration of standard solution	Concentration in the air (µg/m^3)
Standard of mixed carbonyls	0.005 mg/L	0.174
	0.010 mg/L	0.347
	0.050 mg/L	1.736
	0.100 mg/L	3.472
	0.500 mg/L	17.361
	1.000 mg/L	34.722
Standard of mixed BTEX	125 ng/mL	1.736
	250 ng/mL	3.472
	500 ng/mL	6.944
	1,000 ng/mL	13.889
	2,000 ng/mL	27.778
	4,000 ng/mL	55.556
	8,000 ng/mL	111.111

4.1.3 Determination limitations of HPLC and GC

4.1.3.1 IDL and IQL of High Performance Liquid Chromatography

For the quality assurance and the quality control of HPLC, the instrument detection limit (IDL) and the instrument quantification limit (IQL) were implemented in this case. In order to determine those values, 0.05 mg/L of mixed standard carbonyl compounds was prepared and analyzed for seven replicates by using HPLC with UV detector. The calculation of the average value, standard deviation (SD), and % RSD was performed. The values of 3SD and 10SD were used as the values of IDL and IQL, respectively. Additionally, none detected (ND) was the value of IQL for each compound. The values of IDL and IQL were illustrated in Table 4.2.

The detection limit of carbonyl compounds reported in this study was similar to the study of (Dutta et al., 2009) recording in the range of 0.01-0.4 µg/m^3 for ambient air sampling in India; 0.26-6.42 µg/m^3 for outdoor air sampling (W. Liu et al., 2006); 0.17-0.66 µg/m^3 for indoor and outdoor air sampling in Mexico (Báez et al., 2003). However, the range of detection limit of HPLC for carbonyl compounds analysis recorded by (Lu et al., 2007) in the range of 0.05-0.15 µg/m^3 for indoor and outdoor air sampling in China and (Feng et al., 2004) in the range of 0.05-0.15 µg/m^3 for indoor and outdoor air sampling in China and Sandner et al. (2001) with 0.07-0.22 µg/m^3 for sensitive indoor air were relatively lower than the ranges found in this study. On the other hand, the range of detection limit found in Liu et al. (2006) with 0.44-20.1 µg/m^3 for indoor air sampling in residential areas, USA was quite high compared to this study.

Table 4. 2 Results of IDL and IQL for carbonyl compounds analysis

Compound	Dry season		Wet season	
	IDL (mg/L)	IQL (mg/L)	IDL (mg/L)	IQL (mg/L)
Formaldehyde	0.002	0.005	0.001	0.004
Acetaldehyde	0.001	0.005	0.001	0.003
Acetone	0.002	0.008	0.002	0.005
Propionaldehyde	0.002	0.005	0.001	0.004
Crotonaldehyde	0.001	0.004	0.004	0.014
Butyraldehyde	0.002	0.006	0.002	0.005
Benzaldehyde	0.003	0.011	0.002	0.005

Compound	Dry season		Wet season	
	IDL (mg/L)	IQL (mg/L)	IDL (mg/L)	IQL (mg/L)
Isovaleraldehyde	0.002	0.008	0.002	0.006
Valeraldehyde	0.003	0.009	0.005	0.015
o-Tolualdehyde	0.003	0.010	0.004	0.013
m,p-Tolualdehyde	0.002	0.007	0.003	0.011
Hexanaldehyde	0.003	0.008	0.005	0.018
2,5-Dimethylbenzaldehyde	0.003	0.012	0.006	0.019

4.1.3.2 LOD and LOQ of Gas Chromatography

In case of BTEX quantification, the limit of detection used the term of the Limit of Detection (LOD) and the Limit of Quantification (LOQ) for the analysis of gas chromatography. The lowest concentrations of mixed standard BTEX were detected when the signal to noise ratios equaled approximately three for each individual compound. Moreover, the lowest concentration of each BTEX was analyzed triplicates by using GC/FID. After the average peak area and standard deviation (SD) of those peak areas were identified, LOD and LOQ were calculated, respectively. The unit for LOD and LOQ from the actual mixed standard BTEX was ng/mL, then this term was converted into mass of each BTEX per volume of air in term of μg/m^3. Nevertheless, the unit of μg/m^3 depended on the volume of air sampling of this study related with the period of time. The values of LOD and LOQ in two units were given in Table 4.3 for the analysis of BTEX samples in phase 1 at Faculty of Engineering and the values of LOD and LOQ for BTEX samples in phase 2 at the International Program of Hazardous Substance and Waste Management.

While the range of LOD in this study was 0.00542-0.463μg/m^3, other studied might provide the different range of LOD for the detection limit of GC/FID analysis. The previous studies found the LOD of BTEX analyzed by GC in the range of 0.06 - 1.04 μg/m^3 for indoor and outdoor air sampling in Spain (Esplugues et al., 2010); less than 0.2 ppb for indoor and outdoor air sampling in China (LÜ et al., 2006); less than 0.1 μg/m^3 for indoor air sampling in Belgium (Stranger et al., 2008); approximately 1 μg/m^3 for benzene in ambient air (Skov et al., 2001).

Table 4. 3 Results of LOD and LOQ for BTEX analysis

Compound	Dry season		Wet season	
	LOD (ng/mL)	LOQ (ng/mL)	LOD (ng/mL)	LOQ (ng/mL)
Benzene	5.75	19.16	4.45	14.85
Toluene	5.32	17.74	0.39	1.31
Ethylbenzene	1.60	5.34	8.83	29.43
m-,p-Xylene	2.67	8.90	3.51	11.71
o-Xylene	11.08	36.93	33.37	111.25

4.1.4 % Recovery test

Only the instrument's accuracy was defined in this case. In term of carbonyl compounds, the recovery test was performed followed the study of Morknoy (2008) by injection of 100 µL of mix standard solution of carbonyl compounds with the concentration of 0.5 ppm into active 2,4-dinitrophenylhydrazine cartridges (Wako Pure Chemical Industries Ltd., Japan) and then extracted the samples followed the same procedure. All extracted solutions were analyzed by using HPLC/UV. According to the recovery test of 14 carbonyl compounds, the outcome presented the values between 63.8-92.0% as demonstrated in Table 4.4.

For the recovery test of BTEX, the standard solution of BTEX, HC BTEX Mix (Supelco, USA) at the concentration of 8,000 ng/mL was spiked into active activated charcoal glass tubes (SKC Inc., USA) and then injected extracted solution into GC/FID for quantitative and qualitative analysis. The result of the recovery test of BTEX were in range of 95.3 -100.6% which were illustrated in Table 4.5.

Table 4. 4 % recovery of carbonyl compounds

Compounds	% Recovery
Formaldehyde	92.0
Acetaldehyde	87.6
Acetone*	-
Propionaldehyde	82.7

Compounds	% Recovery
Crotonaldehyde	81.3
Butyraldehyde	63.8
Benzaldehyde	88.9
Isovaleraldehyde	83.2
Valeraldehyde	80.2
o-Tolualdehyde	85.8
m,p-Tolualdehyde	90.7
Hexaldehyde	84.9
2,5-Dimethylbenzaldehyde	87.1

* The concentration of acetone could not be determined due to the technical problem, therefore, the % recovery of acetone cannot be reported.

Table 4. 5 % recovery of BTEX

Compounds	% Recovery
Benzene	95.9
Toluene	96.5
Ethylbenzene	100.6
m,p-Xylene	96.5
o-Xylene	95.3

4.1.5 Relative standard deviation (% RSD)

In order in find the %RSD, injection of mix standard TO-11A as the standard solution of carbonyl compounds with the concentration of 0.1 ppm was performed for 10 times. However, the mix standard BTEX with the concentration of 8,000 ng/mL was analyzed 8 times for identification of %RSD. The relative standard deviations of carbonyl compounds and BTEX were demonstrated in Table 4.6 and 4.7, respectively.

Table 4. 6 The relative standard deviation of carbonyl compounds

Compound	%RSD	
	Phase 1	Phase 2
Formaldehyde	0.484	0.864
Acetaldehyde	0.454	0.657
Acetone	0.764	1.087
Propionaldehyde	0.495	0.847
Crotonaldehyde	0.397	3.017
Butyraldehyde	0.535	1.045
Benzaldehyde	1.047	1.158
Isovaleraldehyde	0.743	1.323
Valeraldehyde	0.860	2.918
o-Tolualdehyde	0.973	2.992
m,p-Tolualdehyde	0.639	2.212
Hexaldehyde	0.806	3.600
2,5-Dimethylbenzaldehyde	1.097	4.259

Phase 1 means during dry season; Phase 2 means during wet season.

Table 4. 7 The relative standard deviation of BTEX

Compound	%RSD	
	Phase 1	Phase 2
Benzene	6.563	3.616
Toluene	4.798	1.707
Ethylbenzene	2.621	1.389
m,p-Xylene	1.836	1.252
o-Xylene	4.319	1.252

Phase 1 means during dry season; Phase 2 means during wet season.

4.2 Detectable carbonyl compounds and BTEX at five communities in inner city of Bangkok, Thailand

This study was divided into two phases which comprised of dry (21st April to 24th May, 2013) and wet (22nd September to 25th October, 2013) seasons. For both phases, the active samples were taken from five communities in inner city of Bangkok, as described previously in Chapter 3. In each community, three houses were chosen for sampling and were used as representative indoor air samples. One of those three houses was selected to be an outdoor sampling site. The three houses of each community were collected samples for three times that were held on Sunday, Tuesday, and Friday which covered weekday and weekend.

All active samples were designed for carbonyl compounds and BTEX collection during 24 hours starting from 7:00 a.m. until 7:00 a.m. of the next day. In one sampling device comprised of DNPH cartridge for carbonyl compounds collection and charcoal glass tube for BTEX collection.

According to the information above, 120 DNPH cartridges and 120 charcoal glass tubes were collected from both phases within five communities. For the chemical analysis, 5 individual compounds of BTEX and 14 carbonyl compounds were quantified by using GC/FID and HPLC/UV-VIS, respectively. Those 19 chemicals of carbonyl compounds and BTEX could be detected at selected residential sites as present in Table 4.8. Based on Table 4.9, the target compounds detected in indoor air samples were more frequently found than those in outdoor air samples. The most dominant species that were found in indoor and outdoor air in all residential sites were formaldehyde, acetaldehyde, propionaldehyde, hexanaldehyde, benzene, toluene ethylbenzene, m-, p-xylene and o-xylene. Therefore, these 9 target compounds would be discussed in the next sessions.

There were some previous studies that also studied in the same groups of compounds which were carbonyl compounds and BTEX as provided in Table 4.9. All previous research also determined the concentration of chemicals in indoor and outdoor air in urban environment, for examples, Bangkok, Thailand (Daisy Morknoy et al., 2011); Beijing, Guangzhou, and Shanghai in China (Feng et al., 2004; Hoque et al., 2008; Huang et al., 2008; Q. Liu et al., 2013); Valencia in Spain (Esplugues et al., 2010); Rome in Italy (Santarsiero & Fuselli, 2008); California, New Jersey, and Texas in the United States (Liu et al., 2006); Mexico city and Xalapa in Mexico (Báez et al., 2003); Rio de Janeiro in Brazil (Brickus, Cardoso, & de Aquino Neto, 1998).

Table 4. 8 Detectable carbonyl compounds and BTEX during dry and wet seasons at five residential areas in inner city of Bangkok

Type	Compound name	Dry season					Wet season				
		S	P	B	J	C	S	P	B	J	C
BTEX	Benzene	IO	I	IO	IO	IO	IO	I	IO	IO	IO
	Toluene	IO	IO	IO	IO	IO	IO	IO	IO	IO	IO
	Ethylbenzene	IO	IO	IO	IO	IO	IO	IO	IO	IO	IO
	m-,p-Xylene	IO	IO	IO	IO	IO	IO	IO	IO	IO	IO
	o-Xylene	IO	IO	IO	IO	IO	IO	IO	IO	IO	IO
Carbonyls	Formaldehyde	IO	IO	IO	IO	IO	IO	IO	IO	IO	IO
	Acetaldehyde	IO	IO	IO	IO	IO	IO	IO	IO	IO	IO
	Acetone	IO	IO	IO	IO	IO	IO	-	IO	IO	IO
	Propionaldehyde	IO	IO	IO	IO	IO	IO	IO	IO	IO	IO
	Crotonaldehyde	IO	IO	IO	IO	IO	I	IO	I	IO	IO
	Butyraldehyde	IO	IO	I	IO	IO	I	-	IO	I	I
	Benzaldehyde	IO	IO	IO	IO	IO	IO	IO	IO	IO	IO
	Isovaldehyde	IO	I	-	I	-	IO	IO	IO	IO	IO
	Valeraldehyde	IO	IO	IO	IO	IO	IO	IO	IO	IO	IO
	o-Tolualdehyde	IO	IO	IO	IO	IO	IO	IO	IO	IO	IO
	m-, p-Tolualdehyde	IO	I	IO	IO	I	I	IO	IO	IO	IO
	Hexanaldehyde	IO	IO	IO	IO	IO	I	-	IO	I	I
	2,5-Dimethylbenzaldehyde	IO	IO	IO	I	IO	I	I	I	IO	IO

I means that detectable compounds in indoor air samples, O means that detectable compounds in outdoor air samples, - means that non-detectable compounds

Table 4. 9 Comparison of carbonyl compounds and BTEX found in indoor and outdoor air in other studies

Location	Environment	Carbonyl compounds	BTEX	Reference
Bangkok, Thailand	Indoor and outdoor air	Formaldehyde, Acetaldehyde, Acetone, Propionaldehyde, Crotonaldehyde, Butyraldehyde, Benzaldehyde, Isovaleraldehyde, Valeraldehyde,m-,p-Tolualdehyde, o-Tolualdehyde, Hexaldehyde, 2,5-Dimethylbenzaldehyde	Benzene, Toluene, Ethylbenzene, m,p-Xylene, o-Xylene	This study
Beijing, China	Residential areas	Formaldehyde, Acetaldehyde, Acetone, Acrolein	Benzene, Toluene, Xylenes	Liu et al. (2013)
Bangkok, Thailand	Ambient air and residential areas	Formaldehyde, Acetaldehyde	NS	Morknoy et al. (2011)
Valencia, Spain	Indoor and outdoor air	NS	Benzene, Toluene, Ethylbenzene, m,p-Xylene, o-Xylene	Esplugues et al. (2010)
Shanghai, China	Ambient air	Formaldehyde, Acetaldehyde, Acetone, Acrolein, Propionaldehyde, Butyraldehyde, Benzaldehyde, Cyclohexanone, Isovaleraldehyde, Valeraldehyde, p-Tolualdehyde, m/o-Tolualdehyde, Hexaldehyde, Octylaldehyde,Nonanaldehyde, Decylaldehyde	NS	Huang et al. (2008)
Rome, Italy	Indoor and outdoor air	Acetaldehyde, Acetone, Acrolein, Acrole, Propionaldehyde, n-Butyraldehyde, Benzaldehyde, Isovaleraldehyde, Valeraldehyde, Formaldehyde	NS	Santarsiero and Fuselli (2008)
California,	Indoor and	Formaldehyde, Acetaldehyde,	NS	Liu et al.

Location	Environment	Carbonyl compounds	BTEX	Reference
New Jersey, and Texax, the United States	outdoor air	Acetone, Acrolein, Propionaldehyde, Crotonaldehyde, Benzaldehyde, Glyoxal, Methylglyoxal, Hexaldehyde		(2006)
Guangzhou, China	Indoor and outdoor air	Formaldehyde, Acetaldehyde, Propionaldehyde, Crotonaldehyde, 2-butanone, Butyraldehyde, Benzaldehyde, Isovaleraldehyde, Cyclohexanone, Valeraldehyde, m/o-Tolualdehyde, Hexaldehyde, Heptaldehyde, Decylaldehyde, Octaylaldehyde, Nonanaldehyde	NS	Feng et al. (2004)
Mexico city and Xalapa, Mexico	Indoor and outdoor air	Formaldehyde, Acetaldehyde, Acetone, Propionaldehyde, Butyraldehyde,	NS	Báez et al. (2003)
Rio de Janeiro, Brazil	Indoor and outdoor air	NS	Benzene, Toluene, Ethylbenzene, Xylenes, Ethyltoluene	Brickus et al. (1998)

NS means Not study

4.3 Indoor and outdoor concentrations of carbonyl compounds and BTEX during dry and wet seasons

In order to compare the concentrations of both carbonyl compounds and BTEX among 5 communities, ANOVA test using *SPSS 19.0 for Windows* was used. The results of carbonyl compounds and BTEX were reported and discussed separately.

4.3.1 Comparison of carbonyl compounds at five communities

Since carbonyl compounds are considered to be secondary pollutants, these compounds can be generated in indoor and outdoor environment of residential area where residents have occasionally exposure to them like BTEX. The detectable carbonyl compounds in indoor and outdoor air at all five residential areas were formaldehyde, acetaldehyde, acetone, propionaldehyde, crotonaldehyde, isovaleraldehyde, valeraldehyde, m-,p-, and o-tolualdehyde, hexanaldehyde, and 2,5-dimethylbenzaldehyde as already described in Table 4.11 and 4.12. During summer, the most abundant species of carbonyl compounds in five communities was formaldehyde, followed by acetaldehyde, hexanaldehyde and propionaldehyde, whereas the others were found very low percent contribution of carbonyl compounds in indoor and outdoor air of Bangkok's residential areas. However, acetone concentration was surprisingly high due to lack of humidity control of equipment for sample collection.

For each community, indoor (n=9) and outdoor (n=3) carbonyl compounds samples investigated during dry and wet seasons were calculated as 24-hr average concentrations. The 14 carbonyl compounds at all five residential areas including S, P, B, J, and C communities were separately illustrated into 2 groups, the indoor concentrations of carbonyl compoundsas demonstrated in Figure 4.3 and 4.4, while the outdoor concentrations of carbonyl compounds were demonstrated in Figure 4.5 and 4.6.

Based on Figure 4.3 and 4.4, the high levels of formaldehyde and acetaldehyde were reported for all five residential areas, at S, P, B, J, and C communities excluding acetone which had non-humid controller led to have technique errors. However, 2, 4-dinitrophenylhydrazine active cartridge might be contaminated during long-time storage (Kiwattanavong, 2010). Hence, the concentrations of acetone were not included in discussion. Table 4.10 provided the independent t-test of indoor and outdoor concentrations of carbonyl compounds. The result showed that the indoor concentrations did not have significant difference regarding to the seasonal variation, except butyraldehyde, benzaldehyde, valeraldehyde, m-, p-tolualdehyde, and hexanaldehyde. For outdoor environment, most carbonyl compounds did not have significant difference regarding to seasonal variation, except butyraldehyde, benzaldehyde, valeraldehyde, hexanaldehyde, and 2, 5-dimethylbenzaldehyde. The difference individual characteristic of each carbonyl compounds might cause the different patterns regarding to seasonal variation. It is hard to identify the specific reason since carbonyl compounds had broad indoor sources. The mean differences among all 13 carbonyl compounds detected from all five communities were statistically analyzed by using compared mean-one way ANOVA, *SPSS 19.0 for Window*. The concluded data were reported in Table 4.11 for dry season (phase 1) and Table 4.12 for wet season (phase 2).

According to Table 4.11 and 4.12, the 24-hour average concentrations of indoor and outdoor air could be divided into the major and minor group of carbonyl compounds. To begin with dry season, formaldehyde, acetaldehyde, propionaldehyde, and hexanaldehyde were considered to be the dominant species of carbonyl compounds, while the rest were minor carbonyl compounds. For the major group, the average concentrations of formaldehyde, acetaldehyde, propionaldehyde and hexanaldehyde in indoor were 11.19 (1.40 - 38.73), 4.97 (0.22 - 10.16), 0.77 (0.03 - 2.08) and 2.07 (0.45 - 6.28) µg/m^3, respectively. Whilst those concentrations at the outdoor environment were 5.50 (2.10 - 10.39), 3.48 (1.65 - 7.26), 0.64 (0.24 - 1.78) and 1.25 (0.55 - 3.83) µg/m^3, respectively. For minor group, the average concentrations of crotonaldehyde, butyraldehyde, benzaldehyde, valeraldehyde, o-tolualdehyde, m-, p-tolualdehyde, and 2, 5-dimethylbenzaldehyde in indoor were 1.24 (0.01 - 6.94), 1.35 (0.09 - 16.23), 0.45 (0.07 - 4.03), 0.36 (0.05 - 4.37), 0.63 (0.03 - 11.17), 0.34 (0.03 - 1.34), and 0.72 (0.07 - 3.18) µg/m^3, respectively. Whilst those concentrations at the outdoor environment were 1.35 (0.09 - 16.23), 0.60 (0.02 - 1.84), 0.22 (0.07 - 0.48), 0.32 (0.03 - 0.62), 0.44 (0.03 - 2.03), and 0.63 (0.10 - 1.10) µg/m^3, respectively.

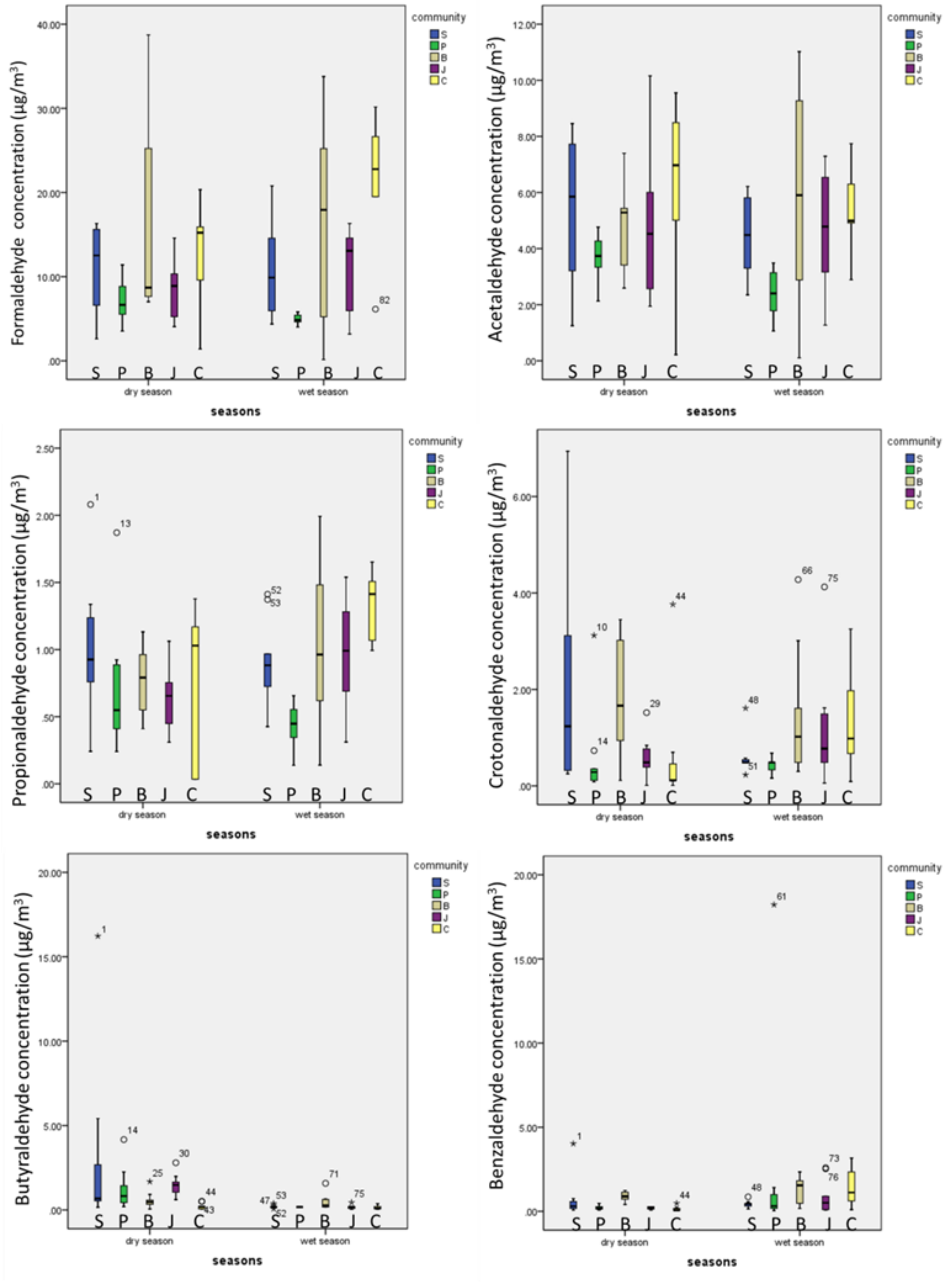


Figure 4. 3 The indoor concentrations of 6 carbonyl compounds measured at all five residential areas during dry and wet seasons (n=9)

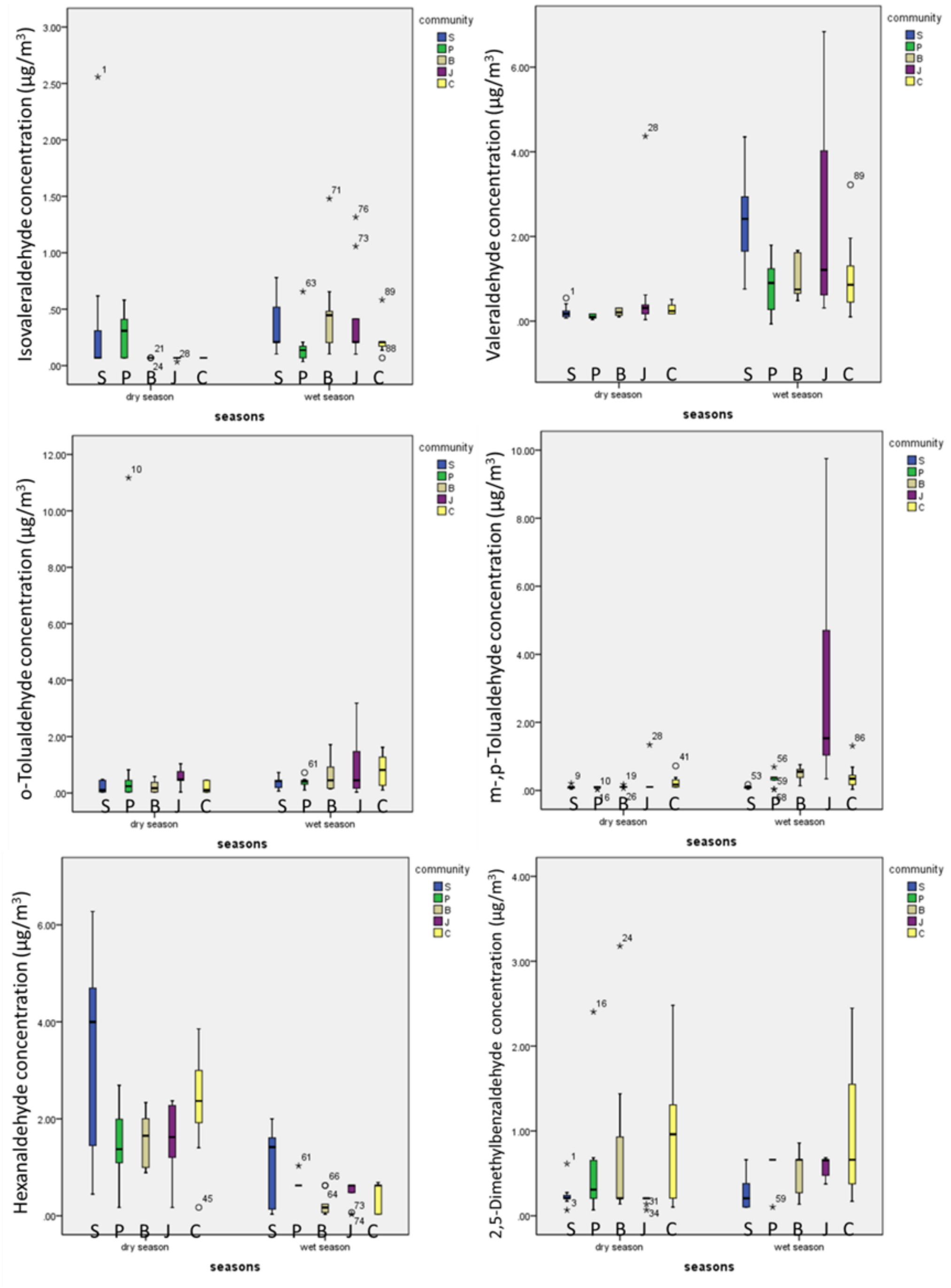


Figure 4. 4 The indoor concentrations of 7 carbonyl compounds measured at all five residential areas during dry and wet seasons (n=9).

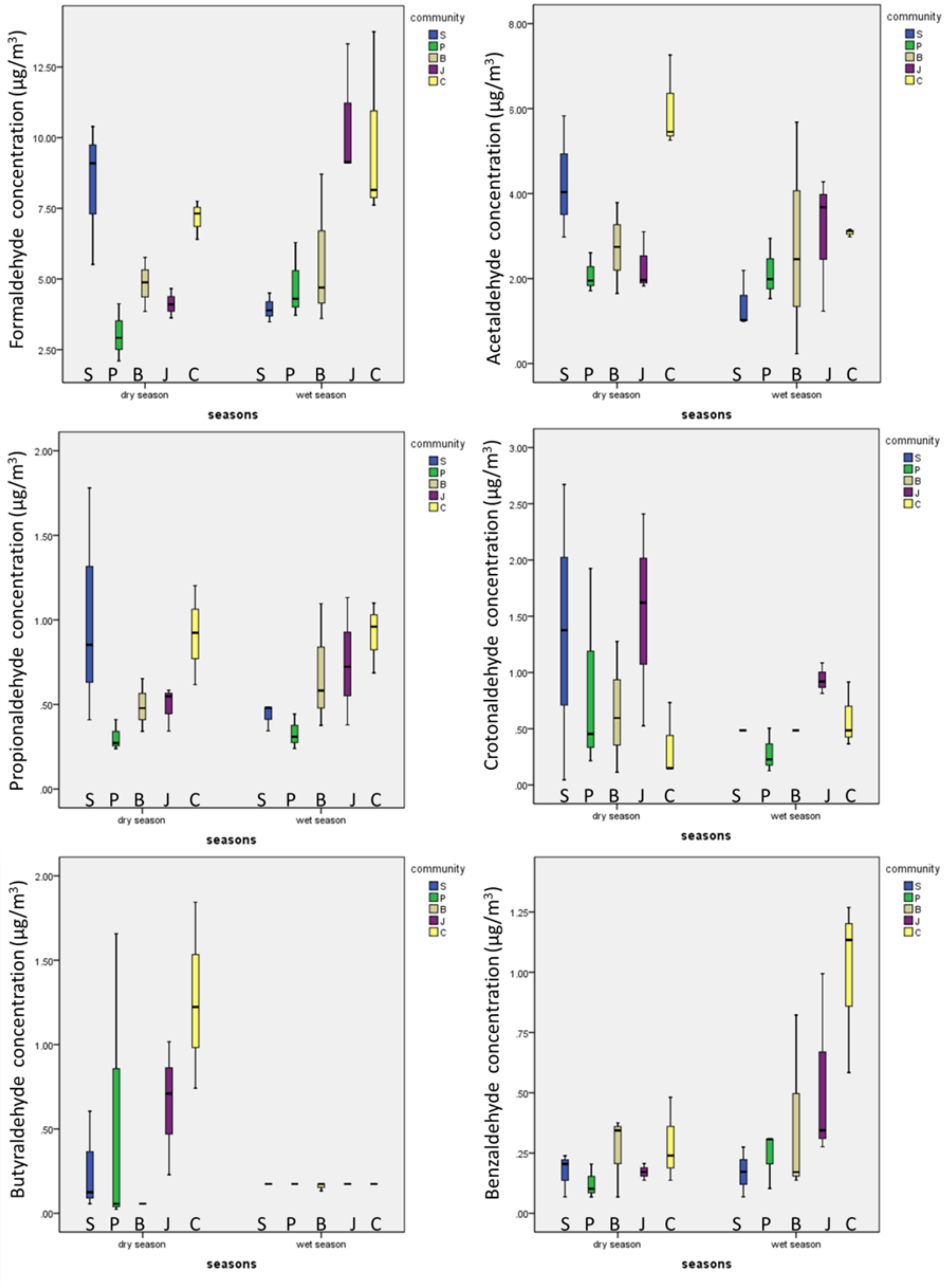


Figure 4. 5 The outdoor concentrations of 6 carbonyl compounds measured at all five residential areas during dry and wet seasons (n=3).

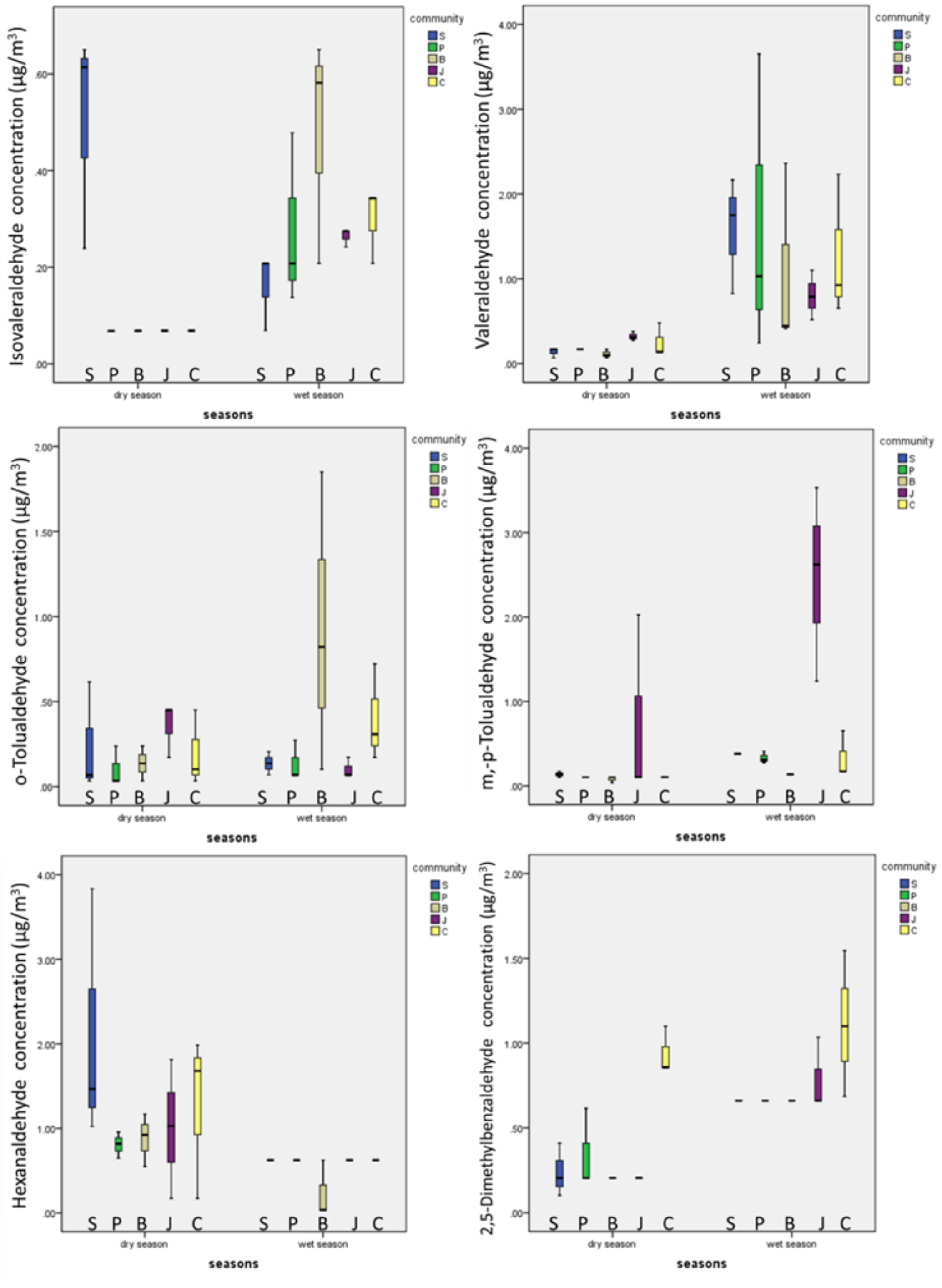


Figure 4. 6 The outdoor concentrations of 7 carbonyl compounds measured at all five residential areas during dry and wet seasons (n=3).

Among five communities, 4 main carbonyl compounds were compared both during dry and wet seasons. Based on the concentrations of formaldehyde found during dry season (Table 4.11), B community provided the highest indoor concentrations, followed by C, S, J, and P communities, respectively. However, the outdoor concentration of formaldehyde were found the highest levels at S community, followed by C, B, J, and P communities, respectively. For acetaldehyde, C community provided the highest concentrations for both indoor and outdoor air, followed by S community, while P community had the lowest concentrations for both indoor and outdoor concentrations. J community had higher indoor concentrations of acetaldehyde than B community, but J community had the lower outdoor concentrations of acetaldehyde than those presented in B community. For propionaldehyde, S community had the highest concentrations for both indoor and outdoor concentrations, followed by C community. The indoor concentrations of propionaldehyde were found at B community were higher than P and J communities, respectively. However, J community provided higher outdoor concentrations than B and P communities, respectively. Surprisingly, both indoor and outdoor concentrations of hexanaldehyde were found the highest at S community, followed by C, J, B, and P communities, respectively.

During wet season (see Table 4.12) of formaldehyde, the highest indoor concentrations were found at C community, followed by B, J, S, and P communities, respectively. Nonetheless, the outdoor concentrations of formaldehyde were the highest at J community, followed by C, B, P, and S communities, respectively. For acetaldehyde, B community provided the highest indoor concentrations, followed by C, J, S, P communities, respectively. Nevertheless, C community provided the highest outdoor concentrations of acetaldehyde, followed by J, B, P, and S communities, respectively. C community also had the highest indoor concentrations of propionaldehyde followed by B, J, S, and P community, respectively. The highest outdoor concentrations of propionaldehyde were found at C community, followed by J, B, S, and P communities, respectively. Noticeably, both indoor and outdoor concentrations of hexanaldehyde were found highest concentrations at S community, followed by P, J, C, and B community.

Table 4. 10 The independent t-test of 13 carbonyl compounds' concentrations between dry and wet seasons.

Compound	Independent t-test *p*-value	
	Dry season	Wet season
Formaldehyde	p=0.005	p=0.014
Acetaldehyde	p=0.031	p=0.004
Propionaldehyde	p=0.317	p=0.018
Crotonaldehyde	p=0.564	p=0.091
Butyraldehyde	p=0.246	p=0.338
Benzaldehyde	p=0.168	p=0.241
Isovaleraldehyde	p=0.788	p=0.685
Valeraldehyde	p=0.494	p=0.554
o-Tolualdehyde	p=0.448	p=0.128
m-,p-Tolualdehyde	p=0.413	p=0.626
Hexanaldehyde	p=0.031	p=0.845
2, 5-Dimethybenzaldehyde	p=0.418	p=0.141

Table 4. 11 Comparison of the 14 carbonyl compounds detected at all five residential areas during dry season

Compound	Environment	Average conc. (µg/m^3)^1	Conc. Range (µg/m^3)	Concentration Ranking (Low → High)^2
Formaldehyde	- Indoor air	11.19±7.34	1.4038-38.7270	$P^a<J^a<S^{ab}<C^{ab}<B^b$
	- Outdoor air	5.50±2.32	2.1004-10.3938	$P^a<J^a<B^{ab}<C^{bc}<S^c$
Acetaldehyde	- Indoor air	4.97±2.41	0.2186-10.1576	$P^a<B^{ab}<J^{ab}<S^{ab}<C^b$
	- Outdoor air	3.48±1.75	1.6519-7.2617	$P^a<J^a<B^{ab}<S^{bc}<C^c$
Propionaldehyde	- Indoor air	0.77±0.44	0.0342-2.0808	$J^a<P^a<B^a<C^a<S^a$
	- Outdoor air	0.64±0.41	0.2384-1.7798	$P^a<B^{ab}<J^{ab}<C^{ab}<S^b$
Crotonaldehyde	- Indoor air	1.24±1.53	0.0114-6.9398	$J^a<P^{ab}<C^{ab}<B^b<S^c$
	- Outdoor air	0.98±0.85	0.0456-2.6713	$C^a<B^a<P^a<S^a<J^a$
Butyraldehyde	- Indoor air	1.35±2.51	0.0913-16.2257	$C^a<B^a<P^{ab}<J^{ab}<S^b$
	- Outdoor air	0.60±0.59	0.0227-1.8441	$B^a<S^a<P^{ab}<J^{ab}<C^b$
Benzaldehyde	- Indoor air	0.45±0.63	0.0690-4.0252	$J^a<C^{ab}<P^{ab}<S^{bc}<B^c$
	- Outdoor air	0.22±0.11	0.0684-0.4811	$P^a<J^a<S^a<B^a<C^a$
Isovaleraldehyde	- Indoor air	0.29±0.36	0.0344-2.5584	$J^a<C^a<B^a<P^a<S^a$
	- Outdoor air	0.27±0.15	0.2083-0.6503	$C^a=J^a=B^a=P^a=S^a$
Valeraldehyde	- Indoor air	0.36±0.63	0.0342-4.3680	$P^a<B^a<S^a<C^a<J^a$
	- Outdoor air	0.29±0.18	0.0682-0.5208	$B^a<C^a<S^a<J^a<P^a$
o-Tolualdehyde	- Indoor air	0.63±1.62	0.0342-11.1731	$B^a<S^a<C^a<J^a<P^a$
	- Outdoor air	0.32±0.18	0.0342-0.6161	$B^a<C^a<J^a<S^a<P^a$
m-,p-Tolualdehyde	- Indoor air	0.34±0.21	0.0342-1.3414	$S^a<P^{ab}<B^{ab}<C^{ab}<J^b$
	- Outdoor air	0.44±0.45	0.0344-2.0265	$S^a<B^a<P^a=C^a<J^a$
Hexanaldehyde	- Indoor air	2.07±1.31	0.4485-6.2765	$P^a<B^a<J^a<C^{ab}<S^b$
	- Outdoor air	1.25±0.85	0.5468-3.8335	$P^a<B^a<J^a<C^a<S^a$
2,5-Dimethylbenzaldehyde	- Indoor air	0.72±0.68	0.0681-3.1790	$S^a<J^{ab}<P^{ab}<B^{ab}<C^b$
	- Outdoor air	0.63±0.24	0.1023-1.0996	$S^a<B^a<P^{ab}<J^{ab}<C^b$
Total Carbonyls	- Indoor air	23.68±11.44	2.6581-58.9106	$P^a<B^{ab}<S^{ab}<J^b<C^b$
	- Outdoor air	13.73±5.30	6.0300-24.5400	$P^a<B^a<J^b<S^b<C^b$

[1] Data were reported as the mean ± 1SD which derived from 45 and 15 samples for indoor and outdoor, respectively. [2] Community codes (see "site descriptive" in materials and method section) followed by a different lowercase superscript letter (a, b, c, d, and e) having significant different ($p < .05$) mean levels.

Table 4. 12 Comparison of the 14 carbonyl compounds detected at all five residential areas during wet season

Compound	Environment	Average conc. $(\mu g/m^3)^1$	Conc. Range $(\mu g/m^3)$	Concentration Ranking (Low→ High)^2
Formaldehyde	- Indoor air	12.97±8.91	0.1389-33.7811	$P^a < S^{ab} < J^{ab} < B^{bc} < C^c$
	- Outdoor air	6.95±3.41	3.4812-13.7421	$S^a < P^a < B^{ab} < C^{bc} < J^c$
Acetaldehyde	- Indoor air	4.59±2.53	0.1042-11.0208	$P^a < S^{ab} < J^b < C^b < B^b$
	- Outdoor air	2.49±1.42	0.2321-5.6806	$S^a < P^a < B^a < J^a < C^a$
Propionaldehyde	- Indoor air	0.94±0.47	0.1375-1.9930	$P^a < S^b < J^{bc} < B^{bc} < C^c$
	- Outdoor air	0.62±0.31	0.2404-1.1316	$P^a < S^a < B^{ab} < J^{ab} < C^b$
Crotonaldehyde	- Indoor air	1.01±1.01	0.0574-4.2774	$P^a < S^{ab} < J^{ab} < C^b < B^b$
	- Outdoor air	0.56±0.26	0.1261-1.0859	$P^a < S^a = B^a < C^a < J^b$
Butyraldehyde	- Indoor air	0.23±0.24	0.0304-1.5788	$C^a < J^a < P^a < S^a < B^b$
	- Outdoor air	0.17±0.01	0.1333-0.1736	$B^a < C^a = J^a = S^a = P^a$
Benzaldehyde	- Indoor air	1.30±2.72	0.0345-18.2233	$S^a < J^a < B^a < C^a < P^a$
	- Outdoor air	0.46±0.39	0.0689-1.2689	$S^a < P^a < B^a < J^{ab} < C^b$
Isovaleraldehyde	- Indoor air	0.33±0.32	0.0346-1.4794	$P^a < C^a < S^a < J^a < B^b$
	- Outdoor air	0.29±0.16	0.0689-0.6506	$S^a < J^{ab} < P^{ab} < C^{ab} < B^b$
Valeraldehyde	- Indoor air	1.52±1.37	0.0691-6.8395	$P^a < B^{ab} < C^{ab} < J^{bc} < S^c$
	- Outdoor air	1.27±0.96	0.2406-3.6541	$J^a < B^a < C^a < S^a < P^a$
o-Tolualdehyde	- Indoor air	0.61±0.63	0.0346-3.1856	$S^a < P^{ab} < B^{ab} < C^{ab} < J^b$
	- Outdoor air	0.34±0.48	0.0686-1.8504	$J^a < P^a < S^a < C^{ab} < B^b$
m-,p-Tolualdehyde	- Indoor air	1.01±2.12	0.0341-9.7528	$S^a < P^a < C^a < B^a < J^b$
	- Outdoor air	0.73±1.01	0.1369-3.5321	$B^a < P^a < C^a < S^a < J^b$
Hexanaldehyde	- Indoor air	0.57±0.48	0.0341-1.9996	$B^a < C^{ab} < J^{ab} < P^b < S^c$
	- Outdoor air	0.55±0.21	0.6597-1.5458	$B^a < C^b = J^b = P^b = S^b$
2,5-Dimethylbenzaldehyde	- Indoor air	0.59±0.44	0.1035-2.4470	$S^a < B^a < J^a < P^a < C^b$
	- Outdoor air	0.77±0.26	0.6597-1.5458	$B^a = P^a = S^a < J^{ab} < C^b$
Total Carbonyls	- Indoor air	25.69±12.78	4.0630-56.0244	$P^a < S^{ab} < J^{bc} < B^{bc} < C^c$
	- Outdoor air	15.22±5.80	7.7210-24.8731	$S^a < P^a < B^{ab} < C^b < J^b$

[1] Data were reported as the mean ± 1SD which derived from 45 and 15 samples for indoor and outdoor, respectively. [2] Community codes (see "site descriptive" in materials and method section) followed by a different lowercase superscript letter (a, b, c, d, and e) having significant different ($p < .05$) mean levels.

During wet season, the dominant species were formaldehyde, acetaldehyde, benzaldehyde, and valeraldehyde, while others were found in low levels. For the major group, the average concentrations of formaldehyde, acetaldehyde, propionaldehyde and hexanaldehyde in indoor were 12.97 (0.14-33.78), 4.59 (0.10-11.02), 0.94 (0.14-1.99), and 0.57 (0.03-1.99) µg/m^3, respectively. Whilst those concentrations at the outdoor environment were 6.95 (3.48-13.74), 2.49 (0.23-5.68), 0.62 (0.24-1.13), and 0.55 (0.66-1.55) µg/m^3, respectively. For minor group, the average concentrations of crotonaldehyde, butyraldehyde, benzaldehyde, valeraldehyde, o-tolualdehyde, m-, p-tolualdehyde, and 2, 5-dimethylbenzaldehyde in indoor were 1.01 (0.06-4.28), 0.23 (0.03-1.58), 1.30 (0.03-18.22), 1.52 (0.07-6.84), 0.61 (0.03-3.19), 1.01 (0.03-9.75), and 0.59 (0.10-2.45) µg/m^3, respectively. Whilst those concentrations at the outdoor environment were 0.56 (0.13-1.09), 0.17 (0.13-0.17), 0.46 (0.07-1.27), 1.27 (0.24-3.65), 0.34 (0.07-1.85), 0.73 (0.14-3.53), and 0.77 (0.66-1.59) µg/m^3, respectively.

The main species of carbonyl compounds recorded in this study were compared with previous studies which determined the residential indoor and outdoor levels collected from Hangzhou-China (Weng, Zhu, Yang, & Chen, 2010), Rome-Italy (Santarsiero and Fuselli, 2008), California, New Jersey, and Texas-The United States (Liu et al., 2006), Mexico City and Xalapa-Mexico (Báez et al., 2003) as provided in Table 4.13. To begin with formaldehyde from summer, the average indoor level of this chemical was lower than all previous studies. The average outdoor level of formaldehyde was greater than those found in Italy and Finland, whereas it was lower than those reported in China, USA, and Mexico. Acetaldehyde had the same trend to both indoor and outdoor levels of formaldehyde. Nonetheless, hexanaldehyde studied in this work was only compared with previous study in USA which had higher indoor and outdoor levels than recorded in this study.

Table 4. 13 Comparison of the major species of carbonyl compounds measured at residential areas during dry and wet seasons and previous studies (µg/m^3)

Location	Comp.	Indoor conc.	Outdoor conc.	Reference
Bangkok, Thailand	Formaldehyde[1]	11.19 (1.40-38.73)	5.50 (2.10-10.40)	This study
	Acetaldehyde[1]	4.97 (0.22-10.16)	3.48 (1.65-7.26)	
	Propionaldehyde[1]	0.77 (0.03-2.08)	0.64 (0.24-1.78)	
	Hexanaldehyde[1]	2.07 (0.45-6.28)	1.25 (0.55-3.83)	
	Formaldehyde[2]	12.97 (0.14-33.78)	6.95 (3.48-13.74)	
	Acetaldehyde[2]	4.59 (0.10-11.02)	2.49 (0.23-5.68)	
	Propionaldehyde[2]	0.94 (0.14-1.99)	0.62 (0.24-1.13)	
	Hexanaldehyde[2]	0.57 (0.03-1.99)	0.55 (0.66-1.55)	
Hangzhou, China [a]	Formaldehyde	85.40 (-)	25.40 (-)	Weng *et al.*, 2010
	Acetaldehyde	26.90 (-)	12.90 (-)	
	Propionaldehyde	6.70 (-)	1.30 (-)	
Rome, Italy[b]	Formaldehyde	12.31 (4.80-32.90)	2.75 (1.20-7.00)	Santarsiero and Fuselli, 2008
	Acetaldehyde	8.03 (3.20-20.90)	2.34 (1.10-7.60)	
	Propionaldehyde	2.48 (0.05-6.00)	1.00 (0.05-2.30)	
California, New Jersey, Texas, USA	Formaldehyde	20.10 (12.50-32.50)	6.42 (2.21-9.95)	Liu *et al.*, 2006
	Acetaldehyde	18.60 (7.53-50.20)	5.44 (1.47-14.90)	
	Propionaldehyde	1.74 (0.23-3.65)	1.37 (0.05-3.68)	
	Hexanaldehyde	3.81 (1.63-9.94)	2.01 (0.23-4.69)	
Xalapa and Mexico City, Mexico[c]	Formaldehyde	47.00 (12.00-18.00)	17.00 (5.00-50.00)	Báez *et al.*, 2003
	Acetaldehyde	27.00 (8.00-52.00)	14.00 (2.00-47.00)	
	Propionaldehyde	6.10 (2.20-14.00)	3.40 (0.20-12.00)	
Helsinki, Finland	Formaldehyde	33.30 (28.30-62.30)	2.60 (1.60-10.90)	(Jurvelin, Edwards, Vartiainen, Pasanen, & Jantunen, 2003)
	Acetaldehyde	10.10 (8.80-22.70)	1.50 (1.10-6.50)	
	Propionaldehyde	0.91 (0.84-1.80)	0.14 (ND-0.37)	
	Hexanaldehyde	4.0 (3.40-8.70)	0.92 (0.73-2.00)	

[1]the result of the first sampling; [2]the result of the second sampling; [a]Focus on living room during summer; [b]Focus on living room; [c]Focus on house in Tlalnepantla

4.3.2 Comparison of BTEX at five communities

Likewise carbonyl compounds, indoor (n=9) and outdoor air samples (n=3) were collected from all five residential areas during summer and rainy season with 24-hour interval. The indoor and outdoor concentration of benzene, toluene, ethylbenzene, m-, p-xylene, and o-xylene detected from S, P, B, J, and C community were presented in Figure 4.7 and 4.8. According to Table 4.14, the result supported that both indoor and outdoor concentrations of BTEX during wet season had significant greater than those found during dry season. Additionally, compared mean-one way ANOVA, *SPSS 19.0 for Window*, was analytical used for determination of the mean differences for BTEX among all five communities. The summarized information was provided in Table 4.15 for dry season (phase 1) and Table 4.16 for wet season (phase 2).

Based on Table 4.15 and 4.16, toluene played an important role of BTEX both dry and wet season, followed by benzene, m-,p-xylene, ethylbenzene, and o-xylene, respectively. During summer, the average concentrations of benzene, toluene, ethylbezene, m-, p-xylene and o-xylene in indoor were 11.54 (0.26 - 57.75), 68.15 (0.25-555.80), 7.50 (0.07 - 132.16), 14.37 (0.12 - 167.18), and 5.36 (0.51 - 59.75) μg/m^3, respectively. Whilst those concentrations at the outdoor environment were 6.09 (0.26 -36.39), 36.19 (13.95 - 87.96), 5.99 (0.67 - 12.83), 11.72 (0.12 - 25.19), and 5.57 (0.51 - 12.19) μg/m^3, respectively.

During rainy season, the average concentrations of benzene, toluene, ethylbezene, m-, p-xylene and o-xylene in indoor were 74.20 (0.21 -510.07), 339.79 (97.77 - 1061.87), 20.99 (4.63 - 55.66), 45.95 (9.17 - 130.34), and 15.85 (2.95 - 54.78) μg/m^3, respectively. Whilst those concentrations at the outdoor environment were 38.87 (0.21 - 239.34), 349.43 (130.38 - 1069.79), 22.24 (7.11 - 60.14), 51.05 (19.28 - 87.17), and 16.39 (6.18 - 31.79) μg/m^3, respectively.

Among five communities, BTEX were also compared both during dry and wet seasons. During dry season (Table 4.15), the indoor concentrations of benzene had the highest concentrations at C community, followed by S, P, B, and J community, respectively. However, the highest outdoor concentrations were found at C community, followed by B, J, S, and P community, respective. For indoor concentrations of toluene, the highest levels were found at J community, followed by C, S, P, and B communities, respectively. Nonetheless, C community provided the highest outdoor concentrations of toluene, followed by B, S, J, and P community, respectively. For ethylbenzene, the highest indoor concentrations were found at J community, C, S, P, and B communities, respectively. Nevertheless, C community provided the highest concentrations for outdoor concentrations of ethylbenzene, followed by S, B, P, J communities, respectively. For m-,p-xylene, the highest indoor concentrations were found at C community, followed by J, S, P, and B communities, respectively, while C community provided the highest outdoor concentrations, followed by S, B, P, and J communities, respectively. The highest concentrations of indoor o-xylene were found at C community, followed by J, S, P, and B community, whereas S community provided the highest concentrations for outdoor concentrations of o-xylene, followed by C, B, P, and J communities.

During wet season, the highest indoor concentrations of benzene were found at C community, followed by S, P, B, and J communities, respectively. On the other hand, C community had the highest outdoor concentrations of benzene, followed by B, J, S, and P communities, respectively. For toluene, B community had the highest indoor concentrations, followed by S, C, J, and P communities, respectively, while the highest outdoor concentrations were found at B community, followed by J, S, C, and P communities, respectively. B community provided the highest indoor and outdoor concentrations of ethylbenzene. The indoor concentrations of ethylbenzene found at S community were higher than P, C, and J communities, respectively, while B community had the highest outdoor concentrations, followed by C, S, P, and J communities, respectively. For m-, p-xylene, the highest indoor concentrations were found at C community, followed by J, S, P, and B communities, while the outdoor concentrations were found at C community, S, B, P, and J communities. For o-xylene, the highest concentrations for both indoor and outdoor were found at S community, followed by B, J, P, and C communities, respectively. According to result of the dry season, the indoor and outdoor concentrations of BTEX in this study were compared with those studied from previous research, which had been investigated in Kolkata-India (Majumdar, Mukherjeea, et al., 2011), Sabadell-Spain (Llop et al., 2010), and Hong Kong-China (Guo, Lee, Li, & Cao, 2003) as shown in Table 4.16. For benzene, both indoor and outdoor concentrations found in this study were greater than those found in Spain and Hong Kong, but lower than those in India. However, both indoor and outdoor levels of toluene in this study were higher than those detected in Spain, Hong Kong, and India. Likewise benzene, indoor and outdoor levels of ethylbenzen, m-, p-xylene, and o-xylene in this study were higher than those in Spain and Hong Kong, but less than those in India.

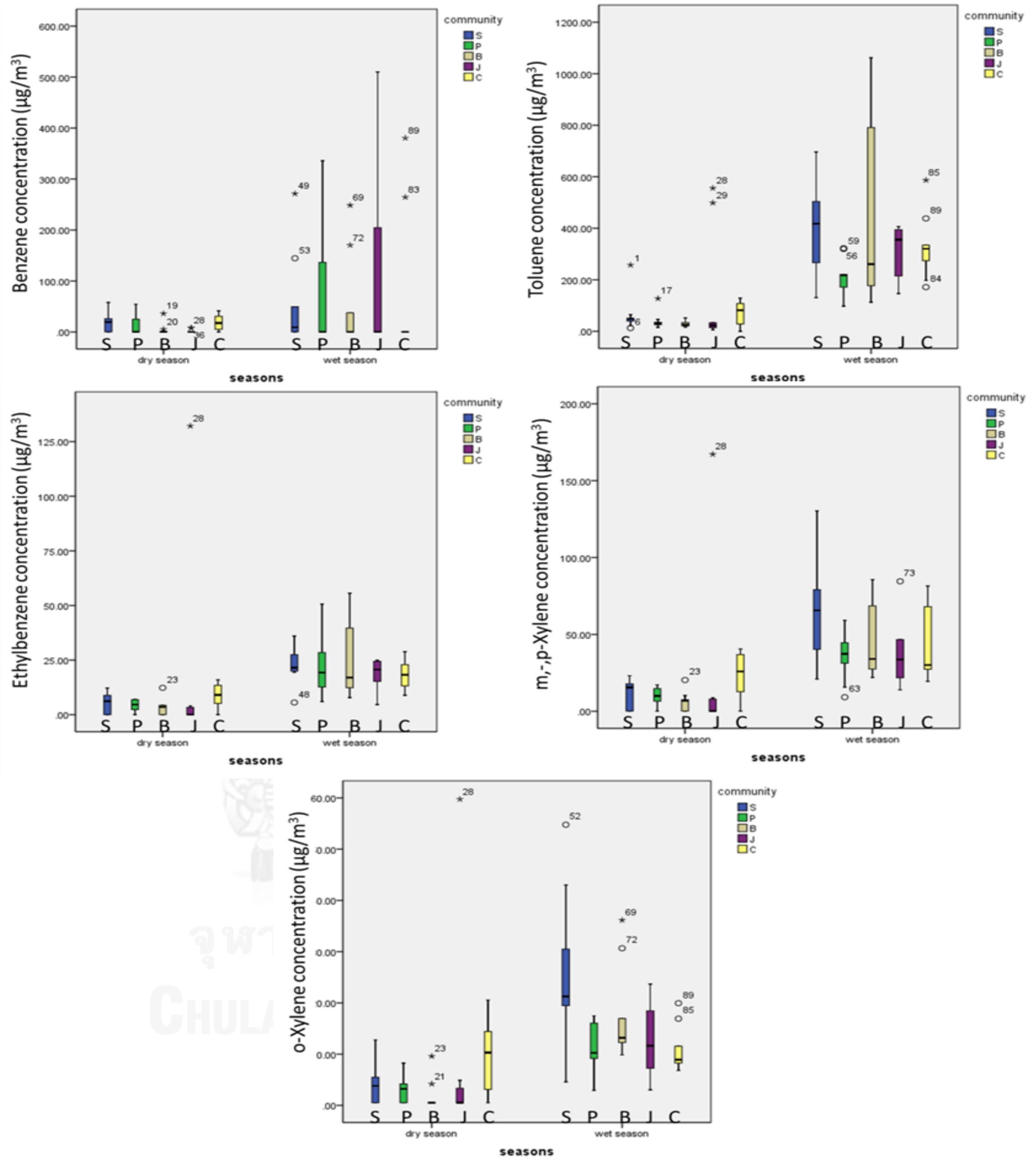


Figure 4. 7 The indoor concentrations of BTEX measured at all five residential areas during dry and wet seasons (n=9)

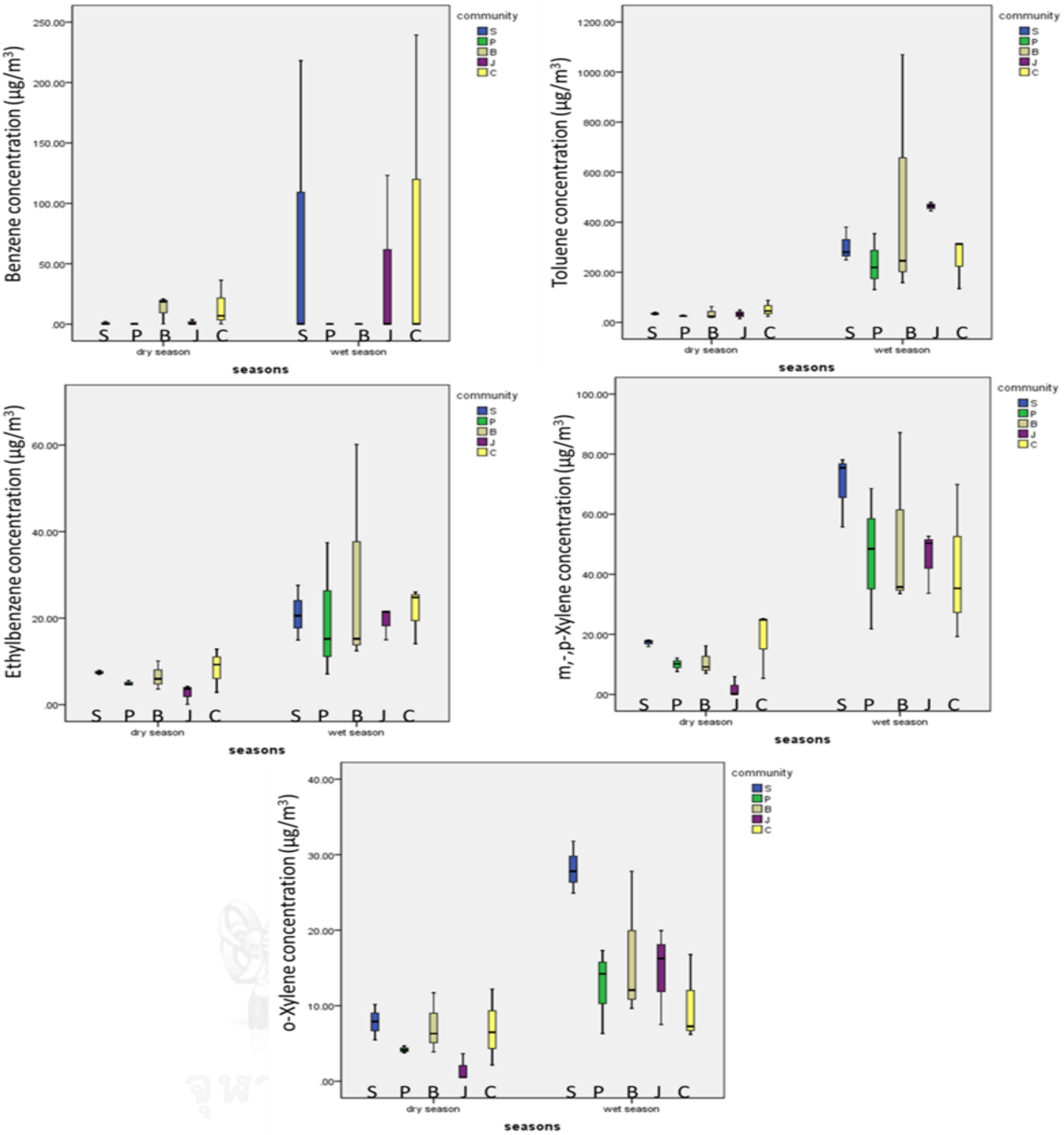


Figure 4. 8 The outdoor concentrations of BTEX measured at all five residential areas during dry and wet seasons (n=3).

Table 4. 14 The independent t-test of BTEX between dry and wet seasons (n_{indoor} =45 and $n_{outdoor}$ =15)

Compound	Independent t-test *p*-value	
	Dry season	Wet season
Benzene	*p*=0.194	*p*=0.324
Toluene	*p*=0.270	*p*=0.882
Ethylbenzene	*p*=0.767	*p*=0.724
m-,p-xylene	*p*=0.696	*p*=0.508
o-xylene	*p*=0.937	*p*=0.859

Table 4. 15 Comparison of BTEX concentrations at all five residential areas during phase 1 (dry season).

Compound	Environment	Average conc. (µg/m^3)	Conc. Range (µg/m^3)	Concentration Ranking (Low→ High)
Benzene	- Indoor air	11.54 ±16.49	0.26-57.75	$J^a < B^a < P^a < S^{ab} < C^b$
	- Outdoor air	6.09±10.76	0.26-36.39	$P^a < S^a < J^a < B^a < C^a$
Toluene	- Indoor air	68.15±109.99	0.25-555.80	$B^a < P^a < S^a < C^a < J^a$
	- Outdoor air	36.19±19.26	13.95-87.96	$P^a < J^a < S^a < B^a < C^a$
Ethylbenzene	- Indoor air	7.50±19.51	0.07-132.16	$B^a < P^a < S^a < C^a < J^a$
	- Outdoor air	5.99±3.20	0.07-12.83	$J^a < P^{ab} < B^{ab} < S^{ab} < C^b$
m-,p-Xylene	- Indoor air	14.37±25.67	0.12-167.18	$B^a < P^a < S^a < J^a < C^a$
	- Outdoor air	11.72±7.84	0.12-25.19	$J^a < P^{ab} < B^{ab} < S^b < C^b$
o-Xylene	- Indoor air	5.36±9.64	0.51-59.75	$B^a < P^a < S^a < J^a < C^a$
	- Outdoor air	5.57±3.63	0.51-12.19	$J^a < P^{ab} < C^{ab} < B^{ab} < S^b$
Total BTEX	- Indoor air	106.93±153.88	1.22-923.05	$B^a < P^a < S^a < C^a < J^a$
	- Outdoor air	65.55±38.75	18.53-174.25	$J^a < P^a < S^a < B^a < C^a$

[1] Data were reported as the mean ± 1SD which derived from 45 and 15 samples for indoor and outdoor, respectively.[2] Community codes (see "site descriptive" in materials and method section) followed by a different lowercase superscript letter (a, b, c, d, and e) having significant different (p < .05) mean levels.

Table 4. 16 Comparison of BTEX concentrations at all five residential areas during phase 2 (wet season).

Compound	Environment	Average conc. (µg/m^3)	Conc. Range (µg/m^3)	Concentration Ranking (Low→ High)
Benzene	- Indoor air	74.20±128.55	0.21-510.07	$B^{a} < S^{a} < C^{a} < P^{a} < J^{a}$
	- Outdoor air	38.87±83.40	0.21-239.34	$B^{a} = P^{a} < J^{a} < S^{a} < C^{a}$
Toluene	- Indoor air	339.79±213.02	97.77-1061.87	$P^{a} < J^{ab} < C^{ab} < S^{ab} < B^{b}$
	- Outdoor air	349.43±229.05	130.38-1069.79	$P^{a} < C^{a} < S^{a} < J^{a} < B^{a}$
Ethylbenzene	- Indoor air	20.99±11.57	4.63-55.66	$J^{a} < C^{a} < P^{a} < S^{a} < B^{a}$
	- Outdoor air	22.24±12.86	7.11-60.14	$J^{a} < P^{a} < S^{a} < C^{a} < B^{a}$
m-,p-Xylene	- Indoor air	45.95±26.97	9.17-130.34	$J^{a} < P^{a} < C^{a} < B^{a} < S^{b}$
	- Outdoor air	51.05±21.18	19.28-87.17	$C^{a} < J^{a} < P^{a} < B^{a} < S^{a}$
o-Xylene	- Indoor air	15.85±10.49	2.95-54.78	$C^{a} < P^{a} < J^{a} < B^{a} < S^{b}$
	- Outdoor air	16.39±8.54	6.18-31.80	$C^{a} < P^{a} < J^{a} < B^{ab} < S^{b}$
Total BTEX	- Indoor air	496.79±306.25	116.09-1487.90	$P^{a} < C^{a} < J^{a} < S^{a} < B^{a}$
	- Outdoor air	477.99±275.43	165.83-1245.11	$P^{a} < C^{a} < S^{a} < J^{a} < B^{a}$

[1] Data were reported as the mean ± 1SD which derived from 45 and 15 samples for indoor and outdoor, respectively. [2] Community codes (see “site descriptive” in materials and method section) followed by a different lowercase superscript letter (a, b, c, d, and e) having significant different ($p < .05$) mean levels.

Table 4. 17 Comparison of indoor and outdoor BTEX concentrations measured at residential areas in the first and the second sampling and other studies (µg/m^3)

Location	Compound	Indoor conc.	Outdoor conc.	Reference
Bangkok, Thailand	Benzene^1	11.54 (0.26-57.75)	6.09 (0.26-36.39)	This study
	Toluene^1	68.15 (0.25-555.80)	36.19 (13.95-87.96)	
	Ethylbenzene^1	7.50 (0.07-132.16)	5.99 (0.07-12.83)	
	m-,p-Xylene^1	14.37 (0.12-167.18)	11.72 (0.12-25.19)	
	o-Xylene^1	5.36 (0.51-59.75)	5.57 (0.51-12.19)	
	Benzene^2	72.2 (0.21-510.07)	38.87 (0.21-239.34)	
	Toluene^2	339.79 (97.77-1061.87)	349.43 (130.38-1069.78)	
	Ethylbenzene^2	20.99 (4.63-55.66)	22.24 (7.11-60.14)	
	m-,p-Xylene^2	45.95 (9.17-130.34)	51.06 (19.28-87.17)	
	o-Xylene^2	15.85 (2.95-54.77)	16.39 (6.18-31.79)	
Kolkata, India	Benzene	33.30 (10.50-188.50)	29.00 (7.60-141.50)	(Majumdar, Mukherjee a, et al., 2011)
	Toluene	58.10 (9.40-213.70)	47.20 (10.50-142.00)	
	Ethylbenzene	18.70 (5.70-61.90)	17.3 (5.90-65.90)	
	m-,p-Xylene	43.40 (7.60-165.30)	41.20 (5.40-112.30)	
	o-Xylene	18.90 (5.10-45.6)	18.60 (5.50-54.10)	
Sabadell, Spain	Benzene	0.32 (0.01-14.29)	0.01 (0.01-12.85)	Llop *et al.*, 2010
	Toluene	10.82 (0.01-75.50)	4.26 (0.01-46.75)	
	Ethylbenzene	1.27 (0.01-121.89)	0.60 (0.01-9.48)	
	m-,p-Xylene	4.04(0.02-254.16)	2.62(0.02-24.98)	
	o-Xylene	0.38(0.01-41.59)	0.01(0.01-5.72)	
Hong Kong, China	Benzene	4.99 (1.43-10.30)	1.94 (0.58-5.20)	Guo *et al.*, 2003
	Toluene	59.13 (29.87-83.11)	36.56 (6.36-142.50)	
	Ethylbenzene	2.72 (ND-6.91)	5.40 (0.044-15.71)	
	m-,p-Xylene	5.27 (1.41-10.82)	5.34 (0.26-21.38)	
	o-Xylene	3.89 (0.97-11.04)	3.48 (0.044-12.54)	

Remark: The concentration result is reported as the average (range) with the unit of µg/m^3

^{1}the result of the first sampling; ^{2}the result of the second sampling

Based on the total carbonyl compounds and total BTEX during for both dry and wet seasons, mostly the highest total concentrations of carbonyl compounds were found at C community, followed by J community, while P community often provided the lowest concentrations of carbonyl compounds. For C community, 3 selected houses (H2 for dry season, H2 for wet season, and H3 for wet season; see photo in Appendix F) were expected to have high promoted conditions for carbonyl compounds. These might cause by H2 or House 2 during dry season having new inside and outside wall and door painting, H2 during wet season storing a lot of paint, wood materials, adhesives and other solvents nearby sampling equipment, and H3 during wet season provided the garage. Unlike C community, all selected houses had shrine of the household god or incense pots near by the house. All three houses used incense every day, but the amounts of incense used and the distant and the air ventilation might be different. H1 of J community had very low air ventilation, but the highest usage of incenses was found here with 5 incense pots (3 inside and 2 outside). For P community, the usage of incense and new painting were not be noticed, Since this community was the lower community compared to others, and many residents emigrate to new place, since the enterprise plan to build new shopping center in this area. Most houses in P community were very old without much renovation, therefore the concentration of total carbonyl compounds was low.

4.4 Correlation between indoor and outdoor concentrations of carbonyl compounds and BTEX

The indoor and outdoor concentrations of carbonyl compounds and BTEX were analyzed the relationship by using Pearson's Correlation (*SPSS 19.0*). Table 4.18 showed the summarized Pearson's correlation coefficient of carbonyl compounds and BTEX during dry and wet seasons. During dry and wet seasons (n=30), acetaldehyde (p=0.050), propionaldehyde (p=0.006), butyraldehyde (p=0.036), benzaldehyde (p=0.000), valeraldehyde (p=0.020), m-, p-tolualdehyde (p=0.001), hexanaldehyde (p=0.000), toluene (p=0.000), ethylbenzene (p=0.000), m-, p-xylene (p=0.000), and o-xylene (p=0.000) had significant correlation between indoor and outdoor concentrations with Pearson's coefficients equaled to 0.361, 0.493, 0.385, 0.767, 0.422, 0.562, 0.678, 0.933, 0.903, 0.912, and 0.820, respectively. The evidences implied that the indoor concentrations of these compounds had statistical relationship with the outdoor concentrations. According to the I/O ratios of these compounds, high I/O above 1 meaning that acetaldehyde

(2.919), propionaldehyde (1.580), butyraldehyde (3.977), benzaldehyde (3.251), valeraldehyde (1.409), m-, p-tolualdehyde (1.727), hexanaldehyde (2.562), toluene (1.306), ethylbenzene (1.058), m-, p-xylene (1.139), and o-xylene (1.236) had substantial sources from indoor environment that effected to their concentrations in outdoor environment.

For the others which were formaldehyde (p=0.138), crotonaldehyde (p=0.794), isovaleraldehyde (p=0.349), o-tolualdehyde (p=0.197), 2, 5-dimethylbenzaldehyde (p=0.087), and benzene (p=0.518) did not have significant correlations between indoor and outdoor concentrations with Pearson's coefficients equaled to 0.277, 0.050, 0.177, 0.242, 0.318, and -0.123, respectively. However the I/O ratios supported that the indoor concentrations of these compounds were greater than their outdoor concentrations. In case of benzene, even though Pearson's correlation promoted the negative correlation meaning that the indoor and outdoor concentrations had the opposite direction, non-significant correlation was found. The major sources of benzene might be indoor environment; however, benzene was very easily volatile or degraded since it has the lowest molecular weight compared to other BTEX. Therefore the average I/O ratio of benzene was very high reached 148.973 caused by three high values of indoor concentrations divided by the non-detectable values of benzene.

According to Table 4.19, the average I/O ratios of formaldehyde, acetaldehyde, propionaldehyde, crotonaldehyde, butyraldehyde, benzaldehyde, valeraldehyde, and hexanaldehyde of this study were reported in similar range to the study of (Missia, Demetriou, Michael, Tolis, & Bartzis, 2010), (B. Wang, Lee, & Ho, 2007), (Jurvelin et al., 2003), (Guo et al., 2003), and (Armando Báez et al., 2003). For I/O ratios of toluene, ethylbenzene, m-,p-xylene, and o-xylene were in similar range to the previous studies (Guo et al., 2003; Kumar et al., 2014; Missia et al., 2010), but were lower than those reported by Báez et al. (2003). Nonetheless, I/O ratio of benzene in this study was in wide range with high average value. This might be the high indoor concentrations while non-detectable outdoor concentrations were found. It was possibly occurred in this case, if the indoor activities generated high atmospheric concentration of benzene while the outdoor concentration was very low. The indoor and outdoor of carbonyl compounds and BTEX correlation coefficients of this study were similar to the study of Kumar et al. (2014).

Table 4. 18 I/O ratios of carbonyl compounds and BTEX (n=30)

Compound	Pearson's Correlation		I/O ratio
	Pearson's coefficient (r)	*P* value	
Formaldehyde	0.277	0.138	2.643
Acetaldehyde	0.361*	0.050	2.919
Propionaldehyde	0.493**	0.006	1.580
Crotonaldehyde	0.050	0.794	2.499
Butyraldehyde	0.385*	0.036	3.977
Benzaldehyde	0.767**	0.000	3.251
Isovaleraldehyde	0.177	0.349	1.488
Valeraldehyde	0.422*	0.020	1.409
o-Tolualdehyde	0.242	0.197	5.845
m-,p-Tolualdehyde	0.562**	0.001	1.727
Hexanaldehyde	0.678**	0.000	2.562
2,5-Dimethylbenzaldehyde	0.318	0.087	1.480
Benzene	-0.123	0.518	148.973
Toluene	0.933**	0.000	1.306
Ethylbenzene	0.903**	0.000	1.058
m-,p-Xylene	0.912**	0.000	1.139
o-Xylene	0.820**	0.000	1.236

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

Table 4. 19 Comparison of I/O ratios, correlation coefficient, correlation *p value* of this study with previous studies.

Compound	I/O ratio	Correlation coefficient	Correlation *p value*	Reference
Formaldehyde	2.64 (0.47-8.60)	0.277	0.138	This study
Acetaldehyde	2.92 (0.42-39.94)	0.361*	0.050	
Propionaldehyde	1.58 (0.06-4.57)	0.493**	0.006	
Crotonaldehyde	2.50 (0.005-24.67)	0.050	0.794	
Butyraldehyde	3.98 (0.05-28.10)	0.385*	0.036	
Benzaldehyde	3.25 (0.14-18.20)	0.767**	0.000	
Valeraldehyde	1.41 (0.14-4.52)	0.422*	0.020	
Hexanaldehyde	2.56 (0.16-21.62)	0.678**	0.000	
Benzene	148.97 (8.62x10^{-4}-1628.48)	-0.123	0.518	
Toluene	1.31 (0.38-3.56)	0.933**	0.000	
Ethylbenzene	1.06 (9.33x10^{-3}-3.17)	0.903**	0.000	
m-,p-Xylene	1.14 (6.81x10^{-3}-4.99)	0.912**	0.000	
o-Xylene	1.24 (6.48x10^{-2}-4.97)	0.820**	0.000	
Benzene	1.4	0.78*	0.875	Kumar *et al.*, 2014
Toluene	1.8	0.92*	0.000	
m-,p-Xylene	1.5	0.88*	0.000	
o-Xylene	2.1	0.41	0.000	
Formaldehyde	5-16.4	-	-	Missia *et al.*, 2010[a]
Acetaldehyde	2.3-31.0			
Propionaldehyde	2.2-25.2			
Hexanaldehyde	1.3-147			
Benzene	0.6-2.6			
Toluene	1.6-12.8			
Ethylbenzene	1.1-24.0			
m-,p-Xylene	1.2-30.4			
o-Xylene	1.1-14.5			

Compound	I/O ratio	Correlation coefficient	Correlation *p value*	Reference
Formaldehyde Acetaldehyde Propionaldehyde Crotonaldehyde Butyraldehyde Benzaldehyde Valeraldehyde Hexanaldehyde	3.65 (1.62-6.37) 1.34 (0.93-1.80) 0.99 (0.57-1.82) 0.93 (0.41-1.50) 1.31 (0.55-2.53) 1.38 (0.78-2.41) 0.79 (0.42-1.49) 0.74 (0.17-2.38)	-	-	Wang *et al.*, 2007[b]
Propionaldehyde Butyraldehyde Benzaldehyde Valeraldehyde Hexanaldehyde	10.8 (1.4-24.4) 2.8 (0.77-6.4) 3.4 (0.27-7.1) 7.2 (1.2-25.0) 7.1 (1.2-14.2)	-	-	Jurvelin *et al.*, 2003
Benzene Toluene Ethylbenzene Xylenes	2.566 1.617 0.505 1.039	0.479 0.013 -0.068 -0.548	-	Guo *et al.*, 2003
Formaldehyde Acetaldehyde Propionaldehyde Butyraldehyde	4.3 3.2 5.3 1.5	-	-	Báez *et al.*, 2003[c]

[a]Focus only houses; [b]During summer; [c]House in Tlanepanta; *p<0.005; **p<0.001

Likewise, indoor sources might have higher influent than outdoor sources when I/O ratios were greater than 1. Nonetheless, butyraldehyde had minus sign showing that indoor and outdoor levels had inverted relation. Paint, nail polish, and tobacco smoke were expected to be the major sources of BTEX and some carbonyl compounds, while building material such as plywood subfloor was the main source of hexanaldehyde. Nonetheless, age of house or renovating interior house less than 2 years had significant impact to indoor concentration of hexanaldehyde recorded in previous study (Machado Corrêa & Arbilla, 2008). Generally, indoor concentrations of all compounds were greater than outdoor concentrations. This might be explained that all sampling sites were located in crowded buildings and low number of opened windows. Almost houses opened only doors which were small when compared to the whole size of houses. This evidence promoted the accumulation of atmospheric chemicals in indoor air. Opening more windows and doors in order to increase air ventilation was recommended for indoor concentration decline.

Furthermore, the correlation (n=30) between indoor and outdoor concentrations of carbonyl compounds and BTEX during both dry and wet seasons were illustrated separately in Figure 4.10 and 4.9, respectively. Only significant relationships between indoor and outdoor concentrations were provided. According to Figure 4.10 and 4.9, r values representing as Pearson's correlation coefficients claimed that acetaldehyde, propionaldehyde, butyraldehyde, benzaldehyde, valeraldehyde, m-, p-tolualdehyde, hexanaldehyde, toluene, ethylbenzene, m-,p-xylene, and o-xylene had significant correlation between indoor and outdoor concentration as already mentioned.

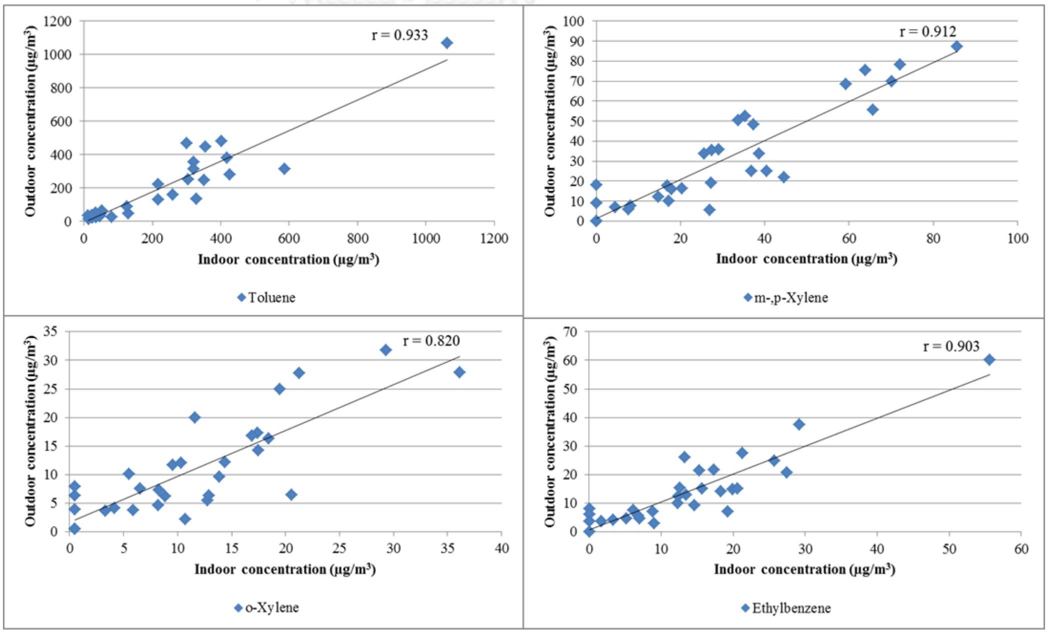


Figure 4. 9 The correlation between indoor and outdoor concentrations of toluene, ethylbenzene, m-, p-xylene and o-xylene providing significant correlation

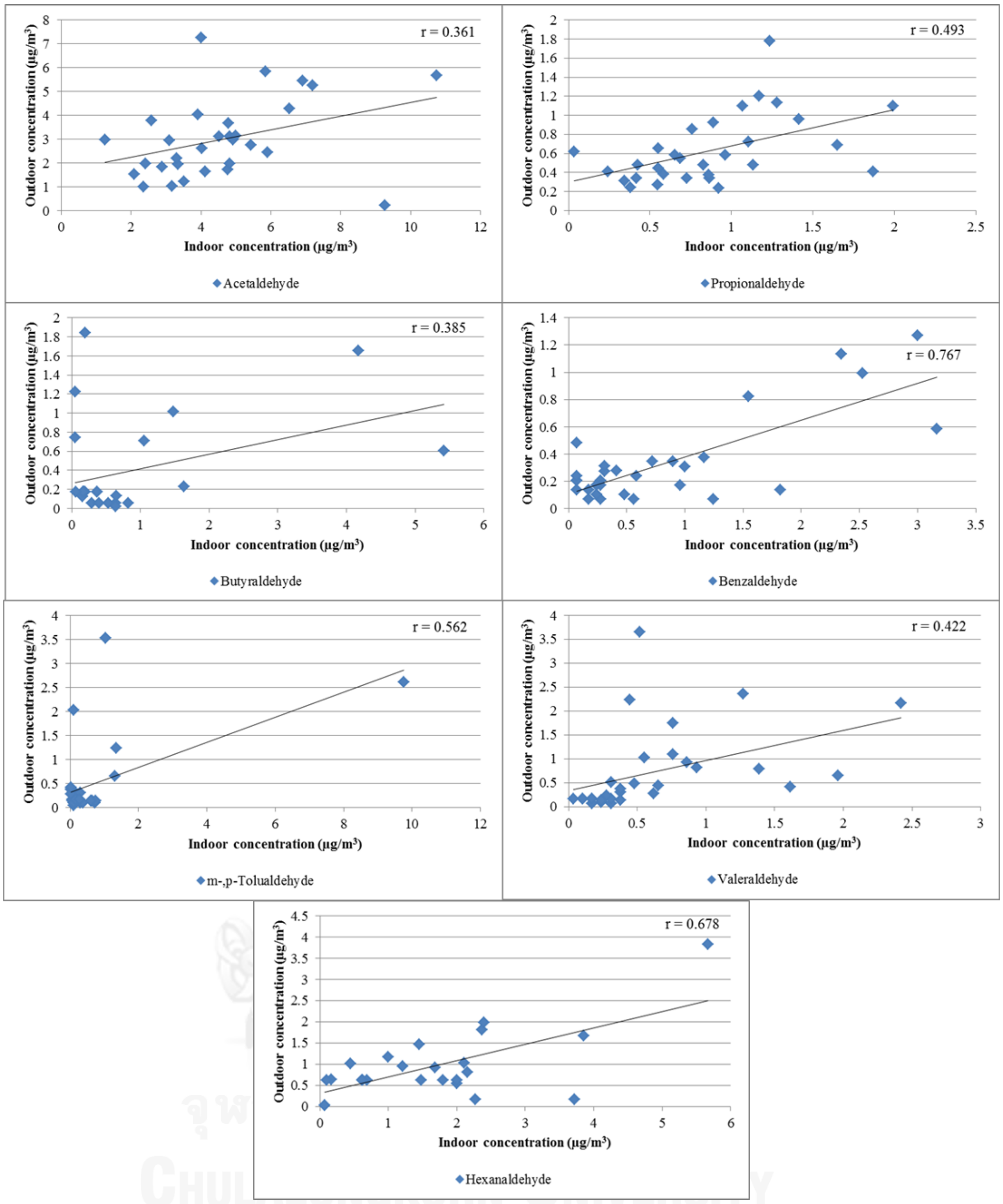


Figure 4. 10 The correlation between indoor and outdoor concentrations of acetaldehyde, propionaldehyde, butyraldehyde, benzaldehyde, valeraldehyde, m-,p-tolualdehyde, and hexanaldehyde providing significant correlation

4.5 Seasonal variations of carbonyl compounds and BTEX in indoor and outdoor air

Both indoor and outdoor air samplings were held during 21st April to 24th May, 2013 representing for summer and during 22nd September to 25th October, 2013 representing for rainy season. The 24-hour average concentrations of four major carbonyl compounds in the phase 1 and phase 2 with indoor (n=9) and outdoor (n=3) samplings for each community were calculated to compare in different seasons as given in Figure 4.11, 4.12, 4.13 and 4.14.

The indoor concentrations of 13 carbonyl compounds were demonstrated separately in Figure 4.11 and 4.12, whereas the outdoor concentrations of 13 carbonyl compounds were provided in Figure 4.13 and 4.14. During summer, formaldehyde was the most abundant carbonyl compounds (1.40-38.73 µg/m^3), followed by acetaldehyde (0.22-10.16 µg/m^3), hexanaldehyde (0.45-6.28 µg/m^3), and propionaldehdye (0.03-2.08 µg/m^3), respectively. Likewise summer, during rainy season, formaldehyde also had the highest levels (0.14-33.78 µg/m^3), followed by acetaldehyde (0.10-11.02 µg/m^3), propionaldehyde (0.14-1.99 µg/m^3), and hexanaldehyde (0.03-1.99 µg/m^3), respectively. The concentration ranges of formaldehyde, benzaldehyde, valeraldehyde, o-tolualdehyde, m-,p-tolualdehyde found during wet season were relatively higher than those found in dry seasons. However, the concentration ranges of crotonaldehyde, butyraldehyde, and hexanaldehyde found during dry season were greater than those found during wet season. The rest carbonyl compounds had similar concentration ranges between dry and wet seasons. Noticeably, B and C community had outstanding levels of formaldehyde and acetaldehyde. It might be claimed that B community had high smoking people in community from the observation during sample collection and it might be affected by the cement industry nearby the community. Nonetheless, one selected house in C community had new wall painting inside and outside the house and one selected housed had carpentered activities stored lots of paint, solvents, glue, and tools for wood work in storeroom where the samples were collected. Moreover, one another provided garage for sampling site. These might be the reason of high concentrations of formaldehyde and acetaldehyde. The concentration ranges of valeraldehyde and m-, p-tolualdehyde were quite high at J community. In this residential area, 2 selected houses used lots of incenses every day, one house had five points of incenses and one house had one big shrine of the household god with lots of incenses. It was difficult to say that what activity that promoted which chemical, since carbonyl compounds had high variety of sources.

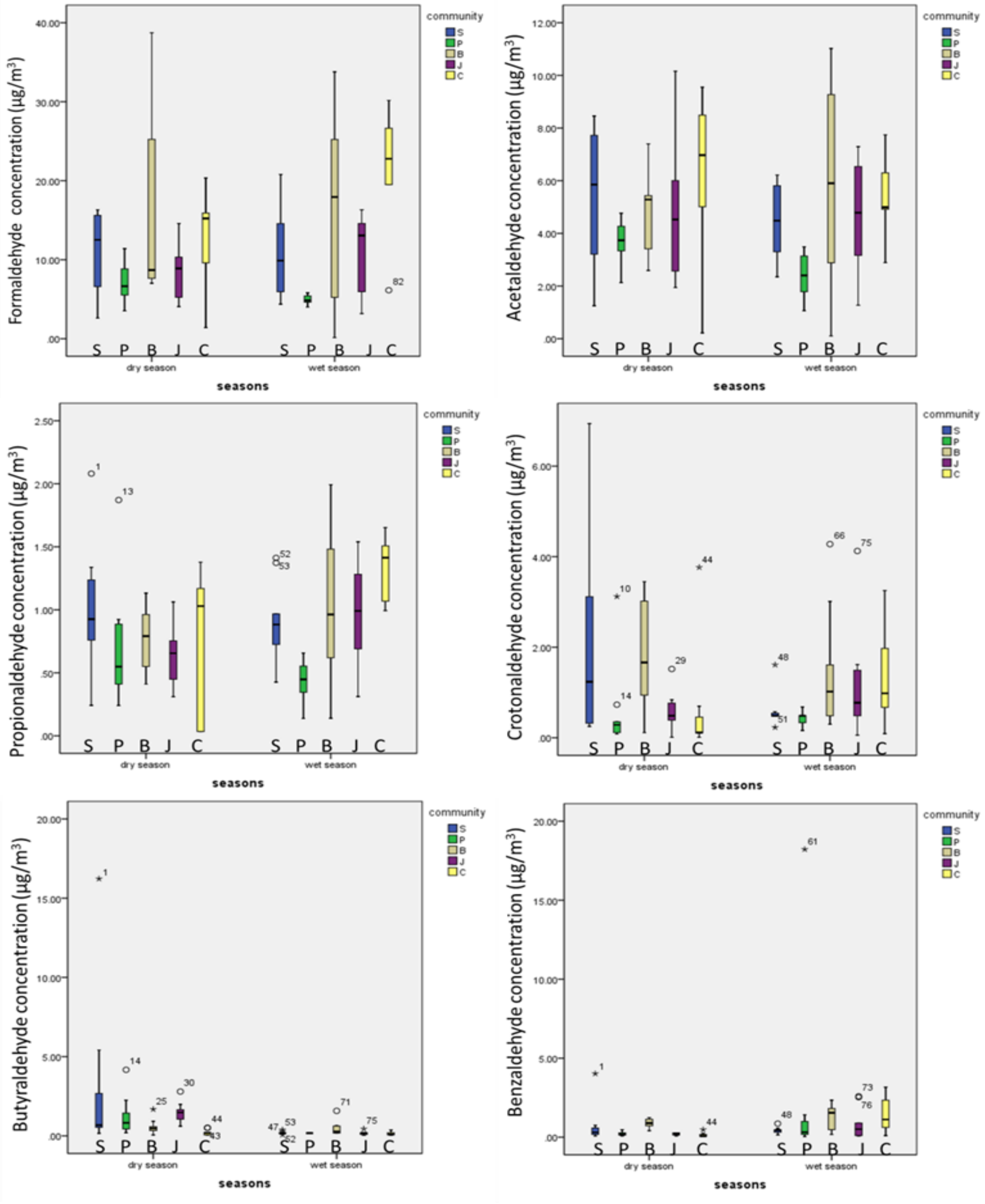


Figure 4. 11 The indoor concentrations of 6 carbonyl compounds during dry and wet seasons (n=9). (The scale is in range of 0-40 µg/m^3)

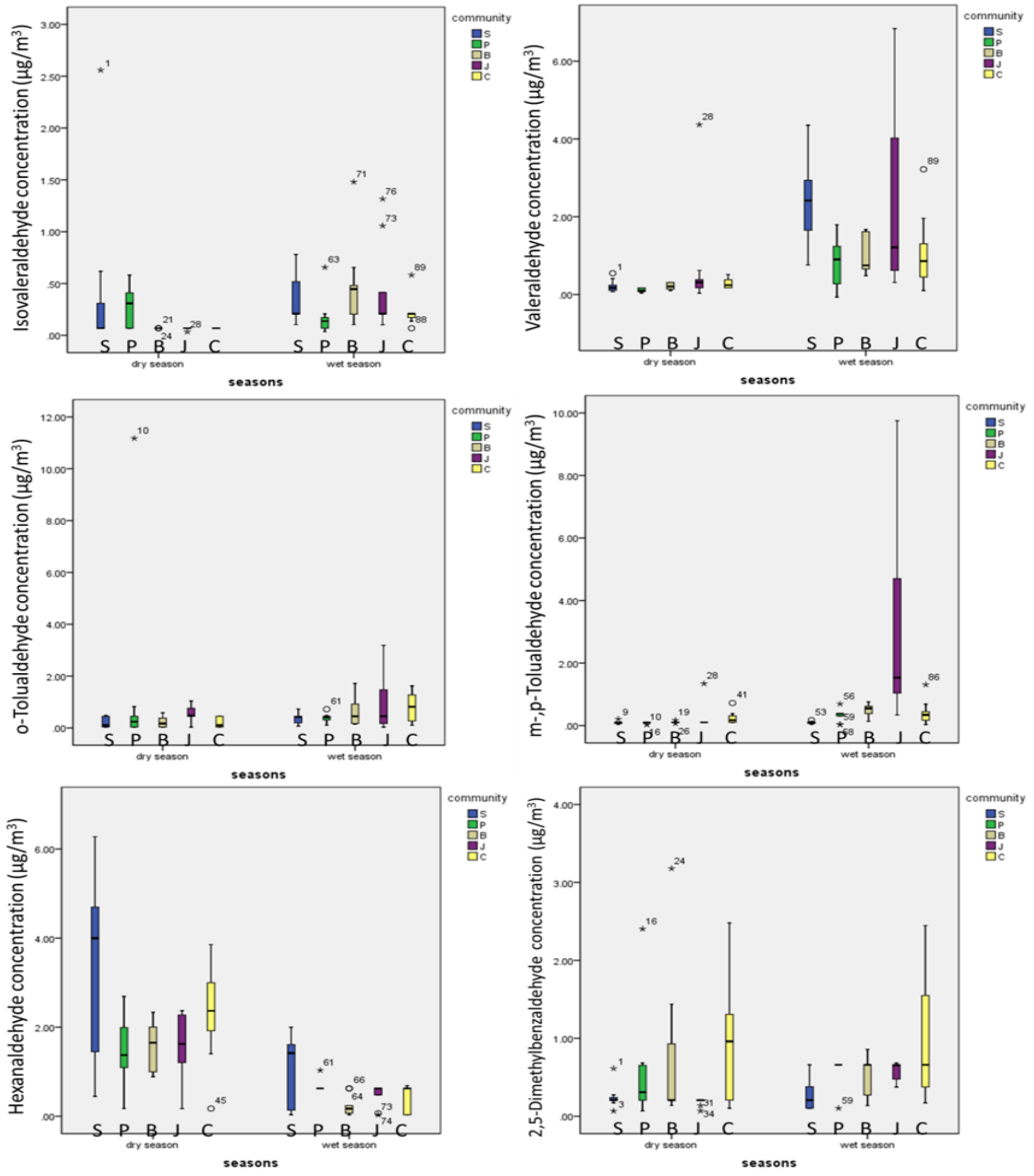


Figure 4. 12 The indoor concentrations of 7 carbonyl compounds during dry and wet seasons (n=9). (The scale is in range of 0-12 μg/m^3)

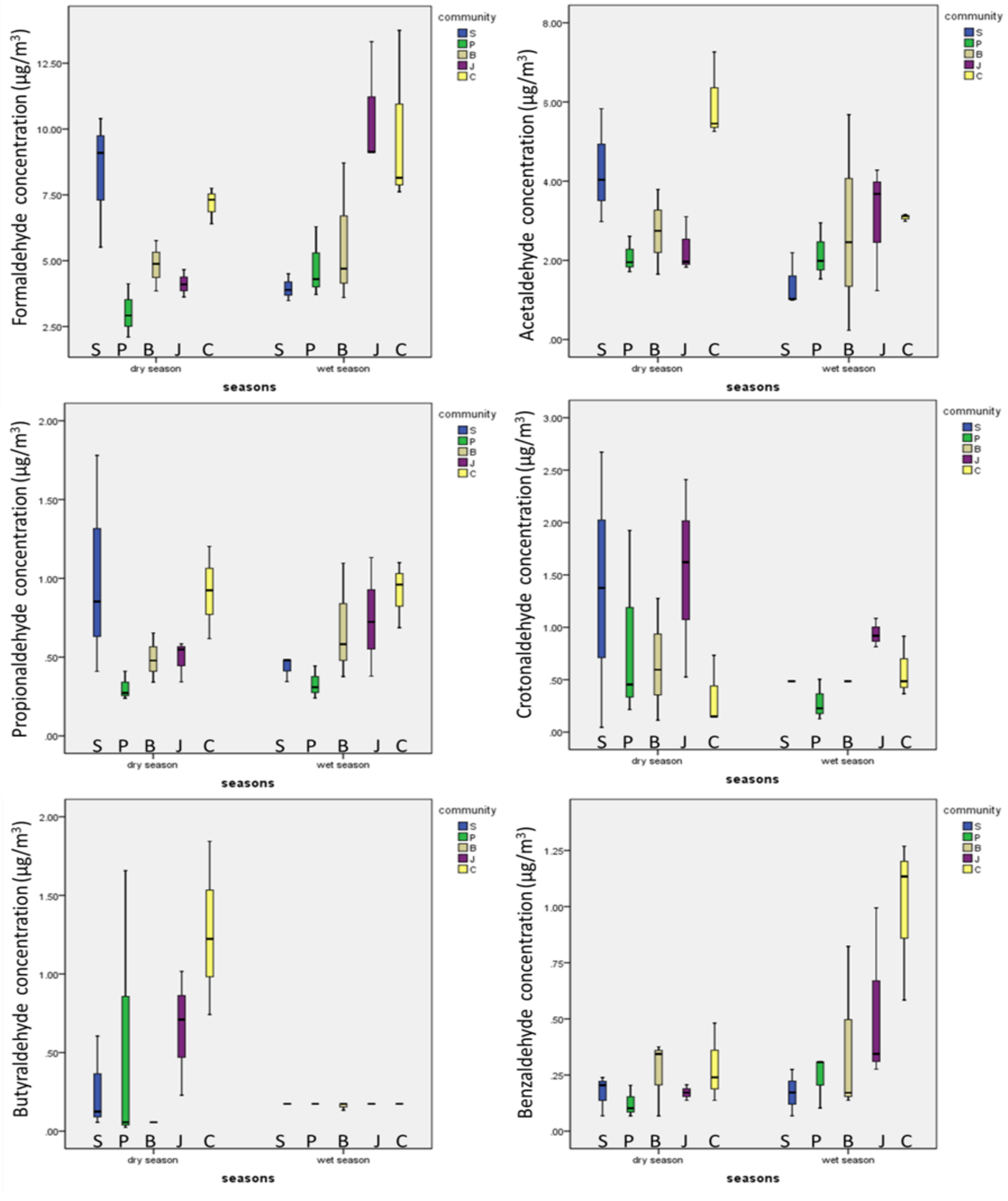


Figure 4. 13 The outdoor concentrations of 6 carbonyl compounds during dry and wet seasons (n=3). (The scale is in range of 0-3μg/m^3)

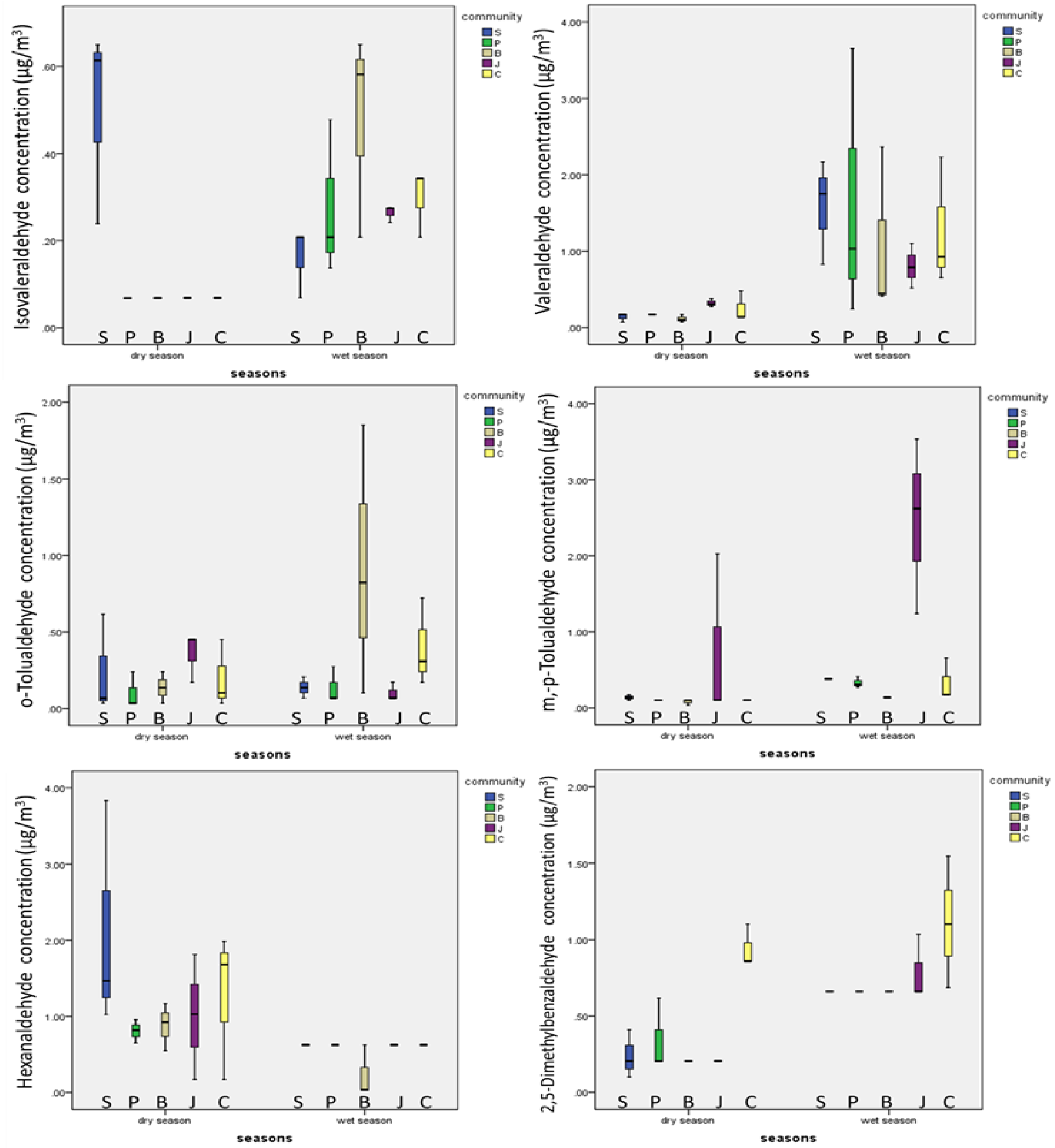


Figure 4. 14 The outdoor concentrations of 7 carbonyl compounds during dry and wet seasons (n=3). (The scale is in range of 0-4 μg/m^3)

The indoor and outdoor concentrations of BTEX during dry and wet season for each community were ranged to compare in different seasons as given in Figure 4.15 and 4.16. For BTEX, all chemicals had been found both summer and rainy season. The concentration ranges of all chemicals found during wet seasons were higher than those found during dry season. Among five compounds, toluene was considered to be the most abundant species for both dry and wet seasons. During dry season, toluene had the highest levels (0.25-555.80 µg/m^3), followed by m-, p-xylene (0.12-167.18 µg/m^3). However, benzene (0.26-57.75 µg/m^3), ethylbenzene (0.07-132.16 µg/m^3), and o-xylene (0.51-59.75 µg/m^3) showed similar ranges. According to toluene concentration range, the highest range was found at B community. Not only lots of smoking people, but also high vehicle used inside the community. Since this community was quite large comparing to other communities and also closed to Rama V road which was 8-lane road. There was assumption that lots of vehicle used and also the cement industry nearby the community might promoted the concentration of toluene, especially during wet season that the air circulation was quite limited. Furthermore, S community was noticed that the concentration range of m-, p-xylene and o-xylene were high. From the observation, there were one selected house that used insecticide quite often whenever the residents saw the cockroach or some insects and one another selected house closed to printing houses. Even though the residents claimed that there was not any printing house around here, but smells were very strong every time of sampling. The results from this house nearby the printing house were very reasonable with high BTEX when compare to two other houses in same community.

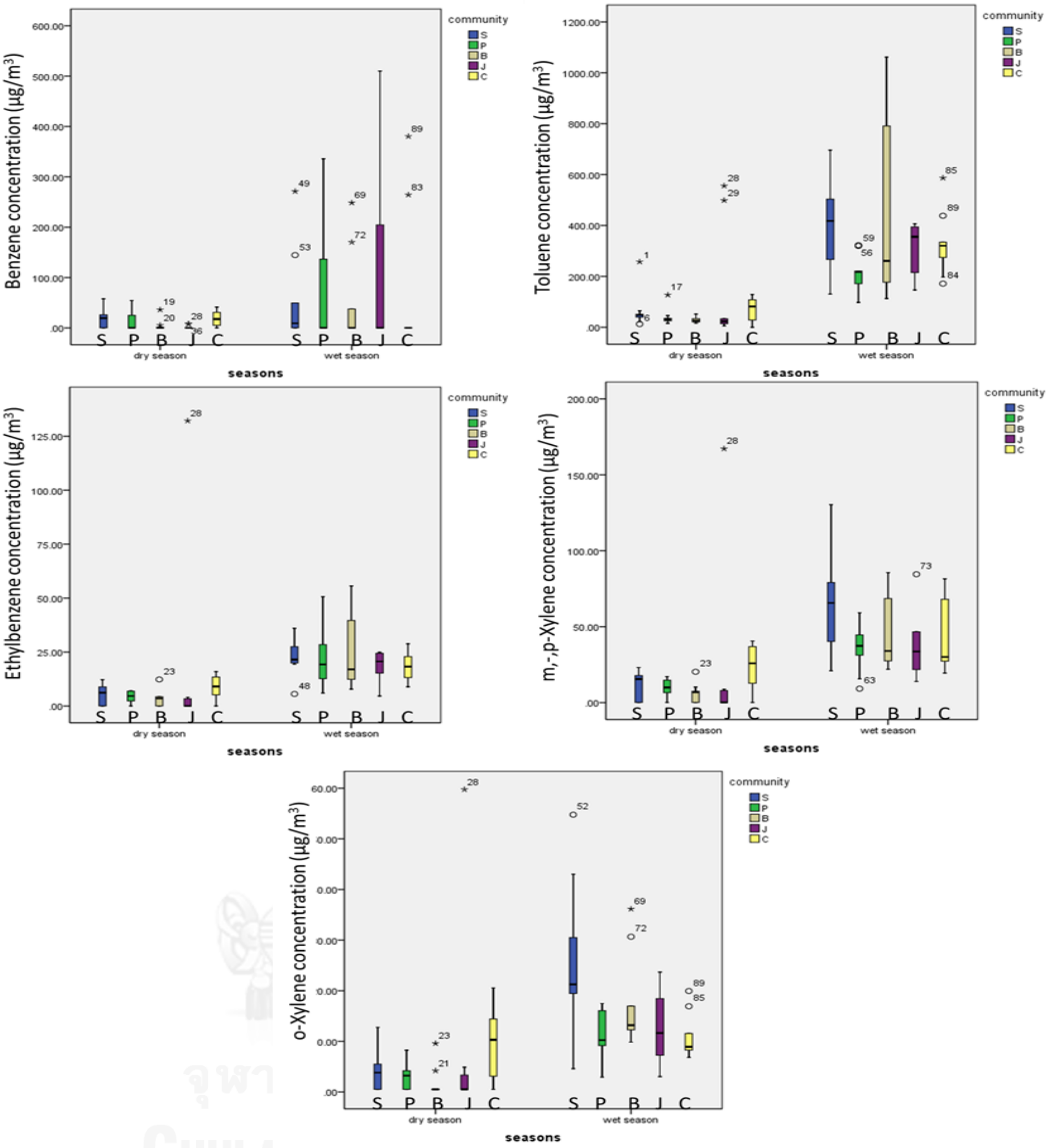


Figure 4. 15 The indoor concentrations of BTEX during dry and wet seasons (n=9). (The scale is in range of 0-1,200 µg/m^3)

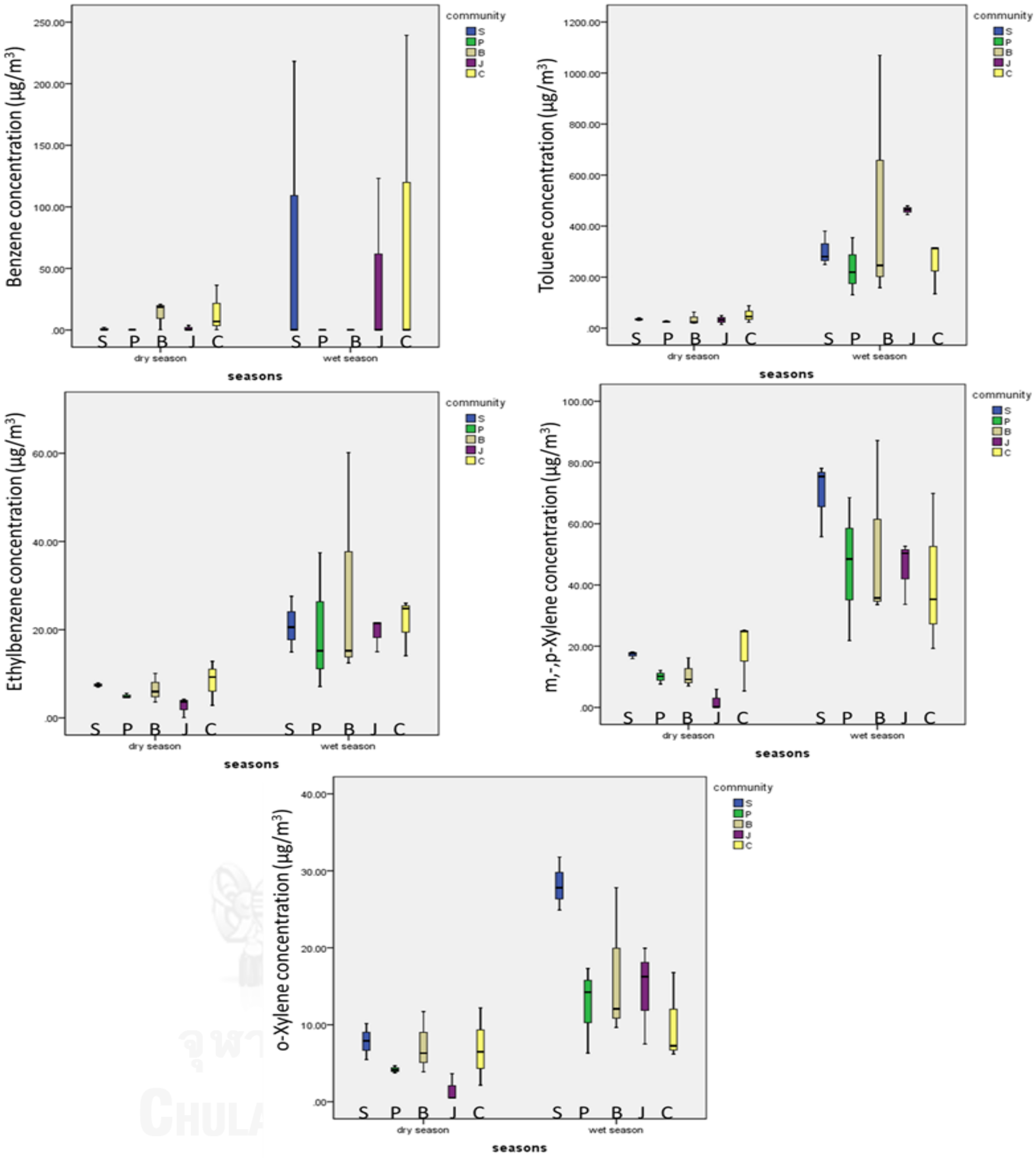


Figure 4. 16 The outdoor concentration of BTEX during dry and wet seasons (n=3). (The scale is in range of 0-1,200 μg/m^3)

The mean differences of carbonyl compounds and BTEX concentrations measured during dry and wet seasons for indoor and outdoor concentrations were also determined as concluded in Table 4.20. To begin with carbonyl compounds, the mean differences of indoor carbonyl concentrations between summer and rainy seasons were statistically analyzed using *SPSS 19.0 for Window* revealing that butyraldehyde (p=0.006), benzaldehyde (p=0.047), valeraldehyde (p=0.000), m-, p-tolualdehyde (p=0.010), and hexanaldehyde (p=0.000) had significantly differences, while the rest carbonyl compounds did not have significant differences. For outdoor levels, butyraldehyde, benzaldehyde, valeraldehyde, hexanaldehyde, and 2,5-dimethybenzaldehyde had significantly differences, while the rest carbonyl compounds did not have significant differences. Since carbonyl compounds were secondary pollutants with high volatile property, the low levels found from residential areas comparing with higher roadside areas (Morknoy, 2008). Even though there were some indoor sources, but there were not higher than ambient roadside which promoting by vehicle exhaust. The fluctuation of indoor and outdoor levels of carbonyl compounds were observed in little. The limit conditions for secondary reaction generating carbonyl compounds might occurred at residential areas during both summer and rainy season.

In addition, paired t-test using *SPSS 19.0 for Window* also revealed (Table 4.20) that the indoor concentrations of benzene (p=0.002), toluene (p=0.000), ethylbenzene (p=0.000), m-,p-xylene (p=0.000), and o-xylene (p=0.000) had statistically differences between concentrations measured during summer and rainy season. Likewise, the outdoor concentrations of toluene (p=0.000), ethylbenzene (p=0.000), m-, p-xylene (p=0.000), and o-xylene (p=0.001) had significantly differences, while benzene (p=0.132) did not have significant difference.The significant differences of all BTEX between dry and wet seasons were obviously noticed. High sunlight, high temperature possibly enhanced the photolysis of BTEX causing low concentrations for both indoor and outdoor levels. In contrast, the high accumulation of BTEX might happen during rainy season. Hoque et al. (2008) claimed that decreasing air ventilation could promote high levels of BTEX. Furthermore, low temperature, low sunlight, and high humidity during raining did not promote the photo degradation of BTEX. Even though all BTEX also had high water solubility which could be washed out by rain they might re-volatile into the air after rain stop and having sunlight due to their easily volatilization. Moreover, indoor levels of BTEX occasionally greater than outdoor levels as same as the report of Llop et al. (2010) which significantly depending on certain pattern of behavior such the use of automobile, the use of air conditioner, and other activities.

Table 4. 20 The mean difference between dry and wet seasons of carbonyl compounds and BTEX

Compound	Sig. (2-tailed)	
	Indoor levels	Outdoor levels
Formaldehyde	0.161	0.204
Acetaldehdye	0.443	0.129
Propionaldehyde	0.093	0.866
Crotonaldehyde	0.486	0.104
Butyraldehyde	0.006*	0.028*
Benzaldehyde	0.047*	0.023*
Isovaleraldehyde	0.071	0.095
Valeraldehyde	0.000*	0.001*
o-Tolualdehyde	0.759	0.365
m-,p-Tolualdehyde	0.010*	0.091
Hexanaldehyde	0.000*	0.012*
2, 5-Dimethylbenzaldehyde	0.656	0.000*
Benzene	0.002*	0.132
Toluene	0.000*	0.000*
Ethylbenzene	0.000*	0.000*
m-, p-Xylene	0.000*	0.000*
o-Xylene	0.000*	0.001*

*means significantly different

4.6 The usage of household products, health information of residents and health risk assessment via inhalation exposure

4.6.1 Household product usage related to carbonyl compounds and BTEX sources

According to the questionnaires, 18 houses were asked to fill the questionnaires (one house with one series of questionnaire). The individual information covered 51 persons as health information. The results of all questions were reported in Appendix B. Some important information was chosen to report in this part. For the results regarding to the frequency of household products usage ranking from 1 (never/rarely), 2 (once a month), 3 (once a week), 4 (more than once a week), and 5 (everyday), the data of 16 household products were calculated as the frequency average as presented in Figure 4.17. The results supported that fragrance, disinfectant, incense, and perfume were the higher used compared to the others which ranged in between 1.7-2.2 meaning as once a month.

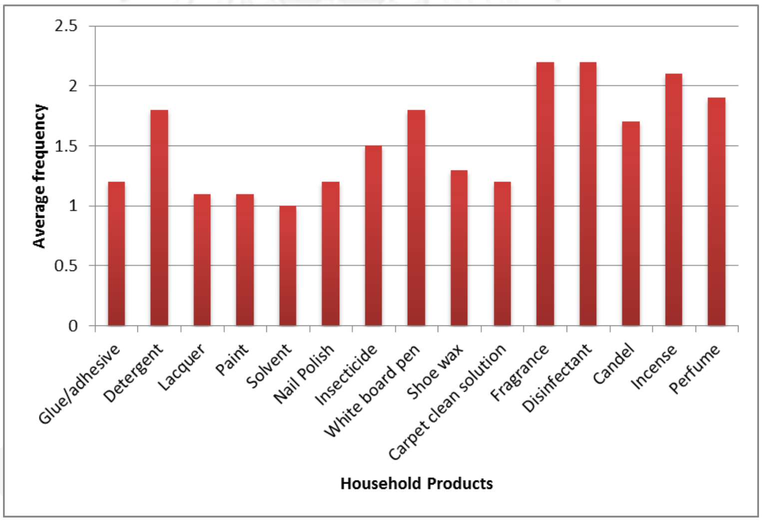


Figure 4. 17 The percentage of household products usage

The percentage of household product used calculated from the frequency of each products in Figure 4.18 (100% means use it every day). When compared the household product usage among five communities, the result revealed that Soi Pra-Chen community used lots of household products with more frequency related to carbonyl compounds and BTEX emission with 22%, followed by Chaw Chu-Cheep community (21%). The third and fourth ranges were Saluk Hin community and Lhun Wat-Pathum community, respectively. The last range was

Patthana Bon-Kai community with 18%. This result could be related the concentrations of valeraldehyde and o-tolualdehyde during both dry and wet seasons, and benzene during wet season that these concentrations peaked in Soi Pra-Chen community. However, the percentage of household usage was just one factor affecting the concentrations of carbonyl compounds and BTEX. Other factor such the house characteristic, the traffic density inside community, air circulation and ventilation of the house, the amount of time that residents spent in their house were influent criteria.

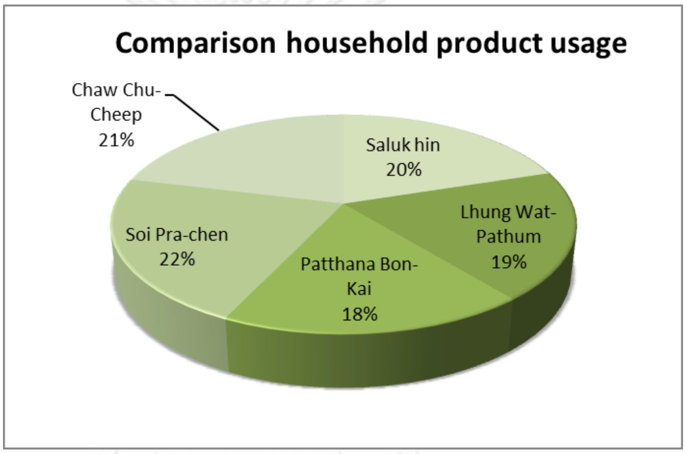


Figure 4. 18 The percentage of household product usage of five residential areas

4.6.2 Health information of the residents

The number of questionnaires gained from five communities was 18. Regarding to the questionnaire that do you have disease related to respiratory tract, there was 50% who claimed that they had disease or symptom related to respiratory tract. In this group, there was 38.89% for allergy, 11.11% for sinus, and 5.56% for asthma as presented in Figure 4.19. For the question asking that do you think that the symptoms might cause by the air in the house, there was 50% who agreed. According to Figure 4.20, the irritations of eyes, nose, respiratory tract, head, skin, and others were 16.28%, 18.6%, 16.28%, 13.95%, 16.28%, 2.33%, respectively.

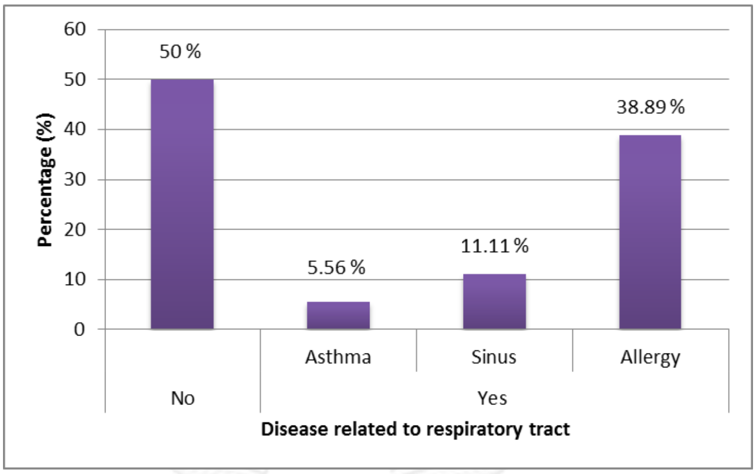


Figure 4. 19 The percentage of disease of residents (n=18)

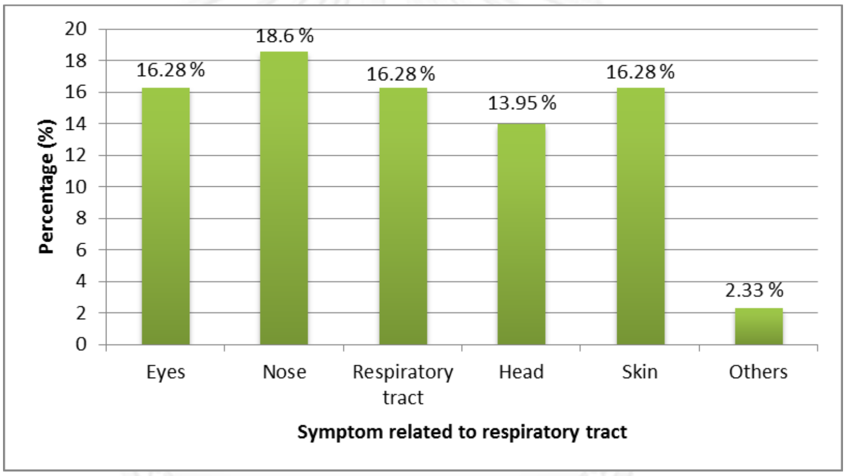


Figure 4. 20 The percentage of symptom related to respiratory tract (n=9)

4.6.3 General information used for risk calculation and recommendations

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 4.21, while Figure 4.21 presented the range of age (year), body weight (kg), and exposure duration (year).

Table 4. 21 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

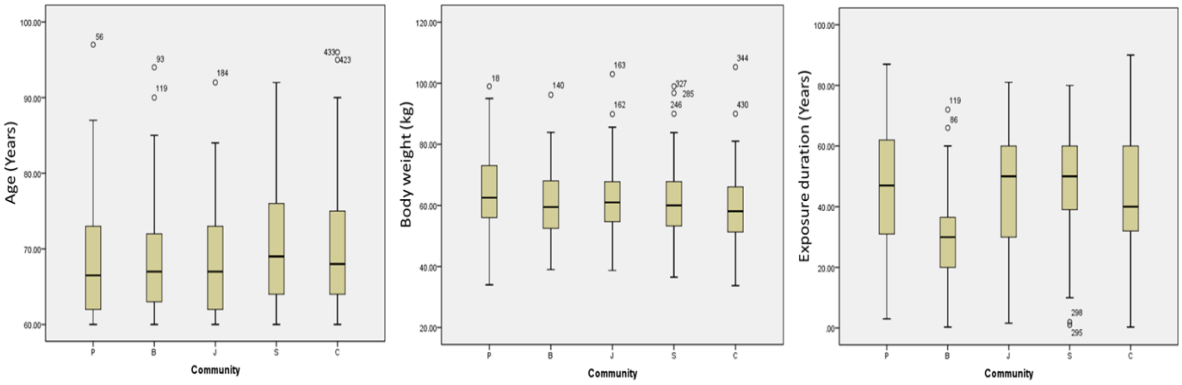


Figure 4. 21 Age (year), body weight (kg), and exposure duration (year) of residents living in five communities (N_P=58, N_B=92, N_J=92, N_S=89, N_C=103)

$$CDI = CA \times IR \times EF \times ED / (BW \times AT) \qquad \text{(Eq. 4.9)}$$

Based on the cancer risk estimation equation (Eq. 4.9), there were the two ways that could reduce the risk: 1) reduce the atmospheric concentrations of pollutant by reducing CA; 2) reduce the exposure duration (ED) that residents living in that area (year). In the case of reducing chemical concentrations, reducing the usage of household products related to chemical emission, new furniture, housed decoration, and so on was recommended. Using electric incense instead of normal incense, reduce or ban the usage of insecticide by using mosquito net instead could reduce the cancer risk for long term and also reduce the payment. Walking or joking instead of staying in house for long time was suggested. Residents particularly elderly people likely to spend their time in house promoting higher exposure than working age were advised to walk or exercise in the garden or park for breathing the fresh air and also good for health. Moreover, increasing air ventilation and air circulation using hood during inside-house cooking could decline the indoor levels that were expected to impact to residents' health risk.

4.6.4 Health risk assessment based on general scenario

The lifetime cancer risks of four carcinogenic substances calculated from general equation for residents living in five communities were reported by 95% CI (A) with error bar graph and box plot (B) of formaldehyde, acetaldehyde, benzene, and ethylbenzene in Figure 4.22 and 4.23. Firstly, the highest average cancer risk for formaldehyde was found in C ($9.43x10^{-5}$) community, followed by S ($5.78x10^{-5}$), J ($4.72x10^{-5}$), B ($4.98x10^{-5}$), and P ($2.20x10^{-5}$) community, respectively. Likewise formaldehyde, C ($1.24x10^{-5}$) community provided the highest cancer risk for acetaldehyde, followed by S ($1.00x10^{-5}$), J ($9.75x10^{-6}$), B ($8.06x10^{-6}$), and P ($4.94x10^{-6}$) community. However, J ($1.25x10^{-3}$) community presented the highest cancer risk for benzene, followed by C ($9.55x10^{-4}$), P ($8.15x10^{-4}$), S ($6.88x10^{-4}$), and B ($3.85x10^{-4}$) community. For ethylbenzene, the greatest cancer risk was found in P ($2.13x10^{-5}$) community, followed by S ($1.92x10^{-5}$), C ($1.66x10^{-5}$), B ($1.60x10^{-5}$), and J ($1.34x10^{-5}$) community. In addition, the minimum and maximum lifetime cancer risks of formaldehyde, acetaldehyde, benzene, and ethylbenzene with % unacceptable risk, and 95% CI were concluded in Table 4.22. The highest %unacceptable cancer risk was formaldehyde (95.8%), followed by acetaldehyde (89.6%), ethylbenzene (80.7%), and benzene (75.8%), respectively. The percent of unacceptable cancer risk also related to the indoor concentration. The CDI and 95% CI of CDI values were also provided in Appendix E.

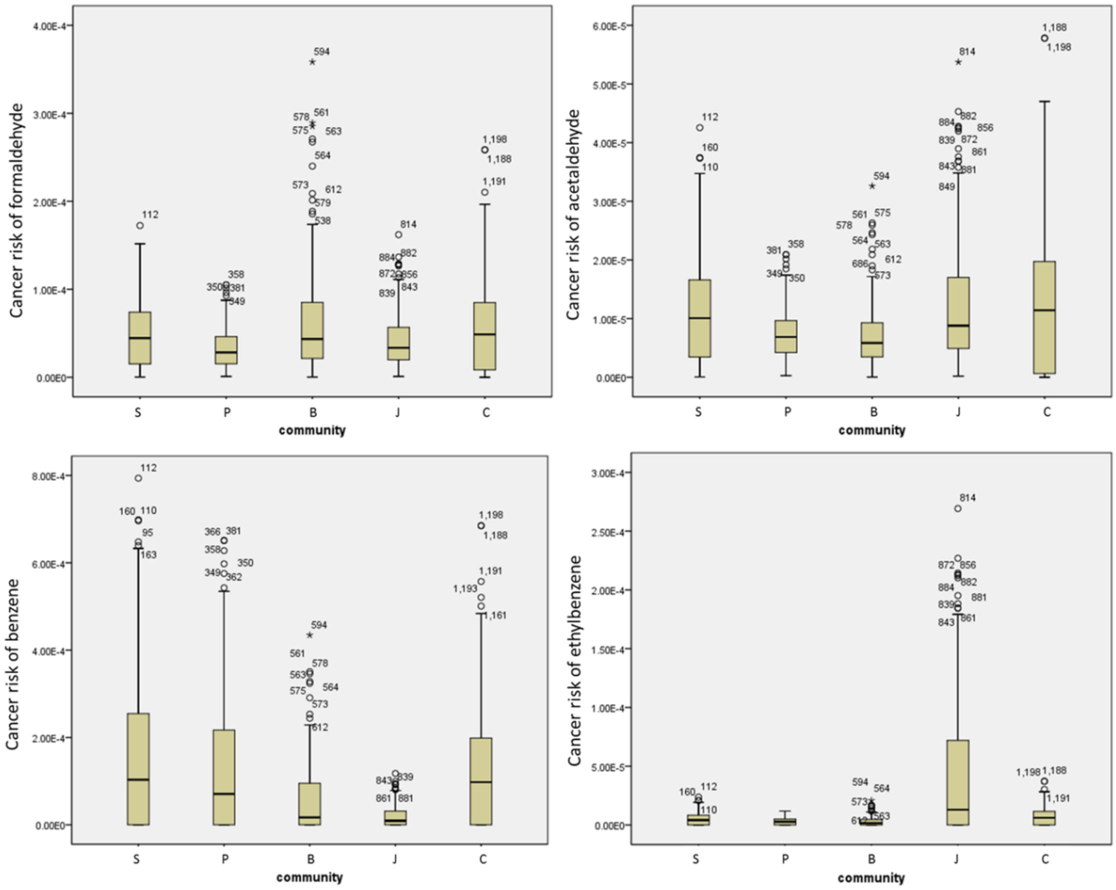


Figure 4. 22 Lifetime cancer risk based on general scenario reported in box plot graphs

Table 4. 22 The lifetime cancer risk of formaldehyde, acetaldehyde, benzene, and ethylbenzene for residents

Compound	Cancer risk			95% CI		%Unacceptable risk
	Min	Max	Mean	Upper	Lower	
Formaldehyde	$4.13x10^{-8}$	$3.58x10^{-4}$	$4.96x10^{-5}$	$5.99x10^{-5}$	$4.72x10^{-5}$	95.8%
Acetaldehyde	$3.06x10^{-9}$	$5.78x10^{-5}$	1.04x10-5	$1.09x10^{-5}$	$9.93x10^{-6}$	89.6%
Benzene	$6.43x10^{-11}$	$7.94x10^{-4}$	9.58x10-5	$1.03x10^{-4}$	$8.83x10^{-5}$	75.8%
Ethylbenzene	$2.54x10^{-12}$	$2.69x10^{-4}$	1.27x10-5	$1.45x10^{-5}$	$1.10x10^{-5}$	80.7%

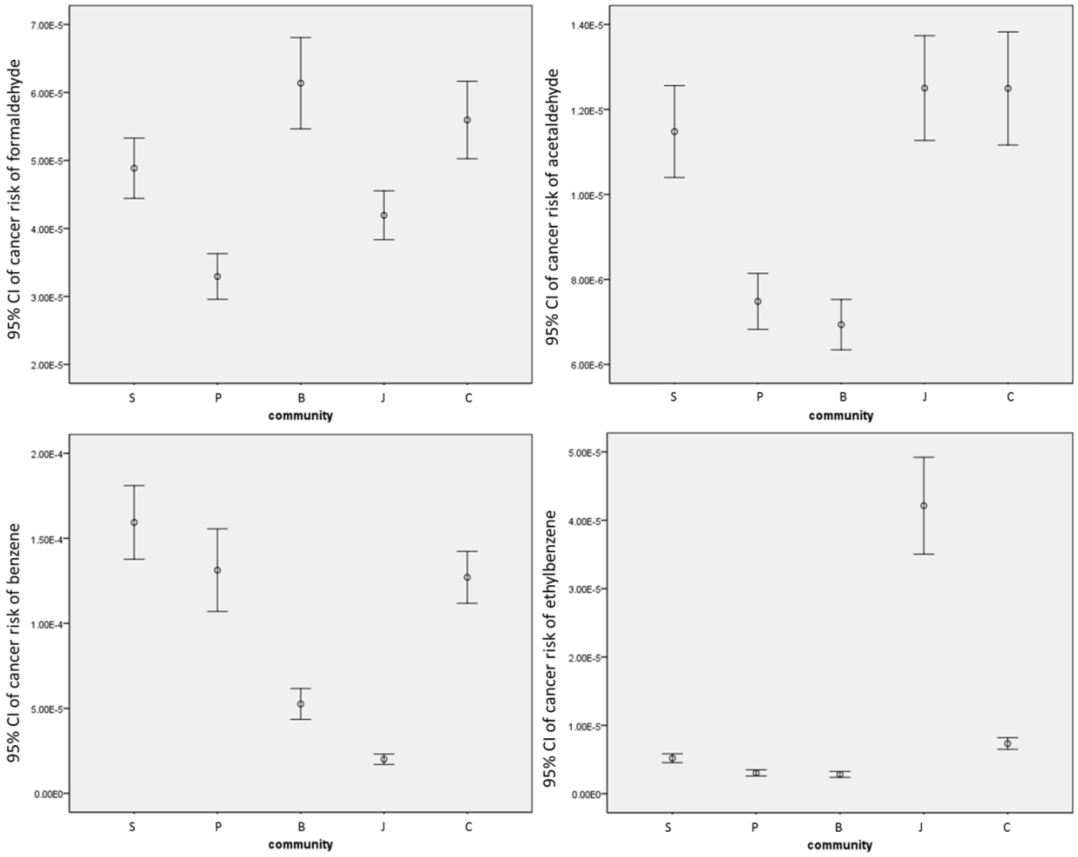


Figure 4. 23 95% Confidential interval of lifetime cancer risk based on general scenario reported in error bar graphs

In case of non-carcinogenic substances, the HQs determined from all five residential areas also demonstrated in Figure 4.24 and 4.25. All compounds provided HQs in an acceptable risk excluding m-, p-xylene for maximum values in S community. B (0.104) community provide the highest HQ for toluene, followed by S (0.078), C (0.070), J (0.055), and P (0.041) community. For m-, p-xylene, the highest HQ value was found at S (0.706) community, followed by B (0.487), C (0.461), J (0.430), and P (0.334) community. S (0.276) community showed the highest HQ for o-xylene, followed by B (0.203), J (0.126), C (0.121), and P (0.101) community. For propionaldehyde, C (0.159) community presented the highest HQ, followed by B (0.127), J (0.114), S (0.110), and P (0.049) community. Moreover, Table 4.23 also illustrated the minimum and maximum of HQs, 95% CI and %unacceptable risk for toluene, m-, p-xylene, o-xylene, and propionaldehyde. Toluene, o-xylene, and propionaldehyde had 0% for unacceptable non-cancer risk, while m-, p-xylene provided 7%. The EC and 95% CI of EC values also provided in Appendix E.

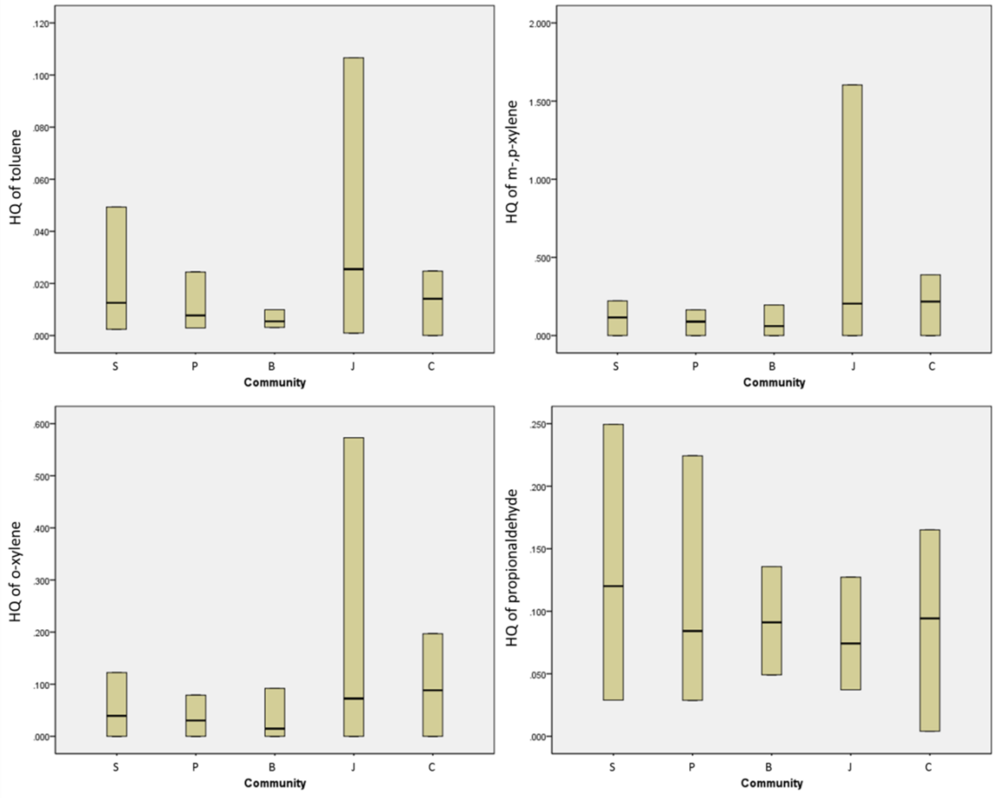


Figure 4. 24 Hazard quotients of non-cancer risk based on general scenario reported in error bar graphs

Table 4. 23 HQs of toluene, m-, p-xylene, o-xylene, and propionaldehyde for residents

Compound	Hazard Quotients			95% CI		% Unacceptable risk
	Min	Max	Mean	Upper	Lower	
Toluene	4.73×10^{-5}	0.107	0.019	0.021	0.018	0%
m-,p-Xylene	7.67×10^{-6}	1.603	0.228	0.249	0.207	7%
o-Xylene	3.07×10^{-5}	0.573	0.092	0.099	0.084	0%
Propionaldehyde	0.004	0.249	0.099	0.103	0.096	0%

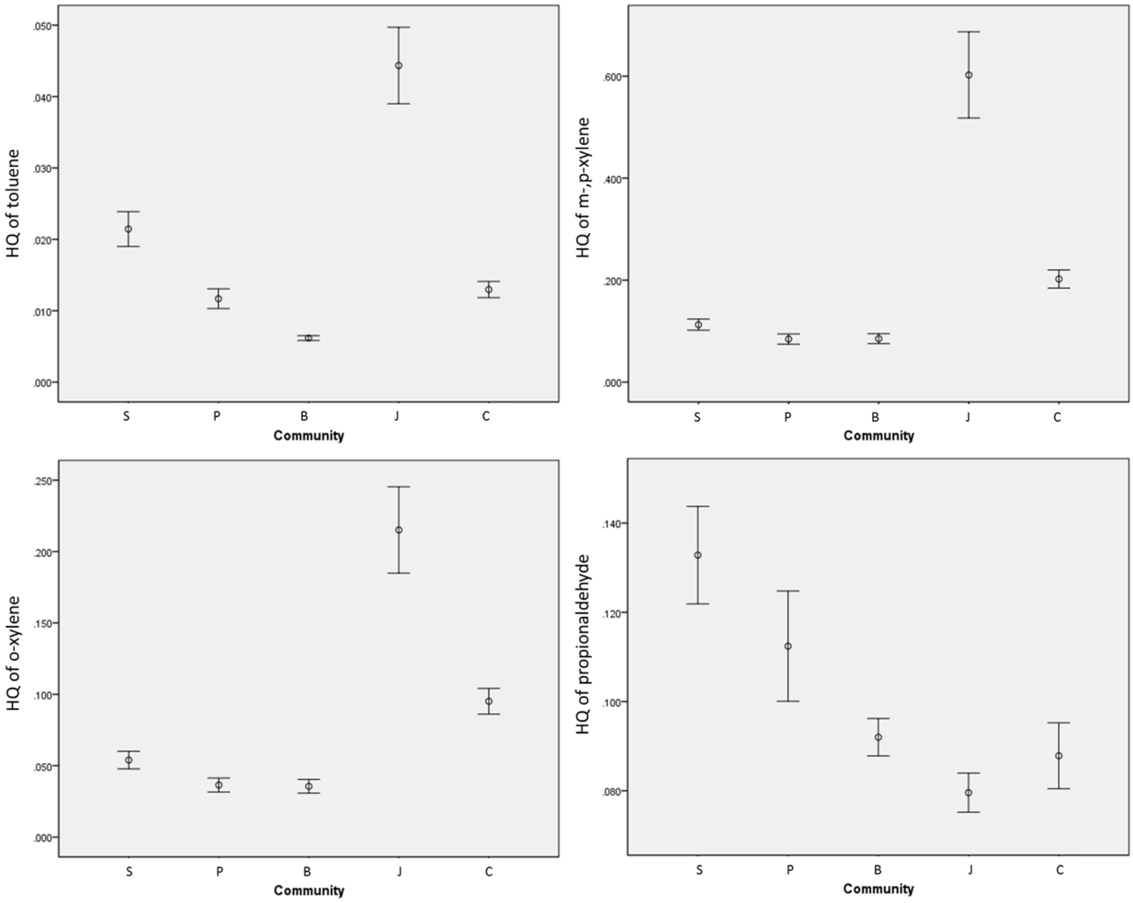


Figure 4. 25 95% Confidential interval of hazard quotients of non-cancer risk based on general scenario reported in error bar graphs

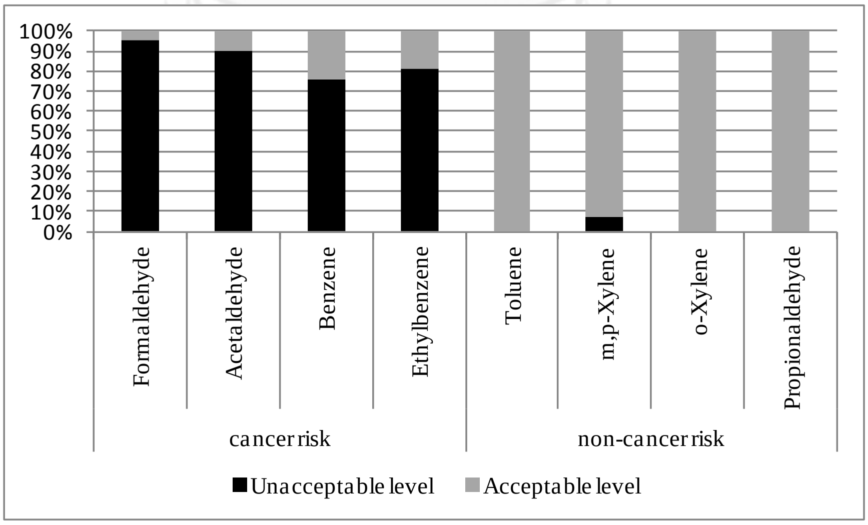


Figure 4. 26 Unacceptable risk and acceptable risk (%) compared to overall residents

Based on Figure 4.26, the overall proportion of unacceptable and acceptable risk for residents calculated from basic equation were demonstrated separately for cancer and non-cancer risk. These risks were estimated from exposure levels of residents during dry and wet season. For carcinogenic substances, the overall residents (100%) were at the risk of developing cancer especially squamous cell carcinoma caused by inhalation of formaldehyde (95.8%) which was found relatively greater than acetaldehyde (89.6%) causing nasal squamous cell carcinoma or adenocarcinoma, following by ethylbenzene (80.7%) causing kidney tumors, and benzene (75.8%) causing leukemia. For non-carcinogenic substances, the overall residents (100%) were not have potential adverse health risk from exposure of atmospheric toluene, o-xylene, and propionaldehyde since their HQ were less than acceptable level ($HQ < 1$). However, m-, p-xylene could have possibility to increase adversed health effects for 7% to residents who exposed.

In order to estimate the total potential health risk, the cancer risk exposed to formaldehyde, acetaldehyde, benzene, and ethylbenzene were combined for the individual resident as provided in Eq. 4.1. However, hazard index (HI) which referred to the total risk of non-carcinogenic substances was calculated from the summation of hazard quotients (HQ) of non-carcinogenic substances as given in Eq. 4.2.

$$\text{Total cancer risk} = \text{Cancer risk}_{\text{Formaldehyde}} + \text{Cancer risk}_{\text{Acetaldehyde}} + \text{Cancer risk}_{\text{Benzene}} + \text{Cancer risk}_{\text{Ethylbenzene}} \qquad \text{(Eq. 4.1)}$$

$$\text{HI} = \text{HQ}_{\text{Toluene}} + \text{HQ}_{\text{m-,p-Xylene}} + \text{HQ}_{\text{o-Xylene}} + \text{HQ}_{\text{Propionaldehyde}} \qquad \text{(Eq. 4.2)}$$

According to Table 4.24, the minimum, maximum, mean values, and 95% CI of total risk also provided for total cancer risk and HI. The percentage of unacceptable risk for total cancer risk was 95.5%, while HI's unacceptable risk was 35.8%.

Table 4. 24 Total cancer risk and hazard index of carcinogenic and non-carcinogenic substances

Total risk	Risk value			95% CI		%Unacceptable risk
	Min	Max	Mean	Upper	Lower	
Total cancer risk	6.10x10^{-8}	7.64x10^{-3}	9.07x10^{-4}	9.73x10^{-4}	8.40x10^{-4}	95.5%
HI	0.151	2.078	0.851	0.880	0.822	35.8%

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 based on general scenario. The lifetime cancer risks of benzene were similar to the lifetime cancer risks reported by previous research that studied residential areas in Beijing-China (1.60x10^{-4}) (Liu *et al.*, 2013) and Kolkata-India (2.72x10^{-5}) (Majumdar *et al.*, 2011), while greater than those found in Hong Kong-China (1.86x10^{-6}) (Huang *et al.*, 2011). Majumdar *et al.* (2011) revealed a similar mean (2.08x10^{-6}) of lifetime cancer risk for ethybenzene as this study. The lifetime cancer risks of formaldehyde and acetaldehyde were lower than those determined for Beijing-China (6.2x10^{-4} and 6.7x10^{-5} respectively) (Liu *et al.*, 2013), Xalapa-Mexico (6.10x10^{-4} and 5.9x10^{-5} respectively) (Báez *et al.*, 2003) and Huangzhou-China (1.05x10^{-5} and 3.05x10^{-6} respectively) (Weng et al., 2010), while the lifetime cancer risks reported in the study of Huang *et al.* (2011) had the same range of cancer risk of formaldehdye (1.30x10^{-3}) but lower in the case of acetaldehyde (7.1x10^{-5}). For non-carcinogenic substances, the previous studies on non-carcinogenic risk from ambient air in Kolkata-India (0.00231-0.00821 for toluene and 0.0787-0.178 for xylenes) (Dutta *et al.*, 2009) and indoor and outdoor air in Tokushima-Japan (0.0144 for toluene and 0.0368 for xylenes) (Sekizawa et al., 2007) also reported similar results; there was no evidence of non-cancer risk of toluene and xylenes with hazard quotients less than 1.

4.6.5 Health risk assessment based on age interval scenario

Other scenario of possible health risk for developing cancer of residents living in inner city of Bangkok was that the exposure of pollutants had sensitivity of effects to an individual differently among their different age. Birth or child was more sensitive since their incomplete developed organs with high age-dependent adjustment factor (ADAF=10). However, adult or elderly people were more mature physical development with lower age-dependent adjustment factor (ADAF=3 or 1). In this scenario, all people were assumed to live in the area since they were born until their own ages. The concentrations of contaminants used in this case were measured from indoor environment during dry and wet seasons. However, US EPA did 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, therefore it should be added the risk for the overall lifetime cancer risk for individual.

According to the results given in Figure 4.27 and 4.28, the range of lifetime cancer risks of formaldehyde, acetaldehyde, benzene, and ethylbenzene in error bar graph with 95% CI and box plot were over acceptable risk which was 1×10^{-6} meaning that 1 of million people can have possibility to have developing cancer with all 100% for unacceptable risk. The average lifetime cancer risk of benzene was the highest (2.56×10^{-3}), followed by formaldehyde (1.87×10^{-4}), ethylbenzene (5.58×10^{-5}), and acetaldehyde (3.10×10^{-5}), respectively. Comparison average lifetime cancer risk among five communities for formaldehyde, acetaldehyde, benzene, and ethylbenzene were defined. For formaldehyde, average lifetime cancer risk found in C community (2.70×10^{-4}) was the most abundant, followed by J (1.92×10^{-4}), S (1.68×10^{-4}), B (1.52×10^{-4}), and P community (6.80×10^{-5}), respectively. Nonetheless, B community (3.85×10^{-5}) provided the highest average lifetime cancer risk for acetaldehyde, followed by C (3.60×10^{-5}), J (2.95×10^{-5}), S (2.93×10^{-5}), and P community (1.55×10^{-5}). For benzene, the greatest average lifetime cancer risk was determined from J community (3.71×10^{-3}), followed by C (2.74×10^{-3}), S (1.99×10^{-3}), P (2.52×10^{-3}), and B community (1.90×10^{-3}), respectively. Nevertheless, B community was found the highest average lifetime cancer risk for ethylbenzene (7.45×10^{-5}), followed by P (6.59×10^{-5}), S (5.56×10^{-5}), C (4.77×10^{-5}), and J community (4.00×10^{-5}), respectively.

Table 4. 25 **The minimum, maximum, and average values of lifetime cancer risk and %unacceptable risk calculated by using age-dependent adjustment factor**

Compound	Cancer risk			95% CI		% Unacceptable risk
	Min	Max	Mean	Upper	Lower	
Formaldehyde	$1.93x10^{-6}$	$4.68x10^{-4}$	$1.87x10^{-4}$	$1.94x10^{-4}$	$1.79x10^{-4}$	100%
Acetaldehyde	$3.17x10^{-6}$	$7.27x10^{-5}$	$3.10x10^{-5}$	$3.20x10^{-5}$	$3.00x10^{-5}$	100%
Benzene	$3.72x10^{-6}$	$9.20x10^{-3}$	$2.56x10^{-3}$	$2.72x10^{-3}$	$2.40x10^{-3}$	100%
Ethylbenzene	$1.18x10^{-5}$	$1.41x10^{-4}$	$5.58x10^{-5}$	$5.78x10^{-5}$	$5.38x10^{-5}$	100%

Since the lifetime cancer risk calculated based on basic equation used different parameters and different values, the lifetime cancer risk calculated using age-dependent adjustment factor could not be comparison. However, more than 75% of unacceptable risk of common scenario showed the same trend of age-bin scenario which 100% of unacceptable risk for all carcinogenic pollutants (Table 4.25). These outcomes also related to the high levels of carbonyl compounds and BTEX in indoor environment, especially BTEX during rainy season. When meteorological variation did not have much influent to indoor levels, the indoor activities and behavior of residents were considerably having higher impact. The reduction of some household usage such as incenses, cigarettes, glues, paints, and some cleaning products were recommended. Furthermore, increase air ventilation by opening windows and doors were also suggested.

Based on the age interval scenario, the local residents living in inner city of Bangkok seemed to face a potential risk for cancer development through inhalation of benzene, ethylbenzene, formaldehyde and acetaldehyde. The lifetime cancer risks of formaldehyde and acetaldehyde were similar to the lifetime cancer risks reported by previous research that studied residential areas in Xalapa-Mexico ($6.1x10^{-4}$ and $5.9x10^{-5}$) (Báez et al., 2003), Beijing-China ($6.2x10^{-4}$ and $6.7x10^{-5}$) (Liu et al., 2003), while the results of Weng et al. (2010) recorded the lower risks ($1.05x10^{-5}$ and $3.05x10^{-6}$), respectively. Moreover, the study at Hong Kong-China (Huang et al., 2011) revealed the higher cancer risk ($1.3x10^{-3}$) for formaldehyde studied from this study, whereas they provided the similar value of acetaldehyde (7.1×10^{-5}) to this study. For benzene, the lifetime cancer risk in this study was higher than studies in Beijing-China (1.6×10^{-4}) (Liu et al., 2013), Kolkata-India (2.72×10^{-5}) (Majumdar et al., 2011), and Hong Kong-China (1.9×10^{-6}) (Huang et al., 2011). Furthermore, Majumdar et al. (2011) reported the lower cancer risk of ethylbenzene (2.1×10^{-6}).

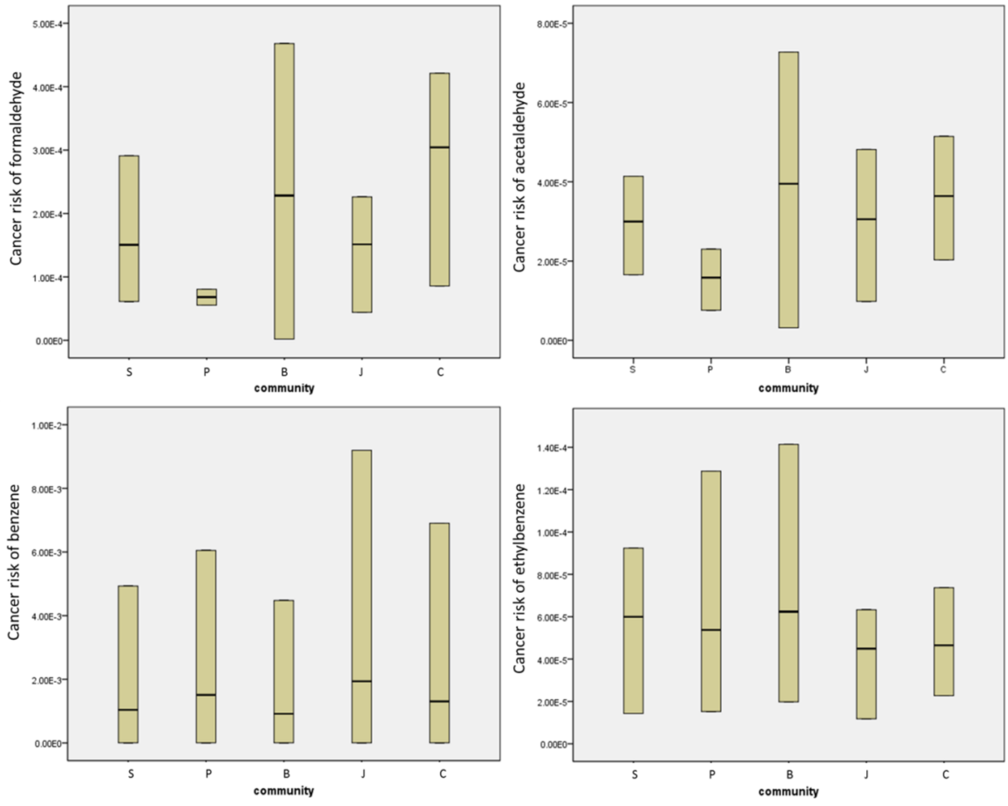


Figure 4. 27 Lifetime cancer risk based on age interval scenario reported in box plot

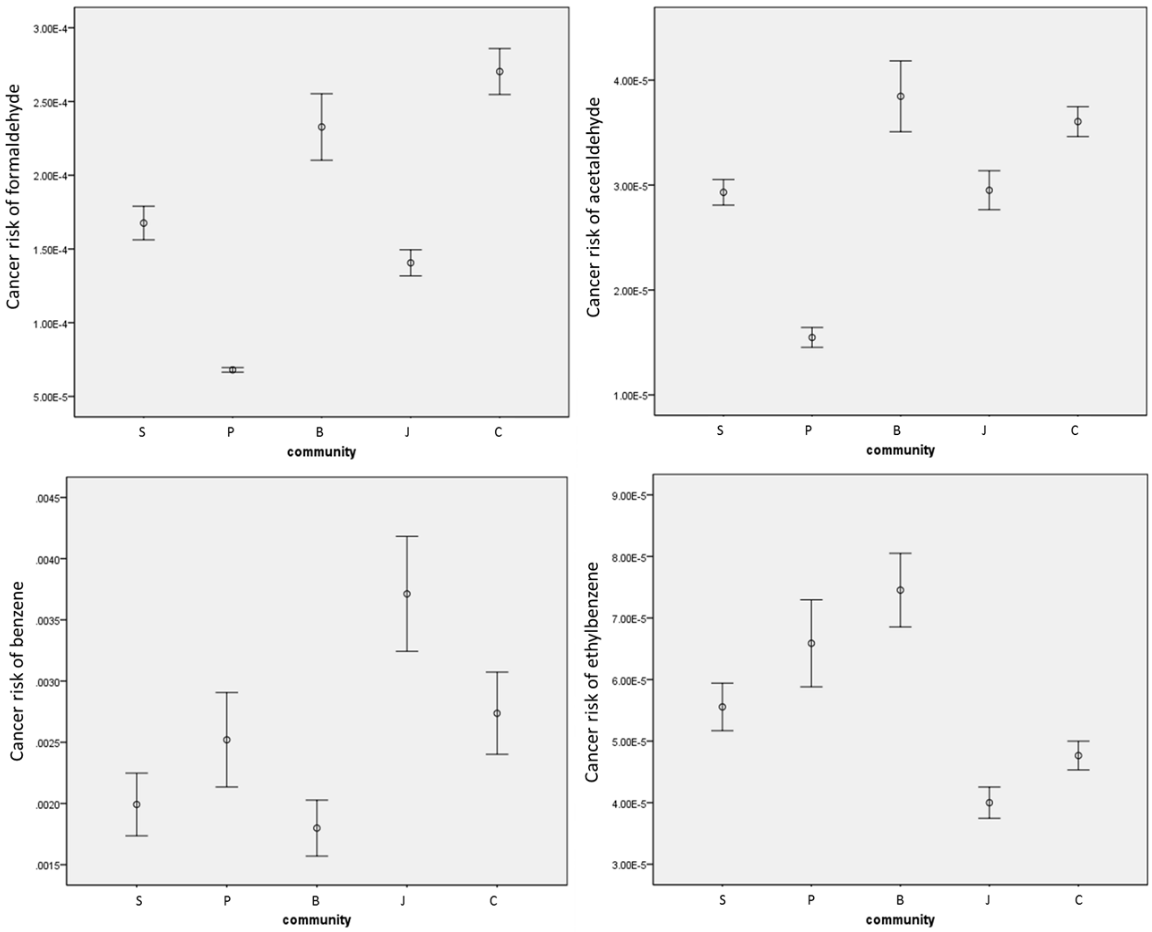


Figure 4. 28 95% Confidential interval of lifetime cancer risk based on age interval scenario reported in error bar graphs.

Table 4.26 provided specific information of each house for sample collection. Most high used household product, especially incense and insecticide house related to high concentrations of carbonyl compounds and BTEX. Only the concentrations of carbonyl compounds and BTEX found at Patthana Bon-Kai community has been affected by nearby tobacco factory more than special activity inside each house. Most, almost selected houses had low air ventilation promoting the accumulation of atmospheric toxic chemicals. The suggestion is that residents should use not use or try to prevent to use insecticide and incenses and also increase air ventilation inside the house.

Table 4. 26 Specific information of each house for sample collection

Community	House	Possible sources and activities	Related concentrations and risks
Saluk Hin	H1	-use incense every day, low air ventilation -locate nearby printing house	High
	H2 (dry season)	-not have special activity, but got effects by vehicles passing the house	High
	H2 (wet season)	-not have special activity, but very low air ventilation	Low
	H3	-use insecticide sometimes, but cooking inside the house every day without hood	High
Lhung Wat-Pathum	H1	-not have special activity. Cement industry nearby did not effect.	Low
	H2	-not have special activity	Low
	H3	-not have special activity	Low
Patthana Bon-Kai	H1	-not have special activity, but located nearby tobacco factory, one smoking people in house.	High
	H2	-not have special activity, but located nearby tobacco factory	High
	H3	-not have special activity, but located nearby tobacco factory	High
Soi Pra-Chen	H1	-lots use of incense everyday with 5 points (2 front door, 2 dowanstair, and 1 upstair) -low air ventilation (narrow door) -drive motorcycle in house sometimes	Very high
	H2	-use incense every day, one smoking people in house, motorcycle mostly pass the house	High
	H3	-use lots of incense every day and has the shrine of household god in front the house	High
Chaw Chu-Cheep	H1	-not have special acitivity	Low
	H2 (dry season)	-have new wall painting both inside and outside the house, with low air ventilation.	Very high
	H2 (wet season)	-store lots of paints, glues, woods, solvents and other carpenter's stuffs	Very high

Community	House	Possible sources and activities	Related concentrations and risks
	H3 (dry season)	-not have special activity	Low
	H3 (wet season)	-collect samples in garage. The vehicle exhaust might affect	High

This study also aimed to mention to residents that some household products and the air ventilation in house were very important to the exposure of atmospheric hazard chemicals. All risk estimation both cancer risk and non-cancer risk derived from both general scenario and age interval scenario also had the uncertainty coming from the reference values used, the variation of exposure levels in the reality which also change by time to time, the individual health profile. Exposure time (ET) in this study was the assumption for 24 hours per day; however, some people did not spend their whole time in their house. Therefore, the ET value used could provide over estimation of the cancer risk for all general and age interval scenarios. However, if the other routes of exposure were considered, these risk estimation might under estimation. Even though carbonyl compounds and BTEX possibly be exposed by other pathway such as dermal and ingestion pathway, the chemicals could be exposed via these two pathways in low levels. In addition, the chemical concentrations were investigated over a short period of time during 2013 (April to May, 2013 and July to August, 2013). This might also have led to rises in atmospheric contributions over time to time. However, as the health risks of only BTEX and four main carbonyl compounds were studies in this research, other chemicals could also lead to higher health risks. Additionally, inhalation exposure was only used to estimate risks for residents in this case, while they could also be exposed to these chemicals through ingestion and dermal adsorption. Furthermore, the uncertainty from difference reference values for the risk calculation could cause higher and lower risk estimations.

The risk values reported in this study might be overestimated, since the risks were calculated based on the indoor concentrations measured at the residential areas located in inner city Bangkok, where the indoor and background levels were expected to be higher than in suburban accommodations. Some people migrated from other parts of Thailand to Bangkok for work, so they had not lived in this inner city environment since birth.

Even through the risk estimation could not be represented for all residents in Thailand, it can be used as a baseline for risk information, for people living over a long period in areas of Bangkok where there are high concentrations of air pollution. It can also serve as an incentive for residents to adopt greater concern about health risk.

CHAPTER V

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusions

This study aimed to determine and compare indoor and outdoor concentrations of carbonyl compounds and BTEX in the inner city of Bangkok during summer (phase 1) and rainy season (phase 2), to investigate the correlation between indoor and outdoor concentrations by using Pearson's correlation, and to estimate the potential health risk via inhalation exposure to carbonyl compounds and BTEX for residents living in the those five communities. All results could be summarized as follows:

1) According to both samplings (during dry and wet seasons), the predominant target compounds measured in both indoor and outdoor atmospheric environment at all five residential areas were formaldehyde, acetaldehyde, propionaldehyde, hexanaldehdye, benzene, toluene, ethylbenzene, m-, p-xylene, and o-xylene.

2) For the results of carbonyl compounds in the inner city of Bangkok, the 24-hour average of predominant species including formaldehyde, acetaldehyde, propionaldehyde, and hexanaldehyde were as follows; the average concentration for formaldehyde were 8.35 (1.40-38.73) µg/m^3 for dry season and 9.96 (0.14-33.78) µg/m^3 for wet season; the average concentration of acetaldehyde were 4.22 (0.22-10.16) µg/m^3 for dry season and 3.54 (0.10-11.02) µg/m^3 for wet season; the average concentration of propionaldehyde were 0.71 (0.03-2.08) µg/m^3 for dry season and 0.78 (0.14-1.99) µg/m^3 for wet season; the average concentration of hexanaldehyde were 1.66 (0.45-6.28) µg/m^3 for dry season and 0.56 (0.03-1.99) µg/m^3 for wet season.

3) For the study in the inner city of Bangkok, the 24-hour average concentrations of BTEX both dry and wet seasons revealed that toluene was the most abundant species with 52.17 (0.25-555.80) µg/m^3 and 344.61 (97.77-1,069.78) µg/m^3, respectively. The average concentrations of benzene were 8.82 (0.26-57.75) µg/m^3 for dry season and 55.54 (0.21-510.07) µg/m^3 for wet season. The average concentration of ethylbenzene were 6.75 (0.07-132.16) µg/m^3 for dry season and 21.62 (4.63-60.14) µg/m^3 for wet season. The average concentrations of m-, p-xylene were

13.05 (0.12-167.18) μg/m^3 for dry season and 48.51 (9.17-130.34) μg/m^3 for wet season. Finally, the average concentrations of o-xylene were 5.47 (0.51-59.75) μg/m^3 for dry season and 16.12 (2.95-54.77) μg/m^3 for wet season.

4) Comparison of four major carbonyl compounds determined in indoor and outdoor environments in the inner city of Bangkok, there were lower outdoor concentrations of formaldehyde, acetaldehyde, propionaldehyde, and hexanaldehyde for both dry and wet seasons. Formaldehyde was the most abundant species, followed by acetaldehyde, hexanaldehyde, and propionaldehyde, respectively. The average concentrations of formaldehyde were 12.09 (0.14-38.73) μg/m^3 for indoor air and 6.23 (2.10-13.74) μg/m^3 for outdoor air. The average concentrations of acetaldehyde were 4.78 (0.10-11.02) μg/m^3 for indoor air and 2.99 (0.23-7.26) μg/m^3 for outdoor air. The average concentrations of hexanaldehyde were 1.32 (0.03-6.28) for indoor air and 0.90 (0.55-3.83) μg/m^3 for outdoor air. Moreover, the average concentrations of propionaldehyde were 0.85 (0.03-2.08) μg/m^3 for indoor air and 0.63 (0.24-1.78) μg/m^3 for outdoor air.

5) Comparison of BTEX determined in indoor and outdoor environments in the inner city of Bangkok, there were lower outdoor concentrations of benzene, toluene, ethylbenzene, m-,p-xylene, and o-xylene for both dry and wet seasons. Toluene was the highest BTEX found in all areas with 203.97 (0.25-1061.87) μg/m^3 for indoor air and 192.81 (13.95-1069.78) μg/m^3 for outdoor air. The average concentrations of benzene were 41.87 (0.21-510.07) μg/m^3 for indoor air and 22.48 (0.21-239.34) μg/m^3 for outdoor air. The average concentrations of ethylbenzene were 14.25 (0.07-132.16) μg/m^3 for indoor air and 14.12 (0.07-87.17) μg/m^3 for outdoor air. The average concentrations of m-, p-xylene were 30.16 (0.12-167.18) μg/m^3 for indoor air and 31.39 (0.12-112.30) μg/m^3 for outdoor air. The average concentrations of o-xylene were 10.61 (0.51-59.75) μg/m^3 for indoor air and 10.98 (0.51-54.10) μg/m^3 for outdoor air.

6) The possible factors affecting indoor concentrations of carbonyl compounds and BTEX were pressed wood, coatings, cigarettes, glues, paints, and household cleaning products, while outdoor sources could be vehicle exhaust, gasoline evaporation, emissions from solvents and paintings, leakage of natural gas and liquefied petroleum gas. The meteorological factor trended to have

higher effect on outdoor concentrations of both carbonyl compounds and BTEX than indoor concentrations of these chemicals.

7) The hazard quotients for non-cancer risk estimation of m-, p-xylene were found as the highest % unacceptable risk with 7% within the range of 7.67x10^{-6} to 1.603. However, toluene, o-xylene, and propionaldehyde had 0% unacceptable risk within the range of 0.001 to 0.204, 3.07x10^{-5} to 0.573, and 0.004 to 0.249, respectively.

8) The lifetime cancer risk calculated based on common scenario revealed that formaldehyde provided the highest cancer risk with 95.8% unacceptable risk for all residents within the range of 4.50x10^{-9} to 3.84x10^{-4}. Acetaldehyde was ranked by the second with 89.6% unacceptable risk and was in the range of 1.61x10^{-9} to 5.78x10^{-5}, followed by ethylbenzene with 80.7% unacceptable risk within the range of 2.54x10^{-12} to 2.69x10^{-4}. The lifetime cancer risk for benzene was ranged between 6.43x10^{-11} to 7.37x10^{-3} with 75.8% unacceptable risk.

9) According to the lifetime cancer risk from age-dependent adjustment factor scenario, all carcinogenic substance including formaldehyde, acetaldehyde, benzene, and ethylbenzene provided 100% unacceptable risk. The lifetime cancer risks of formaldehyde were ranked between 1.93x10^{-6} to 4.68x10^{-4}, whereas acetaldehyde was in the range of 3.17x10^{-6} to 7.27x10^{-5}. The range of the lifetime cancer risk for benzene exposure via inhalation pathway was 3.72x10^{-6} to 9.20x10^{-3}. The lifetime cancer risks of ethylbenzene were in the range of 1.18x10^{-5} to 1.41x10^{-4}.

5.2 Recommendations and suggestions

1) The residents should reduce the usage of some household products such as incenses and insecticides by using electric incenses and mosquito nets instead.

2) The air ventilation should be enhanced by opening windows, doors, or using fans in order to remove indoor pollutants. In case of wall painting house, people should increase air ventilation and not spend a lot of time inside the house, especially the new wall painting area.

3) This study should be applied for other residential sites (e.g., rural areas, semi urban areas) or use as the background information for other residential areas, especially in the city.

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APPENDIX

APPENDIX A: Questionnaire

A.1 Questionaire for residents within five communities (English version)

Collection more information

Questionnaire for behavior and life style of resident

Address...Road..

Subdistrict......................................District...

Bangkok Zip code...

Telephone number..

Date of collection...(DD/MM/YY)

Please make correct mark (√) or fill short information in the blank in front of messages that you seen with proper and close to reality.

Questionnaire for behavior and life style of resident

Part 1: General information

1.Age.............................years

2.Gender Male ☐ 1 Female ☐ 2

3.Education

Elementary school	☐ 1	Junior high school	☐ 2
Senior high school	☐ 3	Diploma	☐ 4
Bachelor	☐ 5	Higher than Bachelor	☐ 6

4.Occupation (please identify)..

Part 2: House information

5.How old is your house? (the nearest year)..(years)

6.How far of your house from the main road? (please estimate in unit of meters)................(meters)

7.Does your house locate nearby the plant?

Yes ☐ 1 No ☐ 2

If yes (please identify the type of it)...

8.What kind of ground materials of your house?

	Carpet (1)	Tile (2)	Board (3)	Parquet (4)	Polished stone (5)	Cement (6)	etc. (7)
8.1 Bedroom							
8.2 Kitchen							
8.3 Drawing room							
8.4 Living room							
8.5 Dining room							

9.Do you renovate or fix your house within 12 months ago?

Yes 1 ☐ No 2 ☐

10.Do you paint inside your house within 12 months ago?

Yes 1 ☐ No 2 ☐

11.If yes, what is the last time (please identify)..

12.Do you paint outside your house within 12 months ago?

Yes 1 ☐ No 2 ☐

13. If yes, what is the last time (please identify)..

14. During summer, do you open the air conditioner?

Yes 1 ☐ No 2 ☐

If no, skip to question 16.

15. If you open the air conditioner, when you open it?

15.1 During the day time ☐

15.2 During the night time ☐

15.3 During the day and the night time ☐

15.4 Open all the time, if temperature is higher than ....degree Celsius

15.5 etc. (please identify)..

16.How about air ventilation in your house?

Open window and door	1	☐
Close window and door	2	☐
Close window and door, but have hole for air ventilation	3	☐
Close window and open door, air conditioner that reuse air	4	☐
Close window and open door, air conditioner have air ventilation	5	☐
Etc. (please identify)	6	☐

17. How often you use candle and incense in house?

Never/rarely	1	☐	Once per month	2	☐
Once per week	3	☐	Everyday	4	☐

18. How often you make aroma therapy in house?

Never/rarely 1 ☐ Once a month 2 ☐

Once a week 3 ☐ Everyday 4 ☐

What kind of aroma oil? (please identify)………………………………………………………

19.What kind of fuel/energy that you use for cooking?

Gas 1 ☐ Electricity 2 ☐ Charcoal 3 ☐

Not sure 4 ☐ etc. (please identify)………………………………………………………

20.Do you use hood for air ventilation when you cook?

Yes 1 ☐ No 2 ☐

Part 3: Behavior information

21.How often that you use these products?

	Never/rarely (1)	Once a month (2)	Once a week (3)	More than once a week (4)	Everyday (5)
21.1Glue/adhesive					
21.2Detergent					
21.3 Lacquer					
21.4 Paint					
21.5 Solvent(For example: kerosene, alcohol, acetone)					
21.6 Nail polish					
21.7 Insecticide					
21.8 White board pen					
21.9 Shoe wax					
21.10 Carpet clean solution					

	Never/rarely (1)	Once a month (2)	Once a week (3)	More than once a week (4)	Everyday (5)
21.12 Fragrance					
21.13 Disinfectant					
21.14 Candle					
21.15 Incense					
21.16 Perfume					
21.17 etc.					

22.Do you smoke?

Yes 1 ☐ No 2 ☐

Part 4: Health information

23. Do you have disease related to respiratory tract?

Yes 1 ☐ No 2 ☐

If no, skip to question 25.

24. What disease related to respiratory tract that you have?

24.1 Asthma 1 ☐

24.2 Sinus 2 ☐

24.3 Allergic 3 ☐

24.4 etc. (please identify) 4 ☐

25. Have you ever have these symptoms?

25.1Eye: eye irritate, eye sting, eye itch, red eye, eye tear 1 ☐

25.2 Nose: cough, sneeze, nose sting, stuffed nose 2 ☐

25.3 Respiratory tract: sore throat, red throat, frequent breath, dense breast 3 ☐

25.4 Head: headache, giddy, sleepy, tired, queasy, dizzy 4 ☐

25.5 Skin: rash, dry, irritating 5 ☐

25.6 etc. (please identify) 6 ☐

Question for family member

1.Number of people in the house...................................people

2.Please fill information in table below

Table A.1 Questionnaire related to health profiles of the residents

No.	Relationship	Age (years)	Weight (kg)	Hour spending in house (hr/day)	How often visiting doctor (once a month, once per three months, once per six months, once a year)	Disease	Disease that often occur

3.Do you plan to stay in this house more than 10 years?

Yes ☐ No ☐ (please identify expected year for living here)........years

A.2 Questionnaire for residents within five communities (Thai version)

การเก็บข้อมูลเพิ่มเติม

แบบสอบถามเกี่ยวกับพฤติกรรมและการดำเนินชีวิตของผู้พักอาศัย

ที่อยู่..ถนน..

แขวง..เขต..

กรุงเทพมหานคร รหัสไปรษณีย์..

โทรศัพท์..

วันที่ทำแบบสอบถาม..(วัน/เดือน/ปี)

โปรดทำเครื่องหมาย (√) หรือเติมข้อความสั้นๆ ลงในช่องว่างหน้าข้อความที่ท่านเห็นว่าเหมาะสมและตรงกับสภาพความเป็นจริงมากที่สุด

แบบสอบถามพฤติกรรมและการดำเนินชีวิตของผู้พักอาศัย

ส่วนที่ 1: ข้อมูลทั่วไป

1. อายุ..ปี

2. เพศ ชาย 1 ☐ หญิง 2 ☐

3. ระดับการศึกษา

ประถมศึกษา	☐	1	มัธยมศึกษาตอนต้น	☐	2
มัธยมปลายหรือเทียบเท่า	☐	3	อนุปริญญา	☐	4
ปริญญาตรี	☐	5	สูงกว่าปริญญาตรี	☐	6

4. อาชีพ (โปรดระบุ) ....

ส่วนที่ 2: ข้อมูลเกี่ยวกับบ้านของคุณ

5. บ้านของคุณมีอายุเท่าไร? (ปีที่ใกล้เคียงที่สุด) ....ปี

6. บ้านของคุณห่างจากถนนทางหลวงหรือถนนสายหลักที่ใกล้บ้านคุณที่สุดเท่าไร?

(โปรดประมาณระยะทางที่ห่างจากถนนเป็นเมตร) ....เมตร

7.บ้านของคุณมีที่ตั้งอยู่ใกล้โรงงานใช่หรือไม่?

ใช่ 1 ☐ ไม่ใช่ 2 ☐

ถ้าใช่ (โปรดระบุชื่อหรือประเภทของโรงงาน) ....

8. ในบ้านของคุณพื้นห้องแต่ละห้องเป็นพื้นประเภทใด?

	พรม (1)	กระเบื้อง(2)	พื้นกระดาน (3)	ปาร์เก้ (4)	หินขัด (5)	พื้นปูน (6)	อื่นๆ (7)
8.1 ห้องนอน							
8.2 ห้องครัว							
8.3 ห้องรับแขก							
8.4 ห้องนั่งเล่น							
8.5 ห้องทานข้าว							

9. ปัจจุบันบ้านของคุณมีการปรับปรุงใหม่ (เช่นเปลี่ยนพรมใหม่, ทำครัวใหม่) หรือมีการซ่อมแซมใหม่เมื่อ 12 เดือนที่ผ่านมาใช่หรือไม่?

ใช่ 1 ☐ ไม่ใช่ 2 ☐

10. ปัจจุบันบ้านของคุณทาสีภายใน (เมื่อ 12 เดือนที่ผ่านมา) ใช่หรือไม่?

ใช่ 1 ☐ ไม่ใช่ 2 ☐

11. ถ้าใช่, ผ่านมาแล้วในเดือน (โปรดระบุ) ....

12. ปัจจุบันบ้านของคุณทาสีภายนอก (เมื่อ 12 เดือนที่ผ่านมา) ใช่หรือไม่?

ใช่ 1 ☐ ไม่ใช่ 2 ☐

13. ใช่, ผ่านมาแล้วในเดือน (โปรดระบุ)...

14. ในฤดูร้อน, ในบ้านของคุณจะใช้เครื่องปรับอากาศหรือไม่?

ใช่ 1 ☐ ไม่ใช่ 2 ☐

ถ้าไม่, ให้ไปที่คำถาม 16.

15. ถ้าคุณใช้เครื่องปรับอากาศ, คุณจะเปิดเครื่องปรับอากาศเมื่อใด?

15.1 เวลากลางวัน ☐

15.2 เวลากลางคืน ☐

15.3 ทั้งกลางวันและกลางคืน ☐

15.4 เปิดเครื่องปรับอากาศตลอดเวลา, ถ้าอุณหภูมิเกิน......................องศาเซลเซียส ☐

(โปรดแสดง) ☐

15.5 อื่นๆ (โปรดระบุ)

16. การระบายอากาศในบ้านของคุณเป็นอย่างไร?

เปิดหน้าต่างและประตูเพื่อระบายอากาศ 1 ☐

ปิดหน้าต่างและประตูไม่มีการระบายอากาศ 2 ☐

ปิดหน้าต่างและประตูมีช่องระบายอากาศ 3 ☐

ปิดหน้าต่างและประตูเปิด เครื่องปรับอากาศที่ฟอกอากาศกลับมาใช้ใหม่ 4 ☐

ปิดหน้าต่างและประตูเปิด เครื่องปรับอากาศที่มีการระบายอากาศ 5 ☐

อื่นๆ (โปรดระบุ) .... 6 ☐

17. คุณจุดเทียนไขและธูปในบ้านบ่อยแค่ไหน?

ไม่เคย/น้อยครั้งมาก 1 ☐ 1 ครั้ง/เดือน 2 ☐

1 ครั้ง/สัปดาห์ 3 ☐ ทุกวัน 4 ☐

18. คุณจุดน้ำมันหอมระเหยในบ้านบ่อยครั้งแค่ไหน?

ไม่เคย/น้อยครั้งมาก 1 ☐ 1 ครั้ง/เดือน 2 ☐

1 ครั้ง/สัปดาห์ 3 ☐ ทุกวัน 4 ☐

น้ำมันหอมระเหยประเภทไหน? (โปรดระบุ) ....

19. ประเภทของเชื้อเพลิง/พลังงานที่คุณใช้ในการหุงต้มคืออะไร?

แก๊ส 1 ☐ ไฟฟ้า 2 ☐ ถ่านไม้ 3 ☐

ไม่แน่ใจ 4 ☐ อื่นๆ (โปรดระบุ) .... 5 ☐

20. เมื่อมีการหุงต้มในบ้านปกติจะใช้พัดลมระบายอากาศหรือใช้ hood ที่ต่อกับท่อปล่องควันภายนอกใช่หรือไม่?

ใช่ 1 ☐ ไม่ใช่ 2 ☐

ส่วนที่ 3: ข้อมูลเกี่ยวข้องกับพฤติกรรม

21. คุณใช้ผลิตภัณฑ์เหล่านี้ในบ้านบ่อยแค่ไหน?

	ไม่เคย/นานๆ ครั้ง (1)	1 ครั้ง/เดือน (2)	1 ครั้ง/สัปดาห์ (3)	มากกว่า 1 ครั้ง/สัปดาห์ (4)	ทุกวัน (5)
21.1 กาว/สารยึดติด					
21.2 น้ำยาขจัดคราบสกปรก					
21.3 น้ำมันขัดเงา/แลกเกอร์					
21.4 สี					
21.5 ตัวทำละลาย (น้ำมันก๊าด, น้ำมันสน, สารละลายแอลกอฮอล์,					

	ไม่เคย/นานๆ ครั้ง (1)	1 ครั้ง/เดือน (2)	1 ครั้ง/สัปดาห์ (3)	มากกว่า 1 ครั้ง/สัปดาห์ (4)	ทุกวัน (5)
acetone, ฯลฯ)					
21.6 น้ำยาทาเล็บ/น้ำยาล้างเล็บ					
21.7 สเปรย์ฆ่าแมลง					
21.8 ปากกาเขียนไวท์บอร์ด					
21.9 ยาขัดรองเท้า					
21.10 ยาขัดเงารถ					
21.11 น้ำยาทำความสะอาดพรม					
21.12 ก้อนดับกลิ่นในห้อง/ห้องน้ำ					
21.13 น้ำยาทำความสะอาด/น้ำยาฆ่าเชื้อโรค					
21.14 เทียนไข					
21.15 ธูป/เครื่องหอมหรือกำยาน					
21.16 สเปรย์น้ำหอม					
21.17 อื่นๆ					

22. คุณสูบบุหรี่ใช่หรือไม่?

ใช่ 1 ☐ ไม่ใช่ 2 ☐

ส่วนที่ 4: ข้อมูลเกี่ยวกับสุขภาพ

23. คุณมีโรคประจำตัวที่เกี่ยวข้องกับระบบทางเดินหายใจใช่หรือไม่?

ใช่ 1 ☐ ไม่ใช่ 2 ☐

ถ้าไม่, ให้ไปที่คำถาม 25

24. คุณมีประจำตัวที่เกี่ยวข้องกับระบบทางเดินหายใจคืออะไร?

24.1 โรคหอบหืด ☐

24.2 โรคไซนัส ☐

24.3 โรคภูมิแพ้ ☐

24.4 อื่นๆ (โปรดแสดง).. ☐

25. คุณเคยมีอาการป่วยที่คาดว่ามีสาเหตุมาจากอากาศภายในบ้านใช่หรือไม่?

ใช่ 1 ☐ ไม่ใช่ 2 ☐

ถ้าใช่, โปรดระบุ

25.1 กลุ่มอาการทางตา เช่น ระคายเคืองตา แสบตา คันตา ตาแดง มีน้ำตาไหล ☐

25.2 กลุ่มอาการทางจมูก เช่น ไอ จาม คัดจมูก แสบจมูก ☐

25.3 กลุ่มอาการที่เกี่ยวข้องกับการติดเชื้อของระบบทางเดินหายใจ เช่น เจ็บคอ คอแดง หายใจถี่ แน่นหน้าอก ☐

25.4 กลุ่มอาการปวดศีรษะ เช่น ปวดศีรษะบริเวณหน้าผาก มึนงง ง่วงนอน เซื่องซึม อ่อนเพลีย วิงเวียนศีรษะ คลื่นไส้ อาเจียน ☐

25.5 กลุ่มอาการทางผิวหนัง เช่น ผิวหนังแห้ง ผิวหนังเป็นผื่นคันหรือแพ้ง่าย ☐

25.6 อื่นๆ (โปรดแสดง).. ☐

APPENDIX B: Information from questionnaires

Part 1: General Information

1. Age of people who filled the questionnaires was ranged between 27-70 years.

2. Gender of people who filled the questionnaires: Male 38.8% and female 61.2%.

3. The education of people who filled the questionnaires:

Elementary school: 52.94%　Junior high school: 5.88%

Senior high school: 11.76%　Bachelor degree: 29.41%

4.The occupation of people who filled the questionnaires:

Trader: 53.33%　Officer: 20%

Housekeeper: 13.33%　Teacher: 6.66%　Government officer: 6.66%

Part 2: House Information

5. The selected houses had 1 - 80 years old.

6. The selected houses were far from the main road in 50 - 500 meters.

7. The factory or firm nearby the community:

S community: -　P community: Cement factory (CPAC)

B community: Tobacco factory　J community: -

C community: Railroad

8. The type of ground materials in the house:

Tile: 54.44%　Board: 20.45%　Cement: 14.77%

Carpet: 4.55%　Polished stone: 3.41%　Others: 2.27%

9. Renovation of the house within 12 months: Yes 38.89%　No 61.11%

10. Having internal-painted houses within 12 months: Yes 38.89% No 61.11%

11. –

12. Having external-painted houses within 12 months: Yes 16.67% No 83.33%

13. –

14. Using or having air conditioner in the house: Yes 44.44% No 55.56%

15. People who had air conditioner mostly turn on it during the night time (88.89%), while they open it sometime that weather was hot (11.11%).

16. The air ventilation inside the house: Open window and door 89.47% Open window or door 10.52%.

17. Using candle or incense inside the house:

Never/rarely: 38.84%
Once a week: 27.78%
Everyday: 33.33%

18. Using aroma oil inside the house:

Never/rarely: 83.33%
Once a week: 16.67%

19. The type of fuel for cooking:

Natural gas: 68.42%
Electricity: 26.32%
Charcoal: 5.26%

20. Using hood or fan in order to remove the air during cooking: Yes 22.22% No 77.78%

Part 3: Behavior Information

21. The usage of household products that might release air pollutants:

21.1 The average frequecy of using household products (1 for useless to 5 using everyday

Glue/adhesive:1.2
Detergent: 1.8
Lacquer:1.1

Solvent:1.0
Nail Polish: 1.2
Insecticide: 1.5

White board pen: 1.8
Shoe wax: 1.3
Car Wax: 1.1

Carpet clean solution: 1.2 Fragrance: 2.2 Candle: 1.7

Incense: 2.1 Perfume: 1.9 Paint: 1.1

21.2 The percentage of using household products of each community (100% means use all products in every day)

S community: 30.31% P community: 28.75%

B community: 27.92% J community: 32.9%

C community: 32% (J > C > S > P > S)

22. Smoking inside the house: Yes 33.33% No 66.67%

Part 4: Health Information

23. Having disease related to respiratory tract: Yes 22.22% No 77.78%

24. Type of disease related to respiratory tract:

Asthma: 9.09% Sinus: 27.27% Allergic: 63.63%

25. Believe that you have disease from the air in your own house: Yes 50% No 50%

Eye: eye irritate, eye sting, eye itch, red eye, eye tear: 16.28%

Nose: cough, sneeze, nose sting, stuffed nose: 18.60%

Respiratory tract: sore throat, red throat, frequent breath, dense breast: 16.28%

Head: headache, giddy, sleepy, tired, queasy, dizzy: 16.28%

Skin: rash, dry, irritating: 13.95%

etc. (please identify): 2.33%

Additional Information related to family member

1. Age

1-2 ys: 3.92%   2-16 ys: 3.92%   16-30 ys: 11.76%

Over 30 ys: 80.39%

2. Weight

Below 40 kg: 5.88%   40-50 kg: 18.97%   50-60 kg: 23.53%

60-70 kg: 23.53%   70-80 kg: 9.8%   80-90 kg: 1.96%

Over 90 kg: 13.73%

3. How many hours that people spend in their house?

6-11.9 hrs: 42.3%   12-17.9 hrs: 13.46%   18-24 hrs: 44.23%

4. How often that people visit doctors or checking their health?

Once a month: 9.8%   Once/ 3 months: 21.57%   Once/ 6 months: 7.84%

Once a year: 45.09%   Once/ more than a year: 1.96%   Never: 13.73%

5. What kind of disease do they have?

High blood pressure: 38.71%   Diabetes: 19.36%   Allergy or asthma: 16.13%

Paralysis: 6.45%   Thyroid: 6.45%   Headache: 6.45%

Heart disease: 3.22%   Lung disease: 3.22%

APPENDIX C: Quality control techniques of carbonyl compounds and BTEX

C.1 Quality control techniques of carbonyl compounds

C.1.1 Standard curves of carbonyl compounds

Table C.1 Peak areas of each carbonyl compounds for standard curves for dry season

Compound	Peak Area					
	0.005 ppm	0.010 ppm	0.050 ppm	0.100 ppm	0.500 ppm	1.00 ppm
Formaldehyde	6412	10700	44754	107203	520826	1016786
Acetaldehyde	4516	7809	32843	79994	388746	760504
Acetone	7863	6158	24576	61542	293808	578932
Propionaldehyde	-	6098	24272	60642	293642	574777
Crotonaldehyde	-	3021	21963	54644	269742	519384
Butyraldehyde	2661	4605	19253	48296	236699	462407
Benzaldehyde	3747	3035	14437	37252	185718	349848
Isovaleraldehyde	-	3350	16875	42440	206556	401384
Valeraldehyde	1295	3587	15918	39301	192332	374333
o-Tolualdehyde	1926	2979	12755	30175	155090	293555
m-,p-Tolualdehyde	-	5572	23276	57186	288972	543849
Hexanaldehyde	1739	3248	13468	33033	162320	315613
2,5-Dimethylbenzaldehyde	595	2224	10134	25393	127755	241062

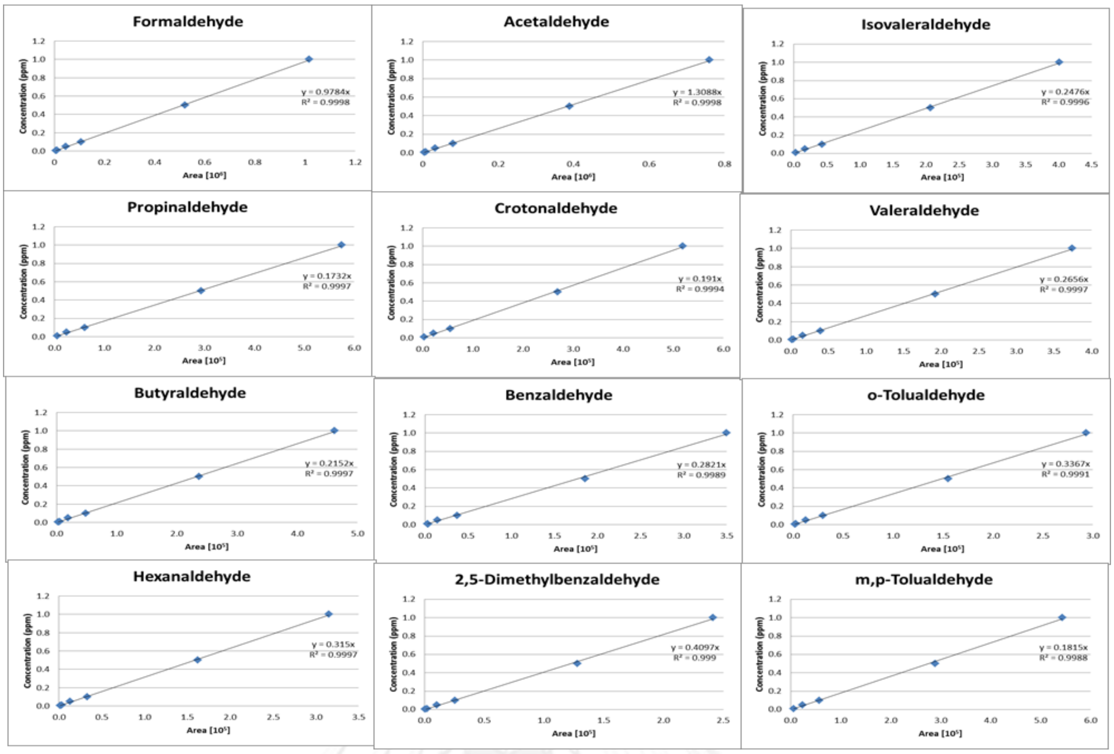
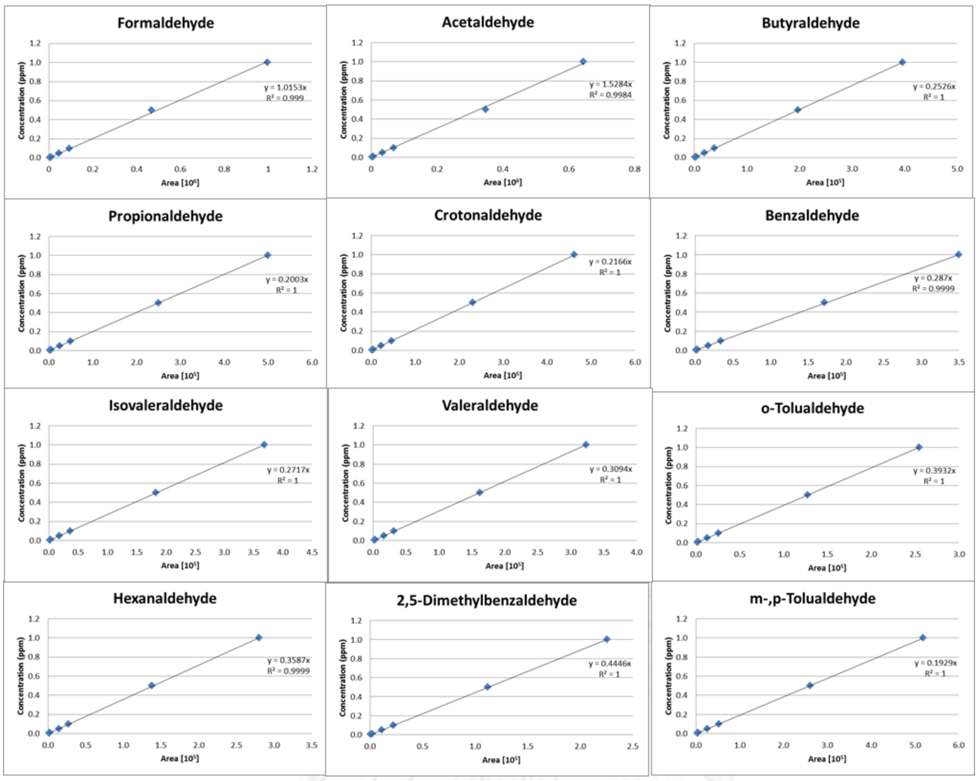


Figure C.1 Standard curve of 13 carbonyl compounds for dry season

Table C.2 Peak areas of each carbonyls for conduction of standard curves for wet season

Compound	Peak Area					
	0.005 ppm	0.010 ppm	0.050 ppm	0.100 ppm	0.500 ppm	1.00 ppm
Formaldehyde	4582	9430	45751	92552	467712	997247
Acetaldehyde	2675	6593	33879	68565	347486	642887
Acetone	2586	5241	25730	51398	259371	520068
Propionaldehyde	2340	5141	24521	48938	249703	499239
Crotonaldehyde	1987	4838	23120	46022	231274	461608
Butyraldehyde	1915	3909	19382	38564	197244	396273
Benzaldehyde	1467	3022	17380	34073	171403	349937
Isovaleraldehyde	1662	3355	18057	36449	182999	368613
Valeraldehyde	1708	3249	16160	31766	161643	323299
o-Tolualdehyde	1349	2528	12663	25364	127075	254385
m-,p-Tolualdehyde	2620	5253	25292	51827	260684	517586
Hexanaldehyde	1256	2398	14114	27270	137640	279730
2,5-Dimethylbenzaldehyde	532	2111	11002	22193	111632	225387



Formaldehyde

Acetaldehyde

Butyraldehyde

Propionaldehyde

Crotonaldehyde

Benzaldehyde

Isovaleraldehyde

Valeraldehyde

o-Tolualdehyde

Hexanaldehyde

2,5-Dimethylbenzaldehyde

m-,p-Tolualdehyde

Figure C.2 Standard curves of 13 carbonyl compounds for wet season

C.1.2 % Recovery of carbonyl compounds

Table C.3 % Recovery of 13 carbonyl compounds for dry and wet seasons

Compound	Blank	Recovery	Recovery-Blank	Standard	% Recovery
Formaldehyde	0.023	0.069	0.046	0.050	92.000
Acetaldehyde	0.012	0.056	0.044	0.050	87.556
Propionaldehyde	0.003	0.044	0.041	0.050	82.667
Crotonaldehyde	0.016	0.057	0.041	0.050	81.333
Butyraldehyde	0.009	0.041	0.032	0.050	63.778
Benzaldehyde	0.003	0.047	0.044	0.050	88.889
Isovaleraldehyde	0.004	0.045	0.042	0.050	83.222
Valeraldehyde	0.000	0.040	0.040	0.050	80.222
o-Tolualdehyde	0.000	0.043	0.043	0.050	85.778
m-,p-Tolualdehyde	0.000	0.045	0.045	0.050	90.667
Hexanaldehyde	0.000	0.042	0.042	0.050	84.889
2,5-Dimethylbenzaldehyde	0.000	0.044	0.044	0.050	87.111

C.1.3 % RSD, IDL and IQL of carbonyl compounds

Table C.4 % RSD, IDL, and IQL of carbonyl compounds for dry season

Times	Compound (injection of mix standard TO-11A 0.1 ppm)											
	Form	Aceta	Prop	Crot	Buty	Benz	Iso	Val	o-To	mpTo	Hex	Dim
Std 0.05 /1	0.106	0.106	0.107	0.106	0.106	0.103	0.105	0.106	0.106	0.106	0.106	0.106
Std 0.05/2	0.106	0.106	0.106	0.106	0.106	0.104	0.107	0.109	0.106	0.107	0.106	0.107
Std 0.05/3	0.106	0.106	0.106	0.106	0.106	0.106	0.106	0.106	0.105	0.105	0.104	0.107
Std 0.05/4	0.106	0.106	0.106	0.107	0.107	0.105	0.106	0.106	0.107	0.105	0.105	0.106
Std 0.05/5	0.107	0.107	0.107	0.106	0.105	0.105	0.105	0.107	0.108	0.105	0.105	0.103
Std 0.05/6	0.107	0.107	0.107	0.107	0.106	0.105	0.107	0.107	0.106	0.106	0.106	0.106
Std 0.05/7	0.107	0.107	0.107	0.106	0.107	0.105	0.106	0.106	0.107	0.106	0.106	0.105
Std 0.05/8	0.107	0.106	0.106	0.106	0.106	0.107	0.107	0.107	0.105	0.106	0.105	0.106
Std 0.05/9	0.107	0.106	0.107	0.106	0.106	0.106	0.107	0.107	0.107	0.106	0.107	0.106
Std 0.05/10	0.107	0.106	0.106	0.106	0.106	0.105	0.106	0.107	0.105	0.105	0.105	0.105
Ave	0.107	0.106	0.107	0.106	0.106	0.105	0.106	0.107	0.106	0.106	0.106	0.106
SD	0.001	0.000	0.001	0.000	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
% RSD	0.484	0.454	0.495	0.397	0.535	1.047	0.743	0.86	0.973	0.639	0.806	1.097
3 SD (IDL)	0.002	0.001	0.002	0.001	0.002	0.003	0.002	0.003	0.003	0.002	0.003	0.003
10 SD (IQL)*	0.005	0.005	0.005	0.004	0.006	0.011	0.008	0.009	0.010	0.007	0.008	0.012

*IQL is used as ND

Table C.5 % RSD, IDL, and IQL of carbonyl compounds for wet season

Times	Compound (injection of mix standard TO-11A 0.1 ppm)											
	Form	Aceta	Prop	Crot	Buty	Benz	Iso	Val	o-To	mpTo	Hex	Dim
Std 0.05 /1	0.048	0.048	0.05	0.045	0.049	0.046	0.047	0.049	0.045	0.048	0.05	0.044
Std 0.05/2	0.048	0.048	0.05	0.049	0.05	0.045	0.048	0.053	0.046	0.048	0.049	0.043
Std 0.05/3	0.049	0.048	0.05	0.045	0.049	0.045	0.048	0.052	0.044	0.049	0.045	0.045
Std 0.05/4	0.049	0.048	0.049	0.048	0.049	0.045	0.048	0.053	0.044	0.047	0.05	0.044
Std 0.05/5	0.049	0.048	0.05	0.047	0.05	0.046	0.048	0.051	0.043	0.049	0.05	0.048
Std 0.05/6	0.049	0.049	0.05	0.048	0.049	0.046	0.048	0.052	0.045	0.049	0.05	0.044
Std 0.05/7	0.049	0.048	0.049	0.047	0.049	0.045	0.047	0.05	0.043	0.048	0.049	0.047
Std 0.05/8	0.049	0.048	0.05	0.048	0.05	0.046	0.048	0.053	0.044	0.048	0.049	0.046
Std 0.05/9	0.049	0.048	0.05	0.048	0.05	0.046	0.049	0.053	0.047	0.051	0.051	0.048

Times	Compound (injection of mix standard TO-11A 0.1 ppm)											
	Form	Aceta	Prop	Crot	Buty	Benz	Iso	Val	o-To	mpTo	Hex	Dim
Std 0.05/10	0.049	0.048	0.05	0.049	0.049	0.045	0.047	0.05	0.046	0.049	0.047	0.048
Ave	0.049	0.048	0.050	0.047	0.049	0.046	0.048	0.052	0.045	0.049	0.049	0.046
SD	0.000	0.000	0.000	0.001	0.001	0.001	0.001	0.002	0.001	0.001	0.002	0.002
% RSD	0.864	0.657	0.847	3.017	1.045	1.158	1.323	2.918	2.992	2.212	3.600	4.259
3 SD (IDL)	0.001	0.001	0.001	0.004	0.002	0.002	0.002	0.005	0.004	0.003	0.005	0.006
10 SD (IQL)*	0.004	0.003	0.004	0.014	0.005	0.005	0.006	0.015	0.013	0.011	0.018	0.019

*IQL is used as ND

C.2 Quality control techniques of BTEX

C.2.1 Standard curves of BTEX

Table C.6 Peak area ratios of benzene, toluene, ethylbenzene, m-, p-xylene, and o-xylene at different concentration of mix standard BTEX divided by peak area of internal standard at 20,000 ng/mL during dry season

Concentration of Standard BTEX (ng/mL)	Peak Area of internal standard at 20,000 ng/mL	Peak Area Ratio				
		Benzene	Toluene	Ethylbenzene	m,p-Xylene	o-Xylene
125	20.5479	ND	0.067165	ND	0.108958	0.026994
250	20.1343	ND	0.076077	ND	0.144337	0.054431
500	20.8921	0.046746	0.129402	0.053074	0.257999	0.094725
1000	20.521	0.088793	0.194559	0.110979	0.473588	0.15222
2000	20.9732	0.207253	0.418391	0.209078	0.784186	0.293618
4000	20.4945	0.432972	0.74478	0.509703	1.559233	0.615702
8000	20.6713	0.884211	1.463367	1.151698	3.215627	1.238026

ND = Non-detectable Amount

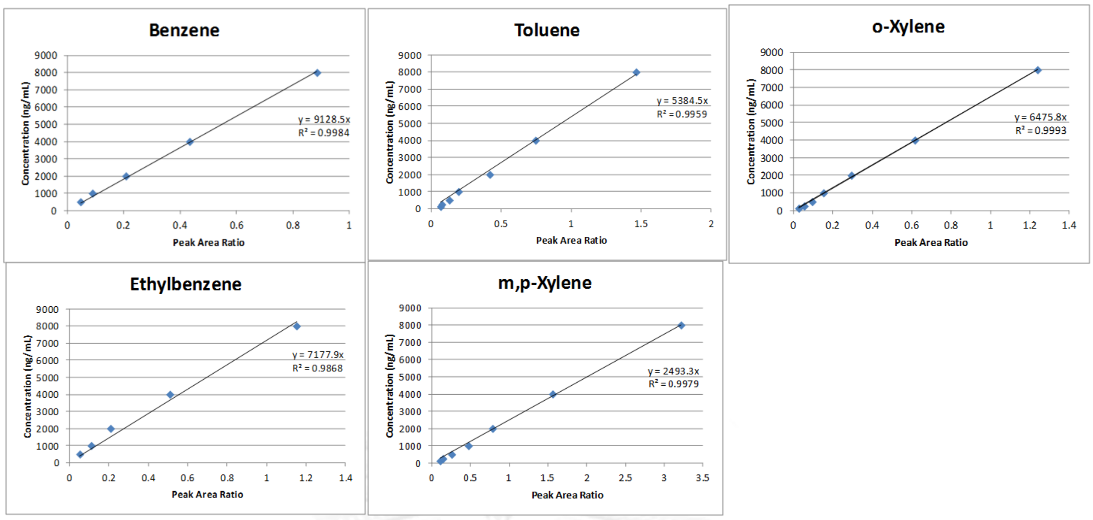


Figure C.3 Standard curves of BTEX for dry season

Table C.7 Peak area ratios of benzene, toluene, ethylbenzene, m-, p-xylene, and o-xylene at different concentration of mix standard BTEX divided by peak area of internal standard at 20,000 ng/mL during wet season

Concentration of Standard BTEX (ng/mL)	Peak Area of internal standard at 20,000 ng/mL	Peak Area Ratio				
		Benzene	Toluene	Ethylbenzene	m-,p-Xylene	o-Xylene
125	30.2076	0.009874	0.015942	0.009043	0.025907	0.016722
250	31.1112	0.013534	0.029999	0.017931	0.049392	0.029306
500	30.2497	0.031928	0.061684	0.040756	0.111526	0.056807
1000	30.6889	0.060408	0.099263	0.083283	0.201841	0.102256
2000	29.6837	0.124686	0.19892	0.196409	0.464929	0.226385
4000	30.4936	0.223277	0.453879	0.429474	0.876787	0.431143
8000	30.6985	0.379361	0.844038	0.805701	1.777764	0.928733

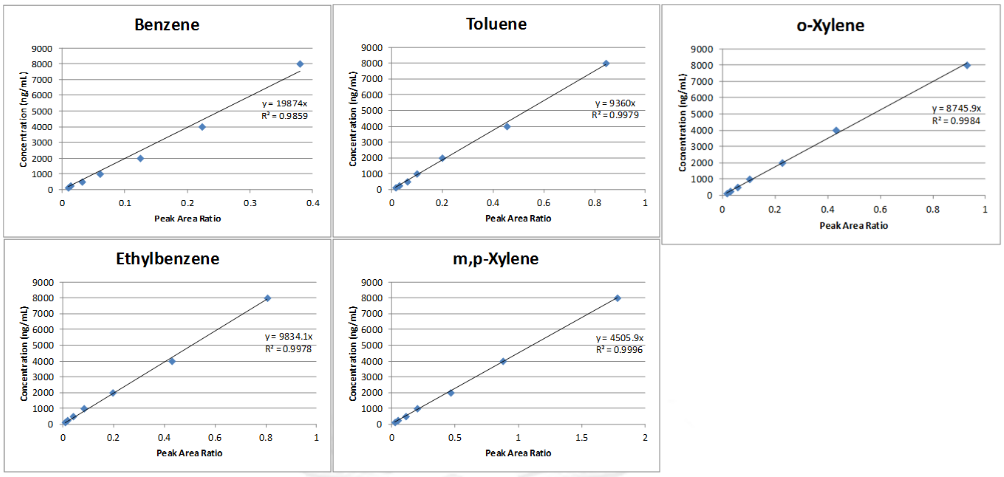


Figure C.4 Standard curves of BTEX for wet season

C.2.2 % Recovery of BTEX

Table C.8 Result of recovery test in five times extractions for dry and wet seasons

Compound	Concentration (ng/mL)						% Recovery
	1	2	3	4	5	Average	
Benzene	4577.851	3703.25	3123.517	3732.616	4034.076	3834.262	95.85655
Toluene	3963.918	3821.886	3783.333	3846.563	3892.73	3861.686	96.54215
Ethylbenzene	3855.76	3951.958	3907.268	4137.593	4260.608	4022.637	100.5659
m-,p-Xylene	3927.89	3839.42	3858.442	3761.143	3920.036	3861.386	96.53465
o-Xylene	4009.2	3701.522	3634.381	3809.687	3903.832	3811.725	95.29311

C.2.3 % RSD of BTEX

Table C.9 % RSD of BTEX for dry season

Times	Concentration (ng/mL)				
	Benzene	Toluene	Ethylbenzene	m-,p-Xylene	o-Xylene
1	7666.908	7697.213	7798.752	8080.07	7717.943
2	7922.972	7806.071	7575.965	7814.458	8313.315
3	6514.8	7357.445	8116.296	8102.41	7702.057
4	7589.353	7316.717	7755.405	7844.804	7303.174
5	7552.665	6853.413	7916.492	7914.886	7768.81
6	8094.98	7372.054	7926.153	8058.548	8008.13
7	7742.091	6875.92	8044.488	7993.108	8030.698

Times	Concentration (ng/mL)				
	Benzene	Toluene	Ethylbenzene	m-,p-Xylene	o-Xylene
8	8073.328	7064.416	8215.659	8256.256	8310.524
Average	7644.637	7292.906	7918.651	8008.068	7894.331
SD	501.7247	349.9057	207.5819	147.0066	340.926
% RSD	6.563094	4.797891	2.621431	1.835731	4.318618

Table C.10 % RSD of BTEX for wet season

Times	Concentration (ng/mL)				
	Benzene	Toluene	Ethylbenzene	m,p-Xylene	o-Xylene
1	7087.884	7662.889	7485.187	7969.744	7976.225
2	7643.876	7605.769	7641.964	7899.827	8112.877
3	7379.178	7601.146	7695.995	7963.33	8052.224
4	7296.547	7573.263	7663.8	8047.234	8112.457
5	7457.822	7682.927	7683.25	7888.753	7943.374
6	7857.605	7930.085	7815.22	8155.076	8219.221
Average	7453.818	7676.013	7664.236	7987.327	8069.396
SD	269.5904	131.0493	7987.327	99.98655	101.0443
% RSD	3.616809	1.707257	1.389691	1.251815	1.252192

C.2.4 LOD and LOQ of BTEX

Table C.11 Signal to noise ratios of each BTEX for dry season

Compound	The lowest concentration (ng/mL)	Height		Signal to noise ratio
		Signal	noise	
Benzene	9	0.1300	0.0410	3.1707
Toluene	34	0.0920	0.0290	3.1724
Ethylbenzene	42	0.0630	0.0200	3.1500
m,p-Xylene	60	0.0730	0.0240	3.0417
o-Xylene	42	0.0630	0.0210	3.0000

Table C.12 The peak areas of BTEX for LOD and LOQ calculation for dry season

Compound	The lowest concentration (ng/mL)	Peak Area			Average	δ	LOD	LOQ
		1	2	3				
Benzene	9	0.3927	0.5837	0.4356	0.4707	0.1002	5.7490	19.1632
Toluene	34	0.90237	0.9546	0.8603	0.9058	0.0473	5.3207	17.7358
Ethylbenzene	42	0.5066	0.4984	0.4940	0.4997	0.0064	1.6031	5.3436
m-,p-Xylene	60	2.6986	2.4823	2.7442	2.6417	0.0392	2.6701	8.9004
o-Xylene	42	1.0190	0.9100	0.8590	0.9294	0.0817	11.0799	36.9331

Table C.13 Signal to noise ratio of each BTEX for wet season

Compound	The lowest concentration (ng/mL)	Height		Signal to noise ratio
		Signal	noise	
Benzene	17	0.0670	0.0210	3.1905
Toluene	5	0.1200	0.0390	3.0769
Ethylbenzene	29	0.0670	0.0230	2.9130
m-,p-Xylene	15	0.0640	0.0220	2.9091
o-Xylene	125	0.0660	0.0210	3.1429

Table C.14 The peak areas of BTEX for LOD and LOQ calculation for wet season

Compound	The lowest concentration (ng/mL)	Peak Area			Average	δ	LOD	LOQ
		1	2	3				
Benzene	17	0.2002	0.2087	0.2361	0.2150	0.0188	4.4546	14.8485
Toluene	5	0.7655	0.7310	0.7330	0.7431	0.0194	0.3916	1.3052
Ethylbenzene	29	0.3456	0.3112	0.3815	0.3461	0.0351	8.8305	29.4350
m-,p-Xylene	15	1.2266	1.0744	1.0745	1.1252	0.0879	3.5141	11.7137
o-Xylene	125	0.7165	0.8245	0.7031	0.7481	0.0666	33.3748	111.2492

Appendix D: Concentration of carbonyl compounds and BTEX at five residential areas during dry and wet seasons

D.1 Concentration of carbonyl compounds at five residential areas during dry season

Table D.1 Concentration of carbonyl compounds at Saluk Hin community during dry season

Comp.	Community/House/Day											
	Indoor sampling									Outdoor sampling		
	SH1S	SH1T	SH1F	SH2S	SH2T	SH2F	SH3S	SH3T	SH3F	SH2S	SH2T	SH2F
Form	12.514	16.04	6.608	12.47	2.611	16.313	15.612	14.18	6.353	9.094	5.514	10.39
Aceta	6.566	8.453	2.138	3.910	1.254	5.854	7.721	8.239	3.211	4.035	2.979	5.830
Aceto	115.941	81.755	231.882	93.942	84.315	102.161	388.690	83.053	65.372	264.616	78.47	ND
Prop	1.029	0.896	0.926	0.759	0.242	1.237	2.081	1.337	0.511	0.853	0.409	1.780
Crot	5.468	0.287	6.940	2.289	0.253	0.321	3.116	0.389	1.237	2.671	1.376	0.046
Butyr	0.538	0.678	0.332	0.644	0.161	5.418	16.226	1.360	2.678	0.057	0.125	0.605
Benz	0.309	0.172	0.755	0.587	0.069	0.172	4.025	0.240	0.511	0.239	0.205	0.068
Iso	0.309	0.138	0.617	0.069	0.069	0.069	2.558	0.069	0.068	0.614	0.239	0.650
Val	0.069	0.103	0.240	0.173	0.173	0.103	0.546	0.171	0.408	0.068	0.171	0.171
oTol	0.480	ND	0.069	0.138	0.035	ND	0.034	0.103	0.034	0.068	0.034	0.616
mpTo	0.103	0.034	0.206	0.069	0.104	0.069	0.102	0.103	0.102	0.171	0.102	0.137
Hex	4.049	3.997	1.235	1.449	0.449	5.670	6.277	4.697	1.906	1.466	1.023	3.833
25Di	0.172	0.207	0.206	0.207	0.207	0.241	0.614	0.274	0.068	0.102	0.205	0.411

H1=house 1, H2=house2, H3=house 3, S=Sunday, T=Tuesday, F=Friday

ND=Non detected (use IQL of each compound reported in chapter 4)

Table D.2 Concentration of carbonyls at Lhung Wat-Pathum community during dry season

Comp.	Community/House/Day											
	Indoor sampling									Outdoor sampling		
	PH1S	PH1T	PH1F	PH2S	PH2T	PH2F	PH3S	PH3T	PH3F	PH2S	PH2T	PH2F
Form	6.102	3.525	5.519	7.577	6.637	9.291	11.401	8.847	5.351	4.122	2.917	2.100
Aceta	3.446	2.243	4.271	4.031	3.336	4.765	3.736	4.747	2.129	2.608	1.952	1.714
Aceto	ND	ND	48.731	3.454	ND	67.638	2.005	47.757	0.467	ND	0.193	54.995
Prop	0.515	0.240	0.550	1.871	0.548	0.923	0.410	0.886	0.376	0.410	0.272	0.238
Crot	0.114	0.286	0.286	0.081	0.731	0.319	3.121	0.352	0.114	1.924	0.216	0.454
Butyr	2.255	1.431	1.328	0.820	4.170	0.638	0.228	0.432	0.194	0.057	1.657	0.023
Benz	0.103	0.172	0.447	0.277	0.069	0.479	0.137	0.204	0.137	0.068	0.204	0.102
Iso	0.069	0.069	0.069	0.381	0.069	0.308	0.581	0.511	0.410	0.068	0.068	0.068
Val	0.069	0.069	0.172	0.104	0.171	0.034	0.103	0.170	0.068	0.171	0.170	0.170
oTol	0.034	0.034	0.240	0.035	0.308	0.821	11.173	0.068	ND	0.034	0.238	0.034

Comp.	Community/House/Day											
	Indoor sampling									Outdoor sampling		
	PH1S	PH1T	PH1F	PH2S	PH2T	PH2F	PH3S	PH3T	PH3F	PH2S	PH2T	PH2F
mpTo	0.034	0.103	0.103	0.104	0.103	0.103	0.034	0.102	0.102	0.102	0.102	0.102
Hex	1.374	0.687	1.992	1.213	0.171	2.155	1.503	2.692	1.093	0.957	0.647	0.817
25Di	2.404	0.652	0.309	0.208	0.685	0.068	0.308	0.102	0.205	0.615	0.204	0.204

H1=house 1, H2=house2, H3=house 3, S=Sunday, T=Tuesday, F=Friday

ND=Non detected (use IQL of each compound reported in chapter 4)

Table D.3 Concentration of carbonyls at Patthana Bon-Kai community during dry season

Comp.	Community/House/Day											
	Indoor sampling									Outdoor sampling		
	BH1S	BH1T	BH1F	BH2S	BH2T	BH2F	BH3S	BH3T	BH3F	BH2S	BH2T	BH2F
Form	10.606	8.310	7.404	25.239	38.727	33.126	7.023	8.690	7.652	5.761	4.876	3.851
Aceta	7.399	5.285	3.395	2.592	5.433	4.124	5.632	5.411	3.413	3.791	2.746	1.652
Aceto	54.864	52.312	74.009	ND	54.442	53.445	68.095	53.984	64.007	49.089	50.265	68.445
Prop	0.962	0.651	0.410	0.550	1.132	0.864	1.000	0.791	0.481	0.653	0.479	0.342
Crot	3.448	3.127	3.019	0.906	1.590	2.810	0.943	1.662	0.115	0.596	1.276	0.114
Butyr	0.470	0.331	0.057	0.298	0.538	0.403	1.678	0.917	0.573	0.057	0.057	0.057
Benz	1.134	0.959	0.889	0.722	1.167	1.244	0.414	0.791	0.412	0.344	0.376	0.068
Iso	0.069	0.068	0.068	0.069	0.069	0.069	0.069	0.069	0.069	0.069	0.068	0.068
Val	0.137	0.137	0.103	0.241	0.309	0.311	0.310	0.206	0.137	0.103	0.068	0.171
oTol	0.584	0.034	ND	0.034	0.377	0.346	0.034	0.172	0.034	0.137	0.239	0.034
mpTo	0.172	0.103	0.103	0.103	0.103	0.104	0.103	0.069	0.103	0.034	0.103	0.103
Hex	2.337	1.575	0.889	0.998	1.681	2.004	2.000	1.651	0.997	1.168	0.923	0.547
25Di	0.206	1.438	0.205	0.138	0.309	3.179	0.207	0.929	0.206	0.206	0.205	0.205

H1=house 1, H2=house2, H3=house 3, S=Sunday, T=Tuesday, F=Friday

ND=Non detected (use IQL of each compound reported in chapter 4)

Table D.4 Concentration of carbonyls at Soi Pra-Chen community during dry season

Com.	Community/House/Day											
	Indoor sampling									Outdoor sampling		
	JH1S	JH1T	JH1F	JH2S	JH2T	JH2F	JH3S	JH3T	JH3F	JH2S	JH2T	JH2F
Form	11.201	10.33	14.583	6.637	9.846	8.891	4.057	5.238	4.545	3.620	4.660	4.099
Aceta	10.158	6.006	8.234	2.886	4.527	4.824	1.943	2.567	2.151	1.827	3.103	1.964
Aceto	93.505	87.34	223.80	74.92	90.39	227.19	63.67	80.89	208.84	61.38	83.076	180.01
Prop	0.757	0.754	1.062	0.416	0.655	0.687	0.310	0.449	0.483	0.343	0.584	0.548
Crot	0.390	1.519	0.765	ND	0.839	0.011	ND	0.495	0.011	1.622	0.527	2.409
Butyr	1.983	1.051	2.798	1.477	1.057	1.638	1.264	0.610	1.645	1.016	0.710	0.228
Benz	0.275	0.206	0.206	0.173	0.276	0.275	0.069	0.138	0.069	0.137	0.206	0.171

Com.	Community/House/Day											
	Indoor sampling									Outdoor sampling		
	JH1S	JH1T	JH1F	JH2S	JH2T	JH2F	JH3S	JH3T	JH3F	JH2S	JH2T	JH2F
Iso	0.034	0.069	0.069	0.069	0.069	0.069	0.069	0.069	0.069	0.069	0.069	0.069
Val	4.368	0.103	0.034	0.381	0.379	0.619	0.310	0.173	0.276	0.308	0.378	0.274
oTol	0.550	0.480	0.480	0.762	1.034	0.962	ND	ND	0.035	ND	0.172	ND
mpTo	1.341	0.103	0.103	0.104	0.103	0.103	0.103	0.104	0.104	0.103	2.027	0.103
Hex	0.172	2.364	0.548	2.112	2.275	2.372	1.207	1.485	1.622	1.028	0.172	1.815
25Di	0.206	0.206	0.206	0.069	0.207	0.206	0.138	0.207	0.207	0.206	0.206	0.206

H1=house 1, H2=house2, H3=house 3, S=Sunday, T=Tuesday, F=Friday

ND=Non detected (use IQL of each compound reported in chapter 4)

Table D.5 Concentration of carbonyls at Chaw Chu-Cheep community during dry season

Comp.	Community/House/Day											
	Indoor sampling									Outdoor sampling		
	CH1S	CH1T	CH1F	CH2S	CH2T	CH2F	CH3S	CH3T	CH3F	CH2S	CH2T	CH2F
Form	20.340	15.221	18.881	8.110	9.587	9.791	15.384	15.899	1.404	6.401	7.314	7.754
Aceta	8.488	5.009	6.972	7.203	6.902	4.001	9.242	9.551	0.219	5.258	5.454	7.262
Aceto	206.65	238.63	218.77	183.05	231.75	177.52	201.85	246.806	238.006	187.711	225.48	192.13
Prop	1.030	0.034	1.166	0.034	0.891	1.169	1.378	1.343	0.035	0.617	0.924	1.203
Crot	0.011	0.217	0.457	0.115	0.697	0.011	0.115	3.765	0.115	0.149	0.148	0.733
Butyr	0.194	0.091	0.194	0.057	0.057	0.195	0.505	0.505	0.058	1.223	0.742	1.844
Benz	0.069	0.171	0.069	0.069	0.069	0.069	0.241	0.482	0.069	0.137	0.240	0.481
Iso	0.069	0.068	0.069	0.069	0.069	0.069	0.069	0.069	0.069	0.069	0.068	0.069
Val	0.515	0.171	0.171	0.379	0.240	0.482	0.241	0.207	0.173	0.137	0.137	0.481
oTol	0.034	0.034	ND	0.034	ND	ND	0.172	0.103	0.035	0.034	0.103	ND
mpTo	0.103	0.103	0.171	0.310	0.720	0.378	0.172	0.241	0.104	0.103	0.103	0.103
Hex	2.368	1.403	1.920	3.854	2.400	3.715	2.308	2.996	0.173	1.680	1.985	0.172
25Di	0.378	2.328	0.103	1.308	0.960	0.963	0.172	2.480	0.207	0.857	0.856	1.100

H1=house 1, H2=house2, H3=house 3, S=Sunday, T=Tuesday, F=Friday

ND=Non detected (use IQL of each compound reported in chapter 4)

D.2 Concentration of carbonyl compounds at five residential areas during wet season

Table D.6 Concentration of carbonyls at Saluk Hin community during wet season

Comp.	Community/House/Day											
	Indoor sampling									Outdoor sampling		
	SH1S	SH1T	SH1F	SH2S	SH2T	SH2F	SH3S	SH3T	SH3F	SH2S	SH2T	SH2F
Form	14.570	20.799	16.412	4.379	5.943	5.003	9.449	9.888	10.430	3.481	3.891	4.500
Aceta	3.452	5.632	4.483	2.352	3.169	3.302	6.070	6.214	5.808	0.991	1.024	2.189
Aceto	60.983	97.803	ND	72.527	92.944	ND	88.548	86.313	ND	88.092	85.219	ND
Prop	0.934	0.657	0.967	0.426	0.725	0.827	1.372	1.412	0.883	0.482	0.344	0.481
Crot	0.577	0.542	1.612	ND	ND	0.230	ND	ND	ND	ND	ND	ND
Butyr	ND	0.065	ND	ND	ND	ND	0.284	0.386	ND	ND	ND	ND
Benz	0.138	0.450	0.864	0.564	0.242	0.310	0.450	0.413	0.447	0.069	0.172	0.275
Iso	0.000	0.000	0.104	0.518	ND	ND	0.611	0.781	0.287	0.069	ND	ND
Val	2.387	3.356	4.353	0.933	2.417	0.758	2.860	2.939	1.652	0.826	2.167	1.751
oTol	ND	0.069	0.069	0.242	0.483	0.724	0.196	0.425	0.424	0.207	0.138	0.069
mpTo	0.104	0.138	0.104	0.035	0.069	0.034	0.086	0.172	0.103	ND	ND	ND
Hex	0.035	0.069	0.138	1.485	1.796	2.000	1.419	1.607	1.078	ND	ND	ND
25Di	0.138	0.104	0.104	0.104	ND	ND	0.346	0.379	0.206	ND	ND	ND

H1=house 1, H2=house2, H3=house 3, S=Sunday, T=Tuesday, F=Friday

ND=Non detected (use IQL of each compound reported in chapter 4)

Table D.7 Concentration of carbonyls at Lhung Wat-Pathum community during wet season

Comp.	Community/House/Day											
	Indoor sampling									Outdoor sampling		
	PH1S	PH1T	PH1F	PH2S	PH2T	PH2F	PH3S	PH3T	PH3F	PH2S	PH2T	PH2F
Form	5.078	4.848	5.467	5.404	4.004	4.763	4.302	4.617	5.804	6.287	4.297	3.717
Aceta	3.202	3.487	3.139	2.091	3.096	2.406	1.333	1.783	1.063	1.529	2.946	1.986
Aceto	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Prop	0.587	0.554	0.657	0.550	0.379	0.345	0.138	0.448	0.207	0.444	0.240	0.309
Crot	0.679	0.334	0.473	ND	ND	ND	ND	0.161	ND	0.228	0.504	0.126
Butyr	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Benz	0.035	0.069	0.173	0.998	0.310	0.241	18.223	1.412	0.967	0.307	0.309	0.103
Iso	0.069	0.138	0.035	0.103	0.138	0.069	0.000	0.172	0.656	0.478	0.137	0.000
Val	1.795	0.900	1.072	ND	0.552	0.276	1.478	1.239	0.069	3.654	1.030	0.241
oTol	0.345	0.415	0.415	ND	0.207	0.103	0.722	0.482	0.311	0.273	0.069	0.069
mpTo	0.000	0.692	0.380	0.034	0.034	0.310	0.000	0.000	0.000	0.273	0.412	0.309
Hex	ND	ND	ND	ND	ND	ND	1.032	ND	ND	ND	ND	ND
25Di	ND	ND	ND	ND	0.103	ND	ND	ND	ND	ND	ND	ND

H1=house 1, H2=house2, H3=house 3, S=Sunday, T=Tuesday, F=Friday

ND=Non detected (use IQL of each compound reported in chapter 4)

Table D.8 Concentration of carbonyls at Patthana Bon-Kai community during wet season

Comp.	Community/House/Day											
	Indoor sampling									Outdoor sampling		
	BH1S	BH1T	BH1F	BH2S	BH2T	BH2F	BH3S	BH3T	BH3F	BH2S	BH2T	BH2F
Form	ND	17.938	25.226	29.659	21.382	33.781	2.483	5.233	12.408	3.599	4.693	8.707
Aceta	ND	4.995	11.021	9.270	5.904	10.747	0.543	2.882	8.399	0.232	2.457	5.681
Aceto	ND	14.008	16.665	12.976	4.111	7.649	ND	ND	6.430	ND	3.101	3.996
Prop	ND	1.089	1.804	0.859	0.962	1.993	0.413	0.619	1.482	0.377	0.582	1.097
Crot	ND	1.384	4.277	0.298	0.951	3.012	ND	1.021	1.608	ND	ND	ND
Butyr	ND	ND	0.269	0.374	0.202	0.649	ND	1.579	0.616	ND	ND	0.133
Benz	ND	0.476	2.110	1.821	0.962	1.546	0.310	2.340	1.585	0.137	0.171	0.822
Iso	ND	0.204	0.204	0.481	0.447	0.481	0.654	1.479	0.103	0.651	0.582	ND
Val	ND	0.749	1.668	1.615	0.653	1.271	0.482	0.688	1.654	0.411	0.445	2.364
oTol	ND	0.170	0.919	0.137	0.378	1.718	ND	0.138	0.930	0.822	0.103	1.850
mpTo	ND	0.579	0.545	0.653	0.756	0.619	0.138	0.138	0.551	0.137	0.137	0.137
Hex	ND	0.204	ND	0.069	0.103	0.069	0.034	0.172	0.241	0.034	ND	0.034
25Dim	ND	0.136	0.272	0.859	0.275	0.137	ND	ND	ND	ND	ND	ND

H1=house 1, H2=house2, H3=house 3, S=Sunday, T=Tuesday, F=Friday

ND=Non detected (use IQL of each compound reported in chapter 4)

Table D.9 Concentration of carbonyl compounds at Soi Pra-Chen community during wet season

Comp.	Community/House/Day											
	Indoor sampling									Outdoor sampling		
	JH1S	JH1T	JH1F	JH2S	JH2T	JH2F	JH3S	JH3T	JH3F	JH2S	JH2T	JH2F
Form	14.361	13.058	14.572	16.313	15.972	10.032	4.764	5.950	3.187	9.125	9.095	13.315
Aceta	7.291	6.622	6.045	6.537	4.786	3.507	3.166	2.412	1.272	4.279	3.677	1.234
Aceto	21.881	ND	ND	18.788	ND	ND	14.163	ND	ND	4.685	ND	ND
Prop	1.501	0.991	1.539	1.281	1.104	0.586	0.690	0.968	0.311	1.132	0.723	0.379
Crot	0.773	1.492	4.126	1.616	0.851	0.057	0.402	ND	ND	1.086	0.815	0.920
Butyr	0.099	0.030	0.441	0.169	ND	ND	0.031	ND	ND	ND	ND	ND
Benz	2.592	0.786	0.513	2.528	0.897	0.414	0.069	0.069	0.104	0.994	0.344	0.276
Iso	1.057	ND	0.103	1.316	0.414	ND	ND	ND	ND	0.274	0.275	0.241
Val	4.024	4.101	6.839	1.385	0.759	0.310	0.621	1.210	0.450	0.789	1.102	0.517
oTol	0.989	1.469	0.171	3.186	1.897	0.207	ND	0.035	0.069	0.069	0.069	0.172
mpTo	1.535	0.547	0.342	1.039	1.345	9.753	9.692	4.702	4.497	3.532	1.240	2.621
Hex	0.034	0.068	0.479	ND	ND	ND	ND	ND	ND	ND	ND	ND
25Di	0.477	0.376	0.684	0.623	0.655	0.448	ND	ND	ND	ND	ND	1.035

H1=house 1, H2=house2, H3=house 3, S=Sunday, T=Tuesday, F=Friday

ND=Non detected (use IQL of each compound reported in chapter 4)

Table D.10 Concentration of carbonyls at Chaw Chu-Cheep community during wet season

Comp.	Community/House/Day											
	Indoor sampling									Outdoor sampling		
	CH1S	CH1T	CH1F	CH2S	CH2T	CH2F	CH3S	CH3T	CH3F	CH2S	CH2T	CH2F
Form	6.137	21.823	19.511	22.889	26.643	30.170	26.696	22.784	19.515	8.145	7.617	13.749
Aceta	2.889	7.741	6.244	4.914	4.817	4.991	6.468	6.296	4.930	2.981	3.113	3.154
Aceto	ND	ND	141.971	ND	ND	166.366	ND	ND	162.351	ND	ND	130.154
Prop	1.533	1.359	1.059	1.652	1.413	1.069	0.994	1.507	1.440	0.687	0.960	1.100
Crot	ND	3.251	0.672	0.092	2.677	1.712	0.982	1.975	0.846	ND	0.915	0.367
Butyr	0.098	0.200	0.030	0.168	0.375	0.065	0.373	0.099	0.030	ND	ND	ND
Benz	0.102	1.122	0.820	3.166	2.998	2.344	0.514	1.405	0.617	0.584	1.269	1.134
Iso	0.136	ND	ND	0.172	0.172	ND	0.069	0.582	ND	ND	0.343	0.344
Val	0.102	0.544	0.410	1.962	0.862	0.448	0.857	3.220	1.303	0.653	0.926	2.234
oTol	0.273	0.816	0.376	1.480	1.620	1.276	0.103	1.233	0.171	0.172	0.309	0.722
mpTo	0.034	0.102	0.444	0.172	1.310	0.276	0.343	0.685	0.377	0.172	0.652	0.172
Hex	ND	0.306	0.034	0.688	ND	ND	0.034	0.034	ND	ND	ND	ND
25Di	0.170	2.447	0.649	1.549	1.620	1.345	0.377	0.308	ND	1.546	0.686	1.100

H1=house 1, H2=house2, H3=house 3, S=Sunday, T=Tuesday, F=Friday

ND=Non detected (use IQL of each compound reported in chapter 4)

D.3 Concentration of BTEX at five residential areas during dry season

Table D.11 Concentration of BTEX at Saluk Hin community during dry season

Comp.	Community/House/Day											
	Indoor sampling									Outdoor sampling		
	SH1S	SH1T	SH1F	SH2S	SH2T	SH2F	SH3S	SH3T	SH3F	SH2S	SH2T	SH2F
B	19.574	31.282	19.629	0.266	0.266	0.266	57.749	25.938	11.092	2.220	0.266	0.266
T	41.241	50.636	39.624	22.395	48.693	12.630	257.319	65.130	51.238	31.177	40.734	33.217
E	4.512	0.074	7.357	6.136	8.875	0.074	0.074	12.220	9.205	7.417	6.987	7.951
MP	13.474	0.124	15.554	16.880	17.839	0.124	0.124	23.175	21.556	17.716	15.913	18.161
O	9.948	0.513	3.823	5.494	12.763	0.513	0.513	0.513	4.951	10.153	5.466	7.918

H1=house 1, H2=house2, H3=house 3, S=Sunday, T=Tuesday, F=Friday

Table D.12 Concentration of BTEX at Lhung Wat-Pathum community during dry season

Comp.	Community/House/Day											
	Indoor sampling									Outdoor sampling		
	PH1S	PH1T	PH1F	PH2S	PH2T	PH2F	PH3S	PH3T	PH3F	PH2S	PH2T	PH2F
B	24.908	0.266	16.707	0.266	0.266	48.571	0.266	0.266	54.361	0.266	0.266	0.266
T	34.461	127.179	29.685	35.369	25.411	45.998	26.700	15.258	22.721	24.654	23.540	29.413
E	7.028	2.386	4.627	7.012	5.221	6.857	0.074	3.919	0.074	4.583	4.694	5.621
MP	16.954	6.576	10.126	17.129	8.073	14.738	0.124	9.972	0.124	10.192	7.622	12.134
O	3.224	2.821	4.049	8.243	5.916	4.187	0.513	0.513	0.513	4.673	3.765	4.133

H1=house 1, H2=house2, H3=house 3, S=Sunday, T=Tuesday, F=Friday

Table D.13 Concentration of BTEX at Patthana Bon-Kai community during dry season

Comp.	Community/House/Day											
	Indoor sampling									Outdoor sampling		
	BH1S	BH1T	BH1F	BH2S	BH2T	BH2F	BH3S	BH3T	BH3F	BH2S	BH2T	BH2F
B	36.112	5.413	0.266	0.266	0.266	0.266	0.266	1.383	0.266	0.266	18.710	20.859
T	20.930	32.903	16.299	33.898	51.688	24.763	25.252	33.794	17.038	23.822	63.020	19.430
E	0.074	0.074	4.287	0.074	12.302	1.741	3.523	4.417	3.657	5.976	10.079	3.609
MP	0.124	0.124	6.953	0.124	20.349	4.420	7.321	10.229	7.539	9.178	16.192	6.975
O	0.513	0.513	4.199	0.513	9.594	0.513	0.513	0.513	0.513	6.306	11.712	3.892

H1=house 1, H2=house2, H3=house 3, S=Sunday, T=Tuesday, F=Friday

Table D.14 Concentration of BTEX at Soi Pra-Chen community during dry season

Comp.	Community/House/Day											
	Indoor sampling									Outdoor sampling		
	JH1S	JH1T	JH1F	JH2S	JH2T	JH2F	JH3S	JH3T	JH3F	JH2S	JH2T	JH2F
B	8.151	0.266	0.266	0.266	0.266	0.266	0.266	0.266	7.848	0.266	0.266	3.781
T	555.803	498.662	33.024	14.332	33.419	23.498	5.042	19.175	13.580	13.950	50.429	32.977
E	132.160	0.074	4.123	0.074	0.074	3.332	0.074	0.074	3.177	3.682	0.074	4.230
MP	167.178	0.124	8.761	0.124	0.124	7.611	0.124	0.124	7.984	0.124	0.124	5.952
O	59.753	0.513	4.879	0.513	0.513	3.342	0.513	0.513	0.513	0.513	0.513	3.638

H1=house 1, H2=house2, H3=house 3, S=Sunday, T=Tuesday, F=Friday

Table D.15 Concentration of BTEX at Chaw Chu-Cheep community during dry season

Comp.	Community/House/Day											
	Indoor sampling									Outdoor sampling		
	CH1S	CH1T	CH1F	CH2S	CH2T	CH2F	CH3S	CH3T	CH3F	CH2S	CH2T	CH2F
B	0.266	30.772	5.211	22.174	35.533	16.318	17.523	41.453	0.266	6.935	36.387	0.266
T	27.573	107.675	28.318	129.043	126.256	81.775	60.634	100.608	0.246	45.511	87.958	23.002
E	5.191	7.160	3.174	14.642	13.472	9.052	9.886	15.956	0.074	9.265	12.833	2.858
MP	12.746	13.523	9.698	40.529	36.814	26.896	25.904	38.363	0.124	25.188	24.877	5.391
O	0.513	7.960	3.105	20.542	14.413	10.708	10.306	15.894	0.513	6.489	12.189	2.156

H1=house 1, H2=house2, H3=house 3, S=Sunday, T=Tuesday, F=Friday

D.4 Concentration of BTEX at five residential areas during wet season

Table D.16 Concentration of BTEX at Saluk Hin community during wet season

Comp.	Community/House/Day											
	Indoor sampling									Outdoor sampling		
	SH1S	SH1T	SH1F	SH2S	SH2T	SH2F	SH3S	SH3T	SH3F	SH2S	SH2T	SH2F
B	0.206	0.206	0.206	271.3	9.243	0.206	39.126	144.65	49.361	0.206	218.19	0.206
T	195.6	266.49	130.64	305.01	417.87	426.57	568.643	696.46	503.534	249.518	380.31	280.61
E	19.356	21.488	5.592	19.948	21.245	27.485	36.025	27.350	31.908	14.928	27.57	20.56
MP	38.34	40.23	20.96	65.63	72.16	63.823	130.34	116.13	79.056	55.758	78.10	75.43
O	18.127	20.353	4.604	19.466	29.290	21.249	54.776	43.000	30.501	24.905	31.796	27.801

H1=house 1, H2=house2, H3=house 3, S=Sunday, T=Tuesday, F=Friday

Table D.17 Concentration of BTEX at Lhung Wat-Pathum community during wet season

Comp.	Community/House/Day											
	Indoor sampling									Outdoor sampling		
	PH1S	PH1T	PH1F	PH2S	PH2T	PH2F	PH3S	PH3T	PH3F	PH2S	PH2T	PH2F
B	136.33	0.206	0.206	335.87	0.206	0.206	279.56	0.206	0.206	0.206	0.206	0.206
T	220.50	322.64	171.35	216.75	319.76	217.388	163.097	216.382	97.773	130.38	354.99	219.50
E	50.673	19.658	8.768	19.261	29.219	15.652	12.700	28.444	5.991	7.110	37.453	15.199
MP	54.483	41.427	31.519	44.568	59.188	37.310	15.652	31.213	9.173	21.817	68.548	48.479
O	16.050	9.169	9.896	12.899	17.383	17.476	5.015	10.244	2.946	6.319	17.307	14.235

H1=house 1, H2=house2, H3=house 3, S=Sunday, T=Tuesday, F=Friday

Table D.18 Concentration of BTEX at Patthana Bon-Kai community during wet season

Comp.	Community/House/Day											
	Indoor sampling									Outdoor sampling		
	BH1S	BH1T	BH1F	BH2S	BH2T	BH2F	BH3S	BH3T	BH3F	BH2S	BH2T	BH2F
B	0.206	0.206	0.206	0.206	0.206	248.550	37.581	0.206	170.280	0.206	0.206	0.206
T	193.10	155.93	790.9*	351.55	260.63	1061.9*	112.88	176.97	1006.4*	246.03	158.77	1069.8*
E	7.796	19.341	39.644	12.372	12.600	55.662	9.855	16.997	46.837	12.444	15.227	60.136
MP	22.030	27.497	68.582	38.635	29.013	85.670	24.752	34.062	71.765	33.574	35.748	87.170
O	9.852	13.186	16.954	10.349	13.854	36.143	12.272	12.852	30.665	12.068	9.647	27.809

H1=house 1, H2=house2, H3=house 3, S=Sunday, T=Tuesday, F=Friday

*High concentrations of toluene were found at Patthana Bon-Kai community on Friday 11st October, 2013. There was not the special day, but it might have special activity at this area.

Table D.19 Concentration of BTEX at Soi Pra-Chen community during wet season

Comp.	Community/House/Day											
	Indoor sampling									Outdoor sampling		
	JH1S	JH1T	JH1F	JH2S	JH2T	JH2F	JH3S	JH3T	JH3F	JH2S	JH2T	JH2F
B	204.472	0.206	510.068	0.206	0.206	11.770	0.206	0.206	240.269	0.206	123.10	0.206
T	406.21	394.29	363.01	402.71	355.78	300.90	146.42	177.83	214.69	479.34	444.78	465.16
E	22.033	24.894	24.658	15.277	17.334	20.656	5.088	24.463	4.632	21.472	21.625	15.006
MP	84.556	46.702	46.647	35.371	33.664	25.623	16.126	21.816	13.963	52.629	50.374	33.661
O	22.297	23.682	12.027	11.636	18.456	6.569	9.756	7.246	3.028	19.947	16.260	7.510

H1=house 1, H2=house2, H3=house 3, S=Sunday, T=Tuesday, F=Friday

Table D.20 Concentration of BTEX at Chaw Chu-Cheep community during wet season

Comp.	Community/House/Day											
	Indoor sampling									Outdoor sampling		
	CH1S	CH1T	CH1F	CH2S	CH2T	CH2F	CH3S	CH3T	CH3F	CH2S	CH2T	CH2F
B	0.206	264.37	0.206	0.206	0.206	0.206	0.206	380.47	0.206	0.206	239.33	0.206
T	274.470	334.580	171.499	586.79	320.47	328.38	310.27	438.24	197.22	313.98	313.44	134.81
E	11.664	20.793	8.900	25.747	13.256	18.262	22.908	28.798	13.197	24.795	26.029	14.093
MP	41.196	24.751	19.494	70.171	27.483	27.328	68.060	81.504	30.104	69.897	35.312	19.279
O	6.822	7.549	11.310	16.926	8.856	8.270	11.558	19.944	8.908	16.775	6.179	7.266

H1=house 1, H2=house2, H3=house 3, S=Sunday, T=Tuesday, F=Friday

Appendix E: Risk assessment data

E.1 Risk assessment for carcinogenic substances based on general scenario

Table E.1 Lifetime cancer risk calculated from general equation for residents living in five communities as presented in term of minimum, maximum, and average values

Compound	Community				
	S	P	B	J	C
Formaldehyde					
-Minimum	4.84×10^{-7}	1.05×10^{-6}	4.50×10^{-9}	7.04×10^{-7}	1.81×10^{-7}
-Maximum	2.20×10^{-4}	5.35×10^{-5}	3.13×10^{-4}	1.81×10^{-4}	3.84×10^{-4}
-Average	5.78×10^{-5}	2.20×10^{-5}	4.98×10^{-5}	4.72×10^{-5}	9.43×10^{-5}
Acetaldehyde					
-Minimum	1.24×10^{-7}	1.33×10^{-7}	1.61×10^{-9}	1.34×10^{-7}	4.05×10^{-8}
-Maximum	3.13×10^{-5}	1.53×10^{-5}	4.86×10^{-5}	3.86×10^{-5}	4.69×10^{-5}
-Average	1.00×10^{-5}	4.94×10^{-6}	8.06×10^{-6}	9.75×10^{-6}	1.24×10^{-5}
Benzene					
-Minimum	2.96×10^{-8}	7.04×10^{-8}	8.68×10^{-9}	5.92×10^{-8}	7.89×10^{-9}
-Maximum	3.73×10^{-3}	4.03×10^{-3}	2.99×10^{-3}	7.37×10^{-3}	6.29×10^{-3}
-Average	6.88×10^{-4}	8.15×10^{-4}	3.85×10^{-4}	1.25×10^{-3}	9.55×10^{-4}
Ethylbenzene					
-Minimum	1.13×10^{-7}	2.88×10^{-7}	4.63×10^{-8}	1.88×10^{-7}	4.80×10^{-8}
-Maximum	6.98×10^{-5}	8.57×10^{-5}	9.44×10^{-5}	5.07×10^{-5}	6.71×10^{-5}
-Average	1.92×10^{-5}	2.13×10^{-5}	1.60×10^{-5}	1.34×10^{-5}	1.66×10^{-5}

Table E.2 95% CI of cancer risk for carcinogenic substances calculated from common scenario

Compound	Community					
	All	S	P	B	J	C
Formaldehyde						
-Upper	5.19×10^{-5}	5.33×10^{-5}	3.63×10^{-5}	6.81×10^{-5}	4.55×10^{-5}	6.17×10^{-5}
-Lower	4.72×10^{-5}	4.44×10^{-5}	2.96×10^{-5}	5.46×10^{-5}	3.83×10^{-5}	5.02×10^{-5}
Acetaldehyde						
-Upper	1.09×10^{-5}	1.26×10^{-5}	8.14×10^{-6}	7.53×10^{-6}	1.37×10^{-5}	1.38×10^{-5}
-Low	9.93×10^{-6}	1.04×10^{-5}	6.82×10^{-6}	6.34×10^{-6}	1.13×10^{-5}	1.12×10^{-5}
Benzene						

Compound	Community					
	All	S	P	B	J	C
-Upper	1.03×10^{-4}	1.81×10^{-4}	1.55×10^{-4}	6.16×10^{-5}	2.31×10^{-5}	1.42×10^{-4}
-Lower	8.83×10^{-5}	1.38×10^{-4}	1.07×10^{-4}	4.35×10^{-5}	1.70×10^{-5}	1.12×10^{-4}
Ethylbenzene						
-Upper	1.45×10^{-5}	5.84×10^{-6}	3.50×10^{-6}	3.26×10^{-6}	4.92×10^{-5}	8.18×10^{-6}
-Lower	1.10×10^{-5}	4.55×10^{-6}	2.60×10^{-6}	2.41×10^{-6}	3.51×10^{-5}	6.50×10^{-6}

Table E.3 95% CI of CDI for carcinogenic substances calculated from common scenario

Compound	Community					
	All	S	P	B	J	C
Formaldehyde						
-Upper	2.43×10^{-3}	2.54×10^{-3}	1.73×10^{-3}	3.24×10^{-3}	2.17×10^{-3}	2.94×10^{-3}
-Lower	2.25×10^{-3}	2.11×10^{-3}	1.41×10^{-3}	2.60×10^{-3}	1.87×10^{-3}	2.39×10^{-3}
Acetaldehyde						
-Upper	1.09×10^{-3}	1.26×10^{-3}	8.14×10^{-4}	7.53×10^{-4}	1.37×10^{-3}	1.38×10^{-3}
-Low	9.93×10^{-4}	1.04×10^{-3}	6.82×10^{-4}	6.34×10^{-4}	1.13×10^{-3}	1.12×10^{-3}
Benzene						
-Upper	3.87×10^{-3}	6.63×10^{-3}	5.70×10^{-3}	2.26×10^{-3}	8.45×10^{-4}	5.21×10^{-3}
-Lower	3.24×10^{-3}	5.04×10^{-3}	3.91×10^{-3}	1.59×10^{-3}	6.23×10^{-4}	4.09×10^{-3}
Ethylbenzene						
-Upper	3.76×10^{-3}	1.52×10^{-3}	9.09×10^{-4}	8.75×10^{-4}	1.28×10^{-2}	2.12×10^{-3}
-Lower	2.86×10^{-3}	1.18×10^{-3}	6.75×10^{-4}	6.25×10^{-4}	9.11×10^{-3}	1.69×10^{-3}

E.2 Risk assessment for non-carcinogenic substances

Table E.4 HQs for non-cancer risk of residents living in five communities as presented in term of minimum, maximum, and average values

Compound	Community				
	S	P	B	J	C
Toluene					
-Minimum	0.025	0.019	0.022	0.028	0.033
-Maximum	0.134	0.062	0.204	0.078	0.113
-Average	0.078	0.041	0.104	0.055	0.070
m-,p-Xylene					
-Minimum	0.201	0.089	0.211	0.134	0.187

Compound	Community				
	S	P	B	J	C
-Maximum	1.250	0.568	0.822	0.811	0.781
-Average	0.706	0.334	0.487	0.430	0.461
o-Xylene					
-Minimum	0.044	0.028	0.095	0.029	0.065
-Maximum	0.525	0.168	0.347	0.227	0.191
-Average	0.276	0.101	0.203	0.126	0.121
Propionaldehyde					
-Minimum	0.051	0.017	0.017	0.037	0.119
-Maximum	0.169	0.079	0.239	0.185	0.198
-Average	0.110	0.049	0.127	0.114	0.159

Table E.5 95% CI of HQs for non-cancer risk of residents living in five communities

Compound	95% CI					
	All	S	P	B	J	C
Toluene						
-Upper	0.0212	0.0239	0.0131	0.0065	0.0497	0.0141
-Lower	0.0183	0.0190	0.0103	0.0058	0.0389	0.0118
m-,p-Xylene						
-Upper	0.2497	0.0945	0.0945	0.0949	0.6869	0.2199
-Lower	0.2066	0.0744	0.0744	0.0755	0.5178	0.1843
o-Xylene						
-Upper	0.0995	0.0601	0.0413	0.0404	0.2454	0.1041
-Lower	0.0838	0.0478	0.0316	0.0308	0.1849	0.0860
Propionaldehyde						
-Upper	0.1031	0.1437	0.1248	0.0962	0.0839	0.0952
-Lower	0.0958	0.1219	0.1001	0.0878	0.0752	0.0804

Table E.6 95% CI of EC for for non-cancer risk of residents living in five communities

Compound	95% CI					
	All	S	P	B	J	C
Toluene						
-Upper	0.1061	0.1194	0.0653	0.0325	0.2486	0.0705
-Lower	0.0913	0.0950	0.0515	0.0292	0.1949	0.0592
m-,p-Xylene						

Compound	95% CI					
	All	S	P	B	J	C
-Upper	0.0249	0.0124	0.0095	0.0095	0.0687	0.0220
-Lower	0.0206	0.0102	0.0074	0.0076	0.0518	0.0184
o-Xylene						
-Upper	0.0099	0.0060	0.0041	0.0040	0.0245	0.0104
-Lower	0.0084	0.0048	0.0031	0.0031	0.0185	0.0086
Propionaldehyde						
-Upper	0.0008	0.0012	0.0009	0.00077	0.00067	0.00076
-Lower	0.0007	0.0009	0.0008	0.00070	0.00060	0.00064

E.3 Total risk

Table E.7 The descriptive of total cancer risk and HI

Risk	Min	Max	Ave
Total cancer risk	$6.10\text{x}10^{-8}$	$7.64\text{x}10^{-3}$	$9.07\text{x}10^{-4}$
HI	0.151	2.078	0.851

Table E.8 95% CI of total cancer risk

Risk	Community					
	All	S	P	B	J	C
Total cancer risk						
-Upper	$9.73\text{x}10^{-4}$	$8.86\text{x}10^{-4}$	$1.02\text{x}10^{-3}$	$5.29\text{x}10^{-4}$	$1.51\text{x}10^{-3}$	$1.23\text{x}10^{-3}$
-Lower	$8.40\text{x}10^{-4}$	$6.65\text{x}10^{-4}$	$7.08\text{x}10^{-4}$	$3.88\text{x}10^{-4}$	$1.12\text{x}10^{-3}$	$9.27\text{x}10^{-4}$
HI						
-Upper	0.880	1.256	0.569	0.983	0.777	0.852
-Lower	0.822	1.083	0.480	0.858	0.673	0.771

E.4 Risk assessment for carcinogenic substances based on Age interval scenario

Table E.9 Lifetime cancer risk using ADAF calculated from indoor concentrations measured from five communities as presented in term of minimum, maximum, and average values

Compound	Community				
	S	P	B	J	C
Formaldehyde					
-Minimum	$6.13\text{x}10^{-5}$	$5.55\text{x}10^{-5}$	$1.93\text{x}10^{-6}$	$4.42\text{x}10^{-5}$	$8.57\text{x}10^{-5}$

Compound	Community				
	S	P	B	J	C
-Maximum	2.91×10^{-4}	8.04×10^{-5}	2.28×10^{-4}	3.04×10^{-4}	4.21×10^{-4}
-Average	1.68×10^{-4}	6.80×10^{-5}	1.52×10^{-4}	1.92×10^{-4}	2.70×10^{-4}
Acetaldehyde					
-Minimum	1.66×10^{-5}	7.58×10^{-6}	3.17×10^{-6}	9.82×10^{-6}	2.03×10^{-5}
-Maximum	4.14×10^{-5}	2.30×10^{-5}	7.27×10^{-5}	4.81×10^{-5}	5.15×10^{-5}
-Average	2.93×10^{-5}	1.55×10^{-5}	3.85×10^{-5}	2.95×10^{-5}	3.60×10^{-5}
Benzene					
-Minimum	3.75×10^{-6}	3.72×10^{-6}	3.72×10^{-6}	3.72×10^{-6}	3.74×10^{-6}
-Maximum	4.93×10^{-3}	6.05×10^{-3}	4.48×10^{-3}	9.20×10^{-3}	6.90×10^{-3}
-Average	1.99×10^{-3}	2.52×10^{-3}	1.90×10^{-3}	3.71×10^{-3}	2.74×10^{-3}
Ethylbenzene					
-Minimum	1.43×10^{-5}	1.52×10^{-5}	1.98×10^{-5}	1.18×10^{-5}	2.28×10^{-5}
-Maximum	9.24×10^{-5}	1.29×10^{-4}	1.41×10^{-4}	6.33×10^{-5}	3.37×10^{-5}
-Average	5.56×10^{-5}	6.59×10^{-5}	7.45×10^{-5}	4.00×10^{-5}	4.77×10^{-5}

Table E.10 95% CI of cancer risk for carcinogenic substances calculated from ADAF scenario

Compound	Community					
	All	S	P	B	J	C
Formaldehyde						
-Upper	1.94×10^{-4}	1.79×10^{-4}	6.96×10^{-5}	2.55×10^{-4}	1.49×10^{-4}	2.86×10^{-4}
-Lower	1.79×10^{-4}	1.56×10^{-4}	6.65×10^{-5}	2.10×10^{-4}	1.32×10^{-4}	2.55×10^{-4}
Acetaldehyde						
-Upper	3.20×10^{-5}	3.05×10^{-5}	1.64×10^{-5}	4.18×10^{-5}	3.14×10^{-5}	3.75×10^{-5}
-Lower	3.00×10^{-5}	2.81×10^{-5}	1.45×10^{-5}	3.51×10^{-5}	2.76×10^{-5}	3.46×10^{-5}
Benzene						
-Upper	2.72×10^{-3}	2.25×10^{-3}	2.91×10^{-3}	2.03×10^{-3}	4.18×10^{-3}	3.07×10^{-3}
-Lower	2.40×10^{-3}	1.74×10^{-3}	2.13×10^{-3}	1.57×10^{-3}	3.24×10^{-3}	2.40×10^{-3}
Ethylbenzene						
-Upper	5.78×10^{-5}	5.94×10^{-5}	7.29×10^{-5}	8.05×10^{-5}	4.25×10^{-5}	4.99×10^{-5}
-Lower	5.38×10^{-5}	5.17×10^{-5}	5.88×10^{-5}	6.86×10^{-5}	3.75×10^{-5}	4.53×10^{-5}

Table E.11 95% CI of CDI for carcinogenic substance calculated from ADAF scenario

Compound	95% CI					
	All	S	P	B	J	C
Formaldehyde						
-Upper	2.29×10^{-3}	2.09×10^{-3}	8.53×10^{-4}	2.95×10^{-3}	1.75×10^{-3}	3.36×10^{-3}
-Lower	2.16×10^{-3}	1.89×10^{-3}	7.83×10^{-4}	2.59×10^{-3}	1.59×10^{-3}	3.07×10^{-3}
Acetaldehyde						
-Upper	7.94×10^{-4}	7.62×10^{-4}	4.08×10^{-4}	1.02×10^{-3}	7.73×10^{-4}	9.35×10^{-4}
-Lower	7.58×10^{-4}	7.03×10^{-4}	3.66×10^{-4}	9.04×10^{-4}	7.02×10^{-4}	8.67×10^{-4}
Benzene						
-Upper	2.44×10^{-2}	1.97×10^{-2}	2.53×10^{-2}	1.78×10^{-2}	3.67×10^{-2}	2.96×10^{-2}
-Lower	2.26×10^{-2}	1.68×10^{-2}	2.09×10^{-2}	1.52×10^{-2}	3.13×10^{-2}	2.32×10^{-2}
Ethylbenzene						
-Upper	3.72×10^{-3}	3.79×10^{-3}	4.59×10^{-3}	5.11×10^{-3}	2.72×10^{-3}	3.22×10^{-3}
-Lower	3.53×10^{-3}	3.42×10^{-3}	3.96×10^{-3}	4.57×10^{-3}	2.47×10^{-3}	2.97×10^{-3}

Appendix F: Sampling site

F.1 Saluk Hin community

H1: This house used insecticide sometime, but cooking inside the house every day. Low air ventilation was found with narrow door gate.

Figure F.1 Indoor sampling at H1 of Saluk Hin community

H2 (for dry season): This house did not have special activity, but the house might be affected by the vehicle exhaust from motocycles passing the house.

Figure F.2 Indoor sampling (left) and outdoor sampling (right) at H2 of Saluk Hin community during dry season

H2 (for wet season): This house did not have special activity inside the house, but the air ventilation was very low.

Figure F.3 Indoor sampling (left) and outdoor sampling (right) at H2 of Saluk Hin community during wet season

H3: This house uses incenses every day and also cooking inside the house without hoods. The printing house was found nearby.

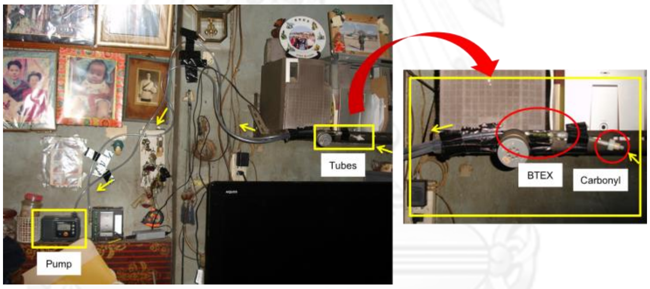


Figure F.4 Indoor sampling at H3 of Saluk Hin community

F.2 Lhung Wat-Pathum community

H1: This house uses incenses sometimes, not much special activity was found.

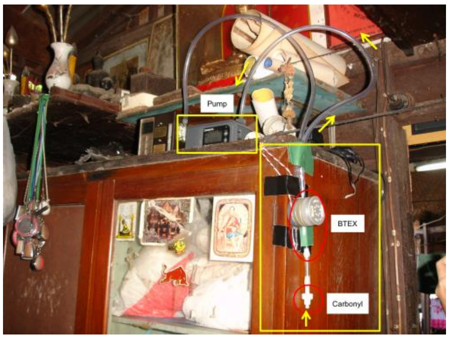


Figure F.5 Indoor sampling at H1 of Lhung Wat-Pathum community

H2: This house did not have special activity that might release target chemicals.

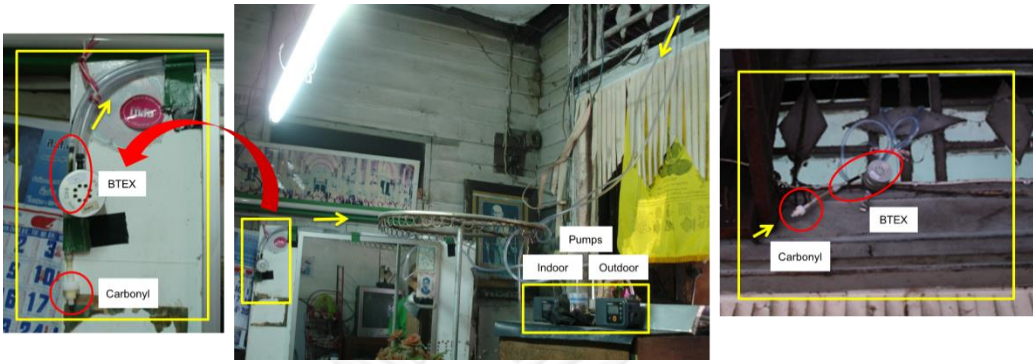


Figure F.6 Indoor sampling (left) and outdoor sampling (right) at H2 of Lhung Wat-Pathum community

H3: This house did not have much special activity. Even through this house is near by the cement factory, but the cement did not related to carbonyl compounds and BTEX concentrations.

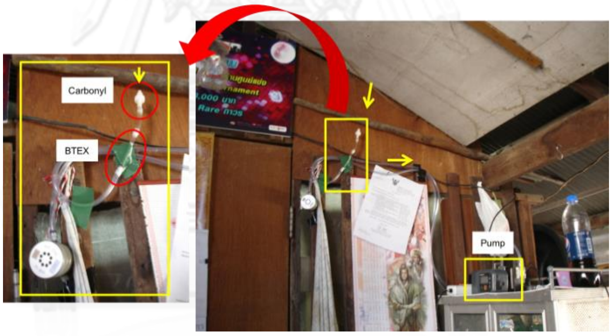


Figure F.7 Indoor sampling at H3 of Lhung Wat-Pathum community

F.3 Patthana Bon-Kai community

H1: This house had cooking activity inside the house and one smoking people was notice. Tobacco factory near by affected all houses in this community.

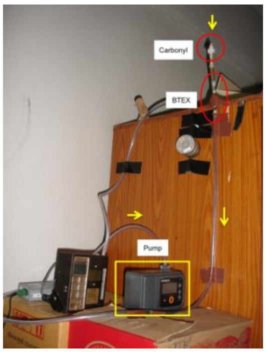


Figure F.8 Indoor sampling at H1 of Patthana Bon-Kai community

H2: This house was near by the tobacco factory, and they sell perfume. The shrine of the household god of neighbor might affect the concentrations.

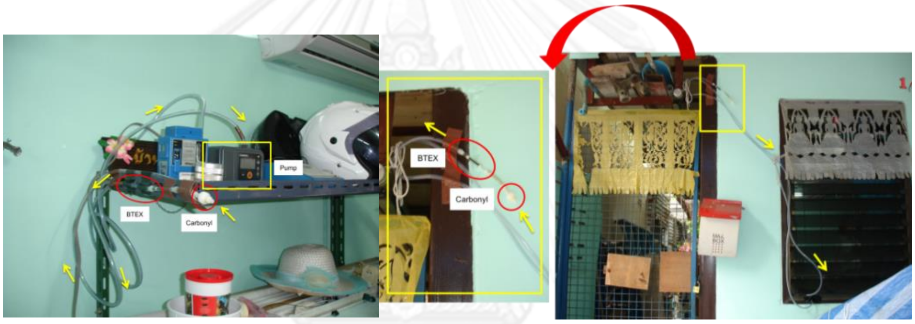


Figure F.9 Indoor sampling (left) and outdoor sampling (right) at H2 of Patthana Bon-Kai community

H3: This house is nursery which did not have much activity and high air ventilations, but affected by tobacco factory.

Figure F.10 Indoor sampling at H3 of Patthana Bon-Kai community

F.4 Soi Pra-Chen community

H1: This house uses incenses everyday with five points (two at the in front of the house; two inside the house; one up stair)

Figure F.11 Indoor sampling at H1 of Soi Pra-Chen community

H2: This house uses incense every day, not have other special activity.

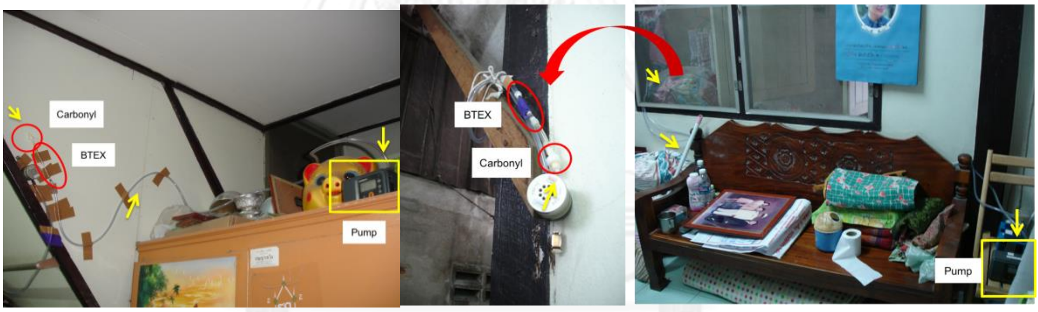


Figure.12 Indoor sampling (left) and outdoor sampling (right) at H2 of Soi Pra-Chen community

H3: This house has the shrine of the household god in front of the house. They uses incense a lot every day.

Figure F.13 Indoor sampling at H3 of Soi Pra-Chen community

F.5 Chaw Chu-Cheep community

H1: This house did not have special activity at all.

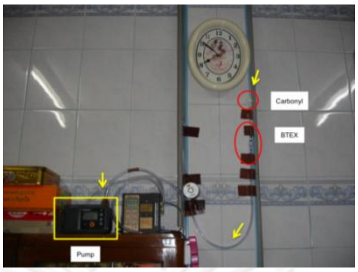


Figure F.14 Indoor sampling at H1 of Chaw Chu-Cheep community

H2 (for dry season): This house has new wall painting both inside and outside the house with low air ventilation related to high concentrations of chemicals.

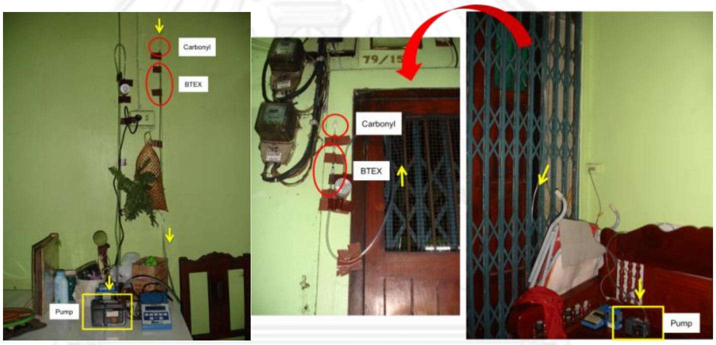


Figure F.15 Indoor sampling (left) and outdoor sampling (right) at H2 of Chaw Chu-Cheep community during dry season

H2 (for wet season): This house stores a lot of paints, glues, woods, and other things related to carpenter work.

Figure F.16 Indoor sampling (left) and outdoor sampling (right) at H2 of Chaw Chu-Cheep community during wet season

H3 (for dry season): This house did not have special activity, but close to the main road nearby.

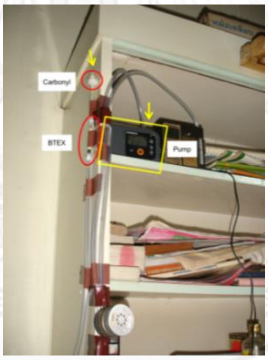


Figure F.17 Indoor sampling at H3 of Chaw Chu-Cheep community during dry season

H3 (for wet season): This house provides garage for sampling site which also provide high concentrations.

Figure F.18 Indoor sampling at H3 of Chaw Chu-Cheep community during wet season

VITA

Name: Miss Rajitpitch Sawatsing

Date of Birth: June 12th, 1990

Nationality: Thai

University Education: 2008-2012 Bachelor’s Degree of Science in Department of Microbiology, Faculty of Science, Chulalongkorn University, Bangkok, Thailand.

Home Address: 21/1 M.11 Soi Ruan Rudee, Boon Nak Road, Nong Pure,
Bang Lamung, Chonburi 20150

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2. Tunsaringkarn, T., Prueksasit, T., Morknoy, D., Sawatsing, R., Chinveschakitvanich, V., Rungsiyothin, A., and Zapaung, K. Indoor Air Assessment, Health Risks and Their Relationship among Elderly Residents in Urban Warrants of Bangkok, Thailand. Air quality, Atmosphere & Health. [Under review]