

**SOURCE APPORTIONMENT ANALYSIS OF AIRBORNE
VOLATILE ORGANIC COMPOUNDS IN MAPTAPHUT,
THAILAND**

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OF THE REQUIREMENTS FOR
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Thesis
entitled
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VOLATILE ORGANIC COMPOUNDS IN MAPTAPHUT,
THAILAND**

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SOURCE APPORTIONMENT ANALYSIS OF AIRBORNE VOLATILE ORGANIC COMPOUNDS IN MAPTAPHUT, THAILAND

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ABSTRACT

Airborne volatile organic compounds (VOCs) were measured by The Pollution Control Department on a monthly basis from January 2009 to December 2012. VOCs concentration data of monitoring station in Maptaphut area and Dindaeng (Bangkok) were analysed for VOCs/Bz ratios, BTEX ratios and principle component analysis (PCA) to identify sources and elaborate the sources profile of VOCs.

The contribution of aromatics to total VOCs was greater than other chemical groups for all monitoring sites. VOCs concentrations at Dindaeng were about 1.32-1.70 times greater than those in Maptaphut area. The results of this study can be classified VOCs into three groups based on emission sources including mobile sources, industrial sources and other sources (household). Moreover, some species of VOCs had background concentration in ambient air.

Overall results suggest that dominant emission source of VOCs was a mobile source. Therefore, an effort to control both mobile and industrial emission sources should be implemented for solving the VOC problem in Maptaphut area.

**KEY WORDS: VOLATILE ORGANIC COMPOUNDS (VOCS) / VOCS AGAINST
BENZENE RATIOS / PRINCIPAL COMPONENT ANALYSIS
(PCA) / MAPTAPHUT**

196 pages

การวิเคราะห์แหล่งกำเนิดของสารอินทรีย์ระเหยง่ายในบรรยากาศในพื้นที่มาบตาพุด ประเทศไทย
SOURCE APPORTIONMENT ANALYSIS OF AIRBORNE VOLATILE ORGANIC
COMPOUNDS IN MAPTAPHUT, THAILAND

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บทคัดย่อ

งานวิจัยนี้มีวัตถุประสงค์เพื่อบ่งชี้และอธิบายแหล่งกำเนิดของสารอินทรีย์ระเหยง่ายในพื้นที่ตำบลมาบตาพุด อำเภอเมืองระยอง จังหวัดระยอง โดยนำข้อมูลความเข้มข้นของสารอินทรีย์ระเหยง่ายที่ตรวจวัดโดยกรมควบคุมมลพิษ บริเวณมาบตาพุด ตั้งแต่เดือนมกราคม 2552 ถึง ธันวาคม 2555 มาทำการวิเคราะห์ด้วยวิธีหาอัตราส่วนของ VOCs/Bz อัตราส่วนของ BTEX และวิธี principle component analysis (PCA) แล้วนำมาเปรียบเทียบกับผลการวิเคราะห์ข้อมูลจากสถานีตรวจวัดดินแดง (กรุงเทพมหานคร) ซึ่งเป็นสถานีตรวจวัดที่เป็นตัวแทนของแหล่งกำเนิดประเภทยานพาหนะ

จากข้อมูลตรวจวัดพบว่า มีสัดส่วนของสารในกลุ่มอะโรมาติกส์มากที่สุดในทุกๆ สถานี สถานีตรวจวัดดินแดงมีค่าความเข้มข้นของสารอินทรีย์ระเหยง่ายมากกว่าค่าความเข้มข้นบริเวณมาบตาพุด ประมาณ 1.32-1.70 เท่า จากผลการศึกษานี้สามารถแบ่งสารอินทรีย์ระเหยง่ายตามแหล่งกำเนิดได้ 3 กลุ่ม ได้แก่ แหล่งกำเนิดจำพวกยานพาหนะ แหล่งกำเนิดประเภทอุตสาหกรรม และแหล่งกำเนิดอื่นๆ (ครัวเรือน) อย่างไรก็ตาม สารอินทรีย์ระเหยง่ายบางชนิดเป็นสารที่มีความเข้มข้นอยู่แล้วในบรรยากาศ

ภาพรวมของผลการศึกษานี้พบว่า แหล่งกำเนิดจำพวกยานพาหนะเป็นแหล่งกำเนิดหลักในการระบายสารอินทรีย์ระเหยง่าย ดังนั้น ในการแก้ปัญหาสารอินทรีย์ระเหยง่ายในพื้นที่มาบตาพุดจึงควรให้ความสำคัญกับแหล่งกำเนิดจำพวกยานพาหนะควบคู่ไปกับการแก้ปัญหาแหล่งกำเนิดประเภทอุตสาหกรรม

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LIST OF ABBREVIATIONS

$\mu\text{g}/\text{m}^3$	Microgram per cubic meter
APCS	Absolute Principal Component Scores
BPLC	Ban Plong Community
BTKH	Ban Ta Kuan Public Health Center
CFCs	Chlorofluorocarbons
CMB	Chemical Mass Balance
CNS	Central Nervous System
EU	European Union
GC/MS	Gas Chromatography/Mass Spectrophotometer
GWP	Global warming Potential
HAPs	Hazardous air pollutants
HCFCs	Hydrochlorofluorocarbons
HMTP	Health Promotion Hospital Maptaphut
IEAT	Industrial Estate Authority of Thailand
MCLT	Map Chalut Temple
MMTP	Muang Mai Maptaphut
MTBE	Methyl-tert-butyl ether
MTPIE	Maptaphut Industrial Estate
NPKV	Nop Pakate Village
ODS	Ozone Depleting Substances
PAHs	Polycyclic Aromatic Hydrocarbons
PC	Principal Component
PCA	Principal Component Analysis
PCD	Pollution Control Department
PMF	Positive Matrix Factorization
ppm	Parts per million
PRTR	Pollutant Release and Transfer Register

LIST OF ABBREVIATIONS (cont.)

US EPA	United States Environmental Protection Agency
VOCs	Volatile Organic Compounds
VOCs/Bz	Volatile organic compounds against benzene ratio
WHO	World Health Organization
WNFS	Wat Nong Fap School

CHAPTER I

INTRODUCTION

1.1 Rationales and Justifications

Volatile organic compounds (VOCs) are a major group of air pollutants that have attracted growing scientific concern due to their harmful effects on human health (Tong et al., 2012) and contribution to secondary pollutants such as photochemical oxidants, suspended particulate matter (Hoshi et al., 2008; Thepanondh et al., 2011). Some VOCs, such as benzene are toxic and carcinogenic and are regulated as hazardous air pollutants or HAPs. VOCs can cause both acute and chronic toxicity in humans. Common short-term health effects of VOCs exposure include eye, nose, throat, and skin irritation. Headaches, nausea, dizziness, fatigue and shortness of breath may occur (US EPA, 2007). Many VOCs produce negative health effects if humans are exposed to high concentrations. Long-term exposure to low concentrations VOCs at or above regulatory standards may result in liver and kidney damage (Wallace, 1991). Emission sources of VOCs include both biogenic and anthropogenic sources (Mintz & McWhinney, 2008; Kansal, 2009). The major source of VOCs is an anthropogenic source such as solvent usage, transportation and storage of VOCs, motor vehicle and industrial processes.

Maptaphut complex consists of five industrial estates and a port. The complex is located in Maptaphut sub-district, Rayong province, East of Thailand. Maptaphut Industrial Estate (MTPIE) is the biggest industrial estate, which is the most important manufacturing base for petrochemicals, chemicals, steels, metals and refineries of the country. It was developed in 1989 by the state enterprise, Industrial Estate Authority of Thailand (IEAT), Ministry of Industry. Rapidly development of industry cause many environmental and health problem such as lack of water and air quality effect. Ambient air monitoring operated by the Pollution Control Department (PCD) routinely report concentration of more than forty VOCs in ambient of Maptaphut. Monitoring results from 2007 to 2012 indicated that there were five VOCs

compounds namely benzene, 1,3-butadiene, chloroform, dichloromethane and 1,2-dichloroethane which their annual concentrations were higher than the Thailand's ambient air quality standards (PCD, 2013). Results were as summarized in Table 1.1.

Table 1.1 Comparison of annual average concentration in 2007 to 2012 with Thailand's annual VOCs standard (unit : $\mu\text{g}/\text{m}^3$) (Thepanondh et al., 2011; PCD, 2013)

VOCs	Annual average concentration ($\mu\text{g}/\text{m}^3$)	Annual standard ($\mu\text{g}/\text{m}^3$)
Benzene	1.20-6.30	1.7
1,3-Butadiene	0.07-0.78	0.33
Chloroform	0.03-0.64	0.43
Dichloromethane	0.36-30.00	22
1,2-Dichloroethane	0.16-21.00	0.40
1,2-Dichloropropane	0.04-0.41	4.0
Tetrachloroethylene	0.05-0.30	200
Trichloroethylene	0.10-1.20	23
Vinyl chloride	0.04-2.70	10

An alternative to examine the contribution of sources is to use receptor models. Receptor models provide a theoretical and mathematical framework for quantifying source contributions. These models interpret measurements of physical and chemical properties taken at different times and places to identify the probable sources of air pollution (Murphy et al., 2007). There are many receptor models such as Chemical Mass Balance (CMB), Positive Matrix Factorization (PMF), UNMIX and Principle Component Analysis (PCA). Principal Component Analysis (PCA) is an effective tool to identify independent factors using the eigenvector decomposition of a matrix of pairwise correlations among compound concentrations (Song et al., 2006).

Diagnostic ratios are also used to identify the source of VOCs in ambient air on the basis of the proximity of the samples ratio to the characteristic range of a particular diagnostic ratio. Use of new diagnostic ratio like VOCs/Benzene (VOCs/Bz) ratio was applied by Hoshi et al. (2008) to identifying sources of VOCs in ambient air in Tokyo. They found that VOCs/Bz ratio can be used in estimating non-registered

VOCs and suggested the possibility of estimating emission sources using VOCs/Bz ratios from the register data (Hoshi et al., 2008).

Further investigations and estimations of VOCs emission sources in Maptaphut sub-district is needed. Therefore, this study is aimed to identify source of VOCs in Maptaphut sub-district, Rayong province, Thailand. VOCs ambient concentrations data from Pollution Control Department (PCD) were analyzed by the receptor model using the principal component analysis (PCA) and the diagnostic ratio method.

1.2 Research Objectives

1. To apply a receptor model and diagnostic ratio in identifying of the emission source of VOCs in ambient air of Maptaphut sub-district, Rayong province, Thailand.
2. To elaborate the source profile of the ambient concentration of airborne VOCs in Maptaphut area.

1.3 Research Hypotheses

Emission source of VOCs in Maptaphut can be identified by receptor model and diagnostic ratio based on the concentration of VOCs contribution.

1.4 Scope of the Study

VOCs monitoring data used in this study were provided by the Pollution Control Department. Data from monitoring stations were analyzed in this study. The monitoring stations were as follows:

Study area: Seven monitoring stations in Maptaphut sub-district, Rayong province.

1. Health Promotion Hospital Maptaphut (HMTP)

2. Ban Ta Kuan Public Health Center (BTKH)
3. Wat Nong Fap School (WNFS)
4. Muang Mai Maptaphut (MMTP)
5. Map Chalut Temple (MCLT)
6. Ban Plong Community (BPLC)
7. Nop Pakate Village (NPKV)

1.5 Expected Outcomes

1. Principal component analysis (PCA) can be applied to identify the emission source of VOCs in Maptaphut sub-district, Rayong province, Thailand.
2. The diagnostic ratio can be applied to identify the emission source of VOCs in Maptaphut sub-district, Rayong province, Thailand.

1.6 Definition of Keywords

Volatile organic compounds (VOCs) are the group of organic compounds that have a boiling temperature of between 50–100 °C and 240–260 °C (WHO,1989).

Volatile organic compounds against benzene ratios (VOCs/Bz ratios) are a diagnostic ratio which used to identify the source of VOCs in ambient air on the basis of the proximity of the samples ratio to the characteristic range of a particular diagnostic ratio.

Principal component analysis (PCA) is a tool to identify independent factors using the eigenvector decomposition of a matrix of pairwise correlations among compound concentrations.

1.7 Conceptual Framework

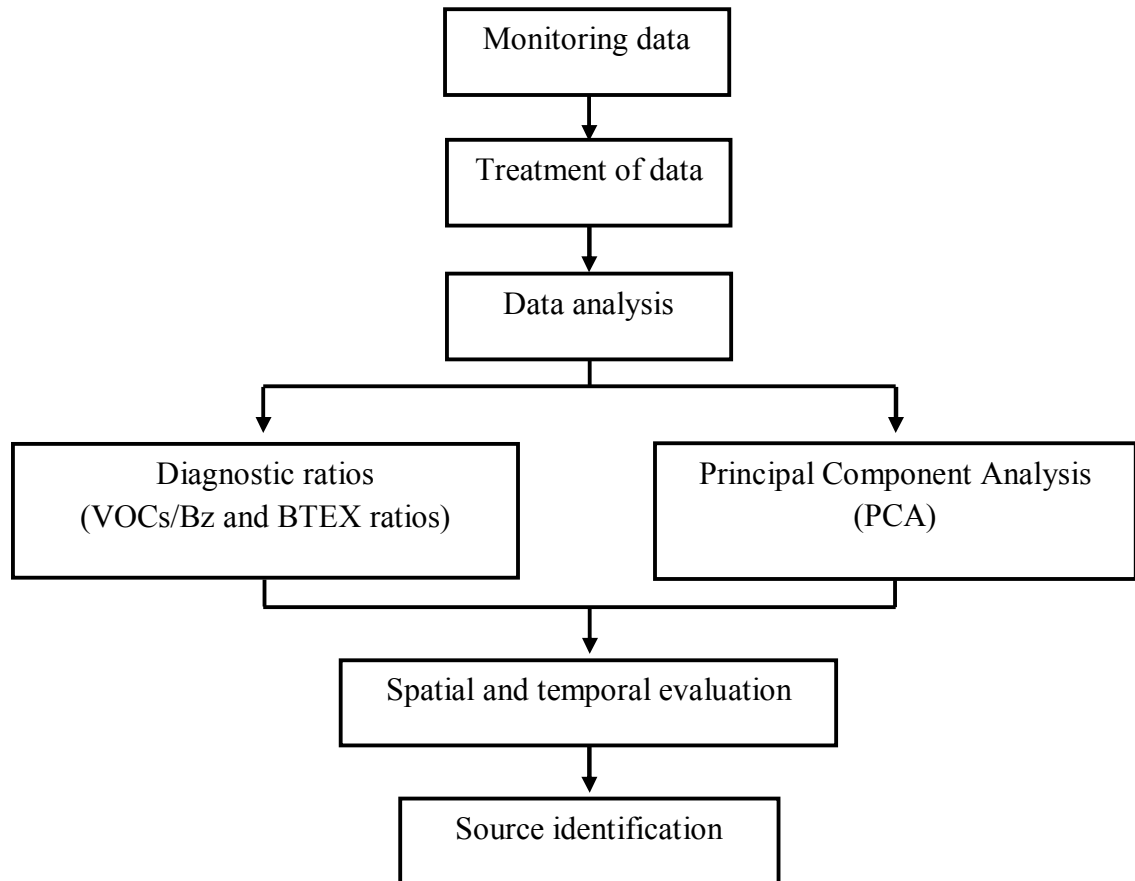


Figure 1.1 Conceptual framework

CHAPTER II

LITERATURE REVIEWS

2.1 Volatile organic compounds (VOCs)

Volatile organic compounds or VOCs are very large and heterogeneous group of organic compounds that include aliphatic hydrocarbons, aromatic hydrocarbons, halogenated compounds, alcohols, ketones, aldehydes, and esters.

2.1.1 Definitions and classifications

The VOCs was defined base on physical properties or oriented effects, so there are many different definitions of VOCs in different organization. According to United States Environmental Protection Agency (US EPA, 2009), VOCs defined as any compound of carbon, except for carbon monoxide, carbon dioxide, carbonic acid, metallic carbides or carbonates, and ammonium carbonate, which participates in atmospheric photochemical reactions. The World Health Organization (WHO, 1989) classes VOCs as the group of organic compounds occurring in air that have a boiling temperature of between 50–100 °C and 240–260 °C. EU Directive 1999/13/EC or Solvent Emissions Directive (EU, 1999), VOCs are functionally defined as organic compounds having at 293.15 K (i.e., 20°C) a vapor pressure of 0.01 kPa or more, or having a corresponding volatility under particular conditions of use. The EU Paint Directive 2004/42/EC (EU, 2004) defines VOCs as organic compounds having an initial boiling point lower than or equal to 250 °C at an atmospheric pressure of 101.3 kPa. Similarly, the European Eco-Labeling scheme, 2002/739/EC (EU, 2002) for paints and varnishes defines VOCs as an organic compound with a boiling point (or initial boiling point) lower than or equal to 250°C.

2.1.2 Source of VOCs

Volatile organic compounds (VOCs) comprise of some thousands of chemicals, many of which are in wide use as paints, adhesives, solvents, fragrances, and other ingredients in processes and consumer products as shown in Table 2.1 (Ott et al., 2007).

Table 2.1 Common volatile organic chemicals and their sources (Ott et al., 2007).

Chemicals	Major sources of exposure
Acetone	Cosmetics
Alcohols (ethanol, isopropanol)	Spirits, cleansers
Aromatic hydrocarbons (toluene, xylenes, ethylbenzene, trimethylbenzenes)	Paints, adhesives, gasoline, combustion, sources
Aliphatic hydrocarbons (octane, decane, undecane)	Paints, adhesives, gasoline, combustion, sources
Benzene	Smoking, auto exhaust, passive smoking, driving, refueling automobiles, parking garages
Butylated hydroxytoluene (BHT)	Urethane-based carpet cushions
Carbon tetrachloride	Fungicides, global background
Chloroform	Showering, washing clothes, dishes
<i>p</i> -Dichlorobenzene	Room deodorizers, moth cakes
Ethylene glycol, Texanol	Paints
Formaldehyde	Pressed wood products
Furfural	Cork parquet flooring
Methylene chloride	Paint stripping, solvent use
Methyl-tert-butyl ether (MTBE)	Gasoline, groundwater contaminant
Phenol	Vinyl flooring, cork parquet flooring
Styrene	Smoking
Terpenes (limonene, α -pinene)	Scented deodorizers, polishes, cigarettes, food, beverages, fabrics, fabric softners
Tetrachloroethylene	Wearing/storing dry-cleaned clothes
Tetrahydrofuran	Sealer for vinyl flooring
1,1,1-Trichloroethane	Aerosol sprays, solvents, many consumer products
Trichloroethylene	Cosmetics, electronic parts, correction fluid

Emission sources of VOCs are both biogenic (mainly vegetation) and anthropogenic sources for instant petroleum refineries, petrochemical industries, automobiles, combustion of fossil fuels and biomass, use of solvents and marketing of petroleum products (Mohan et al, 2012). In addition, many human's activity is a source of VOCs such as maintenance, cleaning and cooking. Moreover, building, furniture materials, copy machines, printing machines, glue, spray cans, pesticides and so on are also sources of VOCs (Yu, 2005).

2.1.3 Effects of VOCs

Volatile organic compounds play a variety of roles in many air environmental problems, including formation of ground-level photochemical ozone, enhancement of the global greenhouse effect and depletion of stratospheric ozone. Additionally, some species can cause serious health effects through toxic, carcinogenic, mutagenic, or neurotoxic (Pimpisut et al., 2005).

2.1.3.1 Effects on human health

Specific VOCs such as benzene, benzo(a)pyrene, 1,3-butadiene and PAHs (polycyclic aromatic hydrocarbons), may also lead to increases in diseases such as lung cancer and leukaemia (Perry & Gee, 1995).

The most significant routes of exposure to VOCs are inhalation and skin. Aliphatic volatile alkanes and alkenes are central nervous system (CNS) depressants in high concentrations. They may also irritate the mucous membrane and the respiratory tract, in addition to causing drying of the skin that may develop into dermatitis. Trichloroethylene occasionally produces euphoria, and consequently it has been abused for the purpose. Trichloroethylene has caused fatal accidents due to overdose, and perhaps through the induction of ventricular fibrillation. Tetrachloroethylene or perchloroethylene may cause liver, oesophageal, intestinal, pancreatic and bladder cancers. Toluene causes induction of microsomal liver enzymes at relatively low concentrations. The major effect of xylene is depression of the CNS, resulting in lightheadedness, nausea, headache and ataxia at low doses. High exposure to xylene produces confusion, respiratory depression and coma: It causes conjunctivitis, nasal irritation, sore throat and respiratory irritation. Xylenes have been shown to induce microsomal enzymes in the liver, although their hepatotoxicity is

considered to be low. Concentrations as high as 10 ppm produce a reversible and mild increase in hepatic aminotransferase activity and reversible renal failure. Styrene is readily absorbed via the lungs and gastrointestinal tract, and also to some extent via the skin. Styrene is metabolized to mandelic acid 70% and phenylglyoxylic acid 30%, which is excreted in the urine. It is also metabolized to styrene oxide, which is more toxic than the parent compound. Hippuric acid is also excreted in the urine following exposure to styrene (Rana, 2006).

2.1.3.2 Stratospheric ozone depletion

Stratospheric ozone is being destroyed by a group of manufactured chemicals, containing chlorine and/or bromine. These chemicals are called ozone-depleting substances or ODS. ODS are very stable, nontoxic and environmentally safe in the lower atmosphere. However, their very stability allows them to float up, intact, to the stratosphere. Once there, they are broken apart by the intense ultraviolet light, releasing chlorine and bromine. Chlorine and bromine demolish ozone at an alarming rate, by stripping an atom from the ozone molecule. A single molecule of chlorine can break apart thousands of molecules of ozone. The main ODS are chlorofluorocarbons (CFCs), hydrochlorofluorocarbons (HCFCs), carbon tetrachloride and methyl chloroform. Halons (brominated fluorocarbons) also play a large role. Their application is quite limited: they are used in specialized fire extinguishers. But the problem with halons is they can destroy up to 10 times as much ozone as CFCs can (British Columbia Air Quality, 2013).

2.1.3.3 Global warming contribution

Some of the more stable VOCs survive the tropospheric removal process in the atmospheric boundary layer and may be transported into the free troposphere above the boundary layer. Some of these longer-lived VOCs are classed as radiatively active gases and can absorb solar or terrestrial infrared radiation and possess high Global Warming Potential (GWP). In this sense, they directly contribute to enhanced greenhouse effect. Many VOCs however are not themselves radiatively active gases, but they have the potential to perturb the global distributions of other radiatively active gases thus acting as secondary greenhouse gases.

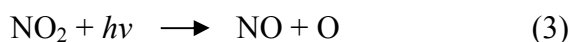
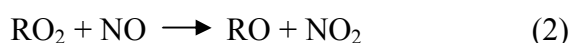
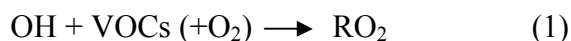
Organic compounds can behave as secondary greenhouse gases by reacting with NO_x to produce ozone in the troposphere and increasing or

decreasing the tropospheric •OH distribution and hence perturbing the distribution of methane.

VOCs can affect an increase of ozone in the free troposphere and this has raised some concern because ozone is an important greenhouse gas. Ozone can effectively absorb infrared light with a wavelength of around 10 microns and thus efficiently absorbs the infrared rays radiated from the earth. Since these wavelengths do not overlap those for water vapor and carbon dioxide, it makes ozone a powerful greenhouse gas (Parao, 2012).

2.1.3.4 Tropospheric ozone formation

Volatile organic compounds (VOCs) are one of the important precursors to the formation of ground-level ozone. Ozone is formed through a series of photochemical reactions involving VOCs and oxides of nitrogen (NO_x) (Doraiswamy et al., 2009). The photochemical reactions of ozone formation are shown in Equation 1-4.



During the daytime, photochemical oxidation of VOCs initiated by hydroxyl radicals OH produces organic peroxy radicals (RO₂), facilitating cycling of NO to NO₂ and formation of tropospheric ozone (Zhang et al., 2004). Tropospheric ozone can harm health. Even relatively low levels of ozone can cause health effects. People with lung disease, children, older adults, and people who are active outdoors may be particularly sensitive to ozone. Ozone also affects sensitive vegetation and ecosystems, including forests, parks, wildlife refuges and wilderness areas. In particular, ozone harms sensitive vegetation, including trees and plants during the growing season (US EPA, 2012).

2.2 VOCs situation in Thailand

In 2008, The Thai government designated national ambient air quality standards for VOCs. The regulation was based on the abundant and carcinogenic properties of VOCs compounds. The standards were regulated for nine VOCs compounds namely benzene, 1,3-butadiene, chloroform, dichloromethane, 1,2-dichloroethane, 1,2-dichloropropane, tetrachloroethylene, trichloroethylene and vinyl chloride. Annual ambient concentration standard of these compounds are listed in Table 2.2.

Table 2.2 Thailand's annual VOCs standard (unit : $\mu\text{g}/\text{m}^3$) (Thepanondh et al., 2011)

VOCs	Annual standard ($\mu\text{g}/\text{m}^3$)
Benzene	1.7
1,3-Butadiene	0.33
Chloroform	0.43
Dichloromethane	22
1,2-Dichloroethane	0.40
1,2-Dichloropropane	4.0
Tetrachloroethylene	200
Trichloroethylene	23
Vinyl chloride	10

VOCs samples are collected by canisters and were analyzed by gas chromatography/mass spectrophotometer following the US EPA TO-15 procedure. The schematic diagram of VOCs measurement is as shown in Figure 2.1.

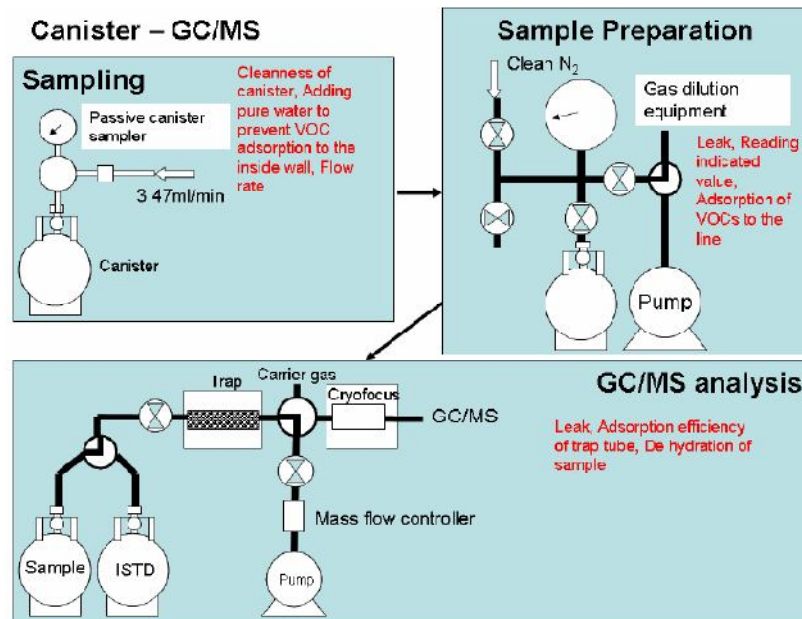


Figure 2.1 Schematic diagram of VOCs measurement (PCD, 2006)

2.2.1 VOCs situation in Maptaphut

Pollution problems at Maptaphut were highlighted in 2006 when villagers living nearby complained about health-related problems and the unusual high number of some cancers. They claimed the illnesses were caused by air and water pollution from the factories.

The annual average concentration of benzene, 1,3-butadiene, chloroform, dichloromethane, 1,2-dichloroethane, 1,2-dichloropropane, tetrachloroethylene, trichloroethylene and vinyl chloride in Maptaphut were reported by Pollution Control Department as shown in Figure 2.2-2.10.

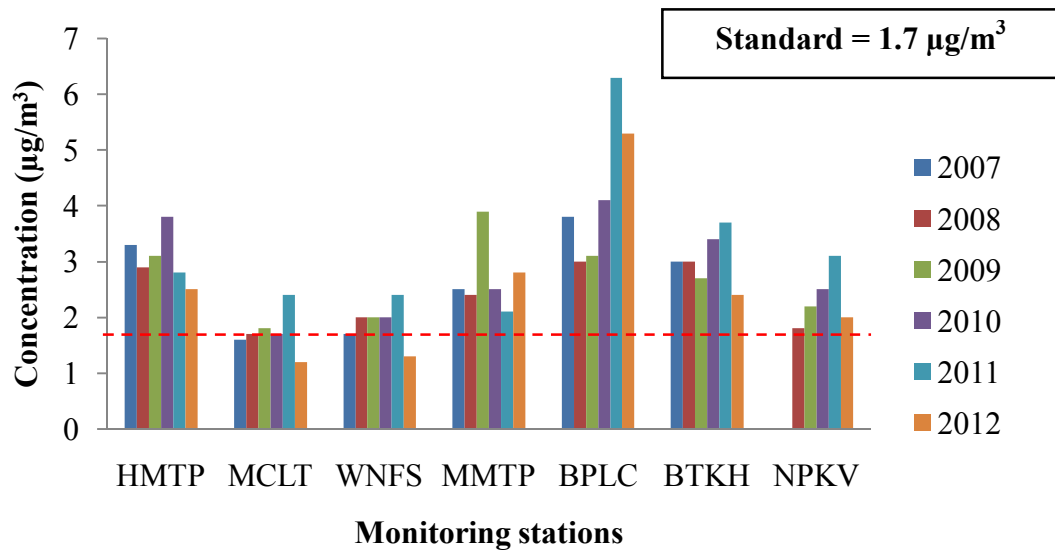


Figure 2.2 Annual average concentration of benzene in Maptaphut

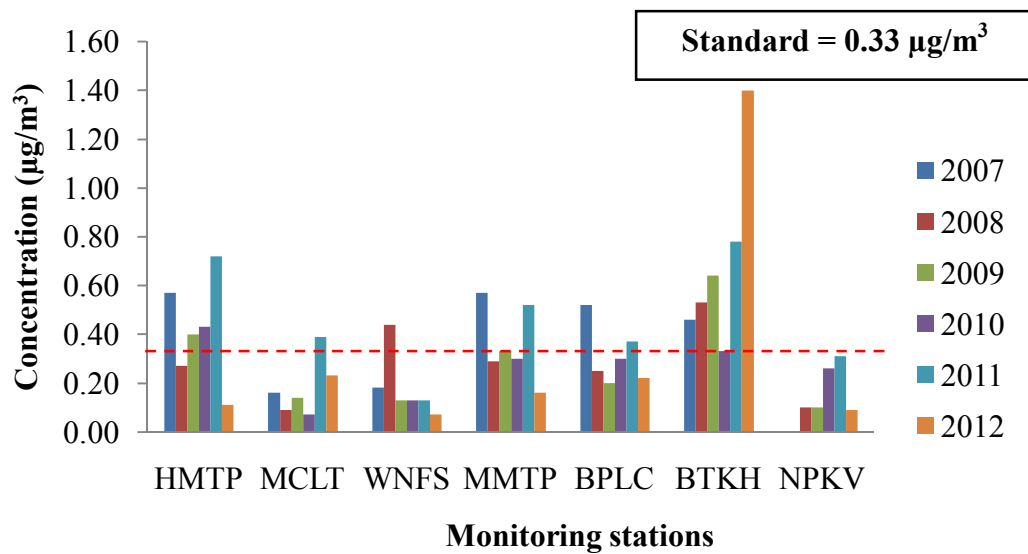


Figure 2.3 Annual average concentration of 1,3-butadiene in Maptaphut

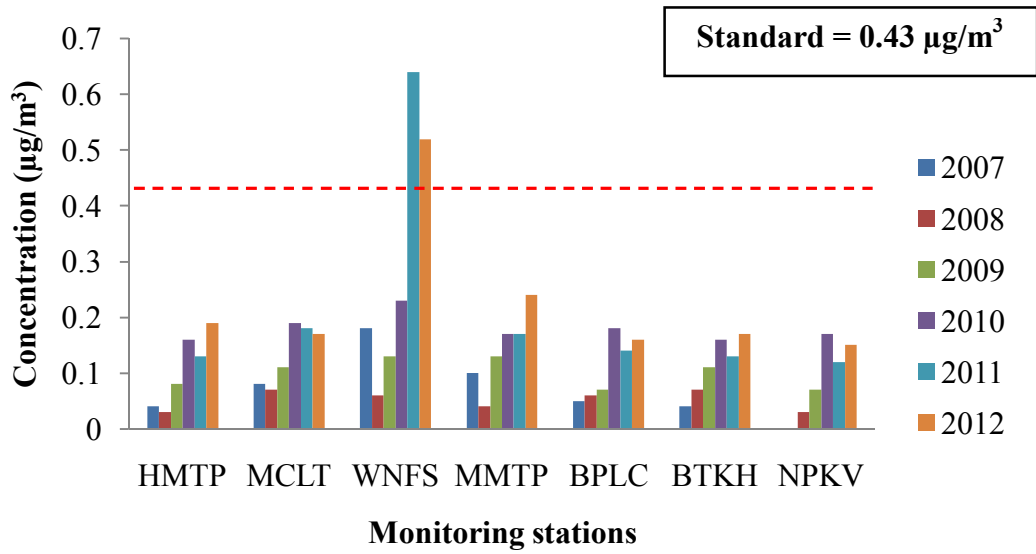


Figure 2.4 Annual average concentration of chloroform in Maptaphut

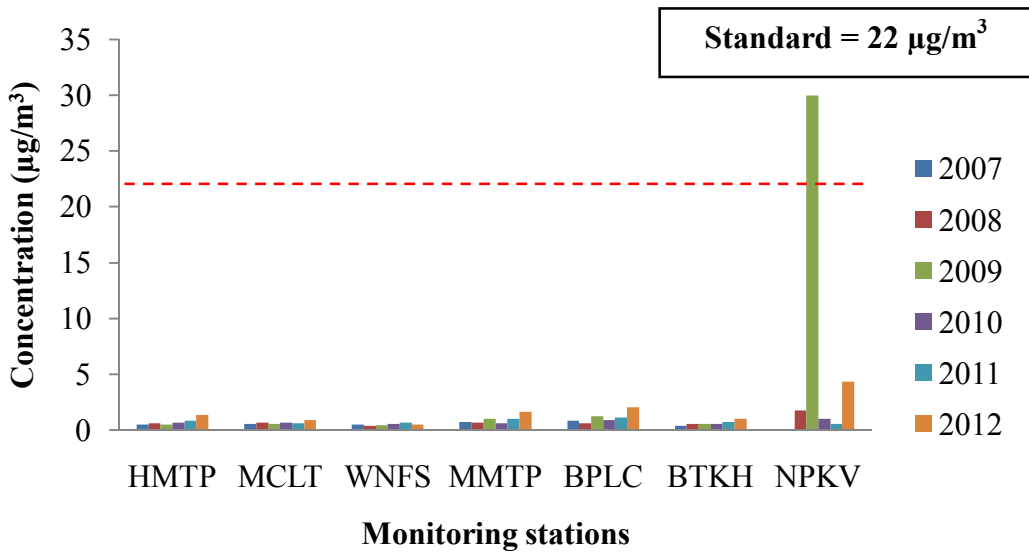


Figure 2.5 Annual average concentration of dichloromethane in Maptaphut

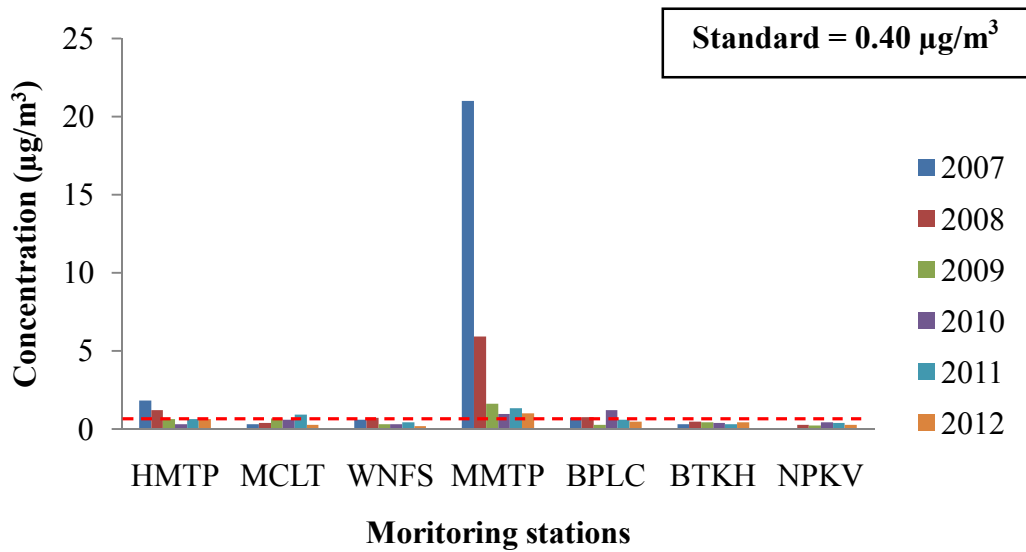


Figure 2.6 Annual average concentration of 1,2-dichloroethane in Maptaphut

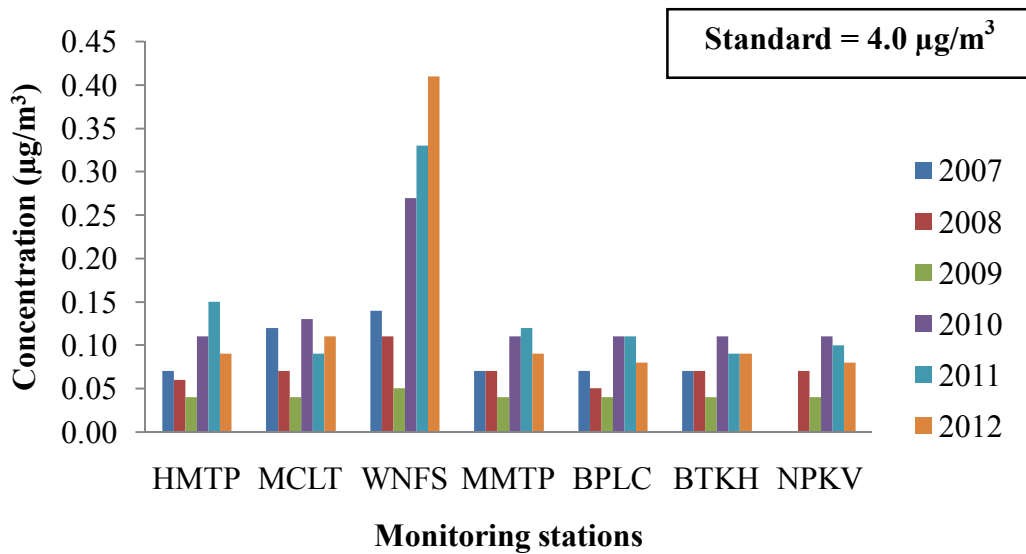


Figure 2.7 Annual average concentration of 1,2-dichloropropane in Maptaphut

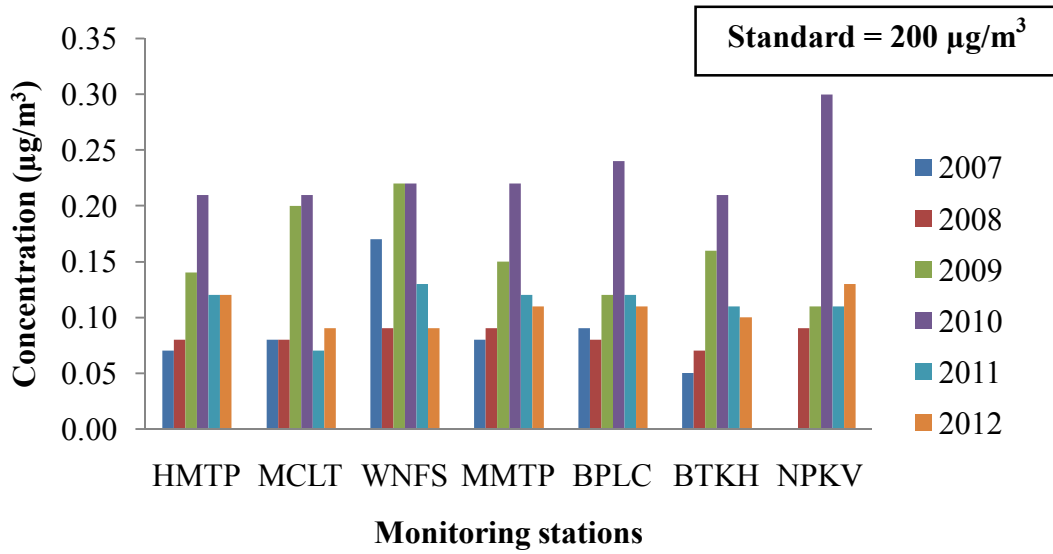


Figure 2.8 Annual average concentration of tetrachloroethylene in Maptaphut

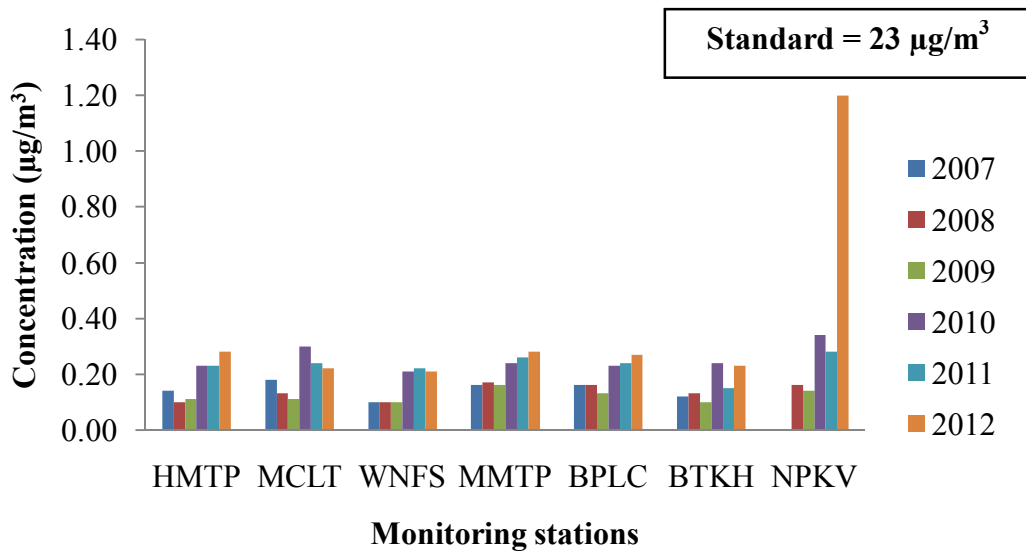


Figure 2.9 Annual average concentration of trichloroethylene in Maptaphut

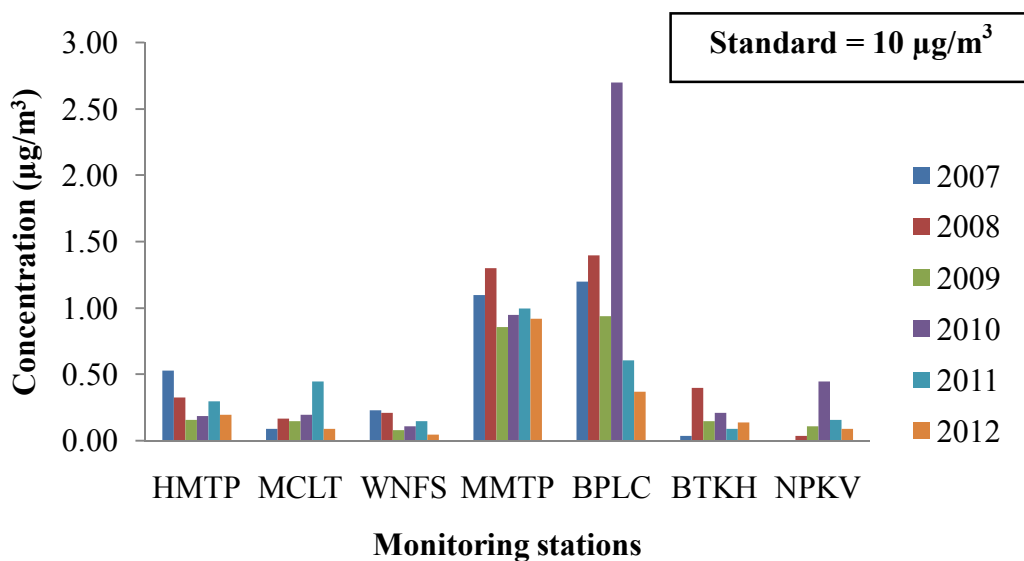


Figure 2.10 Annual average concentration of vinyl chloride in Maptaphut

As shown in Figure 2.2 – 2.10, the VOCs monitoring data in 2007-2012, there were five compounds namely benzene, 1,3-butadiene, chloroform, dichloromethane and 1,2-dichloroethane which their concentration were higher than the Thai annual VOCs standards.

2.3 Source apportionment and identification

2.3.1 Diagnostic ratios

Different organic compounds have different sources and reactivity in the atmosphere, some of their ratios are frequently used to get preliminary information on their sources and transport (Yurdakul et al., 2013).

Yurdakul et al. (2013) used that toluene to benzene ratio (T/B) as an indicator of the non-traffic source contributions. Low T/B ratios (<2.0) are used as indicator of strong influence of motor vehicle emissions on measured VOCs concentrations, whereas ratios more than 2.0 are suggested to indicate contribution from non-traffic sources. The toluene to ethylbenzene (T/E), benzene to ethylbenzene (B/E) and xylene to ethylbenzene (X/E) ratios are useful tool to understand the photochemical age of the VOCs. The ratios between the concentrations of benzene,

toluene, ethylbenzene and xylenes (BTEX ratios) are useful information to infer the sources of ambient concentration of various VOCs (Mohan & Ethirajan, 2012).

VOCs against benzene (VOCs/Bz) ratio was explored by Hoshi et al. (2008) to identify emission sources of VOCs in Tokyo. Moreover, they found that VOCs/Bz ratio can be applied to estimating non-registered VOCs and suggested the possibility of estimating emission sources from VOCs monitoring data.

2.3.2 Receptor Models

Receptor models such as Chemical Mass Balance (CMB) (Anderson et al., 2002), Positive Matrix Factorization (PMF) (Chueinta et al., 2000; Yurdakul, et al., 2013), Principle Component Analysis/Absolute Principle Component Scores (PCA/APCS) and UNMIX (Hopke et al., 2005; Song et al., 2006) have been widely used for estimating source contributions for outdoor air pollution. However, receptor models have more demanding requirements. For example, CMB requires specifications of the complete emission inventory of a region, which may not be always available. The PMF and PCA require sampling of a large number of VOCs variables with small uncertainties (Parao, 2012).

An overview of the wide range of statistical models and modeling approaches is as shown in Figure 2.11.

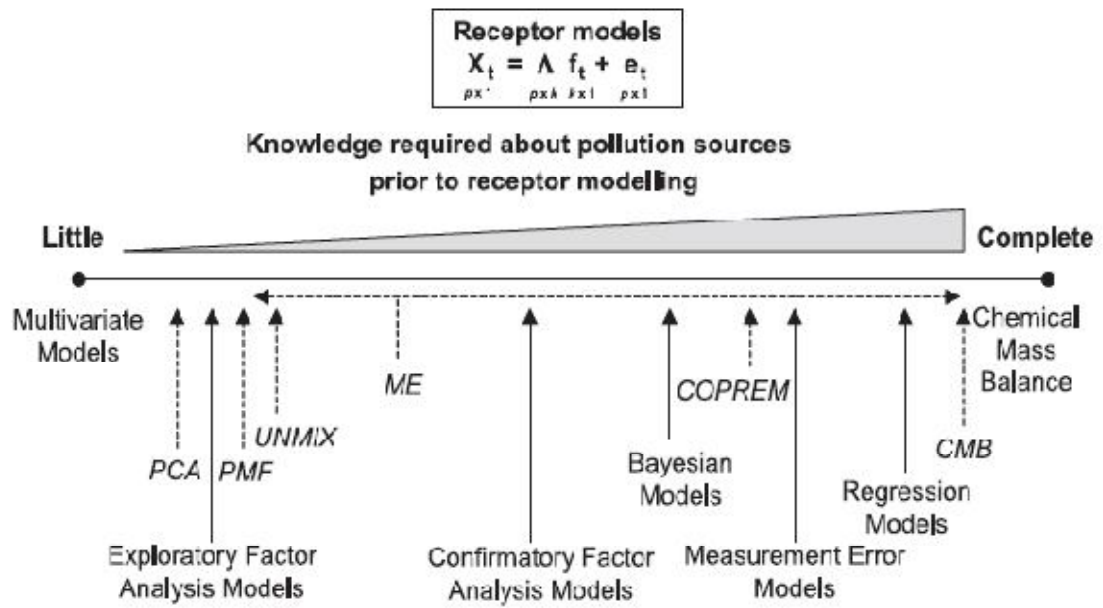


Figure 2.11 Approaches for estimating pollution source contributions using receptor models. Specific models are shown in italics and with dotted arrows (Viana, et al., 2008).

One of the main differences between models is the degree of knowledge required about the pollution sources prior to the application of receptor models. The two main extremes of receptor models are chemical mass balance (CMB) and multivariate models. The CMB model assumes knowledge of the composition of the emissions for all relevant sources. If changes of the source profiles between the emitter and the receptor may be considered minimal, CMB can be regarded as the ideal receptor model. However, these requirements are almost never completely fulfilled, and thus, pure CMB approaches are often problematic. One important characteristic of CMB is that secondary aerosols must be included not as components of emission source profiles but as specific, single chemical compounds. This absence of mixture with other tracer elements is often regarded as a limitation, and may lead to misinterpretation of results. Principal component/factor analysis (e.g., principal component analysis or PCA, positive matrix factorisation or PMF, UNMIX) attempts to apportion the sources on the basis of observations (internal correlations) at the receptor site alone. These are commonly used tools, because software to perform this type of analysis is widely available and detailed prior knowledge of the sources and source profiles is not required. The choice of the model dimension and the search for

non-negative solutions by axis rotations can be based entirely on mathematical criteria. Nevertheless, it has been suggested that factor analysis attempts to get more information out of atmospheric data than is really there. Furthermore, it is a common problem that the resulting components or factors may represent mixtures of emission sources, as opposed to clearly independent source profiles. Source signatures that change with time are a limitation for this and other types of receptor models (Viana, et al., 2008).

2.4 Related Research

Anderson et al., (2002) apply four receptor models namely chemical mass balance model, principal component analysis/absolute principal component scores, positive matrix factorization, and graphical ratio analysis for composition estimates/source apportionment by factors with explicit restriction of toxic volatile organic compounds (VOCs). The measurements are from the total exposure assessment methodology studies conducted from 1980 to 1984 in New Jersey (NJ) and California (CA) and the 1987–1990 CA Indoor Exposure study. They reported that major sources of personal exposure to toxic VOCs appear to have been aromatic sources resembling automobile exhaust, gasoline vapor, or environmental tobacco smoke, and a 1,1,1-trichloroethane-dominated source that may be associated with solvent or pesticide use. Dry cleaning chemicals, deodorizers or mothballs, and building materials or carpet emissions also appear to have been significant sources of exposure. Source apportionment results from the four models agreed reasonably well for the NJ data. The performance of the models was generally poorer for the CA data, and the corresponding source apportionment results were less consistent across the models.

Lee et al., (2002) identify, quantify and characterize volatile organic compounds (VOCs) in different urban areas in Hong Kong. The spatial distribution, temporal variation as well as correlations of VOCs at five roadside sampling sites were discussed. Twelve VOCs were routinely detected in urban areas (Mong Kok, Kwai Chung, Yuen Long and Causeway Bay). Among all of the VOC species, toluene

has the highest concentration. Benzene, toluene, ethylbenzene and xylenes (BTEX) were the major constituents (more than 60% in composition of total VOC detected), mainly contributed from mobile sources. Similar to other Asian cities, the VOCs levels measured in urban areas in Hong Kong were affected both by automobile exhaust and industrial emissions. High toluene to benzene ratios (average T/B ratio = 5) was also found in Hong Kong as in other Asian cities. In general, VOCs concentrations in the winter were higher than those measured in the summer (winter to summer ratio > 1). As toluene and benzene were the major pollutants from vehicle exhausts, there is a necessity to tighten automobile emission standards in Hong Kong.

Miller et al., (2002) apply four receptor-oriented source apportionment models. Data were evaluated to simulate personal exposure from selected VOCs that were generated by Monte Carlo sampling from known source contributions and profiles. The exposure sources modeled were environmental tobacco smoke, paint emissions, cleaning and/or pesticide products, gasoline vapors, automobile exhaust, and wastewater treatment plant emissions. The receptor models used in the analysis were chemical mass balance, principal component analysis/absolute principal component scores, positive matrix factorization (PMF), and graphical ratio analysis for composition estimates/source apportionment by factors with explicit restriction, incorporated in the UNMIX model. All models identified only the major contributors to total exposure concentrations. Results from the analysis indicated that PMF extracted factor profiles that most closely represented the major sources used to generate the simulated data. None of the models were able to distinguish between sources with similar chemical profiles.

Hoshi et al., (2008) investigate 54 species of comprehensive and representative hydrocarbons and aldehydes in the atmosphere at urban and roadside areas in Tokyo metropolitan area, Japan. They found that the annual average concentrations of individual volatile organic compounds (VOCs) at the roadside site were 1.7–1.9 times higher than at the urban site, suggesting that vehicle exhausts strongly affect VOCs concentrations. The VOC concentrations against benzene (VOC/Bz) suggest classifying three groups of VOCs: those mainly from mobile emission sources, those mainly from stationary sources, and those comprising unstable compounds such as aldehydes and 1,3-butadiene. The VOC/Bz technique was applied

to registered VOCs data from the Pollutant Release and Transfer Register (PRTR). Results show that these VOCs in ambient air in Tokyo reflect the PRTR estimated release amounts. The VOC/Bz technique based on environmental monitoring data is useful to estimate non-registered VOCs such as butane and isopentane. Results show the possibility of estimating emission sources using VOC/Bz ratios from environmental monitoring data, even when sufficient information on the emission sources are not available.

Liu et al., (2008) apply the chemical mass balance (CMB) receptor model to the source apportionment of 58 hydrocarbons measured at seven sites in a field campaign that examined regional air quality in the Pearl River Delta (PRD) region in the fall of 2004. A total of 12 VOCs emission sources were considered, including gasoline- and diesel-powered vehicle exhausts, headspace vapors of gasoline and diesel fuel, vehicle evaporative emissions, liquid petroleum gas (LPG) leakage, paint vapors, asphalt emissions from paved roads, biomass combustion, coal combustion, the chemical industry, and petroleum refineries. Results indicated that vehicle exhaust was the largest source of VOCs, contributing to more than 50% of ambient VOCs at the three urban sites including Guangzhou, Foshan, and Zhongshan, respectively. LPG leakage played an important role, representing 8–16% of emissions at most sites in the PRD. Solvent usage was the biggest emitter of VOCs at Dongguan, an industrial site, contributing 33% of ambient VOCs. Similarly, at Xinken, a non-urban site, the evaporation of solvents and coatings was the largest emission source, accounting for 31% of emissions, probably because it was downwind of Dongguan. Local biomass combustion was a noticeable source of VOCs at Xinken; although its contribution was estimated at 14.3%, biomass combustion was the third largest VOC source at this site.

Song et al., (2008) compared VOCs sources in Beijing, China based on chemical mass balance (CMB), UNMIX, and positive matrix factorization (PMF) models. Gasoline-related sources, petrochemical production, and liquefied petroleum gas (LPG) were identified by all three models as the major contributors, with UNMIX and PMF producing quite similar results. The contributions of gasoline-related sources and LPG estimated by the CMB model were higher, and petrochemical emissions were lower than in the UNMIX and PMF results, possibly because the VOCs profiles

used in the CMB model were for fresh emissions and the profiles extracted from ambient measurements by the two-factor analysis models were aged.

Cai et al., (2010) investigated the emission source of VOCs in Shanghai, China. VOCs were measured from 2007 to 2010 at the center of Shanghai. The results showed that the measured VOC concentrations were dominated by alkanes 43%, aromatics 30%, halo-hydrocarbons 14% and alkenes 6%, respectively. A positive matrix factorization (PMF) coupled with the information related to VOC sources (the distribution of major industrial complex, meteorological conditions, etc.) was applied to identify the major VOCs sources in Shanghai based on the measured VOCs concentrations. The result identified seven major VOCs sources, including vehicle related source which contributed to 25% of the measured VOCs concentrations, solvent based industrial source to 17%, fuel evaporation to 15%, paint solvent usage to 15%, steel related industrial production to 12%, biomass/bio-fuel burning to 9%, and coal burning to 7%. VOCs concentrations were generally higher in the weekdays than in the weekends at the sampling site, suggesting that traffic conditions and human activities had important impacts on the VOCs emissions in Shanghai.

CHAPTER III

METHODOLOGY

3.1 Data Collection

VOCs ambient concentrations were obtained from Pollution Control Department (PCD). These data were measured in Maptaphut sub-district, Rayong province and Bangkok province, Thailand from January 2009 to December 2012. VOCs samples were collected by 6 liter evacuated canisters (0.05 mmHg) and were analyzed using gas chromatography/mass spectrophotometer (GC/MS).

The analyze method was based on US.EPA TO15. When the canisters were opened to the atmosphere, the VOCs sample was introduced into the canisters by the differential pressure between atmospheric pressure and vacuum pressure inside each canister. With a flow controller, the sub-atmospheric sampling system maintained a constant flow rate from full vacuum to within about 7 kPa (1.0 psi) or less below ambient pressure. Canister flow rate was controlled by flow controller and was adjusted to 3.3 ml/minute for 24-h sampling. After collecting the ambient VOCs, the sample canister was pressurized by humidified nitrogen about 20 psia in order to prevent the contamination entering the sample canister. Samples were transferred to the thermal desorption unit, working as a preconcentrator prior to being sent to GC/MS (Thepanondh et al., 2011).

Forty-two compounds in each sample were analyzed and reported on a monthly basis. List of measured VOCs were as follows:

1. Freon 11 (Trichlorofluoromethane)
2. Freon 12 (Dichlorodifluoromethane)
3. Freon 113 (1,1,2-Trichloro-1,2,2-trifluoroethane)
4. Freon 114 (Dichlorotetrafluoroethane)
5. Chloromethane (Methyl chloride)
6. Vinyl chloride

7. 1,3 – Butadiene
8. Bromomethane (Methyl bromide)
9. Chloroethane
10. 1,1-Dichloroethylene
11. Acrylonitrile
12. 3-Chloropropene
13. Dichloromethane
14. 1,1-Dichloroethane
15. 1,2-Dichloroethane
16. cis-1,2-Dichloroethylene
17. Chloroform
18. 1,1,1-Trichloroethane
19. Benzene
20. Carbon tetrachloride
21. Trichloroethylene
22. 1,2-Dichloropropane
23. Hexachloro-1,3-butadiene
24. 1,2,4-Trichlorobenzene
25. 1,2-Dichlorobenzene
26. 1,3-Dichlorobenzene
27. 1,4-Dichlorobenzene
28. Benzyl Chloride
29. 1,2,4-Trimethylbenzene
30. 1,3,5-Trimethylbenzene
31. 1-Ethyl-4-methylbenzene
32. 1,1,2,2-Tetrachloroethane
33. o,m,p-Xylene (Total Xylene)
34. Styrene
35. Ethylbenzene
36. Chlorobenzene
37. 1,2-Dibromoethane
38. Tetrachloroethylene

39. cis-1,3-Dichloropropene
40. 1,1,2-Trichloroethane
41. trans-1,3-Dichloropropene
42. Toluene

3.2 Treatment of data

The VOCs ambient concentrations data obtained from Pollution Control Department (PCD) were treated by using the assumption that if the data has “less than” sign (<), it was divided by two of that value and if it has “no data”, it will be replaced by zero. The example of data treatment was shown in Table 3.1.

Table 3.1 The example of data treatment

Compounds	Concentration ($\mu\text{g}/\text{m}^3$)	
	Data	Data treatment
Freon 114	<0.12	0.06
1,3-Butadiene	<0.04	0.02
Acrylonitrile	no data	0.00

3.3 About the monitoring site

3.3.1 Maptaphut sub-district, Rayong

There were seven VOCs monitoring stations in Maptaphut area. Monitoring stations were located at Health Promotion Hospital Maptaphut, Ban Ta Kuan Public Health Center, Wat Nong Fap School, Muang Mai Maptaphut, Map Chalut Temple, Ban Plong Community and Nop Pakate Village, respectively. Spatial distribution of monitoring sites was as shown in Figure 3.1 and information of the site characteristic was as shown in Table 3.1.

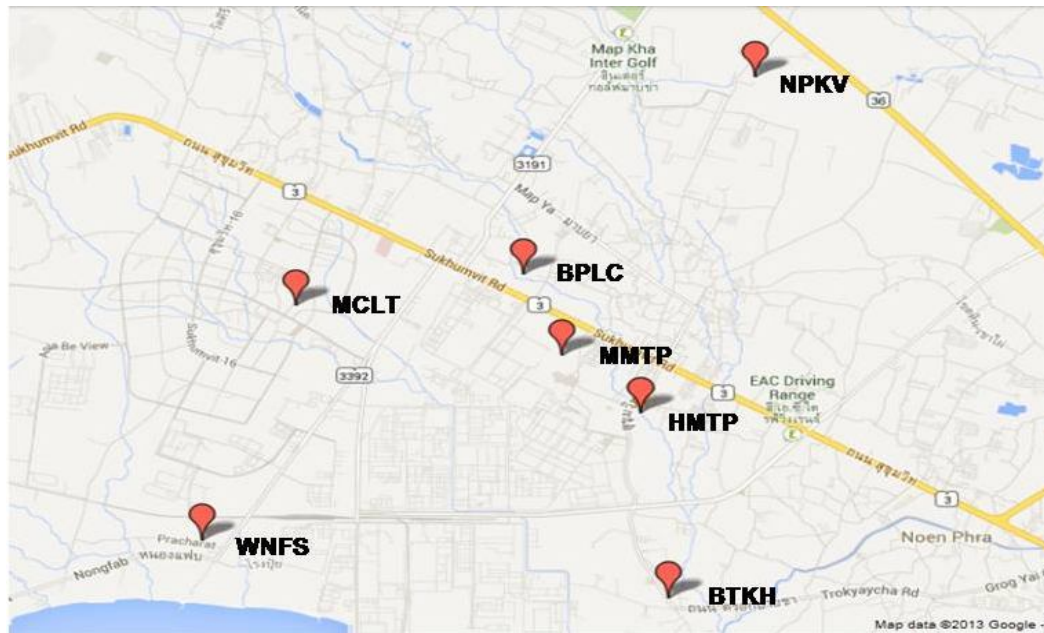


Figure 3.1 Location of stations for VOCs monitoring in Maptaphut (Google, 2013)

Table 3.2 Information of the site characteristic

Monitoring Site	Direction from Maptaphut complex	Distance from Maptaphut complex (km)	Distance to the nearest road (km)	Distance to main road (km)
Health Promotion Hospital Maptaphut (HMTP)	Northeast	0.62	0.03	0.64 (No.3)
Ban Ta Kuan Public Health Center (BTKH)	Southeast	0.98	0.01	3.23 (No.3)
Wat Nong Fap School (WNFS)	Northwest	1.50	0.02	0.02 (No.3392)
Muang Mai Maptaphut (MMTP)	Northeast	0.32	0.08	0.29 (No.3)
Map Chalut Temple (MCLT)	Northwest	1.68	0.04	1.55 (No.3)
Ban Plong Community (BPLC)	Northeast	0.80	0.25	0.63 (No.3)
Nop Pakate Village (NPKV)	Northeast	0.22*	0.01	0.62 (No.36)

Note - * The distance of Nop Pakate Village station was measured from RIL industrial complex

- Main road : Sukhumvit road (route No.3), route No. 36 and route No. 3392

3.3.2 Dindaeng, Bangkok

Dindaeng was a roadside monitoring station, located in Bangkok. This station was used to represent a profile of VOCs influenced by vehicle emissions because since it was not affected by any industrial sources. Location of the monitoring site was as shown in Figure 3.2.



Figure 3.2 Location of Dindaeng monitoring station (Google, 2013)

3.4 Source apportionment and identification

3.4.1 Diagnostic ratio

3.4.1.1 VOCs against benzene ratio (VOCs/Bz)

VOCs/Bz ratio was used to investigate and estimate the relative contributions of stationary and mobile sources of each VOC. Due to benzene has a low potency of ozone formation; its reaction in the atmosphere is known to proceed more slowly than the other. (Hoshi et al, 2008). Then benzene was selected as the reference compound in this study. The forty-two diagnostic ratios will be used in this study as follows:

1. Freon 11/Bz
22. Hexachloro-1,3-butadiene/Bz

2. Freon 12/Bz
3. Freon 113/Bz
4. Freon 114/Bz
5. Chloromethane/Bz
6. Vinyl chloride/Bz
7. 1,3 – Butadiene/Bz
8. Bromomethane/Bz
9. Chloroethane/Bz
10. 1,1-Dichloroethylene/Bz
11. Acrylonitrile/Bz
12. 3-Chloropropene/Bz
13. Dichloromethane/Bz
14. 1,1-Dichloroethane/Bz
15. 1,2-Dichloroethane/Bz
16. Styrene/Bz
17. Chloroform/Bz
18. 1,1,1-Trichloroethane/Bz
19. Carbon tetrachloride/Bz
20. Trichloroethylene/Bz
21. 1,2-Dichloropropane/Bz
23. 1,2,4-Trichlorobenzene/Bz
24. 1,2-Dichlorobenzene/Bz
25. 1,3-Dichlorobenzene/Bz
26. 1,4-Dichlorobenzene/Bz
27. Benzyl Chloride/Bz
28. 1,2,4-Trimethylbenzene/Bz
29. 1,3,5-Trimethylbenzene/Bz
30. 1-Ethyl-4-methylbenzene/Bz
31. 1,1,2,2-Tetrachloroethane/Bz
32. Total Xylene (o,p,m-Xylene) /Bz
33. cis-1,2-Dichloroethylene/Bz
34. Ethylbenzene/Bz
35. Chlorobenzene/Bz
36. 1,2-Dibromoethane/Bz
37. Tetrachloroethylene/Bz
38. cis-1,3-Dichloropropene/Bz
39. 1,1,2-Trichloroethane/Bz
40. trans-1,3-Dichloropropene/Bz
41. Toluene/Bz
42. Total VOCs/Bz

3.4.1.2 BTEX concentration ratios

The BTEX concentration ratio was used to investigate and estimate the relative contributions of mobile sources in this study. Benzene (B), toluene (T), ethylbenzene (E) and xylene (X) are the component of vehicle fuel therefore using BTEX ratio can better identify the source of VOCs particularly when comparing with those analytical data in roadside area.

3.4.2 Principal component analysis (PCA)

Assuming a linear relationship between the total mass concentration and the contributions of each species, PCA factors the data in several steps. First, the chemical composition data are transformed into a dimensionless standardized form:

$$Z_{ij} = \frac{C_{ij} - \bar{C}_j}{\sigma_j}$$

Where ; $i = 1, \dots, n$ samples

$j = 1, \dots, m$ elements

C_{ij} = The concentration of element j in sample i

\bar{C}_j = The arithmetic mean concentration for element j

σ_j = The standard deviation for element j

The PCA model is expressed as

$$Z_{ij} = \sum_{k=1}^p g_{ik} h_{kj}$$

Where; $k = 1, \dots, p$ sources

g_{ik} = The factor loadings

h_{kj} = The factor scores, respectively

This equation is solved by eigenvector decomposition. Varimax rotation is often used to redistribute the variance and provide a more interpretable structure to the factors (Song et al, 2006).

VOCs ambient concentrations from seven monitoring sites in Maptaphut, Rayong and a monitoring sites in Bangkok (Dindaeng) were analyzed using principal component analysis (PCA) to classify the group of VOCs based on emission source. This receptor model was analyzed using a SPSS (PASW Statistics 18.0) software. This was performed by using the orthogonal transformation method with varimax rotation and retention of principal components whose eigenvalues were greater than unity. Factor loadings indicate the correlation of each pollutant species with each component and are related to the source emission composition. SPSS setting for PCA was shown as follows.

Analyze mode: Data reduction (Factor analysis)

Descriptives

Statistics: Initial solution

Correlation matrix: Coefficients

Extraction

Method: Principal components

Analyze: Correlation matrix

Display: Unrotated factor solution, Scree plot

Extract: Eigenvalues over 1

Rotation

Method: Varimax

Display: Rotated solution

3.5 Spatial and temporal evaluation

The diagnostic ratio data from each site in each year was used for the spatial and temporal evaluation because the regulation was different in each year, for instance the policy of the change fuel from EURO2 to EURO4 in 2012 to reduce benzene concentration in gasoline. Principle component analysis data in 2009-2012 from each site was performed in order to evaluate spatial variability of VOCs emission sources.

CHAPTER IV

RESULTS AND DISCUSSIONS

Concentration of VOCs, the results of VOC against benzene ratios, BTEX concentration ratios and source apportionment analysis using principal component analysis were showed in this chapter. The details were as follows.

4.1 Concentration of VOCs

VOCs were measured in Maptaphut area and Dindaeng (Bangkok) from January 2009 to December 2012 on a monthly basis. The concentrations of forty-two compounds were as summarized in Table 4.1-4.8.

Table 4.1 Concentration of VOCs ($\mu\text{g}/\text{m}^3$) at Health Promotion Hospital Maptaphut (HMTP) monitoring station

VOCs	Concentration ($\mu\text{g}/\text{m}^3$)			
	2009	2010	2011	2012
Freon 12	0.00-2.10	1.50-3.50	0.00-5.90	1.50-4.70
Freon 114	0.00-0.28	0.01-0.43	0.00-0.68	0.03-0.07
Chloromethane	0.00-1.30	0.01-1.60	0.01-1.60	0.77-2.50
Vinyl chloride	0.01-0.90	0.01-0.47	0.01-1.70	0.01-1.30
1,3-Butadiene	0.01-1.90	0.01-2.10	0.01-2.90	0.01-1.10
Bromomethane	0.01-0.45	0.02-1.30	0.01-0.91	0.02-1.80
Chloroethane	0.01-0.08	0.01-0.10	0.01-0.17	0.01-0.02
Freon 11	0.36-1.30	0.45-1.20	0.70-1.30	0.63-1.50
1,1-Dichloroethylene	0.01-0.02	0.02-0.03	0.01-0.02	0.02-0.04
Freon 113	0.00-0.63	0.00-0.87	0.00-1.10	0.06-1.10
Acrylonitrile	0.01-0.39	0.01-0.56	0.01-0.60	0.01-0.45
3-Chloropropene	0.01-0.02	0.01-0.02	0.00-0.02	0.00-0.03

Table 4.1 Concentration of VOCs ($\mu\text{g}/\text{m}^3$) at Health Promotion Hospital Maptaphut (HMTP) monitoring station (cont.)

VOCs	Concentration ($\mu\text{g}/\text{m}^3$)			
	2009	2010	2011	2012
Dichloromethane	0.03-1.60	0.04-2.20	0.05-2.40	0.04-3.70
1,1-Dichloroethane	0.00-0.02	0.01	0.01-0.03	0.00-0.03
cis-1,2-Dichloroethylene	0.01-0.02	0.01	0.00-0.02	0.02-0.04
Chloroform	0.01-0.43	0.01-0.49	0.01-0.50	0.03-0.45
1,1,1-Trichloroethane	0.00-0.06	0.00-0.90	0.01-0.37	0.03-0.06
1,2-Dichloroethane	0.00-2.80	0.01-0.96	0.02-1.60	0.04-3.60
Benzene	1.80-5.50	1.40-6.70	1.70-4.70	0.91-5.70
Carbon Tetrachloride	0.00-0.97	0.00-1.50	0.00-0.80	0.06-0.71
Trichloroethylene	0.01-0.74	0.01-0.63	0.01-1.10	0.02-0.24
1,2-Dichloropropane	0.01-0.20	0.01-0.80	0.01-0.63	0.03-0.05
cis-1,3-Dichloropropene	0.00-0.02	0.00-0.01	0.01-0.02	0.02
Toluene	4.10-37.00	4.80-36.00	3.00-27.00	3.20-120.00
trans-1,3-Dichloropropene	0.00-0.03	0.00-0.02	0.01-0.02	0.02
1,1,2-Trichloroethane	0.01-0.02	0.01-0.53	0.01-0.12	0.03-0.04
Tetrachloroethylene	0.01-0.58	0.01-0.66	0.02-0.61	0.03-0.18
1,2-Dibromoethane	0.00-0.03	0.00-0.06	0.01-0.03	0.03-0.22
Chlorobenzene	0.00-0.65	0.01-0.48	0.02-0.58	0.02-0.46
Ethylbenzene	0.00-5.10	0.35-3.90	0.64-2.70	0.00-4.20
Total Xylene	0.00-8.80	1.08-5.40	1.30-7.90	0.99-5.80
Styrene	0.00-2.00	0.02-1.00	0.19-1.80	0.00-1.20
1,1,2,2-Tetrachloroethane	0.00-0.03	0.02	0.00-0.03	0.03-0.05
1-Ethyl-4-methylbenzene	0.00-1.90	0.00-1.30	0.02-2.20	0.00-1.80
1,3,5-Trimethylbenzene	0.00-1.40	0.00-0.98	0.00-1.10	0.00-1.30
1,2,4-Trimethylbenzene	0.00-4.00	0.00-4.30	0.00-3.40	0.00-3.70
1,3-Dichlorobenzene	0.00-0.03	0.00-0.06	0.00-0.79	0.00-0.82
Benzyl Chloride	0.00-0.04	0.01-1.80	0.01-0.02	0.02-0.04
1,4-Dichlorobenzene	0.00-0.21	0.00-0.51	0.02-0.95	0.02-1.40
1,2-Dichlorobenzene	0.00-0.03	0.00-0.03	0.00-0.75	0.00-0.61
1,2,4-Trichlorobenzene	0.00-0.18	0.00-0.09	0.00-0.01	0.00-1.40
Hexachloro-1,3-butadiene	0.00-0.14	0.00-0.15	0.00-0.16	0.00-0.60

Table 4.2 Concentration of VOCs ($\mu\text{g}/\text{m}^3$) at Ban Ta Kuan Public Health Center (BTKH) monitoring station

VOCs	Concentration ($\mu\text{g}/\text{m}^3$)			
	2009	2010	2011	2012
Freon 12	0.00-2.00	1.40-4.00	0.00-7.60	1.50-12.00
Freon 114	0.00-0.46	0.01-0.47	0.00-0.72	0.03-0.07
Chloromethane	0.00-5.60	0.01-1.90	0.01-1.60	0.77-2.40
Vinyl chloride	0.01-0.94	0.01-1.60	0.01-0.45	0.01-1.20
1,3-Butadiene	0.01-4.40	0.02-0.99	0.01-4.50	0.01-10.00
Bromomethane	0.01-0.46	0.01-0.35	0.01-0.52	0.02-0.13
Chloroethane	0.00-0.08	0.01-0.28	0.01-0.18	0.01-0.03
Freon 11	0.25-1.20	0.47-1.40	0.60-1.30	0.46-1.40
1,1-Dichloroethylene	0.00-0.20	0.02-0.04	0.02	0.02-0.04
Freon 113	0.00-1.10	0.00-0.85	0.00-1.10	0.06-0.93
Acrylonitrile	0.01-0.81	0.01-0.60	0.01-1.70	0.01-1.80
3-Chloropropene	0.01-0.02	0.01-0.03	0.00-0.02	0.00-0.03
Dichloromethane	0.02-1.90	0.04-2.00	0.12-2.10	0.13-2.50
1,1-Dichloroethane	0.00-0.02	0.01	0.01-0.03	0.00-0.03
cis-1,2-Dichloroethylene	0.01-0.02	0.01	0.00-0.02	0.02-0.04
Chloroform	0.01-0.53	0.01-0.57	0.02-0.42	0.03-0.16
1,1,1-Trichloroethane	0.00-0.94	0.00-0.98	0.01-0.34	0.03-0.06
1,2-Dichloroethane	0.00-1.40	0.01-1.50	0.02-0.93	0.04-2.00
Benzene	0.98-6.00	1.10-6.50	0.72-20.00	0.53-4.30
Carbon Tetrachloride	0.00-1.60	0.00-1.70	0.00-0.78	0.06-0.67
Trichloroethylene	0.01-0.72	0.01-0.69	0.01-0.67	0.02-0.24
1,2-Dichloropropane	0.01-0.19	0.01-0.87	0.01-0.38	0.03-0.05
cis-1,3-Dichloropropene	0.00-0.02	0.00-0.01	0.01-0.02	0.02
Toluene	1.90-33.00	2.90-24.00	0.59-88.00	2.80-78.00
trans-1,3-Dichloropropene	0.00-0.03	0.00-0.02	0.01-0.02	0.02
1,1,2-Trichloroethane	0.01-0.03	0.01-0.59	0.02-0.04	0.03
Tetrachloroethylene	0.01-0.86	0.01-0.72	0.02-0.56	0.03-0.06
1,2-Dibromoethane	0.00-0.03	0.00-0.06	0.01-0.92	0.04
Chlorobenzene	0.00-1.70	0.01-0.47	0.02-1.00	0.02-1.10
Ethylbenzene	0.00-10.00	0.30-3.40	0.35-10.00	0.00-4.10

Table 4.2 Concentration of VOCs ($\mu\text{g}/\text{m}^3$) at Ban Ta Kuan Public Health Center (BTKH) monitoring station (cont.)

VOCs	Concentration ($\mu\text{g}/\text{m}^3$)			
	2009	2010	2011	2012
Total Xylene	0.00-12.00	1.55-7.80	1.14-36.00	1.59-8.40
Styrene	0.00-4.90	0.07-1.10	0.10-8.10	0.00-2.00
1,1,2,2-Tetrachloroethane	0.00-0.03	0.01-0.02	0.00-0.26	0.04-0.05
1-Ethyl-4-methylbenzene	0.00-2.00	0.00-0.99	0.02-7.80	0.00-2.40
1,3,5-Trimethylbenzene	0.00-1.40	0.00-0.73	0.00-5.60	0.00-1.70
1,2,4-Trimethylbenzene	0.00-5.90	0.00-3.40	0.00-19.00	0.00-4.90
1,3-Dichlorobenzene	0.00-0.04	0.00-0.06	0.00-0.72	0.00-0.73
Benzyl Chloride	0.00-0.04	0.01-0.04	0.01-0.02	0.02-0.04
1,4-Dichlorobenzene	0.00-0.14	0.00-0.27	0.02-0.87	0.02-1.30
1,2-Dichlorobenzene	0.00-0.04	0.00-0.69	0.00-1.10	0.00-0.52
1,2,4-Trichlorobenzene	0.00-0.41	0.00-0.29	0.00-0.01	0.00-0.19
Hexachloro-1,3-butadiene	0.00-0.13	0.00-0.16	0.00-0.16	0.00-0.21

Table 4.3 Concentration of VOCs ($\mu\text{g}/\text{m}^3$) at Wat Nong Fap School (WNFS) monitoring station

VOCs	Concentration ($\mu\text{g}/\text{m}^3$)			
	2009	2010	2011	2012
Freon 12	0.00-2.20	1.50-4.80	0.00-5.50	1.70-4.50
Freon 114	0.00-0.40	0.01-0.45	0.00-0.72	0.03-0.07
Chloromethane	0.00-1.40	0.01-6.70	0.01-2.40	0.90-6.40
Vinyl chloride	0.01-0.48	0.01-0.51	0.01-0.68	0.01-0.18
1,3-Butadiene	0.01-0.58	0.01-0.79	0.01-0.84	0.01-0.50
Bromomethane	0.01-0.46	0.01-0.48	0.02-0.63	0.02-0.06
Chloroethane	0.01-0.08	0.01-0.10	0.01-0.20	0.01-0.03
Freon 11	0.43-1.20	0.50-1.20	0.68-2.50	0.56-1.40
1,1-Dichloroethylene	0.00-0.02	0.02-0.04	0.02	0.02-0.04
Freon 113	0.00-0.94	0.00-0.89	0.00-1.10	0.05-1.00
Acrylonitrile	0.01-0.39	0.01-0.54	0.01-2.20	0.01-1.80
3-Chloropropene	0.01-2.30	0.01-5.00	0.00-2.00	0.00-5.70

Table 4.3 Concentration of VOCs ($\mu\text{g}/\text{m}^3$) at Wat Nong Fap School (WNFS) monitoring station (cont.)

VOCs	Concentration ($\mu\text{g}/\text{m}^3$)			
	2009	2010	2011	2012
Dichloromethane	0.01-1.20	0.03-1.40	0.04-1.60	0.04-2.10
1,1-Dichloroethane	0.00-0.02	0.01	0.01-0.03	0.00-0.03
cis-1,2-Dichloroethylene	0.01-0.02	0.01-0.11	0.01-0.02	0.02-0.04
Chloroform	0.01-0.69	0.01-0.73	0.03-3.80	0.03-3.90
1,1,1-Trichloroethane	0.00-0.79	0.00-0.93	0.01-0.12	0.03-0.06
1,2-Dichloroethane	0.00-0.67	0.01-1.00	0.02-1.20	0.02-0.62
Benzene	0.34-4.10	0.12-4.50	0.40-11.00	0.23-3.80
Carbon Tetrachloride	0.00-1.40	0.00-1.60	0.00-1.10	0.05-0.65
Trichloroethylene	0.02-0.57	0.01-0.56	0.02-1.10	0.02-0.24
1,2-Dichloropropane	0.01-0.24	0.01-1.30	0.03-1.60	0.03-3.60
cis-1,3-Dichloropropene	0.00-0.11	0.00-0.90	0.01-0.71	0.02-0.24
Toluene	0.87-16.00	1.10-13.00	1.30-73.00	0.47-22.00
trans-1,3-Dichloropropene	0.00-0.20	0.00-12.00	0.01-0.02	0.01-0.02
1,1,2-Trichloroethane	0.01-0.03	0.01-0.55	0.02-0.10	0.03
Tetrachloroethylene	0.01-0.71	0.01-0.63	0.02-0.41	0.03-0.06
1,2-Dibromoethane	0.00-0.75	0.00-0.06	0.01-0.03	0.03-0.54
Chlorobenzene	0.00-0.62	0.01-0.46	0.02-0.28	0.02-0.34
Ethylbenzene	0.00-3.60	0.13-3.00	0.19-8.90	0.00-5.60
Total Xylene	0.00-10.10	0.25-6.80	0.75-22.90	0.55-9.10
Styrene	0.00-1.00	0.02-1.10	0.10-1.10	0.00-0.76
1,1,2,2-Tetrachloroethane	0.00-0.39	0.01-0.02	0.00-0.04	0.03-0.05
1-Ethyl-4-methylbenzene	0.00-1.30	0.00-1.20	0.02-2.50	0.00-1.60
1,3,5-Trimethylbenzene	0.00-0.92	0.00-0.78	0.00-0.98	0.00-1.10
1,2,4-Trimethylbenzene	0.00-1.60	0.00-2.70	0.00-4.20	0.00-2.50
1,3-Dichlorobenzene	0.00-0.04	0.00-0.06	0.01-0.83	0.00-0.72
Benzyl Chloride	0.00-0.04	0.01-0.04	0.01-0.02	0.02-2.00
1,4-Dichlorobenzene	0.00-0.09	0.00-0.17	0.02-1.00	0.02-1.30
1,2-Dichlorobenzene	0.00-0.04	0.00-0.07	0.02-0.79	0.00-0.47
1,2,4-Trichlorobenzene	0.00-1.60	0.00-0.09	0.00-0.01	0.00-0.20
Hexachloro-1,3-butadiene	0.00-0.13	0.00-0.15	0.00-0.15	0.00-0.20

Table 4.4 Concentration of VOCs ($\mu\text{g}/\text{m}^3$) at Muang Mai Maptaphut (MMTP) monitoring station

VOCs	Concentration ($\mu\text{g}/\text{m}^3$)			
	2009	2010	2011	2012
Freon 12	0.00-2.20	0.58-9.00	0.00-17.00	1.70-5.40
Freon 114	0.00-0.30	0.01-0.40	0.00-0.75	0.03-0.07
Chloromethane	0.00-3.60	0.01-1.70	0.01-1.60	0.80-2.40
Vinyl chloride	0.01-4.30	0.01-6.60	0.01-4.40	0.02-3.70
1,3-Butadiene	0.01-1.10	0.01-1.10	0.01-1.70	0.01-0.64
Bromomethane	0.01-0.61	0.02-0.52	0.02-0.63	0.02-3.30
Chloroethane	0.01-0.08	0.01-0.12	0.01-0.20	0.01-0.03
Freon 11	0.42-1.50	0.03-1.50	0.63-1.50	0.72-2.00
1,1-Dichloroethylene	0.00-0.02	0.02-0.09	0.01-0.02	0.02-0.04
Freon 113	0.00-0.89	0.00-0.86	0.00-1.20	0.06-0.92
Acrylonitrile	0.01-0.39	0.01-0.55	0.01-0.54	0.01-0.37
3-Chloropropene	0.01-0.02	0.01-0.04	0.00-0.02	0.00-0.03
Dichloromethane	0.04-3.50	0.04-2.40	0.02-2.40	0.02-0.04
1,1-Dichloroethane	0.00-0.02	0.01	0.01-0.03	0.03-0.57
cis-1,2-Dichloroethylene	0.01-0.39	0.00-0.02	0.00-0.02	0.03-0.06
Chloroform	0.01-0.47	0.01-0.55	0.01-0.53	0.04-5.20
1,1,1-Trichloroethane	0.00-0.79	0.00-0.85	0.01-0.34	0.03-0.06
1,2-Dichloroethane	0.00-7.60	0.02-3.50	0.02-5.40	0.04-5.20
Benzene	1.50-12.00	0.90-4.80	0.60-3.50	0.52-6.70
Carbon Tetrachloride	0.00-1.40	0.00-1.40	0.00-0.79	0.06-0.73
Trichloroethylene	0.01-0.72	0.01-0.65	0.01-1.20	0.02-0.67
1,2-Dichloropropane	0.01-0.21	0.01-0.81	0.01-0.39	0.03-0.05
cis-1,3-Dichloropropene	0.00-0.36	0.00-0.77	0.01-0.02	0.02
Toluene	3.90-47.00	3.20-51.00	1.40-41.00	1.50-74.00
trans-1,3-Dichloropropene	0.00-0.07	0.00-0.02	0.01-0.02	0.02
1,1,2-Trichloroethane	0.01-0.02	0.01-0.51	0.01-0.03	0.03
Tetrachloroethylene	0.01-0.73	0.01-0.65	0.02-0.56	0.03-0.18
1,2-Dibromoethane	0.00-0.51	0.00-0.06	0.01-0.04	0.03-0.04
Chlorobenzene	0.00-0.66	0.01-0.48	0.02-0.06	0.02-0.50
Ethylbenzene	0.00-5.00	0.29-3.70	0.51-2.30	0.00-4.00

Table 4.4 Concentration of VOCs ($\mu\text{g}/\text{m}^3$) at Muang Mai Maptaphut (MMTP) monitoring station (cont.)

VOCs	Concentration ($\mu\text{g}/\text{m}^3$)			
	2009	2010	2011	2012
Total Xylene	0.00-19.10	1.11-6.00	1.40-5.20	0.40-6.00
Styrene	0.00-1.10	0.02-0.59	0.21-1.20	0.00-1.40
1,1,2,2-Tetrachloroethane	0.00-1.20	0.02	0.00-0.04	0.04-0.05
1-Ethyl-4-methylbenzene	0.00-1.60	0.00-0.99	0.02-1.20	0.00-1.70
1,3,5-Trimethylbenzene	0.00-1.20	0.00-0.65	0.00-0.74	0.00-1.20
1,2,4-Trimethylbenzene	0.00-5.30	0.00-2.20	0.00-2.90	0.00-2.20
1,3-Dichlorobenzene	0.00-0.38	0.00-0.06	0.00-0.78	0.00-0.85
Benzyl Chloride	0.00-0.04	0.01-0.04	0.01-0.02	0.02-0.04
1,4-Dichlorobenzene	0.00-0.53	0.00-0.25	0.02-0.94	0.02-1.50
1,2-Dichlorobenzene	0.00-0.31	0.00-0.71	0.00-0.75	0.00-0.56
1,2,4-Trichlorobenzene	0.00-0.17	0.00-0.10	0.00-0.01	0.00-0.20
Hexachloro-1,3-butadiene	0.00-0.14	0.00-0.16	0.00-0.15	0.00-0.20

Table 4.5 Concentration of VOCs ($\mu\text{g}/\text{m}^3$) at Map Chalut Temple (MCLT) monitoring station

VOCs	Concentration ($\mu\text{g}/\text{m}^3$)			
	2009	2010	2011	2012
Freon 12	0.00-3.50	1.60-3.40	0.00-9.70	1.70-4.40
Freon 114	0.00-0.38	0.01-0.37	0.00-0.73	0.03-0.07
Chloromethane	0.00-2.90	0.01-1.50	0.01-1.50	0.87-2.20
Vinyl chloride	0.01-0.81	0.01-0.94	0.01-4.20	0.01-0.32
1,3-Butadiene	0.01-0.42	0.01-0.20	0.01-2.70	0.01-2.70
Bromomethane	0.01-0.17	0.01-0.29	0.01-0.55	0.02-0.12
Chloroethane	0.01-0.08	0.01-0.09	0.01-0.15	0.01-0.03
Freon 11	0.14-1.70	0.60-1.20	0.61-1.40	0.60-1.30
1,1-Dichloroethylene	0.00-0.02	0.02-0.03	0.01-0.02	0.02-0.04
Freon 113	0.00-0.98	0.00-0.89	0.00-1.20	0.06-0.96
Acrylonitrile	0.01-0.34	0.01-0.47	0.01-0.76	0.04-1.10
3-Chloropropene	0.01-0.22	0.01-1.40	0.01-0.02	0.00-0.03

Table 4.5 Concentration of VOCs ($\mu\text{g}/\text{m}^3$) at Map Chalut Temple (MCLT) monitoring station (cont.)

VOCs	Concentration ($\mu\text{g}/\text{m}^3$)			
	2009	2010	2011	2012
Dichloromethane	0.04-1.20	0.03-2.00	0.01-1.10	0.04-4.40
1,1-Dichloroethane	0.00-0.02	0.01	0.01-0.03	0.00-0.03
cis-1,2-Dichloroethylene	0.01-0.37	0.00-0.02	0.01-0.02	0.02-0.04
Chloroform	0.01-0.48	0.01-0.54	0.03-0.46	0.02-0.29
1,1,1-Trichloroethane	0.00-0.76	0.00-0.80	0.01-0.12	0.03-0.06
1,2-Dichloroethane	0.00-3.30	0.01-2.40	0.02-6.20	0.04-0.84
Benzene	0.24-3.90	0.14-3.80	0.54-7.50	0.12-3.40
Carbon Tetrachloride	0.00-1.30	0.00-1.40	0.00-0.75	0.05-0.63
Trichloroethylene	0.01-0.53	0.01-1.20	0.02-1.30	0.02-0.55
1,2-Dichloropropane	0.01-0.22	0.01-0.75	0.01-0.39	0.03-0.32
cis-1,3-Dichloropropene	0.00-0.70	0.00-0.60	0.01-0.40	0.02
Toluene	0.83-16.00	1.10-17.00	1.40-50.00	1.00-25.00
trans-1,3-Dichloropropene	0.00-0.03	0.00-0.02	0.01-0.02	0.02
1,1,2-Trichloroethane	0.01-0.61	0.01-0.48	0.01-0.12	0.03-0.04
Tetrachloroethylene	0.01-0.76	0.01-0.63	0.02-0.11	0.03-0.06
1,2-Dibromoethane	0.00-0.03	0.00-0.06	0.01-0.04	0.03-0.04
Chlorobenzene	0.00-0.85	0.01-0.47	0.01-0.02	0.02-0.45
Ethylbenzene	0.00-4.30	0.21-4.80	0.57-5.70	0.00-4.40
Total Xylene	0.00-7.20	1.08-6.50	1.15-17.30	0.41-5.10
Styrene	0.00-1.00	0.02-6.60	0.18-1.20	0.00-1.10
1,1,2,2-Tetrachloroethane	0.00-1.20	0.02	0.00-0.27	0.03-0.05
1-Ethyl-4-methylbenzene	0.00-1.40	0.00-0.81	0.06-2.50	0.00-1.70
1,3,5-Trimethylbenzene	0.00-0.94	0.00-0.50	0.00-1.00	0.00-0.12
1,2,4-Trimethylbenzene	0.00-1.80	0.00-2.10	0.00-4.80	0.00-2.10
1,3-Dichlorobenzene	0.00-0.04	0.00-0.06	0.01-0.83	0.00-0.72
Benzyl Chloride	0.00-0.04	0.01-0.04	0.01-0.02	0.02-0.04
1,4-Dichlorobenzene	0.00-0.08	0.00-0.08	0.02-1.00	0.02-1.30
1,2-Dichlorobenzene	0.00-0.04	0.00-0.03	0.01-0.79	0.00-0.47
1,2,4-Trichlorobenzene	0.00-0.19	0.00-0.09	0.00-0.01	0.00-0.31
Hexachloro-1,3-butadiene	0.00-0.13	0.00-0.15	0.00-0.15	0.00-0.60

Table 4.6 Concentration of VOCs ($\mu\text{g}/\text{m}^3$) at Ban Plong Community (BPLC) monitoring station

VOCs	Concentration ($\mu\text{g}/\text{m}^3$)			
	2009	2010	2011	2012
Freon 12	0.00-2.10	1.50-3.60	0.00-5.50	1.50-4.30
Freon 114	0.00-0.27	0.01-0.44	0.00-0.70	0.03-0.07
Chloromethane	0.00-1.00	0.01-1.70	0.01-1.60	0.78-2.40
Vinyl chloride	0.01-4.80	0.01-19.00	0.01-2.10	0.01-1.20
1,3-Butadiene	0.01-0.47	0.01-0.83	0.01-2.10	0.01-1.80
Bromomethane	0.01-0.21	0.01-0.30	0.02-0.92	0.02-0.52
Chloroethane	0.01-0.17	0.01-0.18	0.01-0.17	0.01-0.08
Freon 11	0.31-1.20	0.50-1.30	0.69-1.60	0.63-1.90
1,1-Dichloroethylene	0.01-0.02	0.02-0.04	0.01-0.02	0.02-0.04
Freon 113	0.00-0.62	0.00-0.93	0.00-1.10	0.07-0.87
Acrylonitrile	0.01-0.38	0.01-0.55	0.01	0.01-0.12
3-Chloropropene	0.01-0.02	0.01-0.02	0.00-0.02	0.00-0.03
Dichloromethane	0.02-7.80	0.03-2.50	0.15-2.30	0.04-14.00
1,1-Dichloroethane	0.00-0.02	0.01-0.15	0.01-0.17	0.00-0.03
cis-1,2-Dichloroethylene	0.01-0.02	0.01	0.00-0.02	0.02-0.04
Chloroform	0.01-0.42	0.01-0.53	0.01-0.48	0.03-0.16
1,1,1-Trichloroethane	0.00-0.06	0.00-0.91	0.03-0.33	0.03-0.06
1,2-Dichloroethane	0.00-1.10	0.02-4.60	0.06-1.60	0.04-1.30
Benzene	1.50-6.60	1.00-7.70	1.90-16.00	0.77-16.00
Carbon Tetrachloride	0.00-0.93	0.00-1.50	0.00-0.77	0.06-0.70
Trichloroethylene	0.01-0.83	0.01-0.63	0.02-1.10	0.02-0.48
1,2-Dichloropropane	0.01-0.20	0.01-0.84	0.01-0.43	0.03-0.05
cis-1,3-Dichloropropene	0.00-0.20	0.00-0.01	0.01-0.27	0.02
Toluene	5.20-87.00	12.00-61.00	8.80-37.00	5.90-140.00
trans-1,3-Dichloropropene	0.00-0.13	0.00-0.02	0.01-0.41	0.02
1,1,2-Trichloroethane	0.01-0.20	0.01-0.55	0.01-0.14	0.03
Tetrachloroethylene	0.01-0.53	0.01-0.64	0.02-0.55	0.03-0.19
1,2-Dibromoethane	0.00-0.03	0.00-0.06	0.01-0.13	0.03-0.10
Chlorobenzene	0.00-0.60	0.01-0.47	0.02-0.05	0.02-0.45
Ethylbenzene	0.00-6.80	0.58-3.40	0.65-3.30	0.00-5.60

Table 4.6 Concentration of VOCs ($\mu\text{g}/\text{m}^3$) at Ban Plong Community (BPLC) monitoring station (cont.)

VOCs	Concentration ($\mu\text{g}/\text{m}^3$)			
	2009	2010	2011	2012
Total Xylene	0.00-14.10	2.20-6.90	1.88-5.80	1.07-6.80
Styrene	0.00-1.00	0.02-0.66	0.14-1.20	0.00-0.93
1,1,2,2-Tetrachloroethane	0.00-0.03	0.02	0.00-0.04	0.03-0.05
1-Ethyl-4-methylbenzene	0.00-3.70	0.00-1.50	0.02-1.60	0.00-2.40
1,3,5-Trimethylbenzene	0.00-2.70	0.00-1.00	0.00-0.97	0.00-1.70
1,2,4-Trimethylbenzene	0.00-10.00	0.00-4.40	0.00-3.80	0.00-4.40
1,3-Dichlorobenzene	0.00-0.03	0.00-0.03	0.00-0.88	0.00-0.67
Benzyl Chloride	0.00-0.04	0.01-0.12	0.01-0.02	0.02-0.04
1,4-Dichlorobenzene	0.00-0.13	0.00-0.08	0.02-1.10	0.02-1.20
1,2-Dichlorobenzene	0.00-0.03	0.00-0.69	0.00-0.84	0.00-0.45
1,2,4-Trichlorobenzene	0.00-0.18	0.00-0.10	0.00-0.01	0.00-0.72
Hexachloro-1,3-butadiene	0.00-0.13	0.00-0.15	0.00-0.16	0.00-0.20

Table 4.7 Concentration of VOCs ($\mu\text{g}/\text{m}^3$) at Nop Pakate Village (NPKV) monitoring station

VOCs	Concentration ($\mu\text{g}/\text{m}^3$)			
	2009	2010	2011	2012
Freon 12	0.00-2.10	1.40-4.80	0.00-11.00	1.50-5.40
Freon 114	0.00-0.32	0.01-0.42	0.00-0.78	0.03-0.07
Chloromethane	0.00-1.00	0.01-1.70	0.01-1.50	0.79-2.20
Vinyl chloride	0.01-0.52	0.01-4.30	0.01-0.77	0.01-0.37
1,3-Butadiene	0.01-0.41	0.01-1.40	0.01-1.70	0.01-0.44
Bromomethane	0.01-0.20	0.01-0.29	0.01-0.60	0.02-0.06
Chloroethane	0.01-0.08	0.01-0.10	0.01	0.01-0.03
Freon 11	0.02-1.50	0.66-1.20	0.56-1.40	0.43-1.40
1,1-Dichloroethylene	0.01-0.02	0.02-0.04	0.02	0.02-0.04
Freon 113	0.00-0.69	0.00-0.85	0.00-1.10	0.07-0.99
Acrylonitrile	0.01-0.40	0.01-0.53	0.01-0.54	0.01-0.04
3-Chloropropene	0.01-0.02	0.01-0.03	0.01-0.02	0.00-0.03

Table 4.7 Concentration of VOCs ($\mu\text{g}/\text{m}^3$) at Nop Pakate Village (NPKV) monitoring station (cont.)

VOCs	Concentration ($\mu\text{g}/\text{m}^3$)			
	2009	2010	2011	2012
Dichloromethane	0.02-270.00	0.04-5.60	0.02-1.50	0.13-11.00
1,1-Dichloroethane	0.00-0.02	0.01	0.01-0.03	0.00-0.04
cis-1,2-Dichloroethylene	0.01-0.02	0.00-0.08	0.00-0.02	0.02-0.04
Chloroform	0.00-0.41	0.01-0.49	0.02-0.52	0.02-0.16
1,1,1-Trichloroethane	0.00-0.07	0.00-0.87	0.01-0.34	0.03-0.06
1,2-Dichloroethane	0.00-1.10	0.04-1.10	0.02-0.74	0.02-0.57
Benzene	0.53-4.90	0.74-4.70	1.30-8.90	0.61-3.70
Carbon Tetrachloride	0.00-1.00	0.00-1.50	0.00-0.77	0.06-0.70
Trichloroethylene	0.01-0.89	0.01-0.74	0.02-1.90	0.07-12.00
1,2-Dichloropropane	0.01-0.23	0.01-0.83	0.01-0.45	0.03-0.05
cis-1,3-Dichloropropene	0.00-0.02	0.00-0.01	0.01-0.66	0.02
Toluene	1.40-33.00	1.60-17.00	2.70-27.00	2.40-23.00
trans-1,3-Dichloropropene	0.00-0.14	0.00-0.02	0.01-0.02	0.02
1,1,2-Trichloroethane	0.01-0.04	0.01-0.52	0.02-0.04	0.03-0.04
Tetrachloroethylene	0.01-0.65	0.01-0.96	0.02-0.57	0.03-0.24
1,2-Dibromoethane	0.00-0.03	0.00-0.06	0.01-0.26	0.03-0.04
Chlorobenzene	0.00-0.67	0.01-0.50	0.02-0.19	0.02-0.34
Ethylbenzene	0.00-5.30	0.19-3.30	0.42-3.60	0.00-5.10
Total Xylene	0.00-16.90	0.80-7.70	1.41-17.80	1.03-11.67
Styrene	0.00-1.70	0.02-0.39	0.01-1.40	0.00-0.75
1,1,2,2-Tetrachloroethane	0.00-0.03	0.01-0.02	0.00-0.04	0.03-0.05
1-Ethyl-4-methylbenzene	0.00-1.60	0.00-0.97	0.02-1.90	0.00-1.80
1,3,5-Trimethylbenzene	0.00-1.00	0.00-0.63	0.00-1.80	0.00-1.30
1,2,4-Trimethylbenzene	0.00-2.60	0.00-2.20	0.00-7.60	0.00-4.00
1,3-Dichlorobenzene	0.00-0.10	0.00-0.06	0.00-0.86	0.00-0.64
Benzyl Chloride	0.00-0.04	0.01-0.04	0.01-0.31	0.02-0.04
1,4-Dichlorobenzene	0.00-0.36	0.00-0.08	0.02-1.00	0.02-1.20
1,2-Dichlorobenzene	0.00-0.98	0.00-0.72	0.00-0.82	0.00-0.43
1,2,4-Trichlorobenzene	0.00-1.60	0.00-0.10	0.00-0.01	0.00-0.20
Hexachloro-1,3-butadiene	0.00-0.14	0.00-0.16	0.00-0.08	0.00-0.21

Table 4.8 Concentration of VOCs ($\mu\text{g}/\text{m}^3$) at Dindaeng monitoring station

VOCs	Concentration ($\mu\text{g}/\text{m}^3$)			
	2009	2010	2011	2012
Freon 12	0.00-2.40	1.60-4.50	0.00-3.80	1.50-7.30
Freon 114	0.00-0.31	0.01-0.42	0.00-0.65	0.03-0.20
Chloromethane	0.00-6.00	0.01-1.70	0.00-2.10	0.80-2.80
Vinyl chloride	0.01-0.02	0.01-0.03	0.01	0.01-0.03
1,3-Butadiene	0.01-2.20	0.01-1.10	0.01-0.67	0.01-0.02
Bromomethane	0.01-0.14	0.01-0.30	0.02-0.19	0.02-0.13
Chloroethane	0.01-0.11	0.00-0.26	0.00-0.01	0.01-0.09
Freon 11	0.15-1.40	0.00-1.30	0.03-2.00	0.18-4.30
1,1-Dichloroethylene	0.01-0.02	0.01-0.04	0.02	0.02-0.04
Freon 113	0.00-0.81	0.09-0.85	0.00-1.10	0.07-0.90
Acrylonitrile	0.01-0.09	0.01-0.60	0.01-0.08	0.00-0.29
3-Chloropropene	0.00-0.02	0.01-0.02	0.01-0.02	0.00-0.03
Dichloromethane	0.01-3.00	0.04-1.80	0.28-2.40	0.37-4.70
1,1-Dichloroethane	0.00-0.02	0.01	0.01-0.03	0.00-0.03
cis-1,2-Dichloroethylene	0.01-0.02	0.01-0.02	0.01-0.02	0.02-0.04
Chloroform	0.01-0.67	0.01-0.62	0.03-0.52	0.03-0.57
1,1,1-Trichloroethane	0.01-0.07	0.01-1.00	0.01-0.12	0.03-0.10
1,2-Dichloroethane	0.01-0.17	0.01-0.74	0.02-0.56	0.02-0.81
Benzene	3.50-11.00	3.50-8.10	3.70-12.00	1.80-9.20
Carbon Tetrachloride	0.02-0.59	0.03-1.70	0.00-0.64	0.06-0.69
Trichloroethylene	0.01-0.78	0.01-0.77	0.02-1.10	0.02-1.10
1,2-Dichloropropane	0.01-0.06	0.01-0.56	0.03-0.35	0.03-0.56
cis-1,3-Dichloropropene	0.00-0.02	0.01	0.01-0.02	0.02
Toluene	0.00-83.00	19.00-57.00	23.00-54.00	23.00-100.00
trans-1,3-Dichloropropene	0.00-0.03	0.01-0.02	0.01-0.02	0.02
1,1,2-Trichloroethane	0.00-0.02	0.01-0.02	23.00-54.00	0.03-0.04
Tetrachloroethylene	0.01-0.60	0.01-0.97	0.01-0.02	0.03-1.20
1,2-Dibromoethane	0.01-0.40	0.00-0.06	0.00-0.03	0.03-0.04
Chlorobenzene	0.00-0.18	0.01-0.50	0.06-1.60	0.02-0.33
Ethylbenzene	0.81-7.40	1.80-5.30	0.00-10.00	0.00-10.00
Total Xylene	2.86-23.80	6.90-16.60	6.80-38.40	3.60-25.60

Table 4.8 Concentration of VOCs ($\mu\text{g}/\text{m}^3$) at Dindaeng monitoring station (cont.)

VOCs	Concentration ($\mu\text{g}/\text{m}^3$)			
	2009	2010	2011	2012
Styrene	0.00-1.80	0.19-0.99	0.00-2.00	0.00-1.60
1,1,2,2-Tetrachloroethane	0.00-0.03	0.01-0.02	0.00-0.04	0.03-0.05
1-Ethyl-4-methylbenzene	1.10-4.40	0.00-2.80	0.00-8.30	0.00-5.50
1,3,5-Trimethylbenzene	0.00-3.40	0.44-2.20	0.72-6.20	0.00-3.50
1,2,4-Trimethylbenzene	1.50-15.00	0.00-9.30	0.00-28.00	0.00-16.00
1,3-Dichlorobenzene	0.00-0.06	0.02-0.97	0.01-1.20	0.01-0.72
Benzyl Chloride	0.00-0.04	0.01-0.04	0.01-0.02	0.02-0.04
1,4-Dichlorobenzene	0.00-1.80	0.02-1.80	0.02-1.90	0.05-4.90
1,2-Dichlorobenzene	0.00-0.03	0.02-0.76	0.02-0.78	0.02-0.60
1,2,4-Trichlorobenzene	0.00-0.18	0.00-0.10	0.00-0.04	0.00-0.20
Hexachloro-1,3-butadiene	0.00-0.13	0.00-0.16	0.00-0.15	0.00-0.20

VOCs were grouped base on type of compound. Aromatics refer to benzene, toluene, chlorobenzene, ethylbenzene, total xylene (o,m,p-xylene), styrene, 1-ethyl-4-methylbenzene, 1,2,4-trimethylbenzene, 1,3,5-trimethylbenzene, 1,2-dichlorobenzene, 1,3-dichlorobenzene, 1,4-dichlorobenzene, benzyl chloride and 1,2,4-trichlorobenzene.

Alkenes refer to vinyl chloride, 1,3-butadiene, 1,1-dichloroethylene, 3-chloropropene, cis-1,2-dichloroethylene, trichloroethylene, cis-1,3-dichloropropene, trans-1,3-dichloropropene, tetrachloroethylene and hexachloro-1,3-butadiene.

Alkanes refer to chloromethane, bromomethane, chloroethane, dichloromethane, 1,1-dichloroethane, chloroform, 1,1,1-trichloroethane, 1,2-dichloroethane, carbon tetrachloride, 1,2-dichloropropane, 1,1,2-trichloroethane, 1,2-dibromoethane and 1,1,2,2-tetrachloroethane.

Nitrile refers to acrylonitrile and CFCs refer to freon11, freon12, freon113 and freon114.

Comparisons of VOCs composition of monitoring station in Maptaphut area and Dindaeng monitoring station in 2009-2012 were as shown in Table 4.9-4.12 and Figure 4.1-4.4, respectively.

Table 4.9 VOCs composition of monitoring station in Maptaphut area and Dindaeng monitoring station in 2009 (unit: % of total concentration)

Monitoring stations	HMTF	BTKH	WNFS	MMTP	MCLT	BPLC	NPKV	Dindaeng
Aromatics	82.83	80.32	73.86	77.81	72.55	85.34	35.57	92.41
Alkenes	3.27	3.97	5.66	4.71	3.98	3.97	1.07	1.47
Alkanes	8.56	9.72	11.86	12.29	14.23	6.80	60.51	4.13
Nitrile	0.15	0.57	0.24	0.18	0.19	0.11	0.11	0.02
CFCs	5.19	5.43	8.38	5.01	9.05	3.78	2.74	1.97

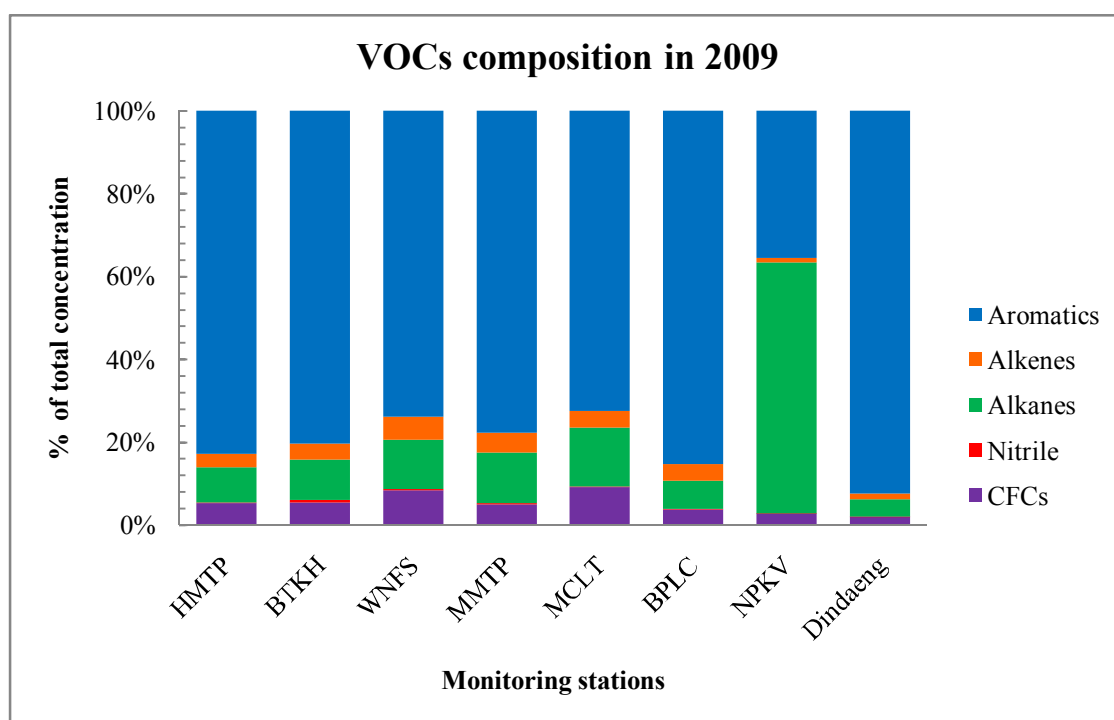


Figure 4.1 VOCs composition in % of total concentration in Maptaphut area vs. Dindaeng monitoring station in 2009

Table 4.10 VOCs composition of monitoring station in Maptaphut area and Dindaeng monitoring station in 2010 (unit: % of total concentration)

Monitoring stations	HMTF	BTKH	WNFS	MMTP	MCLT	BPLC	NPKV	Dindaeng
Aromatics	77.50	73.55	59.88	69.02	67.08	79.06	68.85	88.45
Alkenes	3.39	3.71	6.62	6.22	4.55	6.71	5.34	1.49
Alkanes	9.25	10.64	17.66	12.36	14.13	8.04	12.99	4.79
Nitrile	0.24	0.44	0.33	0.30	0.31	0.15	0.29	0.12
CFCs	9.62	11.66	15.51	12.11	13.94	6.04	12.54	5.15

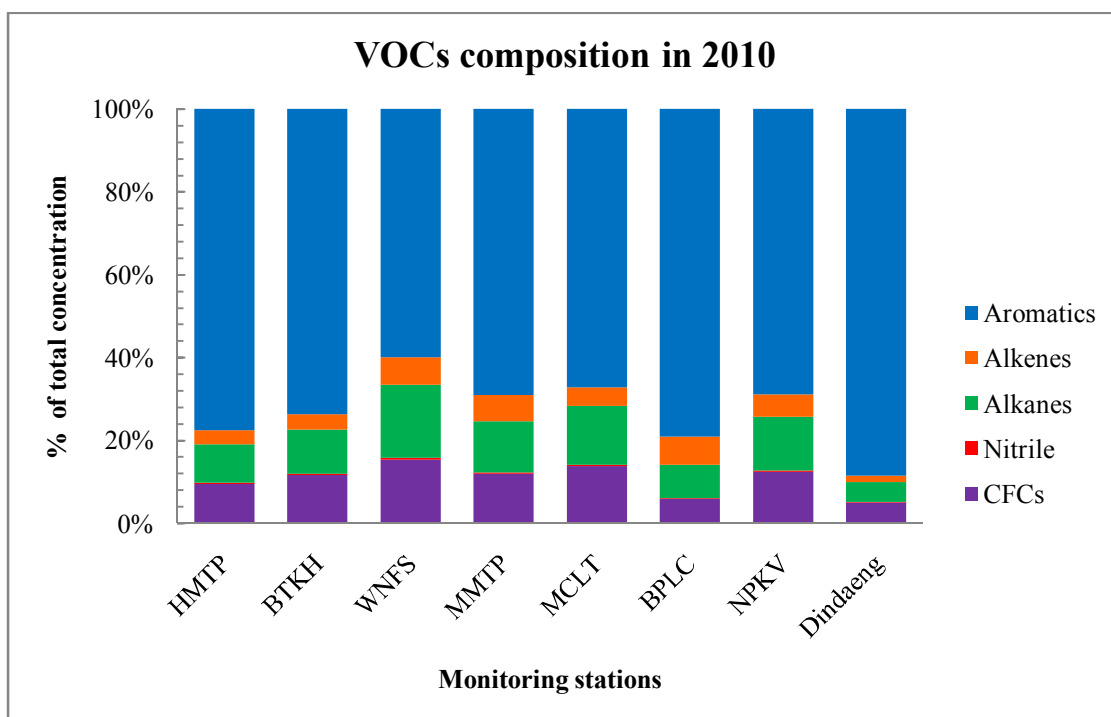


Figure 4.2 VOCs composition in % of total concentration in Maptaphut area vs. Dindaeng monitoring station in 2010

Table 4.11 VOCs composition of monitoring station in Maptaphut area and Dindaeng monitoring station in 2011 (unit: % of total concentration)

Monitoring stations	HMTP	BTKH	WNFS	MMTP	MCLT	BPLC	NPKV	Dindaeng
Aromatics	72.23	79.39	73.41	66.40	68.76	79.59	75.76	91.02
Alkenes	4.48	2.95	2.56	6.02	4.20	3.26	3.06	1.12
Alkanes	10.78	7.50	11.43	13.47	11.47	8.44	8.39	3.64
Nitrile	0.31	1.05	1.05	0.33	0.40	0.02	0.90	0.02
CFCs	12.20	9.11	11.55	13.78	15.16	8.69	12.60	4.20

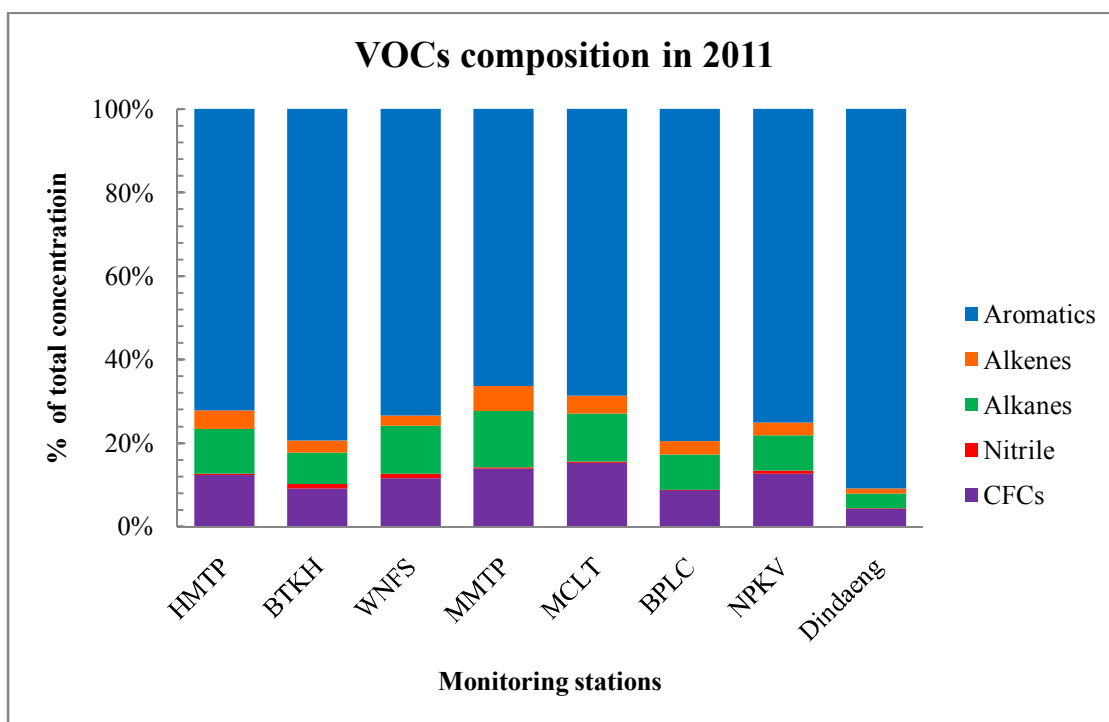


Figure 4.3 VOCs composition in % of total concentration in Maptaphut area vs. Dindaeng monitoring station in 2011

Table 4.12 VOCs composition of monitoring station in Maptaphut area and Dindaeng monitoring station in 2012 (unit: % of total concentration)

Monitoring stations	HMTP	BTKH	WNFS	MMTP	MCLT	BPLC	NPKV	Dindaeng
Aromatics	78.24	74.05	59.50	71.79	64.11	84.70	66.62	88.98
Alkenes	1.84	4.93	3.99	4.03	3.30	1.67	4.45	0.92
Alkanes	10.48	9.05	18.90	13.73	14.64	7.42	18.21	4.99
Nitrile	0.24	1.00	0.75	0.17	1.00	0.06	0.08	0.07
CFCs	9.19	10.97	16.86	10.27	16.96	6.16	10.63	5.05

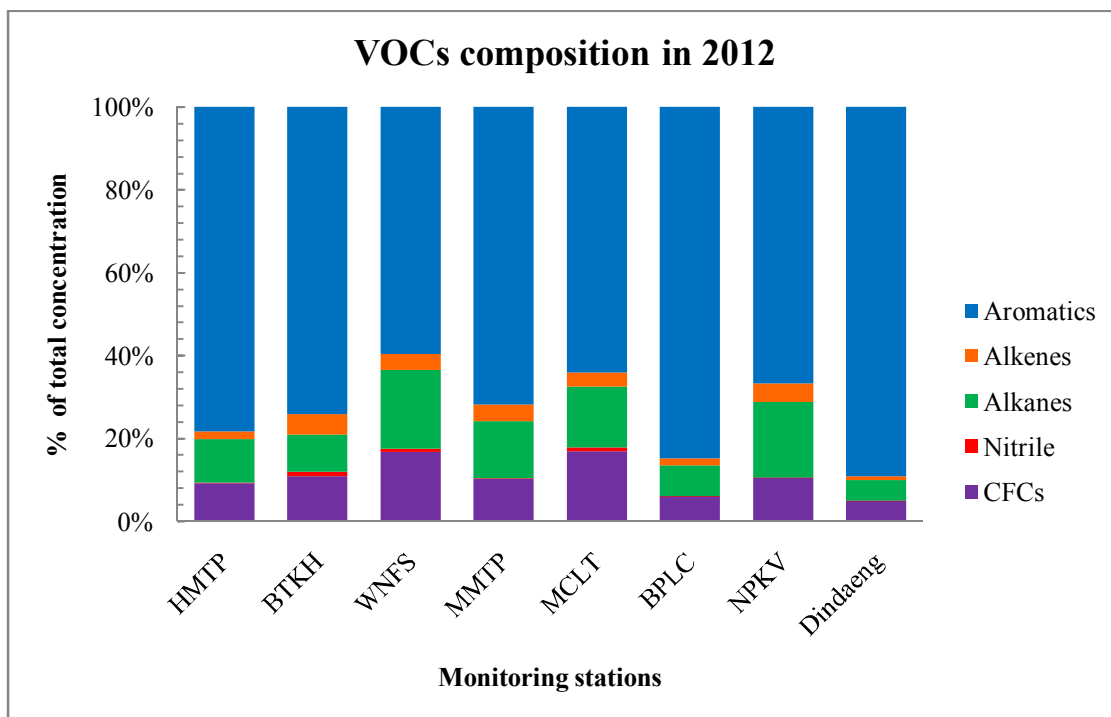


Figure 4.4 VOCs composition in % of total concentration in Maptaphut area vs. Dindaeng monitoring station in 2012

In 2009 (Figure 4.1), the contribution of aromatics (72.55-92.41%) to total VOCs was greater than other groups for all monitoring sites except for Nop Pakate Village (NPKV) monitoring station where the maximum concentration was contributed by dichloromethane ($270 \mu\text{g}/\text{m}^3$), followed by alkanes (4.13-14.23%), CFCs (1.97-9.05%), alkenes (1.47-5.66) and nitrile (0.02-0.57%), respectively. For Nop Pakate Village (NPKV) monitoring station, alkanes contribution was about 60.51%, followed by aromatics (35.57%), CFCs (2.74%), alkenes (1.07%) and nitrile (0.02%), respectively.

Since, Nop Pakate Village (NPKV) monitoring station is located close to RIL industrial complex. RIL industrial complex is petrochemical industry, which was established in 2008. Therefore, high concentration of dichloromethane at Nop Pakate Village (NPKV) monitoring station in 2009 might be resulted by unstable operation process at the beginning of RIL industrial complex. This suggestion was supported by the VOCs concentration data at Nop Pakate Village (NPKV) monitoring station in 2010 to 2012 was commonly monitoring data.

In 2010 (Figure 4.2), the contribution of aromatics (59.88-88.45%) to total VOCs was greater than other groups for all monitoring sites, followed by alkanes (4.79-17.66%), CFCs (5.15-15.51%), alkenes (1.49-6.71%) and nitrile (0.12-0.44%), respectively.

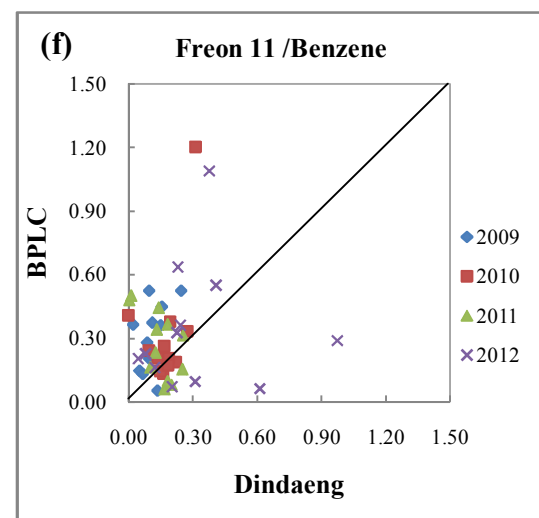
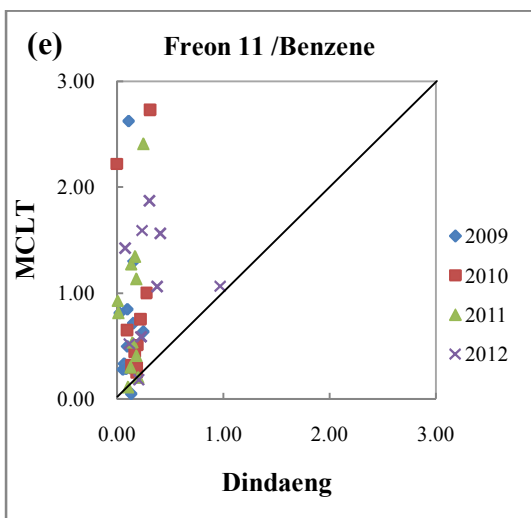
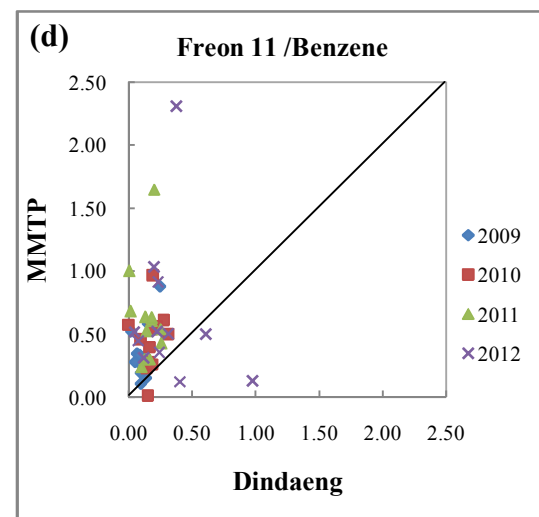
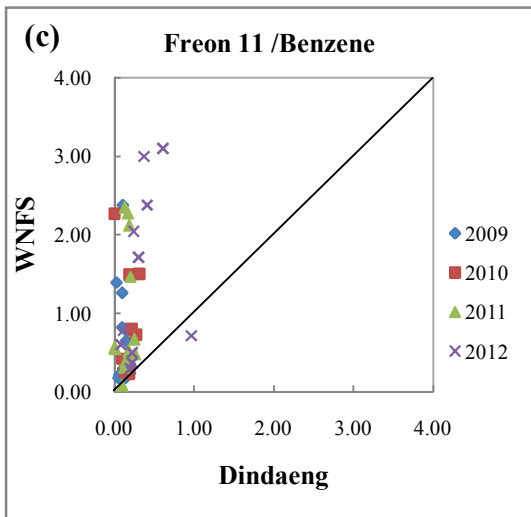
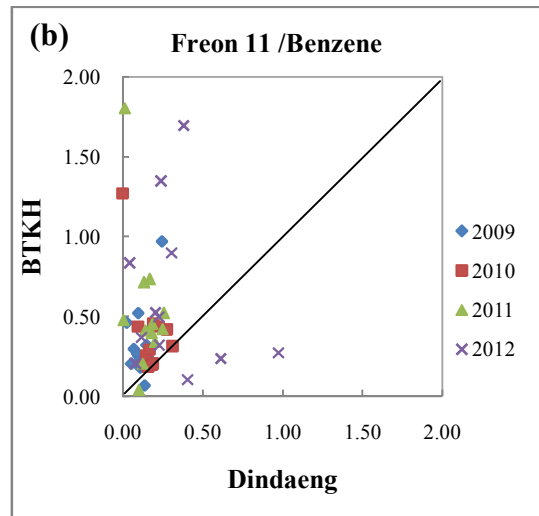
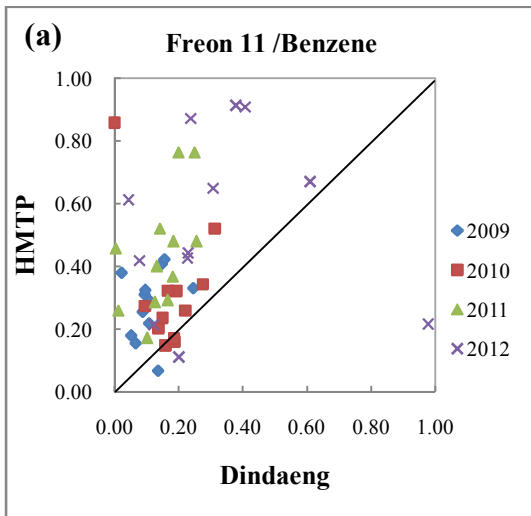
In 2011 (Figure 4.3), the contribution of aromatics (66.4-91.02%) to total VOCs was greater than other groups for all monitoring sites, followed by CFCs (4.2-15.16%), alkanes (3.64-13.47%), alkenes (1.12-6.02%) and nitrile (0.02-1.05%), respectively.

In 2012 (Figure 4.4), the contribution of aromatics (59.5-88.98%) to total VOCs was greater than other groups for all monitoring sites, followed by alkanes (4.99-18.9%), CFCs (5.05-16.96%), alkenes (0.92-4.93%) and nitrile (0.06-1%), respectively.

4.2 Diagnostic ratio

4.2.1 VOCs against benzene (VOCs/Bz) ratios

VOCs/Bz ratio was used to investigate and estimate the relative contributions of stationary and mobile sources of each VOC. Scatter plots of VOCs/Bz ratio in 2009-2012 of monitoring stations in Maptaphut area were compared with Dindaeng (roadside site) monitoring station. Results were as shown in Figure 4.5-4.46.



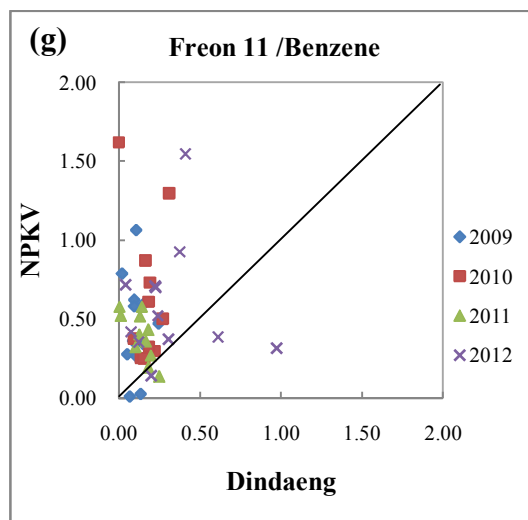
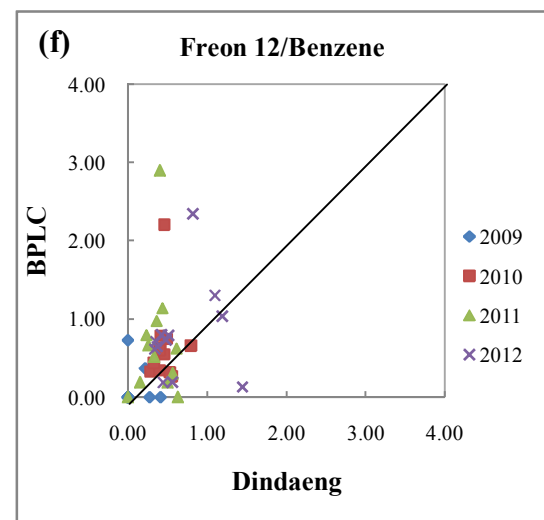
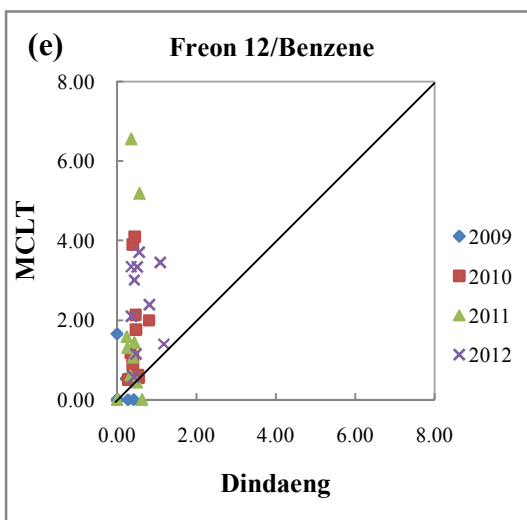
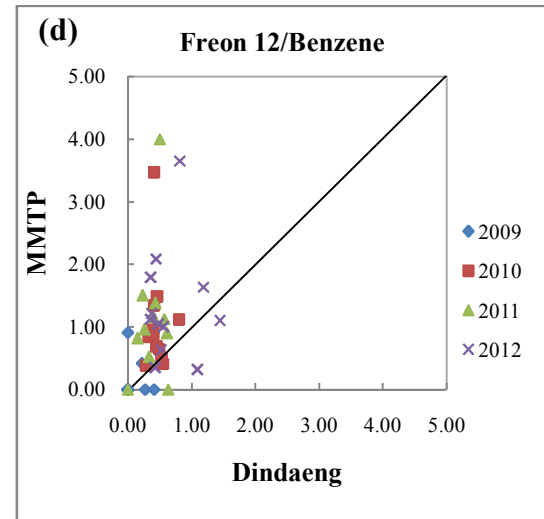
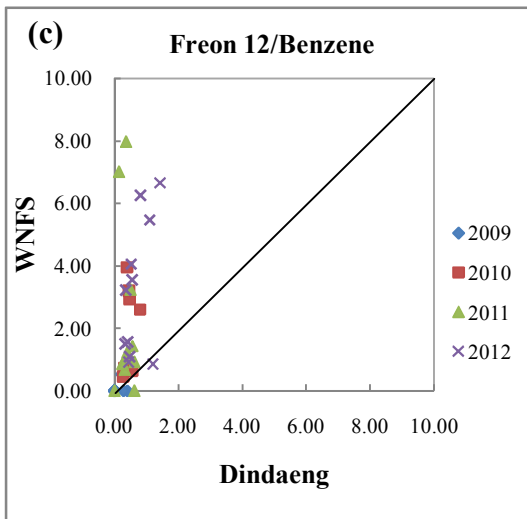
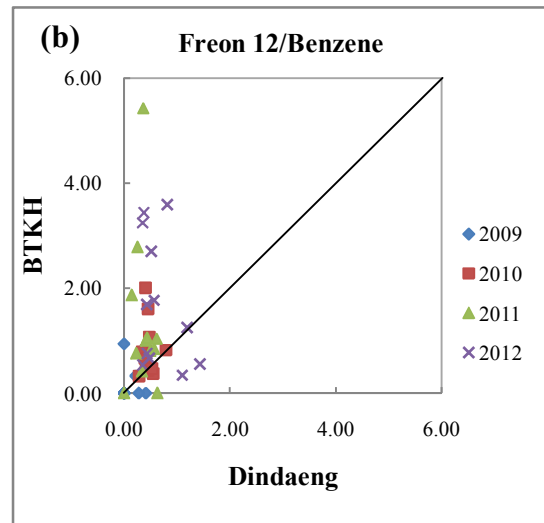
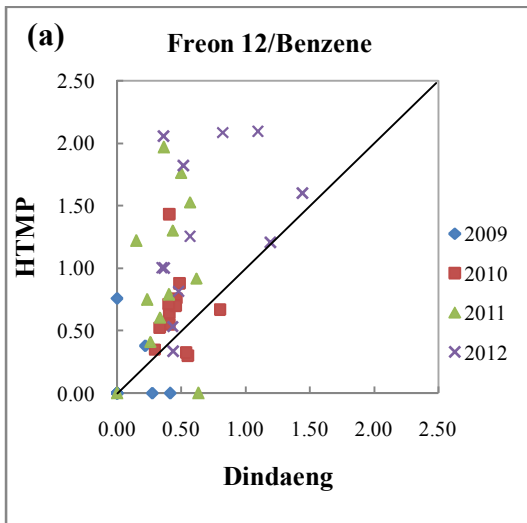


Figure 4.5 Scatter plots of freon 11 against benzene ratio of monitoring stations in Maptaphut area vs. Dindaeng (roadside site) in 2009-2012



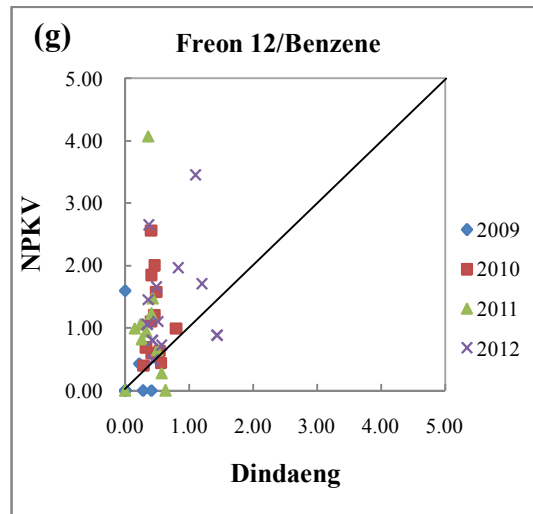
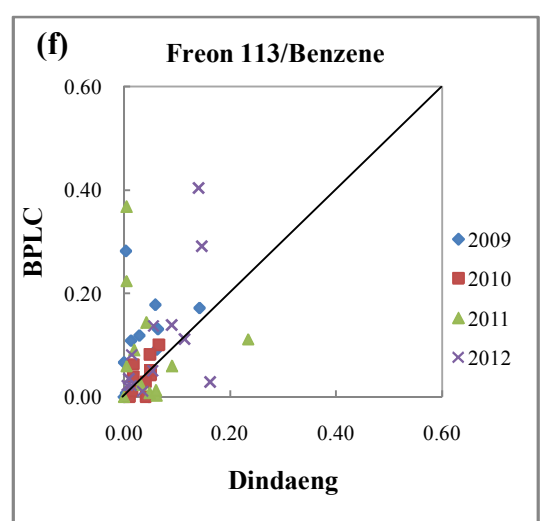
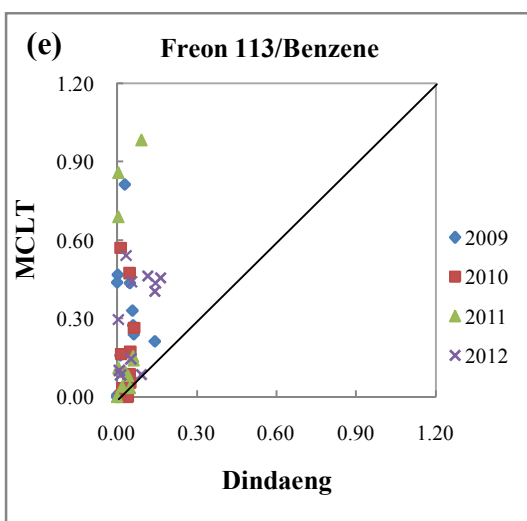
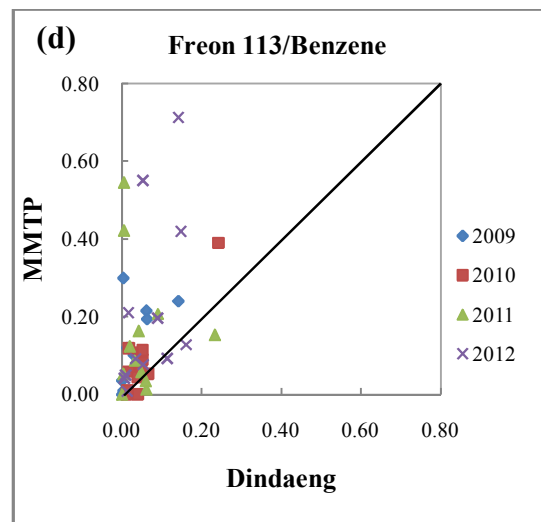
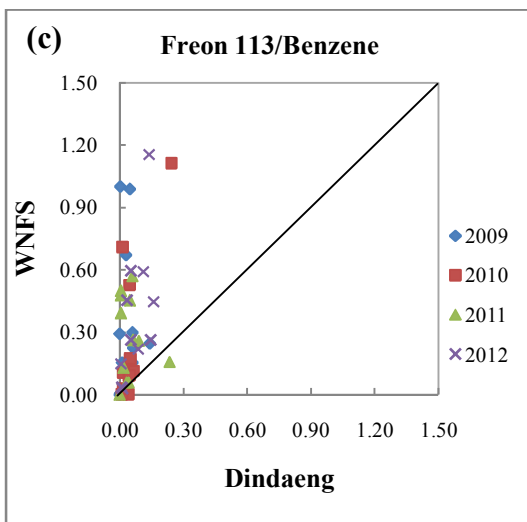
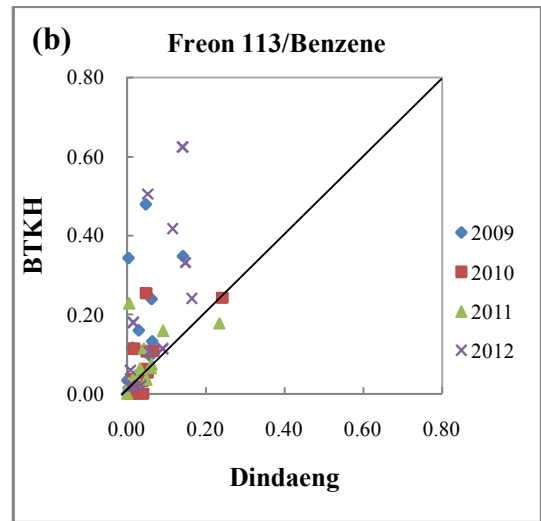
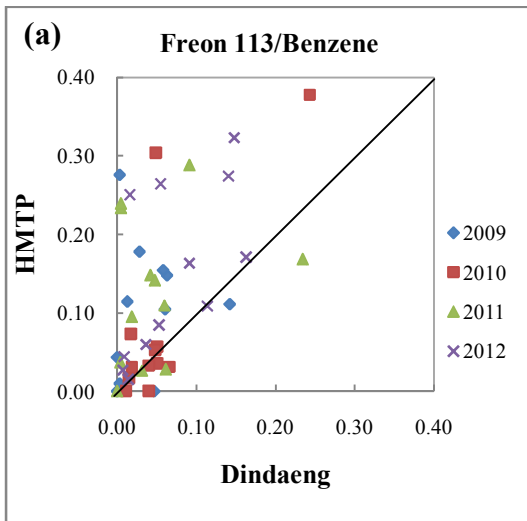


Figure 4.6 Scatter plots of freon 12 against benzene ratio of monitoring stations in Maptaphut area vs. Dindaeng (roadside site) in 2009-2012



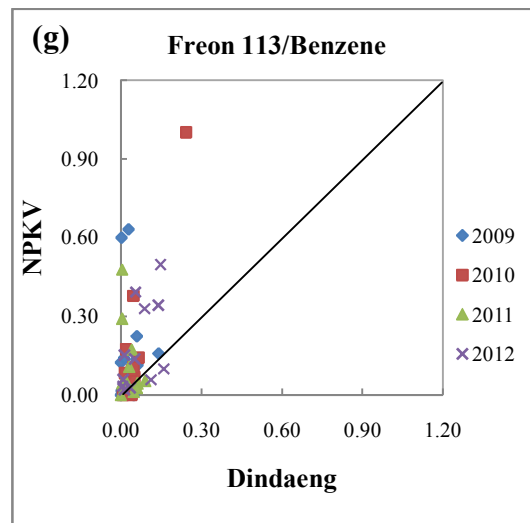
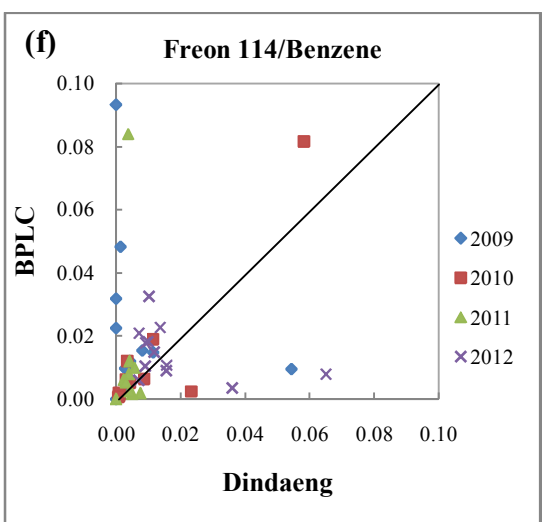
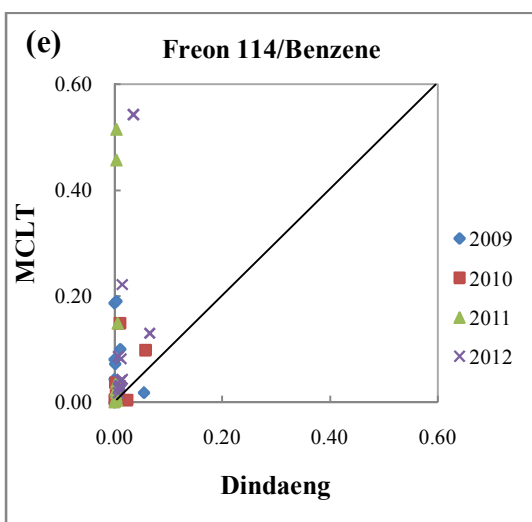
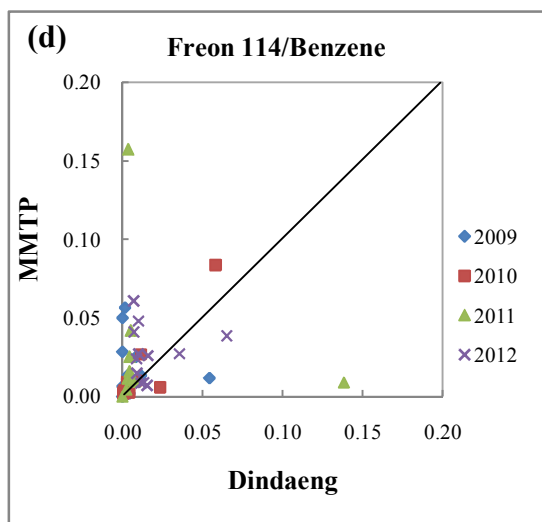
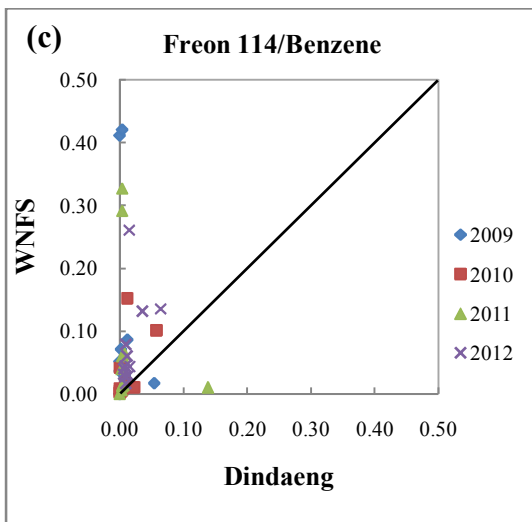
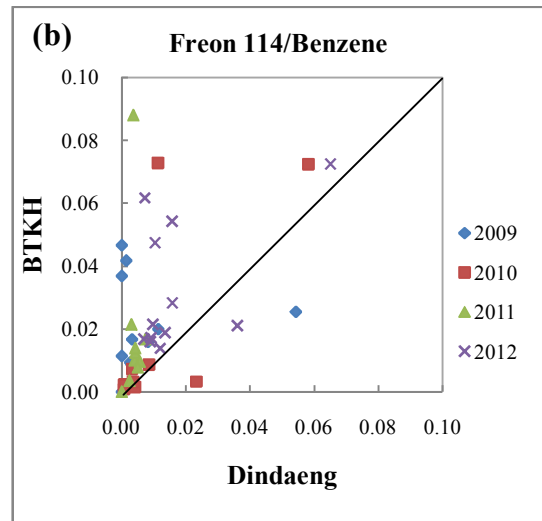
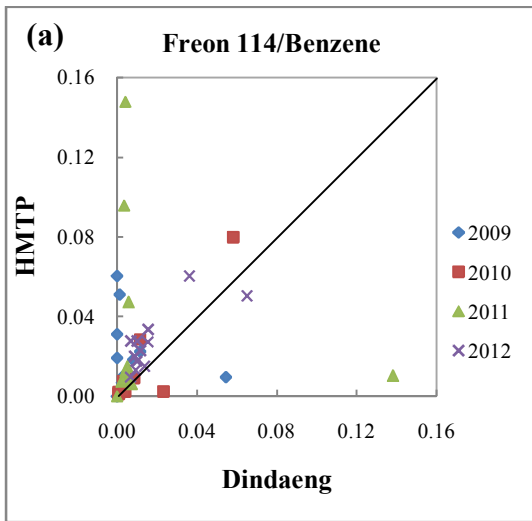


Figure 4.7 Scatter plots of freon 113 against benzene ratio of monitoring stations in Maptaphut area vs. Dindaeng (roadside site) in 2009-2012



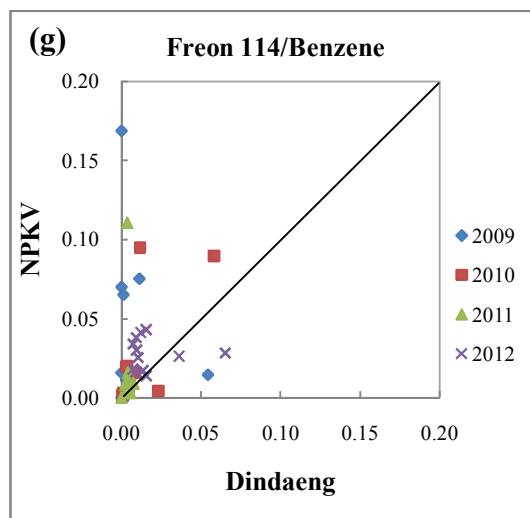
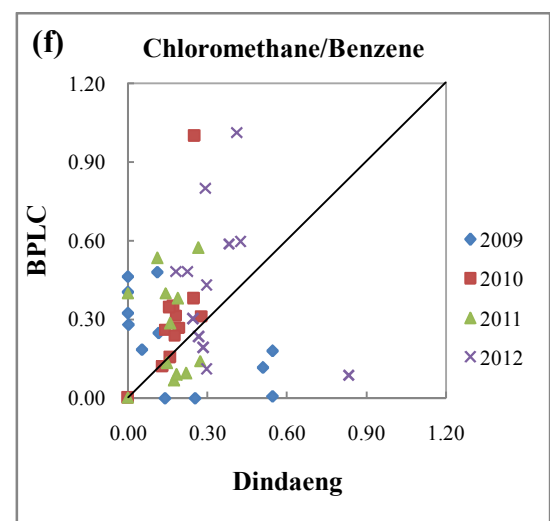
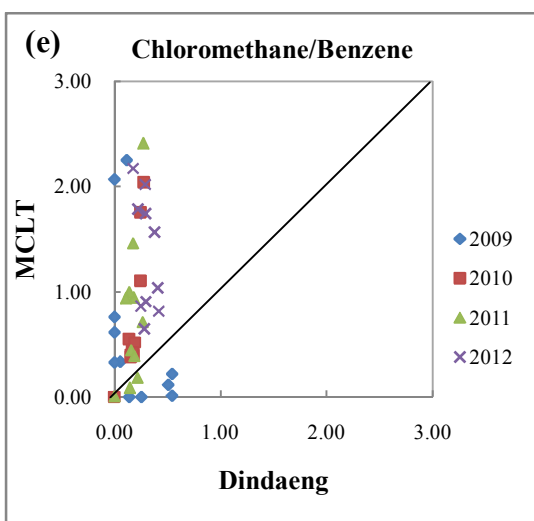
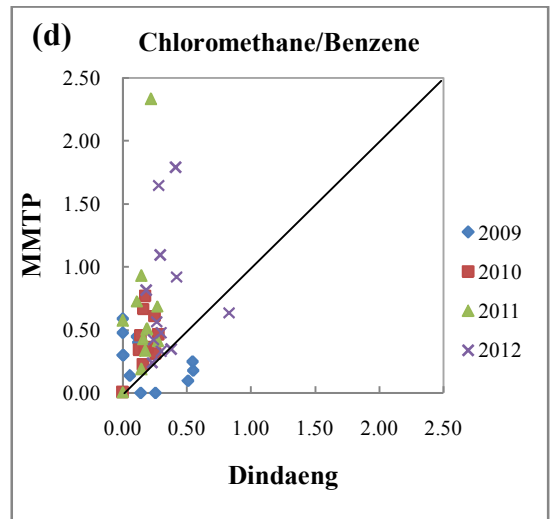
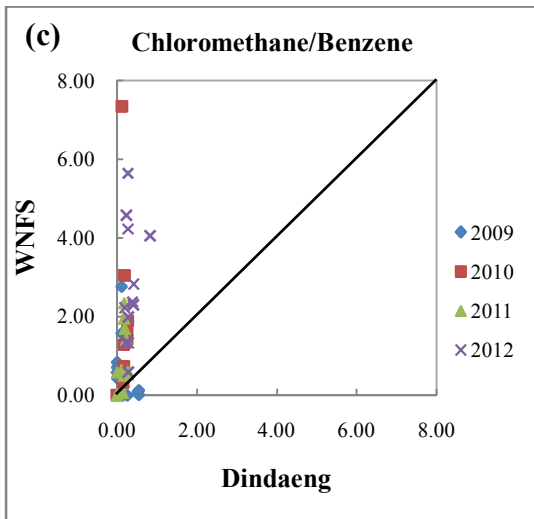
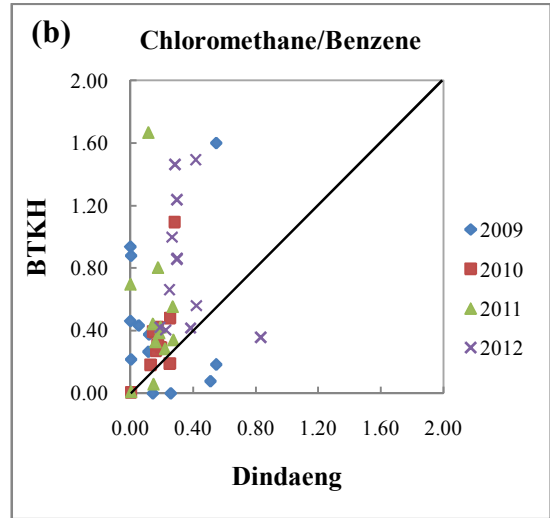
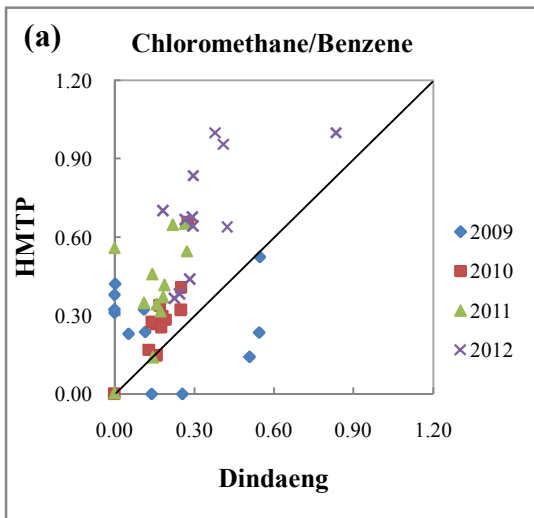


Figure 4.8 Scatter plots of freon 114 against benzene ratio of monitoring stations in Maptaphut area vs. Dindaeng (roadside site) in 2009-2012



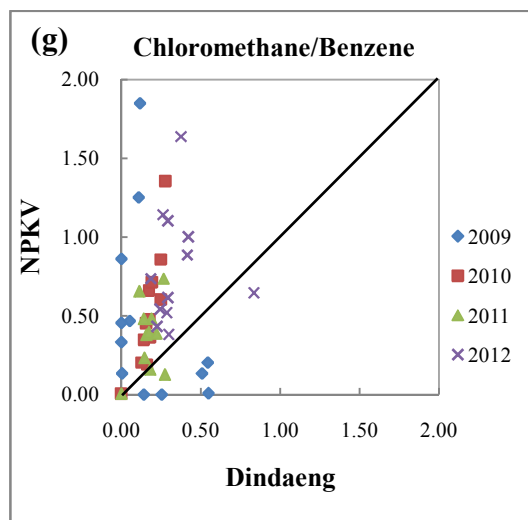
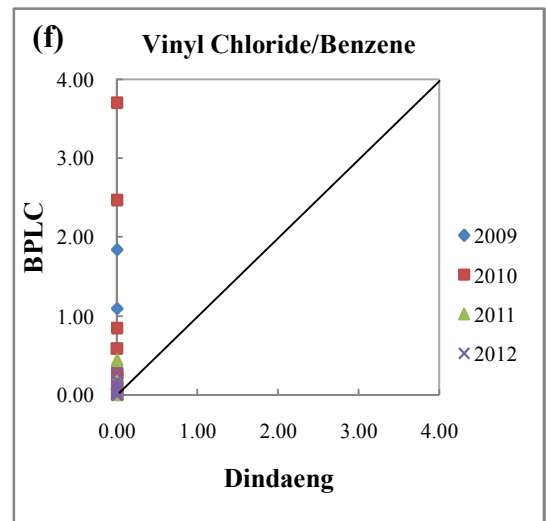
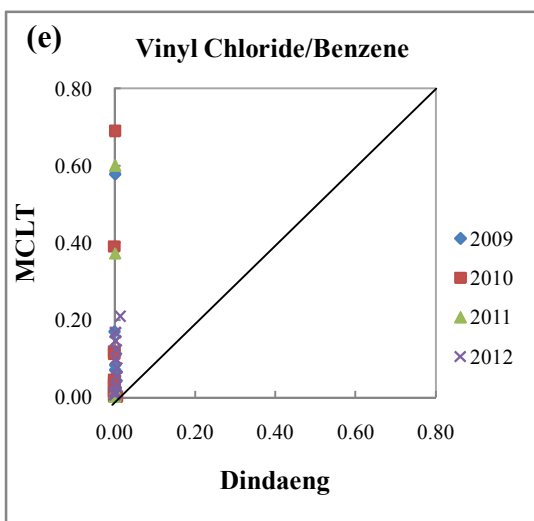
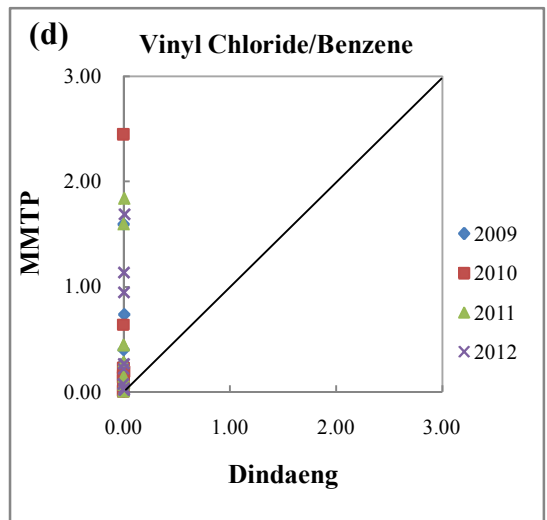
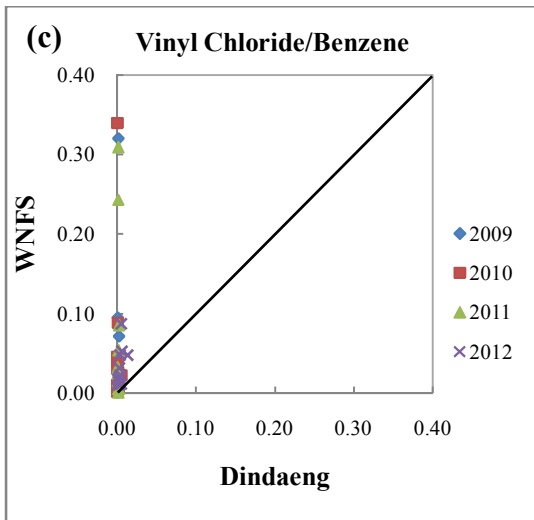
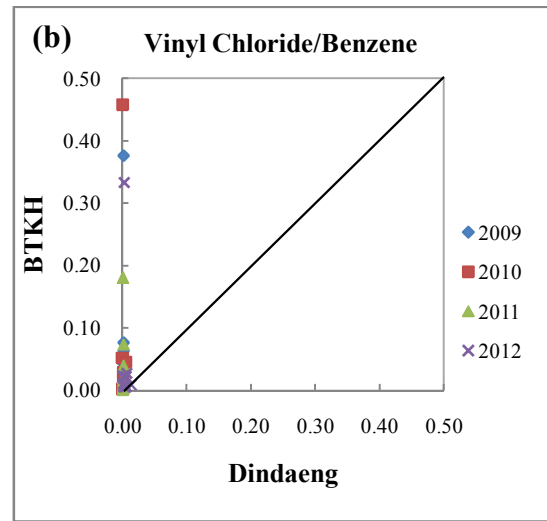
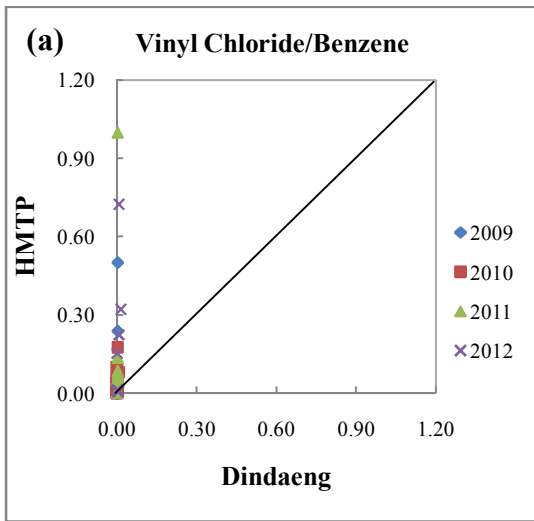


Figure 4.9 Scatter plots of chloromethane against benzene ratio of monitoring stations in Maptaphut area vs. Dindaeng (roadside site) in 2009-2012



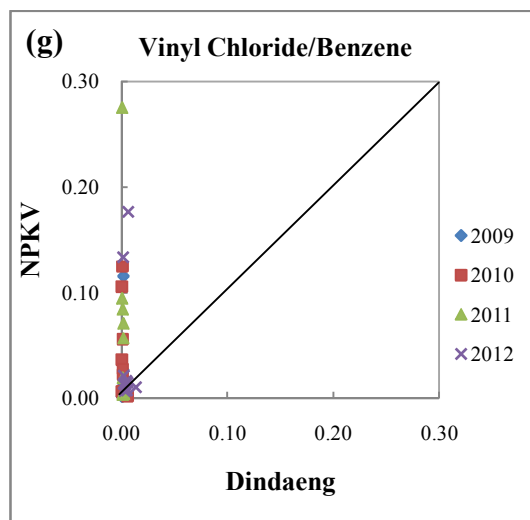
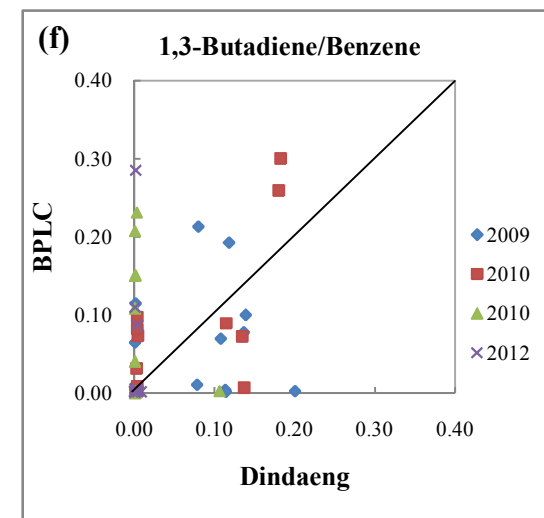
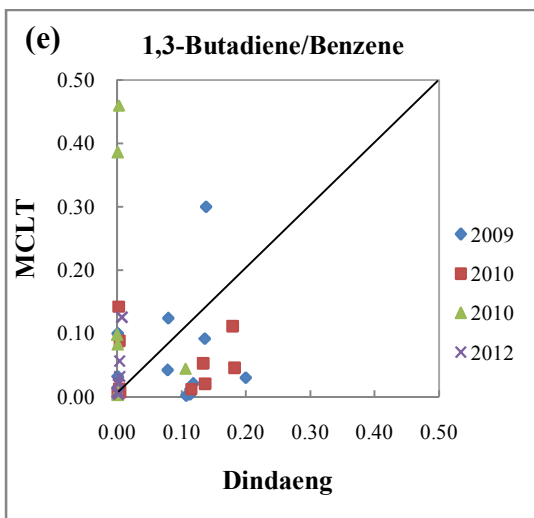
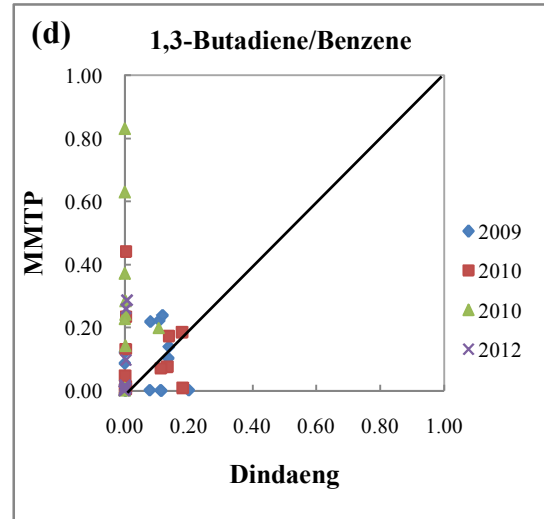
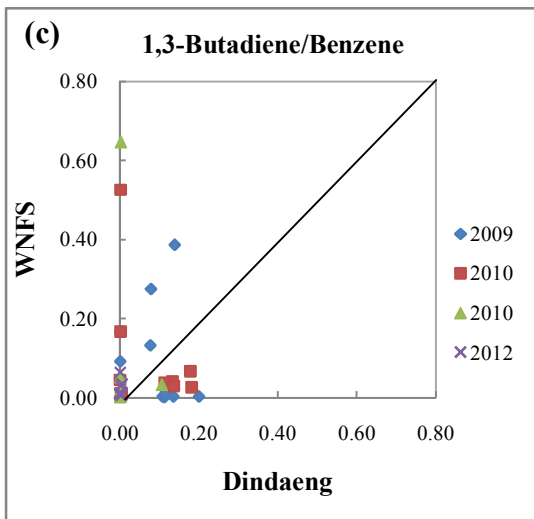
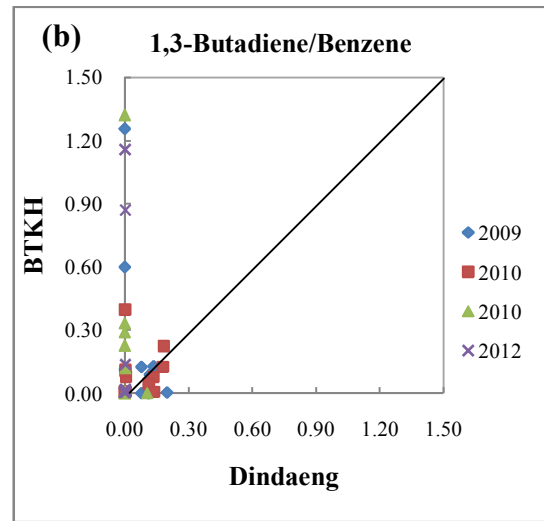
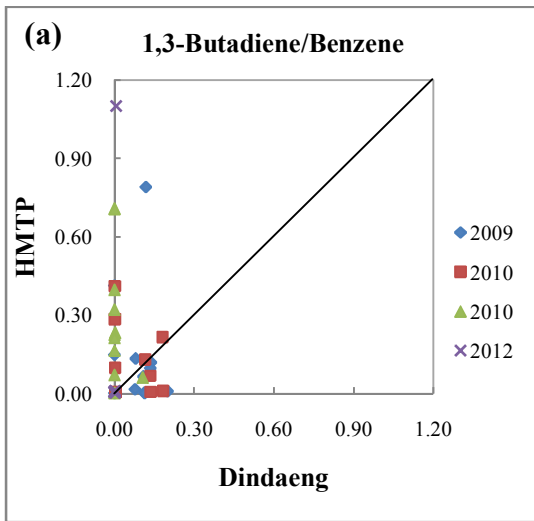


Figure 4.10 Scatter plots of vinyl chloride against benzene ratio of monitoring stations in Maptaphut area vs. Dindaeng (roadside site) in 2009-2012



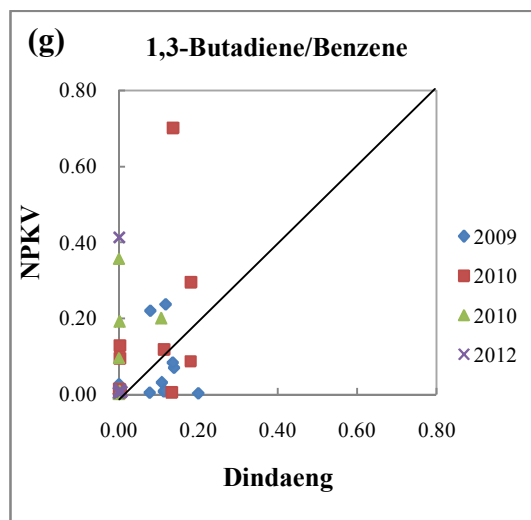
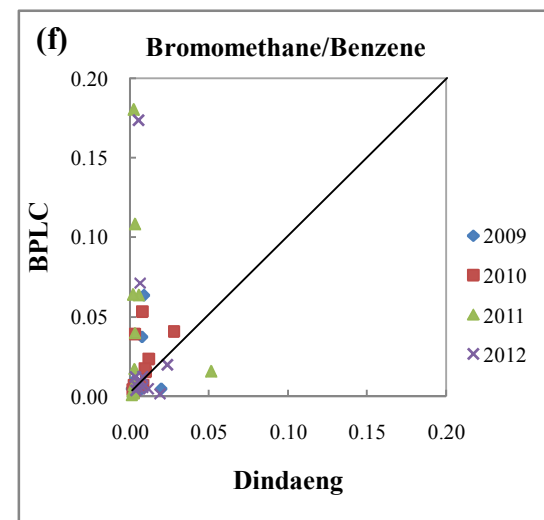
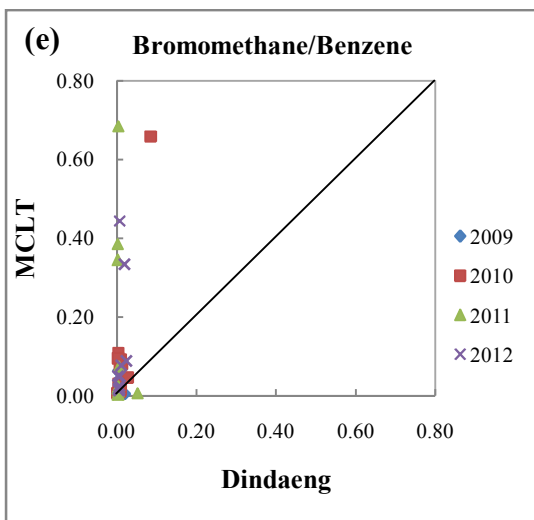
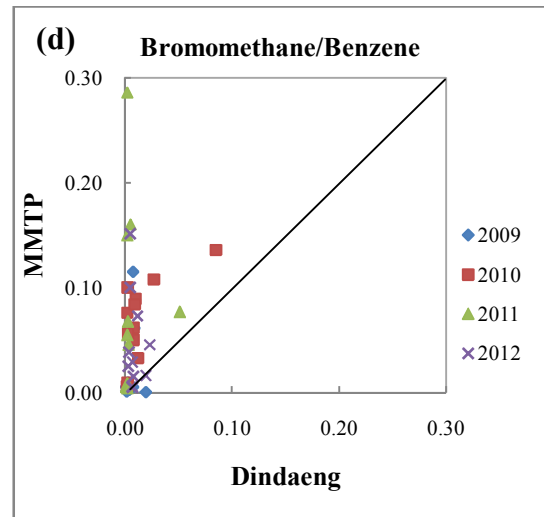
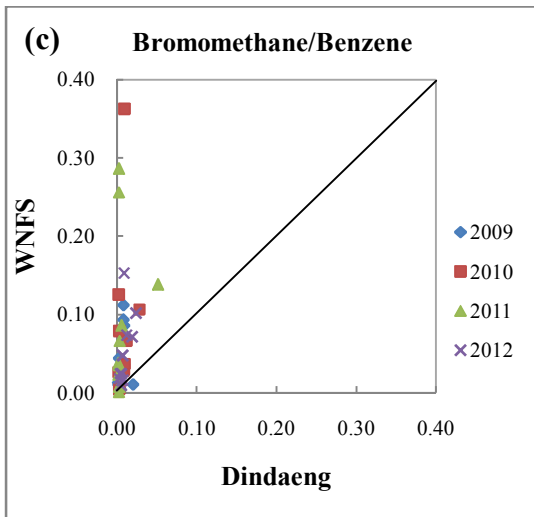
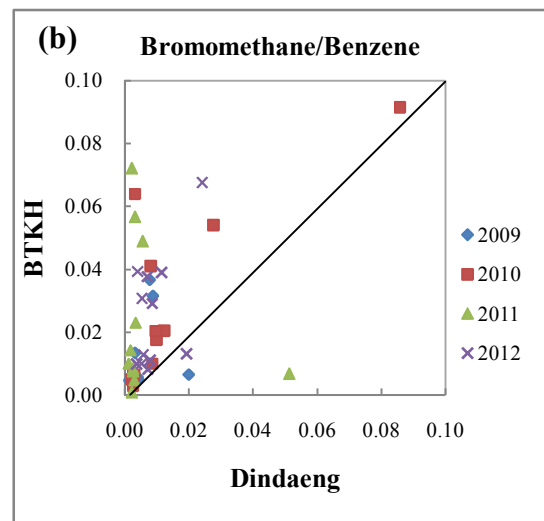
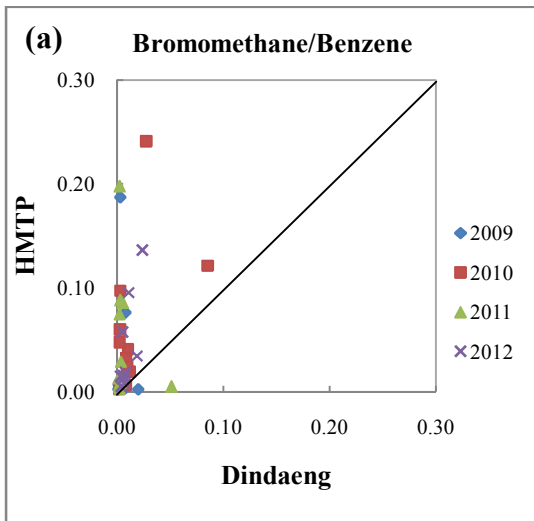


Figure 4.11 Scatter plots of 1,3-butadiene against benzene ratio of monitoring stations in Maptaphut area vs. Dindaeng (roadside site) in 2009-2012



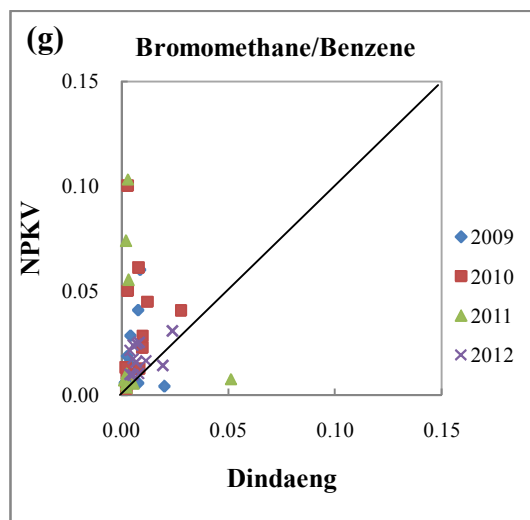
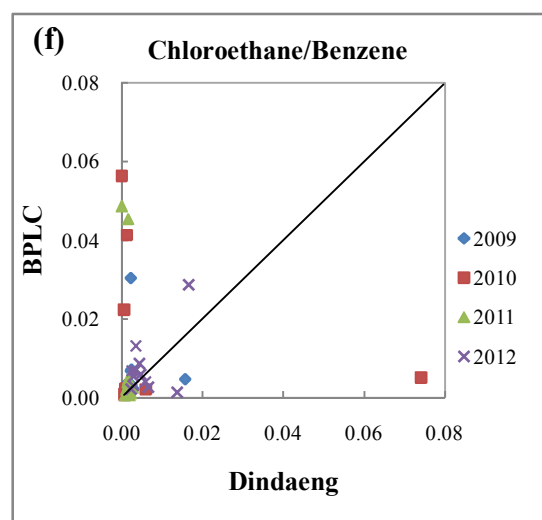
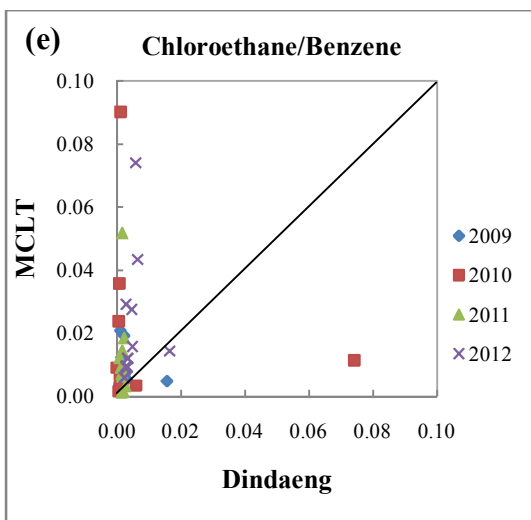
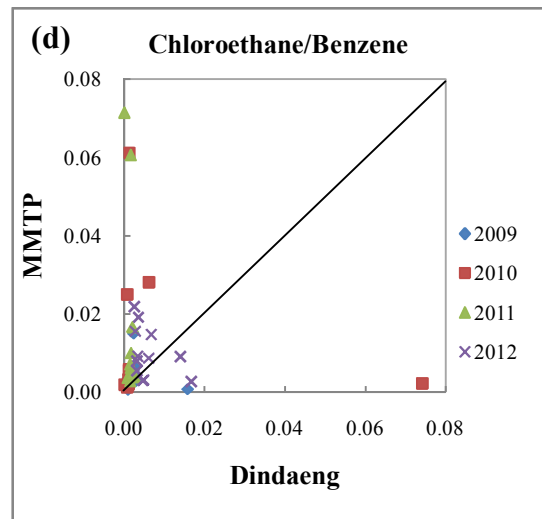
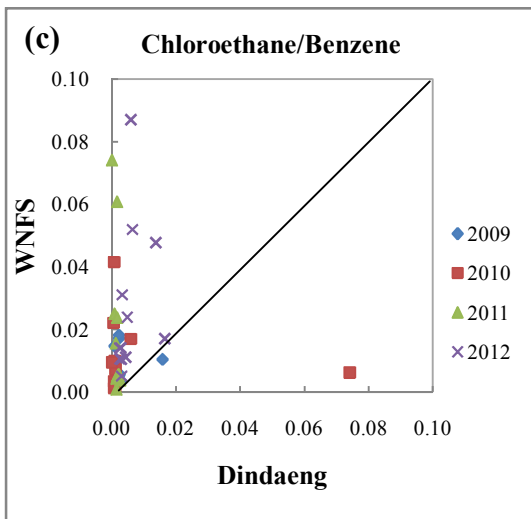
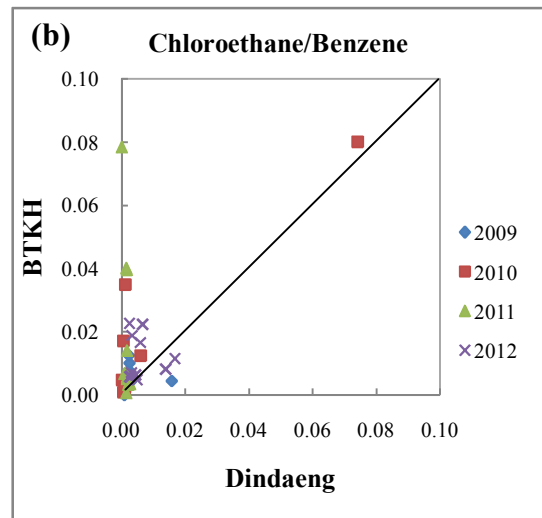
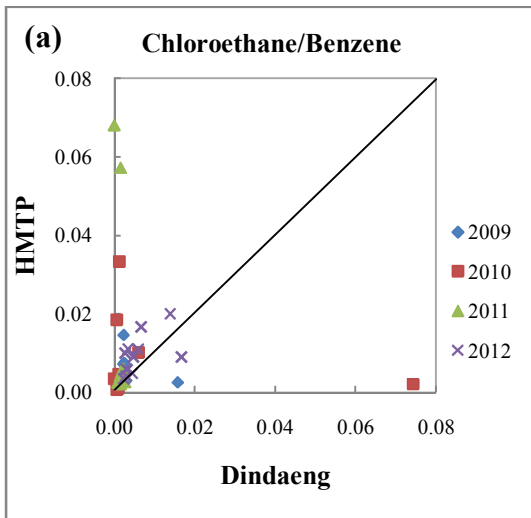


Figure 4.12 Scatter plots of bromomethane against benzene ratio of monitoring stations in Maptaphut area vs. Dindaeng (roadside site) in 2009-2012



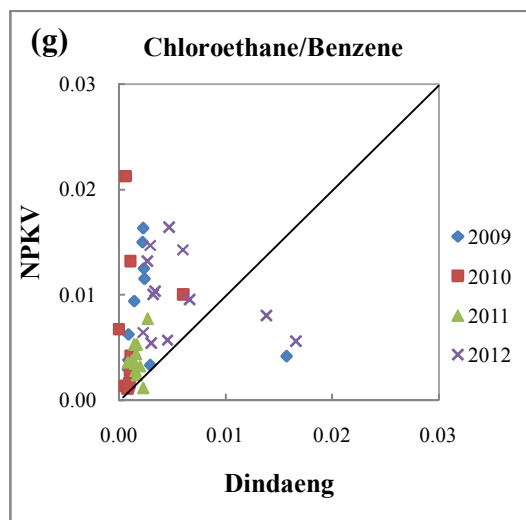
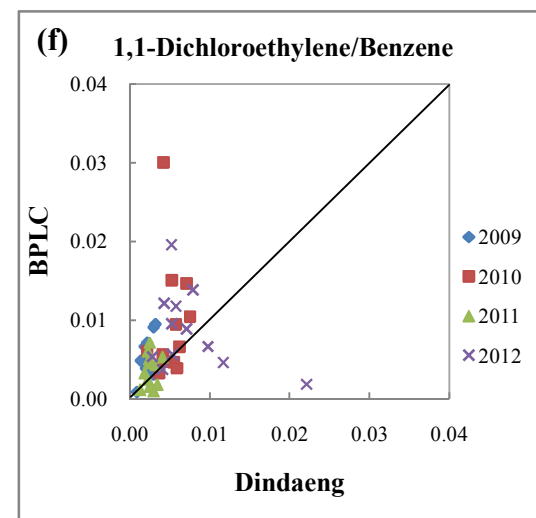
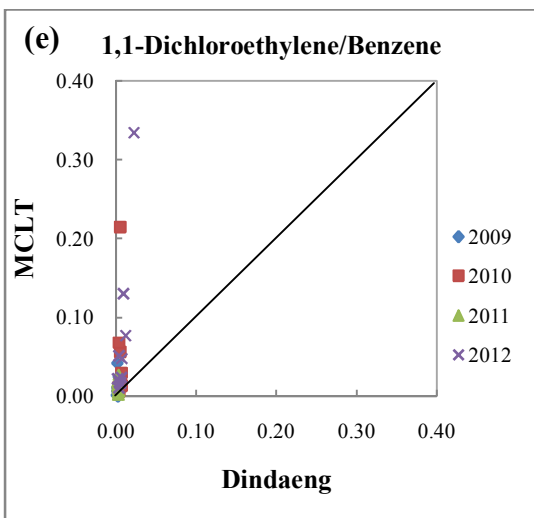
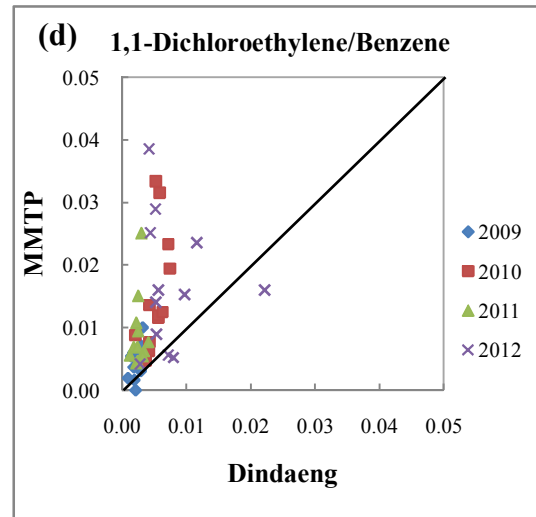
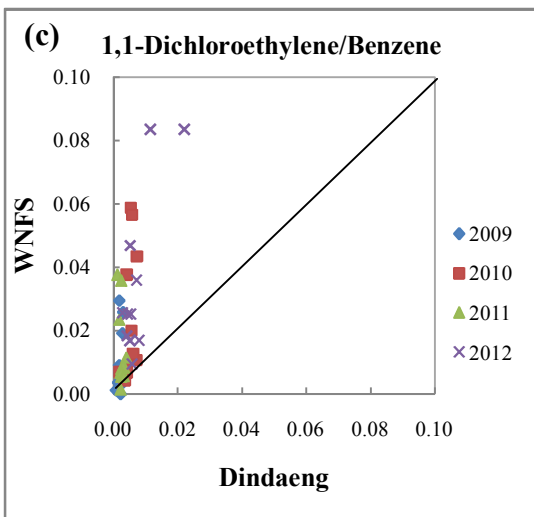
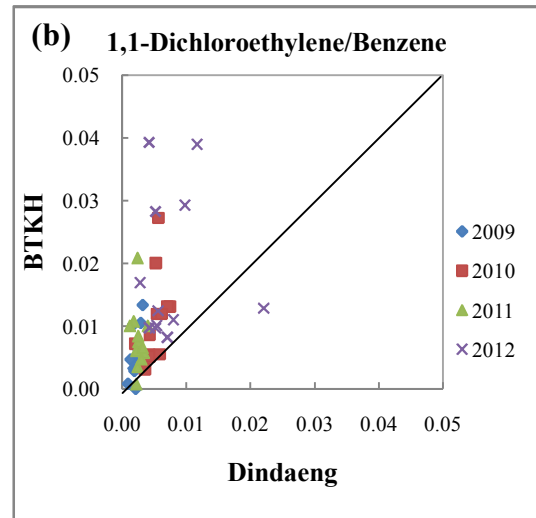
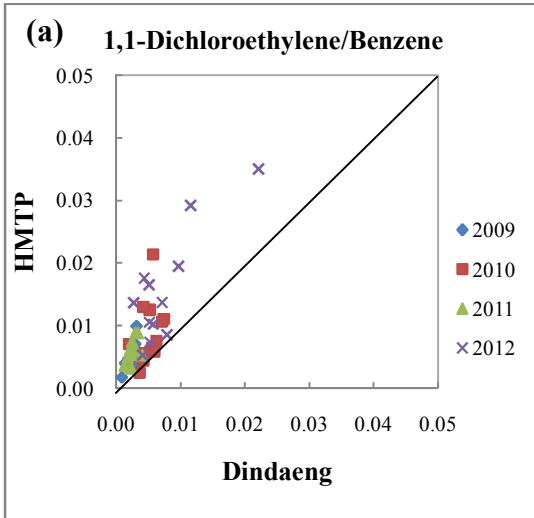


Figure 4.13 Scatter plots of chloroethane against benzene ratio of monitoring stations in Maptaphut area vs. Dindaeng (roadside site) in 2009-2012



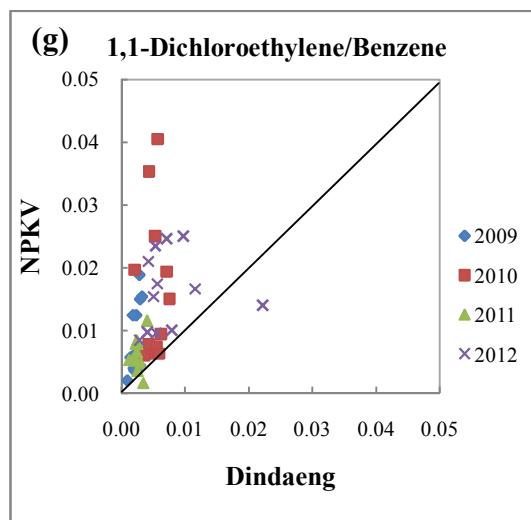
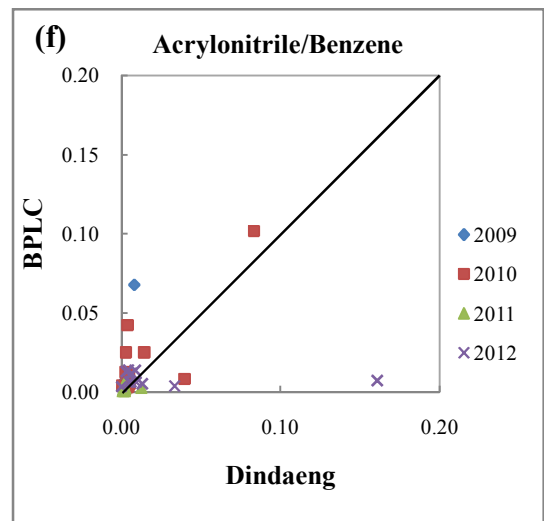
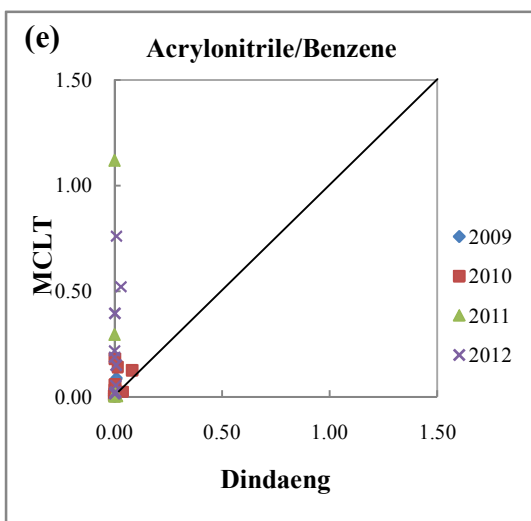
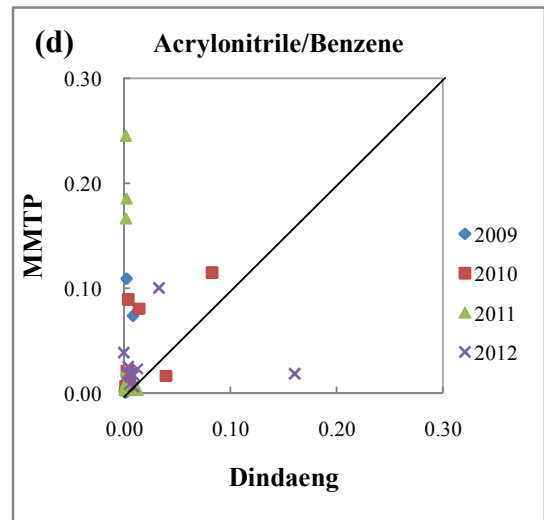
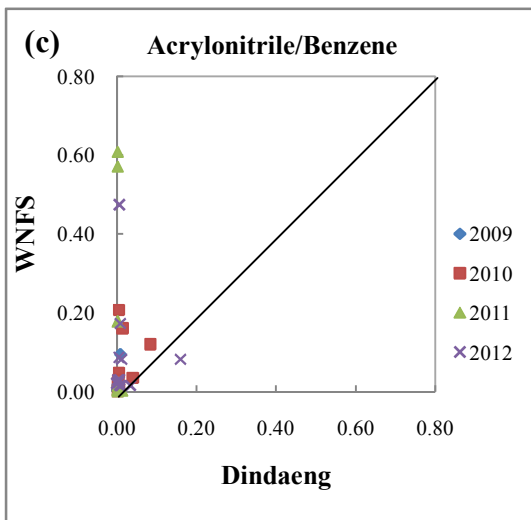
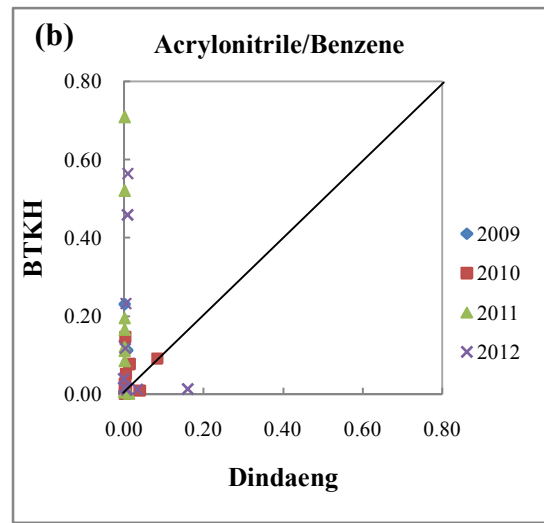
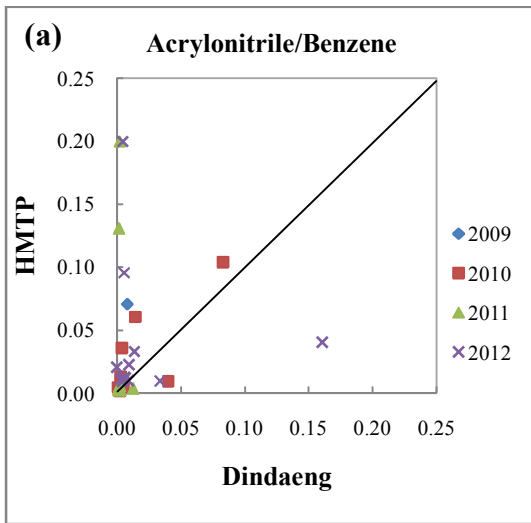


Figure 4.14 Scatter plots of 1,1-dichloroethylene against benzene ratio of monitoring stations in Maptaphut area vs. Dindaeng (roadside site) in 2009-2012



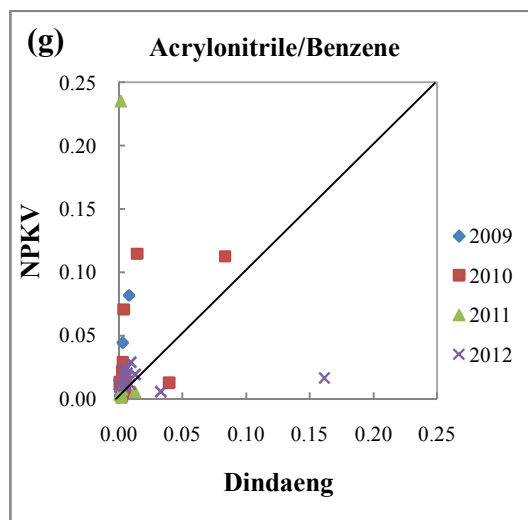
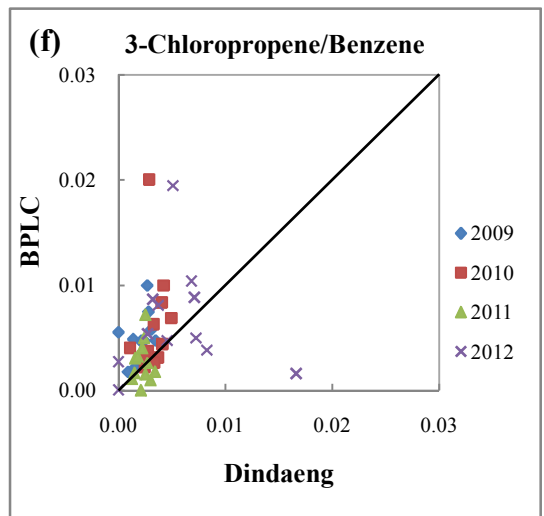
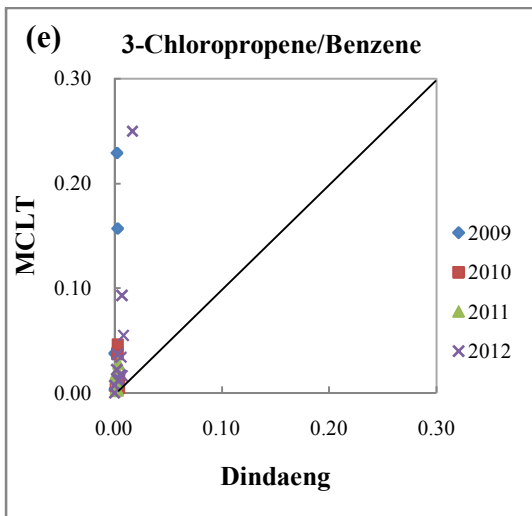
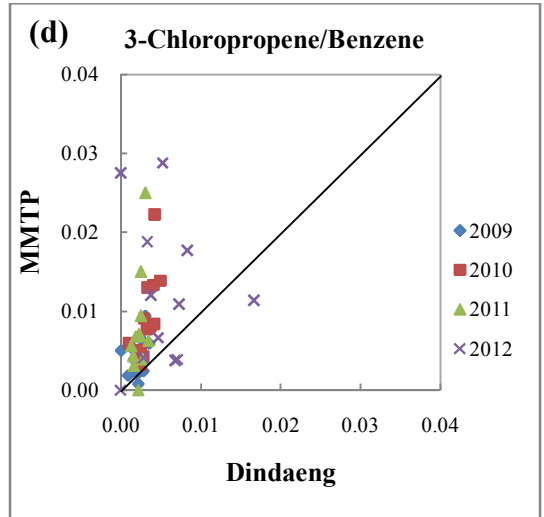
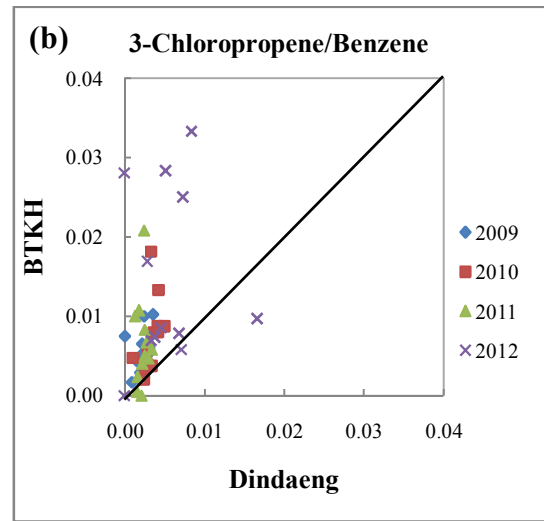
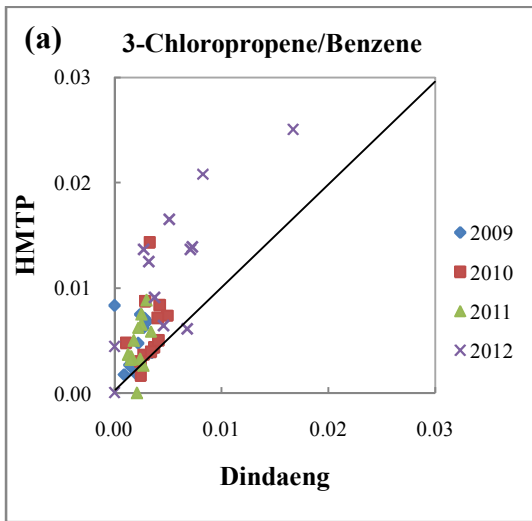


Figure 4.15 Scatter plots of acrylonitrile against benzene ratio of monitoring stations in Maptaphut area vs. Dindaeng (roadside site) in 2009-2012



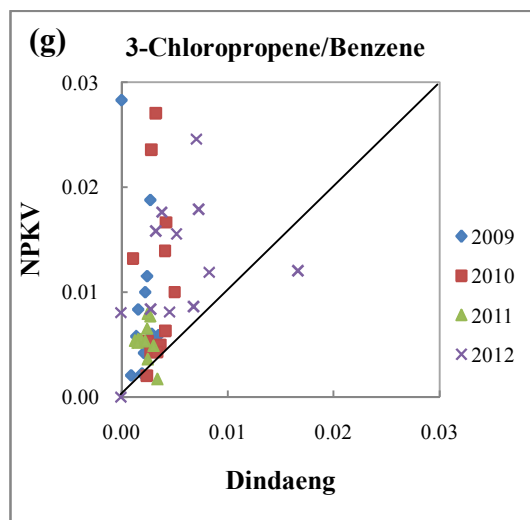
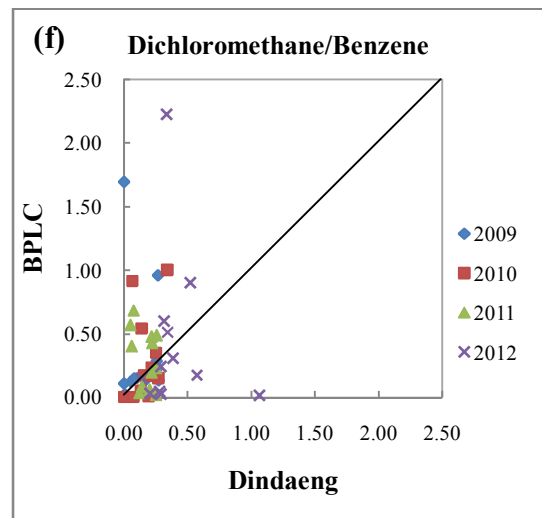
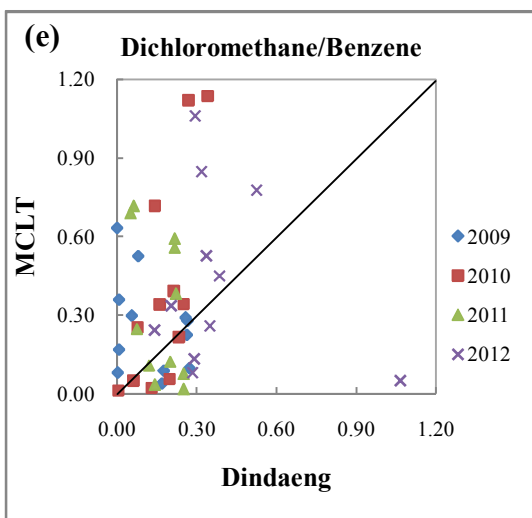
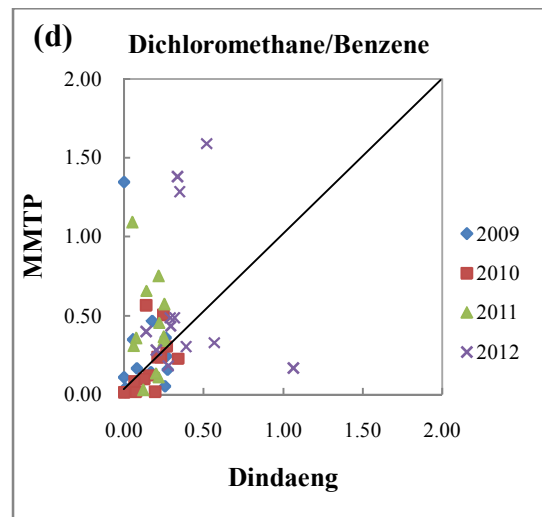
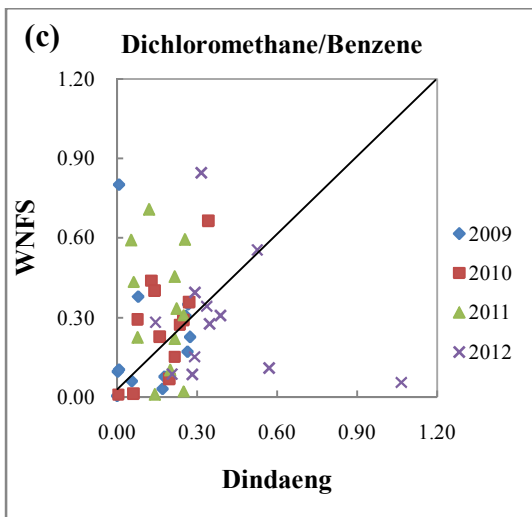
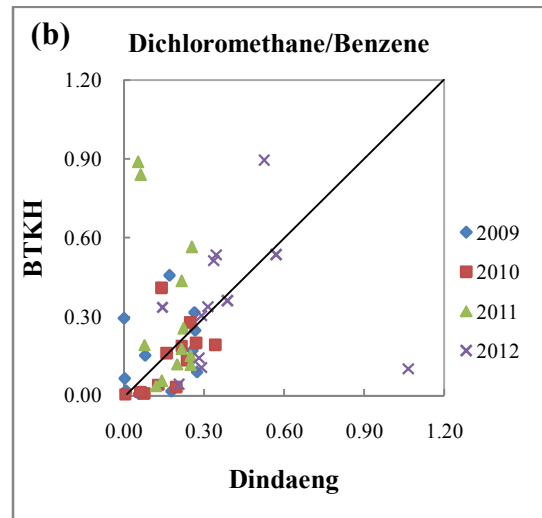
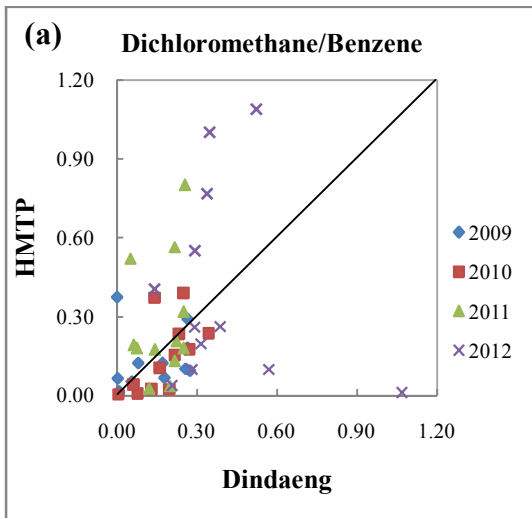


Figure 4.16 Scatter plots of 3-chloropropene against benzene ratio of monitoring stations in Maptaphut area vs. Dindaeng (roadside site) in 2009-2012



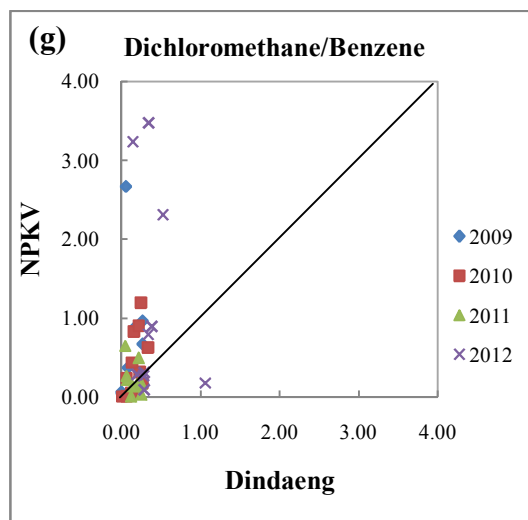
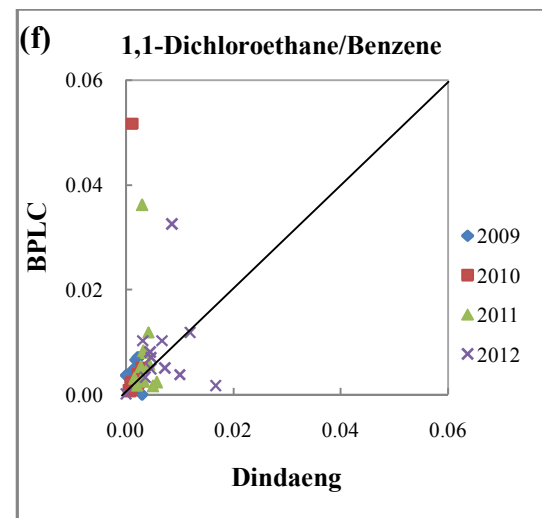
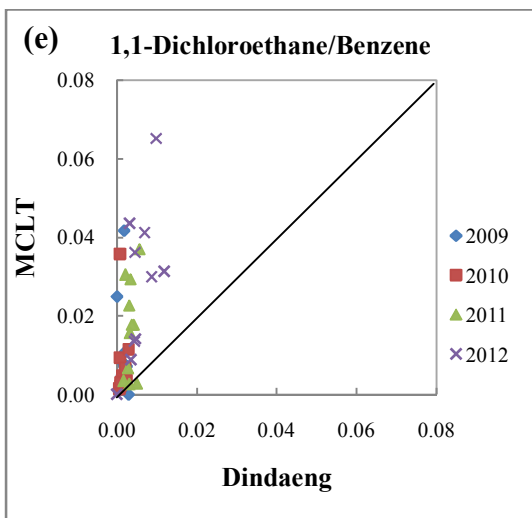
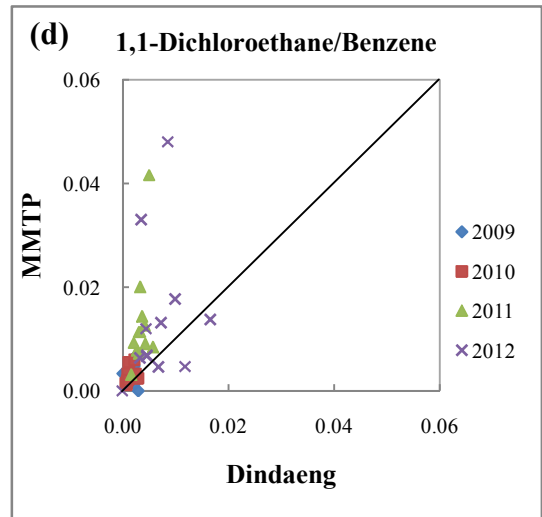
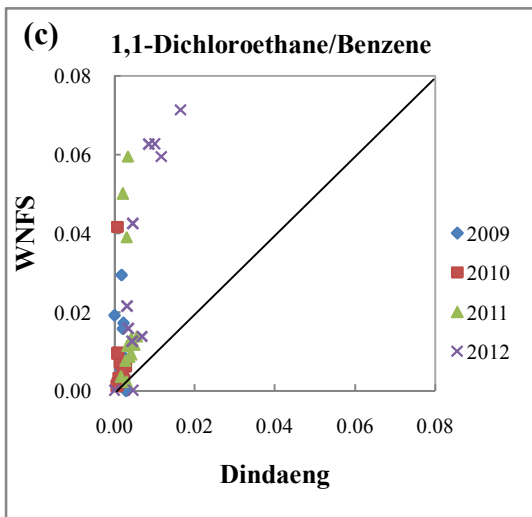
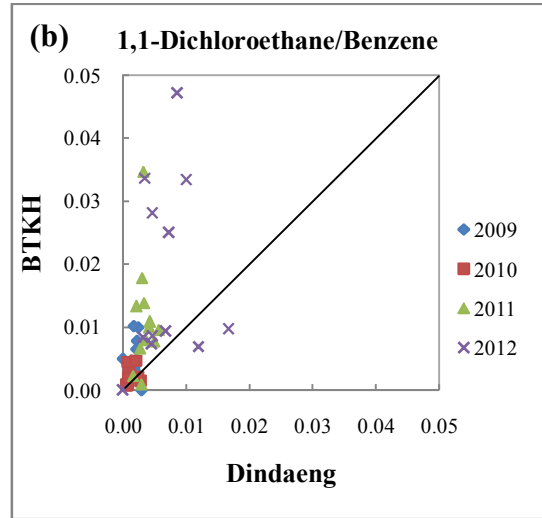
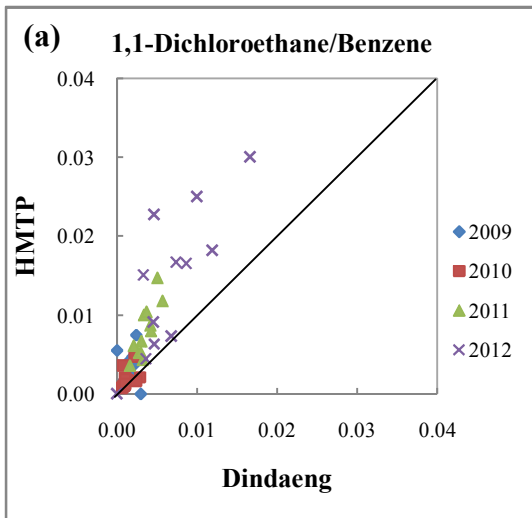


Figure 4.17 Scatter plots of dichloromethane against benzene ratio of monitoring stations in Maptaphut area vs. Dindaeng (roadside site) in 2009-2012



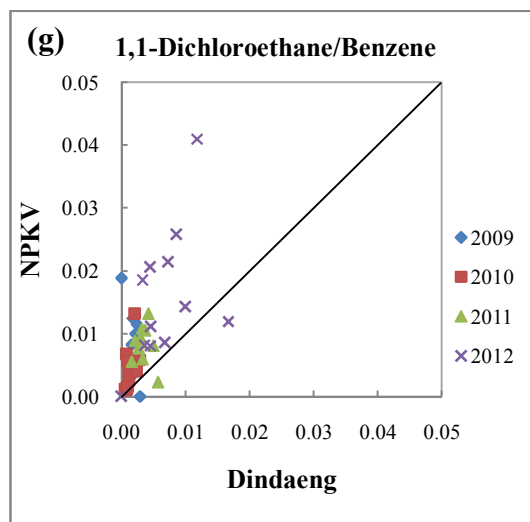
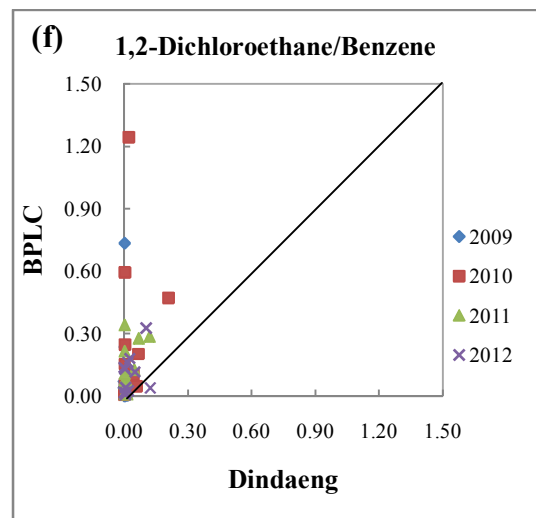
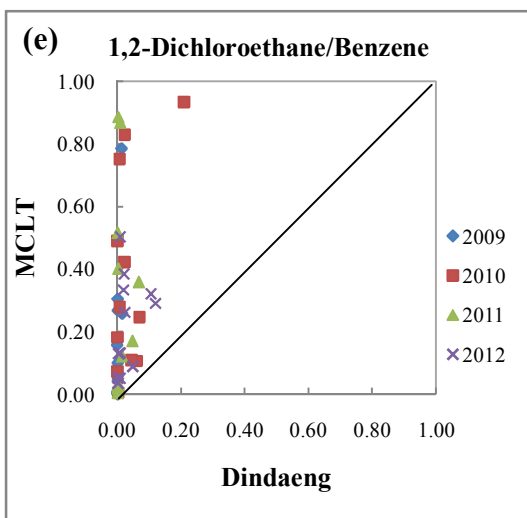
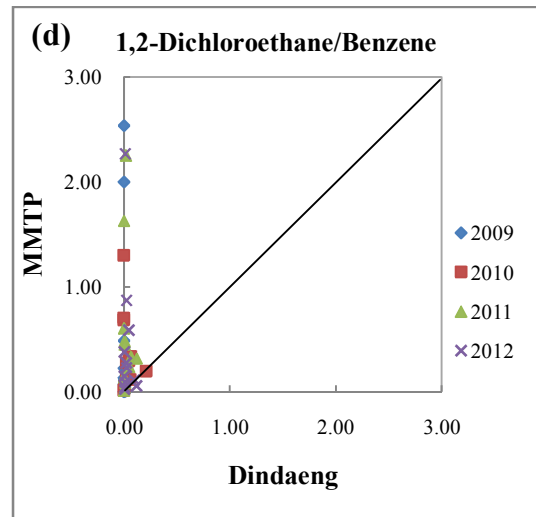
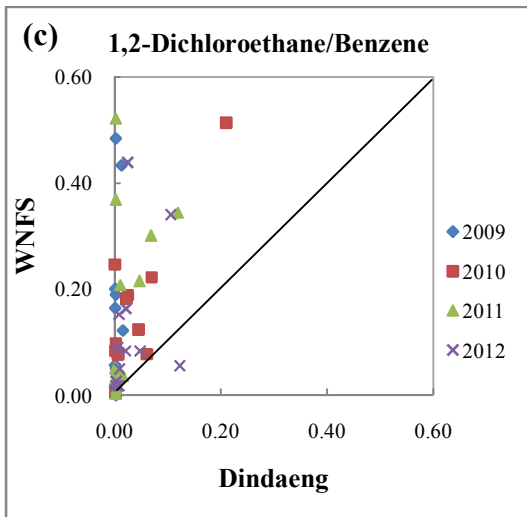
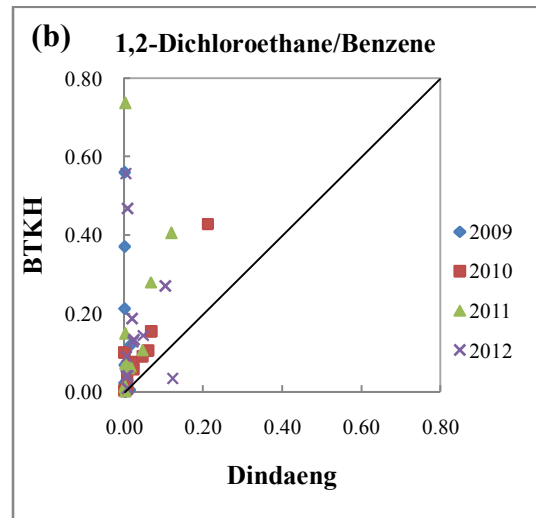
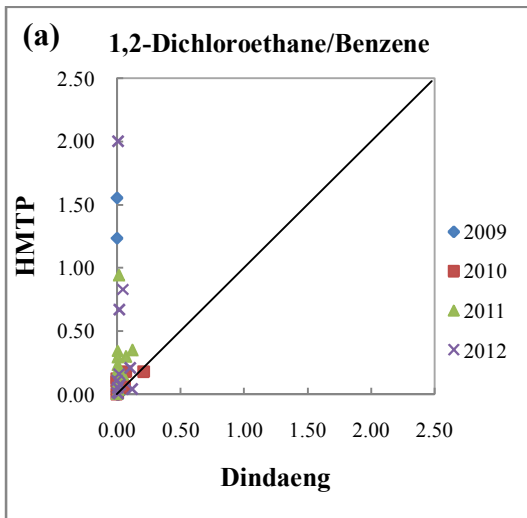


Figure 4.18 Scatter plots of 1,1-dichloroethane against benzene ratio of monitoring stations in Maptaphut area vs. Dindaeng (roadside site) in 2009-2012



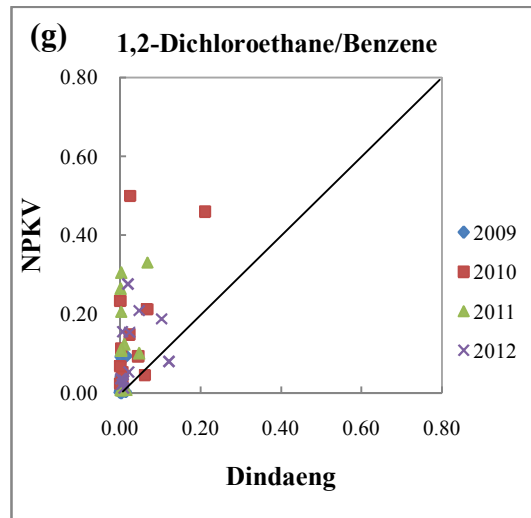
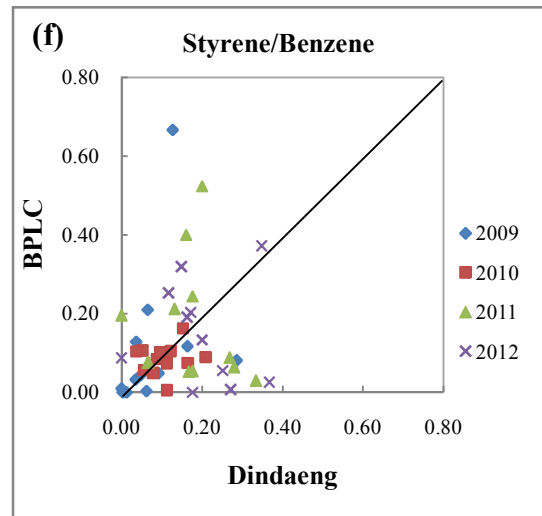
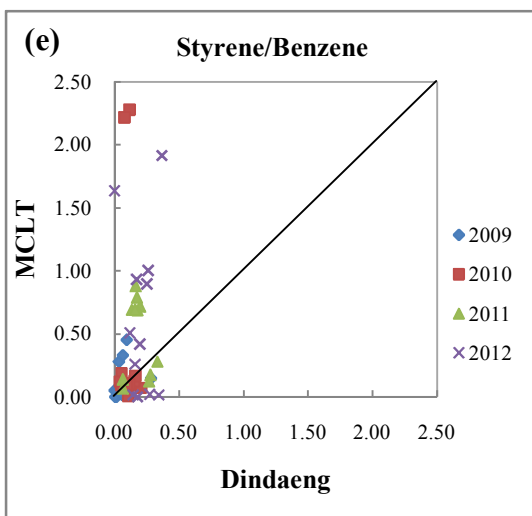
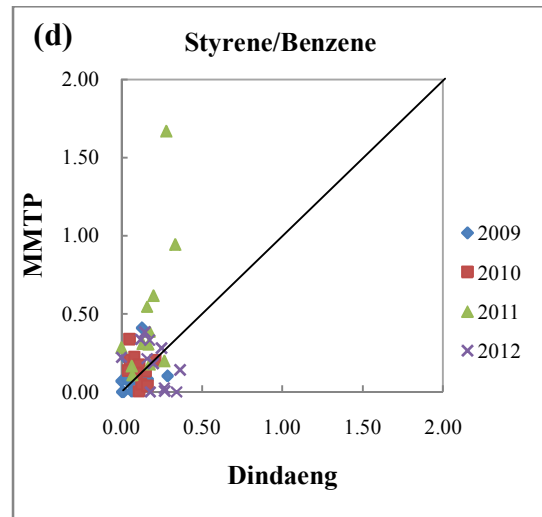
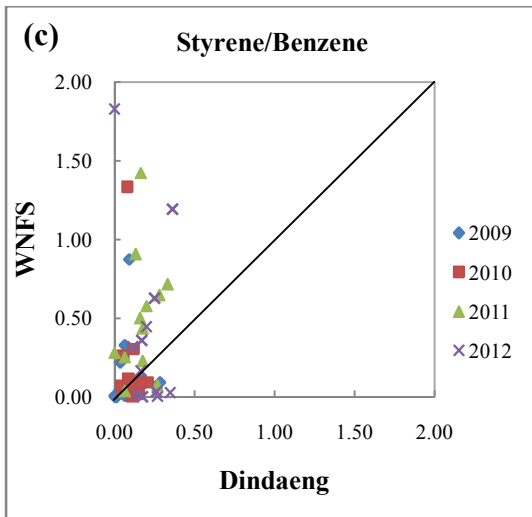
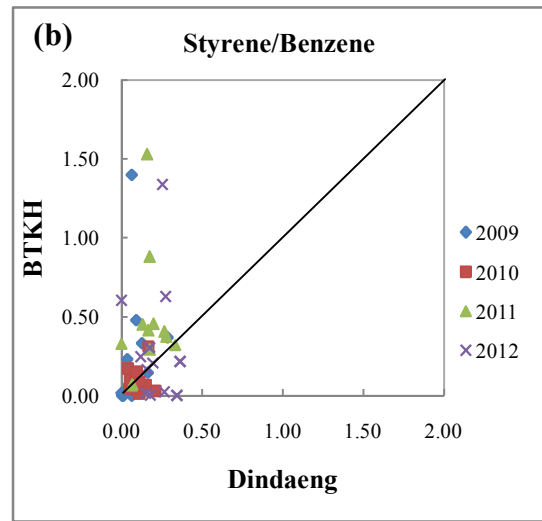
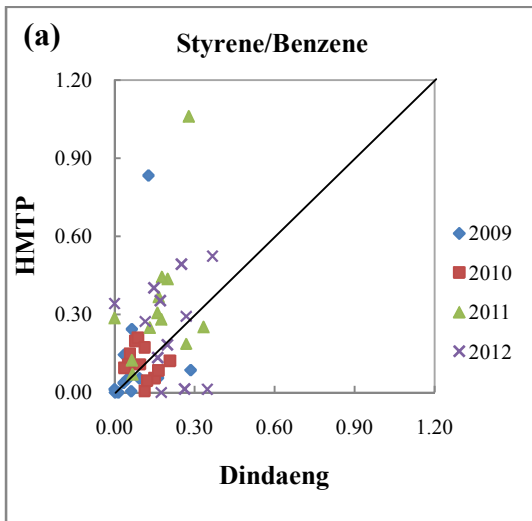


Figure 4.19 Scatter plots of 1,2-dichloroethane against benzene ratio of monitoring stations in Maptaphut area vs. Dindaeng (roadside site) in 2009-2012



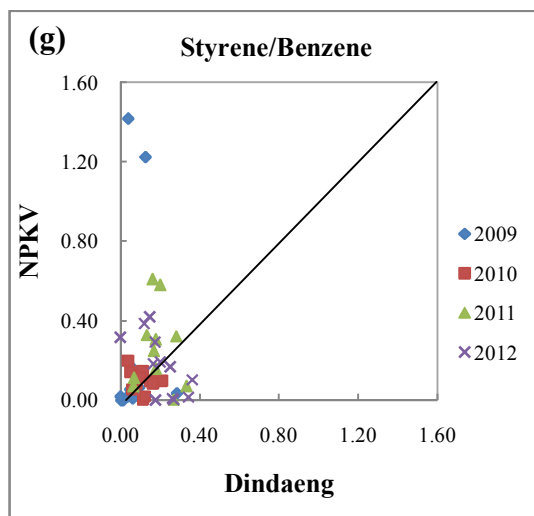
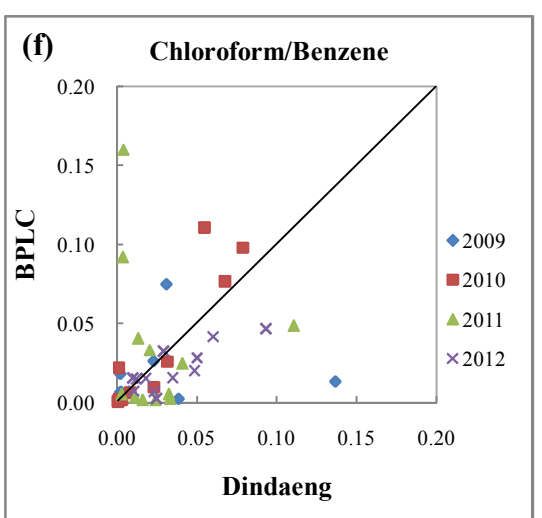
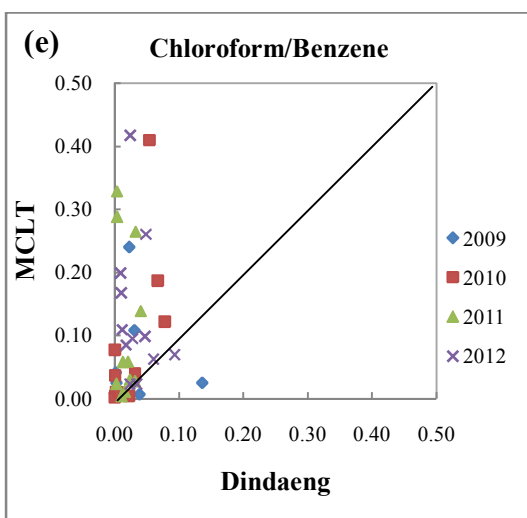
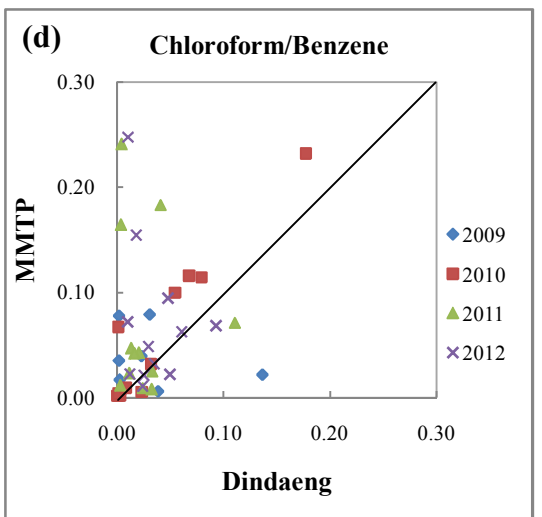
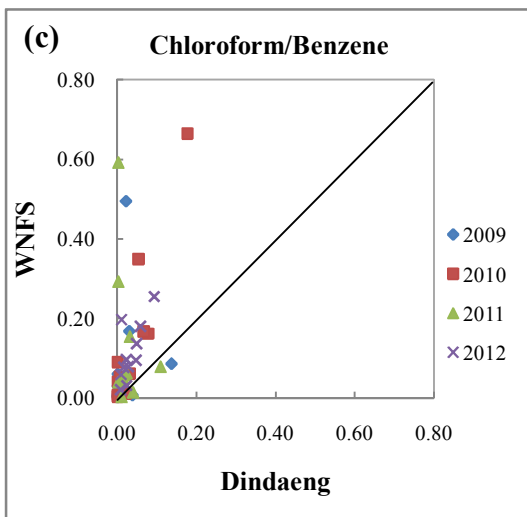
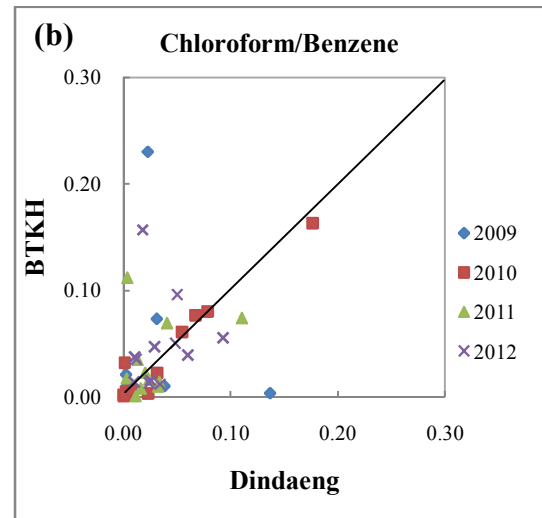
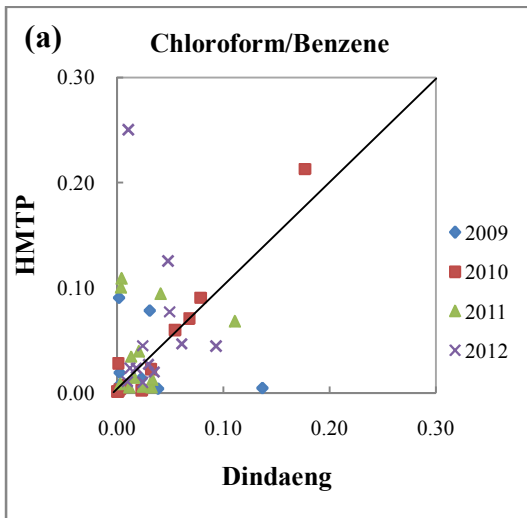


Figure 4.20 Scatter plots of styrene against benzene ratio of monitoring stations in Maptaphut area vs. Dindaeng (roadside site) in 2009-2012



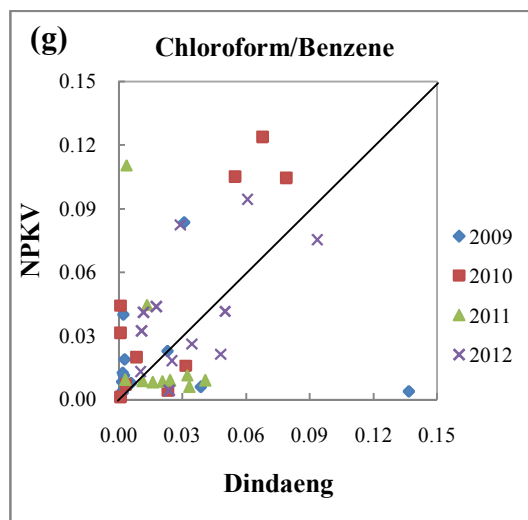
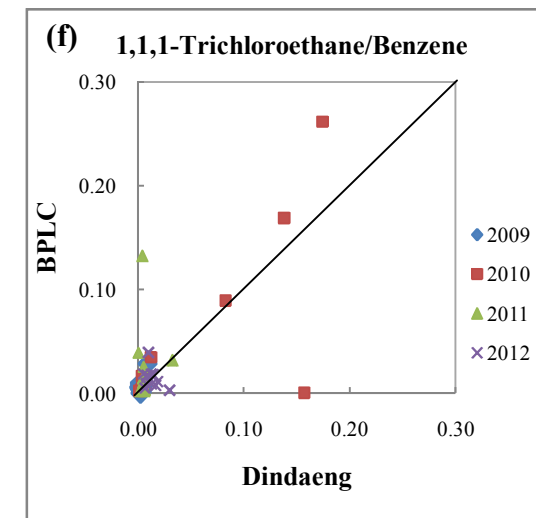
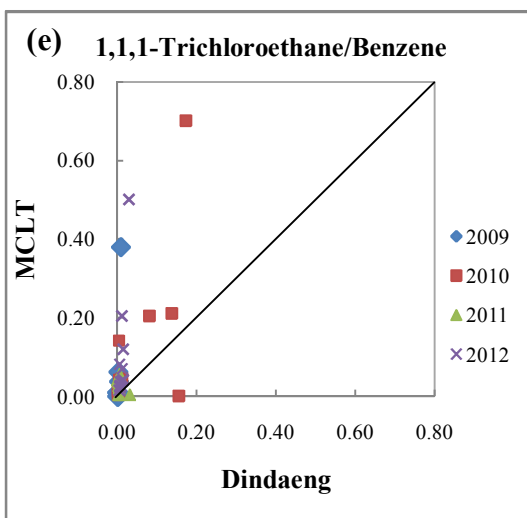
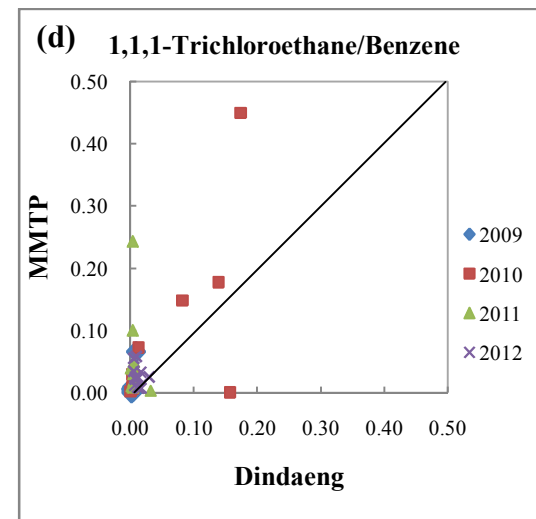
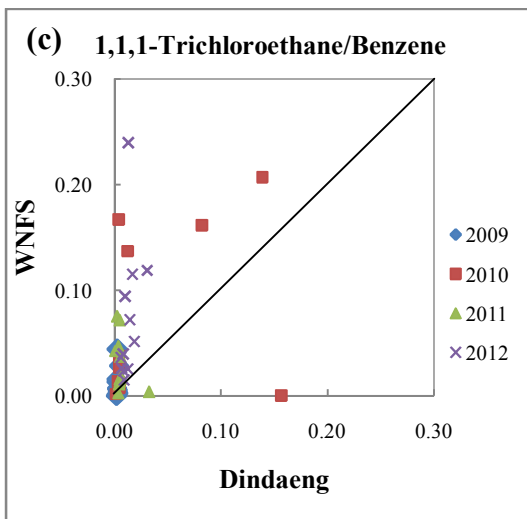
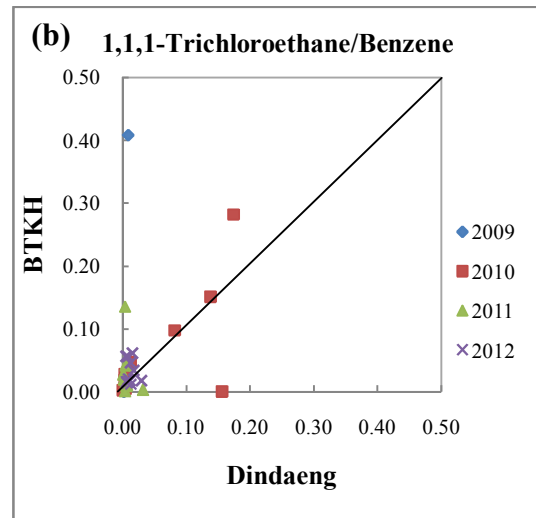
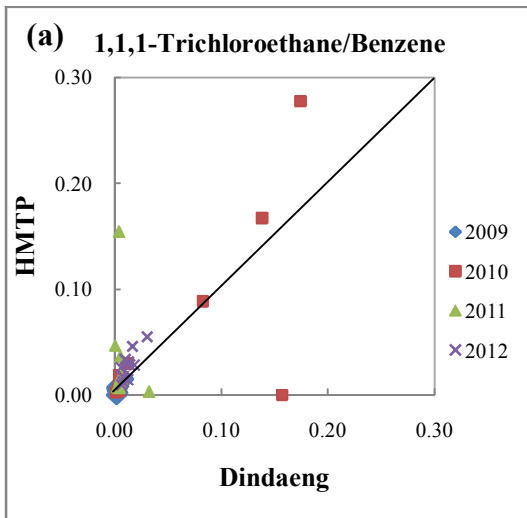


Figure 4.21 Scatter plots of chloroform against benzene ratio of monitoring stations in Maptaphut area vs. Dindaeng (roadside site) in 2009-2012



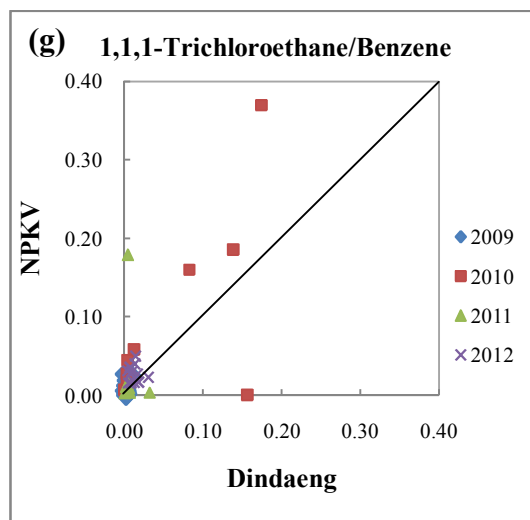
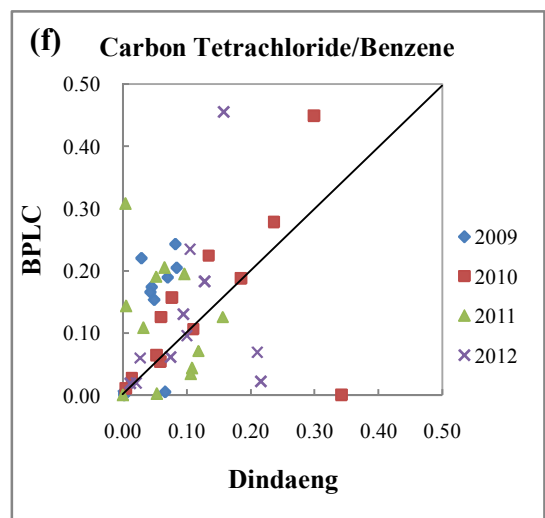
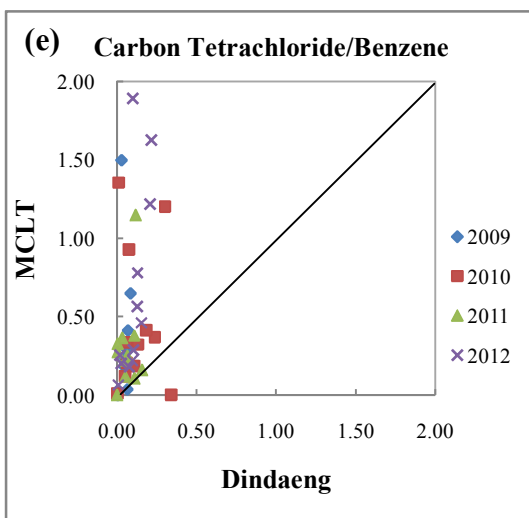
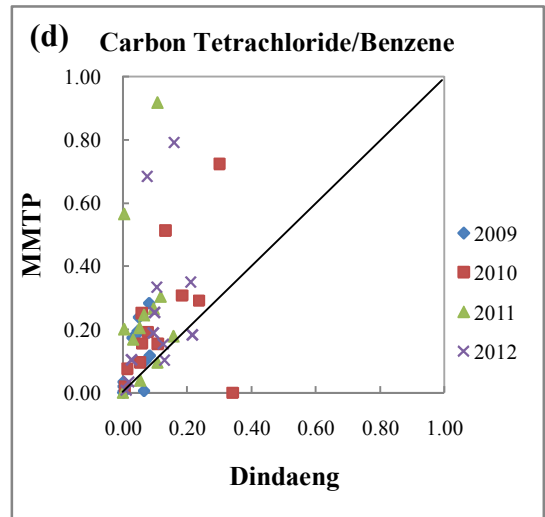
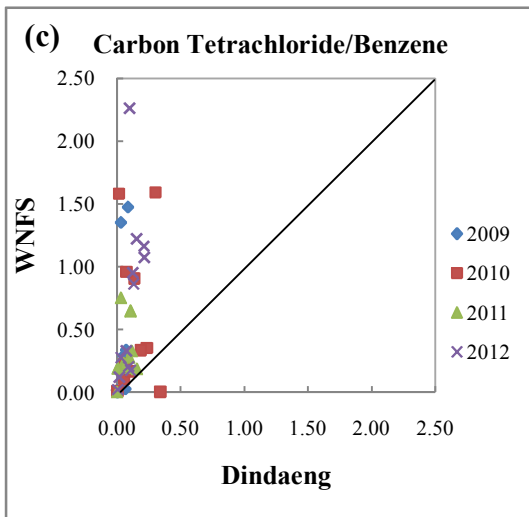
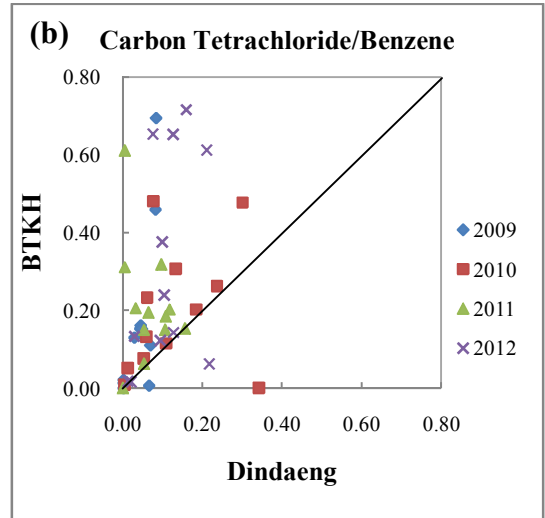
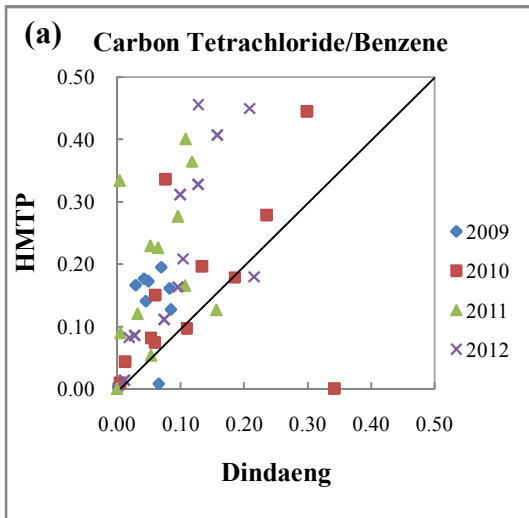


Figure 4.22 Scatter plots of 1,1,1-trichloroethane against benzene ratio of monitoring stations in Maptaphut area vs. Dindaeng (roadside site) in 2009-2012



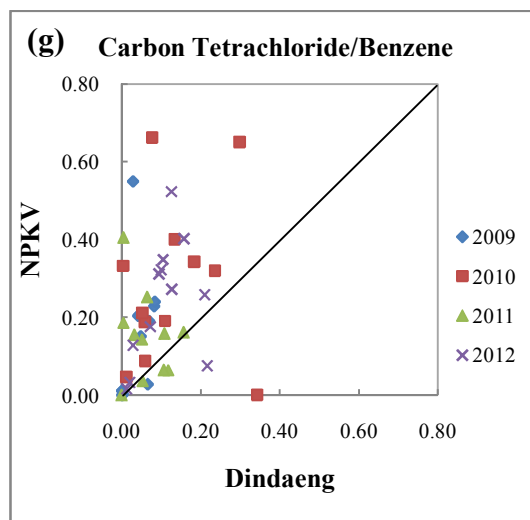
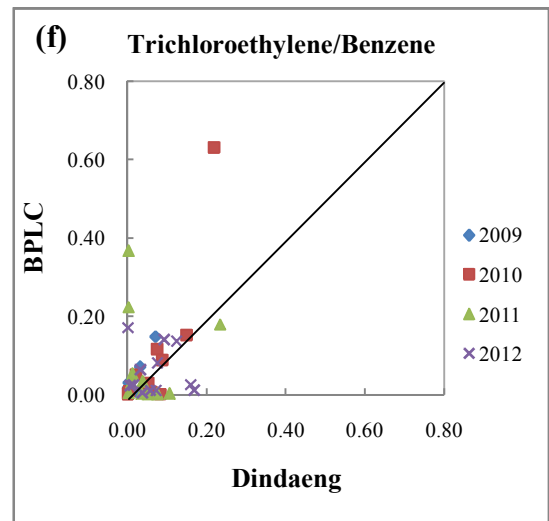
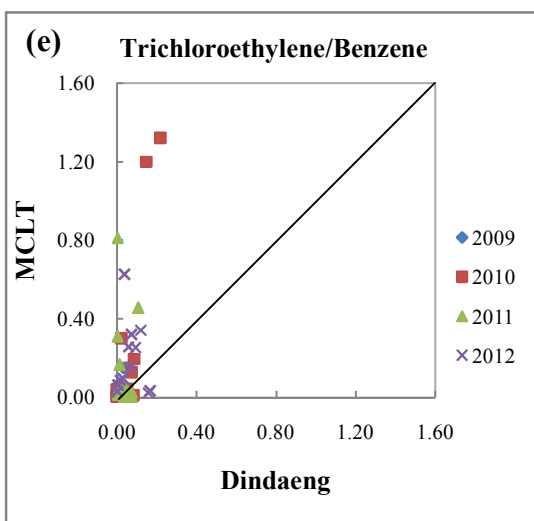
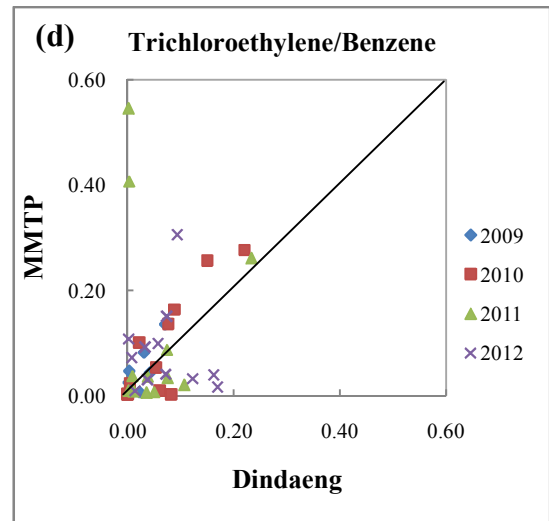
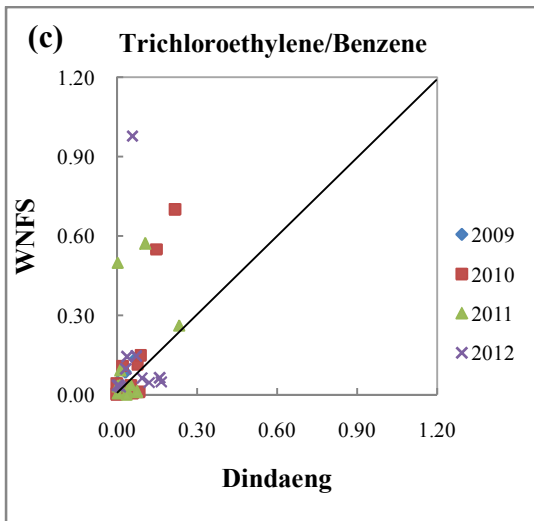
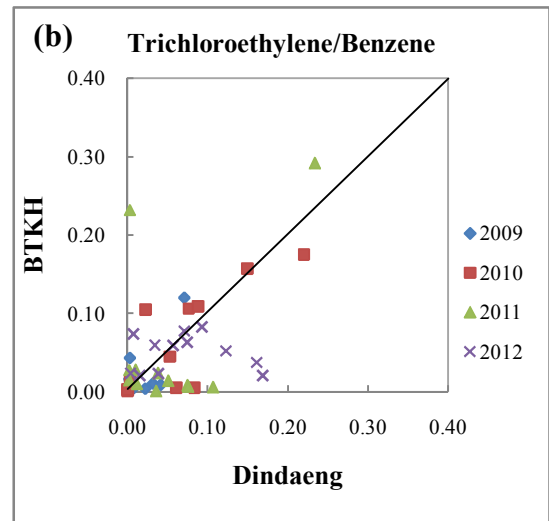
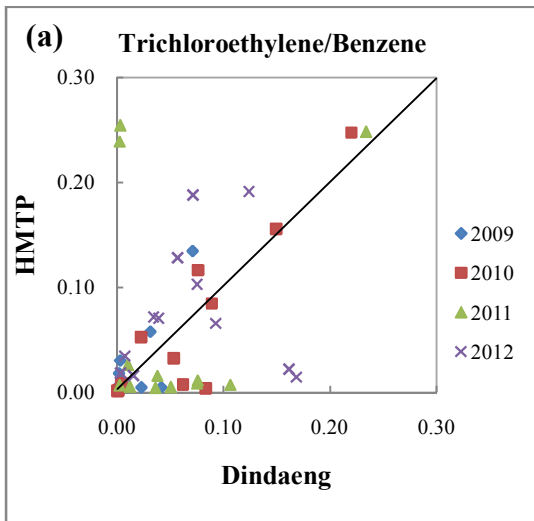


Figure 4.23 Scatter plots of carbon tetrachloride against benzene ratio of monitoring stations in Maptaphut area vs. Dindaeng (roadside site) in 2009-2012



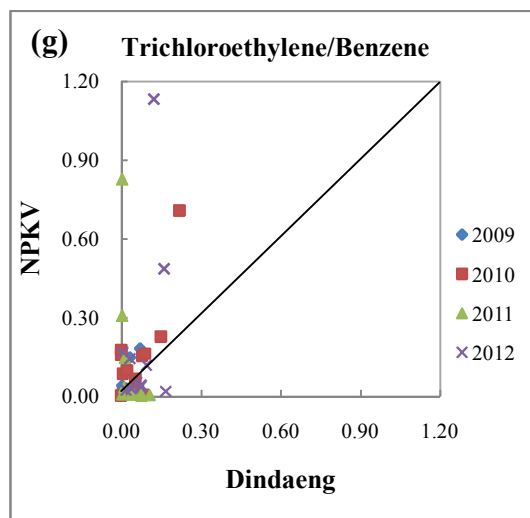
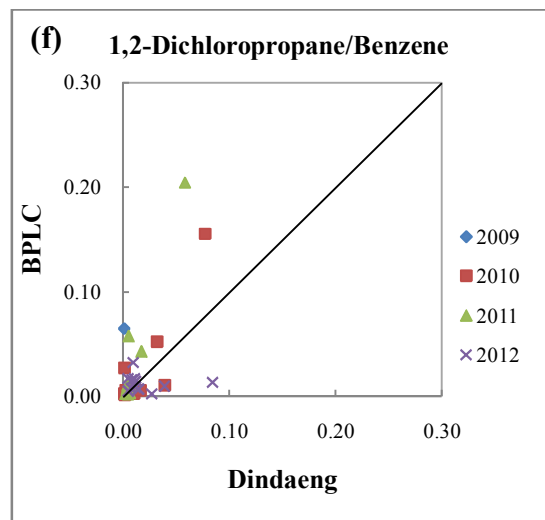
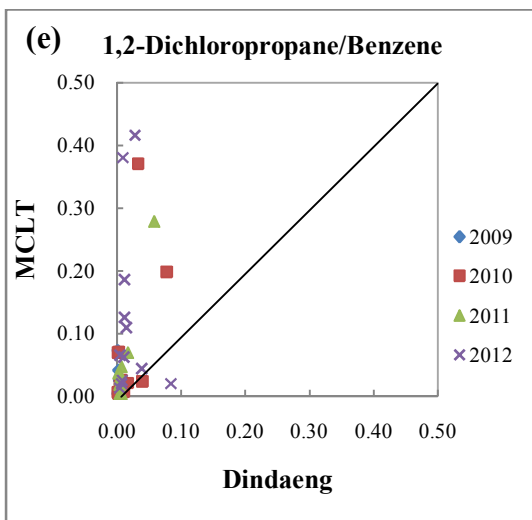
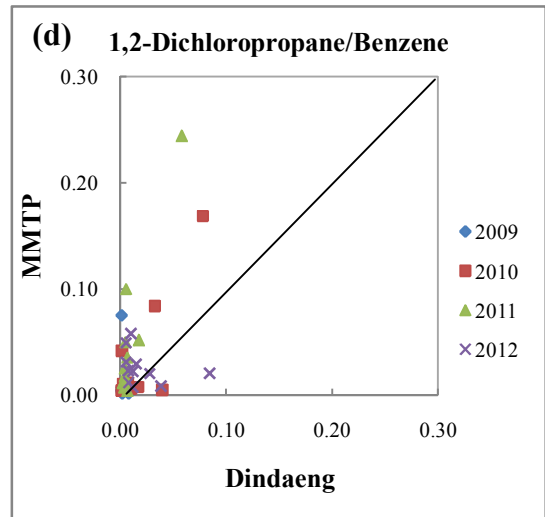
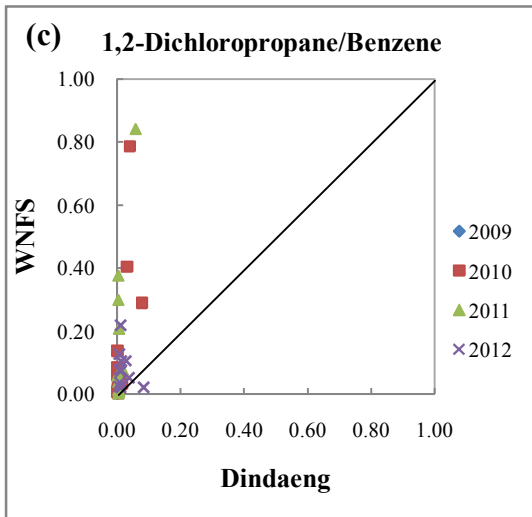
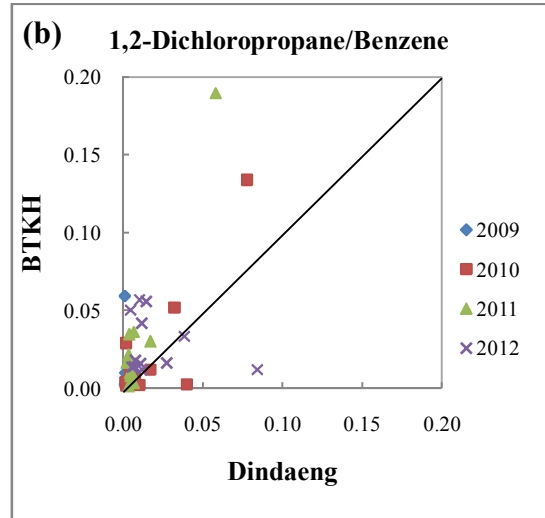
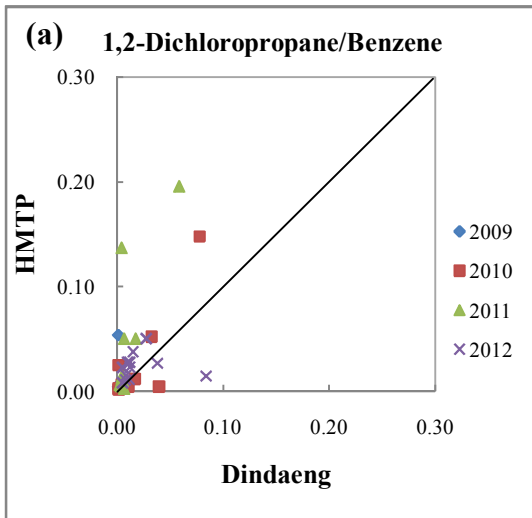


Figure 4.24 Scatter plots of trichloroethylene against benzene ratio of monitoring stations in Maptaphut area vs. Dindaeng (roadside site) in 2009-2012



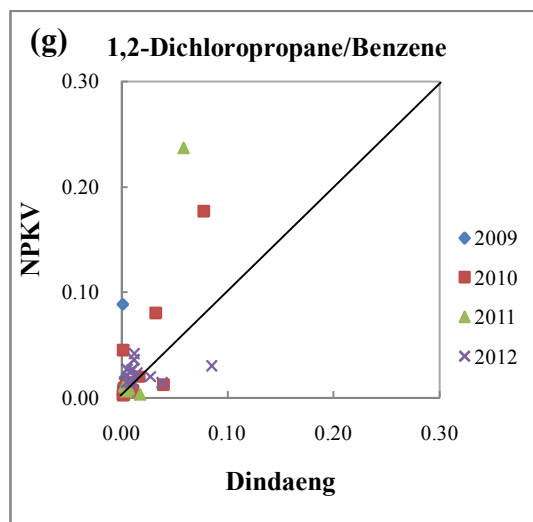
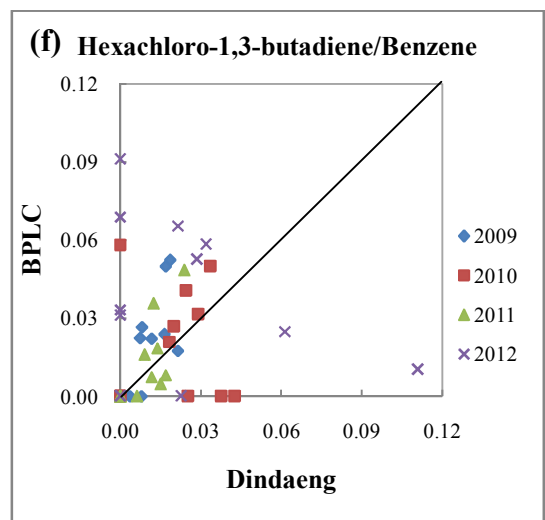
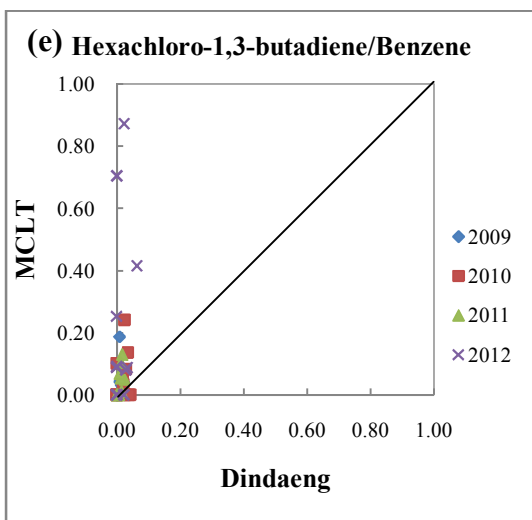
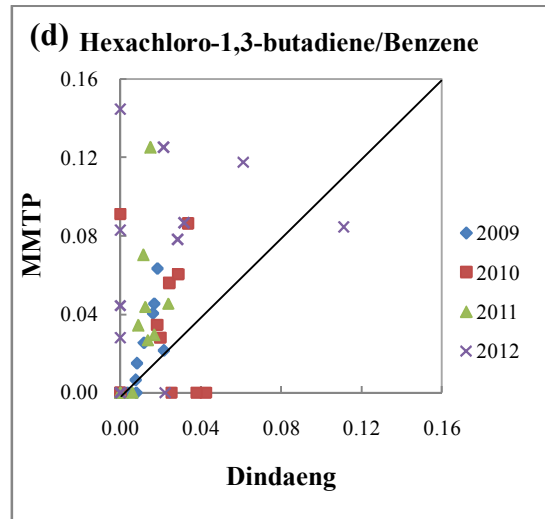
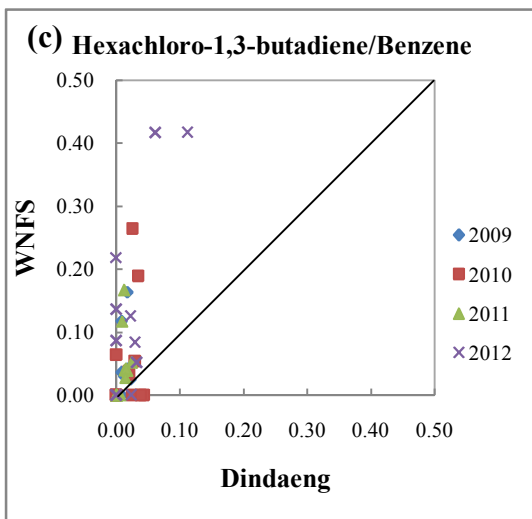
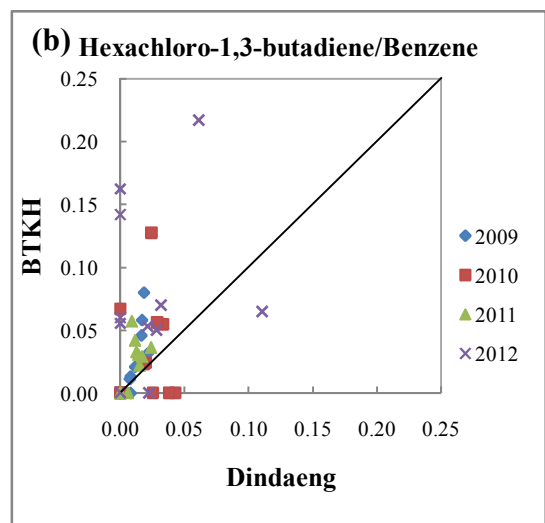
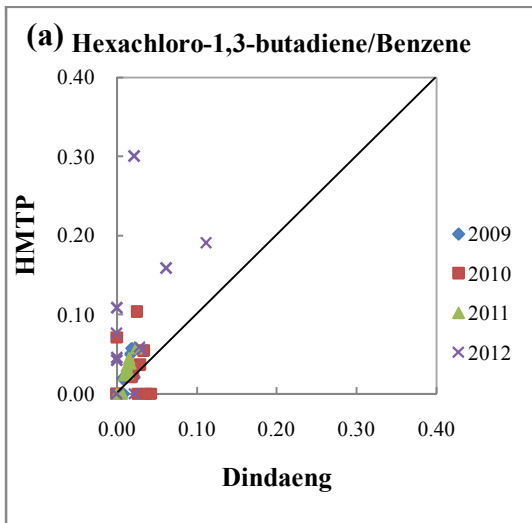


Figure 4.25 Scatter plots of 1,2-dichloropropane against benzene ratio of monitoring stations in Maptaphut area vs. Dindaeng (roadside site) in 2009-2012



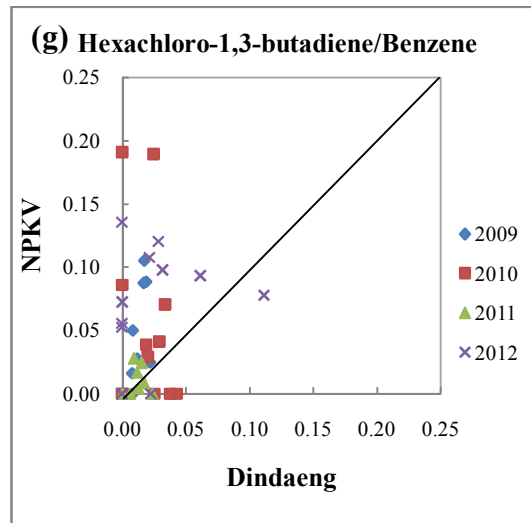
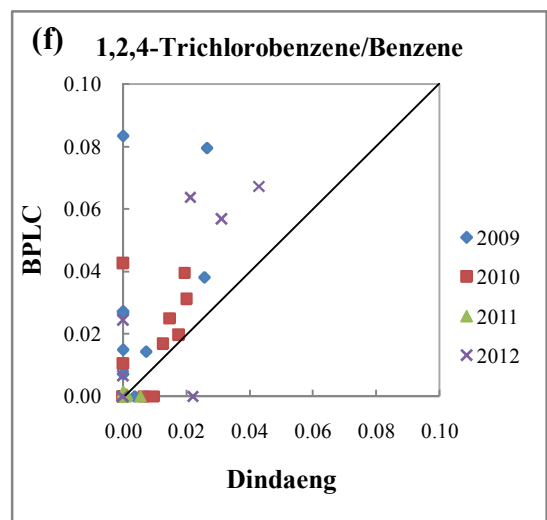
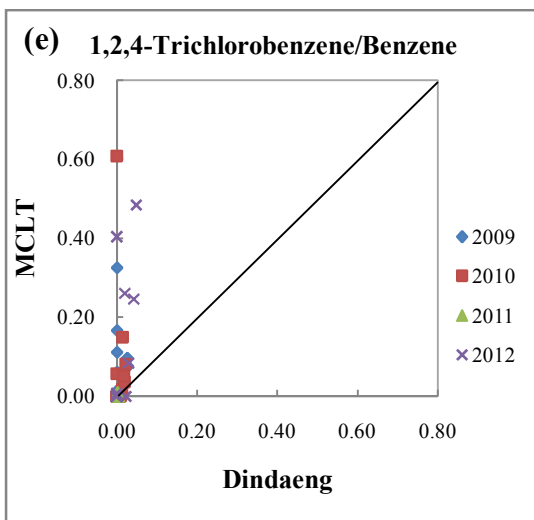
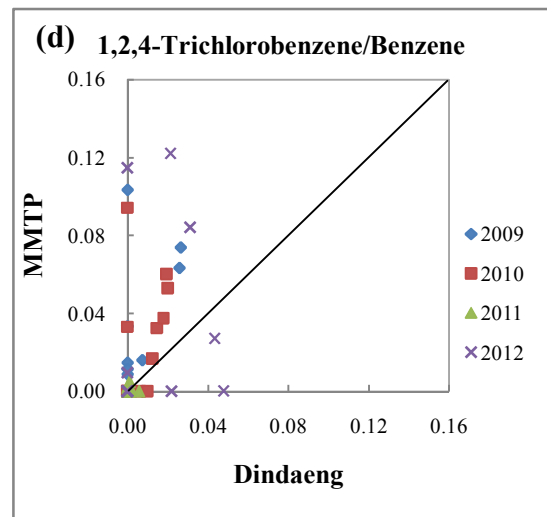
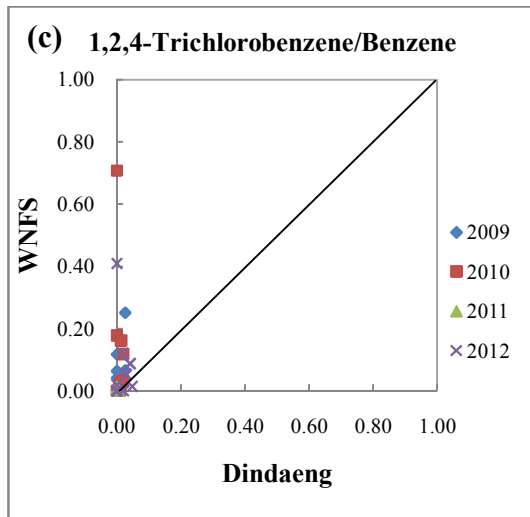
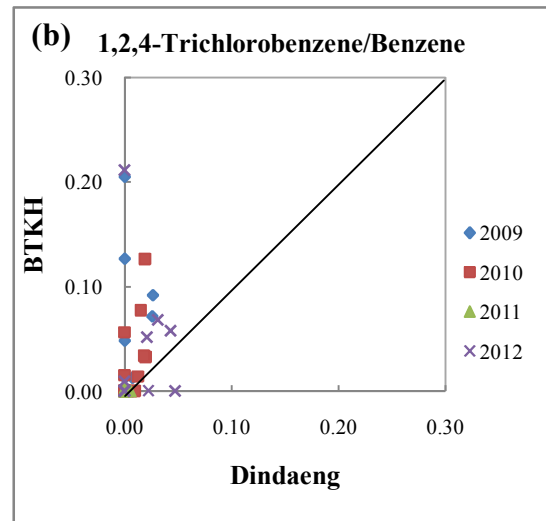
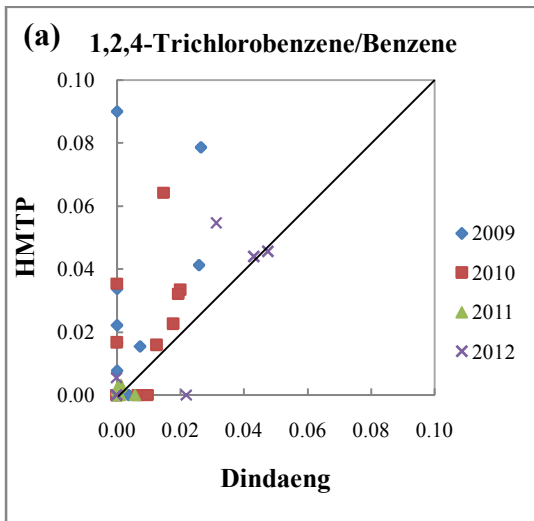


Figure 4.26 Scatter plots of hexachloro-1,3-butadiene against benzene ratio of monitoring stations in Maptaphut area vs. Dindaeng (roadside site) in 2009-2012



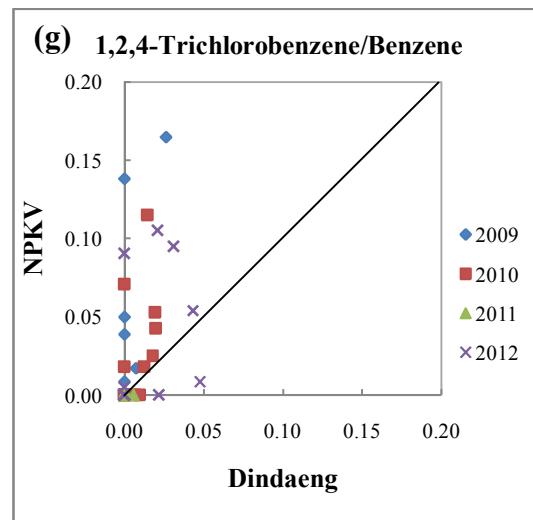
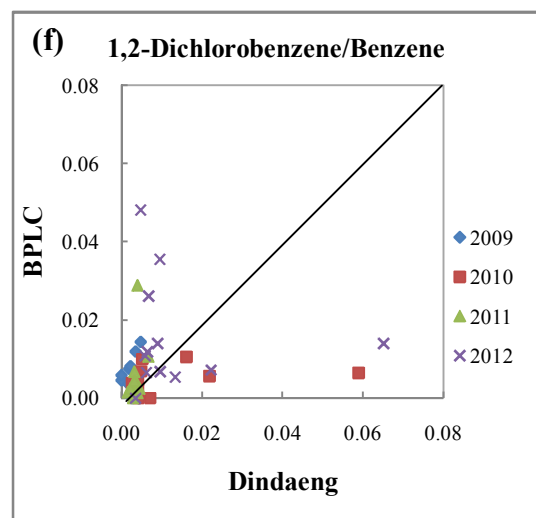
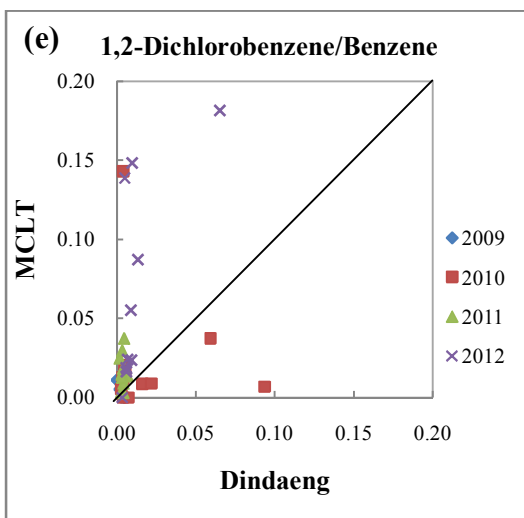
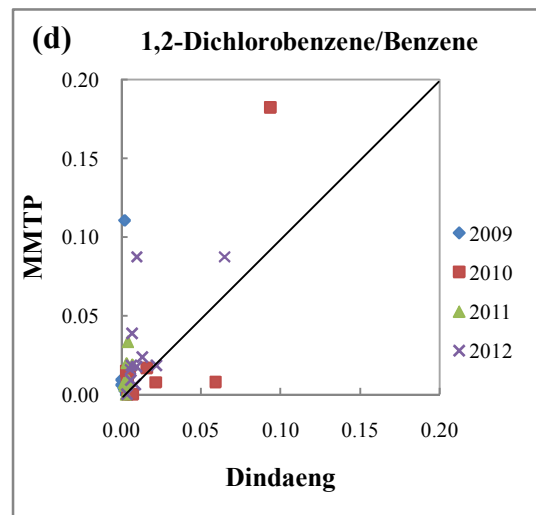
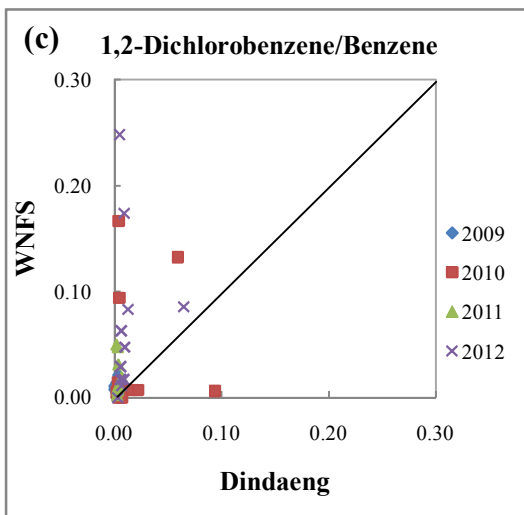
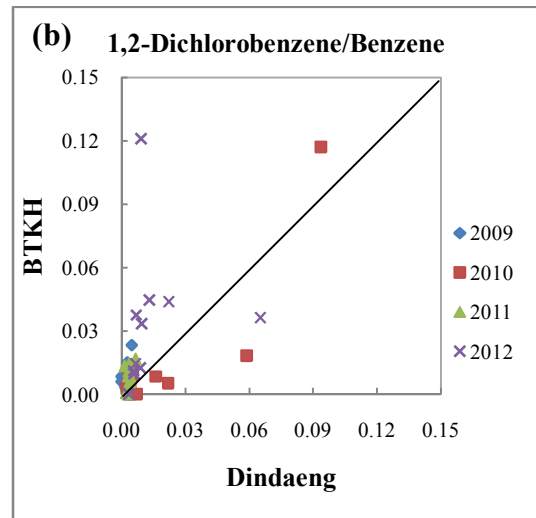
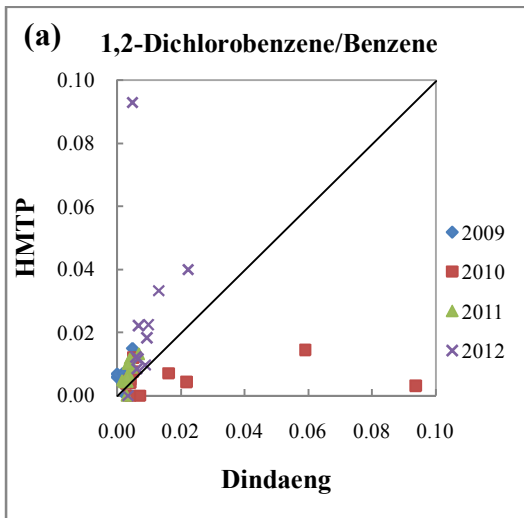


Figure 4.27 Scatter plots of 1,2,4-trichlorobenzene against benzene ratio of monitoring stations in Maptaphut area vs. Dindaeng (roadside site) in 2009-2012



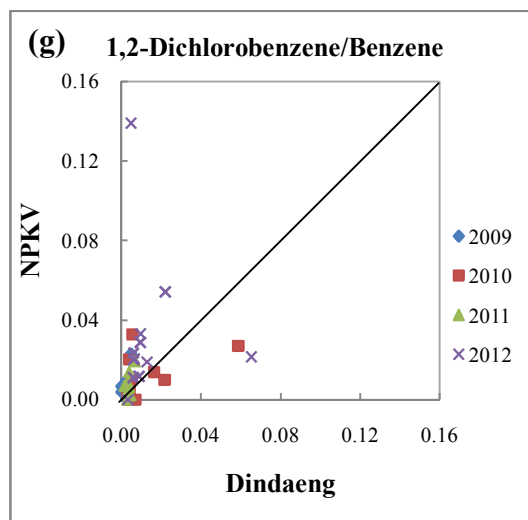
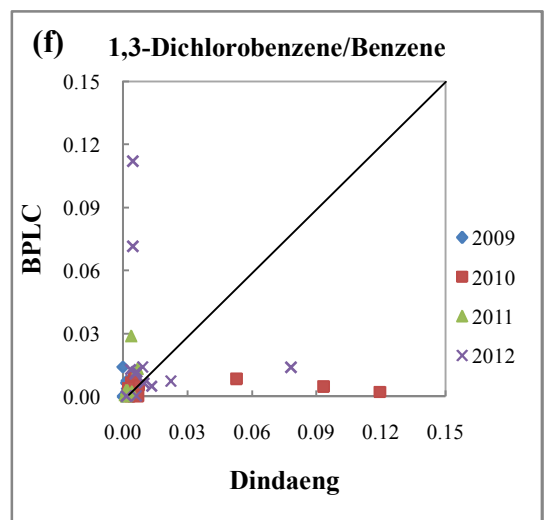
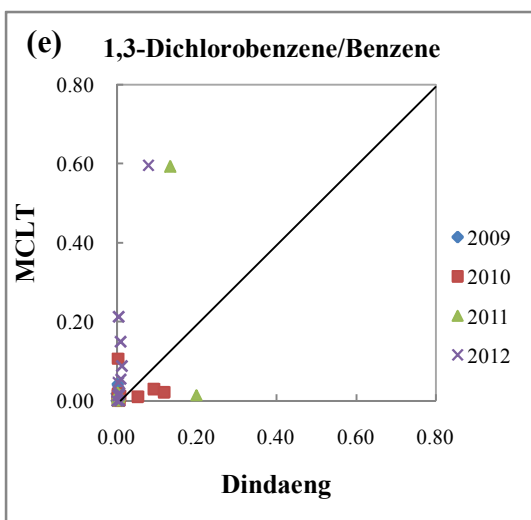
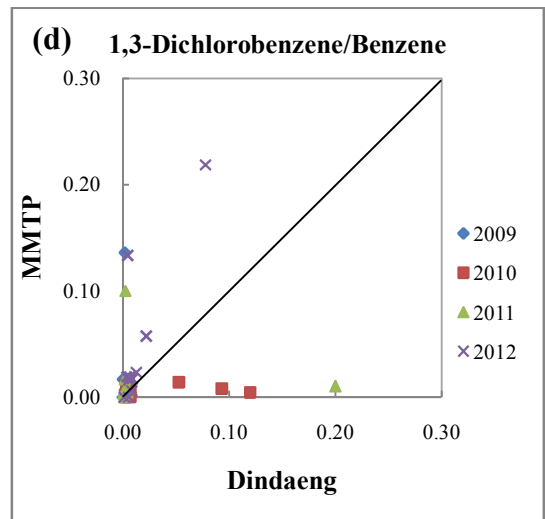
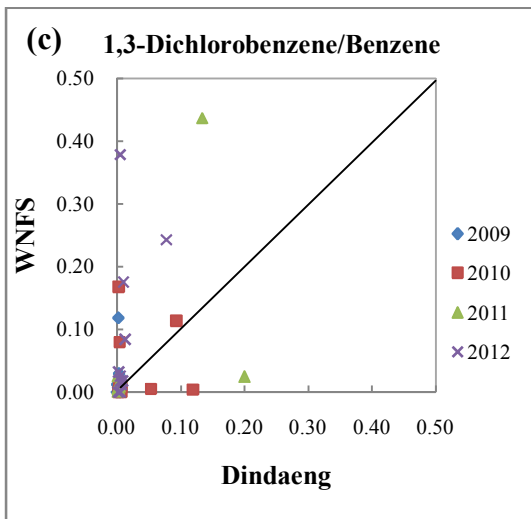
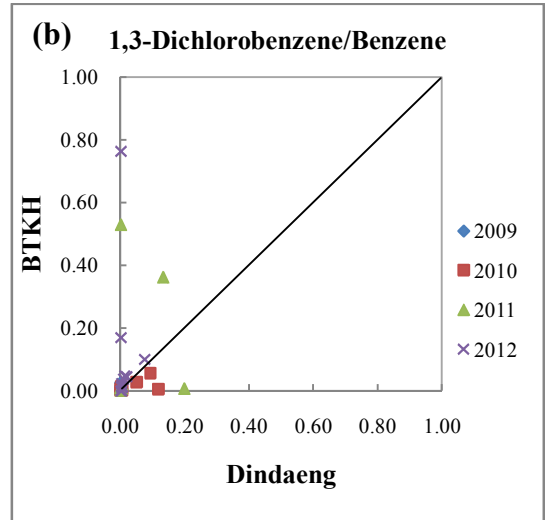
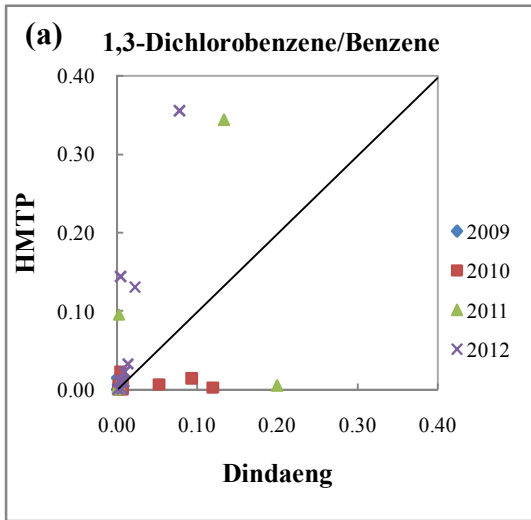


Figure 4.28 Scatter plots of 1,2-dichlorobenzene against benzene ratio of monitoring stations in Maptaphut area vs. Dindaeng (roadside site) in 2009-2012



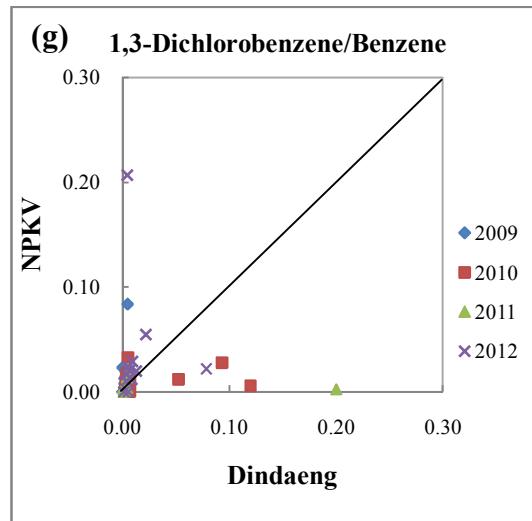
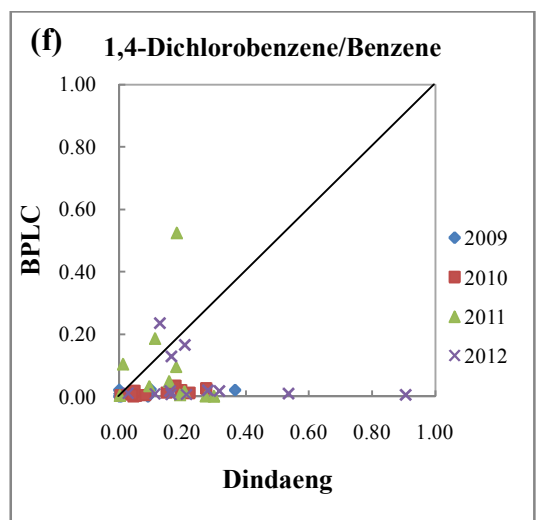
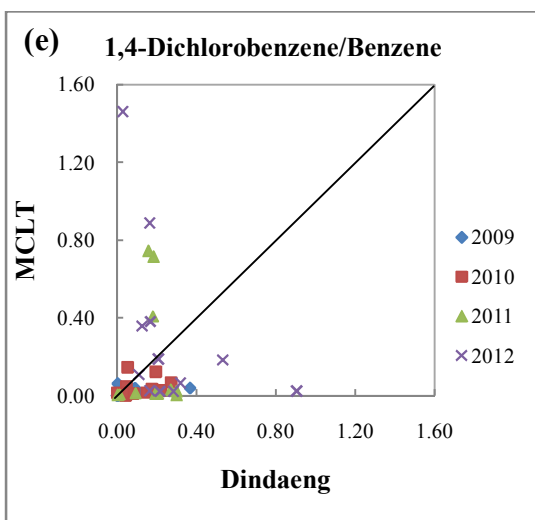
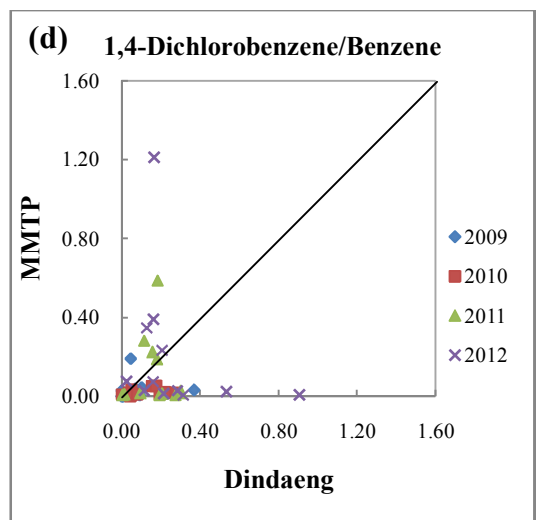
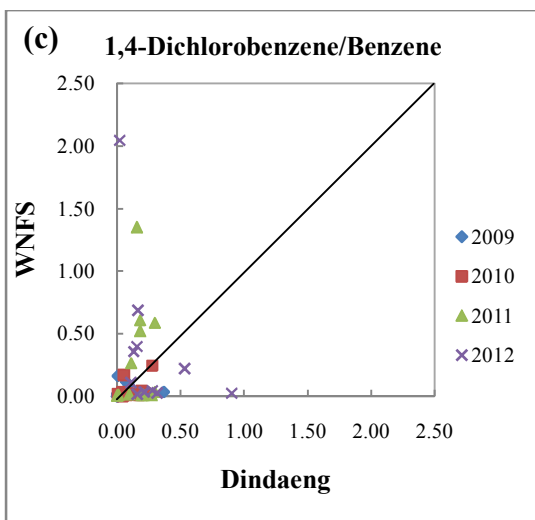
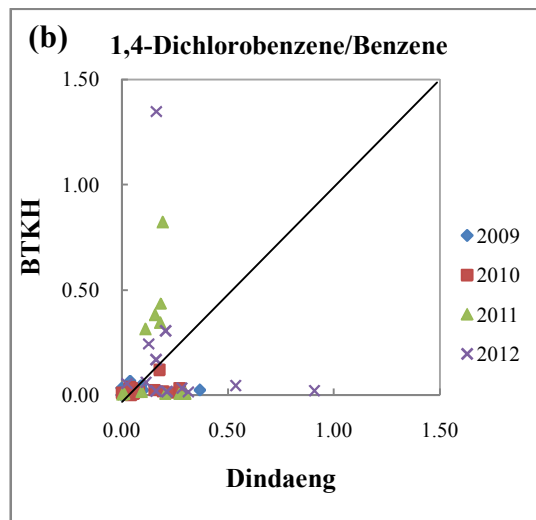
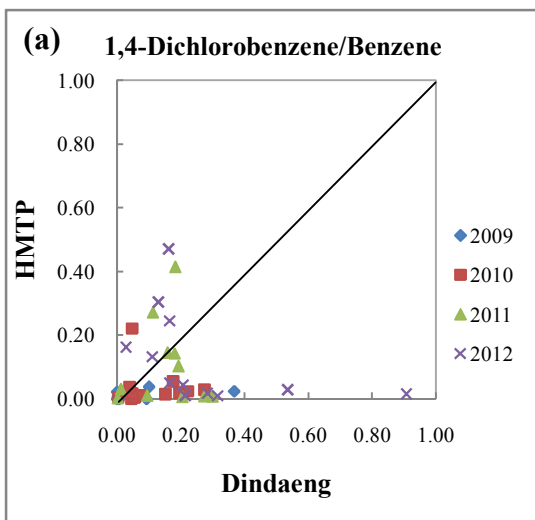


Figure 4.29 Scatter plots of 1,3-dichlorobenzene against benzene ratio of monitoring stations in Maptaphut area vs. Dindaeng (roadside site) in 2009-2012



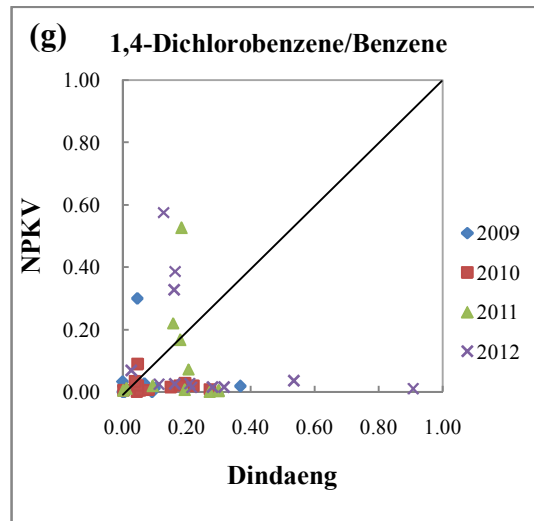
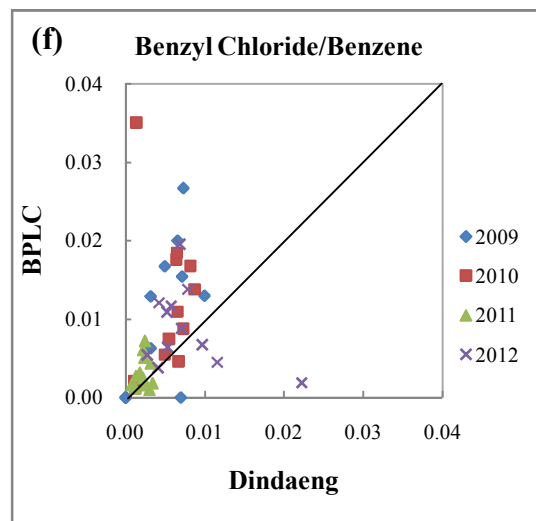
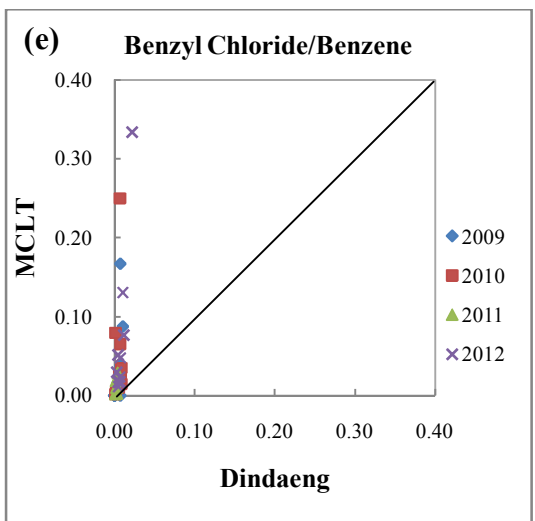
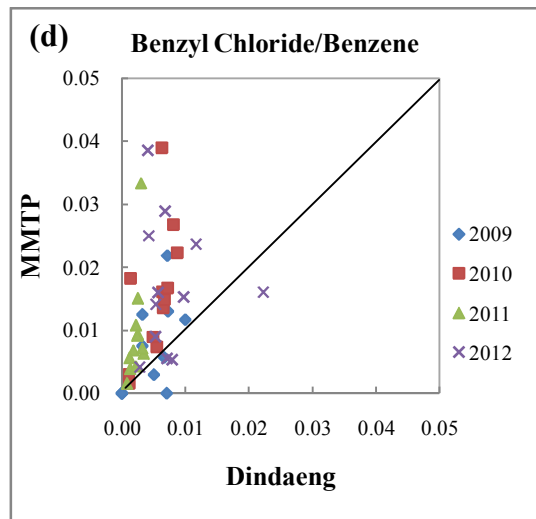
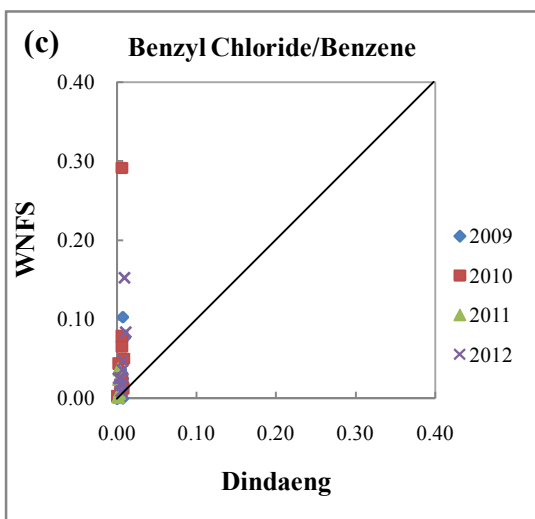
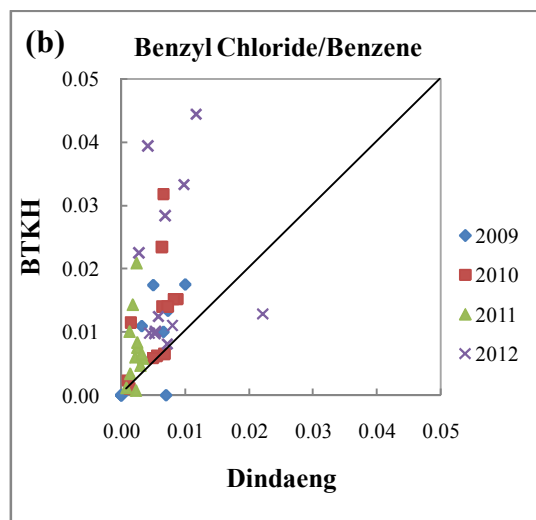
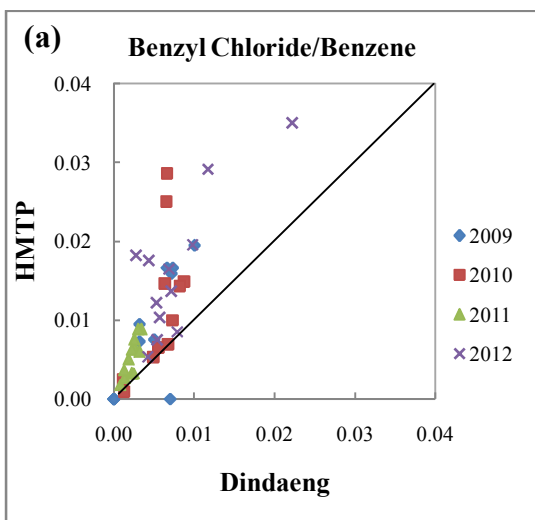


Figure 4.30 Scatter plots of 1,4-dichlorobenzene against benzene ratio of monitoring stations in Maptaphut area vs. Dindaeng (roadside site) in 2009-2012



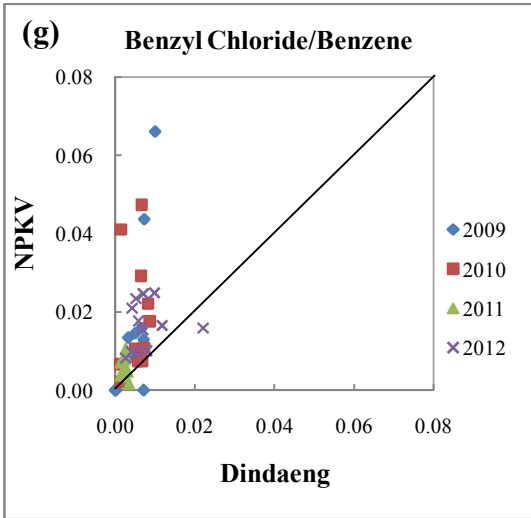
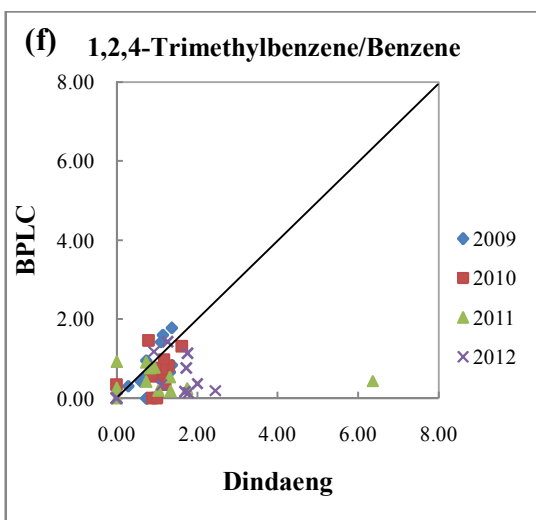
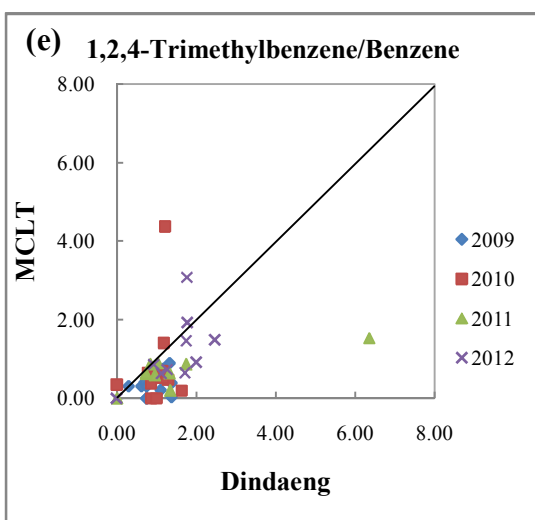
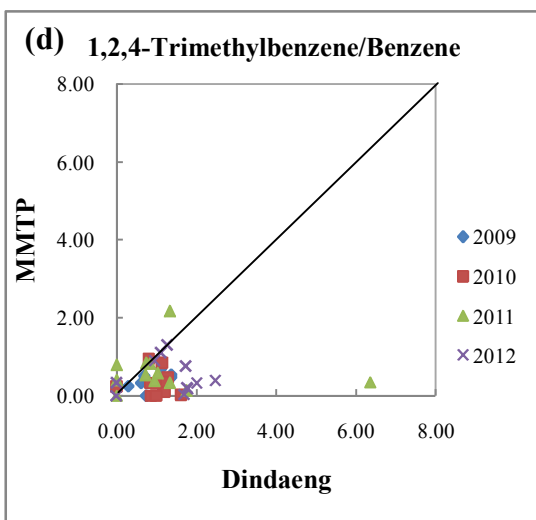
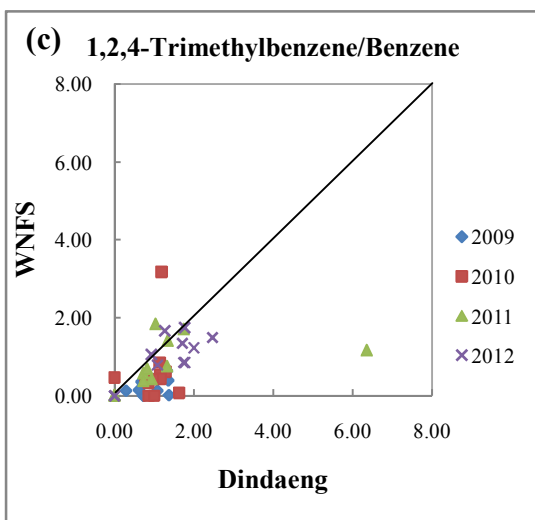
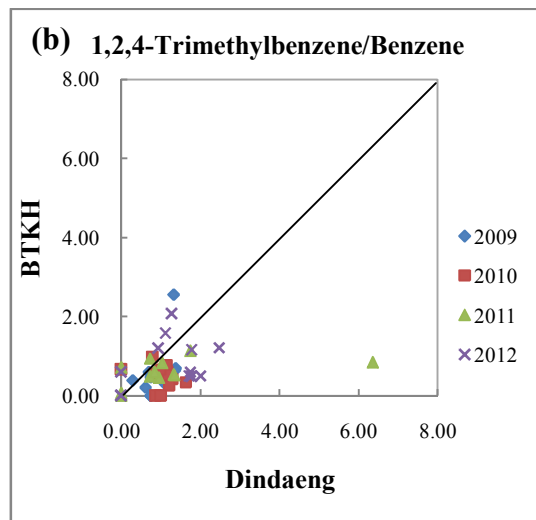
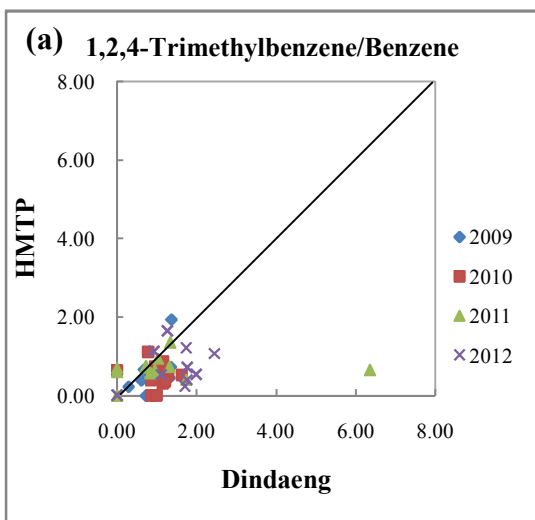


Figure 4.31 Scatter plots of benzyl chloride against benzene ratio of monitoring stations in Maptaphut area vs. Dindaeng (roadside site) in 2009-2012



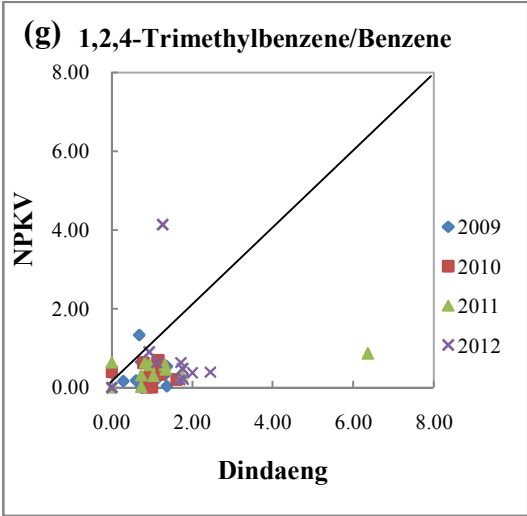
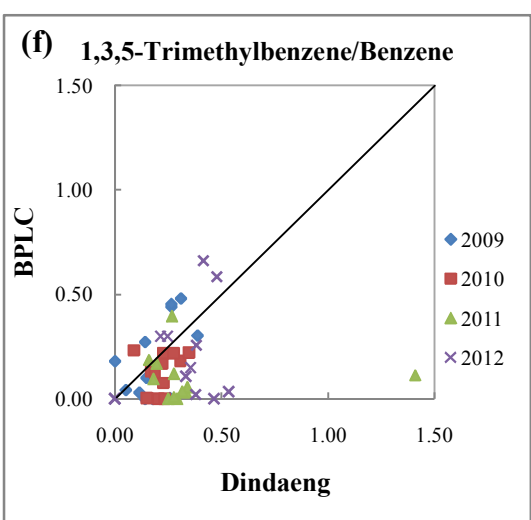
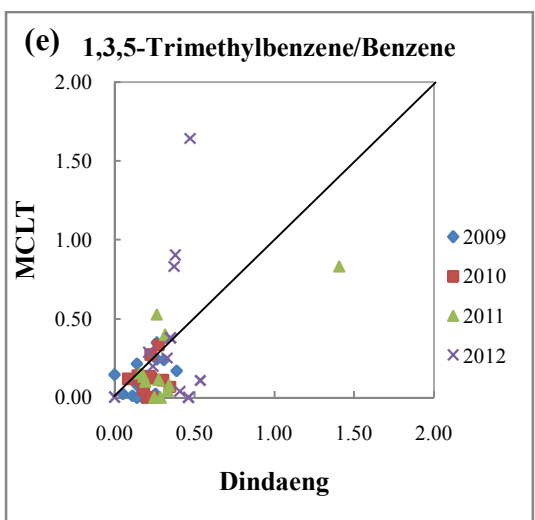
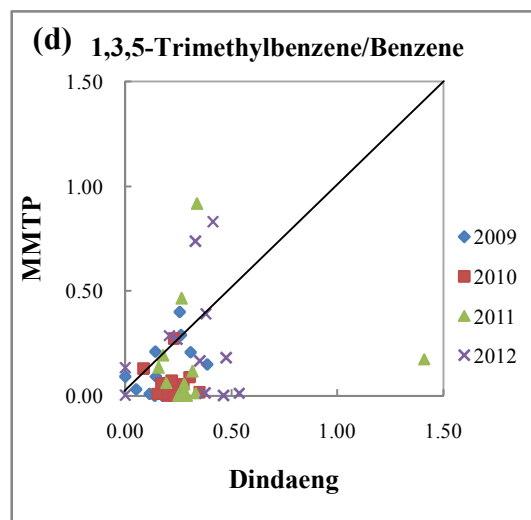
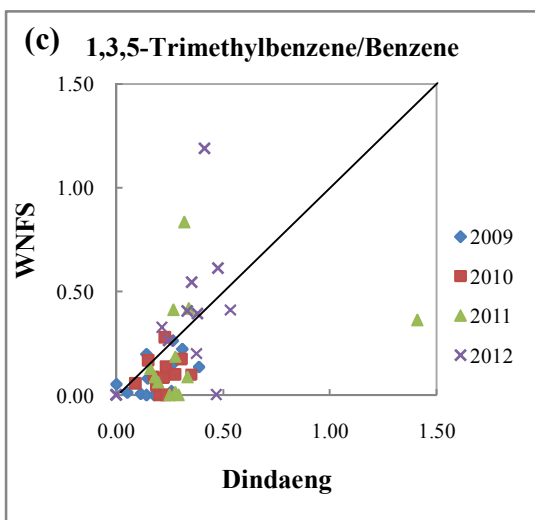
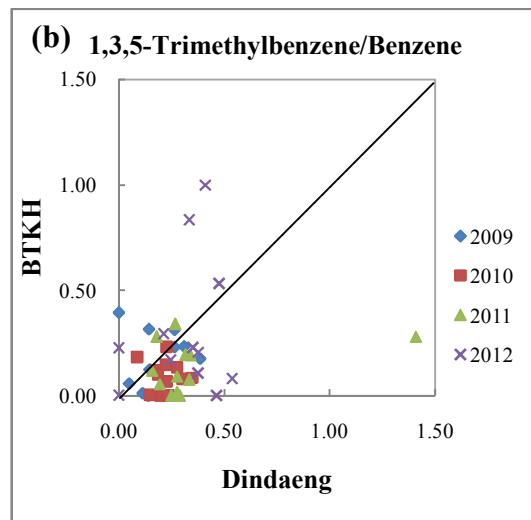
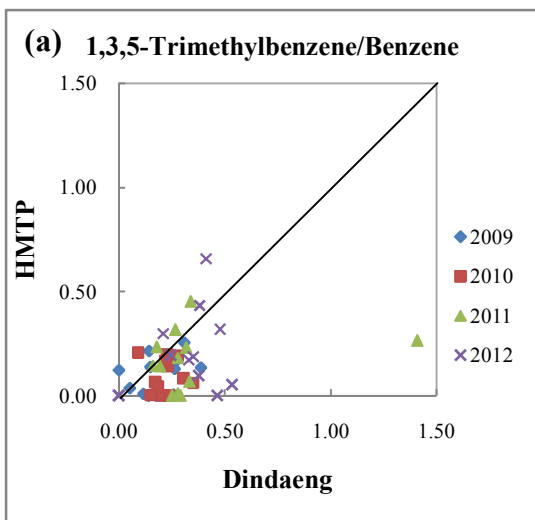


Figure 4.32 Scatter plots of 1,2,4-trimethylbenzene against benzene ratio of monitoring stations in Maptaphut area vs. Dindaeng (roadside site) in 2009-2012



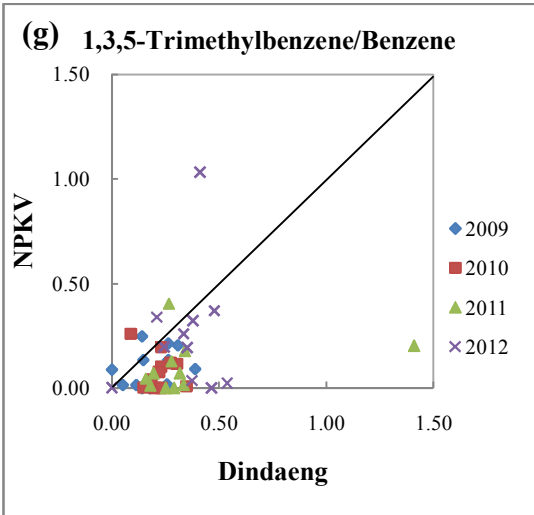
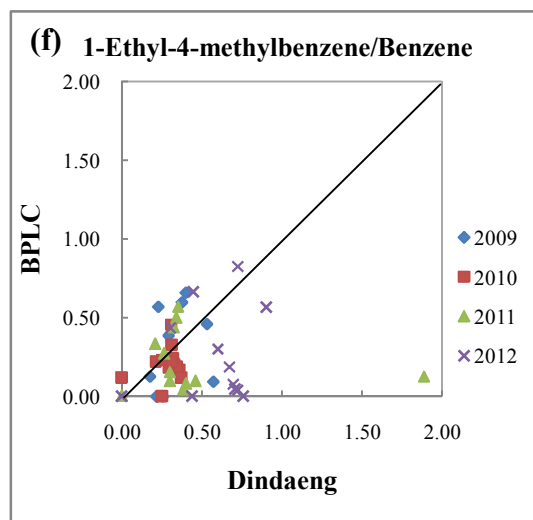
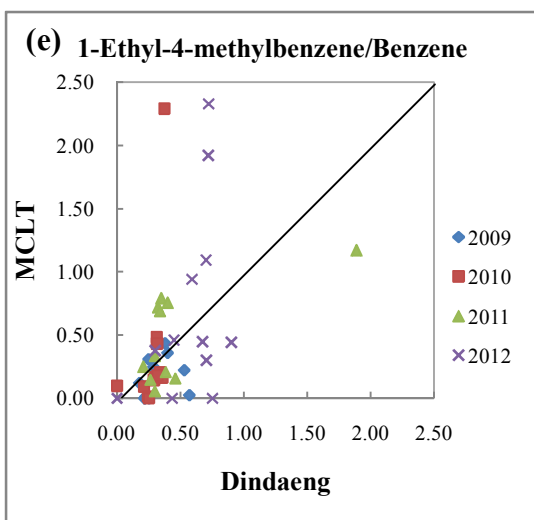
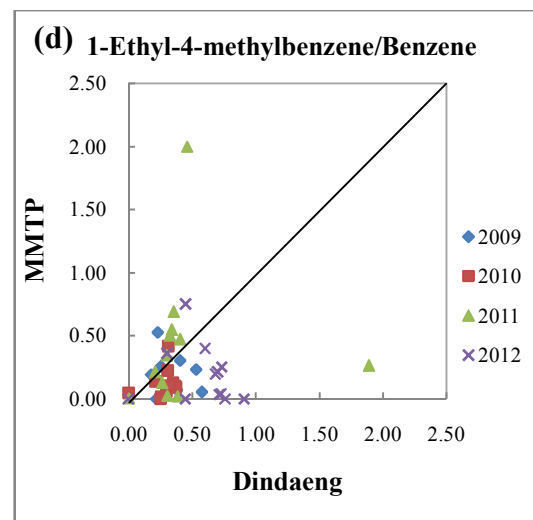
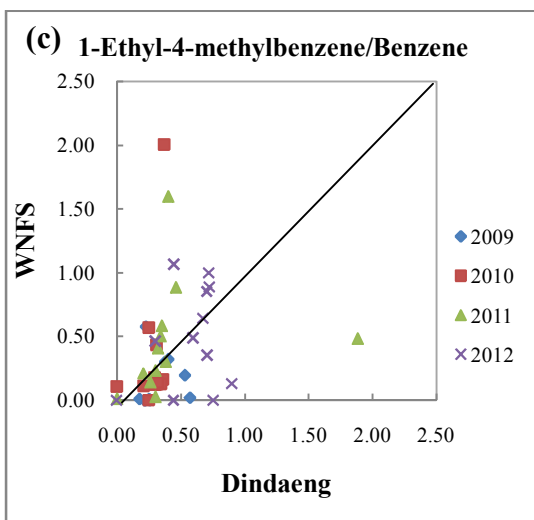
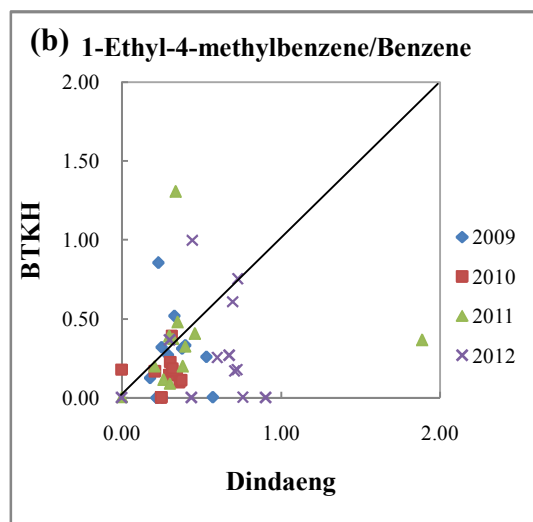
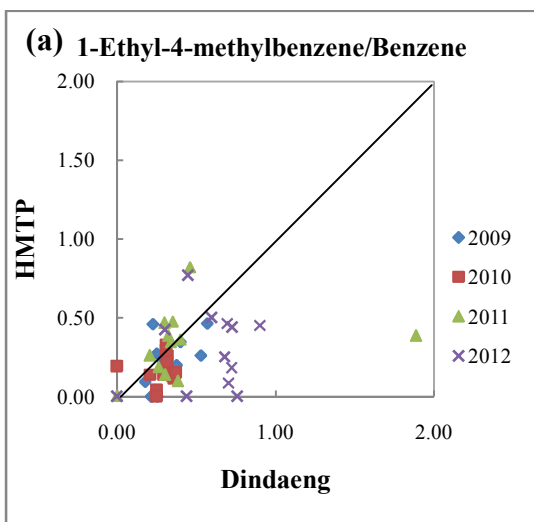


Figure 4.33 Scatter plots of 1,3,5-trimethylbenzene against benzene ratio of monitoring stations in Maptaphut area vs. Dindaeng (roadside site) in 2009-2012



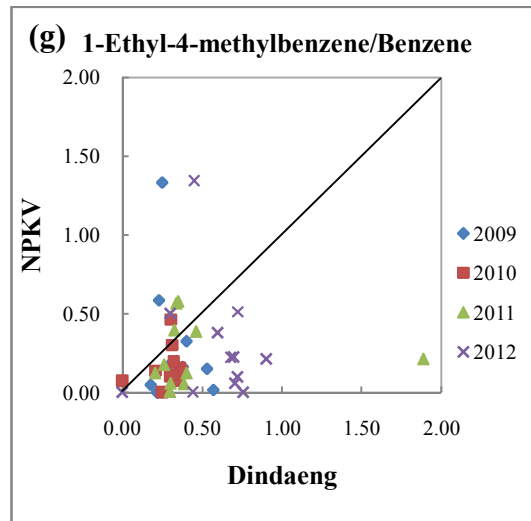
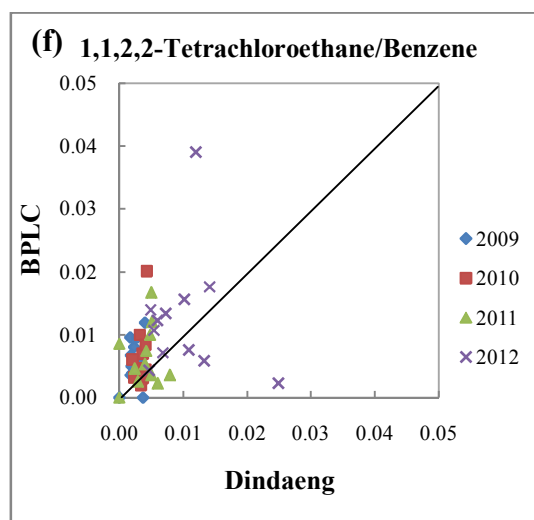
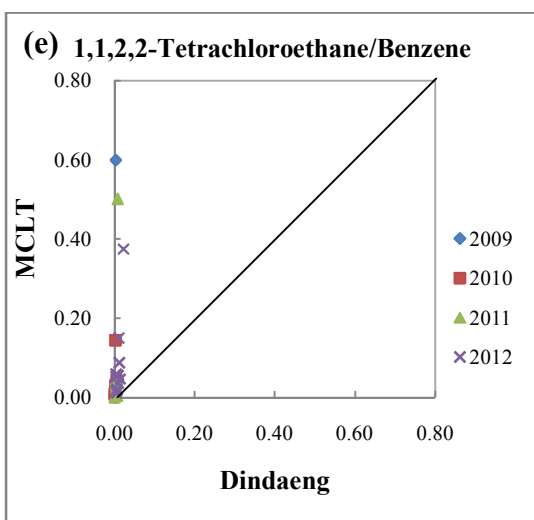
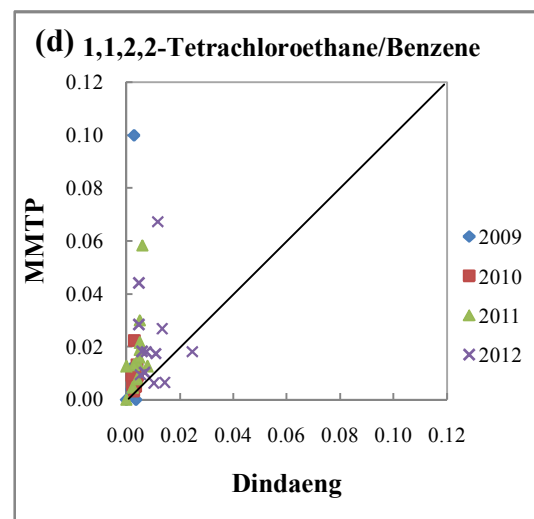
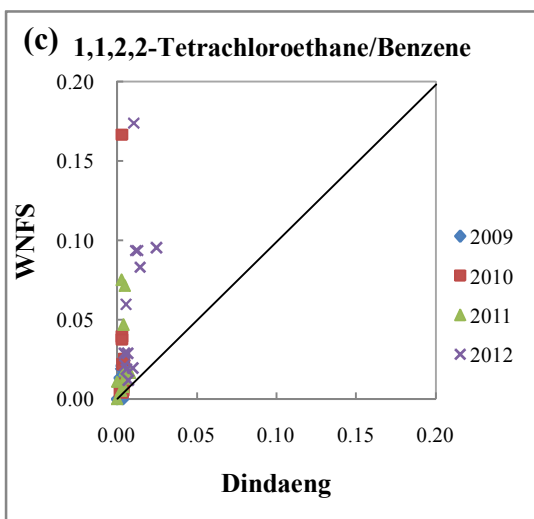
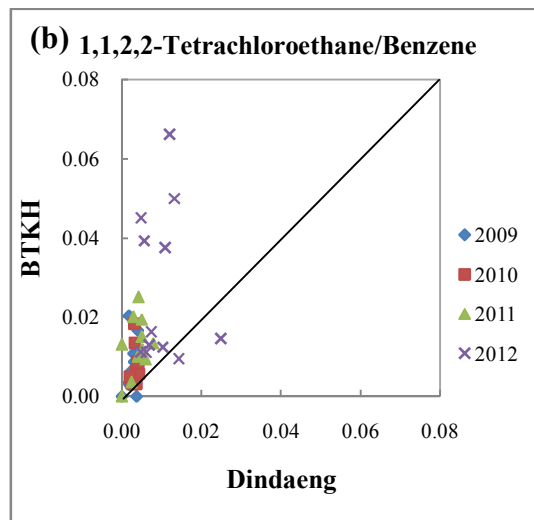
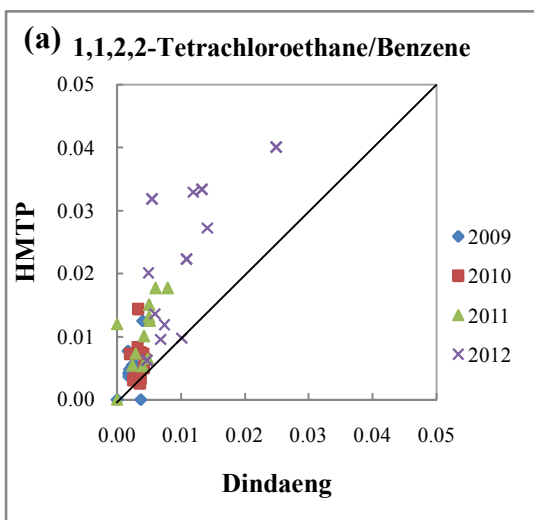


Figure 4.34 Scatter plots of 1-ethyl-4-methylbenzene against benzene ratio of monitoring stations in Maptaphut area vs. Dindaeng (roadside site) in 2009-2012



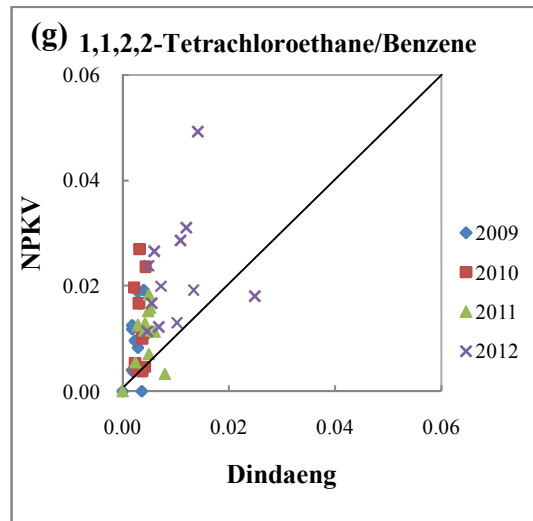
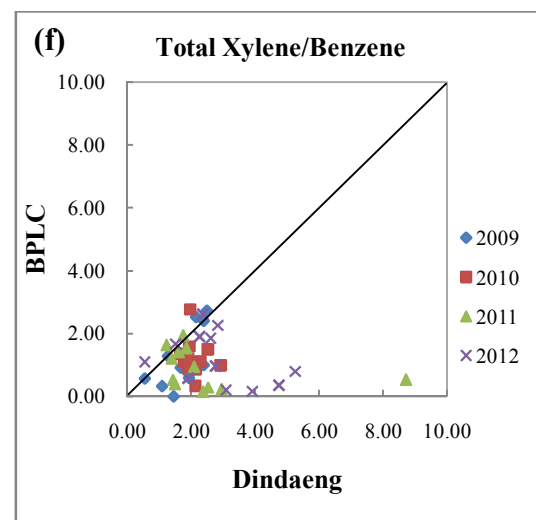
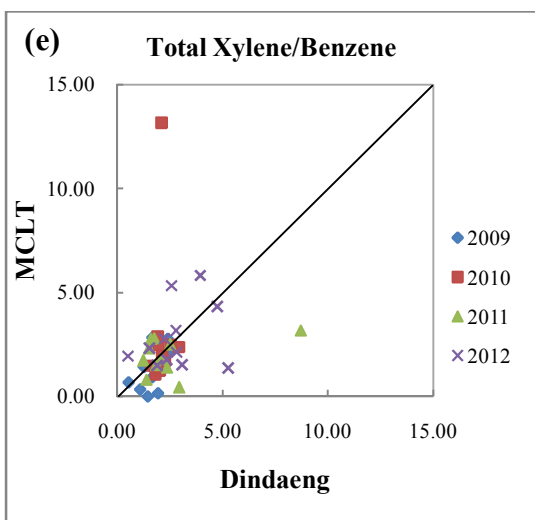
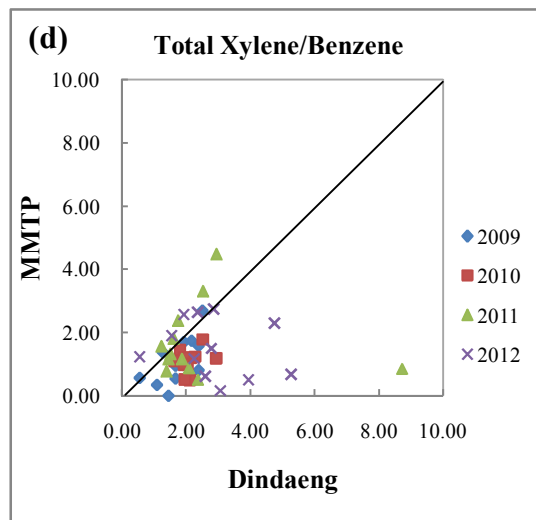
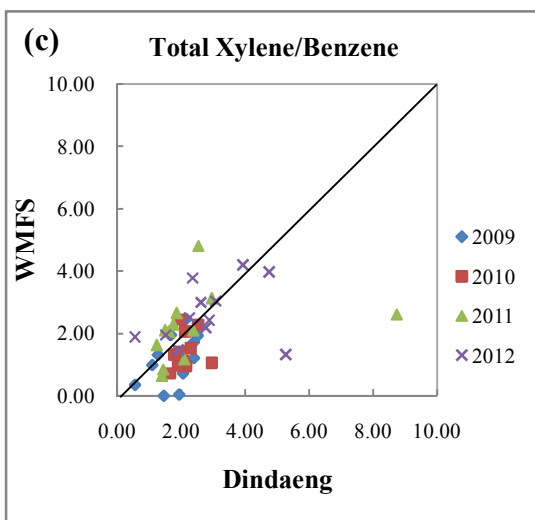
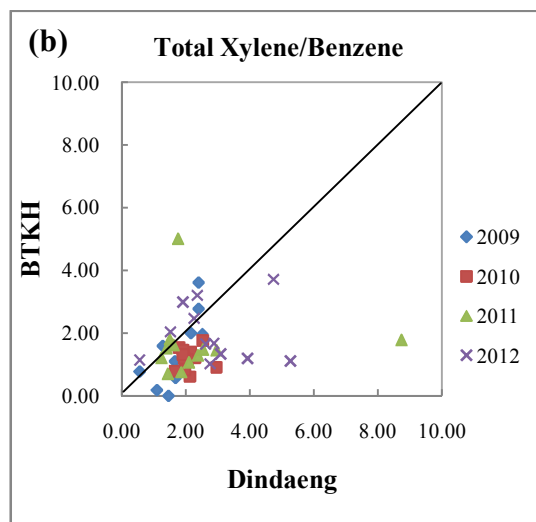
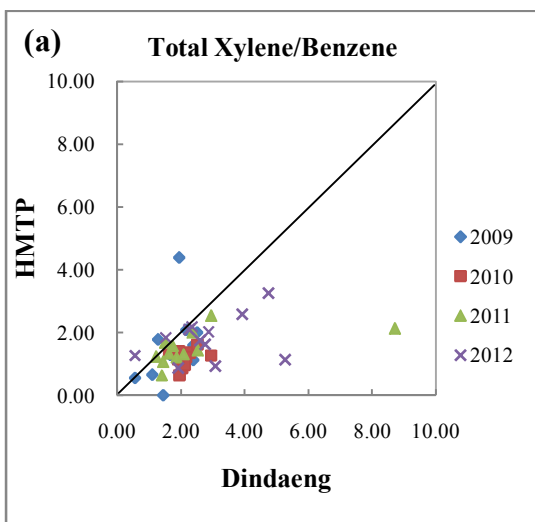


Figure 4.35 Scatter plots of 1,1,2,2-tetrachloroethane against benzene ratio of monitoring stations in Maptaphut area vs. Dindaeng (roadside site) in 2009-2012



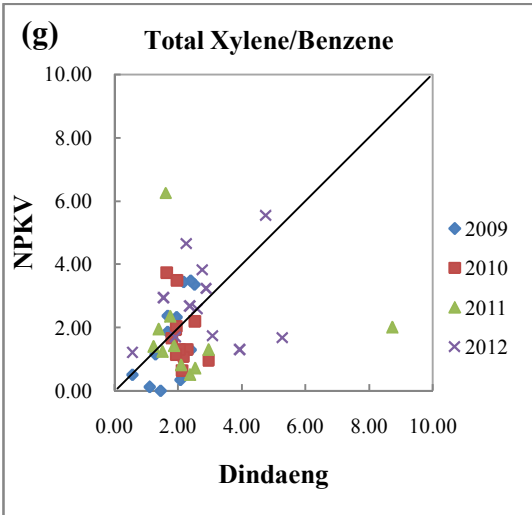
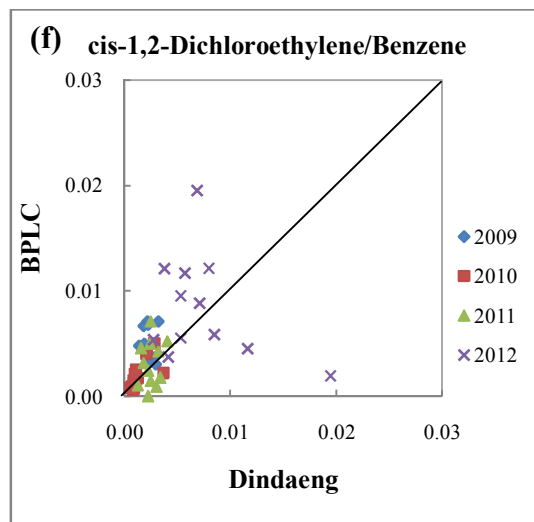
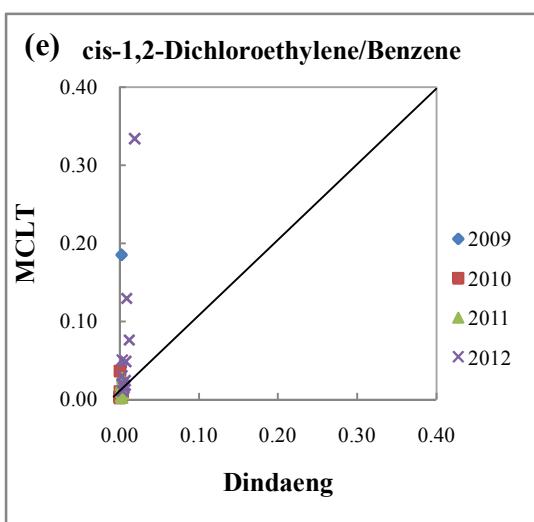
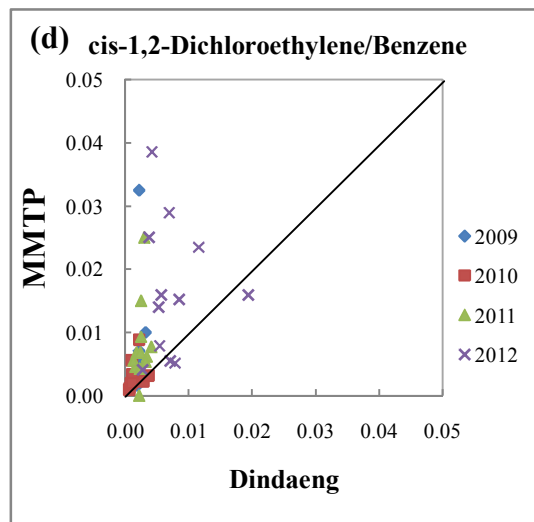
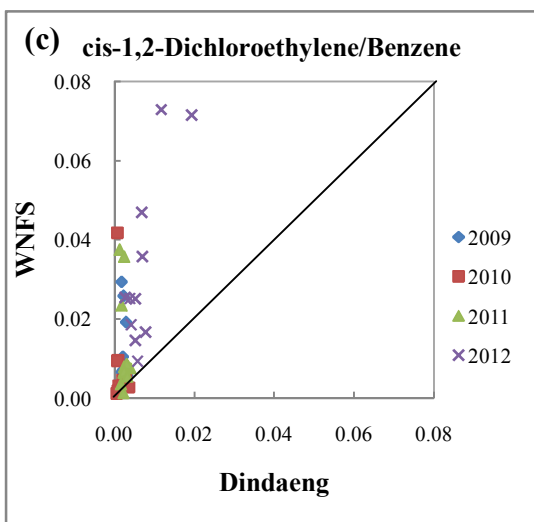
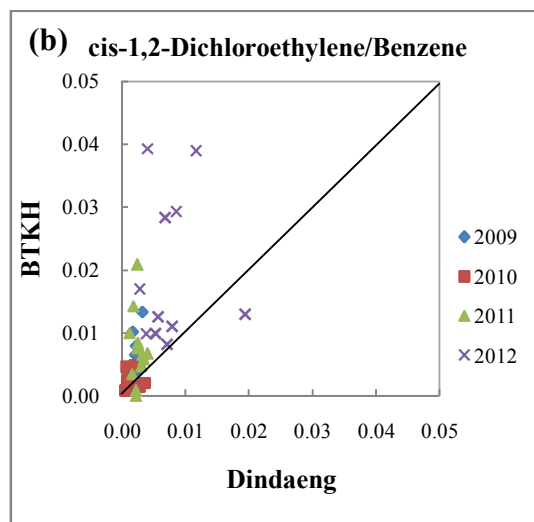
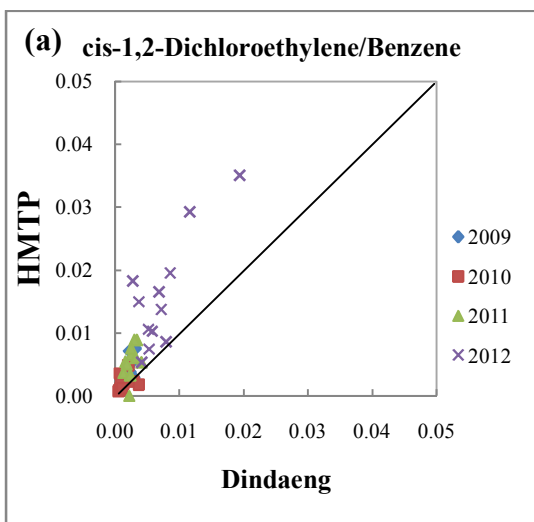


Figure 4.36 Scatter plots of total xylene against benzene ratio of monitoring stations in Maptaphut area vs. Dindaeng (roadside site) in 2009-2012



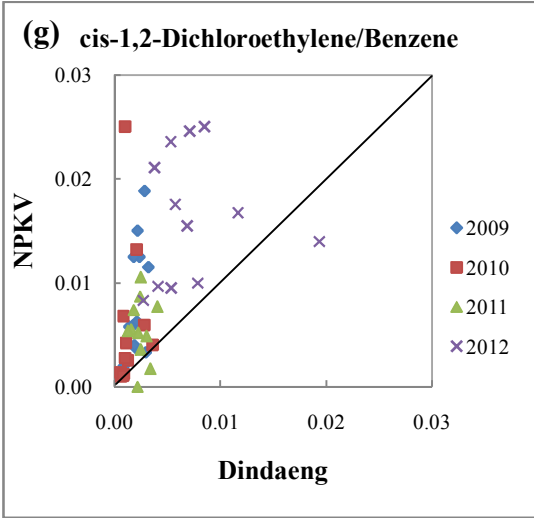
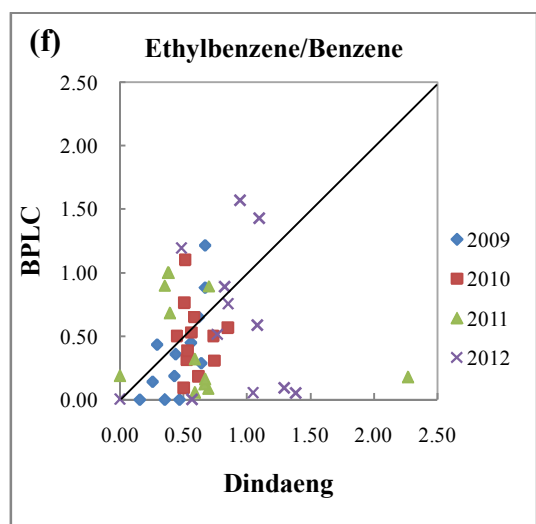
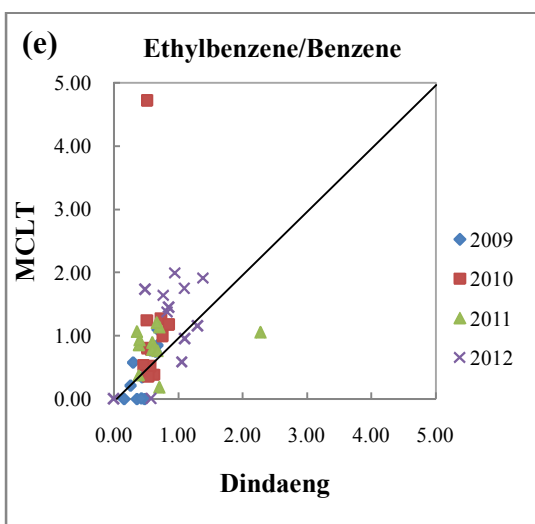
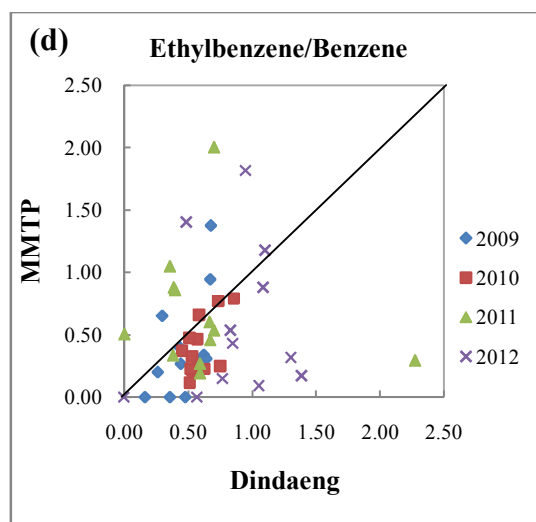
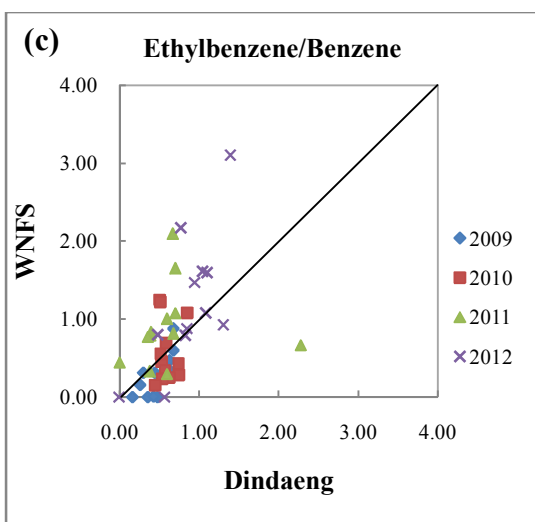
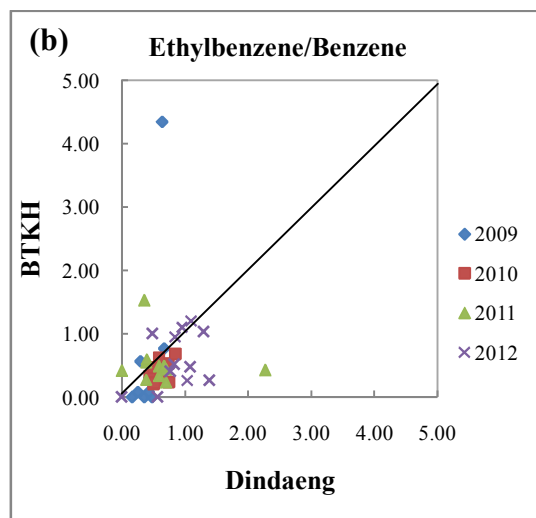
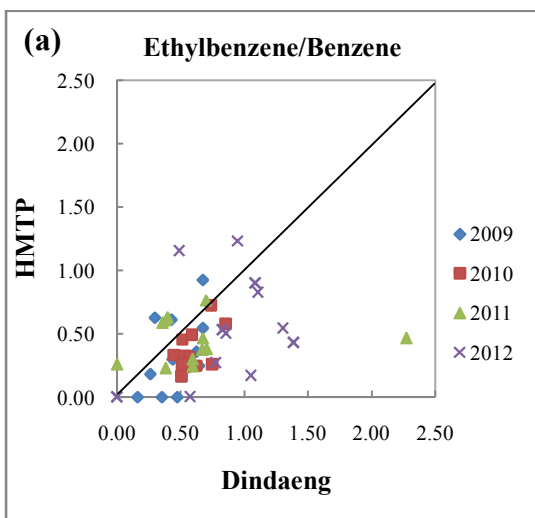


Figure 4.37 Scatter plots of cis-1,2-dichloroethylene against benzene ratio of monitoring stations in Maptaphut area vs. Dindaeng (roadside site) in 2009-2012



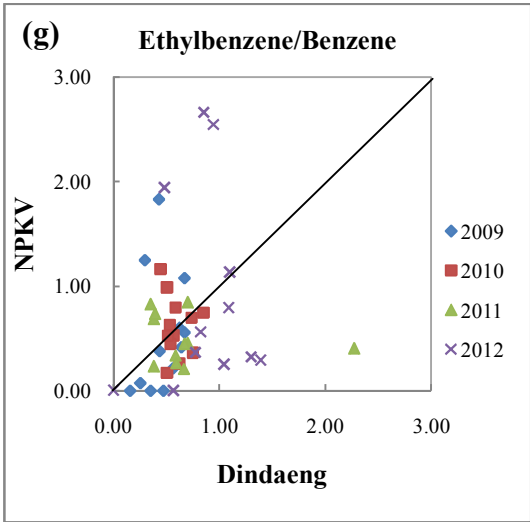
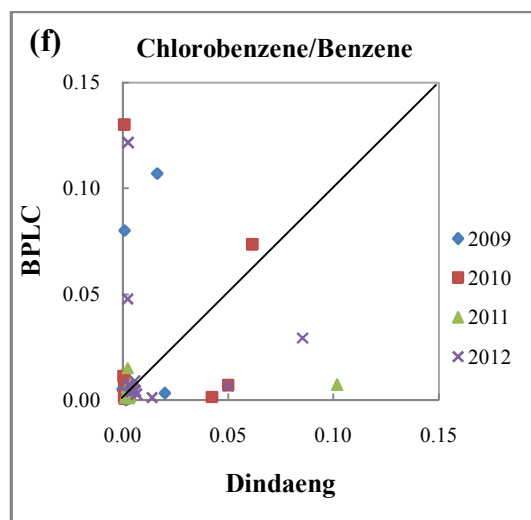
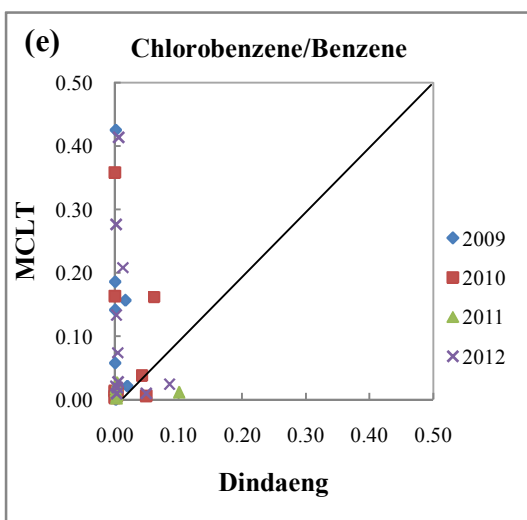
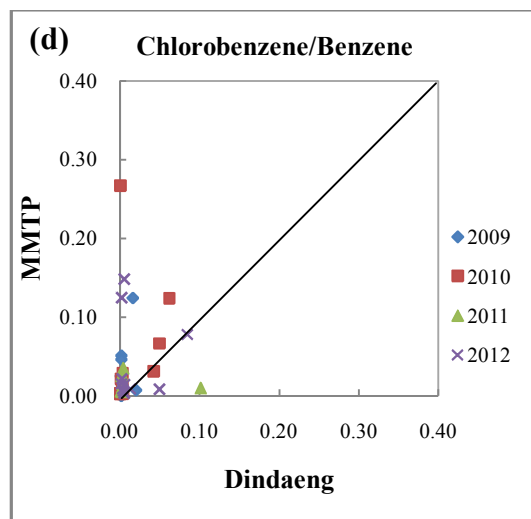
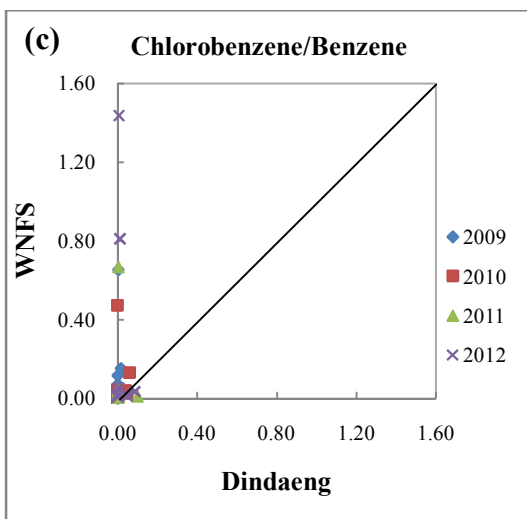
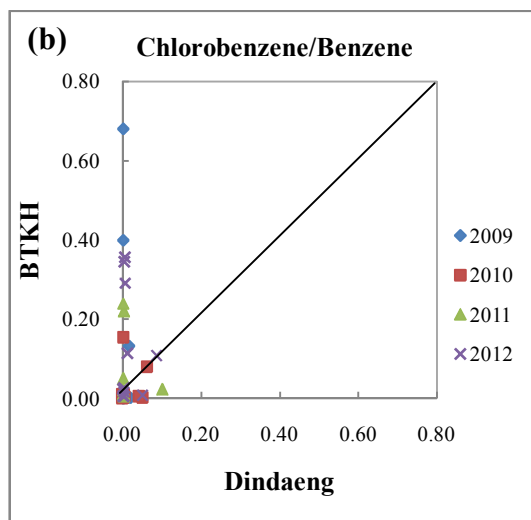
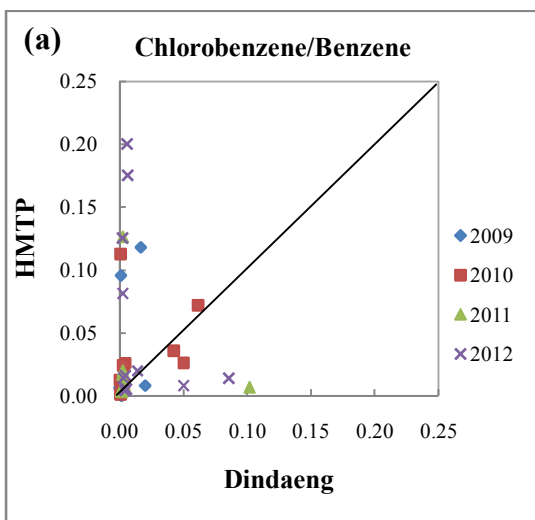


Figure 4.38 Scatter plots of ethylbenzene against benzene ratio of monitoring stations in Maptaphut area vs. Dindaeng (roadside site) in 2009-2012



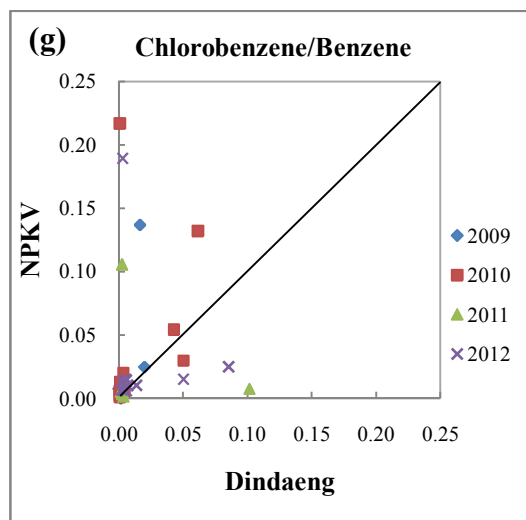
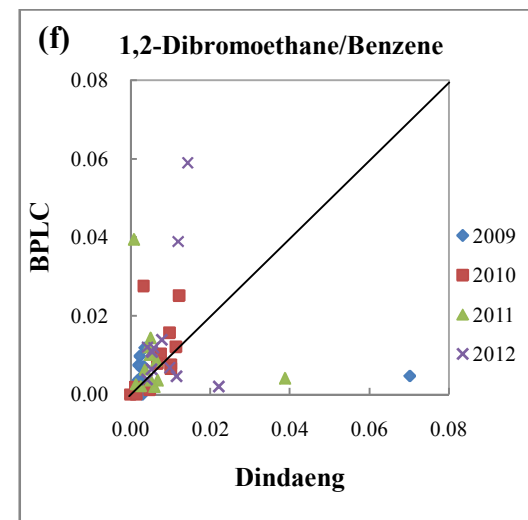
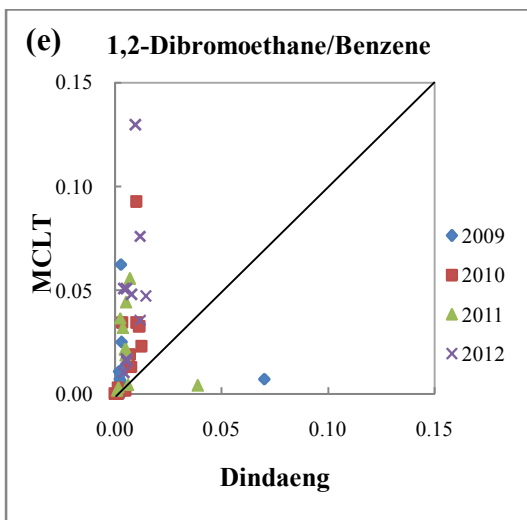
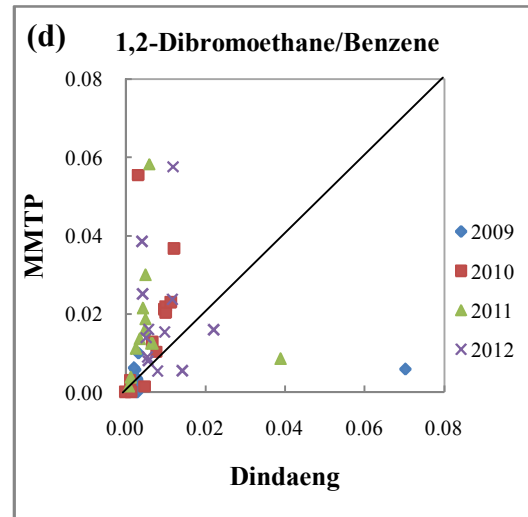
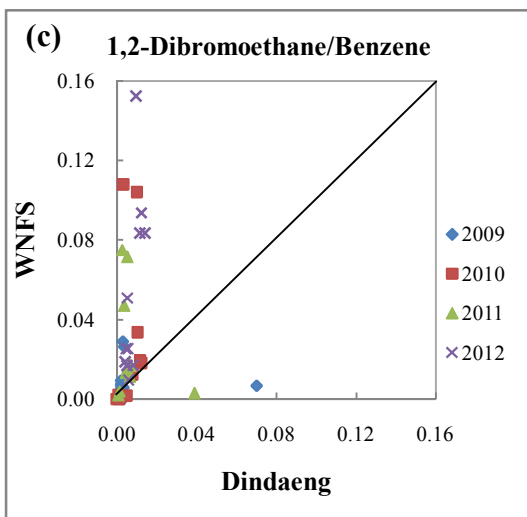
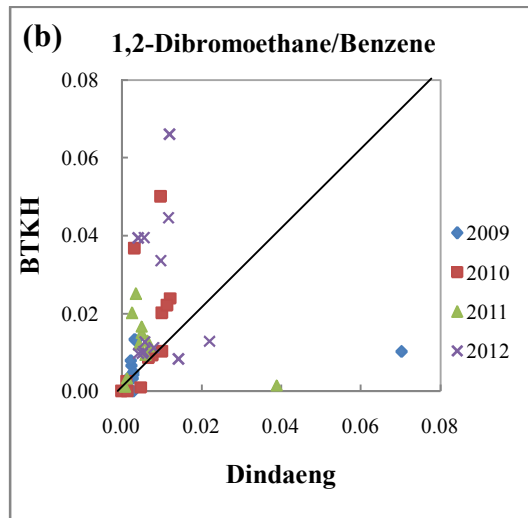
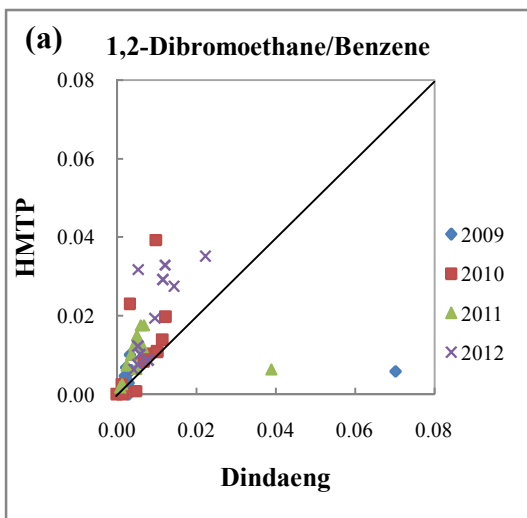


Figure 4.39 Scatter plots of chlorobenzene against benzene ratio of monitoring stations in Maptaphut area vs. Dindaeng (roadside site) in 2009-2012



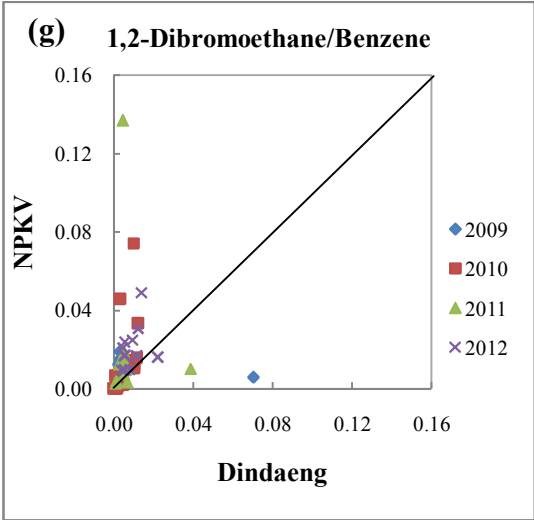
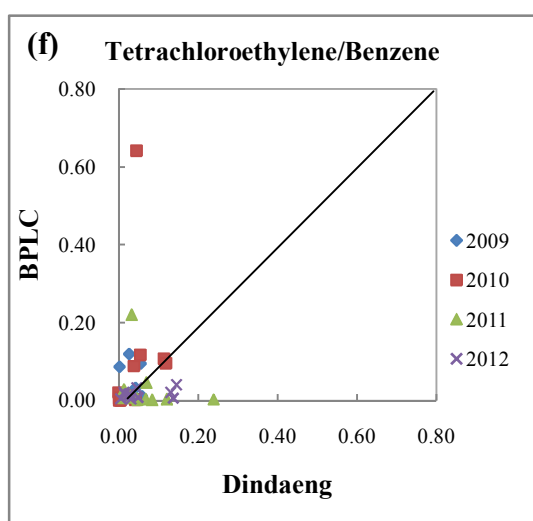
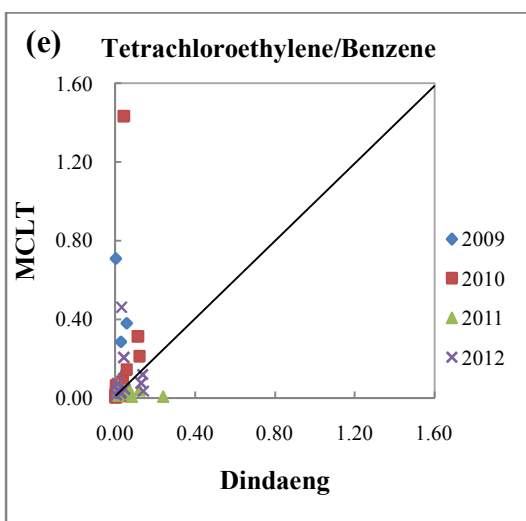
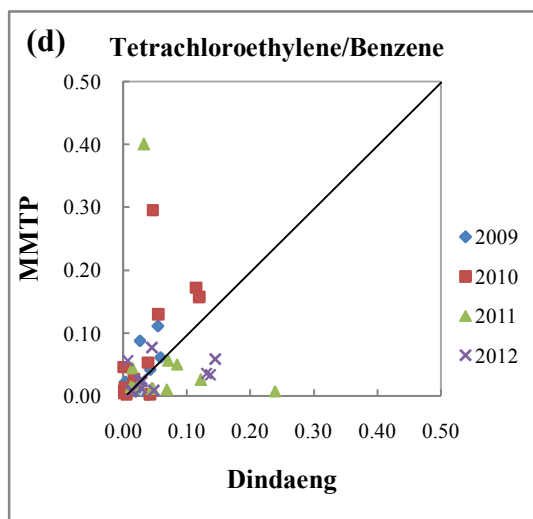
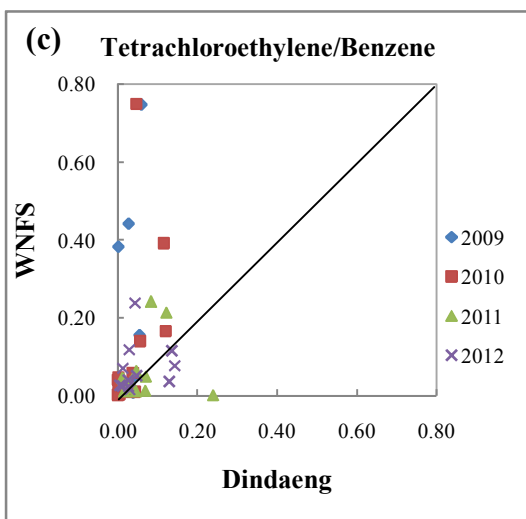
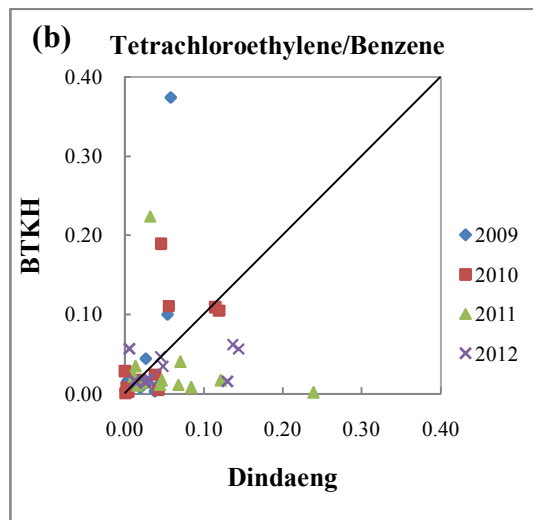
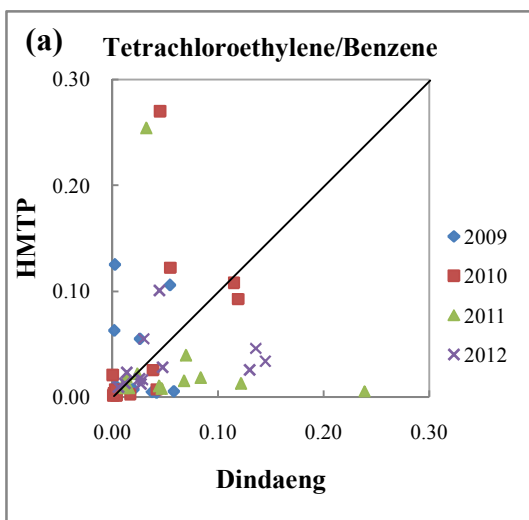


Figure 4.40 Scatter plots of 1,2-dibromoethane against benzene ratio of monitoring stations in Maptaphut area vs. Dindaeng (roadside site) in 2009-2012



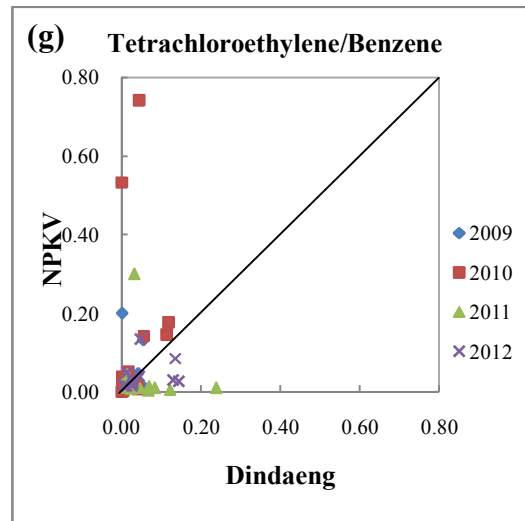
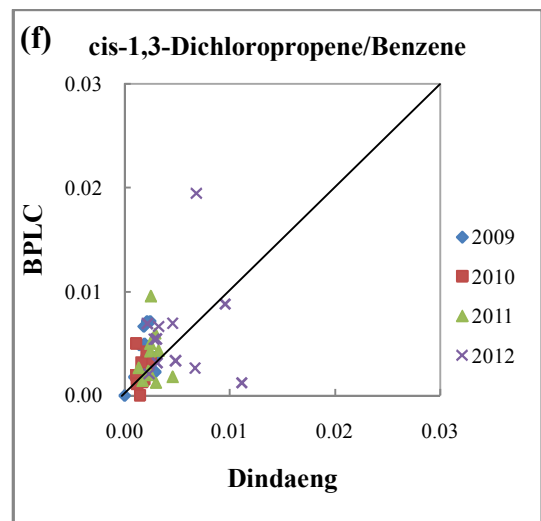
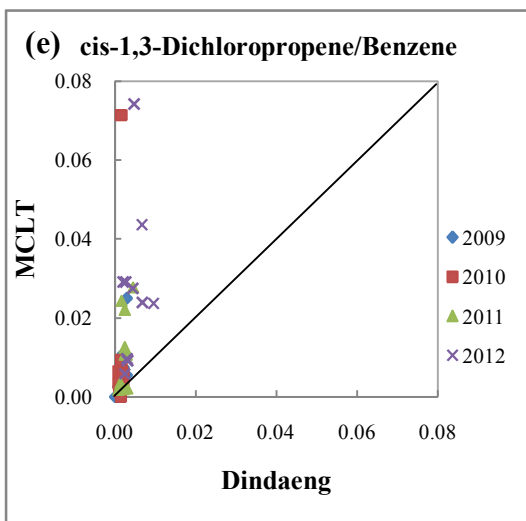
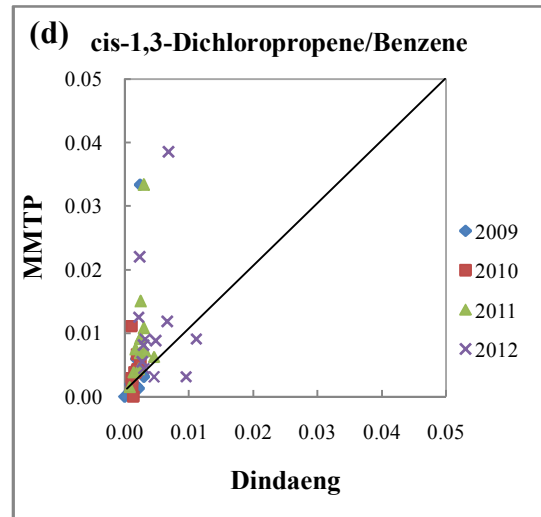
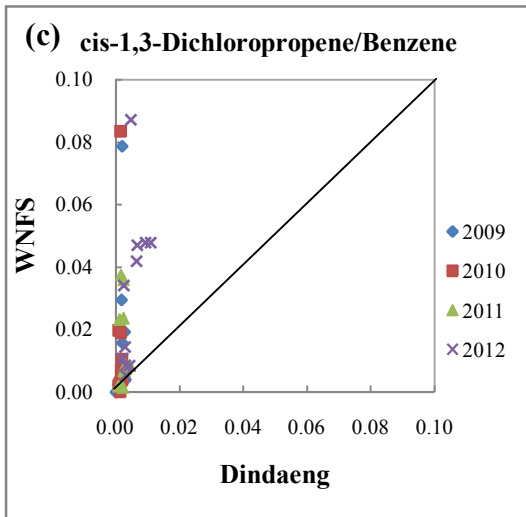
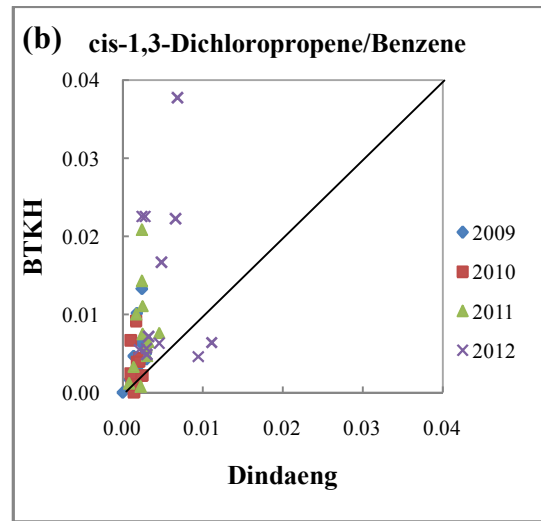
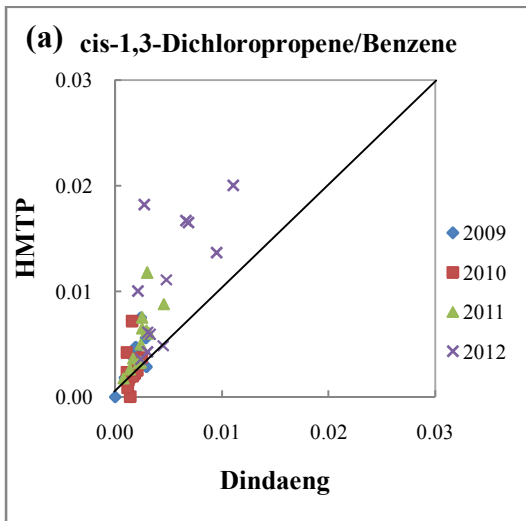


Figure 4.41 Scatter plots of tetrachloroethylene against benzene ratio of monitoring stations in Maptaphut area vs. Dindaeng (roadside site) in 2009-2012



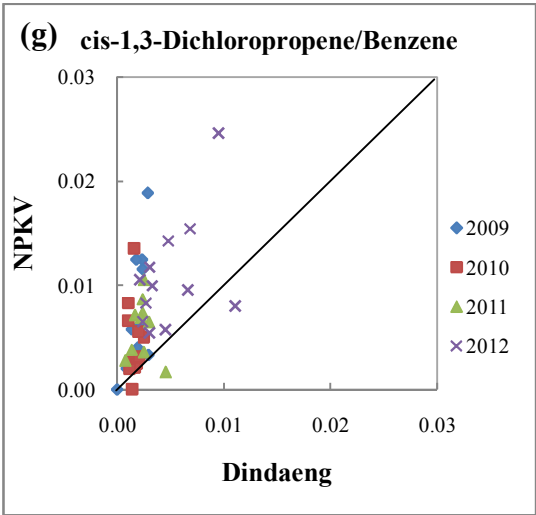
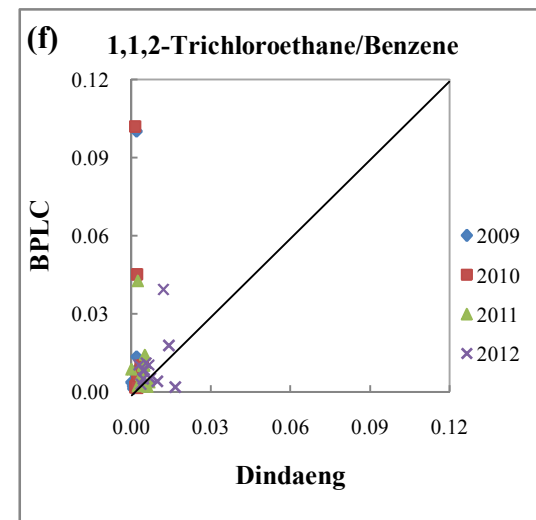
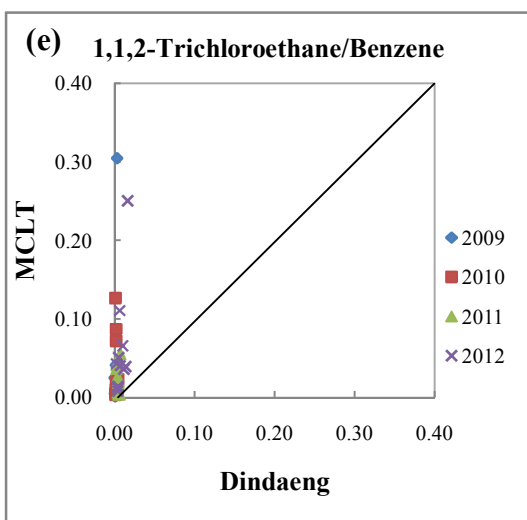
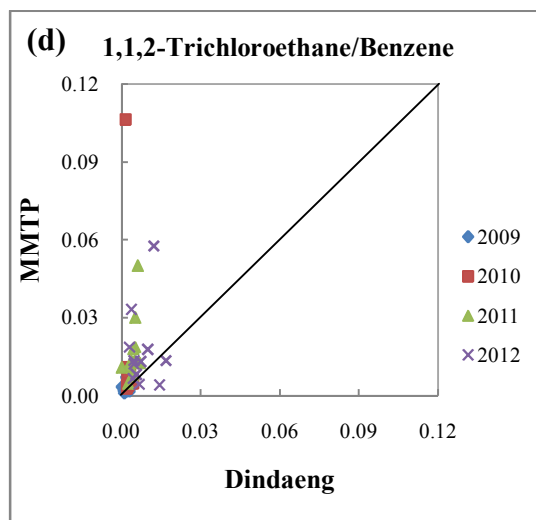
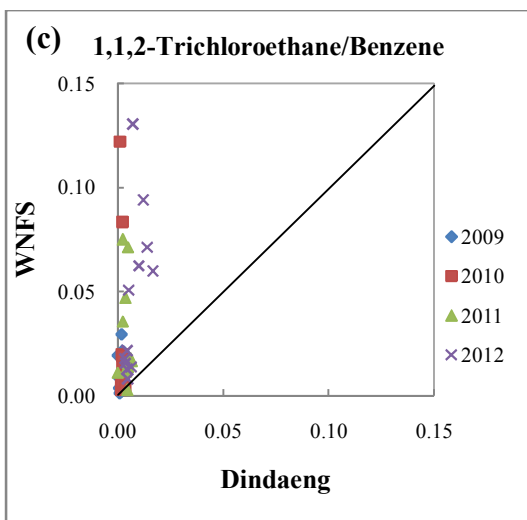
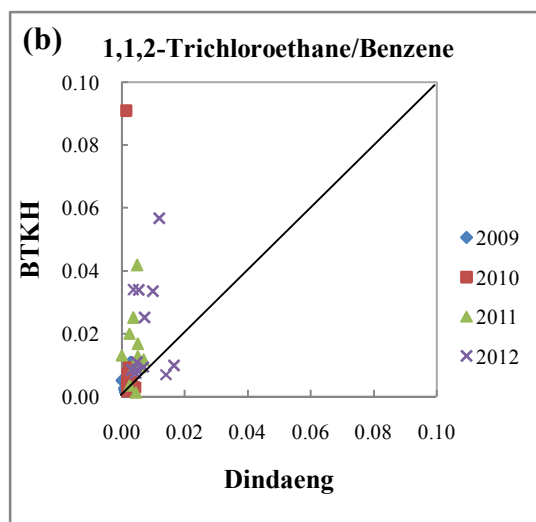
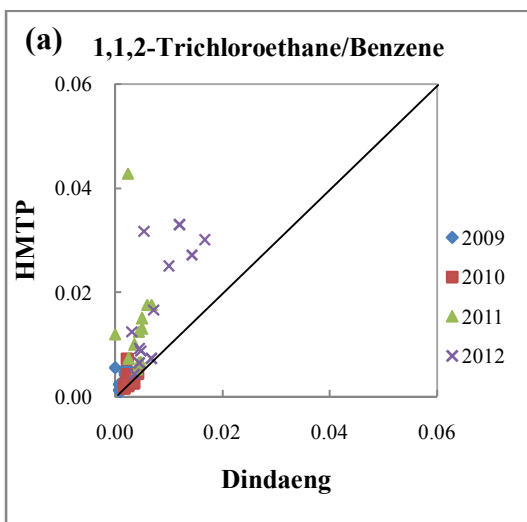


Figure 4.42 Scatter plots of cis-1,3-dichloropropene against benzene ratio of monitoring stations in Maptaphut area vs. Dindaeng (roadside site) in 2009-2012



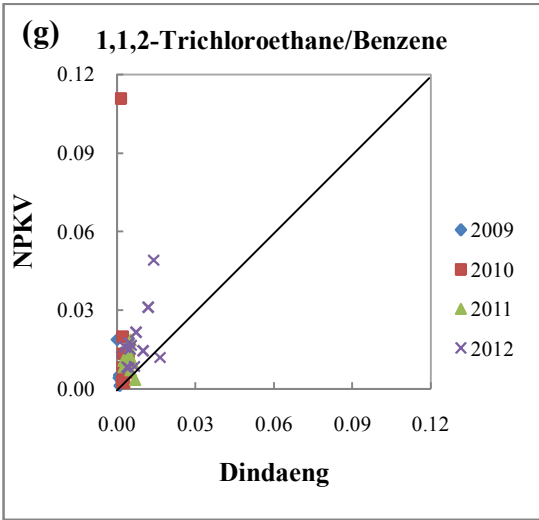
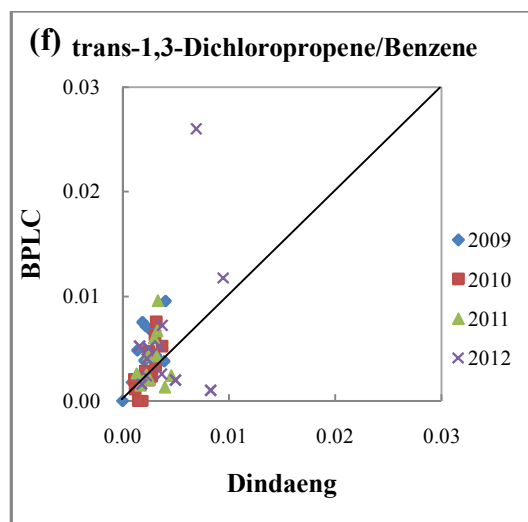
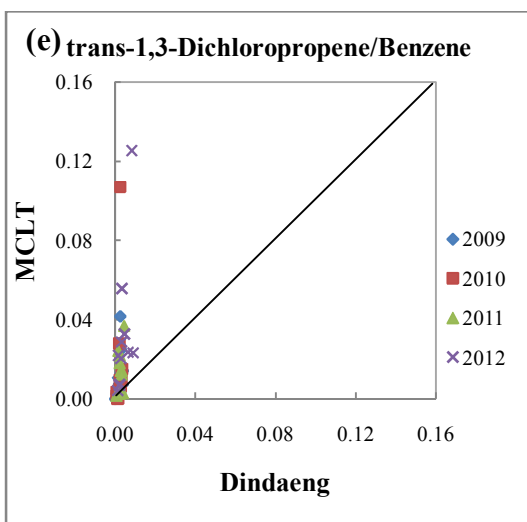
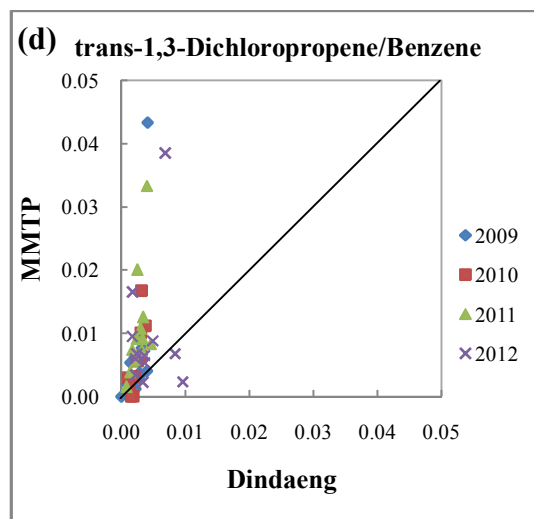
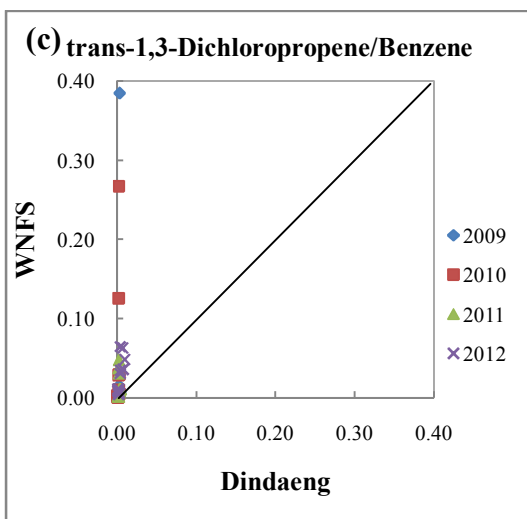
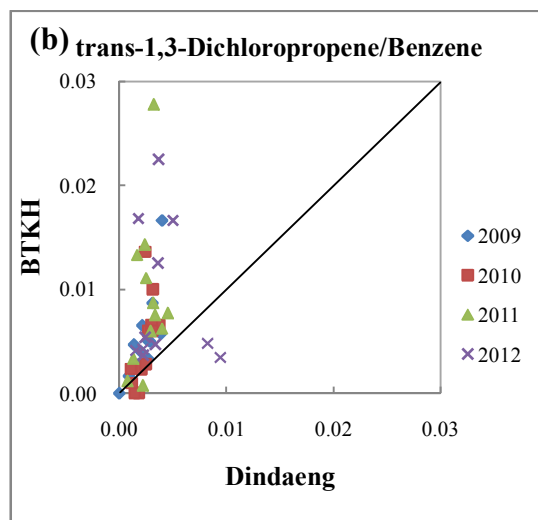
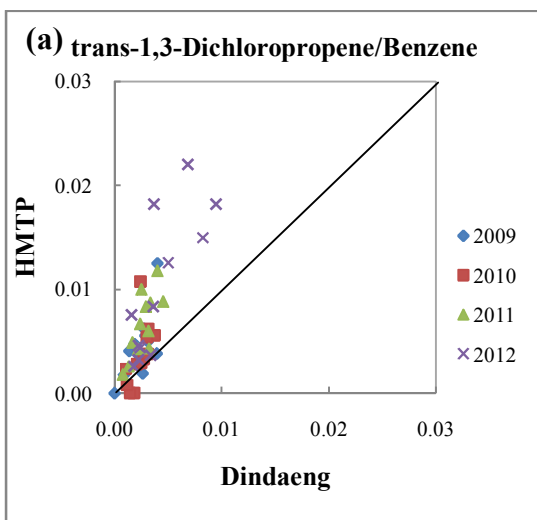


Figure 4.43 Scatter plots of 1,1,2-trichloroethane against benzene ratio of monitoring stations in Maptaphut area vs. Dindaeng (roadside site) in 2009-2012



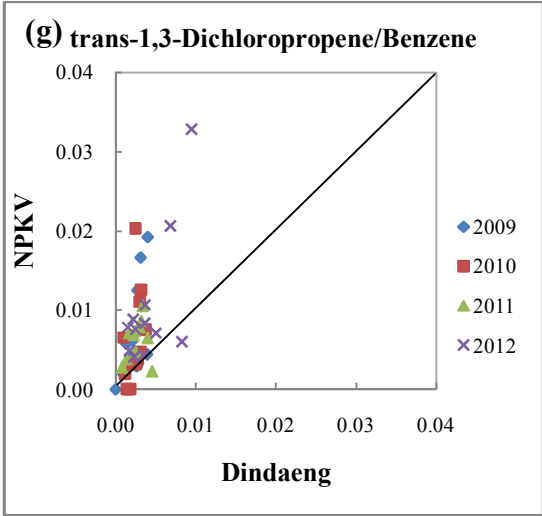
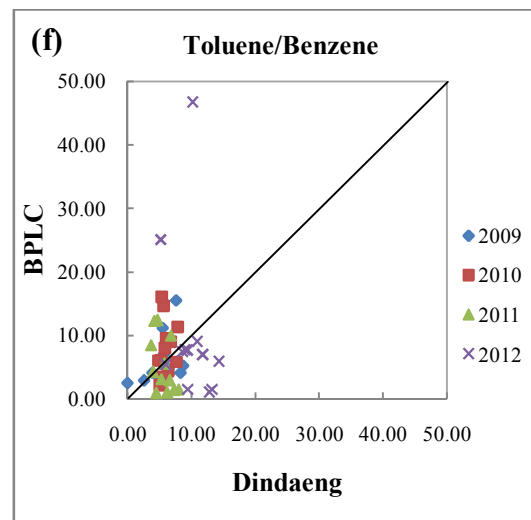
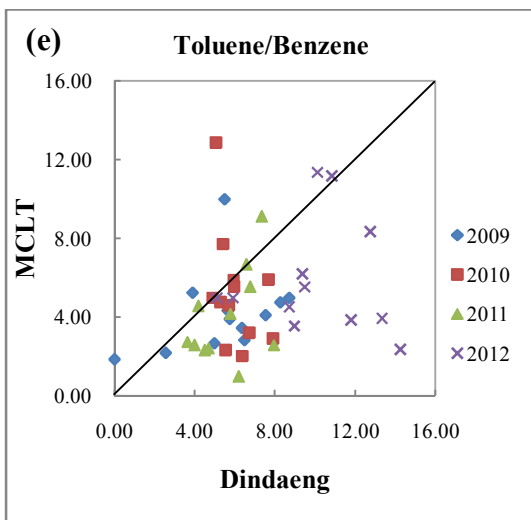
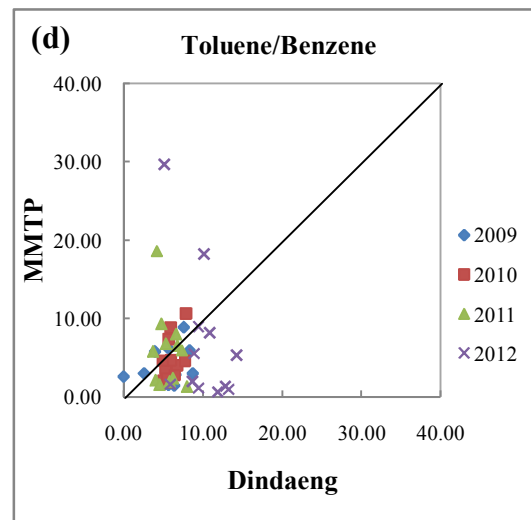
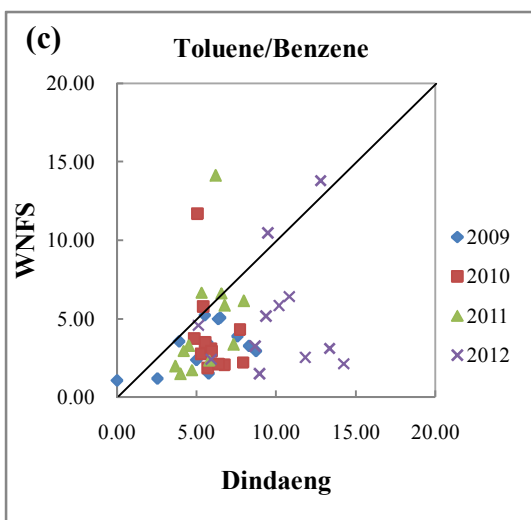
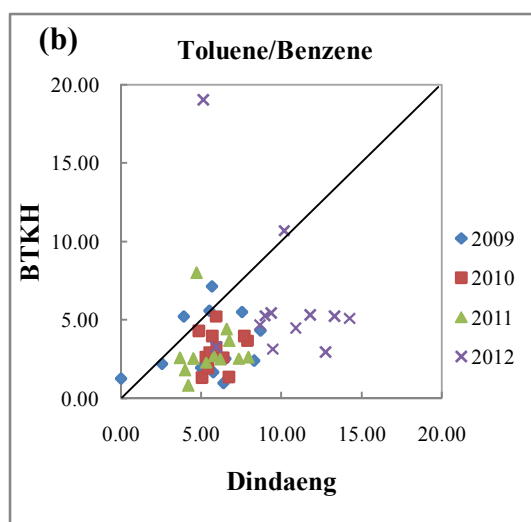
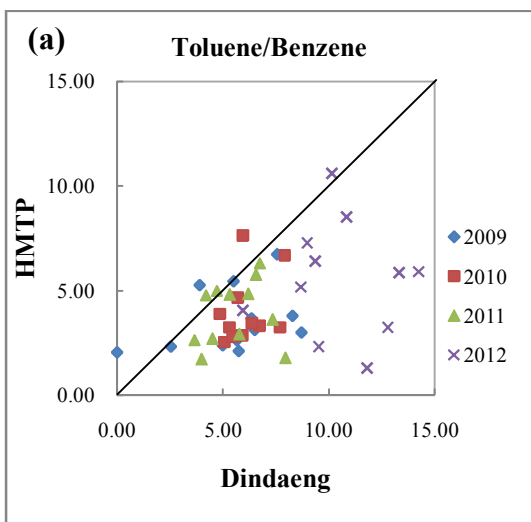


Figure 4.44 Scatter plots of trans-1,3-dichloropropene against benzene ratio of monitoring stations in Maptaphut area vs. Dindaeng (roadside site) in 2009-2012



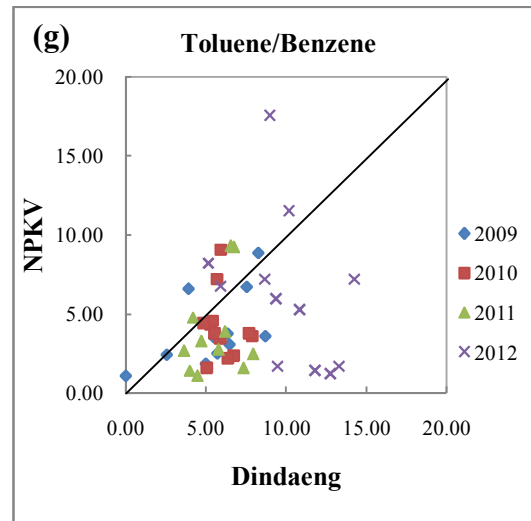
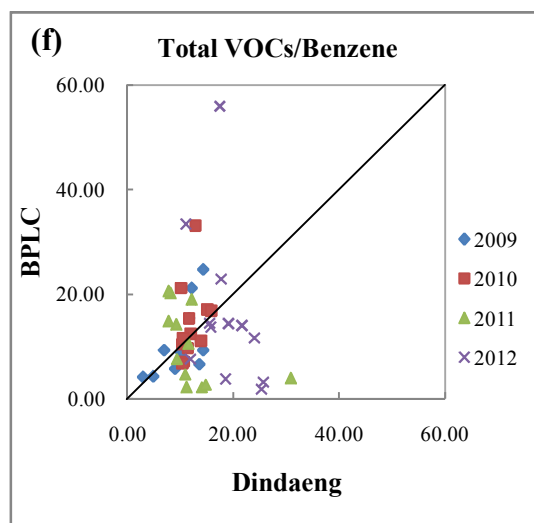
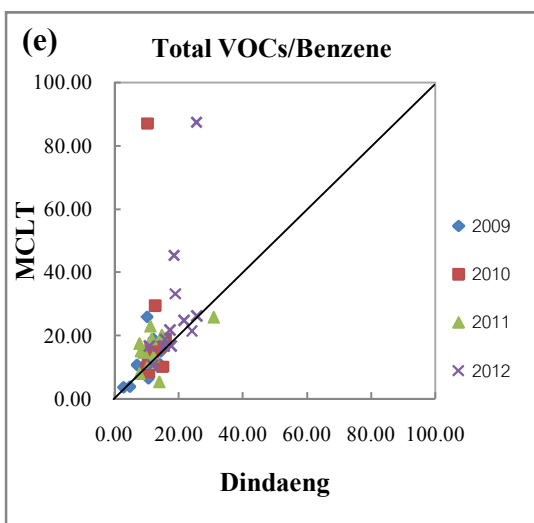
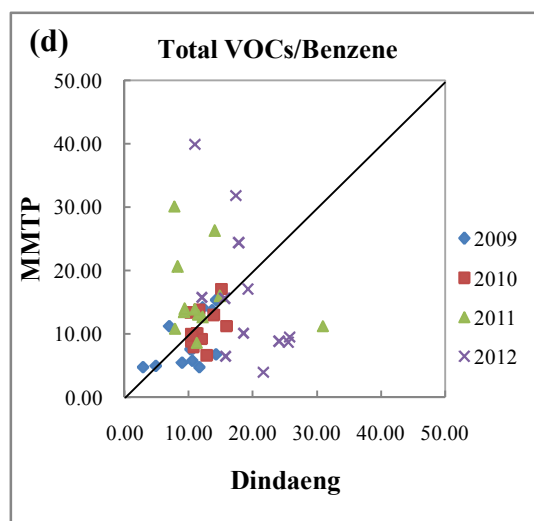
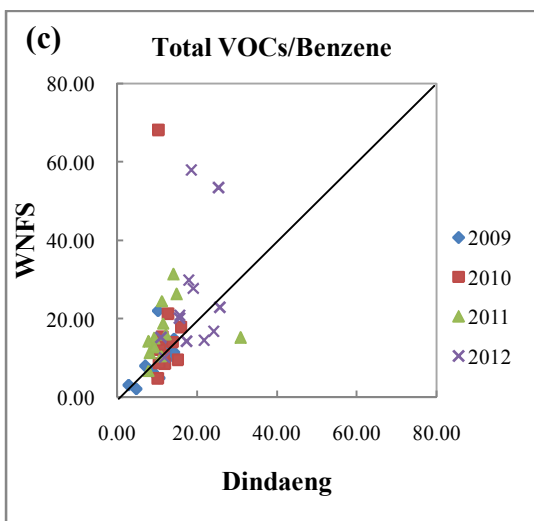
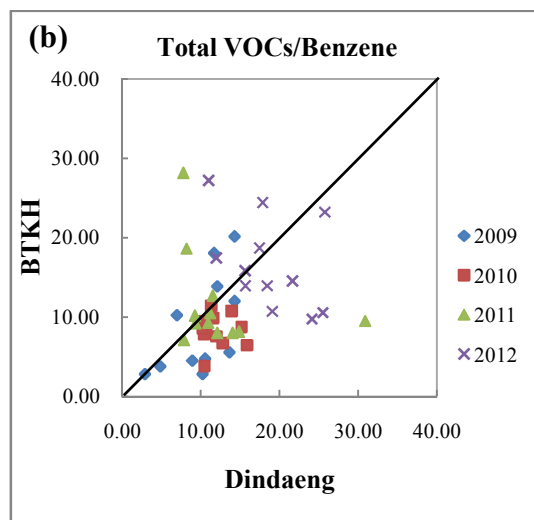
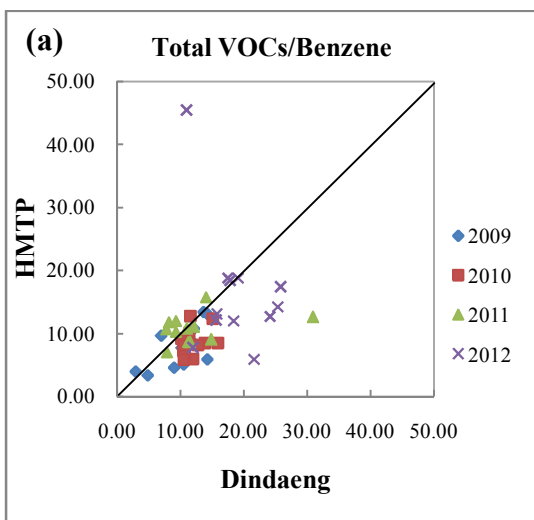


Figure 4.45 Scatter plots of toluene against benzene ratio of monitoring stations in Maptaphut area vs. Dindaeng (roadside site) in 2009-2012



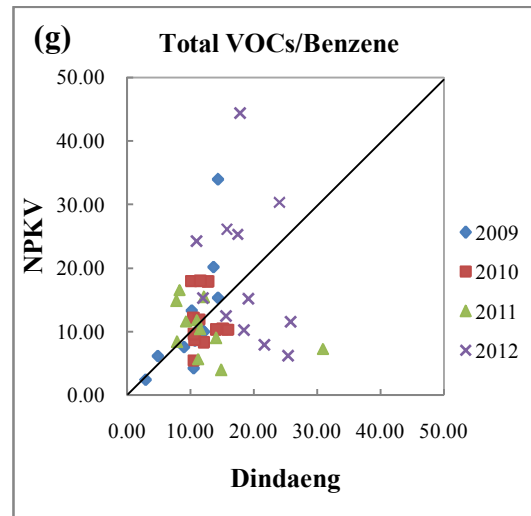


Figure 4.46 Scatter plots of total VOCs against benzene ratio of monitoring stations in Maptaphut area vs. Dindaeng (roadside site) in 2009-2012

Comparison of each VOCs/Bz ratios for monitoring stations in Maptaphut area with those in Dindaeng, where represent a roadside monitoring station, suggests that VOCs can be categorized into three groups as followed.

The first group shows that VOCs/Bz ratios at the monitoring station in Maptaphut area is higher than those at Dindaeng monitoring station (above the 1:1 line > 75%), indicated that VOCs in this group was mainly emitted from non-mobile sources.

VOCs in the second group shows that VOCs/Bz ratios at the monitoring station in Maptaphut area is lower than those at Dindaeng monitoring station (below the 1:1 line > 75%), indicated that VOCs in this group was mainly emitted from mobile sources (vehicle exhaust and gasoline evaporation).

The third group shows that VOCs/Bz ratios above and below the 1:1 line, indicated that VOCs in this group was emitted from both stationary and mobile sources. Results of VOCs/Bz ratios were shown in Table 4.13-4.19.

Table 4.13 Results of VOCs/Bz ratios for Health Promotion Hospital Maptaphut (HMTP) monitoring station in 2009-2012

Shown above 1:1 line	Shown below 1:1 line	Shown above and below 1:1 line
<u>Freon 11</u>	<u>1,2,4-Trimethylbenzene</u>	<u>1,3-Butadiene</u>
<u>Freon 12</u>	<u>Ethylbenzene</u>	<u>Dichloromethane</u>
Freon 113	<u>Total xylene</u>	<u>Styrene</u>
Freon 114	<u>Toluene</u>	<u>Chloroform</u>
<u>Chloromethane</u>	Total VOCs	<u>Trichloroethylene</u>
<u>Vinyl chloride</u>		1,4-Dichlorobenzene
Bromomethane		<u>1,3,5-Trimethylbenzene</u>
Chloroethane		<u>1-Ethyl-4-methylbenzene</u>
1,1-Dichloroethylene		<u>Tetrachloroethylene</u>
Acrylonitrile		
3-Chloropropene		
1,1-Dichloroethane		
<u>1,2-Dichloroethane</u>		
1,1,1-Trichloroethane		
<u>Carbon tetrachloride</u>		
<u>1,2-Dichloropropane</u>		
Hexachloro-1,3-butadiene		
1,2,4-Trichlorobenzene		
1,2-Dichlorobenzene		
1,3-Dichlorobenzene		
Benzyl chloride		
1,1,2,2-Tetrachloroethane		
cis-1,2-Dichloroethylene		
Chlorobenzene		
1,2-Dibromoethane		
cis-1,3-Dichloropropene		
1,1,2-Trichloroethane		
Trans-1,3-dichloropropene		

Note: Prioritize VOCs (20 compounds including benzene)

Table 4.14 Results of VOCs/Bz ratios for Ban Ta Kuan Public Health Center (BTKH) monitoring station in 2009-2012

Shown above 1:1 line	Shown below 1:1 line	Shown above and below 1:1 line
<u>Freon 11</u>	<u>1,2,4-Trimethylbenzene</u>	<u>1,3-Butadiene</u>
<u>Freon 12</u>	<u>Ethylbenzene</u>	<u>Dichloromethane</u>
Freon 113	<u>Total xylene</u>	<u>Styrene</u>
Freon 114	<u>Toluene</u>	<u>Chloroform</u>
<u>Chloromethane</u>		<u>Trichloroethylene</u>
<u>Vinyl chloride</u>		1,4-Dichlorobenzene
Bromomethane		<u>1,3,5-Trimethylbenzene</u>
Chloroethane		<u>1-Ethyl-4-methylbenzene</u>
1,1-Dichloroethylene		<u>Tetrachloroethylene</u>
Acrylonitrile		Total VOCs
3-Chloropropene		
1,1-Dichloroethane		
<u>1,2-Dichloroethane</u>		
1,1,1-Trichloroethane		
<u>Carbon tetrachloride</u>		
<u>1,2-Dichloropropane</u>		
Hexachloro-1,3-butadiene		
1,2,4-Trichlorobenzene		
1,2-Dichlorobenzene		
1,3-Dichlorobenzene		
Benzyl chloride		
1,1,2,2-Tetrachloroethane		
cis-1,2-Dichloroethylene		
Chlorobenzene		
1,2-Dibromoethane		
cis-1,3-Dichloropropene		
1,1,2-Trichloroethane		
trans-1,3-Dichloropropene		

Note: Prioritize VOCs (20 compounds including benzene)

Table 4.15 Results of VOCs/Bz ratios for Wat Nong Fap School (WNFS) monitoring station in 2009-2012

Shown above 1:1 line	Shown below 1:1 line	Shown above and below 1:1 line
<u>Freon 11</u>	<u>1,2,4-Trimethylbenzene</u>	<u>1,3-Butadiene</u>
<u>Freon 12</u>	<u>Toluene</u>	<u>Dichloromethane</u>
Freon 113		<u>Styrene</u>
Freon 114		<u>Trichloroethylene</u>
<u>Chloromethane</u>		1,4-Dichlorobenzene
<u>Vinyl chloride</u>		<u>1,3,5-Trimethylbenzene</u>
Bromomethane		<u>1-Ethyl-4-methylbenzene</u>
Chloroethane		<u>Total xylene</u>
1,1-Dichloroethylene		<u>Ethylbenzene</u>
Acrylonitrile		Total VOCs
3-Chloropropene		
1,1-Dichloroethane		
<u>1,2-Dichloroethane</u>		
<u>Chloroform</u>		
1,1,1-Trichloroethane		
<u>Carbon tetrachloride</u>		
<u>1,2-Dichloropropane</u>		
Hexachloro-1,3-butadiene		
1,2,4-Trichlorobenzene		
1,2-Dichlorobenzene		
1,3-Dichlorobenzene		
Benzyl chloride		
1,1,2,2-Tetrachloroethane		
cis-1,2-Dichloroethylene		
Chlorobenzene		
1,2-Dibromoethane		
<u>Tetrachloroethylene</u>		
cis-1,3,-Dichloropropene		
1,1,2-Trichloroethane		
trans-1,3-Dichloropropene		

Note: Prioritize VOCs (20 compounds including benzene)

Table 4.16 Results of VOCs/Bz ratios for Muang Mai Maptaphut (MMTP) monitoring station in 2009-2012

Shown above 1:1 line	Shown below 1:1 line	Shown above and below 1:1 line
<u>Freon 11</u>	<u>1,2,4-Trimethylbenzene</u>	<u>1,3-Butadiene</u>
<u>Freon 12</u>	<u>Total xylene</u>	<u>Dichloromethane</u>
Freon 113	<u>Toluene</u>	<u>Styrene</u>
Freon 114		<u>Chloroform</u>
<u>Chloromethane</u>		<u>Trichloroethylene</u>
<u>Vinyl chloride</u>		1,4-Dichlorobenzene
Bromomethane		<u>1,3,5-Trimethylbenzene</u>
Chloroethane		<u>1-Ethyl-4-methylbenzene</u>
1,1-Dichloroethylene		<u>Ethylbenzene</u>
Acrylonitrile		<u>Tetrachloroethylene</u>
3-Chloropropene		Total VOCs
1,1-Dichloroethane		
<u>1,2-Dichloroethane</u>		
1,1,1-Trichloroethane		
<u>Carbon tetrachloride</u>		
<u>1,2-Dichloropropane</u>		
Hexachloro-1,3-butadiene		
1,2,4-Trichlorobenzene		
1,2-Dichlorobenzene		
1,3-Dichlorobenzene		
Benzyl chloride		
1,1,2,2-Tetrachloroethane		
cis-1,2-Dichloroethylene		
Chlorobenzene		
1,2-Dibromoethane		
cis-1,3-Dichloropropene		
1,1,2-Trichloroethane		
trans-1,3-Dichloropropene		

Note: Prioritize VOCs (20 compounds including benzene)

Table 4.17 Results of VOCs/Bz ratios for Map Chalut Temple (MCLT) monitoring station in 2009-2012

Shown above 1:1 line	Shown below 1:1 line	Shown above and below 1:1 line
<u>Freon 11</u>	<u>1,2,4-Trimethylbenzene</u>	<u>1,3-Butadiene</u>
<u>Freon 12</u>	<u>Toluene</u>	<u>Dichloromethane</u>
Freon 113		<u>Styrene</u>
Freon 114		1,4-Dichlorobenzene
<u>Chloromethane</u>		<u>1,3,5-Trimethylbenzene</u>
<u>Vinyl chloride</u>		<u>1-Ethyl-4-methylbenzene</u>
Bromomethane		<u>Ethylbenzene</u>
Chloroethane		<u>Total xylene</u>
1,1-Dichloroethylene		<u>Tetrachloroethylene</u>
Acrylonitrile		Total VOCs
3-Chloropropene		
1,1-Dichloroethane		
<u>1,2-Dichloroethane</u>		
<u>Chloroform</u>		
1,1,1-Trichloroethane		
<u>Carbon tetrachloride</u>		
<u>Trichloroethylene</u>		
<u>1,2-Dichloropropane</u>		
Hexachloro-1,3-butadiene		
1,2,4-Trichlorobenzene		
1,2-Dichlorobenzene		
1,3-Dichlorobenzene		
Benzyl chloride		
1,1,2,2-Tetrachloroethane		
cis-1,2-Dichloroethylene		
Chlorobenzene		
1,2-Dibromoethane		
cis-1,3,-Dichloropropene		
1,1,2-Trichloroethane		
trans-1,3-Dichloropropene		

Note: Prioritize VOCs (20 compounds including benzene)

Table 4.18 Results of VOCs/Bz ratios for Ban Plong Community (BPLC) monitoring station in 2009-2012

Shown above 1:1 line	Shown below 1:1 line	Shown above and below 1:1 line
<u>Freon 11</u>	<u>1,2,4-Trimethylbenzene</u>	<u>Chloromethane</u>
<u>Freon 12</u>	<u>Total xylene</u>	<u>1,3-Butadiene</u>
Freon 113		<u>Dichloromethane</u>
Freon 114		1,1-Dichloroethane
<u>Vinyl chloride</u>		<u>Styrene</u>
Bromomethane		<u>Chloroform</u>
Chloroethane		<u>Carbon tetrachloride</u>
1,1-Dichloroethylene		<u>Trichloroethylene</u>
Acrylonitrile		<u>1,2-Dichloropropane</u>
3-Chloropropene		Hexachloro-1,3-butadiene
<u>1,2-Dichloroethane</u>		1,4-Dichlorobenzene
1,1,1-Trichloroethane		cis-1,2-Dichloroethylene
1,2,4-Trichlorobenzene		<u>1,3,5-Trimethylbenzene</u>
1,2-Dichlorobenzene		<u>1-Ethyl-4-methylbenzene</u>
1,3-Dichlorobenzene		<u>Ethylbenzene</u>
Benzyl chloride		Chlorobenzene
1,1,2,2-Tetrachloroethane		<u>Tetrachloroethylene</u>
1,2-Dibromoethane		cis-1,3,-Dichloropropene
1,1,2-Trichloroethane		<u>Toluene</u>
trans-1,3-Dichloropropene		Total VOCs

Note: Prioritize VOCs (20 compounds including benzene)

Table 4.19 Results of VOCs/Bz ratios for Nop Pakate Village (NPKV) monitoring station in 2009-2012

Shown above 1:1 line	Shown below 1:1 line	Shown above and below 1:1 line
<u>Freon 11</u>	<u>1,2,4-Trimethylbenzene</u>	<u>1,3-Butadiene</u>
<u>Freon 12</u>	<u>Toluene</u>	<u>Styrene</u>
Freon 113		<u>Chloroform</u>
Freon 114		<u>Trichloroethylene</u>
<u>Chloromethane</u>		<u>1,2-Dichloropropane</u>
<u>Vinyl chloride</u>		1,4-Dichlorobenzene
Bromomethane		<u>1,3,5-Trimethylbenzene</u>
Chloroethane		<u>1-Ethyl-4-methylbenzene</u>
1,1-Dichloroethylene		<u>Total xylene</u>
Acrylonitrile		<u>Ethylbenzene</u>
3-Chloropropene		<u>Tetrachloroethylene</u>
<u>Dichloromethane</u>		Total VOCs
1,1-Dichloroethane		
<u>1,2-Dichloroethane</u>		
1,1,1-Trichloroethane		
<u>Carbon tetrachloride</u>		
Hexachloro-1,3-butadiene		
1,2,4-Trichlorobenzene		
1,2-Dichlorobenzene		
1,3-Dichlorobenzene		
Benzyl chloride		
1,1,2,2-Tetrachloroethane		
cis-1,2-Dichloroethylene		
Chlorobenzene		
1,2-Dibromoethane		
cis-1,3-Dichloropropene		
1,1,2-Trichloroethane		
trans-1,3-Dichloropropene		

Note: Prioritize VOCs (20 compounds including benzene)

Contribution of emission source of VOCs was calculated by the equation as below;

$$z_i = \left[\frac{x_i}{\sum_{i=1}^3 x_i} \right] \times 100$$

Where; z_i = Contribution of group i (% of total concentration)

x_i = VOCs concentration of group i

The contribution of emission sources for monitoring station in Maptaphut area as shown in Figure 4.47-4.74

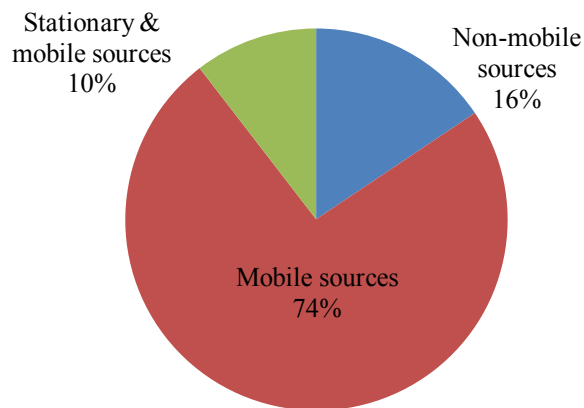


Figure 4.47 Contribution of emission sources for Health Promotion Hospital Maptaphut (HMTP) monitoring station in 2009

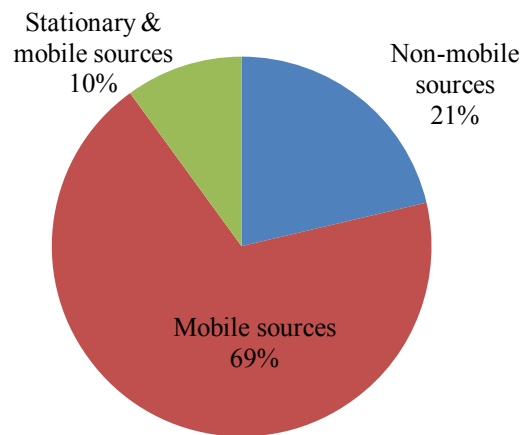


Figure 4.48 Contribution of emission sources for Health Promotion Hospital Maptaphut (HMTP) monitoring station in 2010

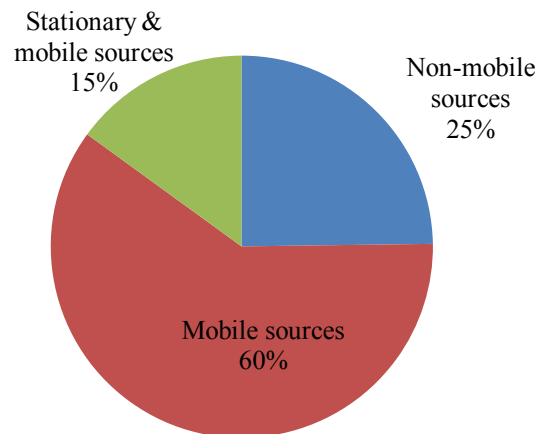


Figure 4.49 Contribution of emission sources for Health Promotion Hospital Maptaphut (HMTP) monitoring station in 2011

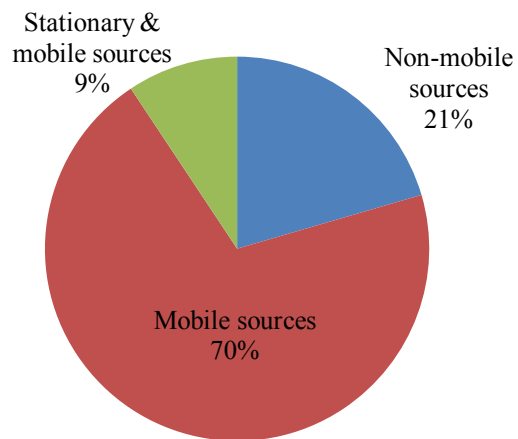


Figure 4.50 Contribution of emission sources for Health Promotion Hospital Maptaphut (HMTP) monitoring station in 2012

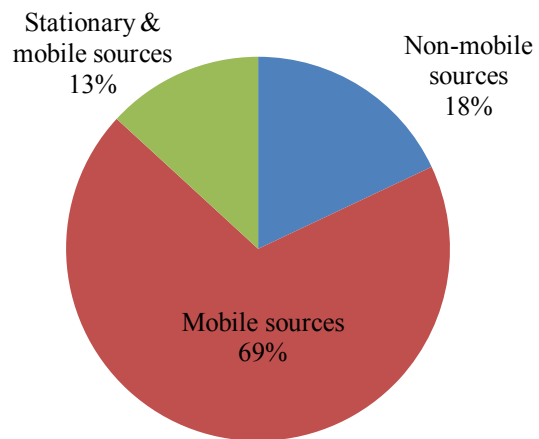


Figure 4.51 Contribution of emission sources for Ban Ta Kuan Public Health Center (BTKH) monitoring station in 2009

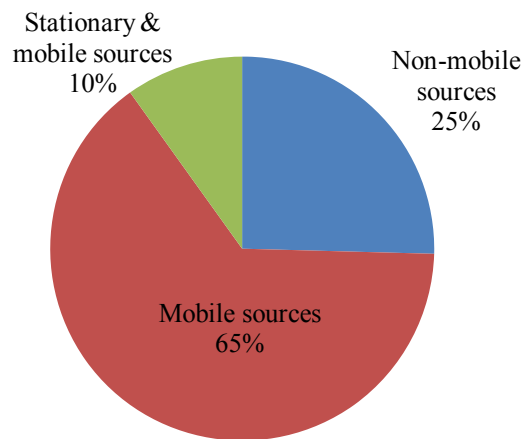


Figure 4.52 Contribution of emission sources for Ban Ta Kuan Public Health Center (BTKH) monitoring station in 2010

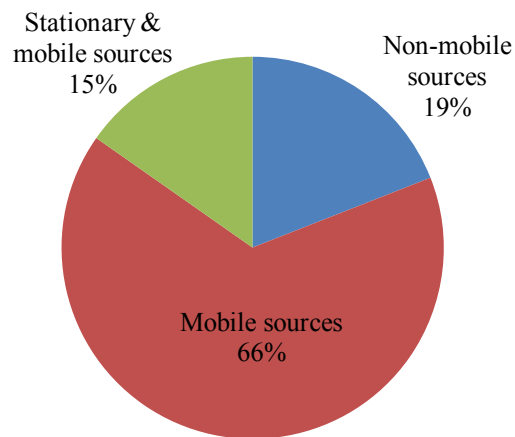


Figure 4.53 Contribution of emission sources for Ban Ta Kuan Public Health Center (BTKH) monitoring station in 2011

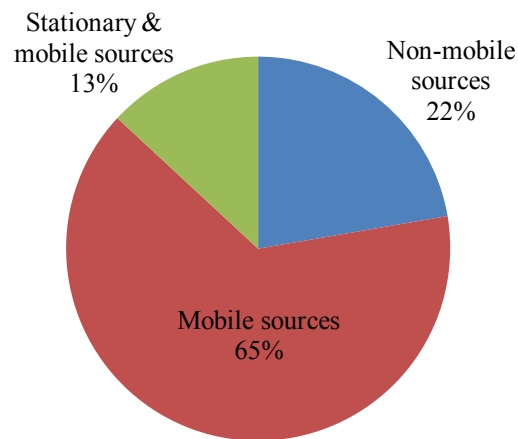


Figure 4.54 Contribution of emission sources for Ban Ta Kuan Public Health Center (BTKH) monitoring station in 2012

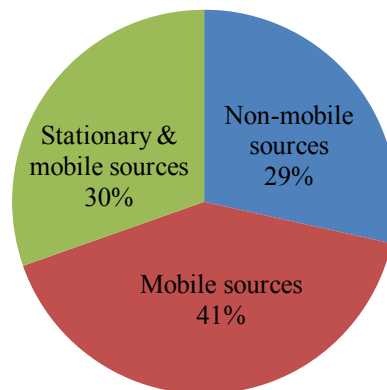


Figure 4.55 Contribution of emission sources for Wat Nong Fap School (WNFS) monitoring station in 2009

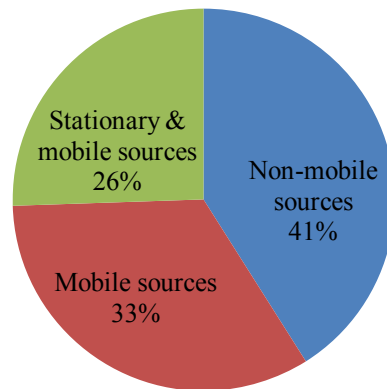


Figure 4.56 Contribution of emission sources for Wat Nong Fap School (WNFS) monitoring station in 2010

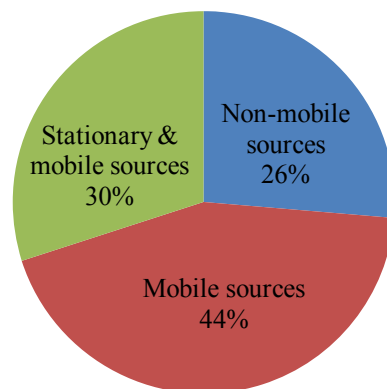


Figure 4.57 Contribution of emission sources for Wat Nong Fap School (WNFS) monitoring station in 2011

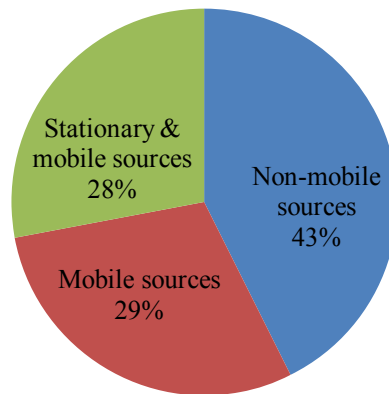


Figure 4.58 Contribution of emission sources for Wat Nong Fap School (WNFS) monitoring station in 2012

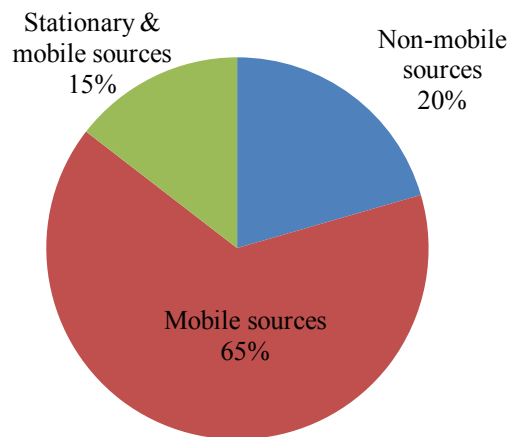


Figure 4.59 Contribution of emission sources for Muang Mai Maptaphut (MMTP) monitoring station in 2009

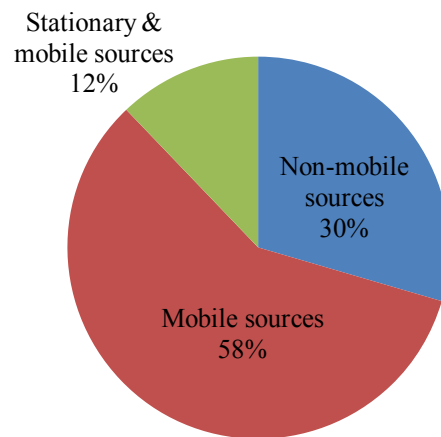


Figure 4.60 Contribution of emission sources for Muang Mai Maptaphut (MMTP) monitoring station in 2010

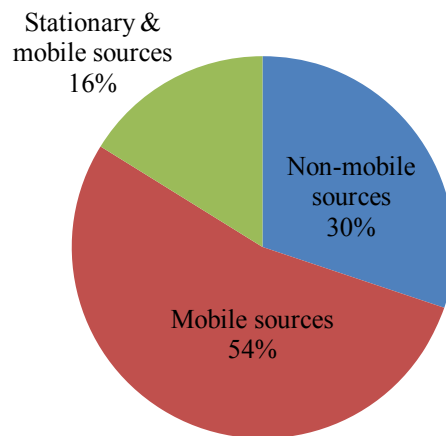


Figure 4.61 Contribution of emission sources for Muang Mai Maptaphut (MMTP) monitoring station in 2011

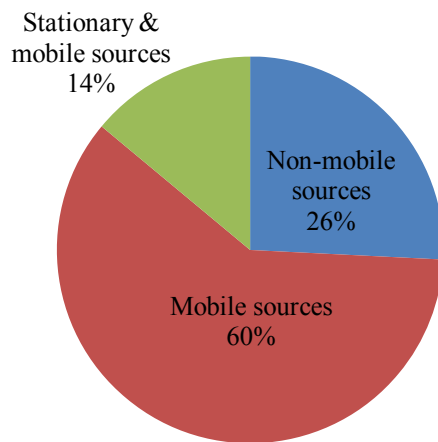


Figure 4.62 Contribution of emission sources for Muang Mai Maptaphut (MMTP) monitoring station in 2012

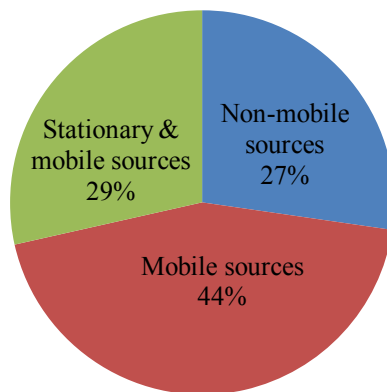


Figure 4.63 Contribution of emission sources for Map Chalut Temple (MCLT) monitoring station in 2009

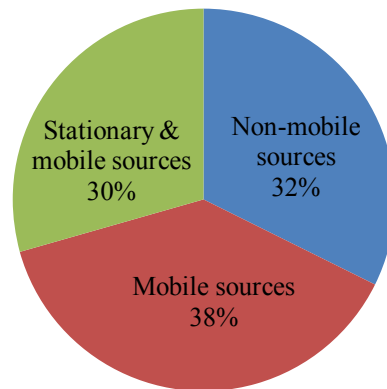


Figure 4.64 Contribution of emission sources for Map Chalut Temple (MCLT) monitoring station in 2010

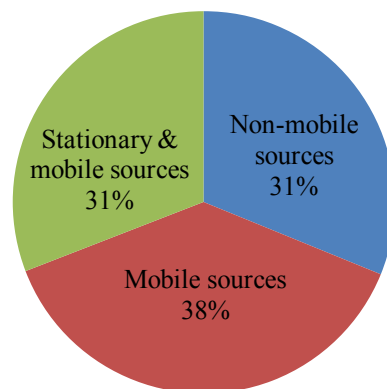


Figure 4.65 Contribution of emission sources for Map Chalut Temple (MCLT) monitoring station in 2011

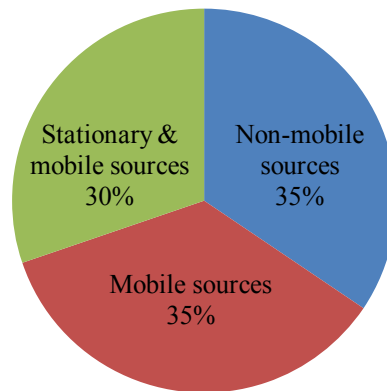


Figure 4.66 Contribution of emission sources for Map Chalut Temple (MCLT) monitoring station in 2012

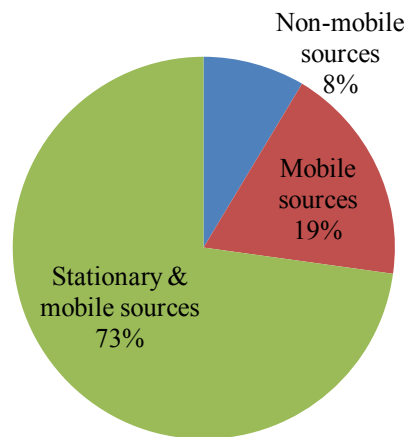


Figure 4.67 Contribution of emission sources for Ban Plong Community (BPLC) monitoring station in 2009

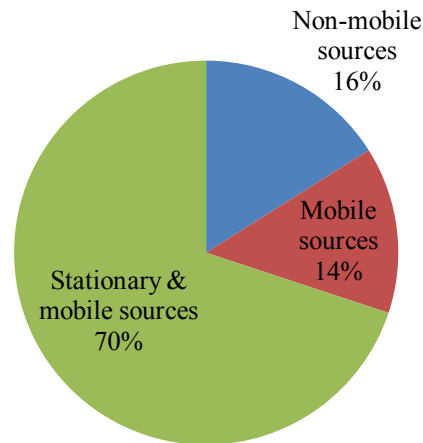


Figure 4.68 Contribution of emission sources for Ban Plong Community (BPLC) monitoring station in 2010

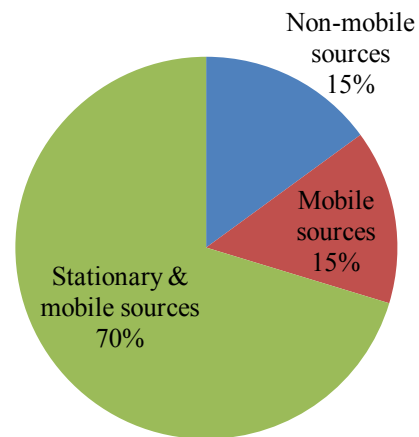


Figure 4.69 Contribution of emission sources for Ban Plong Community (BPLC) monitoring station in 2011

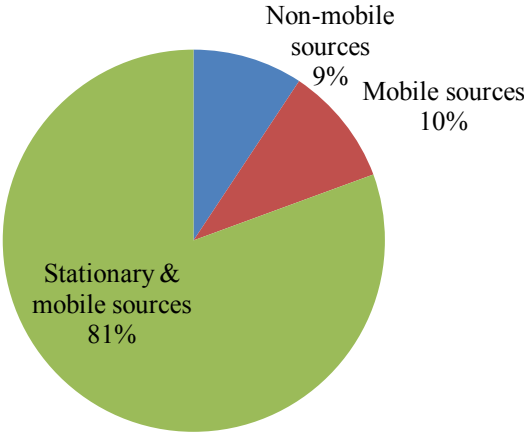


Figure 4.70 Contribution of emission sources for Ban Plong Community (BPLC) monitoring station in 2012

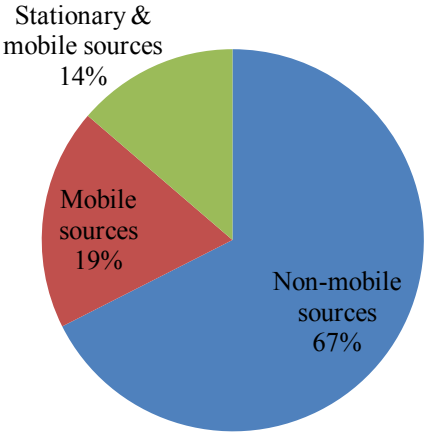


Figure 4.71 Contribution of emission sources for Nop Pakate Village (NPKV) monitoring station in 2009

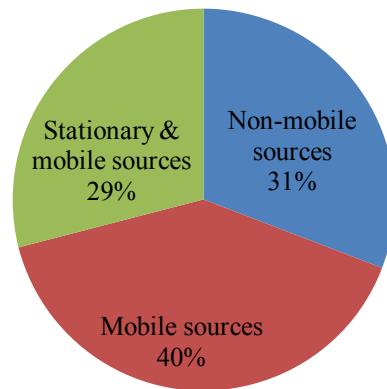


Figure 4.72 Contribution of emission sources for Nop Pakate Village (NPKV) monitoring station in 2010

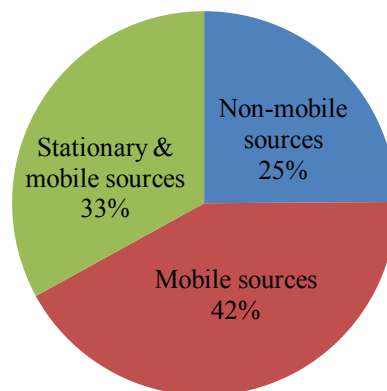


Figure 4.73 Contribution of emission sources for Nop Pakate Village (NPKV) monitoring station in 2011

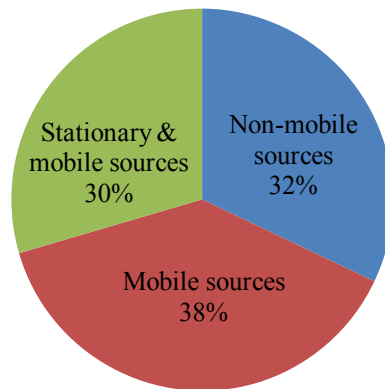


Figure 4.74 Contribution of emission sources for Nop Pakate Village (NPKV) monitoring station in 2012

4.2.2 BTEX concentration ratios

Ratios of benzene, toluene and o,m,p-xylene to ethylbenzene at each monitoring site in Maptaphut area were compared with those calculated data from Dindaeng monitoring station. These data were used to interpret for similarity of VOCs profile as comparing with roadside station. The results were shown in Figure 4.75-4.77.

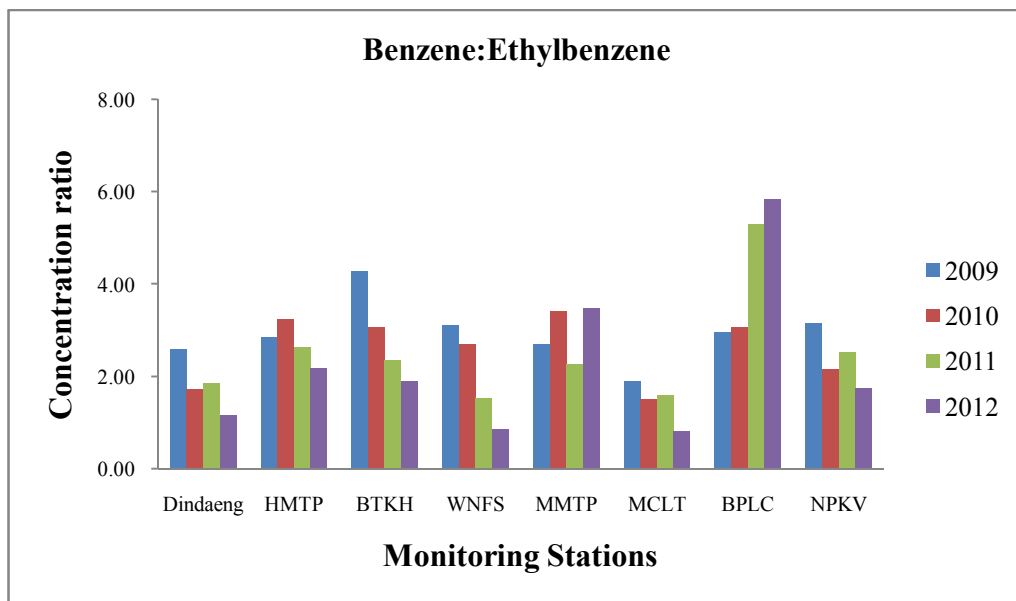


Figure 4.75 Comparison of benzene to ethylbenzene ratio of Maptaphut monitoring stations with Dindaeng monitoring station

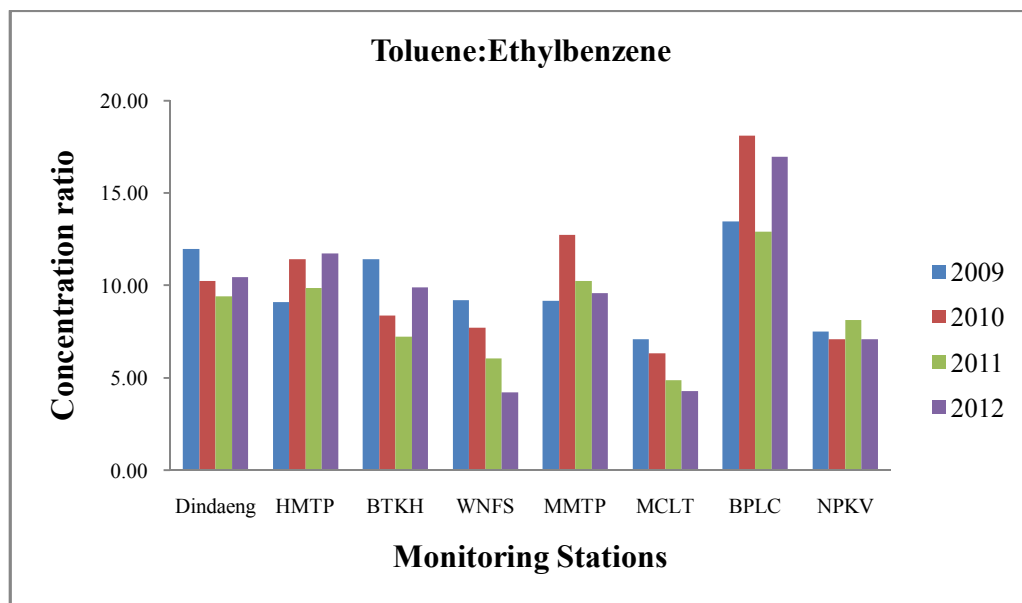


Figure 4.76 Comparison of toluene to ethylbenzene ratio of Maptaphut monitoring stations with Dindaeng monitoring station

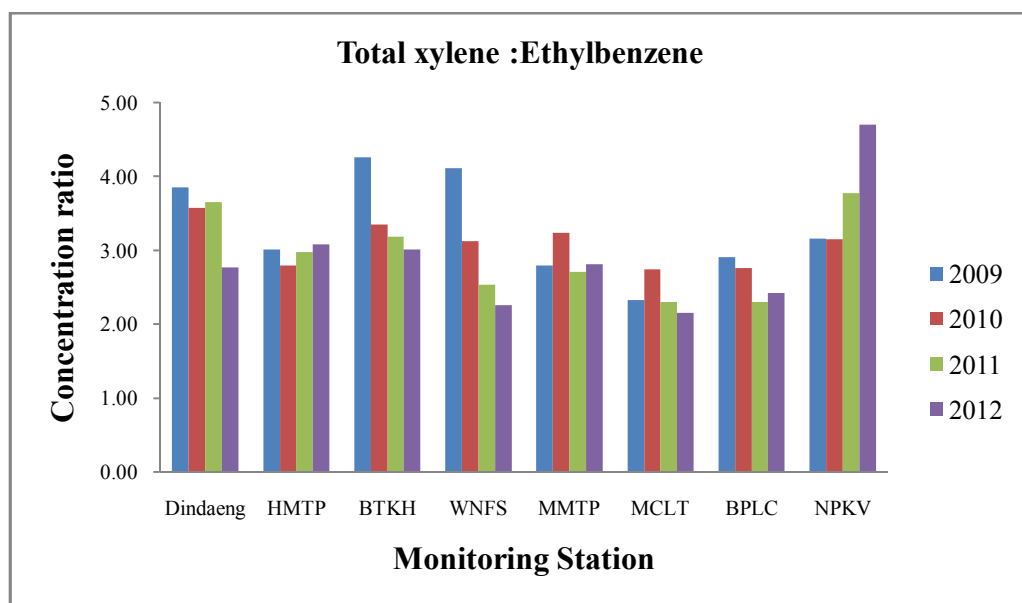


Figure 4.77 Comparison of total xylene to ethylbenzene ratio of Maptaphut monitoring stations with Dindaeng monitoring station

Benzene to ethylbenzene ratio at every monitoring stations in Maptaphut in 2009-2012 were resemble with those at Dindaeng except for Ban Plong Community

(BPLC) monitoring station in 2011 and 2012 where the ratios were higher than Dindaeng monitoring station.

Benzene to ethylbenzene ratio of Dindaeng, Health Promotion Hospital Maptaphut (HMTP), Ban Ta Kuan Public Health Center (BTKH), Wat Nong Fap School (WNFS), Map Chalut Temple (MCLT) and Nop Pakate Village (NPKV) monitoring station in 2012 were lower than those in 2009-2011. Therefore, reducing of benzene content in gasoline from 5% (EURO2) to 1% (EURO4) started on January 1, 2011, was expected to reduction of benzene concentration in ambient air. Moreover, benzene to ethylbenzene ratio for Muang Mai Maptaphut (MMTP) and Ban Plong Community (BPLC) monitoring station in 2012 were higher than those in 2009-2011. These results indicated that benzene might be emitted from other additional sources apart from mobile source emission.

Toluene to ethylbenzene ratio at every monitoring stations in Maptaphut in 2009-2012 were resemble with those Dindaeng excepted for Wat Nong Fab School (WNFS) monitoring station in 2012 and Map Chalut Temple (MCLT) station in 2009-2012. Moreover, toluene to ethylbenzene ratios of Ban Plong Community (BPLC) station in 2010 and 2012 were higher than Dindaeng station.

Total xylene to ethylbenzene ratio at every monitoring stations in 2009-2012 were resemble with Dindaeng station excepted for Nop Pakate Village (NPKV) monitoring station in 2012 where the ratio was higher than Dindaeng monitoring station.

The difference indicated that emission source of VOCs found at these sites might be originated from other additional sources apart from mobile sources emission.

4.3 Source apportionment by using principal component analysis

Fifteen highest concentrations and Thailand's annual standard VOCs were selected to classify the group of VOCs by using principal component analysis (PCA) based on emission source. Ambient concentrations of twenty VOCs used in PCA analysis were freon 11, freon 12, chloromethane, vinyl chloride, 1,3-butadiene, dichloromethane, chloroform, 1,2-dichloroethane, benzene, carbon tetrachloride,

trichloroethylene, tetrachloroethylene, 1,2-dichloropropane, toluene, ethylbenzene, total xylene, styrene, 1-ethyl-4-methylbenzene, 1,2,4-trimethylbenzene and 1,3,5-trimethylbenzene.

The method of rotation was varimax with Kaiser Normalization. Each principal component (PC) had eigenvalues greater than unity. Only loading values which were greater than or equal to ± 0.5 were included in PCA interpretations. The results of PCA were as shown in Table 4.20-4.27.

Table 4.20 Principal component analysis for VOCs of Health Promotion Hospital Maptaphut (HMTP) monitoring station in 2009-2012

VOCs	PC 1	PC 2	PC 3	PC 4	PC 5
Freon 12			0.64		
Chloromethane			0.77		
Vinyl Chloride				0.91	
1,3-Butadiene					0.84
Freon 11			0.66		
Dichloromethane			0.74		
Chloroform		0.86			
1,2-Dichloroethane				0.94	
Benzene	0.63				
Carbon Tetrachloride		0.67			
Trichloroethylene		0.86			
1,2-Dichloropropane		0.65			
Toluene	0.52		0.54		
Tetrachloroethylene		0.83			
Ethylbenzene	0.68				
Total Xylene	0.80				
Styrene					0.76
1-Ethyl-4-methylbenzene	0.81				
1,3,5-Trimethylbenzene	0.80				
1,2,4-Trimethylbenzene	0.86				
Initial Eigenvalues	6.09	3.03	2.12	1.87	1.40
Variance (%)	30.45	15.13	10.58	9.37	7.00
Cumulative variance (%)	30.45	45.58	56.16	65.53	72.53

The cumulative variance of Health Promotion Hospital Maptaphut monitoring station was about 72.53%. PC1 explained about 30.45% of the total variance of the data, consisted of benzene, toluene, ethylbenzene, total xylene, 1-ethyl-4-methylbenzene, 1,2,4-trimethylbenzene and 1,3,5-trimethylbenzene. These compounds were signature of mobile source emission.

PC2 (15.13%) consists of chloroform, carbon tetrachloride, trichloroethylene, 1,2-dichloropropane, and tetrachloroethylene. These compounds were chemical use in household.

PC3 (10.58%) consists of freon 12, chloromethane, freon 11, dichloromethane and toluene. PC4 (9.37%) consists of vinyl chloride and 1,2-dichloroethane. PC5 (7%) consists of 1,3-butadiene and styrene. VOCs in PC3 through PC5 are raw material of petrochemical process. Therefore, PC3 through PC5 were emitted from industrial process emission.

Table 4.21 Principal component analysis for VOCs of Ban Ta Kuan Public Health Center (BTKH) monitoring station in 2009-2012

VOCs	PC 1	PC 2	PC 3	PC 4	PC 5
Freon 12					0.84
Chloromethane				0.89	
Vinyl Chloride			0.96		
1,3-Butadiene					
Freon 11					0.75
Dichloromethane				0.64	
Chloroform		0.81			
1,2-Dichloroethane			0.79		
Benzene	0.91				
Carbon Tetrachloride		0.88			
Trichloroethylene		0.69			
1,2-Dichloropropane		0.70			
Toluene	0.83				
Tetrachloroethylene		0.83			
Ethylbenzene	0.81				
Total Xylene	0.97				
Styrene	0.84				
1-Ethyl-4-methylbenzene	0.97				
1,3,5-Trimethylbenzene	0.95				
1,2,4-Trimethylbenzene	0.98				
Initial Eigenvalues	7.32	4.20	1.93	1.67	1.06
Variance (%)	36.59	20.99	9.67	8.36	5.30
Cumulative variance (%)	36.59	57.58	67.25	75.61	80.91

The cumulative variance of Ban Ta Kuan Public Health Center (BTKH) monitoring station was about 80.91%. PC1 explained about 36.59% of the total variance of the data, consisted of benzene, toluene, ethylbenzene, total xylene, styrene, 1-ethyl-4-methylbenzene, 1,2,4-trimethylbenzene and 1,3,5-trimethylbenzene. These compounds were signature of mobile source emission.

PC2 (20.99%) consists of chloroform, carbon tetrachloride, trichloroethylene, 1,2-dichloropropane and tetrachloroethylene. These compounds were chemical use in household.

PC3 (9.67%) consists of vinyl chloride and 1,2-dichloroethane and chloromethane and dichloromethane in PC4 (8.36%) were emitted from industrial process emission.

PC5 (5.3%) consists of freon 11 and freon 12 were VOCs background concentration in ambient air.

Table 4.22 Principal component analysis for VOCs of Wat Nong Fap School (WNFS) monitoring station in 2009-2012

VOCs	PC 1	PC 2	PC 3	PC 4	PC 5	PC 6
Freon 12				0.84		
Chloromethane						0.80
Vinyl Chloride		0.87				
1,3-Butadiene						
Freon 11				0.84		
Dichloromethane		0.74				
Chloroform			0.96			
1,2-Dichloroethane		0.88				
Benzene	0.87					
Carbon Tetrachloride					0.78	
Trichloroethylene		0.57				
1,2-Dichloropropane			0.90			
Toluene	0.92					
Tetrachloroethylene					0.85	
Ethylbenzene	0.91					
Total Xylene	0.96					
Styrene				0.53		
1-Ethyl-4-methylbenzene	0.81					
1,3,5-Trimethylbenzene	0.73					
1,2,4-Trimethylbenzene	0.82					
Initial Eigenvalues	6.22	3.28	2.01	1.91	1.40	1.03
Variance (%)	31.09	16.42	10.05	9.54	7.00	5.16
Cumulative variance (%)	31.09	47.51	57.56	67.10	74.10	79.26

The cumulative variance of Wat Nong Fap School (WNFS) monitoring station was about 79.26%. PC1 explained about 31.09% of the total variance of the data, consisted of benzene, toluene, ethylbenzene, total xylene, 1-ethyl-4-methylbenzene, 1,2,4-trimethylbenzene and 1,3,5-trimethylbenzene. These compounds were signature of mobile source emission.

PC2 (16.42%) consists of vinyl chloride, dichloromethane, 1,2-dichloroethane and trichloroethylene. PC3 (10.05%) consists of chloroform and 1,2-dichloropropane and freon 11, freon 12 and styrene in PC4 (9.54%). Thus, VOCs in PC2 through PC4 were emitted from industrial process emission

PC5 (7%) consists of carbon tetrachloride and tetrachloroethylene. These compounds were chemical use in household.

PC6 (5.16%) include chloromethane only. Therefore, chloromethane which affect to Wat Nong Fap School (WNFS) monitoring station, emitted from loading/unloading activities or storage tank.

Table 4.23 Principal component analysis for VOCs of Muang Mai Maptaphut (MMTP) monitoring station in 2009-2012

VOCs	PC 1	PC 2	PC 3	PC 4	PC 5	PC 6
Freon 12					0.82	
Chloromethane	0.59					
Vinyl Chloride			0.92			
1,3-Butadiene			0.66			
Freon 11					0.62	
Dichloromethane				0.87		
Chloroform		0.81				
1,2-Dichloroethane			0.90			
Benzene	0.80					
Carbon Tetrachloride		0.75				
Trichloroethylene		0.82				
1,2-Dichloropropane						
Toluene				0.73		
Tetrachloroethylene		0.82				
Ethylbenzene	0.50			0.54		
Total Xylene	0.83					
Styrene						0.81
1-Ethyl-4-methylbenzene	0.55					
1,3,5-Trimethylbenzene	0.81					
1,2,4-Trimethylbenzene	0.88					
Initial Eigenvalues	6.64	2.41	2.16	1.68	1.15	1.02
Variance (%)	33.22	12.04	10.82	8.42	5.76	5.12
Cumulative variance (%)	33.22	45.26	56.08	64.50	70.26	75.38

The cumulative variance of Muang Mai Maptaphut (MMTP) monitoring station was about 75.38%. PC1 explained about 33.22% of the total variance of the data, consisted of chloromethane, benzene, ethylbenzene, total xylene, 1-ethyl-4-methylbenzene, 1,2,4-trimethylbenzene and 1,3,5-trimethylbenzene. These compounds were signature of mobile source emission.

PC2 (12.04%) consists of chloroform, carbon tetrachloride, trichloroethylene and tetrachloroethylene. These compounds were chemical use in household.

PC3 (10.82%) consists of vinyl chloride, 1,3-butadiene and 1,2-dichloroethane and PC4 (8.42%) consists of dichloromethane, toluene and ethylbenzene were emitted from industrial process emission.

PC5 (5.76%) consists of freon 11 and freon 12 were identified as background concentration in ambient air.

PC6 (5.12%) include styrene only. Therefore, styrene which affect to Muang Mai Maptaphut (MMTP) monitoring station, emitted from loading/unloading activities or storage tank.

Table 4.24 Principal component analysis for VOCs of Map Chalut Temple (MCLT) monitoring station in 2009-2012

VOCs	PC 1	PC 2	PC 3	PC 4	PC 5
Freon 12				0.80	
Chloromethane				0.54	
Vinyl Chloride			0.94		
1,3-Butadiene			0.79		
Freon 11				0.82	
Dichloromethane					0.78
Chloroform		0.87			
1,2-Dichloroethane			0.91		
Benzene	0.74		0.55		
Carbon Tetrachloride		0.80			
Trichloroethylene		0.69			
1,2-Dichloropropane		0.58			
Toluene	0.86				
Tetrachloroethylene		0.81			
Ethylbenzene	0.82				
Total Xylene	0.95				
Styrene					-0.63
1-Ethyl-4-methylbenzene	0.82				
1,3,5-Trimethylbenzene	0.79				
1,2,4-Trimethylbenzene	0.90				
Initial Eigenvalues	5.70	3.21	2.57	1.59	1.13
Variance (%)	28.49	16.03	12.86	7.96	5.67
Cumulative variance (%)	28.49	44.52	57.38	65.34	71.01

The cumulative variance of Map Chalut Temple (MCLT) monitoring station was about 71.01%. PC1 explained about 28.49% of the total variance of the data, consisted of benzene, toluene, ethylbenzene, total xylene, 1-ethyl-4-methylbenzene,

1,2,4-trimethylbenzene and 1,3,5-trimethylbenzene. These compounds were signature of mobile source emission.

PC2 (16.03%) consists of chloroform, carbon tetrachloride, trichloroethylene, 1,2-dichloropropane and tetrachloroethylene. These compounds were chemical use in household.

PC3 (12.86%) consists of vinyl chloride, 1,3-butadiene, 1,2-dichloroethane and benzene. PC4 (7.96%) consists of freon 11, freon 12 and chloromethane and dichloromethane and styrene in PC5 (5.67%). VOCs in PC3 through PC5 were emitted from industrial process emission.

Table 4.25 Principal component analysis for VOCs of Ban Plong Community (BPLC) monitoring station in 2009-2012

VOCs	PC 1	PC 2	PC 3	PC 4	PC 5	PC 6
Freon 12			0.64			
Chloromethane			0.68			
Vinyl Chloride				0.92		
1,3-Butadiene					0.81	
Freon 11			0.77			
Dichloromethane					0.80	
Chloroform		0.87				
1,2-Dichloroethane				0.83		
Benzene						0.75
Carbon Tetrachloride		0.74				
Trichloroethylene		0.71				
1,2-Dichloropropane		0.73				
Toluene	0.50		0.51			
Tetrachloroethylene		0.81				
Ethylbenzene	0.72					
Total Xylene	0.85					
Styrene			0.68			
1-Ethyl-4-methylbenzene	0.87					
1,3,5-Trimethylbenzene	0.90					
1,2,4-Trimethylbenzene	0.88					
Initial Eigenvalues	6.02	2.50	2.25	1.79	1.25	1.20
Variance (%)	30.11	12.51	11.25	8.94	6.26	6.01
Cumulative variance (%)	30.11	42.62	53.87	62.81	69.07	75.08

The cumulative variance of Ban Plong Community (BPLC) monitoring station was about 75.08%. PC1 explained about 30.11% of the total variance of the data, consisted of toluene, ethylbenzene, total xylene, 1-ethyl-4-methylbenzene, 1,2,4-trimethylbenzene and 1,3,5-trimethylbenzene. These compounds were signature of mobile source emission.

PC2 (12.51%) consists of chloroform, carbon tetrachloride, trichloroethylene, 1,2-dichloropropane and tetrachloroethylene. These compounds were chemical use in household.

PC3 (11.25%) consists of freon 11, freon 12, chloromethane, toluene and styrene. PC4 (8.94%) consists of vinyl chloride and 1,2-dichloroethane and 1,3-butadiene and dichloromethane in PC5 (6.26%) were emitted from industrial process emission.

PC6 (6.01%) include benzene only. Therefore, benzene which affect to Ban Plong Community (BPLC) monitoring station, emitted from loading/unloading activities or storage tank.

Table 4.26 Principal component analysis for VOCs of Nop Pakate Village (NPKV) monitoring station in 2009-2012

VOCs	PC 1	PC 2	PC 3	PC 4	PC 5	PC 6
Freon 12			0.77			
Chloromethane			0.59			
Vinyl Chloride					0.84	
1,3-Butadiene	0.50				0.54	
Freon 11			0.70			
Dichloromethane						0.77
Chloroform		0.80				
1,2-Dichloroethane		0.59			0.64	
Benzene	0.74					
Carbon Tetrachloride		0.78				
Trichloroethylene				0.78		
1,2-Dichloropropane		0.75				
Toluene	0.61					
Tetrachloroethylene		0.74				
Ethylbenzene				0.65		
Total Xylene	0.71					
Styrene						0.78
1-Ethyl-4-methylbenzene	0.72					
1,3,5-Trimethylbenzene	0.86					
1,2,4-Trimethylbenzene	0.92					
Initial Eigenvalues	5.44	2.83	1.80	1.62	1.48	1.30
Variance (%)	27.20	14.13	9.00	8.08	7.40	6.52
Cumulative variance (%)	27.20	41.33	50.33	58.41	65.81	72.33

The cumulative variance of Nop Pakate Village (NPKV) monitoring station was about 72.33%. PC1 explained about 27.2% of the total variance of the data, consisted of 1,3-butadiene, benzene, toluene, total xylene, 1-ethyl-4-methylbenzene,

1,2,4-trimethylbenzene and 1,3,5-trimethylbenzene. These compounds were signature of mobile source emission.

PC2 (14.13%) consists of chloroform, 1,2-dichloroethane, carbon tetrachloride, 1,2-dichloropropane and tetrachloroethylene. These compounds were chemical use in household.

PC3 (9%) consists of freon 11, freon 12 and chloromethane. PC4 (8.08%) consists of trichloroethylene and ethylbenzene. PC5 (7.4%) consists of vinyl chloride, 1,3-butadiene and 1,2-dichloroethane and dichloromethane and styrene in PC6 (6.52%) were emitted from industrial process emission.

Table 4.27 Principal component analysis for VOCs of Dindaeng monitoring station in 2009-2012

VOCs	PC 1	PC 2	PC 3	PC 4	PC 5
Freon 12					
Chloromethane					0.76
Vinyl Chloride				0.80	
1,3-Butadiene					0.88
Freon 11				0.69	
Dichloromethane				0.74	
Chloroform		0.71			
1,2-Dichloroethane		0.88			
Benzene					0.62
Carbon Tetrachloride		0.79			
Trichloroethylene			0.68		
1,2-Dichloropropane		0.79			
Toluene			0.53		
Tetrachloroethylene			0.79		
Ethylbenzene	0.82				
Total Xylene	0.87				
Styrene			0.63		
1-Ethyl-4-methylbenzene	0.91				
1,3,5-Trimethylbenzene	0.88				
1,2,4-Trimethylbenzene	0.93				
Initial Eigenvalues	7.00	3.10	1.90	1.54	1.31
Variance (%)	35.00	15.52	9.48	7.68	6.54
Cumulative variance (%)	35.00	50.52	60.00	67.68	74.22

The cumulative variance of Dindaeng monitoring station was about 74.22%. PC1 explained about 35% of the total variance of the data, consisted of ethylbenzene, total xylene, 1-ethyl-4-methylbenzene, 1,2,4-trimethylbenzene and 1,3,5-trimethylbenzene and PC5 (6.54%) consists of chloromethane, 1,3-butadiene and benzene. These compounds were signature of mobile source emission.

PC2 (15.52%) was composed of chloroform, 1,2-dichloroethane, carbon tetrachloride and 1,2-dichloropropane and trichloroethylene, toluene, tetrachloroethylene and styrene in PC3 (9.48%). These compounds were chemical use in household.

Since there are no petrochemical industries in Bangkok, vinyl chloride emerging in Bangkok area is expected to come from a degradation product of trichloroethylene and tetrachloroethylene. Therefore, vinyl chloride, freon 11 and dichloromethane in PC4 (7.68%) were identified as background concentration in ambient air.

CHAPTER V

CONCLUSIONS

The forty-two VOCs concentrations were measured on a monthly basis from January 2009 to December 2012 in Bangkok (Dindaeng) and seven monitoring stations in the vicinity of Maptaphut industrial complex, located in the Eastern region of Thailand. The contribution of aromatics to total VOCs was greater than other chemical groups for all monitoring sites. VOCs concentration of Dindaeng was about 1.32-1.70 times higher than those in Maptaphut area. VOCs ambient concentrations data were analyzed by using VOCs to benzene (VOCs/Bz) ratios, BTEX ratios and principal component analysis (PCA) to identify sources of VOCs. The result of this study was summarized as follows.

5.1 Diagnostic ratio

5.1.1 VOCs against benzene (VOCs/Bz) ratios

By using VOCs/Bz ratios, results of the calculation can be categorized into three groups. The first group mainly emitted from non-mobile sources such as household and industrial activity. Second group mainly discharged from mobile sources and the third group was emitted from both stationary sources and mobile sources. Thus, emission sources of VOCs that affect to each monitoring station in Maptaphut area was summarized in Table 5.1-5.7.

Table 5.1 Emission sources of VOCs that affect to Health Promotion Hospital Maptaphut (HMTP) monitoring station

Emission sources	Compounds
Other sources (Non-mobile sources; 16-25%)	Freon 11, freon 12, freon 113, freon 114, chloromethane, vinyl chloride, bromomethane, chloroethane, 1,1-dichloroethylene, acrylonitrile, 3-chloropropene, 1,1-dichloroethane, 1,2-dichloroethane, 1,1,1-trichloroethane, carbon tetrachloride, 1,2-dichloropropane, hexachloro-1,3-butadiene, 1,2,4-trichlorobenzene, 1,2-dichlorobenzene, 1,3-dichlorobenzene, benzyl chloride, 1,1,2,2-tetrachloroethane, cis-1,2-dichloroethylene, chlorobenzene, 1,2-dibromoethane, cis-1,3-dichloropropene, 1,1,2-trichloroethane, trans-1,3-dichloropropene
Mobile sources (60-74%)	1,2,4-Trimethylbenzene, ethylbenzene, total xylene, toluene
Stationary sources and mobile sources (9-15%)	1,3-Butadiene, dichloromethane, styrene, chloroform, trichloroethylene, 1,4-dichlorobenzene, 1,3,5-trimethylbenzene, 1-ethyl-4-methylbenzene, tetrachloroethylene

Table 5.2 Emission sources of VOCs that affect to Ban Ta Kuan Public Health Center (BTKH) monitoring station

Emission sources	Compounds
Other sources (Non-mobile sources; 18-25%)	Freon 11, freon 12, freon 113, freon 114, chloromethane, vinyl chloride, bromomethane, chloroethane, 1,1-dichloroethylene, acrylonitrile, 3-chloropropene, 1,1-dichloroethane, 1,2-dichloroethane, 1,1,1-trichloroethane, carbon tetrachloride, 1,2-dichloropropane, hexachloro-1,3-butadiene, 1,2,4-trichlorobenzene, 1,2-dichlorobenzene, 1,3-dichlorobenzene, benzyl chloride, 1,1,2,2-tetrachloroethane, cis-1,2-dichloroethylene, chlorobenzene, 1,2-dibromoethane, cis-1,3,-dichloropropene, 1,1,2-trichloroethane, trans-1,3-dichloropropene
Mobile sources (65-69%)	1,2,4-Trimethylbenzene, ethylbenzene, total xylene, toluene
Stationary sources and mobile sources (10-15%)	1,3-Butadiene, dichloromethane, styrene, chloroform, trichloroethylene, 1,4-dichlorobenzene, 1,3,5-trimethylbenzene, 1-ethyl-4-methylbenzene, tetrachloroethylene

Table 5.3 Emission sources of VOCs that affect to Wat Nong Fap School (WNFS) monitoring station

Emission sources	Compounds
Other sources (Non- mobile sources; 26-43%)	Freon 11, freon 12, freon 113, freon 114, chloromethane, vinyl chloride, bromomethane, chloroethane, 1,1-dichloroethylene, acrylonitrile, 3-chloropropene, 1,1-dichloroethane, 1,2-dichloroethane, chloroform, 1,1,1-trichloroethane, carbon tetrachloride, 1,2-dichloropropane, hexachloro-1,3-butadiene, 1,2,4-trichlorobenzene, 1,2-dichlorobenzene, 1,3-dichlorobenzene, benzyl chloride, 1,1,2,2-tetrachloroethane, cis-1,2-dichloroethylene, chlorobenzene, 1,2-dibromoethane, tetrachloroethylene, cis-1,3,-dichloropropene, 1,1,2-trichloroethane, trans-1,3-dichloropropene
Mobile sources (29-44%)	1,2,4-Trimethylbenzene, toluene
Stationary sources and mobile sources (26-30%)	1,3-Butadiene, dichloromethane, styrene, trichloroethylene, 1,4-dichlorobenzene, 1,3,5-trimethylbenzene, 1-ethyl-4-methylbenzene, total xylene, ethylbenzene

Table 5.4 Emission sources of VOCs that affect to Muang Mai Maptaphut (MMTP) monitoring station

Emission sources	Compounds
Other sources (Non-mobile sources; 20-30%)	Freon 11, freon 12, freon 113, freon 114, chloromethane, vinyl chloride, bromomethane, chloroethane, 1,1-dichloroethylene, acrylonitrile, 3-chloropropene, 1,1-dichloroethane, 1,2-dichloroethane, 1,1,1-trichloroethane, carbon tetrachloride, 1,2-dichloropropane, hexachloro-1,3-butadiene, 1,2,4-trichlorobenzene, 1,2-dichlorobenzene, 1,3-dichlorobenzene, benzyl chloride, 1,1,2,2-tetrachloroethane, cis-1,2-dichloroethylene, chlorobenzene, 1,2-dibromoethane, cis-1,3,-dichloropropene, 1,1,2-trichloroethane, trans-1,3-dichloropropene
Mobile sources (54-65%)	1,2,4-Trimethylbenzene, total xylene, toluene
Stationary sources and mobile sources (12-16%)	1,3-Butadiene, dichloromethane, styrene, chloroform, trichloroethylene, 1,4-dichlorobenzene, 1,3,5-trimethylbenzene, 1-ethyl-4-methylbenzene, ethylbenzene, tetrachloroethylene

Table 5.5 Emission sources of VOCs that affect to Map Chalut Temple (MCLT) monitoring station

Emission sources	Compounds
Other sources (Non-mobile sources; 27-35%)	Freon 11, freon 12, freon 113, freon 114, chloromethane, vinyl chloride, bromomethane, chloroethane, 1,1-dichloroethylene, acrylonitrile, 3-chloropropene, 1,1-dichloroethane, 1,2-dichloroethane, chloroform, 1,1,1-trichloroethane, carbon tetrachloride, trichloroethylene, 1,2-dichloropropane, hexachloro-1,3-butadiene, 1,2,4-trichlorobenzene, 1,2-dichlorobenzene, 1,3-dichlorobenzene, benzyl chloride, 1,1,2,2-tetrachloroethane, cis-1,2-dichloroethylene, chlorobenzene, 1,2-dibromoethane, cis-1,3,-dichloropropene, 1,1,2-trichloroethane, trans-1,3-dichloropropene
Mobile sources (35-44%)	1,2,4-Trimethylbenzene, toluene
Stationary sources and mobile sources (29-31%)	1,3-Butadiene, dichloromethane, styrene, 1,4-dichlorobenzene, 1,3,5-trimethylbenzene, 1-ethyl-4-methylbenzene, ethylbenzene, total xylene, tetrachloroethylene

Table 5.6 Emission sources of VOCs that affect to Ban Plong Community (BPLC) monitoring station

Emission sources	Compounds
Other sources (Non-mobile sources; 8-16%)	Freon 11, freon 12, freon 113, freon 114, vinyl chloride, bromomethane, chloroethane, 1,1-dichloroethylene, acrylonitrile, 3-chloropropene, 1,2-dichloroethane, 1,1,1-trichloroethane, 1,2,4-trichlorobenzene, 1,2-dichlorobenzene, 1,3-dichlorobenzene, benzyl chloride, 1,1,2,2-tetrachloroethane, 1,2-dibromoethane, 1,1,2-trichloroethane, trans-1,3-dichloropropene
Mobile sources (10-19%)	1,2,4-Trimethylbenzene, total xylene
Stationary sources and mobile sources (70-81%)	Chloromethane, 1,3-butadiene, dichloromethane, 1,1-dichloroethane, styrene, chloroform, carbon tetrachloride, trichloroethylene, 1,2-dichloropropane, hexachloro-1,3-butadiene, 1,4-dichlorobenzene, cis-1,2-dichloroethylene, 1,3,5-trimethylbenzene, 1-ethyl-4-methylbenzene, ethylbenzene, chlorobenzene, tetrachloroethylene, cis-1,3,-dichloropropene, toluene

Table 5.7 Emission sources of VOCs that affect to Nop Pakate Village (NPKV) monitoring station

Emission sources	Compounds
Other sources (Non-mobile sources; 25-67)	Freon 11, freon 12, freon 113, freon 114, chloromethane, vinyl chloride, bromomethane, chloroethane, 1,1-dichloroethylene, acrylonitrile, 3-chloropropene, dichloromethane, 1,1-dichloroethane, 1,2-dichloroethane, 1,1,1-trichloroethane, carbon tetrachloride, hexachloro-1,3-butadiene, 1,2,4-trichlorobenzene, 1,2-dichlorobenzene, 1,3-dichlorobenzene, benzyl chloride, 1,1,2,2-tetrachloroethane, cis-1,2-dichloroethylene, chlorobenzene, 1,2-dibromoethane, cis-1,3,-dichloropropene, 1,1,2-trichloroethane, trans-1,3-dichloropropene
Mobile sources (19-42%)	1,2,4-Trimethylbenzene, toluene
Stationary sources and mobile sources (14-33%)	1,3-Butadiene, styrene, chloroform, trichloroethylene, 1,2-dichloropropane, 1,4-dichlorobenzene, 1,3,5-trimethylbenzene, 1-ethyl-4-methylbenzene, total xylene, ethylbenzene, tetrachloroethylene

5.1.2 BTEX concentration ratios

Calculated result of ratio of benzene, toluene and o,m,p-xylene to ethylbenzene were summarized as follows:

Benzene to ethylbenzene ratio of Ban Plong Community (BPLC) monitoring station in 2011 and 2012 were significantly higher than Dindaeng monitoring station.

Toluene to ethylbenzene ratio of Wat Nong Fab School (WNFS) monitoring station in 2012 and Map Chalut Temple (MCLT) station in 2009 to 2012 were lower than Dindaeng station. Moreover, toluene to ethylbenzene ratio of Ban

Plong Community (BPLC) station in 2010 and 2012 were higher than Dindaeng station.

This difference indicated that emission source of VOCs found at these sites might be originated from other sources rather than mobile source emission.

Total xylene to ethylbenzene ratio of all monitoring sites were resemble with Dindaeng station.

In summary, the results of BTEX concentration ratios showed that dominant emission source of VOCs in Maptaphut area was mobile source.

5.2 Source apportionment by using principal component analysis

Ambient concentrations of twenty VOCs from seven monitoring sites in Maptaphut area and Dindaeng in 2009-2012 were analyzed using principal component analysis.

Result of PCA analysis at Health Promotion Hospital Maptaphut (HMTP) monitoring station, suggested that VOCs can be classified into three groups based on emission sources as summarized in Table 5.8.

Table 5.8 Emission sources of Health Promotion Hospital Maptaphut (HMTP) monitoring station by principal component analysis

Emission sources	Compounds
Mobile sources	Benzene, toluene, ethylbenzene, total xylene, 1-ethyl-4-methylbenzene, 1,2,4-trimethylbenzene, 1,3,5-trimethylbenzene
Household (Chemical use)	Chloroform, carbon tetrachloride, trichloroethylene, 1,2-dichloropropane, tetrachloroethylene
Industrial process	Freon 11, freon 12, chloromethane, dichloromethane, toluene, vinyl chloride, 1,2-dichloroethane, 1,3-butadiene, styrene

Result of PCA analysis at Ban Ta Kuan Public Health Center (BTKH) monitoring station, suggested that VOCs can be classified into four groups based on emission sources as summarized in Table 5.9.

Table 5.9 Emission sources of Ban Ta Kuan Public Health Center (BTKH) monitoring station by principal component analysis

Emission sources	Compounds
Mobile sources	Benzene, toluene, ethylbenzene, total xylene, styrene, 1-ethyl-4-methylbenzene, 1,2,4-trimethylbenzene, 1,3,5-trimethylbenzene
Household (Chemical use)	Chloroform, carbon tetrachloride, trichloroethylene, 1,2-dichloropropane, tetrachloroethylene
Industrial process	Vinyl chloride, 1,2-dichloroethane, chloromethane, dichloromethane
Background concentration in ambient air	Freon 11, freon 12

Result of PCA analysis at Wat Nong Fap School (WNFS) monitoring station, suggested that VOCs can be classified into four groups based on emission sources as summarized in Table 5.10.

Table 5.10 Emission sources of Wat Nong Fap School (WNFS) monitoring station by principal component analysis

Emission sources	Compounds
Mobile sources	Benzene, toluene, ethylbenzene, total xylene, 1-ethyl-4-methylbenzene, 1,2,4-trimethylbenzene, 1,3,5-trimethylbenzene
Industrial process	Vinyl chloride, dichloromethane, 1,2-dichloroethane, trichloroethylene, chloroform, 1,2-dichloropropane, freon 11, freon 12, styrene
Household (Chemical use)	Carbon tetrachloride, tetrachloroethylene
Loading/unloading activities or storage tank	Chloromethane

Result of PCA analysis at Muang Mai Maptaphut (MMTP) monitoring station, suggested that VOCs can be classified into five groups based on emission sources as summarized in Table 5.11.

Table 5.11 Emission sources of Muang Mai Maptaphut (MMTP) monitoring station by principal component analysis

Emission sources	Compounds
Mobile sources	Chloromethane, benzene, ethylbenzene, total xylene, 1-ethyl-4-methylbenzene, 1,2,4-trimethylbenzene, 1,3,5-trimethylbenzene
Household (Chemical use)	Chloroform, carbon tetrachloride, trichloroethylene, tetrachloroethylene
Industrial process	Vinyl chloride, 1,3-butadiene, 1,2-dichloroethane, dichloromethane, toluene, ethylbenzene
Background concentration in ambient air	Freon 11, freon 12
Loading/unloading activities or storage tank	Styrene

Result of PCA analysis at Map Chalut Temple (MCLT) monitoring station, suggested that VOCs can be classified into three groups based on emission sources as summarized in Table 5.12.

Table 5.12 Emission sources of Map Chalut Temple (MCLT) monitoring station by principal component analysis

Emission sources	Compounds
Mobile sources	Benzene, toluene, ethylbenzene, total xylene, 1-ethyl-4-methylbenzene, 1,2,4-trimethylbenzene, 1,3,5-trimethylbenzene
Household (Chemical use)	Chloroform, carbon tetrachloride, trichloroethylene, 1,2-dichloropropane, tetrachloroethylene
Industrial process	Vinyl chloride, 1,3-butadiene, 1,2-dichloroethane, benzene, freon 11, freon 12, chloromethane, dichloromethane, styrene

Result of PCA analysis at of Ban Plong Community (BPLC) monitoring station, suggested that VOCs can be classified into four groups based on emission sources as summarized in Table 5.13.

Table 5.13 Emission sources of Ban Plong Community (BPLC) monitoring station by principal component analysis

Emission sources	Compounds
Mobile sources	Toluene, ethylbenzene, total xylene, 1-ethyl-4-methylbenzene, 1,2,4-trimethylbenzene, 1,3,5-trimethylbenzene
Household (Chemical use)	Chloroform, carbon tetrachloride, trichloroethylene, 1,2-dichloropropane, tetrachloroethylene
Industrial process	Freon 11, freon 12, chloromethane, toluene, styrene, vinyl chloride, 1,2-dichloroethane, 1,3-butadiene, dichloromethane
Loading/unloading activities or storage tank	Benzene

Result of PCA analysis at of Nop Pakate Village (NPKV) monitoring station, suggested that VOCs can be classified into four groups based on emission sources as summarized in Table 5.14.

Table 5.14 Emission sources of Nop Pakate Village (NPKV) monitoring station by principal component analysis

Emission sources	Compounds
Mobile sources	1,3-Butadiene, benzene, toluene, total xylene, 1-ethyl-4-methylbenzene, 1,2,4-trimethylbenzene, 1,3,5-trimethylbenzene
Household (Chemical use)	Chloroform, 1,2-dichloroethane, carbon tetrachloride, 1,2-dichloropropane, tetrachloroethylene
Industrial process	Freon 11, freon 12, chloromethane, trichloroethylene, ethylbenzene, vinyl chloride, 1,3-butadiene, 1,2-dichloroethane, dichloromethane, styrene

Result of PCA analysis at of Dindaeng monitoring station, suggested that VOCs can be classified into three groups based on emission sources as summarized in Table 5.15.

Table 5.15 Emission sources of Dindaeng monitoring station by principal component analysis

Emission sources	Compounds
Mobile sources	Ethylbenzene, total xylene, 1-ethyl-4-methylbenzene, 1,2,4-trimethylbenzene, 1,3,5-trimethylbenzene, chloromethane, 1,3-butadiene, benzene
Household (Chemical use)	Chloroform, 1,2-dichloroethane, carbon tetrachloride, 1,2-dichloropropane, trichloroethylene, toluene, tetrachloroethylene, styrene
Background concentration in ambient air	Vinyl chloride, freon 11, dichloromethane

The summary of emission sources of VOCs which affect to each monitoring station in Maptaphut area and Dindaeng monitoring station by principle component analysis was as shown in Table 5.16.

Table 5.16 Summary of emission sources of all monitoring stations by principal component analysis

Emission sources/Stations	HMTP	BTKH	WNFS	MMTP	MCLT	BPLC	NPKV	Dindaeng
Mobile sources	✓	✓	✓	✓	✓	✓	✓	✓
Households (Chemical uses)	✓	✓	✓	✓	✓	✓	✓	✓
Industrial processes	✓	✓	✓	✓	✓	✓	✓	-
Background concentration in ambient air	-	✓	-	✓	-	-	-	✓
Loading/ unloading activities or storage tanks	-	-	✓	✓	-	✓	-	-

5.3 Recommendation

The results of this study suggested that VOCs in Maptaphut area were mainly emitted from mobile sources. Therefore, management of VOCs pollution in this area should be focused on reducing the emission from mobile sources. However, there were some VOCs compounds which were mainly emitted from industrial sources. Therefore, effort in controlling for both mobile and industrial emission sources should be implemented together for combating VOCs problem in Maptaphut area.

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APPENDIX

APPENDIX A

SUMMARY OF VOCs CONCENTRATION

Table A-1 Summary of VOCs concentration ($\mu\text{g}/\text{m}^3$) at Health Promotion Hospital Maptaphut (HMTP) monitoring station in 2009-2012 (BDL : Below detection limit)

Compounds	Mean	Min	Max	SD	BDL (%)	No data (%)
Freon 12	2.44	1.50	5.90	1.06	0.00	25.00
Freon 114	0.29	0.04	0.68	0.24	4.17	83.33
Chloromethane	1.12	0.43	2.50	0.45	4.17	4.17
Vinyl chloride	0.43	0.09	1.70	0.40	54.17	0.00
1,3-Butadiene	0.77	0.07	2.90	0.71	47.92	0.00
Bromomethane	0.49	0.10	1.80	0.51	62.50	0.00
Chloroethane	0.12	0.06	0.17	0.05	89.58	0.00
Freon 11	0.96	0.36	1.50	0.27	0.00	0.00
1,1-Dichloroethylene	0.00	0.00	0.00	0.00	100.00	0.00
Freon 113	0.49	0.18	1.10	0.27	47.92	10.42
Acrylonitrile	0.48	0.39	0.60	0.09	87.50	0.00
3-Chloropropene	0.00	0.00	0.00	0.00	95.83	4.17
Dichloromethane	1.01	0.11	3.70	1.03	25.00	0.00
1,1-Dichloroethane	0.00	0.00	0.00	0.00	95.83	4.17
cis-1,2-Dichloroethylene	0.00	0.00	0.00	0.00	97.92	2.08
Chloroform	0.29	0.11	0.50	0.16	0.00	0.00
1,1,1-Trichloroethane	0.55	0.13	0.90	0.31	0.00	0.00
1,2-Dichloroethane	0.73	0.07	3.60	0.81	0.00	0.00
Benzene	3.06	0.91	6.70	1.50	0.00	0.00
Carbon Tetrachloride	0.55	0.17	1.50	0.28	0.00	0.00
Trichloroethylene	0.48	0.15	1.10	0.28	0.00	0.00
1,2-Dichloropropane	0.33	0.07	0.80	0.27	0.00	0.00
cis-1,3-Dichloropropene	0.00	0.00	0.00	0.00	95.83	4.17
Toluene	14.86	3.00	120.00	17.85	0.00	0.00
trans-1,3-Dichloropropene	0.00	0.00	0.00	0.00	0.00	0.00
1,1,2-Trichloroethane	0.33	0.12	0.53	0.29	95.83	0.00
Tetrachloroethylene	0.40	0.08	0.66	0.24	77.08	0.00
1,2-Dibromoethane	0.22	0.22	0.22	0.00	91.67	6.25
Chlorobenzene	0.29	0.05	0.65	0.21	70.83	2.08
Ethylbenzene	1.44	0.30	5.10	1.14	0.00	10.42
Total Xylene	4.28	0.00	11.50	2.33	0.00	0.00
Styrene	0.65	0.13	2.00	0.45	12.50	6.25
1,1,2,2-Tetrachloroethane	0.00	0.00	0.00	0.00	93.75	6.25
1-Ethyl-4-methylbenzene	0.83	0.11	2.20	0.50	2.08	14.58
1,3,5-Trimethylbenzene	0.60	0.17	1.40	0.32	12.50	18.75
1,2,4-Trimethylbenzene	2.01	0.40	4.30	0.94	0.00	16.67

Table A-1 Summary of VOCs concentration ($\mu\text{g}/\text{m}^3$) at Health Promotion Hospital Maptaphut (HMTP) monitoring station in 2009-2012 (BDL : Below detection limit) (cont.)

Compounds	Mean	Min	Max	SD	BDL (%)	No data (%)
1,3-Dichlorobenzene	0.64	0.24	0.82	0.27	75.00	16.67
Benzyl Chloride	1.80	1.80	1.80	0.00	87.50	10.42
1,4-Dichlorobenzene	0.63	0.15	1.40	0.39	66.67	8.33
1,2-Dichlorobenzene	0.63	0.53	0.75	0.11	79.17	14.58
1,2,4-Trichlorobenzene	0.73	0.05	1.40	0.95	50.00	45.83
Hexachloro-1,3-butadiene	0.00	0.00	0.00	0.00	60.42	39.58

Table A-2 Summary of VOCs concentration ($\mu\text{g}/\text{m}^3$) at Ban Ta Kuan Public Health Center (BTKH) monitoring station in 2009-2012 (BDL : Below detection limit)

Compounds	Mean	Min	Max	SD	BDL (%)	No data (%)
Freon 12	2.61	1.40	12.00	1.95	0.00	25.00
Freon 114	0.32	0.05	0.72	0.24	81.25	4.17
Chloromethane	1.27	0.25	5.60	0.83	4.17	4.17
Vinyl chloride	0.43	0.07	1.60	0.47	70.83	0.00
1,3-Butadiene	1.56	0.11	10.00	2.27	50.00	0.00
Bromomethane	0.25	0.10	0.52	0.14	77.08	0.00
Chloroethane	0.14	0.06	0.28	0.08	85.42	0.00
Freon 11	0.93	0.25	1.40	0.29	0.00	0.00
1,1-Dichloroethylene	0.00	0.00	0.00	0.00	97.92	2.08
Freon 113	0.55	0.23	1.10	0.27	52.08	8.33
Acrylonitrile	0.70	0.17	1.80	0.46	62.50	0.00
3-Chloropropene	0.00	0.00	0.00	0.00	95.83	4.17
Dichloromethane	0.87	0.10	2.50	0.75	25.00	0.00
1,1-Dichloroethane	0.00	0.00	0.00	0.00	95.83	4.17
cis-1,2-Dichloroethylene	0.00	0.00	0.00	0.00	97.92	2.08
Chloroform	0.31	0.08	0.57	0.19	72.92	0.00
1,1,1-Trichloroethane	0.60	0.12	0.98	0.33	83.33	4.17
1,2-Dichloroethane	0.60	0.09	2.00	0.48	43.75	2.08
Benzene	3.04	0.53	20.00	2.88	0.00	0.00
Carbon Tetrachloride	0.59	0.16	1.70	0.34	18.75	6.25
Trichloroethylene	0.45	0.10	0.72	0.24	77.08	0.00
1,2-Dichloropropane	0.27	0.06	0.87	0.28	85.42	0.00
cis-1,3-Dichloropropene	0.00	0.00	0.00	0.00	95.83	4.17
Toluene	12.89	0.59	88.00	16.77	0.00	0.00
trans-1,3-Dichloropropene	0.00	0.00	0.00	0.00	91.67	8.33
1,1,2-Trichloroethane	0.59	0.59	0.59	0.00	97.92	0.00
Tetrachloroethylene	0.46	0.07	0.86	0.29	79.17	0.00
1,2-Dibromoethane	0.92	0.92	0.92	0.00	91.67	6.25
Chlorobenzene	0.67	0.06	1.70	0.47	68.75	2.08

Table A-2 Summary of VOCs concentration ($\mu\text{g}/\text{m}^3$) at Ban Ta Kuan Public Health Center (BTKH) monitoring station in 2009-2012 (BDL : Below detection limit) (cont.)

Compounds	Mean	Min	Max	SD	BDL (%)	No data (%)
Ethylbenzene	1.68	0.13	10.00	2.11	0.00	10.42
Total Xylene	4.47	0.26	36.00	5.29	0.00	2.08
Styrene	1.06	0.06	8.10	1.47	16.67	8.33
1,1,2,2-Tetrachloroethane	0.26	0.26	0.26	0.00	91.67	6.25
1-Ethyl-4-methylbenzene	0.97	0.13	7.80	1.25	6.25	16.67
1,3,5-Trimethylbenzene	0.81	0.20	5.60	0.96	18.75	16.67
1,2,4-Trimethylbenzene	2.27	0.16	19.00	2.94	0.00	14.58
1,3-Dichlorobenzene	0.57	0.36	0.73	0.19	75.00	14.58
Benzyl Chloride	0.00	0.00	0.00	0.00	89.58	10.42
1,4-Dichlorobenzene	0.66	0.14	1.30	0.38	68.75	6.25
1,2-Dichlorobenzene	0.69	0.43	1.10	0.26	75.00	14.58
1,2,4-Trichlorobenzene	0.41	0.41	0.41	0.00	50.00	47.92
Hexachloro-1,3-butadiene	0.00	0.00	0.00	0.00	60.42	39.58

Table A-3 Summary of VOCs concentration ($\mu\text{g}/\text{m}^3$) at Wat Nong Fap School (WNFS) monitoring station 2009-2012 (BDL : Below detection limit)

Compounds	Mean	Min	Max	SD	BDL (%)	No data (%)
Freon 12	2.55	1.50	5.50	1.01	2.08	25.00
Freon 114	0.38	0.06	0.72	0.26	81.25	4.17
Chloromethane	1.69	0.37	6.70	1.44	6.25	4.17
Vinyl chloride	0.25	0.07	0.68	0.20	68.75	0.00
1,3-Butadiene	0.37	0.09	0.84	0.27	75.00	0.00
Bromomethane	0.32	0.13	0.63	0.17	72.92	0.00
Chloroethane	0.13	0.06	0.20	0.06	91.67	0.00
Freon 11	1.02	0.43	2.50	0.34	0.00	0.00
1,1-Dichloroethylene	0.00	0.00	0.00	0.00	97.92	2.08
Freon 113	0.52	0.17	1.10	0.29	41.67	8.33
Acrylonitrile	1.01	0.24	2.20	0.78	85.42	0.00
3-Chloropropene	2.84	0.34	5.70	2.07	83.33	4.17
Dichloromethane	0.71	0.10	2.10	0.50	35.42	0.00
1,1-Dichloroethane	0.00	0.00	0.00	0.00	95.83	4.17
cis-1,2-Dichloroethylene	0.11	0.11	0.11	0.00	97.92	0.00
Chloroform	0.83	0.12	3.90	1.08	58.33	0.00
1,1,1-Trichloroethane	0.52	0.04	0.93	0.36	83.33	4.17
1,2-Dichloroethane	0.47	0.11	1.20	0.30	45.83	2.08
Benzene	1.92	0.12	11.00	1.82	0.00	0.00
Carbon Tetrachloride	0.59	0.19	1.60	0.32	16.67	6.25
Trichloroethylene	0.42	0.12	1.10	0.28	72.92	0.00
1,2-Dichloropropane	0.73	0.09	3.60	0.91	68.75	0.00
cis-1,3-Dichloropropene	0.43	0.03	0.90	0.35	83.33	4.17
Toluene	7.70	0.47	73.00	11.08	0.00	0.00

Table A-3 Summary of VOCs concentration ($\mu\text{g}/\text{m}^3$) at Wat Nong Fap School (WNFS) monitoring station 2009-2012 (BDL : Below detection limit) (cont.)

Compounds	Mean	Min	Max	SD	BDL (%)	No data (%)
trans-1,3-Dichloropropene	0.87	0.20	1.20	0.58	87.50	6.25
1,1,2-Trichloroethane	0.33	0.10	0.55	0.32	95.83	0.00
Tetrachloroethylene	0.42	0.07	0.71	0.24	75.00	0.00
1,2-Dibromoethane	0.65	0.54	0.75	0.15	89.58	6.25
Chlorobenzene	0.35	0.05	0.62	0.20	77.08	2.08
Ethylbenzene	1.43	0.13	8.90	1.65	2.08	10.42
Total Xylene	3.34	0.22	22.90	3.66	2.08	2.08
Styrene	0.55	0.10	1.10	0.31	22.92	6.25
1,1,2,2-Tetrachloroethane	0.39	0.39	0.39	0.00	91.67	6.25
1-Ethyl-4-methylbenzene	0.71	0.12	2.50	0.52	18.75	14.58
1,3,5-Trimethylbenzene	0.57	0.16	1.10	0.29	29.17	18.75
1,2,4-Trimethylbenzene	1.18	0.24	4.20	0.85	6.25	18.75
1,3-Dichlorobenzene	0.60	0.34	0.83	0.22	79.17	12.50
Benzyl Chloride	2.00	2.00	2.00	0.00	87.50	10.42
1,4-Dichlorobenzene	0.74	0.17	1.30	0.33	72.92	6.25
1,2-Dichlorobenzene	0.51	0.26	0.79	0.27	81.25	12.50
1,2,4-Trichlorobenzene	1.60	1.60	1.60	0.00	52.08	45.83
Hexachloro-1,3-butadiene	0.00	0.00	0.00	0.00	60.42	39.58

Table A-4 Summary of VOCs concentration ($\mu\text{g}/\text{m}^3$) at Muang Mai Maptaphut (MMTP) monitoring station 2009-2012 (BDL : Below detection limit)

Compounds	Mean	Min	Max	SD	BDL (%)	No data (%)
Freon 12	2.84	0.58	17.00	2.80	0.00	25.00
Freon 114	0.30	0.04	0.75	0.26	83.33	4.17
Chloromethane	1.21	0.27	3.60	0.60	4.17	4.17
Vinyl chloride	1.29	0.09	6.60	1.58	27.08	0.00
1,3-Butadiene	0.61	0.14	1.70	0.37	47.92	0.00
Bromomethane	0.42	0.10	3.30	0.67	54.17	0.00
Chloroethane	0.14	0.09	0.20	0.05	89.58	0.00
Freon 11	1.07	0.42	2.00	0.31	2.08	0.00
1,1-Dichloroethylene	0.00	0.00	0.00	0.00	97.92	2.08
Freon 113	0.54	0.16	1.20	0.26	47.92	8.33
Acrylonitrile	0.36	0.10	0.55	0.17	83.33	0.00
3-Chloropropene	0.00	0.00	0.00	0.00	95.83	4.17
Dichloromethane	1.25	0.16	6.20	1.23	16.67	0.00
1,1-Dichloroethane	0.00	0.00	0.00	0.00	95.83	4.17
cis-1,2-Dichloroethylene	0.39	0.39	0.39	0.00	95.83	2.08
Chloroform	0.34	0.10	0.57	0.17	64.58	0.00
1,1,1-Trichloroethane	0.53	0.13	0.85	0.30	81.25	4.17
1,2-Dichloroethane	1.52	0.10	7.60	1.84	18.75	2.08
Benzene	2.85	0.52	12.00	1.98	0.00	0.00

Table A-4 Summary of VOCs concentration ($\mu\text{g}/\text{m}^3$) at Muang Mai Maptaphut (MMTP) monitoring station 2009-2012 (BDL : Below detection limit) (cont.)

Compounds	Mean	Min	Max	SD	BDL (%)	No data (%)
Carbon Tetrachloride	0.61	0.16	1.40	0.31	18.75	6.25
Trichloroethylene	0.49	0.12	1.20	0.28	64.58	0.00
1,2-Dichloropropane	0.31	0.15	0.81	0.24	85.42	0.00
cis-1,3-Dichloropropene	0.57	0.36	0.77	0.29	91.67	4.17
Toluene	14.65	1.40	74.00	15.78	0.00	0.00
trans-1,3-Dichloropropene	0.00	0.00	0.00	0.00	93.75	6.25
1,1,2-Trichloroethane	0.51	0.51	0.51	0.00	97.92	0.00
Tetrachloroethylene	0.39	0.07	0.73	0.26	75.00	0.00
1,2-Dibromoethane	0.51	0.51	0.51	0.00	91.67	6.25
Chlorobenzene	0.32	0.04	0.66	0.21	70.83	2.08
Ethylbenzene	1.39	0.20	5.00	1.15	0.00	10.42
Total Xylene	3.42	0.35	19.10	2.92	0.00	2.08
Styrene	0.55	0.10	1.40	0.32	10.42	8.33
1,1,2,2-Tetrachloroethane	1.20	1.20	1.20	0.00	91.67	6.25
1-Ethyl-4-methylbenzene	0.64	0.11	1.70	0.43	12.50	16.67
1,3,5-Trimethylbenzene	0.59	0.15	1.20	0.31	27.08	16.67
1,2,4-Trimethylbenzene	1.25	0.24	5.30	0.92	4.17	14.58
1,3-Dichlorobenzene	0.55	0.28	0.85	0.24	72.92	14.58
Benzyl Chloride	0.00	0.00	0.00	0.00	89.58	10.42
1,4-Dichlorobenzene	0.66	0.11	1.50	0.40	68.75	6.25
1,2-Dichlorobenzene	0.55	0.31	0.75	0.19	75.00	14.58
1,2,4-Trichlorobenzene	0.00	0.00	0.00	0.00	52.08	47.92
Hexachloro-1,3-butadiene	0.00	0.00	0.00	0.00	60.42	39.58

Table A-5 Summary of VOCs concentration ($\mu\text{g}/\text{m}^3$) at Map Chalut Temple (MCLT) monitoring station 2009-2012 (BDL : Below detection limit)

Compounds	Mean	Min	Max	SD	BDL (%)	No data (%)
Freon 12	2.68	1.60	9.70	1.59	0.00	25.00
Freon 114	0.35	0.04	0.73	0.26	79.17	4.17
Chloromethane	1.19	0.36	2.90	0.50	6.25	4.17
Vinyl chloride	0.54	0.08	4.20	0.95	62.50	0.00
1,3-Butadiene	0.55	0.03	2.70	0.86	66.67	0.00
Bromomethane	0.26	0.09	0.55	0.16	77.08	0.00
Chloroethane	0.11	0.09	0.15	0.03	93.75	0.00
Freon 11	0.97	0.14	1.70	0.30	0.00	0.00
1,1-Dichloroethylene	0.00	0.00	0.00	0.00	97.92	2.08
Freon 113	0.58	0.24	1.20	0.32	52.08	8.33
Acrylonitrile	0.47	0.14	1.10	0.27	79.17	0.00
3-Chloropropene	0.73	0.22	1.40	0.61	91.67	2.08
Dichloromethane	0.88	0.10	4.40	0.78	29.17	0.00
1,1-Dichloroethane	0.00	0.00	0.00	0.00	95.83	4.17

Table A-5 Summary of VOCs concentration ($\mu\text{g}/\text{m}^3$) at Map Chalut Temple (MCLT) monitoring station 2009-2012 (BDL : Below detection limit) (cont.)

Compounds	Mean	Min	Max	SD	BDL (%)	No data (%)
cis-1,2-Dichloroethylene	0.37	0.37	0.37	0.00	97.92	0.00
Chloroform	0.33	0.11	0.54	0.16	68.75	0.00
1,1,1-Trichloroethane	0.59	0.12	0.80	0.28	85.42	4.17
1,2-Dichloroethane	0.86	0.09	6.20	1.20	33.33	2.08
Benzene	1.77	0.14	7.50	1.51	2.08	0.00
Carbon Tetrachloride	0.56	0.18	1.40	0.30	18.75	6.25
Trichloroethylene	0.45	0.07	1.30	0.35	64.58	0.00
1,2-Dichloropropane	0.31	0.06	0.75	0.21	83.33	0.00
cis-1,3-Dichloropropene	0.57	0.40	0.70	0.15	89.58	4.17
Toluene	7.68	0.83	50.00	8.18	0.00	0.00
trans-1,3-Dichloropropene	0.00	0.00	0.00	0.00	93.75	6.25
1,1,2-Trichloroethane	0.34	0.12	0.61	0.25	91.67	0.00
Tetrachloroethylene	0.38	0.11	0.76	0.23	75.00	0.00
1,2-Dibromoethane	0.00	0.00	0.00	0.00	93.75	6.25
Chlorobenzene	0.32	0.05	0.85	0.25	75.00	2.08
Ethylbenzene	1.49	0.16	5.70	1.31	2.08	10.42
Total Xylene	2.92	0.00	17.30	2.67	0.00	0.00
Styrene	0.71	0.14	6.60	1.07	18.75	6.25
1,1,2,2-Tetrachloroethane	0.74	0.27	1.20	0.66	89.58	6.25
1-Ethyl-4-methylbenzene	0.67	0.14	2.50	0.49	12.50	14.58
1,3,5-Trimethylbenzene	0.51	0.15	1.20	0.27	25.00	18.75
1,2,4-Trimethylbenzene	1.12	0.17	4.80	0.83	2.08	18.75
1,3-Dichlorobenzene	0.65	0.41	0.83	0.22	81.25	12.50
Benzyl Chloride	0.00	0.00	0.00	0.00	89.58	10.42
1,4-Dichlorobenzene	0.70	0.12	1.30	0.38	79.17	6.25
1,2-Dichlorobenzene	0.63	0.47	0.79	0.23	85.42	10.42
1,2,4-Trichlorobenzene	0.31	0.31	0.31	0.00	52.08	45.83
Hexachloro-1,3-butadiene	0.00	0.00	0.00	0.00	60.42	39.58

Table A-6 Summary of VOCs concentration ($\mu\text{g}/\text{m}^3$) at Ban Plong Community (BPLC) monitoring station 2009-2012 (BDL : Below detection limit)

Compounds	Mean	Min	Max	SD	BDL (%)	No data (%)
Freon 12	2.41	1.50	5.50	0.95	0.00	25.00
Freon 114	0.29	0.04	0.70	0.25	83.33	4.17
Chloromethane	1.12	0.36	2.40	0.42	6.25	4.17
Vinyl chloride	1.52	0.07	19.00	3.19	22.92	0.00
1,3-Butadiene	0.50	0.05	2.10	0.47	47.92	0.00
Bromomethane	0.28	0.08	0.92	0.22	68.75	0.00
Chloroethane	0.14	0.08	0.18	0.04	85.42	0.00
Freon 11	0.96	0.31	1.90	0.31	0.00	0.00
1,1-Dichloroethylene	0.00	0.00	0.00	0.00	100.00	0.00

Table A-6 Summary of VOCs concentration ($\mu\text{g}/\text{m}^3$) at Ban Plong Community (BPLC) monitoring station 2009-2012 (BDL : Below detection limit) (cont.)

Compounds	Mean	Min	Max	SD	BDL (%)	No data (%)
Freon 113	0.48	0.17	1.10	0.25	47.92	10.42
Acrylonitrile	0.47	0.38	0.55	0.12	95.83	0.00
3-Chloropropene	0.00	0.00	0.00	0.00	95.83	4.17
Dichloromethane	1.52	0.15	14.00	2.40	16.67	0.00
1,1-Dichloroethane	0.16	0.15	0.17	0.01	91.67	4.17
cis-1,2-Dichloroethylene	0.00	0.00	0.00	0.00	97.92	2.08
Chloroform	0.31	0.10	0.53	0.17	75.00	0.00
1,1,1-Trichloroethane	0.46	0.06	0.91	0.34	83.33	4.17
1,2-Dichloroethane	0.80	0.07	4.60	0.93	22.92	2.08
Benzene	4.70	0.77	16.00	3.57	0.00	0.00
Carbon Tetrachloride	0.55	0.16	1.50	0.29	16.67	6.25
Trichloroethylene	0.44	0.10	1.10	0.28	64.58	0.00
1,2-Dichloropropane	0.30	0.14	0.84	0.26	85.42	0.00
cis-1,3-Dichloropropene	0.27	0.27	0.27	0.00	93.75	4.17
Toluene	25.95	5.20	140.00	25.21	0.00	0.00
trans-1,3-Dichloropropene	0.27	0.13	0.41	0.20	89.58	6.25
1,1,2-Trichloroethane	0.25	0.09	0.55	0.21	91.67	0.00
Tetrachloroethylene	0.39	0.07	0.64	0.22	77.08	0.00
1,2-Dibromoethane	0.13	0.13	0.13	0.00	91.67	6.25
Chlorobenzene	0.32	0.06	0.60	0.19	79.17	2.08
Ethylbenzene	1.85	0.30	6.80	1.42	0.00	10.42
Total Xylene	3.87	0.00	14.10	2.39	0.00	2.08
Styrene	0.54	0.09	1.20	0.30	10.42	6.25
1,1,2,2-Tetrachloroethane	0.00	0.00	0.00	0.00	93.75	6.25
1-Ethyl-4-methylbenzene	1.02	0.26	3.70	0.62	2.08	14.58
1,3,5-Trimethylbenzene	0.77	0.20	2.70	0.47	8.33	18.75
1,2,4-Trimethylbenzene	2.74	0.90	10.00	1.54	0.00	16.67
1,3-Dichlorobenzene	0.58	0.19	0.88	0.35	77.08	16.67
Benzyl Chloride	0.00	0.00	0.00	0.00	89.58	10.42
1,4-Dichlorobenzene	0.63	0.13	1.20	0.37	72.92	8.33
1,2-Dichlorobenzene	0.66	0.45	0.84	0.20	79.17	14.58
1,2,4-Trichlorobenzene	0.72	0.72	0.72	0.00	52.08	45.83
Hexachloro-1,3-butadiene	0.00	0.00	0.00	0.00	60.42	39.58

Table A-7 Summary of VOCs concentration ($\mu\text{g}/\text{m}^3$) at Nop Pakate Village (NPKV) monitoring station 2009-2012 (BDL : Below detection limit)

Compounds	Mean	Min	Max	SD	BDL (%)	No data (%)
Freon 12	2.53	1.40	11.00	1.69	0.00	25.00
Freon 114	0.31	0.06	0.78	0.27	83.33	4.17
Chloromethane	1.06	0.35	2.20	0.42	6.25	4.17
Vinyl chloride	0.51	0.09	4.30	0.99	64.58	0.00
1,3-Butadiene	0.47	0.07	1.70	0.46	64.58	0.00
Bromomethane	0.26	0.07	0.60	0.16	77.08	0.00
Chloroethane	0.10	0.10	0.10	0.00	95.83	0.00
Freon 11	0.97	0.12	1.50	0.29	2.08	0.00
1,1-Dichloroethylene	0.00	0.00	0.00	0.00	100.00	0.00
Freon 113	0.50	0.19	1.10	0.27	54.17	10.42
Acrylonitrile	0.42	0.20	0.54	0.16	91.67	0.00
3-Chloropropene	0.00	0.00	0.00	0.00	97.92	2.08
Dichloromethane	10.70	0.08	270.00	43.29	16.67	0.00
1,1-Dichloroethane	0.00	0.00	0.00	0.00	95.83	4.17
cis-1,2-Dichloroethylene	0.08	0.08	0.08	0.00	95.83	2.08
Chloroform	0.33	0.08	0.52	0.18	81.25	0.00
1,1,1-Trichloroethane	0.64	0.34	0.87	0.23	87.50	4.17
1,2-Dichloroethane	0.45	0.08	1.10	0.32	39.58	2.08
Benzene	2.43	0.53	8.90	1.52	0.00	0.00
Carbon Tetrachloride	0.54	0.16	1.50	0.29	16.67	6.25
Trichloroethylene	1.11	0.10	12.00	2.59	58.33	0.00
1,2-Dichloropropane	0.32	0.05	0.83	0.28	87.50	0.00
cis-1,3-Dichloropropene	0.66	0.66	0.66	0.00	93.75	4.17
Toluene	10.03	1.40	33.00	7.20	0.00	0.00
trans-1,3-Dichloropropene	0.14	0.14	0.14	0.00	91.67	6.25
1,1,2-Trichloroethane	0.52	0.52	0.52	0.00	97.92	0.00
Tetrachloroethylene	0.43	0.06	0.96	0.30	75.00	0.00
1,2-Dibromoethane	0.26	0.26	0.26	0.00	91.67	6.25
Chlorobenzene	0.27	0.04	0.67	0.23	81.25	2.08
Ethylbenzene	1.57	0.10	5.30	1.25	0.00	10.42
Total Xylene	4.75	0.14	17.80	3.93	0.00	2.08
Styrene	0.54	0.09	1.70	0.42	25.00	6.25
1,1,2,2-Tetrachloroethane	0.00	0.00	0.00	0.00	93.75	6.25
1-Ethyl-4-methylbenzene	0.73	0.13	1.90	0.52	12.50	14.58
1,3,5-Trimethylbenzene	0.61	0.16	1.80	0.39	29.17	18.75
1,2,4-Trimethylbenzene	1.41	0.22	7.60	1.34	4.17	16.67
1,3-Dichlorobenzene	0.75	0.64	0.86	0.16	79.17	16.67
Benzyl Chloride	0.31	0.31	0.31	0.00	87.50	10.42
1,4-Dichlorobenzene	0.67	0.14	1.20	0.36	75.00	8.33
1,2-Dichlorobenzene	0.74	0.43	0.98	0.23	77.08	14.58
1,2,4-Trichlorobenzene	1.60	1.60	1.60	0.00	50.00	45.83
Hexachloro-1,3-butadiene	0.00	0.00	0.00	0.00	60.42	39.58

Table A-8 Summary of VOCs concentration ($\mu\text{g}/\text{m}^3$) at Dindaeng monitoring station 2009-2012 (BDL : Below detection limit)

Compounds	Mean	Min	Max	SD	BDL (%)	No data (%)
Freon 12	2.52	1.50	7.30	1.05	0.00	20.83
Freon 114	0.27	0.07	0.65	0.23	77.08	10.42
Chloromethane	1.43	0.34	6.00	1.16	8.33	6.25
Vinyl chloride	0.00	0.00	0.00	0.00	100.00	0.00
1,3-Butadiene	0.77	0.04	2.20	0.50	66.67	0.00
Bromomethane	0.18	0.10	0.30	0.07	87.50	0.00
Chloroethane	0.15	0.09	0.26	0.09	89.58	4.17
Freon 11	1.02	0.15	4.30	0.62	6.25	2.08
1,1-Dichloroethylene	0.00	0.00	0.00	0.00	100.00	0.00
Freon 113	0.48	0.14	1.10	0.27	52.08	6.25
Acrylonitrile	0.23	0.08	0.60	0.19	85.42	2.08
3-Chloropropene	0.00	0.00	0.00	0.00	93.75	6.25
Dichloromethane	1.34	0.28	4.70	0.94	10.42	0.00
1,1-Dichloroethane	0.00	0.00	0.00	0.00	95.83	4.17
cis-1,2-Dichloroethylene	0.00	0.00	0.00	0.00	100.00	0.00
Chloroform	0.33	0.11	0.67	0.19	58.33	0.00
1,1,1-Trichloroethane	0.61	0.12	1.00	0.32	89.58	0.00
1,2-Dichloroethane	0.40	0.08	0.81	0.24	75.00	0.00
Benzene	5.80	1.80	12.00	2.13	0.00	0.00
Carbon Tetrachloride	0.56	0.16	1.70	0.34	22.92	2.08
Trichloroethylene	0.49	0.11	1.10	0.28	50.00	0.00
1,2-Dichloropropane	0.22	0.03	0.56	0.20	79.17	0.00
cis-1,3-Dichloropropene	0.00	0.00	0.00	0.00	97.92	2.08
Toluene	38.23	13.00	100.00	16.76	0.00	2.08
trans-1,3-Dichloropropene	0.00	0.00	0.00	0.00	97.92	2.08
1,1,2-Trichloroethane	0.00	0.00	0.00	0.00	95.83	4.17
Tetrachloroethylene	0.42	0.08	1.60	0.35	43.75	0.00
1,2-Dibromoethane	0.33	0.26	0.40	0.10	93.75	2.08
Chlorobenzene	0.30	0.11	0.61	0.17	79.17	4.17
Ethylbenzene	3.77	0.81	10.00	1.97	0.00	4.17
Total Xylene	12.51	2.86	38.40	6.57	0.00	0.00
Styrene	0.86	0.19	2.00	0.51	4.17	6.25
1,1,2,2-Tetrachloroethane	0.00	0.00	0.00	0.00	93.75	6.25
1-Ethyl-4-methylbenzene	2.35	0.88	8.30	1.41	0.00	6.25
1,3,5-Trimethylbenzene	1.63	0.26	6.20	1.07	0.00	6.25
1,2,4-Trimethylbenzene	7.38	1.50	28.00	5.11	0.00	14.58
1,3-Dichlorobenzene	0.75	0.26	1.20	0.32	83.33	4.17
Benzyl Chloride	0.00	0.00	0.00	0.00	91.67	8.33
1,4-Dichlorobenzene	1.03	0.17	4.90	0.85	12.50	4.17
1,2-Dichlorobenzene	0.63	0.36	0.78	0.19	87.50	4.17
1,2,4-Trichlorobenzene	0.10	0.10	0.10	0.00	43.75	54.17
Hexachloro-1,3-butadiene	0.00	0.00	0.00	0.00	64.58	35.42

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