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Indoor-Outdoor Volatile Organic Compounds (VOCs) levels in Urban and Industrial Area of Dhaka City, Bangladesh

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DEDICATION

Dedicate to my loving cute daughter

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ABSTRACT

Volatile organic compounds (VOCs) are of concern both as indoor and outdoor air pollutants for their potential adverse impact on health of people who are exposed and ability to create photochemical smog under certain conditions. Although VOCs are expected to be an important environmental and health risk factor for the rapidly industrializing countries like Bangladesh but there are limited studies on the outdoor and indoor air levels of VOCs in different environments such as industrial and urban areas. On the other hand, there is no known published data yet to assess the indoor VOCs of residential houses in Bangladesh.

Therefore, the presence and concentration levels of VOCs were investigated for urban (Mirpur) and industrial (Tejgaon) areas of Dhaka city, Bangladesh in this study. For this purpose six places were selected in two areas (urban and industrial area) for sampling campaigns from 30 of August 2013 to 11 September 2013. Outdoor and indoor samples from both areas were obtained by means of active sampling using Tenax TA tubes as sorbent material during the sampling time. Analysis and quantification were done by thermal desorption-gas chromatography-mass spectrometry (TD-GC-MS) and internal standard calibration. A total set of 44 VOCs consisting of (cyclo)-alkanes, aromatic compounds, halogenated compounds, oxygenated compounds and terpenes were identified from the six sampling sites. Considering safe sampling volume (SSV) 5 VOCs excluded from the data interpretation. Data were interpreted in terms of total volatile organic compounds(TVOCs) which is the sum of 39 VOCs, individual groups and subgroups of TVOCs; benzene, toluene, ethylbenzene and xylenes (BTEX) levels; indoor-to-outdoor ratio (I/O); source identification based on diagnostic ratios and correlations coefficient and ozone formation potential (OFP) based on update MIR-10 and MIR-12 (Maximum Incremental Reactivity) scale. The highest mean of TVOCs was measured in the roadside of the industrial street (mean: 96μg/m^3; maximum: around 151μg/m^3). The lowest mean of TVOCs was measured in the park of the urban area (mean: 28μg/m^3; minimum: around 14μg/m^3). Total aromatic compounds were dominant VOCs ranging from 42 to 61% of the TVOCs in all the sampling sites. The highest mean ΣBTEX were measured around 47μg/m^3 in the industrial ambient and the lowest mean around 10μg/m^3 in the urban park. Toluene has the highest concentration level among the 39 VOCs (mean 5-22μg/m^3). Based on the result source identification, it observed there were significant positive correlations at the 0.05 level ($r>0.81$; $p<0.05$) among most of the aromatic compounds which indicate the influence of traffic emissions and less significant correlations in the ambient industrial environment which is indicative of multiple sources.The estimated total OFP (TOFP) were calculated which shows that 2 of the 4 outdoor sites exceed the the threshold value 235μg/m^3 (0.12ppm) for 1 hour (d) of Bangladesh National Ambient Air Quality Standards (NAAQS), 2005 for ozone and 3 out of 4 outdoor sites exceeded the WHO recommended level 100μg/m^3 and 157μg/m^3 (0.08ppm) Bangladesh NAAQS, 2005 (8 hour average) of ozone but it worth nothing that caution should be exercised in making comparison because the sampling time was 30 minutes in duration and sample size was limited.

Although this work has brought forward new data on VOCs concentrations level on wide range of VOCs, further studies concerning more sites and seasonal variations are recommended.

Keywords:

VOC, BTEX, TD-GC-MS, OFP, MIR.

LIST OF ABBREVIATIONS

AQMP	Air Quality Management Project
BD	Bangladesh
BE	Belgium
BIBM	Bangladesh Institute of Bank Management
BITAC	Bangladesh Industrial Technical Assistance Centre
BARC	Bangladesh Agricultural Research Council
B/T	Benzene-to-toluene concentration ratio
BTEX	Benzene, toluene, ethylbenzene and meta-, para-, and ortho-xylene
∑BTEX	Total sum of BTEX
BTV	Breakthrough volume
CO	Carbon monoxide
CAMS	Continuous Air Monitoring Station
CASE	Clean Air and Sustainable Environment project
CNG	Compressed natural gas
CNS	Central nervous system
CTS	Closed two-phase system
D	Detected
DoE	Department of Environment
EPA	Environmental Protection Agency
ET	Ethiopia
EU	European Union
GC	Gas chromatography
He	Helium
HC	Hydrocarbons
H/P	Indoor urban house to outdoor urban park concentration ratio
H/S	Indoor urban house to outdoor urban street concentration ratio
IARC	International Agency for Research on Cancer
IH/IA	Indoor industrial house to outdoor industrial ambient concentration ratio
IH/IR	Indoor industrial house to outdoor industrial roadside concentration ratio
IS	Internal standard
IPCC	Intergovernmental Panel on Climate Change
I/O	Indoor to outdoor concentration ratio
I/M	In-use vehicle emission inspection and maintenance
LOD	Limit of detection
LOQ	Limit of quantification
LPG	Liquefied petroleum gas
MIR	Maximum incremental reactivity
MoEF	Ministry of Environment and Forest
MS	Mass spectrometry
MW	Molecular weight
NA	Not available
ND	Not detected

NAAQS	National Ambient Air Quality Standards
NIH	US National Institutes of Health
NIST	US National Institute of Science and Technology
NO_x	Nitrogen oxides
NMHC	Non-methane hydrocarbons
O_3	Ozone
ODS	Ozone depleting substance
OFP	Ozone formation potential
OH	Hydroxyl radical
HO_2	Hydroperoxyl radical
PM	Particulate matter
$PM_{2.5}$	Particulate matter with an aerodynamic diameter less than 2.5 micrometers
PM_{10}	Particulate matter with an aerodynamic diameter less than 10 micrometers
PH	Philippines
ppb	Parts per billion
ppm	Parts per million
RF	Response factor
RSRF	Relative sample response factor
S/N	Signal-to-noise ratio
SO_2	Sulfur dioxide
SAPRC	Statewide Air Pollution Research Centre
SIM	Selective ion monitoring
SIS	Scientific Instrument Services
SRF	Sample response factor
SSV	Safe sampling volume
TD	Thermal desorption
TIC	Total ion current
TOFP	Total ozone formation potential
TSP	Total suspended particles
TVOCs	Total volatile organic compounds
USEPA	United States Environmental Protection Agency
UV	Ultraviolet
VOCs	Volatile organic compounds
VN	Vietnam
WB	World Bank
WHO	World Health Organization

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CHAPTER ONE: GENERAL INTRODUCTION

1.1 Background of the study

Poor air quality is one of the most serious environmental problems in different urban areas around the world, especially in developing countries. Bangladesh is a south Asian country with a total population of 156.6 million in 2013 and population density 1203 per sq. km (http://data.worldbank.org) is facing the same problem (Azad and Kitada, 1998). The urban environmental problems in Bangladesh are numerous and inter-related. Localized urban areas and along with the major roads, poor vehicle maintenance and enforcement mechanisms, and ineffective regulation of industrial emission were identified as the major causes of air pollution in urbanized Bangladesh (Rab, 2001). According to World Bank (WB) Bangladesh Country Environmental Analysis report (2006), if exposure to urban air pollution is reduced by 20% to 80%, between 1,200 to 3,500 lives can be saved and 80 to 230 million cases of respiratory diseases can be avoided per annum. In economic terms, this is equivalent to an estimated US$170 to 500 million in savings due to reduced health care costs and increased productivity per annum (WB, Bangladesh Country Environmental Analysis report, 2006). Recent studies of WB (2006) that assess and value the adverse health impacts of exposure to air pollution reveal the magnitude of the costs to society that calls for immediate actions. Thus, air pollution impedes the overall development in the urbanized areas that again impedes to the sustainable development of Bangladesh.

Monitoring the air pollution is a very recent phenomenon in Bangladesh. Since April 2002 upto 2007, there was only one Continuous Air Monitoring Station (CAMS) that established during Air Quality Management Project (AQMP) of the Department of Environment (DoE) financed by WB. At present in Bangladesh, real-time measurements of ambient level criteria/common pollutants at 11 CAMS are made at 8 major cities (namely, Dhaka, Narayangonj, Gazipur, Chittagong, Rajshahi, Khulna, Barisal and Sylhet) of Bangladesh by the Clean Air and Sustainable Environment (CASE) project of DoE which is the follow-up of the former project AQMP. Concentration of common ambient air pollutants e.g., carbon monoxide (CO), oxides of nitrogen (NO_X), sulfur dioxide (SO_2), ozone (O_3), PM_{10} (particulate matter with an aerodynamic diameter less than 10 micrometers) and $PM_{2.5}$ (particulate matter with an aerodynamic diameter less than 2.5 micrometers) are measured at the CAMS stations and Hydrocarbons (HC) emission are regulated in transportation sector by vehicle emission standards and I/M(in-use vehicle emission inspection and maintenance) program of the CASE project. The data that generated used to define the nature and severity of pollution in the cities; identify pollution trends in the country; and develop air models and emission inventories. The CASE project of the DoE operates air quality monitoring program in Dhaka through 3 CAMS from 2010. Monitoring results of the CAMS have shown that particulate matter is the main pollutant of concern for Dhaka city. The concentration of the key air pollutant of concern (Particulate Matter or PM) in Dhaka and other major cities has been steadily increasing in recent years, with an annual average much higher than the World Health Organization (WHO) guidelines, 2005. Ministry of Environment and Forest (MoEF), Government of People's Republic of Bangladesh has been adopted the United States

Environmental Protection Agency's (USEPA) National Ambient Air Quality Standards (NAAQS) as an ambient air quality standard for Bangladesh that includes the standards for both PM_{10} and $PM_{2.5}$, CO, NO_X, SO_2, O_3 while vehicle emission standards includes the standards for CO, HC/NMHC, SO_2, NO_X and PM are in line with Euro 2 limits for the light duty vehicles(CNG and gasoline vehicles) and Euro 1 for the heavy duty vehicles (Diesel vehicles)(The Bangladesh Gazette, 2005). From July 2014, separate vehicle emission standards have been implemented for Dhaka and Chittagong to meet more cost effective stringent emission regulations depending on the vehicle type and fuel type use, Euro 3 limits for the light duty vehicles (CNG and gasoline vehicles) and Euro 2 for the heavy duty vehicles (Diesel vehicles)(http://www.case-moef.gov.bd).

Dhaka, the capital city, is the center of all administrative, economic and cultural activities. Dhaka is one of the most populated cities of the country. Dhaka has an estimated population of more than 15 million people, making it the largest city in Bangladesh and the 8th largest city in the world (http://en.wikipedia.org). Population density of Dhaka is 45,000 per sq. km (http://en.wikipedia.org). Among the environmental issues, air quality is one of the burning issues in Bangladesh as well as in urbanized Dhaka as all are interrelated. There are a lot of reports of measured primary pollutants (such as PM) in Dhaka and alarming levels of pollutants at roadside locations (Azad and Kitada, 1998; Karim, 1999; Begum *et.al*., 2006; Begum *et.al*., 2011). According to MoEF, there are two major sources of air pollution in Bangladesh, vehicular emissions and industrial emissions (http://www.moef.gov.bd). It has been started that Dhaka city has VOC beyond tolerable limits, some of which cause cancer (http://www.banglapedia.org). It was found that the emissions from two-stroke auto-rickshaws in Dhaka were contained 4 to 7 times the maximum permissible level of VOC (http://www.banglapedia.org). In rural areas, wood, coal, and biomass are used as sources of energy. In rural areas, the principal air contaminants are particulate matter and VOCs (http://www.moef.gov.bd). The measures taken by Government of Bangladesh, the shift from gasoline/diesel fuelled engines to CNG (compressed natural gas), which began in 1999–2000 (Bose and Rahman, 2009 and Iqbal *et al*., 2011). In Bangladesh, the number of CNG vehicles is currently estimated to be around 200,000 (GVR, 2011) of which about 95% are located in Dhaka and 58.5% of the total vehicles in Dhaka (325,000) are thought to be running on CNG (Jeeranut *et al.*, 2012). Moreover, enforcement of the regulations which prohibit the use of poor condition vehicles that do not pass annual inspections, banning the use of old buses (over 20 years) and trucks (over 25 years), phasing out diesel-run two-stroke three wheeler vehicles (Bose and Rahman, 2009), and introducing environmental friendly brick kiln technologies (Hossain, 2008) is believed to have resulted in a significant decrease of airborne fine particle concentrations during the year 2000–2003 (Begum *et al*., 2006), while ambient VOCs remained unregulated and are rarely monitored in Bangladesh as well as in Dhaka. There is no existing indoor and ambient air standard for volatile organic compounds (VOCs) such as benzene concentration limit in Bangladesh except vehicle emission standards for HC.

Among the different anthropogenic pollutants emitted into the troposphere, VOCs contribute to two of the most serious air quality problems as major precursors for the formation of photochemical smog and ground level ozone. In the presence of VOCs, NO_X and sunlight O_3

is photochemically produced which is known to be harmful to living organisms as well as a powerful greenhouse gas (Jeeranut *et al.*, 2012). Several VOCs directly affect the health conditions of humans as some VOCs found in urban air are classified as carcinogens (Barletta *et al.*, 2008). Some VOCs such as benzene, toluene, ethylbenzene and xylenes (BTEX) have gained interest in the field of both indoor and outdoor air quality (Cocheo *et al.*, 2000; Borton *et al.*, 2002). Limited studies (only 2 published studies on VOCs) on the ambient and indoor air levels of VOCs in different environments such as industrial and urban areas have been done in Bangladesh. VOCs are expected to be an important environmental and health risk factor for the rapidly industrializing countries (Han and Naeher, 2006). But there is still very lack of knowledge and measurement of indoor and ambient concentration levels of the VOCs. On the other hand, there is no known published data yet to assess the indoor VOCs of residential houses in Bangladesh. Beyond this, proper information on VOC levels for urban and industrial areas in the Bangladesh is still lacking. Dhaka still need to assess the indoor and ambient level of VOCs concentration to reduce the health impact of air pollution, to address the accurate emission control measures and to take effective policy implication to combat further air pollution and improve quality of life.

The main focus of this study is to determine the presence and concentrations levels of VOCs in outdoor ambient and indoor levels of VOCs, their source profile identification and effect on health due to exposure. These are necessary in creating development programs, planning efficient and effective implementing regulations, improving the air quality and increase the awareness about pollution impacts. This study therefore aimed to investigate the levels and nature of VOCs in urban and industrial areas of Dhaka city, Bangladesh as well to provide information that would be useful in environmental and health policy making process in Bangladesh.

1.2 Study scope and objectives

The scope and objectives of this study is based on the problems are formulated and the information discussed in the background of the study.

Considering the high population density, incremental environmental issues, alarming levels of pollutants due to high levels of traffic jam and lack of awareness of environmental impacts it can be said that there is a scope to measure the ambient level of VOCs in relation to different sources is a vital issue. Again to reduce further worsening air quality, provide information on the ambient level of VOCs level of both as primary and secondary pollutants in the capital city Dhaka is necessary for efficient regulations and suitable policy formulation to combat the air pollution.

The main objective of my research is to investigate the presence and ambient concentration levels of VOCs in both indoor and outdoor environment in urban and industrial areas Dhaka city, Bangladesh.

Specifically the study objectives:

- To assess and make a comparison on the indoor and outdoor ambient levels of VOCs in the urban and industrial environment of Dhaka city;
- To evaluate the differences in air quality in relation to the emission of TVOCs, BTEX and benzene concentration levels;
- To assess the differences in air quality in relation to the emission as individual group and subgroup of TVOCs;
- To evaluate the effectiveness and applicability of the diagnostic ratios and statistical approaches in source identification of VOCs;
- To estimate the ozone formation potential of the measured VOCs in the outdoor sites of industrial and urban areas;
- To draw meaningful discussion regarding the status and extent of effects of VOCs on air quality in the ambient outdoor and indoor environment of urban and industrial areas in the Bangladesh;
- To evaluate and search for similarities in VOC profiles of the two environments and compare with other studies from the literature.

CHAPTER TWO: LITERATURE REVIEW

2.1 Volatile organic compounds

As VOCs is a relatively minor component of the atmosphere but yet are widely recognized to have important roles in air quality and climate (Guenther, A., 2012). It is stated as an important greenhouse gas, atmospheric VOCs are primarily of interest because of their impact on other atmospheric constituents, including oxidants and aerosol but with the exception of methane (Guenther, A., 2012). Methane is often considered separately as it is an organic gas and much less reactive than other hydrocarbons in the troposphere (Demeestere *et al.*, 2007; USEPA, 2010).

On the other hand, VOCs are as concern both as indoor and outdoor pollutants to USEPA considering the health impacts. The USEPA regulates VOCs outdoors mainly because of their ability to create photochemical smog under certain conditions whereas main concern indoors VOCs is the potential for VOCs to adversely impact the health of people that are exposed (http://www.epa.gov). Because VOCs have become essential ingredients in many products and materials they are usually present in both indoor and outdoor environments (http://www.epa.gov). In indoors VOCs are mostly released into the air from the use of products and materials containing VOCs whereas outdoors, VOCs are volatized or released into the air mostly during manufacture or use of everyday products and materials (http://www.epa.gov).

Due to the overwhelming number of compounds, a comprehensive characterization of atmospheric VOC is challenging (Guenther, A., 2012). According to Goldstein and Galbally (2007), tens of thousands of VOC have been measured in the atmosphere and there may be hundreds of thousands more that have not been measured. There are many ways of classifying VOC including source types, chemical characteristics, and atmospheric impacts. Surface-atmosphere exchange behaviour is typically not considered when categorizing VOC (Guenther, A., 2012).

2.2 Definitions

The general definition of VOCs is used in the scientific literature which is consistent with the definition used for indoor air quality of the USEPA. According to USEPA in their regulations for indoor air, Volatile organic compounds or VOCs are organic chemical compounds whose composition makes it possible for them to evaporate under normal indoor atmospheric conditions of temperature and pressure.

Volatility is indicated by a substance's vapor pressure. As the volatility of a compound is generally higher, the lower its boiling point temperature and that’s why the volatility of organic compounds are sometimes defined and classified by their boiling points.

The European Union uses the boiling point, rather than its volatility in its definition of VOCs. According to the EU Paint Directive, 2004/42/EC (EU, 2004), defines VOC as an organic compound having an initial boiling point lower than or equal to 250 °C at an atmospheric pressure of 101.3kPa. Similarly, the European Eco-Labelling scheme (2002/739/EC amending 1999/10/EC) for paints and varnishes defines a VOC as an organic compound with a boiling point (or initial boiling point) lower than or equal to 250ºC.

2.3 Sources

The emission sources of VOCs can be divided into two main source such as natural and anthropogenic emission sources (Kansal, 2009; Talapatra and Srivastava, 2011; Sahu, 2012).The anthropogenic sources can be subdivided into two such as stationary sources and mobile sources (Talapatra and Srivastava, 2011).

2.3.1 Natural sources

The natural sources of atmospheric VOCs include emissions from vegetation, specifically rural forested areas, oceans, marine phytoplankton's, soil microbiota and geological hydrocarbon reservoirs (Stavrakou *et al.,* 2009; Sahu, 2012). It is found that on the global scale, vegetation is the dominant source among the natural sources; natural emissions of nonmethane hydrocarbons (NMHCs) and VOCs exceed anthropogenic emissions (Talapatra and Srivastava, 2011).

2.3.2 Anthropogenic sources

It is found that anthropogenic sources of VOCs usually dominate in urban areas (Kansal, 2009). Ambient anthropogenic sources of VOCs mainly include mobile sources emissions (transport sector), and stationary sources (industrial solvent use, production and storage processes, combustion processes). Vehicle emissions is often the main source of VOCs in urban areas (Theloke and Friedrich, 2007; Huang *et al.,* 2011; Talapatra and Srivastava, 2011).

2.3.2.1 Stationary sources

Stationary anthropogenic sources of VOCs are grouped into several categories which include energy production, industries, solvent evaporation, waste treatment and disposal and agriculture and food industries and among them, use of organic solvents is the most important (Van Langenhove, 2010). Industrial zones can be a significant source of stationary VOCs as it involves emissions from all these categories. For instance, high concentrations of BTEX were observed at many industrial locations (Tiwari *et al.*, 2010). Emission of VOCs from dye industry (Jo *et al*., 2004), petroleum refinery (Lin *et al.*, 2004) and printing industry (Leung *et al.,* 2005) have been published. Industrial process also cited as important industrial sources of VOCs after industrial combustion for example polymer industry, rendering industry and pulp and paper industry (Van Langenhove, 2010).

2.3.2.2 Mobile sources

It is found that the largest anthropogenic source of organic gases including NMHCs and VOCs related to emission from mobile source (Kansal, 2009). Whereas according to Do *et.*

al. (2013), the most common source of emission is considered from vehicle exhaust. Among the exhaust VOCs, approximately half of the mass emitted is unburned fuel (Caplain *et al*., 2006). Traffic related VOCs include alkanes, alkenes, alkynes and aromatic hydrocarbons. Among traffic related VOCs, aromatic compounds, including BTEX, have public health importance and are of great concern because of their relative abundance (Han and Naeher, 2006; Buczynska *et al*., 2009). Vehicular VOC emission depends on a variety of factors. For instance, composition of exhaust was also found to be dependent on the type of vehicle and use of catalytic converters (Verma and des Tombe, 2002). Light alkanes and alkenes were reported to constitute the highest proportions of VOCs from catalyst-equipped, gasoline-driven passenger cars (Stemmler *et al*., 2005; Lai and Peng, 2012). The BTEX level in exhaust was also reported to decrease for all vehicles fuelled with methanol/gasoline blends but increase in formaldehyde levels was also noted (Zhao *et al*., 2011). On the other hand, vehicles using unleaded fuels without catalytic converters were observed to generate more VOCs (Wang and Zhao, 2008). The influence of the type of fuel and fuel composition was also reported (Watson, *et al*., 2001). Chemical composition and magnitude of vehicle exhaust emissions was shown to be directly related to the gasoline composition used (Schuetzle *et al*., 1994). Decrease of aromatic compounds in vehicle exhaust was reported by shifting from Euro 1 to Euro 3 fuel standards (Caplain *et al*., 2006).

2.3.2.3 Indoor sources

According to Logue *et al.* (2011), the meta-analysis of 77 surveys of VOCs in homes in the US found the top ten riskiest indoor air VOCs were acrolein, formaldehyde, benzene, hexachlorobutadiene, acetaldehyde, 1,3-butadiene, benzyl chloride, 1,4-dichlorobenzene, carbon tetrachloride, acrylonitrile, and vinyl chloride. These compounds in most homes exceeded health standards (Logue *et al*., 2011). Human activities such as cooking and smoking also contribute to indoor VOCs (Talapatra and Srivastava, 2011). Other contributors had been cited which includes, solid fuel combustion (Duricova *et al*., 2010), emissions following house renovations (Herbarth and Matysik, 2010), poor ventilation (Dimitroulopoulou, 2012) and insecticide application (Bukowski and Meyer, 1995; Pentamwa *et al*., 2011). Outdoor sources (e.g. industrial emissions, exhaust from vehicles) also contribute to indoor VOCs (Adgate *et al*., 2004; Talapatra and Srivastava, 2011). In indoor, the main sources of VOCs are building materials, furnishings, cleaning products, dry cleaning agents, paints, varnishes, waxes, solvents, glues, aerosol propellants, refrigerants, fungicides, germicides, cosmetics and textiles, appliances, air fresheners and clothing (Weschler, 2009; Sarigiannis *et al*., 2011; Talapatra and Srivastava 2011). Attention to ambient and indoor VOCs has been increased ever since with the growing concern for quality life in safe and clean environment (Kumar and Víden, 2007).

2.4 Indoor to Outdoor concentration ratio (I/O)

The indoor to outdoor concentration ratio(I/O) are frequently found to be higher than one and can reach up to 100 (Jia *et al*., 2008; Caselli *et al.*, 2009). Indoor levels of VOCs may be 1,000 times than outdoor levels during and for several hours immediately after certain activities like paint stripping (USEPA, 2012b). The indoor to outdoor concentration (I/O) ratio depends on the type of VOC (BTEX or terpenes or others), the sampling region (the country-the status and the location of the country), the sampling location within the country (road or park for outdoor), and product use inside the apartment (Do *et al*., 2013).

2.5 Source identification

Identification of emission sources has common methods such as diagnostic ratio determination and correlation analysis. Benzene-to-toluene concentration ratio (B/T) is a common diagnostic ratio utilized in source identification (Jeeranut *et al.*, 2012). The B/T ratio from recent studies ranges from 0.33 to 0.67 with variations attributed to differences in vehicle type and composition (Miller *et al*., 2011). On the other hand it mentioned a range of 0.25 to 0.5 as a common B/T ratio associated with traffic emissions but pointed out that B/T ratio from the samples in Manila and Bangkok were much lower at 0.1 due to high toluene content of the fuel (Gee and Sollars, 1998). In the recent study of Jeeranut *et al.,* (2012) in the Dhaka city found that the B/T ratio was 0.21 in Dhaka University, 0.49 in the roadside Shabagh junction and 0.51 in Gulshan road.

Correlation analysis is also a useful tool for source identification. Good correlations usually indicate common sources of atmospheric pollutant concentrations and provide additional information of any relationships between pollutants (Wang *et al*., 2002). It is reported that good correlations between aromatic species were found in the areas dominated by traffic emissions while industrial areas are characterized by poor correlation (Tiwari *et al*., 2010). High correlations in areas where traffic was the dominant source and poor correlations were noted in the vicinity of industrial sites (Dollard *et al*., 2007). It is also noted low correlations associated with multiple emissions (Chan *et al.,* 2002; Barletta *et al.*, 2008).

2.6 Effects of VOCs

Airborne VOCs deserve special attention mainly because of the growing awareness of the impact of VOCs on both human health and global environment (Demeestere *et al*., 2007; Do *et al*., 2013). VOCs play a vital role in a number related issues such as (i) pose potential risks to human health as some VOCs are toxic (ii) halogenated VOCs can deplete O_3 in the stratosphere (iii) global-scale increase in VOCs can also induce greenhouse effects and (iv) they can serve as precursors of ground-level photochemical formation of O_3 (Demeestere *et al.,* 2007; Goldstein and Galbally, 2007; Sahu, 2012).

2.6.1 Health effects

The health effects of VOCs can be considered both direct and indirect. The direct health effects such as benzene can cause cancer in humans and the key symptoms associated with exposure to VOCs include conjunctival irritation, nose and throat discomfort, headache, allergic skin reaction, dyspnoea, declines in serum cholinesterase levels, nausea, emesis, epistaxis, fatigue, and dizziness (IARC, 2013; USEPA, 2013). Human exposure to benzene can have acute and long-term adverse health effects and diseases such as cancer; it can have also toxic effects on the blood and marrow (Lan *et al*., 2004). The threshold limit for benzene according to the EU Directive/2008/50 ambient benzene concentration is 5µg/m^3 and according to the Flemish indoor quality guidelines 2007, benzene concentration is 2µg/m^3. Benzene is classified as Group 1 that means carcinogenic to human (IARC, 2013). General guideline of the concentrations of airborne benzene associated with an excess lifetime risk of leukaemia of 10^{-4} for 17µg/m^3, 10^{-5} for 1.7µg/m^3 and 10^{-6} for 0.17µg/m^3 (WHO, 2010). Indirect impacts via photochemical ozone formation which is also associated with health risks (Choi *et al.*, 2011).

2.6.2 Environmental effects

Among the major environmental problems such as global warming, stratospheric ozone depletion, tropospheric ozone formation by photochemical smog and to the enforcement of the greenhouse effect, VOCs has considerable contribution (Demeestere *et al.,* 2007, Theloke and Friedrich, 2007).

2.6.2.1 Stratospheric ozone depletion

In the stratosphere there is limited number of VOCs. The VOCs that contribute to ozone depletion are termed ozone depleting substances (ODS) which include many chlorinated solvents and refrigerants, and bromine-containing fire retardants and fire extinguishers (Derwent, 1995; Van Langenhove, 2010). The stratospheric photolysis of VOCs containing chlorine or bromine substituent leads to the release of active radicals that destroy ozone.

2.6.2.2 Tropospheric ozone formation

Tropospheric ozone and other secondary pollutants are formed during the oxidation of reactive VOCs in the presence of NO_x and intense UV radiation (Grant *et al*., 2008; Mao *et al*., 2010; Van Langenhove, 2010; Butler *et al*., 2011). Photochemical ozone formation depends on the relative abundances of both VOCs and NO_x (Elshorbany *et al*., 2009). VOCs and nitrogen oxides (NO_x) combine photochemically to produce tropospheric ozone (Goldstein and Galbally, 2007; Carla *et al.,* 2014).

2.6.2.3 Global warming through Greenhouse effect

The Intergovernmental Panel on Climate Change (IPCC) called Tropospheric ozone is as "third greenhouse gas" due to the relative large effect (Akimoto *et al*., 2006). For example, Stevenson *et al.* (2000) presented a range of estimates for future radioactive forcing due to changes in tropospheric ozone in relation with climate change. The behaviour of ozone in the urban atmosphere in relation with VOCs and NOx is very complex (Graedel and Crutzen, 1997; Sadanaga *et al*., 2008).

2.7 Estimation of ozone formation potential

Ozone formation potential (OFP) is the potential of VOCs to form ozone (O_3) in the atmosphere. OFP is as rate constant of VOCs reacting with OH radical at 298K (g O_3/g VOCs) (Atkinson, 1985 and Atkinson and Arey, 2003). OFP is a measure of reactivity of a VOC to form photochemical ozone. VOC oxidation contributes to O_3 formation when sufficient NO_x is available in the atmosphere (Sadanaga *et al*., 2003; Stockwell *et al*., Carla *et al*., 2014). In the presence of VOCs, NO_X and sunlight O_3 is photochemically produced is known to be harmful to living organisms as well as being a powerful greenhouse gas (Jeeranut *et al.*, 2012). The Photochemical interactions can be according to equation 4.2

O_3=VOCs + NO_x+ Sunlight…………………………………………………………..……2.1

Used of MIR is a widely used method for estimating tropospheric ozone formation as function of different VOCs in the ambient air (Hung-Lung *et al.*, 2007; Jeeranut *et al*., 2012; Do *et al*., 2013; Carla *et al.*, 2014). Between 1994 and 2012, Carter developed and updated ozone reactivity scales for VOCs, making use of maximum incremental reactivity (MIR) values (Carter, 1994; Carter, 2010; Carter and Hoe, 2012). The MIR is defined as the highest amount of ozone formed per unit amount of VOC added to, or subtracted from, an urban or rural mixture of VOCs (Carter, 1994; Atkinson, 2000). MIR is defined by Jeeranut *et al.*, 2012 as the maximum increment of O_3 per additional individual VOC added with the assumption of sufficient NOx and light intensity. Ozone formation from one VOC depends on both its concentration and MIR value.

The formula using MIR:

OFP (i) = Concentration (i) × MIR coefficient (i)………………………….........................2.2

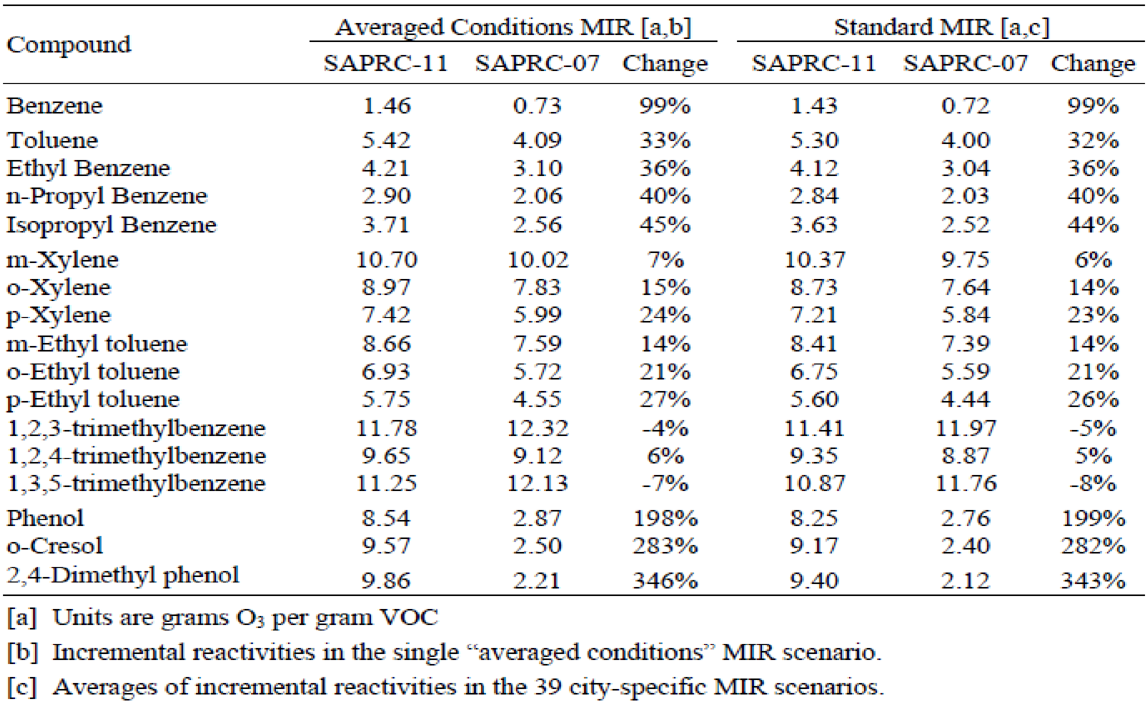
OFP ($\mu g/m^3$) = concentration of VOC ($\mu g/m^3$) × MIR……………………………………...2.3

In this study, the contribution of VOC to O_3 formation is based on Maximum Incremental Reactivity (MIR) provided by Carter 2010(SAPRC-07) and update revised MIR-12 of Aromatic compounds by Carter and Heo,2012(SAPRC-11).

To give better simulations of recent environmental chamber experiments, the representation of the gas-phase atmospheric reactions of aromatic hydrocarbons in the SAPRC-07 (Statewide Air Pollution Research Centre-07) mechanism has been updated and revised by Carter and Heo, 2012. Because the SAPRC-07 mechanism consistently under-predicted NO oxidation and O_3 formation rates observed in recent aromatic-NO_x environmental chamber experiments carried out using generally lower reactant concentrations than the set of experiments used to develop SAPRC-07 and earlier mechanisms by Carter and Heo, 2012. The new aromatics mechanism, designated SAPRC-11 (Statewide Air Pollution Research Centre-11), was evaluated against the expanded chamber database and gave better simulations of ozone formation in almost all experiments was found except for higher (>100 ppb) NOx benzene and (to a lesser extent) toluene experiments where O_3 formation rates were consistently over-predicted(Carter and Heo, 2012). Carter and Heo (2012) found that the over-prediction can be corrected if the aromatics mechanism is parameterized to include a new NO_x dependence on photo-reactive product yields because it is inconsistent with available laboratory data that parameterization was not incorporated in SAPRC-11. Carter and Heo (2012) found that the new version incorporates a few minor updates to the base mechanism concerning acetylene, glyoxal and acyl peroxy+HO_2 (hydroperoxyl radical), incorporates modifications and readjustments to the parameterized mechanisms representing reactive ring-opening products and has new parameterized mechanisms for phenolic compounds but otherwise is the same as SAPRC-07. It is found that the new mechanism gives up to~15% higher ozone concentrations under maximum incremental reactivity (MIR) conditions and gives ~0-50% higher MIR values for most aromatic compounds and much higher reactivates for benzene and phenolic compounds(Carter and Heo, 2012). On the other hand, Carter and Heo (2012) also found that the mechanism revision has relatively small effects on O_3 predictions under NO_x limited conditions, and the MIR values for non-aromatic compounds are not significantly affected.

The Table 2.1 provides the incremental reactivity's of the 17 aromatic compounds whose mechanisms were developed by Carter and Heo, 2012, calculated both with the SAPRC-11 and SAPRC-07 mechanisms. Results are shown for both the "averaged conditions" MIR scenario and the standard MIR scale, which are the averages of the reactivities in the city-specific MIR scales. According to Carter and Heo, 2012, the differences between the "averaged conditions" and the actual MIR values are very small, and that the changes in the averaged conditions MIR values gives a good approximation of the actual MIR values calculated using all the city specific MIR scenarios.

Table 2.1 SAPRC-11 and SAPRC-07 MIR values calculated for the aromatic compounds whose mechanisms were developed for the project by Carter and Heo, 2012.



Compound	Averaged Conditions MIR [a,b]			Standard MIR [a,c]		
	SAPRC-11	SAPRC-07	Change	SAPRC-11	SAPRC-07	Change
Benzene	1.46	0.73	99%	1.43	0.72	99%
Toluene	5.42	4.09	33%	5.30	4.00	32%
Ethyl Benzene	4.21	3.10	36%	4.12	3.04	36%
n-Propyl Benzene	2.90	2.06	40%	2.84	2.03	40%
Isopropyl Benzene	3.71	2.56	45%	3.63	2.52	44%
m-Xylene	10.70	10.02	7%	10.37	9.75	6%
o-Xylene	8.97	7.83	15%	8.73	7.64	14%
p-Xylene	7.42	5.99	24%	7.21	5.84	23%
m-Ethyl toluene	8.66	7.59	14%	8.41	7.39	14%
o-Ethyl toluene	6.93	5.72	21%	6.75	5.59	21%
p-Ethyl toluene	5.75	4.55	27%	5.60	4.44	26%
1,2,3-trimethylbenzene	11.78	12.32	-4%	11.41	11.97	-5%
1,2,4-trimethylbenzene	9.65	9.12	6%	9.35	8.87	5%
1,3,5-trimethylbenzene	11.25	12.13	-7%	10.87	11.76	-8%
Phenol	8.54	2.87	198%	8.25	2.76	199%
o-Cresol	9.57	2.50	283%	9.17	2.40	282%
2,4-Dimethyl phenol	9.86	2.21	346%	9.40	2.12	343%

[a] Units are grams O_3 per gram VOC

[b] Incremental reactivities in the single "averaged conditions" MIR scenario.

[c] Averages of incremental reactivities in the 39 city-specific MIR scenarios.

Source: http://www.engr.ucr.edu/~carter/SAPRC/saprc11.pdf

CHAPTER THREE: MATERIALS AND METHODS

3.1 Sample Preparation

3.1.1 Tenax TA tube description

Marks International Limited stainless steel sorbent tubes are suitable across a wide range of compound types and atmospheric concentrations for the majority of VOC air monitoring applications (Markes International Limited, 2014). Markes International Limited stainless steel sorbent tubes (Tenax TA) were used to sample ambient air by pump. The outer diameter of the tubes were 1/4-inch; length 3.5-inch; 200mg Tenax TA; mesh size 35/60 (Markes, Llanstrisant, UK). Tenax TA is a porous polymer resin based on 2,6-diphenylene-oxide (SIS, 2014). The physical properties of Tenax TA adsorbent resin are temperature limit 350°C with $35m^2/g$ specific surface area and 60/80 mesh size; $2.4cm^3/g$ pore volume and $0.25g/cm^3$ density (SIS, 2014). The tubes are closed with brass closure caps containing white Teflon ferrules (Alltech SF-400T) airtight seal for storage. The sampling side for each tube is indicated by an external groove. According to Markes International Limited, the Tenax TA tube can be recycled about 100 times.

3.1.2 Conditioning of Tenax TA tubes

On 24 June 2013, a total 42 Tenax tubes were conditioned for 1h using a continuous flow of 22-34mL/ min of pure helium (He) gas at elevated temperature of 300°C in an oven to clean the tubes and remove all residuals. Helium gas (less than 1ppm of oxygen) was used because oxygen can be detrimental to the adsorbent (SIS, 2014). Maximum nine and minimum six desorption tubes were conditioned during one run. During conditioning the tubes were attached to the oven with heat resistant black ferrules. After conditioning, the tubes were warped with aluminium foil and stored them in desiccator.

3.1.3 Preparation of closed two-phase system (CTS)

On 24 June 2013, Gaseous standards were prepared by preparing a closed two-phase system (CTS). In CTS a stock solution containing 223.68ng/µL of $^2H_8$Toluene (Tol-d_8) was used that was prepared on 07 December 2011 by dissolving 24µL of Tol-d_8 (Figure 3.1) in 100mL methanol (MeOH). The stock solution was stored in the dark at temperature of -18°C. The stock solution was kept half an hour at room temperature before use. To prepare the CTS 20µL of stock solution was added to 20mL of deionized water present in 119.8mL glass bottle. The bottle was gas tightly sealed with a minimart valve and wrapped into aluminium foil. The CTS was incubated in a thermostatic water bath at 25.01 ± 0.2°C for at least 12h (Figure 3.2).

3.1.4 Loading with internal standard (Tol-d_8)

On 25 June 2013, all tubes were loaded with Tol-d_8. At first 0.5mL of headspace was taken from the CTS with 0.5mL gastight pressure-Lock VICI precision analytical syringe. Then the desired volume was loaded on to the sorbent tubes through a homemade heated (150°C) injection system flushed with He flow rate of 100mL/min (Figure 3.3). Finally, the He stream was held on for 3 minutes before the tubes were sealed with .inch brass long-term storage end caps, equipped with inch one – piece PTFE ferrules.

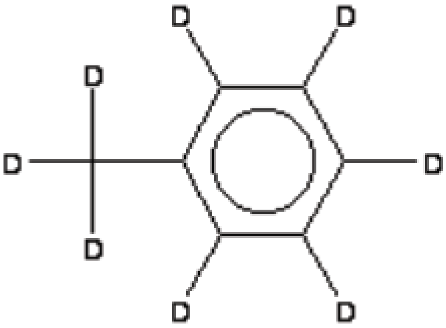


Figure: 3.1 Chemical structure of Tol-d_8 (NIST, 2013)

Figure: 3.2 Closed two-phase system (CTS)

Figure: 3.3 Loading with internal standard

3.1.5 Calculation of mass of the internal standard (IS)

By computing the total mass and Henry's law coefficient of Tol-d_8 (Demeestere *et al.*, 2008) at a given temperature, and air and water volumes, the headspace concentration of the IS can be calculated from the mass balance at equilibrium.

The mass of Tol-d_8 was used for calculation of the concentration of the sampled VOCs. Stock solution containing 223.68ng/µL of Tol-d_8 was prepared by dissolving 24µL of Tol-d_8 in 100mL of methanol.

The total mass of Tol-d_8 (m_{total}) added in the CTS can be calculated from the Volume (V) and density of the stock (D_{stock}) as equation 3.1

$m_{total} = V \times D_{stock} = 20\text{mL} \times 223.68\text{ng/mL} = 4473.6ng$ ……………………………………...….3.1

Mass balance at equilibrium (equation 3.2)

$m_{total} = m_{water} + m_{air} = (C_{water} \times V_{water}) + (C_{air} \times V_{air})$……………………………………….…..….3.2

Henry constant of Tol-d_8 at 25°C (H = 0.183)

$H = \frac{C_{air}}{C_{water}} = 0.18$ ……………………………………………………………………….3.3

Equation 2.3 can be rewrite as equation 3.4

$$C_{water} = \frac{C_{air}}{0.183} \quad \ldots\ldots 3.4$$

Equation 2.2 can be rewrite as equation 3.5

$$m_{total} = \left(\frac{C_{air}}{0.183} \times V_{water}\right) + (C_{air} \times V_{air}) \ldots\ldots 3.5$$

$$C_{air} = \frac{m_{total}}{V_{water}/0.183 + V_{air}} \ldots\ldots 3.6$$

$$C_{air} = \frac{4473.6ng}{(20mL/0.183) + 99.8mL} \ldots\ldots 3.7$$

Where $V_{water} = 20mL$ and $V_{air} = 99.8mL$
$C_{air} = 21.4ng/mL$

The amount of Tol-d_8 in 0.5mL air in the CTS is= (21.4ng/mL×0.5mL) = 10.7ng

The concentration of Tol-d_8 is 21.4ng/mL therefore 0.5mL air in the CTS contains 10.7ng of Tol-d_8.

3.1.6 Pump calibration

The pump GilAir-3 was used for active sampling (Figure 3.4). The pump was calibrated 20 times both before and after sampling campaigns to check the consistency of the flow rate by using a Primary Flow Calibrator Gilian Gilibrator-2(Figure 3.5). The mean flow of the pump was 93mL/min which was the average of the flow rates of the pump before sampling (mean flow rate 93mL/min) and after sampling campaigns (mean flow rate 93mL/min).

Figure: 3.4 Pump GilAir-3

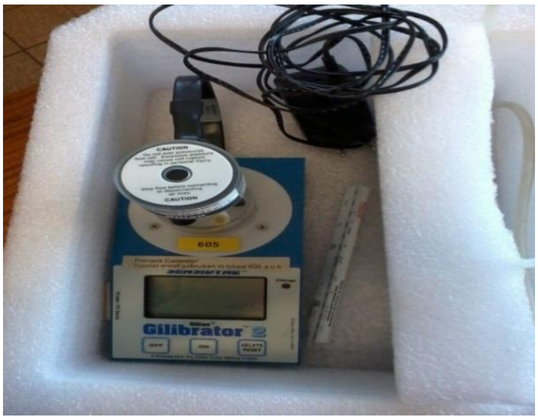


Figure: 3.5 Gilian Gilibrator-2

3.1.7 Sampling technique

Active sampling technique was used to take samples. The samples were collected by pumping the known volume of air by portable pump through a sorbent tube at about 1.5 meters above the ground for outdoor sampling. Roadside samples were taken 15 meters away from the road. With respect to indoor sampling strategies, samplers were placed in the apartment at least 0.6 meter above the floor and below the ceiling, away from windows, doors, at least 0.5 meter away from bookshelves (Jia *et al.*, 2008). The sampling time and the flow rates were 30 minutes and around 93mL/min, respectively for both of the campaign.

3.2 Sampling Campaigns

Bangladesh is a developing country in the South Asia with an area of 147,570 sq. km and situated between 20°34′ to 26°38′ north latitude and 88°01′ to 92°42′ east longitude (http://www.moef.gov.bd). In 2013, the population was estimated at 160 million (http://en.wikipedia.org). The climate is characterized by high temperature and high humidity during most of the year and distinctly marked seasonal variations in precipitation in Bangladesh (Begum, *et al.*, 2006). Based on these meteorological conditions according to Salam *et al.*, 2003, the year can be divided into four seasons, pre-monsoon (March–May), monsoon (June–September), post-monsoon (October–November) and winter (December–February).The capital of Bangladesh is Dhaka (Figure 3.6). Dhaka has an estimated population of more than 15 million people, making it the largest city in Bangladesh and the 8th largest city in the world(http://en.wikipedia.org). Population density of Dhaka is 45,000/km^2 (http://en.wikipedia.org). Dhaka is located in central of Bangladesh at 23°42′0″N and 90°22′30″E (http://en.wikipedia.org). The city lies on the lower reaches of the Ganges Delta and covers a total area of 360 square kilometres (140 sq. mile).

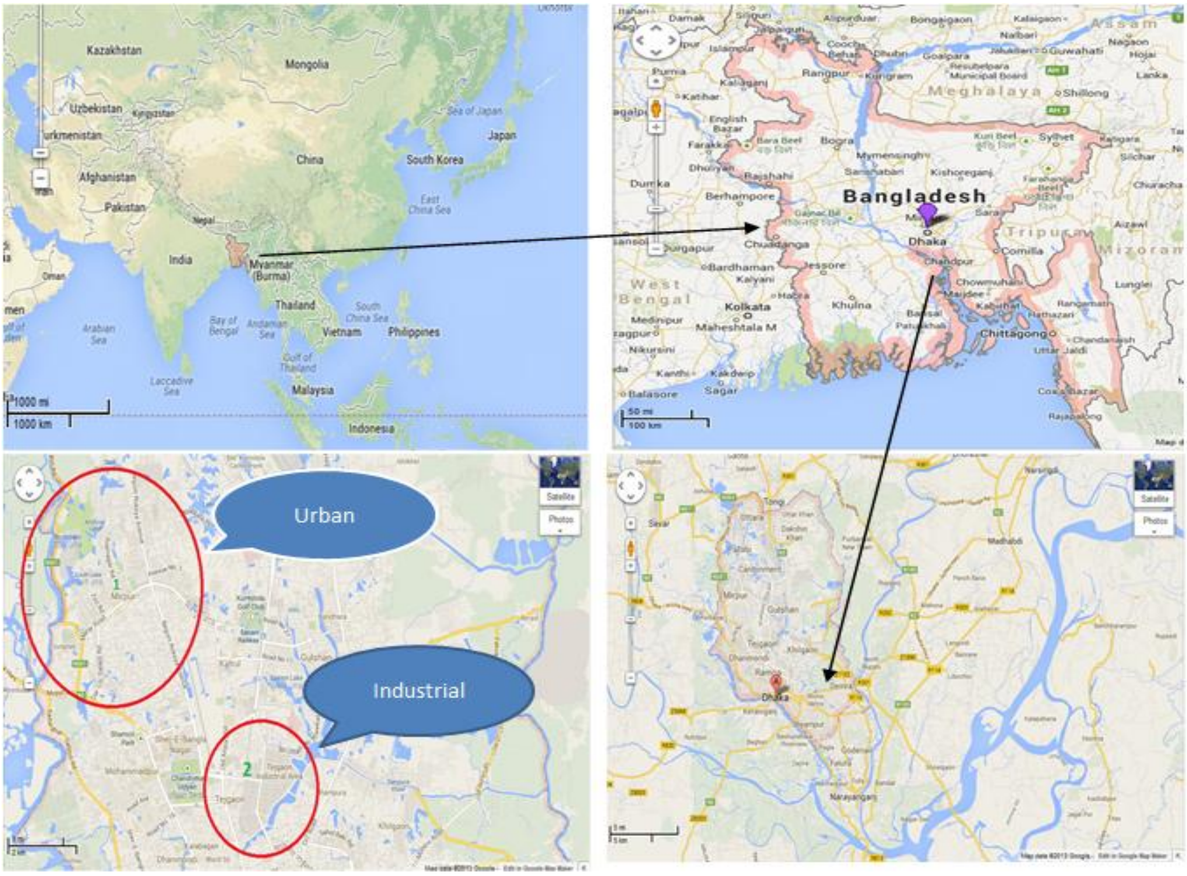


Figure 3.6: Location of campaign sites in Dhaka, Bangladesh: (1) Urban area; (2) Industrial area. Source: https://maps.google.com

Two sampling campaigns were carried out in Dhaka city. One sample campaigns was for urban area and the other one for industrial area of Dhaka city for determination of ambient VOCs levels. Mirpur area was selected as urban area and Tejgaon Area was selected for industrial area for sampling (Figure 3.6). Each sampling campaign has 3 locations both indoor and outdoor. Therefore, six locations were selected in two areas (urban and industrial area) for sampling campaigns from 30 of August 2013 to 11 September 2013(Figure 3.7). The sampling period of Dhaka was under monsoon influence and clean marine air mass are known to govern the area blowing from the south-west between May and September and bringing rain (the *wet monsoon*). During the whole sampling period the temperature was ranged between 28.1°C to 33.3°C and humidity ranged between 92.1% to more than 100%. Sample were taken each day two times-morning and evening (7.00 am to 11.00 am and 4.30 to 8.30 pm) for three days- one weekend and two weekdays for each campaign. Overview of the sampling locations description and date of sampling for the six sampling locations is given in Table 3.1.

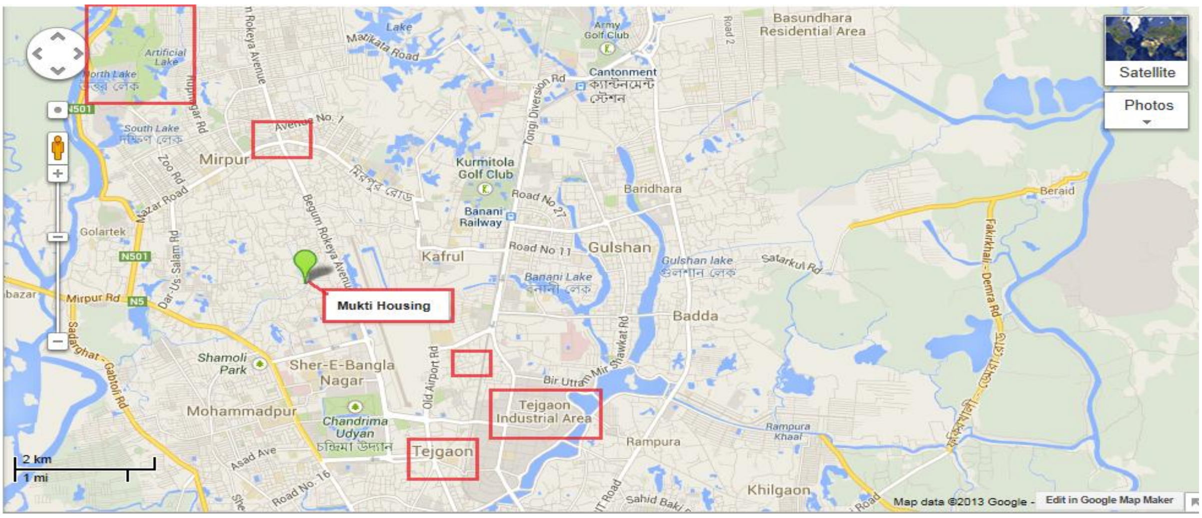


Figure: 3.7 Overview of six sampling locations of both urban (Mirpur) and industrial (Tejgaon) area. Source: https://maps.google.com

Table: 3.1 Sampling locations description and date of sampling for the six sampling locations

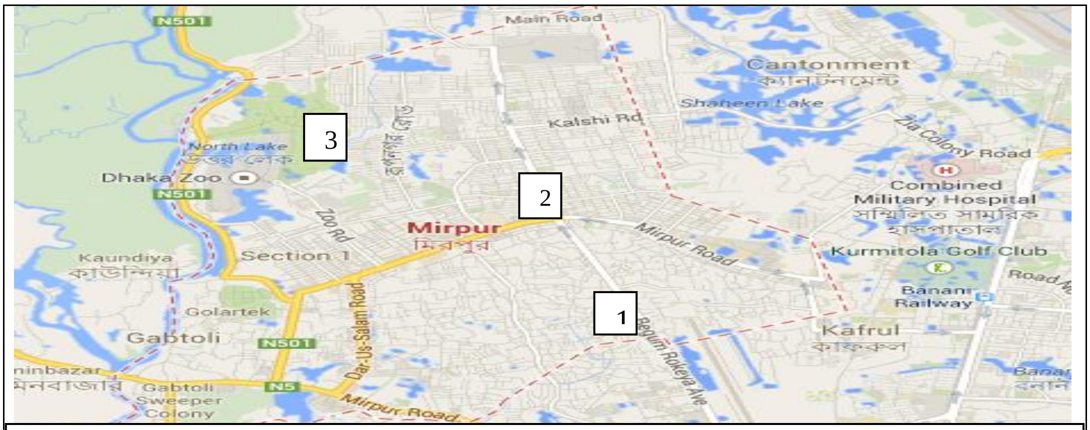
No	Sampling locations		Description of the Sampling locations	Latitude & Longitude	Sampling Date	Time
First campaign	Urban area (Mirpur)	House indoor sample	A apartment of Mukti housing, Agargaon, South Pirerbag, Mirpur. The house is around 1.0km away from main road Begum Rokeya Avenue and Old Air Port	23°47'09.8"N 90°22'22.2"E 23.786052, 90.372845	30/08/13 01/09/13 03/09/13	Morning 7.00 to 11.00 am and Afternoon 4.30 to 8.30 pm
		Roadside outdoor sample	In the office area of Fire Service and Civil Defence at the busy road of Begum Rokeya Avenue and Mirpur road at Mirpur-10 roundabout of Dhaka city	23°48'27.3"N 90°22'05.0"E 23.807583, 90.368056	30/08/13 01/09/13 03/09/13	
		Outdoor park sample	The National Botanical Garden of Bangladesh is located at Mirpur in Dhaka	23°49'17.7"N 90°20'52.6"E 23.821583, 90.347944	30/08/13 01/09/13 03/09/13	
Second campaign	Industrial area (Tejgaon)	House indoor sample	A house of Shahinbag, Nakhalpara, Tejgaon area. The house is about 1.0km away from Old Airport road and about 1.0km from Tejgaon industrial area	23°46'18.5"N 90°23'39.8"E 23.771807, 90.394399	06/09/13 09/09/13 11/09/13	Morning 7.00 to 11.00 am and Afternoon 4.30 to 8.30 pm
		Roadside outdoor sample	Hot spot. Farmgate is one of the busiest roads of Dhaka city. Farmgate is the major transportation hubs of Dhaka which is a junction of Kazi Nazrul Islam Avenue, Indria Road, Khamer Bari Road, Green Road, Holy Cross College road and Farmgate-Tajturi Bazar Road	23°45'31.4"N 90°23'20.8"E 23.758736, 90.389118	06/09/13 09/09/13 11/09/13	
		Ambient outdoor industrial area	In front of the office building of Bangladesh Industrial Technical Assistance Centre (BITAC), Tejgaon industrial Area	23°45'39.3"N 90°24'08.2"E 23.760926, 90.402265	06/09/13 09/09/13 11/09/13	

N.B. Latitude and Longitude of the six locations are taken from https://maps.google.com

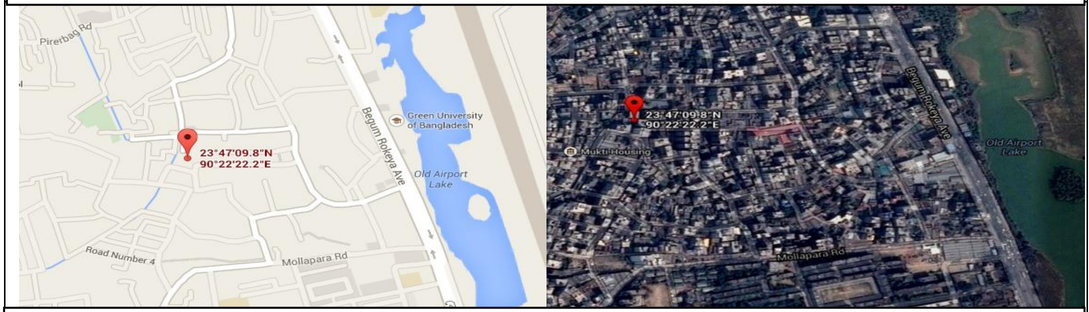
The first week urban sampling was carried out in Mirpur of Dhaka from 30 August 2013 to 03 September 2013 where 30/08/2013 was weekend and both 01/09/2013 and 03/09/2013 were weekdays. Three sampling sites were (i) indoor of a residential apartment of 151/12/1 Mukti housing, Agargaon, South Pirerbag, Mirpur (ii) roadside outdoor-Begum Rokeya Sarani Avenue and Mirpur road, Mipur-10 roundabout and (iii) outdoor park-National Botanical Garden, Mirpur. During the sampling period of urban area, the temperature was ranged between 28.6°C to 33.3°C and humidity ranged between 99.9% to more than 100%.

3.2.1 Urban sampling campaign

Mirpur is a residential area of Dhaka city (Figure 3.8). Its area is about 7.4 km² and population density is 67,618 inhabitants/km² in 2011(www.citypopulation.de , access date 29/9/13). The Dhaka Zoo, the National Botanical Garden of Bangladesh, Sher-e-Bangla Cricket Stadium, the Nobel Prize-winning Grameen Bank’s head office, Mirpur Cantonment and renowned educational institutions, Bangladesh Institute of Bank Management (BIBM) are also located here.

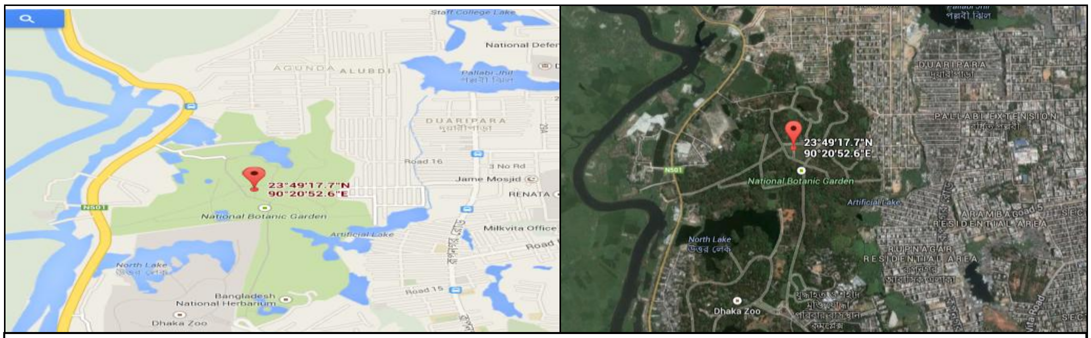


Map of urban sampling (Mirpur Area)



(1) Indoor house: 151/12/1 Mukti housing, Agargaon, South Pirerbag, Mirpur

(2) Roadside outdoor: Begum Rokeya Avenue and Mirpur road, Mipur-10, Dhaka



(3) Outdoor urban park: National Botanical Garden, Mirpur, Dhaka

Figure: 3.8 Map of urban sampling (Mirpur Area). (1) indoor residential apartment 151/12/1 Mukti housing, Agargaon, South Pirerbag, Mirpur (2) roadside outdoor Mipur-10, Dhaka and (3) outdoor park National Botanical Garden. Source: https://maps.google.com

3.2.1.1 Urban indoor house

Urban indoor house sample was taken in Mukti housing which is located at south Pirerbag, Agargaon, Taltola, Mirpur Dhaka. The apartment 151/12/1 of Mukti housing was selected for sampling. It is a six storey building. Sample was taken in 3rd floor and living room of that apartment (Figure 3.9). It was a three room apartment including dining space. Dining space is combined with living room with two balconies. The apartment is 1.0 km away from main road Begum Rokeya Avenue and Old Airport. The house is adjacent of a small link road. The ventilation system was natural and enough. Every room has big window, door and balcony. The family size was three and no one smoke. Chemicals such as aerosol and floor cleaning product were not used except toilet cleaning product, laundry, air freshener and personal care product. Natural gas was used for cooking. The residential area is about 4.0 km away from the place roadside Mirpur-10 roundabout where sample was taken and around 13.0 km away from the park National Botanical Garden of Dhaka.

Figure: 3.9 Sampling of Residential Area in urban area

3.2.1.2 Urban outdoor roadside

Urban outdoor sample was taken in Mirpur-10 roundabout at Begum Rokeya Avenue and Mirpur road which are the busiest roads of Mirpur residential area of Dhaka city. The roadside sample was taken in the office area of Fire Service and Civil Defence Training Complex of Mirpur-10 roundabout, which is adjacent to Begum Rokeya Sarani Road, Dhaka 1216 of Bangladesh (Figure 3.10). Both are the busiest roads in Mirpur area and the transportation hubs. Traffic congestion is a regular senior of this area. For the cricket world cup of 2011, Mirpur's Sher-e-Bangla Cricket Stadium was selected as a venue which is very close of the sampling point.

Figure: 3.10 Sampling Roadside Mirpur-10 in urban sampling

3.2.1.3 Urban outdoor park

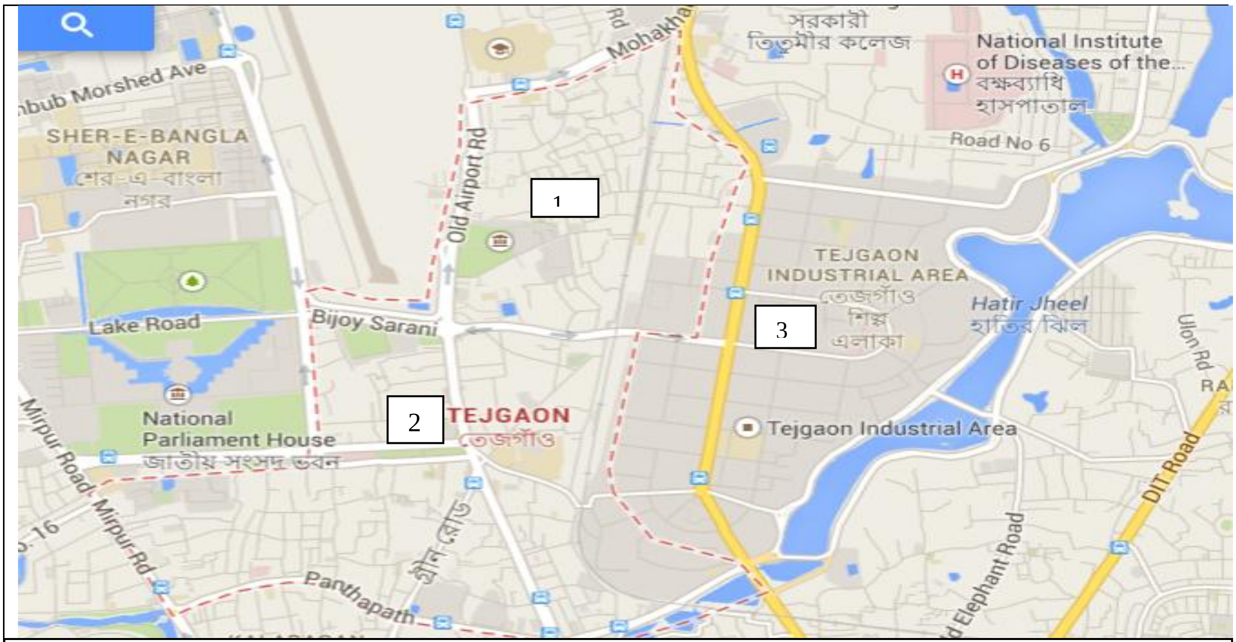
Urban outdoor park sample was taken in the National Botanical Garden of Bangladesh is located at Mirpur in Dhakawhich is the largest plant conservation centre in Bangladesh, with an area of around 84 hectares (210 acres)(http://en.wikipedia.org). It was established in 1961 and beside the Dhaka Zoo of Mirpur (http://en.wikipedia.org). It is situated at 23°49'6"N and 90°20'50"E (http://wikimapia.org). It is one of the greatest botanical gardens of Bangladesh and a tourist destination (Figure 3.11). The garden houses nearly 56,000 species of trees, herbs, and shrubs including a large collection of aquatic plants (http://en.wikipedia.org). It is divided into 57 sections, and is managed by Forest Department under MoEF, Government of Bangladesh (http://en.wikipedia.org).

Figure: 3.11 Sampling in park -National Botanical Garden of Bangladesh

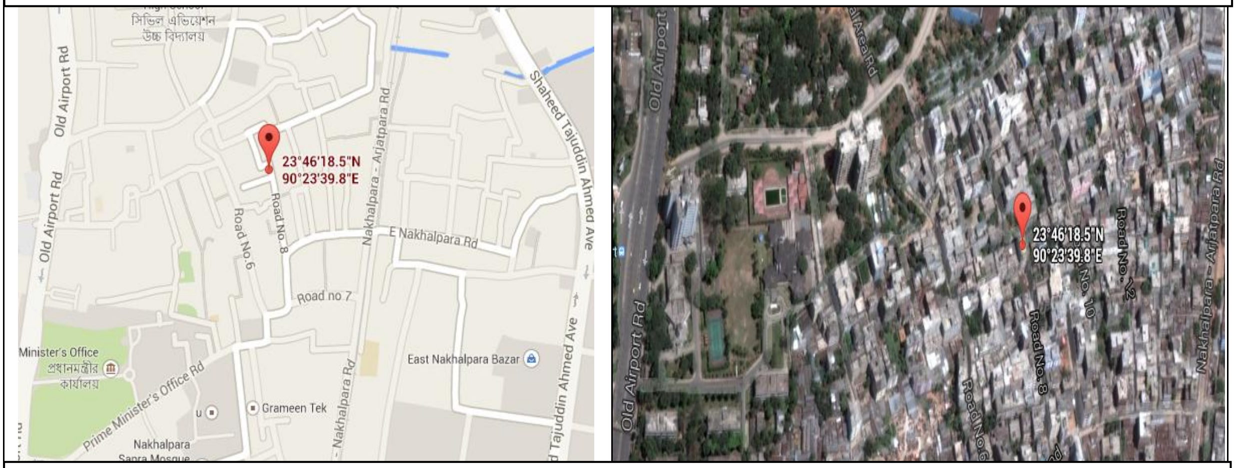
3.2.2 Industrial sampling campaign

The second week industrial sampling was carried out in Tejgaon area of Dhaka from 06 September to 11 September 2013 where 06/09/2013 was weekend and both 09/09/2013 and 110/9/2013 were weekdays. Tejgaon is a large area in the centre of Dhaka, the capital of Bangladesh (Figure 3.12). This is an important area of Dhaka city as prime minister's office is located here. It is bounded by Mohakhali to the north, Old Airport Road to the east and Moghbazar-Malibagh to the south and Dhanmondi to the west. It consists of several localities, including Tejgaon Industrial Area, Kawran Bazar, Nakhalpara, Shaheen Bag, Arjat para, East Rajabazar, West Rajabazar, Tejturi Bazar and Tejkunipara.

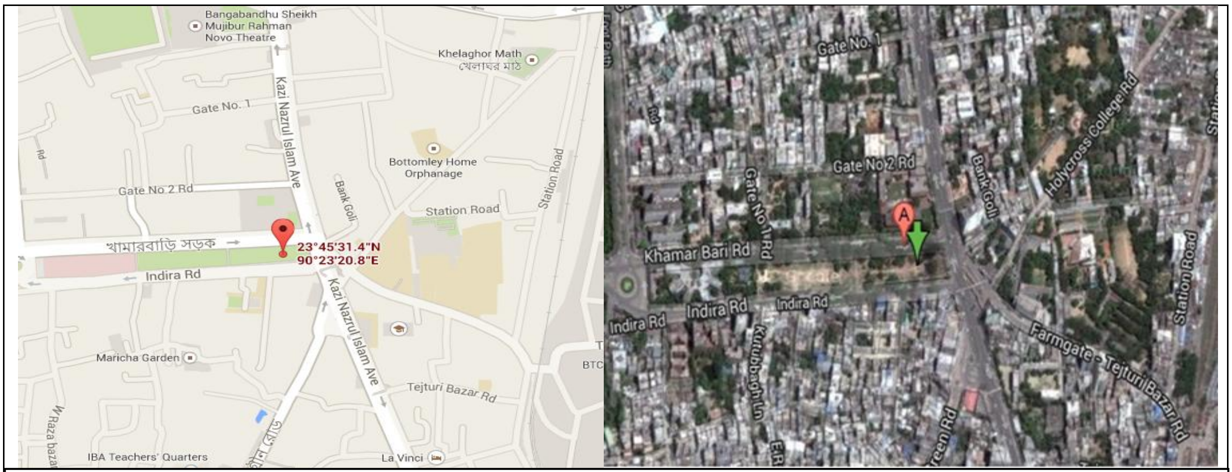
Three sampling sites were (i) the indoor of a residential apartment of 540/1 Shahinbag, Nakhalpara of Tejgaon, (ii) roadside outdoor Farmgate (iii) outdoor industrial ambient in front of office building BITAC (Bangladesh Industrial Technical Assistance Centre), Tejgaon industrial area of Dhaka. During the sampling period of industrial area, the temperature was ranged between 28.1°C to 31.4°C and humidity ranged between 92.1% to more than 100%.



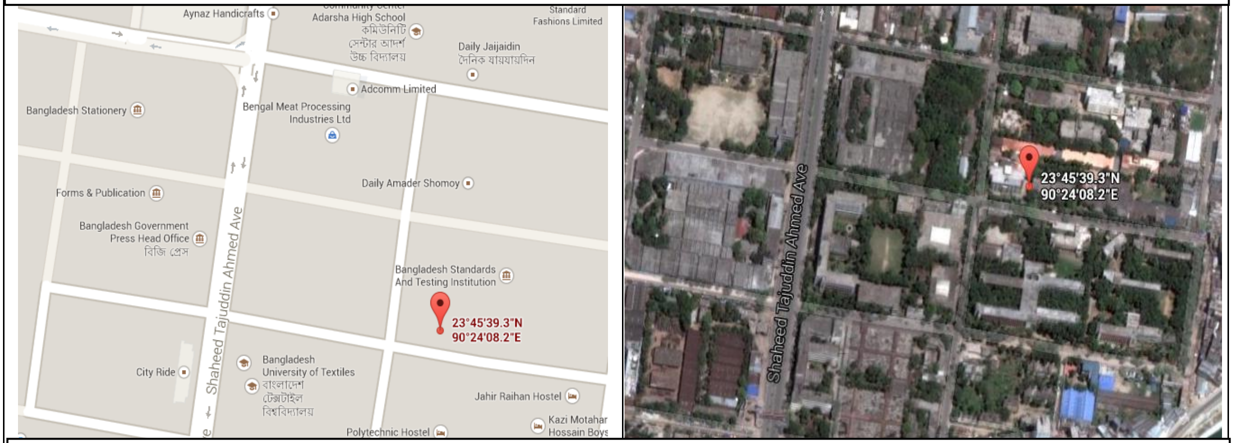
Map of industrial sampling (Tejgaon Area)



(1) Indoor residential apartment 540/1, Shahinbag,Nakhalpar, Tejgaon Area



(2) Roadside outdoor Farmgate, Tejgaon Area, Dhaka



(3) Outdoor industrial ambient Tejgaon industrial area, Dhaka

Figure: 3.12 Map of industrial sampling (Tejgaon Area). (1) Indoor residential apartment 540/1, Shahinbag, Nakhalpar, Tejgaon Area (2) Roadside outdoor Farmgate, Tejgaon Area and (3) Outdoor industrial ambient Tejgaon industrial area, Dhaka. Source: https://maps.google.com

3.2.2.1 Industrial indoor house

Industrial indoor house sample was taken in the apartment 540/1 in Shahinbag, Nakhalpara of Tejgaon residential area (Figure 3.13). It is a six storey building. Sample was taken in 3rd floor of that apartment and in the living room which is combined with dining space.

Figure 3.13: Industrial indoor house sampling (540/1 Shahinbag, Nakhalpara,Tejgaon)

It was a five room apartment including dining space with five balconies. The apartment was around 1 km away from main road Old Airport road and 1 km from Tejgaon Industrial Area. The family size was 4 and they have a permanent home servant and no one smoke there. Chemicals such as air freshener, aerosols, floor cleaning product, toilet cleaning product, laundry and personal care product were used in that house. Natural gas was used for cooking.

3.2.2.2 Industrial outdoor roadside

Industrial outdoor roadside sample was taken at Farmgate which is an important place and hotspot for air pollution. It is named as Farmgate because there used to be a big farm in the area and the gate of the farm was located on the Mymensingh Road known as Old Airport Road (http://en.wikipedia.org). Farmgate is one of the busiest and most crowded areas of Dhaka city. Farmgate is a busy focal point and nerve in Dhaka City. It has become one of the major transportation hubs of Dhaka city. Bus, CNGs and rickshaws connect Farmgate to all important places in Dhaka City. Traffic jam is a common scene of Farmgate. This is one of the biggest street markets in Dhaka City and everyday large numbers of people gather in Farmgate to conduct business. Beside the market there is a nice small park in this area, which is a good place for the wayfarers to rest and refresh and enjoy themselves where samples were taken (Figure 3.14). Farmgate often remains crowded and thousands of cars, rickshaws, minibus, bus, trucks and motor-cycle remain stranded even for hours. Farmgate is a junction of Kazi Nazrul Islam Avenue, Indria Road, Khamer Bari Road, Green Road, Holy Cross College road and Farmgate-Tajturi Bazar Road.

Figure: 3.14 Industrial Roadside sampling (Farmgate, Tejgaon, Dhaka)

3.2.2.3 Industrial outdoor ambient

This sample site is located in Tejgaon industrial area and sample was taken in front of main gate Bangladesh Industrial Technical Assistance Centre (BITAC) and a heavily trafficked road is 100 meter away from the sampling location (Figure 3.15). Population density is lower compared to the other sampling sites. One of the busiest bus terminals is located within 1 km of the sampling site. Both industrial and motor vehicle sources make an important contribution to long-term and peak concentrations. Bangladesh government printing press, Bangladesh Security Printing Press, Bangladesh Forms and Publishing Press, Essential Drugs

Co. Ltd., Shah Jute Processing Industries Ltd., Bangladesh Rubber Industries, Kohinoor Chemical Industries Ltd., pharmaceutical companies, garments and some other industries are in the vicinity of BITAC. A big metal workshop is also located within the immediate vicinity of the sampling site.

Figure 3.15: Industrial ambient area sampling (BITAC, Tejgaon industrial area)

3.3 Sample Analysis

3.3.1 Loading of calibration mixture

The 4 Tenax TA conditioned tubes were loaded with mixture (Target VOCs + Tol-d_8) 2 USEPA and 2 EnVOC stock solution precision analytical syringe. The desired volume was loaded on to the sorbent tubes through a homemade heated (150°C) injection system flushed with He flow rate of 96 mL/min. The He stream was held on for 3 minute before the tubes were sealed with .inch brass long-term storage end caps equipped with inch one –piece PTFE ferrules.

3.3.2 Calibration of the TD-GC-MS

The first thermal desorption-gas chromatography-mass spectrometry(TD-GC-MS) calibration was carried out in the EnVOC lab on 26 September 2013 but that calibration was rejected because of technical problem. Second one was done on 7 February 2014. Two mixtures were used for the calibration of the TD-GC-MS. The first mixture was EPA 502/524 Volatiles Organic Calibration Mix A (without gases) 200µg/mL each component in 1mL methanol, analytical standard (www.sigmaaldrich.com) containing 53VOCs. The first mixture were volumetrically taken by a micropipette and dissolved and further diluted in methanol (LC–MS grade, 99.95%, Biosolve, Valkenswaard, The Netherlands) to obtain final concentrations of 50ng/µL for each individual target compound for each VOC in Mix A (Tol-d_8 in MixA: 69.9ng/µL). The second mixture (Mix B) containing 31 target VOCs was prepared in the same way as documented in the previous study (Do *et al.*, 2013). The final concentrations in this case range from 32.7 to 54.4ng/µL for the target VOCs (Tol-d_8 in MixB: 46.6ng/µL). Target compounds were purchased having a purity of at least 99.8%. [$^2H_8$]Toluene (Tol-d_8; 99.5+ atom%D; Acros Organics, Geel, Belgium) was used as an internal standard. The detail information can be further seen in Table 3.2 in Appendix.

3.3.3 Analysis of Tenax TA sampling tubes

After sampling on 26, 27 and 30 September 2013 all the Tenax TA tubes used for the sampling were analysed by using TD-GC-MS system using the method described by Do *et al*. (2013)(Figure 2.16).

Figure 3.16: Thermal Desorption (TD)-Gas Chromatography (GC)-Mass Spectrometer (MS)

In a Unity Thermal Desorption system, desorption of the analytes pre-concentrated on the Tenax TA sorbent tubes were performed (Markes, Llantrisant, UK). Each Tenax TA tube was closed in the TD system by two special caps. Desorption process was done at 50°C for 1 min and then at 260°C for 7 min. Analytes were refocused on a microtrap filled with 22mg of Tenax TA and 34mg of Carbograph 1TD sorbent (volumetric ratio 50/50), cooled at −10°C. The temperature was rapidly raised up to 280°C within 3 min. The analytes were then carried by a He flow and injected onto a 30 m Factor Four VF-1 ms low bleed bounded phase capillary GC column (Varian, Sint–Katelijne–Waver, Belgium; 100% polydimethylsiloxane, internal diameter 0.25mm, film thickness 1μm), after splitting the He flow at a ratio of 1:5. The column head pressure was set at 45kPa, resulting into a flow of 1.0mL/min (at 33°C) through the GC column. The vent flow rate, controlled by a mass flow controller built in the Unity Thermal Desorption device, was measured to be 5.211 ± 0.007mL/min (n = 3) using a Gilian Gilibrator 2 flow calibration system (Sensidyne, FL, USA). The GC (Trace 2000, Thermo Finnigan, Milan, Italy) oven temperature was initially set at 35°C. The temperature in the GC was increased gradually up to 220°C in four stages. The temperature was ramped from 35°C to 60°C at a heating rate of 2°C/min during in the first phase. Temperature was then increased to 170°C at 8°C/min in the second phase. Temperature of 220°C was obtained by heating the GC oven at 15°C/min during the third phase. Finally, this maximum temperature (220°C) was held for 10 min before cooling down to 35°C.

In full scan mode masses from m/z 29 to 300 were recorded (200 ms per scan) on a Trace DSQ Quadrupole MS (Thermo Finnigan, Austin, TX, USA), hyphenated to the GC, and operating at an electron impact energy of 70eV. Chromatograms and mass spectra were processed using X-calibur software (Thermo Finnigan, version 1.4). For quantification, data were processed in both by Selective ion monitoring (SIM) and Total ion current (TIC) mode of chromatogram.

Identification of the VOCs were based on (i) their fragmentation patterns and by comparison of their mass spectra with the US National Institute of Science and Technology (NIST, Gaithersburg, MD, USA) V2.0 database [NIST/US Environmental Protection Agency (EPA)/US National Institutes of Health (NIH) Mass Spectral Library], and (ii) comparison of their retention time with the standards. Therefore, identification of the VOCs were based on chromatogram, mass spectrum, both TIC and SIM mode, Standard Calibration and Library using X-calibur.

3.3.4 Determination of RSRF

In the gas chromatography, the signal output per unit of mass of a substance injected is defined as the sample response factor (SRF) and can be calculated using the equation 3.8.

$$\boldsymbol{SRF_i = \frac{A_i}{m_i}} \text{..} 3.8$$

Where, A_i= the peak area and m_i= the mass (ng) of substance i on the sorbent tube.

The RSRF (relative sample response factor) is the ratio of the sample response factor of the analyte (SRF_a) and the response factor (SRF_{st}) of internal standard of Tol-d_8 as equation 3.9.

$$\mathbf{RSRF} = \frac{\mathbf{SRF_a}}{\mathbf{SRF_{st}}} = \frac{(\mathbf{A_a}/\mathbf{m_a})}{(\mathbf{A_{st}}/\mathbf{m_{st}})} = \left(\mathbf{A_a}/\mathbf{A_{st}}\right) \times (\mathbf{m_{st}}/\mathbf{m_a}) \text{...} 3.9$$

This equation 3.9 can be rewritten as

$$\mathbf{RSRF_{L,L}} = \frac{\mathbf{SRF_a}}{\mathbf{SRF_{st}}} \text{..} 3.10$$

The RSRF$_{L,L}$ (both loaded from liquid phase) and RSRF$_{G,G}$ (both loaded from gas phase) are the same according to Demeestere *et al*. (2008).

$$\mathbf{RSRF_{L,L}} \approx \mathbf{RSRF_{G,G}} = \frac{(\mathbf{A_a}/\mathbf{m_a})}{(\mathbf{A_{st}}/\mathbf{m_{st}})} = \left(\mathbf{A_a}/\mathbf{A_{st}}\right) \times (\mathbf{m_{st}}/\mathbf{m_a}) \text{.............................} 3.11$$

3.3.5 Quantification

3.3.5.1 Mass of the analyte

The mass of the analytic substance will be determined rearranging the equation 3.11

$$\mathbf{m_a} = \frac{\mathbf{A_a \times m_{st}}}{\mathbf{RSRF_i \times A_{st}}} \text{..} 3.12$$

Where m_a = mass of analytic compound (ng), m_{st} = mass of internal standard of Tol-d_8 (10.7ng), A_a =the peak area of the analyte and A_{st} = the peak area of the internal standard, and the RSRF$_{L,L}$ from the calibration of TD-GC-MS.

Whenever a component was quantified in the blanks, a blank correction has been performed by subtracting the quantified amount of the analyte in the blanks from the mass quantified in the sampling tubes.

3.3.5.2 Concentration of the analyte

The concentration of the analytic compound of the air drawn into the sampling tubes (C_a) can be calculated as:

$$\mathbf{C_a = \frac{m_a}{Q \times t} = \frac{m_a}{V}} \text{……………………………………………………………………..3.13}$$

The concentration of the analyte C_a was determined by dividing the calculated mass of the analyte (ma) in the sampling tube by the volume of the air (V). The volume of the air (V) is the product of the volumetric flow rate of the air sampler and the sampling time. In this study, sampling time was 30 min and during sampling flow rate was around 93mL/min. Therefore, the volume of the air (V) was about 2790mL.

3.3.5.3 Determination of LOD and LOQ

Limits of detection (LOD) and limits of quantification (LOQ) have been defined on the basis of the signal to noise ratio (S/N) of the peak of a component in the SIM (Selective ion monitoring) chromatogram. For estimating LOD a signal to noise ratio (S/N) greater than three was accepted and for LOQ a signal to noise ratio (S/N) greater than ten was accepted in the calculation as equations 3.14, 3.15, 3.16 and 3.17.

$$\mathbf{LOD_{mass}} = \frac{\mathbf{3\times} \boldsymbol{m_a}}{\mathbf{(S/N)}} \text{ where (S/N) of the analyte >3 ………………………………………….3.14}$$

$$\mathbf{LOQ_{mass}} = \frac{\mathbf{10\times} \boldsymbol{m_a}}{\mathbf{(S/N)}} \text{ where (S/N) of the analyte >10……………………...…...................3.15}$$

Where m_a = mass of the analyte in sample & signal to noise ratio (S/N) of the analyte

$$\mathbf{LOD_{con}} = \frac{\mathbf{3\times} \boldsymbol{C_a}}{\mathbf{(S/N)}} \text{ where (S/N) of the analyte >3 ……………………………..………..3.16}$$

$$\mathbf{LOQ_{con}} = \frac{\mathbf{10\times} \boldsymbol{C_a}}{\mathbf{(S/N)}} \text{ where (S/N) of the analyte >10……………………………….………3.17}$$

Where C_a = concentration of the analyte in sample and signal to noise ratio (S/N) of the analyte.

There are several terms that have been used to define the LOD and LOQ. The LOD is taken as the lowest concentration of an analyte in a sample that can be detected, but not necessarily quantified, under the stated conditions of the test. The LOQ is the lowest concentration of an analyte in a sample that can be determined with acceptable precision and accuracy under the stated conditions of test.

3.3.6 Statistical Analysis

Data quantification, analysis and graphical presentation were done using Excel and S-plus statistical software package (Spotfire S+ 8.2). The S-plus statistical software package was used to determine the statistical significant difference among the concentration levels and the correlation analysis among the VOC concentration. The non-parametric Kruskal-Wallis test (two-sided) was conducted to examine site differences considering the sample was not perfectly normally distributed and independent samples. If the difference was found to be significant ($p<0.05$), pairwise multiple comparison tests were followed with the significance determined by Bonferroni's corrected alpha (0.05/6=0.0083).

3.3.7 Quantitative concentration profiles

1. TVOCs considering Safe Sampling Volume (SSV)
There are some of the target VOCs has the SSV smaller than the sampling volume 2790mL. The TVOCs is the sum of 39 VOCs. The calculation of TVOCs has done by considering Safe Sampling Volume (SSV) of Marks International, Breakthrough Volume (BTV) of Scientific Instrument Services (SIS) and update data. For quantification, to calculate the SSV, we have used the equation (3.18).

SSV= BTV/2…………………. ……………………………………………………………(3.18)

2. As during calibration, it was not possible to separate the compounds m- xylene and p-xylene as two different compounds for their close structure. The calculation of RSRF was done using double mass (50ng×2=100ng) of m, p- xylene. So, the combined concentration of the two compounds represents in the calculation of TVOCs as one single concentration of m, p- xylene.

3. Update data used calculation of OFP using the update standard MIR-10(SAPRC-07) and MIR-12(SAPRC-11) for aromatic compounds of Carter, 2010 and Carter and Hoe, 2012. In this study, the two compounds m-Xylene and p-Xylene are not separate each other and the concentrations presented as the sum of the two compounds as the gas chromatogram used in this study cannot separate these two compounds. The sum of m-Xylene and p-Xylene was separated as m-Xylene/p-Xylene equal to 2.33 according to Carla *et al.*, 2014 and Monod *et al.* 2001 because their MIR for O_3 production are not same.

CHAPTER FOUR: RESULTS AND DISCUSSIONS

In this chapter, the results of the VOCs identification and quantification analysis are presented. Data are interpreted, presented, discussed and compared in terms of **T**otal **V**olatile **O**rganic **C**ompounds (TVOCs), subgroup of TVOCs; **B**enzene, **t**oluene, **e**thylbenzene, and **x**ylene (BTEX) levels; **I**ndoor-to-**O**utdoor ratio(I/O); **S**ource identification based on diagnostic ratios and correlations coefficient and **O**zone **F**ormation **P**otential (OFP) based on update **M**aximum **I**ncremental **R**eactivity scale (MIR, 2010 full scale and MIR, 2012 for aromatic compounds).

4.1Qualitative analysis

As mentioned in chapter three, among the 84 target compounds, there are 53 VOCs from the mix of USEPA. The 84 target compounds can be divided into 5 groups of VOCs which included 12 VOCs as (cyclo)-alkanes, 17 VOCs as aromatic compounds, 12 VOCs as oxygenated compounds, 39 VOCs as halogenated compounds and 4 VOCs as terpenes. Among the 84 targets compounds 40 VOCs never detected (ND) in this study. The VOCs that were not detected (ND) in any samples of the two sampling campaign are mentioned separately in the Table 4.1. The VOCs that are either quantified or detected (D) are mentioned in the Table 4.2.

Table 4.1: Not Detected (ND) compounds (40 VOCs)

Name of the Not Detected (ND) compounds

- 1,1-Dichloroethylene
- trans-1,2-Dichloroethylene
- 1,1-Dichloroethane
- tert-Butyl_methyl_ether
- cis-1,2-Dichloroethylene
- Bromochloromethane
- 2,2-Dichloropropane
- 2-methyl-1-propanol
- 1,1,1-Trichloroethane
- 1,1-Dichloro-1-propene
- Isopropylacetate
- 1-Butanol
- 1,2-Dichloropropane
- Dibromomethane
- Bromodichloromethnae
- Trichloroethylene
- cis-1,3-Dichloropropene
- trans-1,3-Dichloropropene
- 1,1,2-Trichloroethane
- 1,3-Dichloropropane
- Isobutylacetate
- 2-Hexanone
- Dibromochloromethane
- 1,2-Dibromoethane
- Tetrachloroethylene
- Chlorobenzene
- 1,1,1,2-Tetrachloroethane
- 1,1,2,2-Tetrachloroethane
- 1,2,3-Trichloropropane
- Bromobenzene
- 2-Chlorotoluene
- 4-Chlorotoluene
- tert-Butylbenzene
- 1,3-Dichlorobenzene
- n-Butylbenzene
- 1,2-Dibromo-3-chloropropane
- Linalool
- 1,2,4-Trichlorobenzene
- Hexachloro-1,3-butadiene
- 1,3,5_triisopropylbenzene

Table 4.2: Quantify/Detected (D) VOCs (44 VOCs)

Name of the Quantified/Detected(D) VOCS(Quantified:√; Not quantified:×)					
Dichloromethane	×	Heptane	√	1,3,5-Trimethylbenzene	√
2-methylpentane	×	Toluene	√	Beta-pinene	√
2-Butanone	√	Hexanal	√	1,2,4-Trimethylbenzene	√
3-Methylpentane	×	Octane	√	Decane	√
Hexane	√	Ethylbenzene	√	1,4-Dichlorobenzene	√
Ethyl_acetate	√	m,p-Xylene	√	sec-Butylbenzene	√
Chloroform	×	Styrene	√	2-Ethyl-1-hexanol	√
Methylcyclopentane	√	Heptanal	√	p-Isopropyltoluene	√
1,2-Dichloroethane	×	o-Xylene	√	1,2-Dichlorobenzene	√
Benzene	√	Nonane	√	Limonene	√
Carbon_tetrachloride	√	Isopropylbenzene	√	Methylbenzoate	√
Cyclohexane	√	Alpha_pinene	√	Undecane	√
3-Pentanone	√	Benzaldehyde	√	Naphtalene	√
2,2,4-trimethylpentane	√	Propylbenzene	√	Dodecane	√
				1,2,3-Trichlorobenzene	√

A total set of 44 VOCs consisting of alkanes, aromatic compounds, halogenated compounds, oxygen containing compounds and terpenes were identified from the six sampling sites. The quantification has done by excluding 5 compounds (Dichloromethane, 2-methylpentane, 3-Methylpentane, Chloroform and 1,2-Dichloroethane) as the compounds has SSV less than the sample volume 2290mL documented in Table A 4.1 in the Appendix.

4.2 Quantitative Analysis

4.2.1 Concentration levels of VOCs

An overview of the measured compounds of the six sampling sites is given in the Table 4.3. The summary quantification of 39 VOCs with statistical analyses is mentioned separately for each site in the Appendix (Table A4.2 to Table A4.7in the Appendix). The VOCs which have a SSV smaller than the sampling volume (2790mL) or not detected (ND) did not report in the Tables (Table A4.2 to Table A4.7 in the Appendix). The detail and actual concentrations levels each day per site can be found in the Appendix A to B.

Table 4.3: An overview of the quantify VOCs groups mean concentration (µg/m^3) in six sampling sites of Dhaka city

Compound Group	Urban Area(Mirpur) Dhaka			Industrial Area(Tejgaon) Dhaka		
	Indoor Urban house	Outdoor Urban Roadside	Outdoor Urban Park	Indoor Industrial House	Outdoor Industrial Roadside	Outdoor Industrial Ambient
	Arithmetic mean concentration (µg/m^3)					
Total Alkanes	8.70	14.03	3.73	13.67	17.32	15.58
Total Cyclo-alkanes	4.06	4.82	1.17	5.87	6.62	5.81
Total (Cyclo)-alkanes	12.76	18.84	4.89	19.54	23.94	21.39
Total Aromatic compounds	30.33	37.00	11.76	47.15	53.27	49.51
Total Aldehyde	4.13	3.06	5.18	4.18	5.07	2.24
Total Alcohols	3.00	2.52	2.14	0.95	1.78	1.15
Total Ketones	0.78	0.83	0.56	1.56	1.68	1.65
Total Esters	2.88	3.80	2.91	8.14	8.77	3.47
Total Oxygenated compounds	10.79	10.21	10.78	14.83	17.30	8.51
Total Halogenated compounds	0.39	0.32	0.28	0.48	0.53	0.33
Total Terpenes	0.57	0.53	0.37	1.83	0.95	0.94
TVOCs	54.84	66.90	28.08	83.83	95.99	80.36

From the overview of summary Table 4.3 it can be observed the contribution of the different VOC groups ((cyclo-) alkanes, aromatic hydrocarbons, halogenated compounds, oxygen containing hydrocarbons and terpenes) to grand total TVOCs. It can be noted that among the VOCs identified, the aromatic compounds has the highest contribution (mean concentration around 11.76µg/m^3 in urban park to around 53.27µg/m^3 in industrial roadside) in all the sampling sites in both areas where toluene has the highest contribution (mean concentration around 4.64µg/m^3 in urban park to around 21.94µg/m^3 in industrial roadside) among the 39 VOCs in all the six sampling sites (Table 4.3). The relative high contribution of toluene in the roadside environment may be related to vehicular emissions (Balanay and Lungu, 2009). Total (cyclo)-alkanes accounted for the next most abundant group in all sites except in the urban park where a relatively higher level of total aldehydes(mean concentration around 5.18µg/m^3) was observed. Among total (cyclo)-alkanes subgroups total alkanes has the second highest contribution (mean concentration around 3.73µg/m^3 in urban park to around

17.32µg/m^3 in industrial roadside). The total oxygenates (e.g., total aldehydes, total alcohols, total ketones, and total esters) has the third highest contribution (mean concentration around 8.51µg/m^3 in industrial ambient to around 17.30µg/m^3 in industrial roadside) in all the places except in the urban park. In the urban park, total oxygenates compounds has the second highest contribution (mean concentration around 10.78µg/m^3). In the urban park, benzaldehyde was also dominant and as mentioned before in all the sites toluene was dominant compound which can be possibly ascribed to the formation of benzaldehyde in the air through photochemical oxidation of toluene and other aromatic hydrocarbons (Han *et al.*, 2003; HSDB, 2011). The highly reactive VOCs from vehicular emissions have reacted, dispersed and diffused to lower concentration areas. The contribution of total terpenes in the TVOCs also detected which has fourth level of contribution (mean concentration around 0.37µg/m^3 in urban park to around 1.83µg/m^3 in industrial house). Total halogenated compounds were also found in all sampling sites but it has very low contribution (mean concentration around 0.28µg/m^3 in urban park to around 0.53µg/m^3 in industrial roadside) in all sites.

4.2.2 Ambient mean TVOCs in urban and industrial environment

The Table 4.4 give an overview of the Total Volatile Organic Compounds (TVOCs) which is the sum of the quantified 39VOCs, mean TVOCs with standard deviations at six sampling sites both indoor and outdoor environments in the urban and industrial area of Dhaka city, Bangladesh which is based on six samples each site. It can be observed from the Table 4.4 that the TVOCs concentrations levels are higher in industrial areas (mean concentration around 83.84-95.99µg/m^3) compare to urban areas (mean concentration around 28.09-66.90µg/m^3).

Table 4.4: An overview of the TVOCs (∑39 VOCs), mean TVOCs and standard deviation

Sampling locations	TVOCS concentrations in µg/m^3						Mean TVOCs	Standard deviation
	Weekend (am)	Weekend (pm)	Weekday (am)	Weekday (pm)	Weekday (am)	Weekday (pm)		
Urban house(indoor)	54.49	56.15	52.68	54.02	42.94	68.75	54.84	8.27
Urban street(outdoor)	51.71	74.76	43.95	102.01	53.91	75.09	66.90	21.39
Urban park (outdoor)	16.38	51.46	17.37	32.06	13.74	37.52	28.09	14.89
Industrial house(indoor)	64.70	95.25	90.21	99.28	81.84	71.74	83.84	13.61
Industrial street(outdoor)	77.92	150.69	77.41	68.45	78.54	123.03	95.99	33.04
Industrial ambient(outdoor)	30.47	130.39	33.77	113.73	55.86	119.95	80.70	45.70

The overview Table 4.4 of the 36 samples reveals the information that the TVOCs concentrations level was lower in the morning compare to evening that indicate the temporal diurnal variation of emission sources. The large difference of TVOCs concentration illustrates the dependence of concentration on the local source in the two sampling areas with diurnal variation of emission sources. In the study done by Jeeranut *et al.* (2012) in Dhaka city found that emissions from gasoline and CNG-fuelled vehicles were dominant during the day time and emissions from diesel fuelled vehicles became significant during the night time. Moreover Jia *et. al.* (2008) found that outdoors, VOC concentrations are affected by season and temperature (Cheng *et al.*, 1997), proximity to emission sources such as industry, traffic and gas stations, and meteorology, e.g., mixing height, wind speed and precipitation (Kwon *et al*., 2006).

A comparison of the mean TVOCs of the quantified 39 VOCs can be figure out from the Table 4.4 of the six sampling sites of both urban and industrial area. The highest mean concentration level of TVOCs found in industrial roadside around 95.99µg/m^3 and the lowest in urban park around 28.09µg/m^3. Outdoor roadside has the highest mean TVOCs concentration level in both urban and industrial environment, (mean TVOCs concentration in urban street around 66.90µg/m^3 and industrial street 95.99µg/m^3). In both urban and industrial environment, indoor house has the second highest mean TVOCs concentration level. In both urban and industrial environment, outdoor ambient urban park and industrial ambient has the lowest mean TVOCs concentration level.

It is found by Jia *et. al.* (2008) that indoors, concentrations are affected by outdoor levels due to the exchange of indoor and outdoor air (Wallace, 2001), and by the numerous VOC sources present indoors, which include building materials and furnishings (e.g., particle board, underlayment, and carpets), cleaning products, moth repellents, solvents, deodorants, fragrances, and hobby supplies (e.g., paints and glues). It is also found that VOCs are associated with many routine indoor activities, e.g., cooking, cleaning, and painting (Clobes *et al.*, 1992), storing vehicles and fuel in attached garages (Batterman *et al*., 2007), storing and using solvents, and tobacco smoking (Charles *et al*., 2007). In both environment (urban and industrial), indoor concentrations exceed outdoor ambient levels, showing the dominance of indoor sources.

4.2.3 Box plot of TVOCs

From the box plot, the distribution of the measured TVOCs (µg/m^3) of the six sampling locations can be observed the side-by-side TVOCs which were based on 6 samples each location (Figure 4.1). The Figure 4.1 box plot shows the TVOCs indoor and outdoor concentrations varied from place to place in both areas. From the box plot it can be observed that the concentration levels of TVOCs was higher in industrial areas compare to urban areas. Among the 36 samples (N=36), the highest mean of TVOCs was measured in the roadside of the industrial environment (mean: 95.99µg/m^3 and the maximum: 150.65µg/m^3) and the lowest value in the urban park (mean: 28.09µg/m^3 and the minimum: 13.74µg/m^3) among the six sites (Figure 4.1).

In the urban area, among the 18 samples (N=18), the highest TVOCs found in outdoor roadside around 102.01µg/m^3 and mean concentration around 66.90µg/m^3 and the lowest concentration in outdoor urban park around 13.74µg/m^3 with mean concentration of 28.08µg/m^3. Among the 3 sites of urban area, the second highest mean TVOCs concentration found in indoor around 54.84µg/m^3 with the lowest variance (variance: 68.45). More detailed information about summary of statistics including variance of each site VOCs concentration levels are given in the Table A4.8 in the appendix. The mean TVOCs in urban roadside about 2 times higher than the urban background concentration level in urban park. The high TVOCs in roadside related to vehicular emissions (Hwa *et al.,* 2002; Do *et al*., 2013). It is found that

VOCs variability is caused by spatial and temporal changes in emission sources, meteorological parameters, ventilation rates, and other factors (Jia *et al*., 2012).

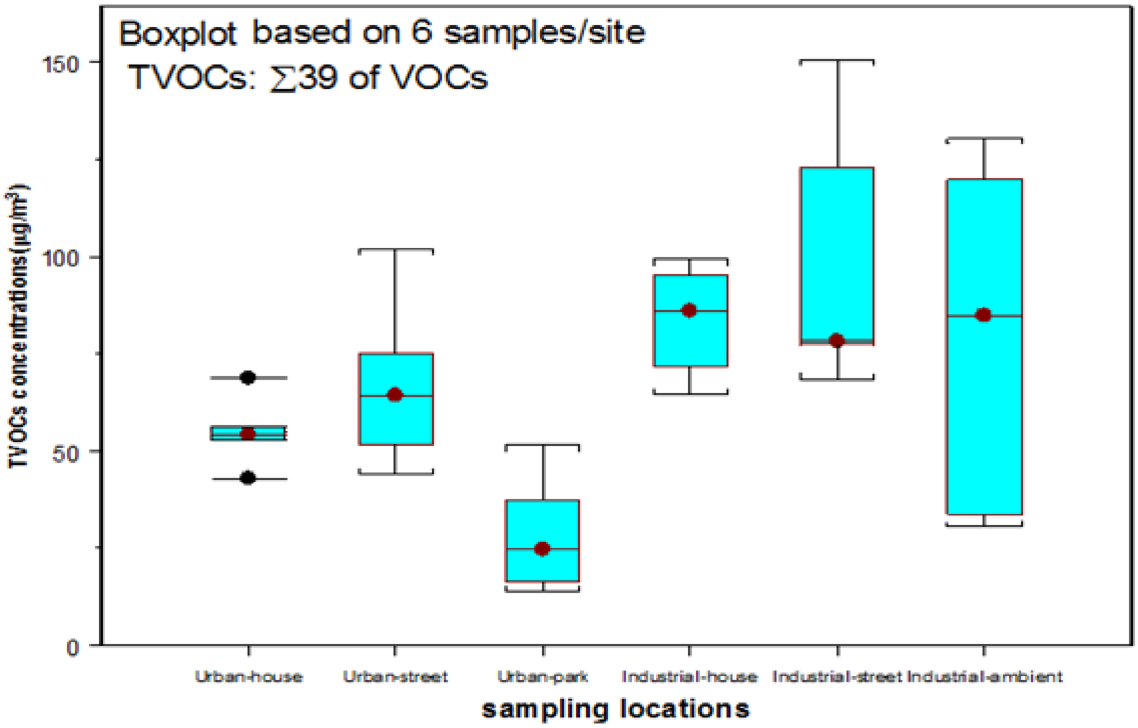


Figure 4.1: Box plots of the measured TVOCs (µg/m^3) of the six sampling locations in Dhaka city (middle line: median, box: 1st quartile (25%)-3rd quartile (75%), whisker: the lowest and the highest value).

In the industrial area among the 18 samples (N=18), the highest TVOCs found in outdoor roadside around 150.69µg/m^3 and mean concentration around 95.99µg/m^3 and the lowest concentration in outdoor industrial ambient around 30.47µg/m^3 with mean concentration of 80.69µg/m^3. Among the 3 sites of industrial area, the second highest mean TVOCs concentration found in indoor around 83.84µg/m^3. The highest variance and standard deviation were found in industrial ambient (variance: 2088.63 and standard deviation: 45.70) with the mean concentration of 80.69µg/m^3. The mean TVOCs in industrial roadside about 3 times higher than the urban background concentration level of the urban park. The high TVOCs in roadside related to vehicular emissions (Hwa *et al*., 2002; Do *et al*., 2013).

The high variation in the TVOCs seen in industrial environment compare to urban environment which shows the significance of different factors in the industrial environment. The highest variance found in industrial ambient besides, the second highest variance found in industrial roadside and the variance in industrial indoor is lower compare to other two sites of industrial area. The variance show the relative importance of spatial, temporal and measurement uncertainties, which have significant implications for understanding and identifying factors that affect variability (Jia *et al.*, 2012). The difference between the levels of VOCs and the type of VOCs identified among the industrial sites shows the effect of the type of industrial sources of VOCs. Various studies have found the high variability of the concentration of VOCs in the ambient air of the industrial area (Chan *et al*., 2002; Pimpisut *et al*., 2003; Xiang *et al*., 2012). According to the study of Chan *et al.* (2002), the maximum concentration was found to be highest in the industrial district. This was credited to the additional sources of VOCs from the industries present. This may relate to fugitive emissions of the industrial emission sources (Van Deun *et al.,* 2007). Irregular and intermittent emissions which are related to manufacturing activities may also be a factor in the observed variability of concentrations.

In the urban area, the highest variance was found in the urban roadside. The high variances in the roadside of both areas indicate the influence of fuel types. According to the study Jeeranut *et al.* (2012) which is done in Dhaka found that the extensive uses of CNG heavily influence the atmospheric composition. The relative high contribution of toluene in the roadside environment could be related to vehicular emissions (Balanay and Lungu, 2009). Several studies in the world indicated that the dominant anthropogenic sources in the urban areas are vehicle exhaust, gasoline evaporation, emissions from the commercial and industrial use of solvents and from liquefied petroleum gas (Na *et al.,* 2004; Barletta *et al.,* 2008; Parra *et al*., 2009; Crala *et al.,* 2014).

On the other hand, outdoors VOCs levels show both long- and short-term trends, seasonal and diurnal patterns (McCarthy *et al.,* 2007), and spatial differences across industrial, urban (Jia *et al.,* 2008a; Logue *et al*., 2010 and Miller *et al*., 2009). Indoors VOCs concentrations depend on season (Schlink *et al*., 2004), the presence of strong indoor sources such as an attached garage (Batterman *et al*., 2007), mothballs, air fresheners, dry cleaned clothing (D'Souza *et al.,* 2009), personal activities such as smoking (Baek and Jenkins, 2004), among many other factors. Jia *et al.* (2012) found that concentrations of VOCs and other pollutants reflect emissions, environmental factors that disperse or remove pollutants, e.g., mixing, wind speed, temperature and humidity, and measurement uncertainty. The climate is characterized by high temperature and high humidity during most of the year and distinctly marked seasonal variations in precipitation in Bangladesh (Begum, *et al.,* 2006). During the sampling period of urban area, the temperature was ranged between 28.6°C to 33.3°C and humidity ranged between 99.9% to more than 100%. While in industrial area, the temperature was ranged between 28.1°C to 31.4°C and humidity ranged between 92.1% to more than 100%. It should be noted that at the time of sampling Bangladesh was under monsoon influence and clean marine air mass are known to govern the area blowing from the south-west between May and September and bringing rain (the *wet monsoon*). Furthermore, the meteorological factors such as wind strength and the direction should also be considered. In the industrial ambient for example, the wind speed and direction may have affected the concentration of TVOCs since the sample was taken in the ambient air and wind direction and speed was changing during the sampling.

4.3 Individual groups in TVOCs

4.3.1 Mean of individual groups in TVOCs

As mentioned before the TVOCs is the sum of 39VOCs can be divided into 5 groups. The TVOCs included the sum of total (cyclo)-alkanes (∑10 VOCs), total aromatic compounds (∑14 VOCs), total oxygenated compounds (∑08 VOCs), total halogenated compounds (∑04

VOCs) and total terpenes (∑03 VOCs). Figure 4.2 shows the TVOCs of each group of pollutants to the TVOCs (µg/m^3) during each sampling campaign of 36 samples.

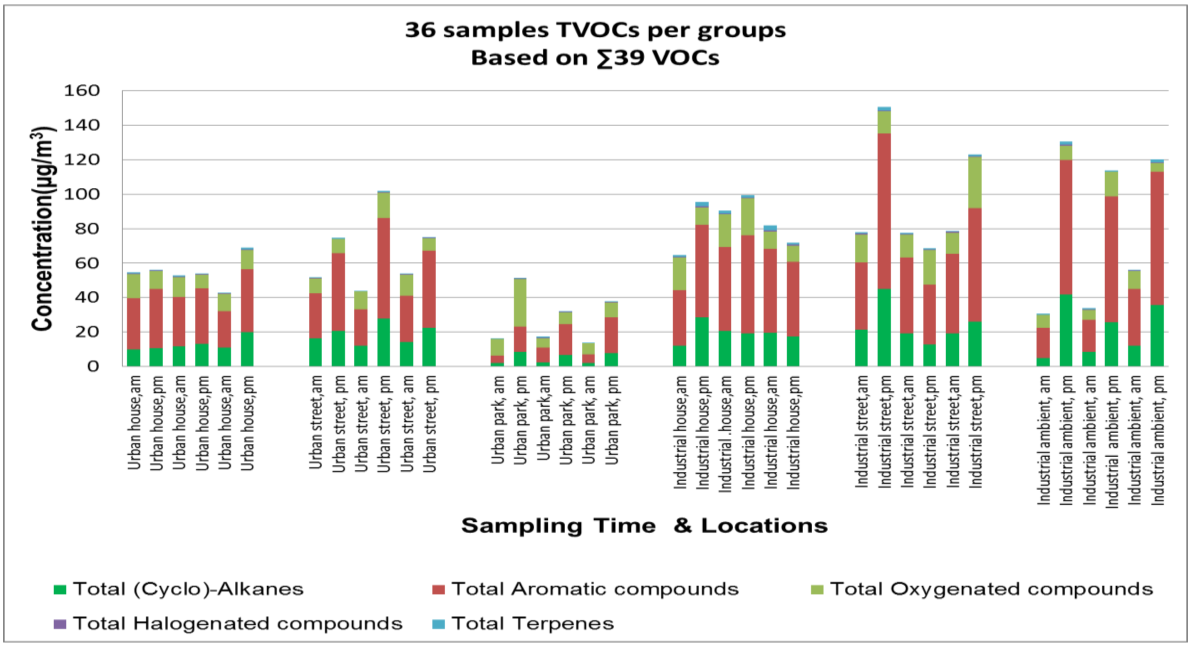


Figure 4.2: Contribution of TVOCs per group into TVOCs of 36 samples

It can be observed from the Figure 4.2 that most of the time concentration in the afternoon is higher than morning especially total aromatics and total (cyclo)-alkanes. Aromatic compounds have the highest contribution for all the six sampling sites. In urban park, the highest peak in weekend and the highest contribution of total oxygenated compounds. The highest difference in the TVOCs concentration levels between morning and afternoon in the industrial ambient site indicates the contribution of industrial sources. Total (cyclo)-alkanes, on the other hand, are the second largest contributors except in the urban park where oxygenated compounds showed substantial contribution to TVOCs. Total oxygenated compounds were the third largest contributors. Total terpenes have less contribution in all the sites and total halogenated compounds have negligible contribution.

4.3.2 Stacked column (100%) contribution of each group to TVOCs

Figure 4.3 shows the stacked column proportional (100%) contribution of each group to the mean TVOCs of the six sites measured during two sampling campaigns in Dhaka city. It can be observed from the Figure 4.3 that total aromatic compounds are the dominant group and major contributor (42-61%) in all the six sampling locations(urban indoor house: 55%, urban street: 55%, urban park: 42%; industrial indoor house: 56%, industrial street: 55%, industrial ambient: 61%). The lowest percentage contribution of total aromatic compounds found in outdoor urban park (42%) and the highest percentage contribution found in outdoor industrial ambient (62%).

On the other hand, second major contributors were total (cyclo)-alkanes (17-28%) with the exception in urban park. The highest (28%) contribution of total (cyclo)-alkanes was found in urban street and the lowest (17%) in urban park. Whereas, total oxygenated compounds are 2nd major contributors in urban park 38% and the range (11-38%) in the six sites. As mentioned before? benzaldehyde can form in the air through photochemical oxidation of toluene and other aromatic hydrocarbons (Han *et al.*, 2003; HSDB, 2011). This may explain why benzaldehyde is dominant in the urban park in terms of percentage contribution in the TVOC compared to the roadside (industrial street: 18%). Total terpenes account 1-2% whereas urban street has the lowest contribution around 0.79% and industrial house has the highest contribution around 2% (urban indoor house:1.03%, urban street: 0.79%, urban park: 1.32%; industrial indoor house: 2.18%, industrial street: 0.99%, industrial ambient: 1.17%). Total halogenated compounds are the minor contributors less than 1% (0.41-0.99%) whereas urban park has the highest contribution 0.99% and industrial ambient has the lowest contribution 0.41% (urban indoor house: 0.72%, urban street: 0.48%, urban park: 0.99%; industrial indoor house: 0.58%, industrial street: 0.56%, industrial ambient: 0.41%).

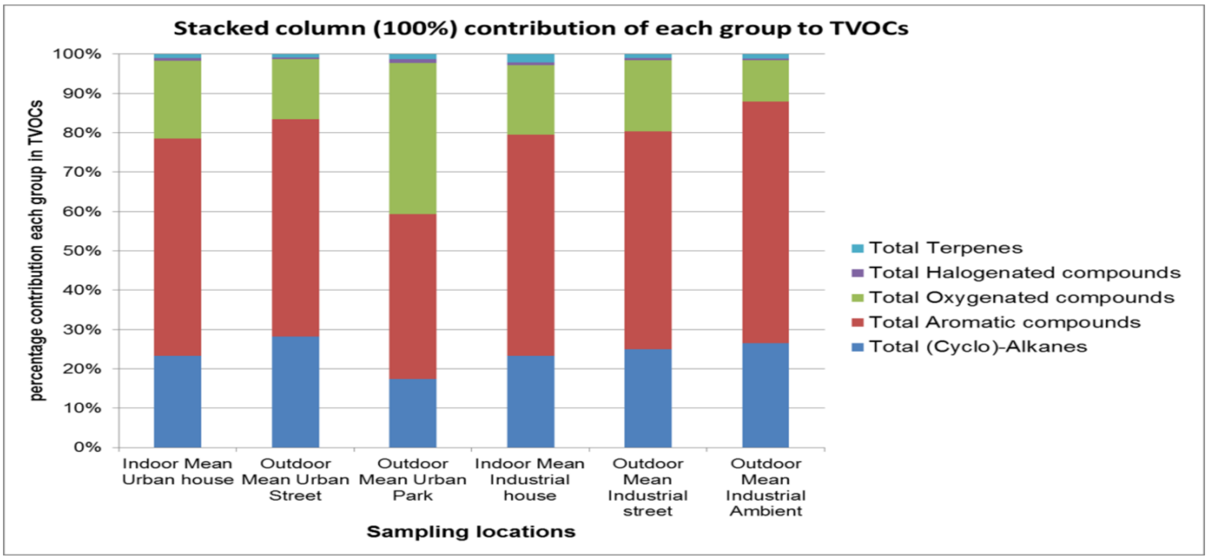


Figure 4.3: Stacked column (100%) contribution of each group to the TVOCs

From Figure 4.3 it can be observed that outdoor sources may have influence on the indoor air concentration levels on the similarity of the profiles of VOCs of the two indoor environments to the outdoor ambient air VOCs concentration levels. The observable deviation however can be attributed to the presence of additional indoor sources of VOC like terpenes and Naphthalene. In this study, aromatic compounds were observed to be the most abundant group in the TVOC in all the sites. Depending on the sources variations of TVOC concentrations level are reported in some studies for both industrial or traffic related sources of emissions. In the case of traffic related emissions, aromatic s are usually reported to be the most abundant and significant contributor to TVOCs. However, variation in exhaust emission as a result of the differences in fuel and vehicle fleet types from region to region found in by Verma and des Tombe, 2002. In a study found that VOC levels in Asian and Latin American countries showed that aromatic levels in fuels used in Asian countries are higher than those used in Latin American cities which they correlated with the higher BTEX levels in ambient air in Asian cities (Gee and Sollars, 1998). On the other hand, the difference in profiles of vehicle exhausts depending on the fuel type (Schuetzle *et al.*, 1994; Caplain *et al.*, 2006). It also found that emission of VOCs from vehicle depends on vehicle condition, speed and type of fuel used (Watson *et al.*, 2001, Do *et al.*, 2013).

In Bangladesh, CNG is an inexpensive, indigenous energy resource which currently accounts for the majority of automobile and domestic energy consumption (Jeeranut *et al.*, 2012). In the study done by Jeeranut *et al.*(2012) found that emissions from gasoline and CNG-fuelled vehicles were dominant during the daytime; emissions from these vehicles only became significant during the night while in contrast due to restrictions imposed on diesel fuelled vehicles entering Dhaka City. Within the capital city the extensive CNG usage heavily influences the atmospheric composition (Jeeranut *et al.*, 2012). The Bangladeshi government has implemented various mitigation measures aiming to assess the anticipated escalated air pollution problem and improve air quality. These measures include the shift from gasoline/diesel fuelled engines to CNG, which began in 1999–2000 (Bose and Rahman, 2009 and Iqbal *et al*., 2011). In Bangladesh, the number of CNG vehicles is currently estimated to be around 200,000 (GVR, 2011) of which about 95% are located in Dhaka and 58.5% of the total vehicles in Dhaka (325,000) are thought to be running on CNG (Jeeranut *et al.*, 2012). Moreover, other factors such as metrological conditions such as season, wind speed, road conditions and other possible non-traffic sources of VOCs could be affecting factors (Do *et al*., 2013).

4.4 TVOCs individual subgroups

The TVOCs group's total (cyclo)-alkanes can be divided into subgroups as total alkanes (∑07VOCs) and total cyclo-alkanes (∑03VOCs). The TVOCs group total oxygenated compounds can be subdivided as total aldehyde (∑03VOCs), total alcohols (1VOC), total ketones (∑02VOCs) and total esters (∑02VOCs). Figure 4.4 which representing the specific subgroups of the main groups in TVOCs are discussed detail in this section.

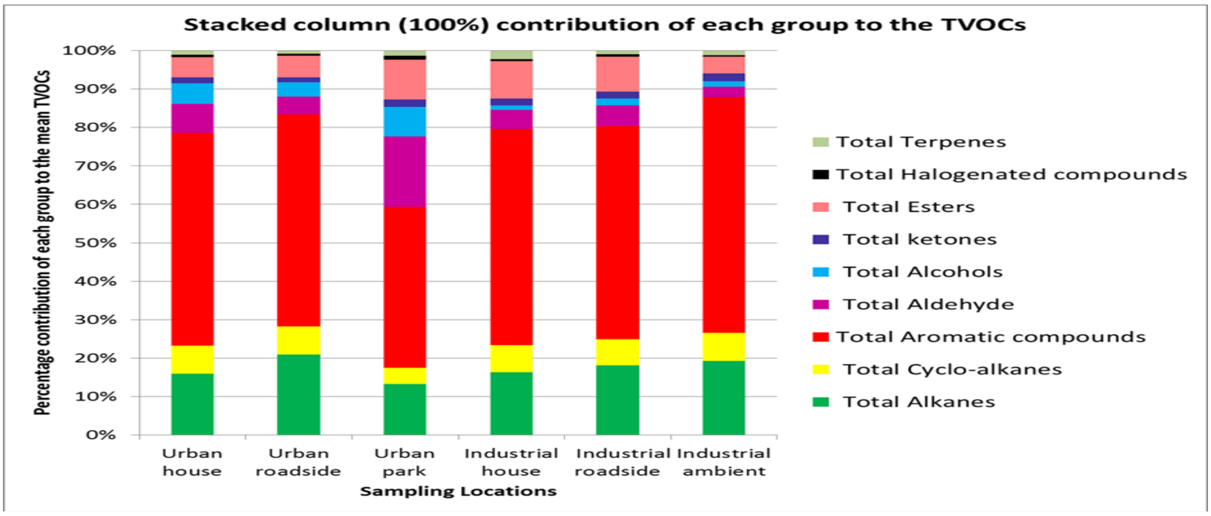


Figure 4.4: Stacked column (100%) contribution of subgroups to the TVOCs

As mentioned in section 4.3.2 that second major contributors were total (cyclo)-alkanes (17-28%) with the exception in urban park which can be divided into two subgroups. From the Figure 4.5 it can be found that total alkanes contribution range (13-21%) and the highest found in the urban roadside around 21% and the lowest in urban park around 13%. On the other hand, total cyclo-alkanes contribution (4-7%) and the highest was around 7% found in 5 sites except urban park and the lowest in urban park around 4%.

Whereas, as mentioned in section 4.3.2 that total oxygenated compounds are 2nd major contributors in urban park 38% and the range 11-38% in the six sites. Among the subgroups of total oxygenated compounds, total esters are the prevailing group (4-10%) except in urban park where total aldehydes is dominant than total esters (Figure 4.4). The lowest percentage contribution of total esters was found in outdoor industrial ambient (4%) and the highest percentage contribution (10%) found in urban park and industrial house. Whereas the second major contributors were total aldehydes (3-18%) to TVOCs. The highest percentage contribution of total aldehydes was found in urban park (18%) and the lowest in industrial ambient (3%). In all the sites toluene was dominant compound and in the urban park, benzaldehyde was also dominant which can be possibly ascribed to the formation of benzaldehyde in the air through photochemical oxidation of toluene and other aromatic hydrocarbons (Han *et al.*, 2003; HSDB, 2011). The percentage contribution of total alcohols was (1-8%) to TVOCs. The highest percentage contribution of total alcohols was in urban park (8%) and the lowest in industrial house and industrial ambient (1%). The percentage contribution of total ketones was (1-2%) to TVOCs.

4.4.1 Mean concentration of total (cyclo)-alkanes in TVOCs

As mentioned before that total (cyclo)-alkanes compounds (∑10VOCs) are the second dominant group in TVOCs (mean around 5-24µg/m^3) except in urban park. Figure 4.5 deliver the information that all the 3 sites of industrial area(mean around 20-24µg/m^3) have higher total (cyclo)-alkanes compounds compare to urban areas(mean around 5-19µg/m^3). The highest contribution of mean total (cyclo)-alkanes found in industrial street (mean around 24µg/m^3) and the lowest in urban park (mean around 5µg/m^3) based on 6 samples per site.

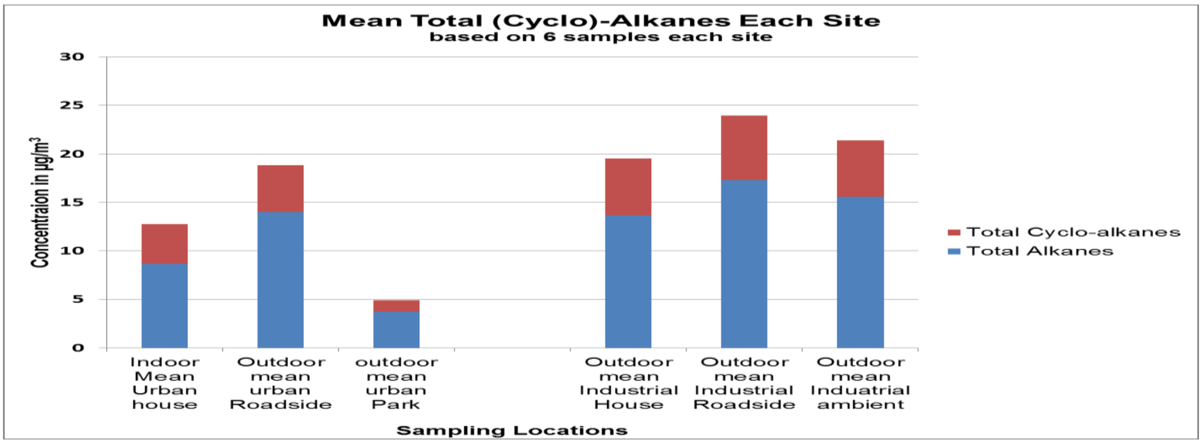


Figure 4.5: Mean total (cyclo)-alkanes in TVOCs

In both urban and industrial areas roadside has the highest contribution of total (cyclo)-alkanes (mean around in urban street: 19µg/m^3 and 24µg/m^3 in industrial street) which reveals that the sources may be from vehicle emissions and vehicle fuel. Again total (cyclo)-alkanes are subdivided into total alkanes and total cycloalkanes. It could be seen from the Figure 4.5 that the contribution of total alkanes (mean around 4-17µg/m^3) are higher in all the six sites compare to total cycloalkanes (1-7µg/m^3). Jeeranut *et al.*(2012) also found a large fraction of low carbon number alkanes present in Dhaka. The mean of the total (cyclo)-alkanes of all the 36 samples are given in appendix Figure A3.

As mentioned before the capital city of Dhaka mainly used CNG as fuel in vehicles and natural gas for cooking. Natural gas is especially rich in methane and also contains ethane and propane, along with smaller amounts of other low molecular-weight alkanes (http://dent.uokufa.edu.iq). Natural gas is often found associated with petroleum deposits. Petroleum is a liquid mixture containing hundreds of substances, including approximately 150 hydrocarbons, roughly half of which are alkanes or cycloalkanes (http://dent.uokufa.edu.iq). It can be said that most probably the source of alkanes or cycloalkanes is from CNG or petroleum product in outdoor or natural gas from indoor cooking.

4.4.2 Stacked column (100%) contribution of subgroups to total (cyclo)-alkanes

As mentioned before total (cyclo)-alkanes (17-28%) was the second major contributors in TVOCs except in urban park. From the Figure 4.6 it can be found that total alkanes contribution range (68-76%) to total (cyclo)-alkanes and the highest found in the urban park around 76% and the lowest in urban house around 68%. On the other hand, total cyclo-alkanes has contribution (24-32%) to total (cyclo)-alkanes and the highest in urban house around 32% and the lowest in urban park around 24%. The stacked column of percentage contribution (100%) of total cyclo-alkanes has higher contribution in indoor houses in both areas among the six sampling sites (urban indoor house: 32%; industrial indoor house: 30%).

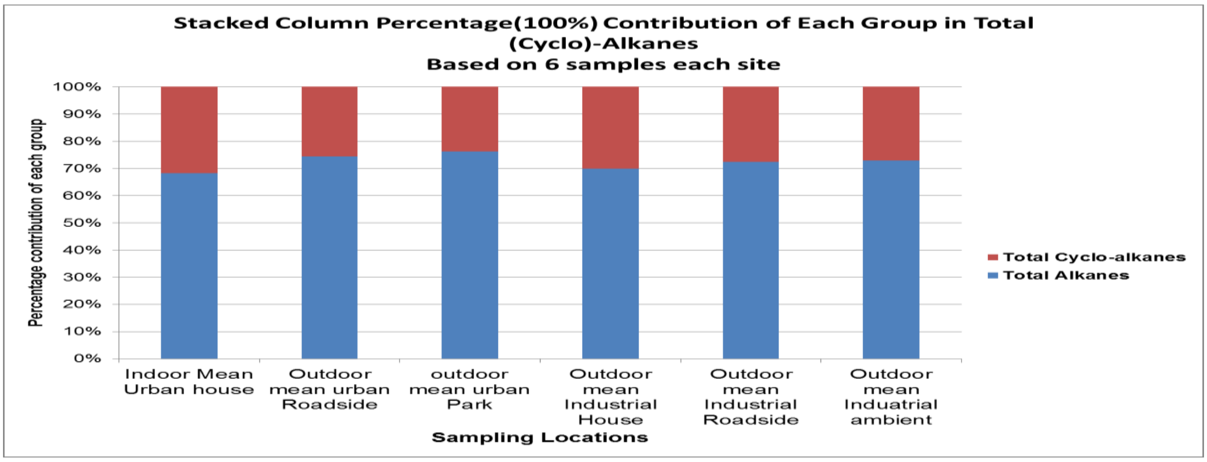


Figure 4.6: Stacked column (100%) contribution of subgroups to the total (cyclo)-alkanes

4.4.3 Mean concentration of total oxygenated compounds in TVOCs

From the Figure 4.7 it can be observed that the highest mean concentration of total oxygenated compounds (∑8VOCs) was around 17.30µg/m^3 in industrial street and the lowest mean in industrial ambient around 8.51µg/m^3. In urban area, mean concentration of total oxygenated compounds was restively little bit less compare to industrial areas. Among the 18 samples (N=18) in urban area, the highest concentration of total oxygenated compounds was noticed 27.50µg/m^3 in urban park in the weekend afternoon. While among the 18 samples (N=18) in industrial area, 29.56µg/m^3 was the highest concentration found in industrial street in the afternoon (Contribution of total oxygenated compounds in 36 samples given in Figure A4 in the appendix). As mentioned before total oxygenated compounds were further subdivided as total aldehydes, total alcohols, total ketones and total esters. The contributions of the individual subgroups were total aldehydes (2.24-5.18µg/m^3), total alcohols (0.95-3.00µg/m^3), total ketones (0.56-1.68µg/m^3) and total esters (2.88-8.77µg/m^3) to total oxygenated compounds.

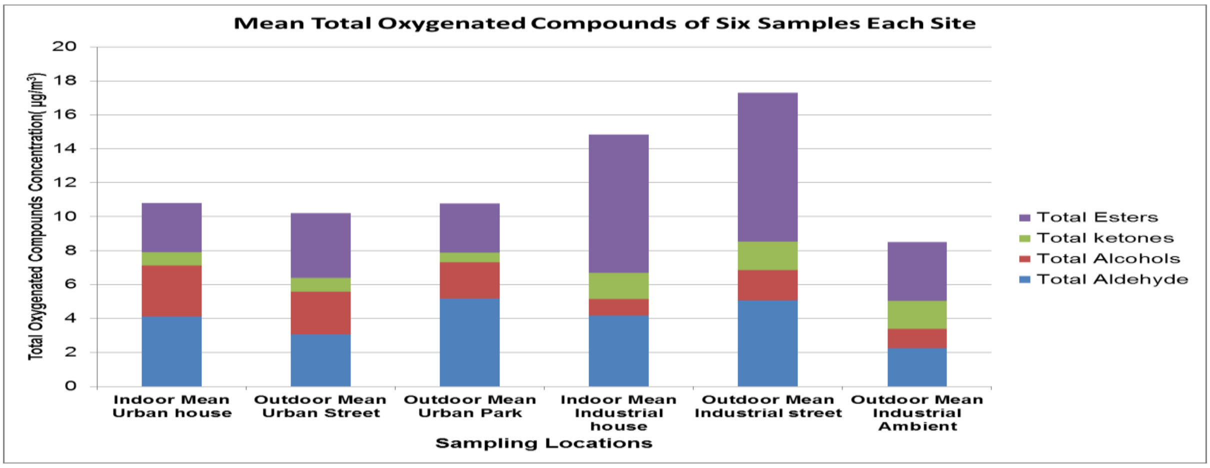


Figure 4.7: Mean Total Oxygenated Compounds of the six sites

Figure 4.7 provide the information that among the 4 subgroups, total esters were dominated in all 4 sites except in the urban park (mean around 2.91µg/m^3) and urban house (mean around 2.88µg/m^3) where total aldehydes has the highest contribution. The highest concentration of total esters was found in industrial roadside (mean 8.77µg/m^3) and the lowest in urban house (mean around 2.88µg/m^3). In both areas urban and industrial area among the 3 sites, roadside had the highest contribution of total esters (urban road: mean 3.80µg/m^3; industrial road: mean 8.77µg/m^3). Total aldehydes have the highest contribution in urban park (mean 5.18µg/m^3) and the lowest in industrial ambient (mean 2.24µg/m^3). The highest concentration of total ketones was found in industrial roadside (mean 1.68µg/m^3) and the lowest in urban park (mean around 0.56µg/m^3). The highest concentration of total alcohols was found in urban house (mean 3.00µg/m^3) and lowest in industrial house (mean around 0.95µg/m^3).

4.4.4 Stacked column (100%) contribution of subgroups to total oxygenated compounds

It can be found from the Figure 4.8 among the subgroups of total oxygenated compounds that total esters are the dominant group except in urban park and urban house and contribution range 27-55%. The lowest percentage contribution of total esters was found in outdoor urban park (27%) and the highest percentage contribution (55%) in industrial house. Whereas the second major contributors were total aldehydes (26-48%) to total oxygenated compounds. The highest percentage contribution of total aldehydes was found in urban park (48%) and the lowest in industrial ambient (26%). The percentage contribution of total alcohols (6-28%) was the highest in urban house (28%) and the lowest in industrial house (6%). The percentage contribution of total ketones was 5-19% where the highest found in industrial ambient (19%) and the lowest in urban park (5%).

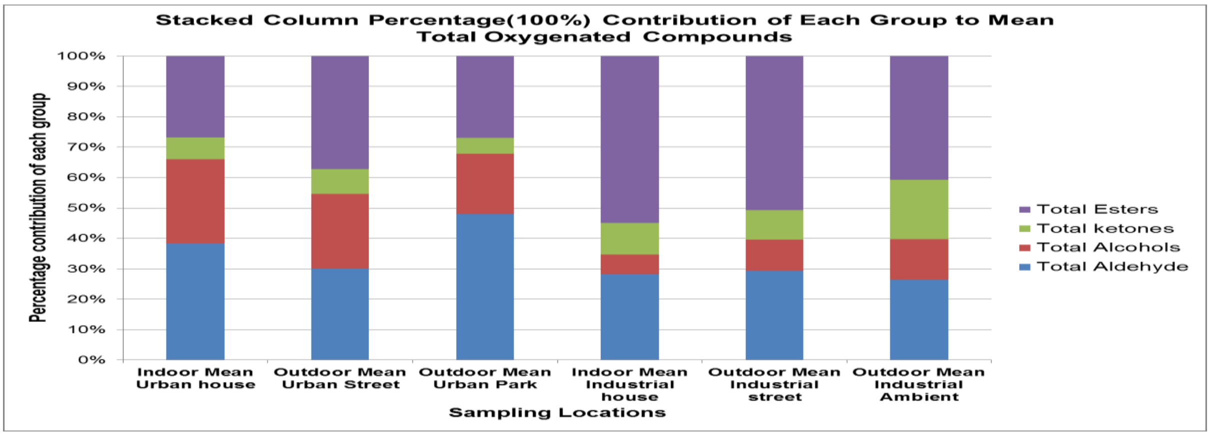


Figure 4.8: Stacked column (100%) contribution of subgroups to total oxygenated compounds

4.5 Total Aromatic Compounds in TVOCs

4.5.1 Mean concentration of total aromatic compounds in TVOCs

As mentioned before that total aromatic compounds are the dominant group and major contributor (mean around 11.76-53.27µg/m^3) in all the six sampling locations. As total aromatics compounds the dominant group and important group, here focus on total aromatic compounds. Due to the carcinogenic nature of some compounds researchers have focused on urban VOC levels, especially aromatic organic compounds (Do *et al*., 2013; Carla *et al.*, 2014). VOCs are emitted from various urban, industrial and natural sources. Former studies have shown that the dominant anthropogenic sources in the urban areas are vehicle exhaust, gasoline evaporation, emissions from the commercial and industrial use of solvents and from liquefied petroleum gas (LPG) (Na *et al*., 2004; Barletta *et al*., 2008).

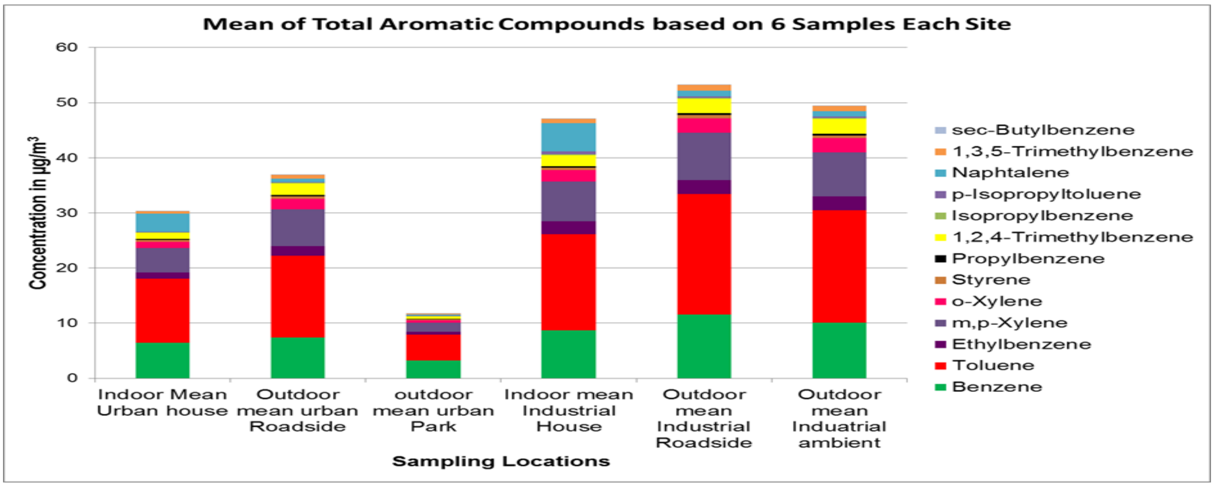


Figure 4.9: Mean of Total Aromatic Compounds (subgroup of TVOCs)

From the Figure 4.9 it is also found that in both areas outdoor roadside has the highest mean concentration of total aromatic compounds and was higher in industrial area (mean concentration around 47.15-53.27µg/m^3) compare to urban area (mean concentration around 11.76-37.00µg/m^3). The lowest mean concentration level of total aromatic compounds found in outdoor urban park (mean around 11.76µg/m^3) and the highest mean concentration of total aromatic compounds found in outdoor industrial roadside (mean around 53.27µg/m^3). The second highest mean concentration of total aromatic compounds was found in industrial ambient around 49.51µg/m^3.

4.5.2 Stacked column (100%) contribution of each compound to total aromatic compounds

As mentioned before that total aromatic compounds are the dominant group and major contributor (42-61%) in TVOCs in all the six sampling locations. From the Figure 4.10 it can be seen that highest percentage contributor in the total aromatic compounds was toluene (37-41%). The highest percentage contribution of toluene was in industrial ambient and industrial roadside (around 41%) and the lowest in industrial house (37%). In urban area, the highest percentage contribution of Toluene was found in urban roadside (40%). The percentage contribution of toluene in urban house was around 38% and in urban park around 39%.

The second higher percentage contributor was benzene (18-28%) in the total aromatic compounds. The highest percentage contribution was in urban park around 28% and the lowest in industrial house around 18%.

The third major percentage contributor in the total aromatic compounds was the combined contribution of m-xylene and p-xylene (18-28%). The highest percentage contribution of the combined the two compounds m-xylene and p-xylene was in urban roadside around 18% and lowest in urban park (18%). The percentage contribution of o-xylene was around (4-5%) where the highest percentage contribution (around 5%) of o-xylene was found in 3 sites in urban roadside, industrial ambient and industrial roadside and the lowest percentage contribution (around 4%) in the other 3 sites urban house, urban park and industrial house. The percentage contribution of o-xylene was relatively consistent in all the six sites.

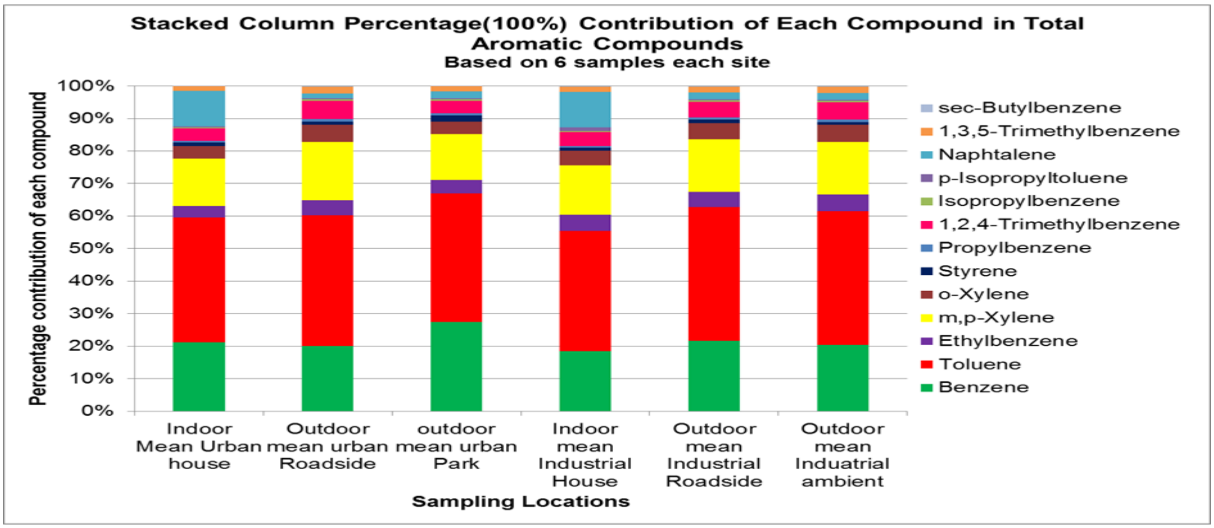


Figure 4.10: Stacked column (100%) contribution of each compound to total aromatic compounds

The percentage contribution of 1,2,4-trimethylbenzene was around (4-6%) where the highest percentage contribution was found in urban roadside around 6% and the lowest in urban park around 4%. The percentage contribution of ethylbenzene was around (4-5%) where the highest percentage contribution (around 5%) was found in industrial ambient and the lowest percentage contribution (around 4%) in urban house. The percentage contribution of the other compounds such as 1,3,5-trimethylbenzene, styrene, propylbenzene, isopropylbenzene, p-isopropyltoluene and sec-butylbenzene was around (0-2%); relatively negligible contribution.

4.6 Mean of sum of BTEX (∑BTEX) level

From the above discussion of section 4.5 before it can be observed that among the total aromatic compounds, the sums of BTEX are cited to be the most abundant. Among the aromatic compounds BTEX is highly monitored may be considering their abundance and health impacts. For instance, benzene is known as carcinogen and exposure to high ambient concentrations represents a considerable health risk (WHO, 2010). According to USEPA, the central nervous system (CNS) is the primary target organ for toluene toxicity. According to USEPA, acute (short-term) inhalation exposure to mixed xylenes in humans results in irritation of the eyes, nose and throat, gastrointestinal effects and neurological effects and chronic (long-term) inhalation exposure of humans to mixed xylenes results primarily in central CNS effects. The USEPA has classified mixed xylenes as a Group D, not classifiable as to human carcinogenicity. Acute (short-term) exposure to ethylbenzene in humans results in respiratory effects and chronic (long-term) exposure to ethylbenzene by inhalation in humans has shown conflicting results regarding its effects on the blood (http://www.epa.gov). Limited information is available on the carcinogenic effects of ethylbenzene in humans (http://www.epa.gov). The USEPA has classified ethylbenzene as a Group D, not classifiable as to human carcinogenicity.

From the Figure 4.11 it can be observed that highest mean concentration of ∑BTEX was found in industrial street (around 47.14µg/m^3) and lowest in urban park (around 10.50µg/m^3). From the Figure 4.11 it can also be found that relatively higher level of mean ∑BTEX was found in all the 3 sampling sites of industrial areas (mean ∑BTEX around 37.78-47.14µg/m^3) compared to urban areas (mean ∑BTEX around 10.50-32.59µg/m^3). The highest mean ∑BTEX level was found in roadside in both urban and industrial areas (urban road: abound 32.59µg/m^3 and industrial road: around 47.14µg/m^3). In the several studies mentioned that the main reason for the higher concentration of BTEX in the road is most probably the emissions from different vehicles (Murena, 2007; Buczynska *et al*., 2009).

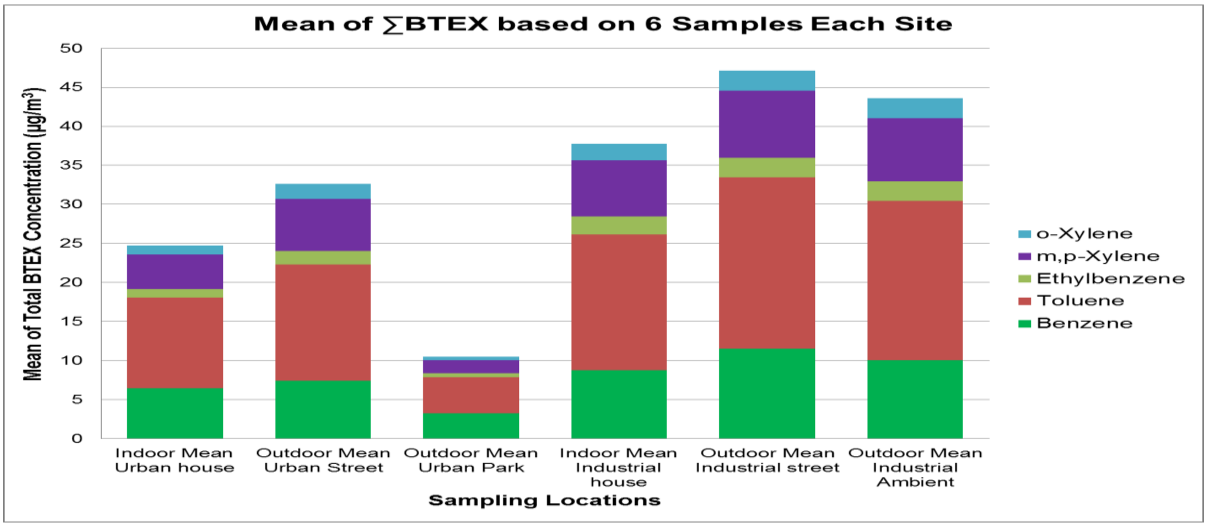


Figure 4.11: Mean of total benzene-toluene-ethylbenzene-xylene (∑BTEX) level

From the Figure 4.11 reveals that in the ∑BTEX compounds, toluene has the highest concentration (mean around 4.64-21.94µg/m^3). The highest mean concentration of toluene was found around 21.94µg/m^{3}in industrial ambient and the lowest in urban park around 4.64µg/m^3. The concentration level of toluene was higher in industrial areas (mean around17.41-21.94µg/m^3) compared to urban area (mean around 4.64-14.87µg/m^3). According to USEPA, the major use of toluene is as a mixture added to gasoline to improve octane ratings and also used to produce benzene, as a solvent in paints, coatings, synthetic fragrances, adhesives, inks, and cleaning agents.

Benzene was the second highest mean concentration level (mean around 3.24-11.53µg/m^3) in the sum of total BTEX. The highest mean concentration of benzene was around 11.53µg/m^3 found in industrial roadside and the lowest in urban park around 3.24µg/m^3. The highest mean concentration of benzene level was found in roadside in both urban and industrial areas (urban road: around 7.40µg/m^3 and industrial road: around 11.53µg/m^3). Exposure can occur occupationally and domestically as a result of the ubiquitous use of benzene-containing petroleum products, including motor fuels and solvents (WHO, 2010).

The third major contributor in the BTEX was the combined contribution of m-xylene and p-xylene (1.66-8.61µg/m^3). The highest concentration of the combined the two compounds m-xylene and p-xylene was in industrial roadside around 8.61µg/m^{3}and the lowest in urban park 1.66µg/m^3. The concentration of the combined the two compounds m-xylene and p-xylene was higher in industrial areas compare to urban areas. In both areas roadside has the highest contribution which indicate the sources may be from traffic.

The contribution of o-xylene was around (3.74- 5.22 µg/m^3) where the highest concentration of o-xylene was found in industrial ambient 5.22 µg/m^3 and the lowest in the urban house 3.74 µg/m^3. In industrial areas the concentration levels of o-xylene was relatively little bit higher compare to urban areas. Mixed xylenes are used in the production of ethylbenzene, as solvents in products such as paints and coatings, and are blended into gasoline (http://www.epa.gov).

The concentration of ethylbenzene was around (0.51-2.51µg/m^3) where the highest concentration (around 2.51µg/m^3) was found in industrial ambient and the lowest concentration (around 0.51µg/m^3) in urban park. It is found that ethylbenzene is mainly used in the manufacture of styrene (http://www.epa.gov).

4.7 Mean benzene concentration level

Several studies have done focused on benzene. As mentioned before, benzene is known as carcinogen and exposure to high ambient concentrations represents a considerable health risk (WHO, 2010). Benzene can have acute and long-term adverse health effects such as cancer due to its toxic effects on the blood and marrow (Lan, *et al.*, 2004; IARC, 2013). According to WHO guideline 2010, the concentrations of airborne benzene associated with an excess lifetime risk of leukaemia of 10^{-4} is 17µg/m^3, 10^{-5} is 1.7µg/m^3, and 10^{-6} is 0.17µg/m^3. As the result, there are some guidelines for benzene concentrations for both indoor and ambient environments. According to EU Directive/2008/50 the ambient air guideline for benzene the threshold limit is 5µg/m^3 (yearly average) and the Flemish indoor air quality guidelines 2007, long time average of benzene concentration threshold limit is 2µg/m^3.

From the Figure 4.12 it can be found that mean concentration level of benzene, the maximum and minimum level of each site of the six sites based on six samples per site (measured concentration level of benzene was in urban indoor house:5.39-8.01µg/m^3 with mean 6.41µg/m^3, urban street: 4.56-10.85µg/m^3 with mean 7.40µg/m^3, urban park: 1.42-5.32µg/m^3 with mean 3.24µg/m^3; industrial indoor house: 5.98-11.16µg/m^3 with mean 8.72µg/m^3, industrial street: 4.56-22.05µg/m^3 with mean 11.53µg/m^3, industrial ambient: 3.79-22.45µg/m^3 with mean 10.04µg/m^3). From the Figure 4.12 it can be observed that the mean concentration of benzene was around 3.24-11.53µg/m^3. The highest mean concentration of benzene around 11.53µg/m^3 was found in industrial roadside and the lowest in urban park around 3.24µg/m^3. Among the 36 samples (N=36), the highest maximum concentration level of benzene was found in the industrial ambient around 22.45µg/m^3 and the lowest minimum in the urban park around 1.42µg/m^3. The highest mean concentration of benzene level was found in roadside in both urban and industrial areas (urban road: around 7.40µg/m^3 and industrial road: around 11.53µg/m^3).

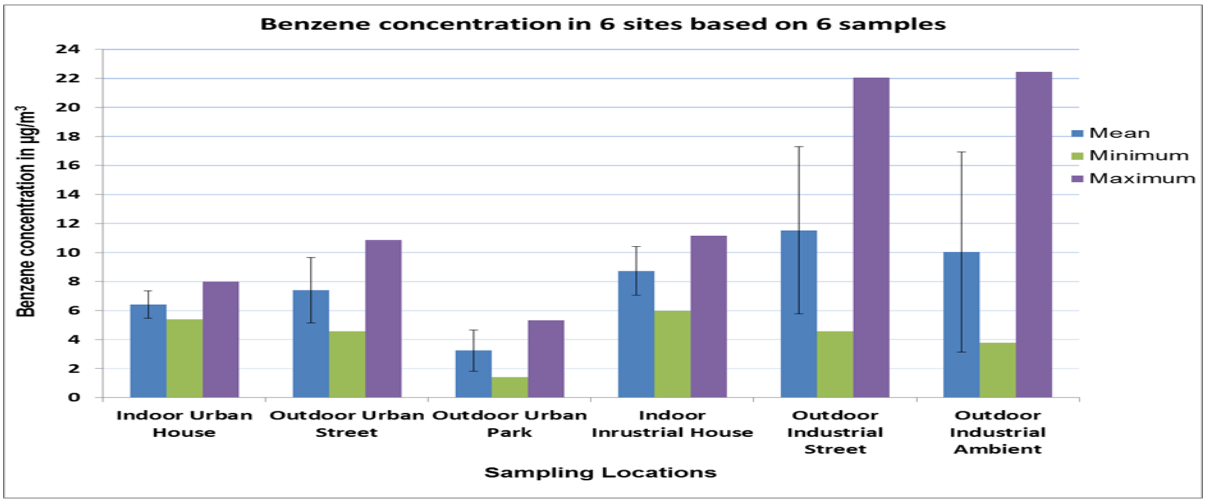


Figure 4.12: Mean benzene concentration with standard deviation, maximum and minimum levels

So far my knowledge, no standard limit has been legislated for benzene for air in Bangladesh. The mean concentration of benzene measured in urban indoor was 6.41µg/m^3 and industrial indoor 8.72µg/m^3 (Figure 4.13). The mean concentration levels of benzene in the indoor houses of the both areas are above the guidelines of benzene concentration 2µg/m^3 given by the Flemish indoor air quality guidelines, 2007. However, the guideline value differs from one region to other region (Chinese indoor air quality guideline 90µg/m^3). In the outdoor, 3 sites among the 4 sites are above the guidelines of benzene concentration given by EU Directive/2008/50 the ambient threshold limit yearly average 5µg/m^3 only urban park under the limit (urban street: mean 7.40µg/m^3, urban park: mean 3.24µg/m^3, industrial street mean 11.53µg/m^3, industrial ambient: mean 10.04µg/m^3). But the result is based on selected location with limited number of sample, where guideline is set for average concentration of longer timeframe; so it is difficult to reach in a strong conclusion.

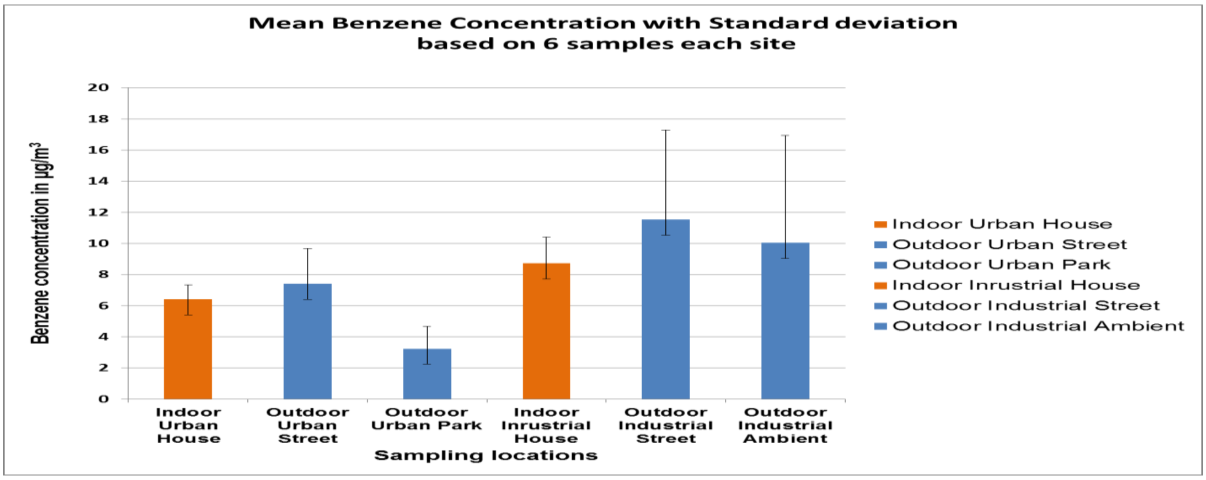


Figure 4.13: Mean concentration level of benzene of six sites based on six samples per site

4.8 Indoor to outdoor concentration ratio (I/O)

Indoor to outdoor (I/O) ratios for the urban area is presented in Table 4.5 (groups) and Table A4.10 (each compound separately in the appendix) whereas for industrial area in Table 4.6 (groups) and Table A4.11 (each compound separately in the appendix) into groups and each compound separately. The mean ratio for each site was calculated by getting the ratio of the mean concentration of each compound group from the indoor to that of the mean concentration from the outdoor. For the urban house indoor, VOC level was compared with the outdoor level at urban roadside sampling site and at the urban park.

Table 4.5: Mean concentration of TVOC groups and I/O ratios of the three sampling sites in urban area of Dhaka city, Bangladesh

Urban Area, Mirpur, Dhaka city					
Compound Group	Mean concentration (µg/m^3)			I/O Ratio	
	Indoor urban house(H)	Outdoor urban roadside(S)	Outdoor urban Park(P)	Ratio H/S	Ratio H/P
Total Alkanes	8.70	14.03	3.73	0.62	2.33
Total Cyclo-alkanes	4.06	4.82	1.17	0.84	3.48
Total (Cyclo)-alkanes	12.76	18.84	4.89	0.68	2.61
Total Aromatic compounds	30.33	37.00	11.76	0.82	2.58
Total Aldehyde	4.13	3.06	5.18	1.35	0.80
Total Alcohols	3.00	2.52	2.14	1.19	1.40
Total Ketones	0.78	0.83	0.56	0.94	1.40
Total Esters	2.88	3.80	2.91	0.76	0.99
Total Oxygenated compounds	10.79	10.21	10.78	1.06	1.00
Total Halogenated compounds	0.39	0.32	0.28	1.23	1.42
Total Terpenes	0.57	0.53	0.37	1.07	1.53
TVOCs	54.84	66.90	28.08	0.82	1.95

From Table 4.5 it can be observed that, the I/O ratio for TVOCs and most of the groups except total aldehyde, total alcohols, total oxygenated compounds, total halogenated compounds and total terpenes are less than or equal to 1 when the indoor sample is compared to the outdoor roadside site with a known immediate source of emission like the traffic site (i.e., H/S). When the urban indoor was compared to an outdoor urban background sample urban park with no known or little sources of emission, the I/O ratio of TVOC and most of the compound groups is greater than 1 except total aldehyde and total esters(i.e., H/P).

In Table A4.10 mean concentration of TVOC of each compound and I/O ratios of the three sampling sites in urban area of Dhaka city, Bangladesh is given in the appendix. It has found that the I/O ratio for TVOCs and most of the compounds except hexanal, heptanal, 2-ethyl-1-hexanol, 3-pentanone, methylbenzoate, carbon_tetrachloride or tetrachloromethane, 1,4-dichlorobenzene, 1,2-dichlorobenzene, 1,2,3-trichlorobenzene, beta-pinene and limonene are less than or equal to 1 when the indoor sample is compared to the outdoor roadside site with a known immediate source of emission like the traffic site (i.e., H/S)(Table A4.10). When the urban indoor was compared to an outdoor urban background sample urban park with no known or little sources of emission, the I/O ratio of TVOC and most of the compound groups is greater than 1 except benzaldehyde, hexanal, heptanal, 2-butanone, ethyl_acetate, carbon_tetrachloride or tetrachloromethane, alpha-pinene, beta-pinene and methylbenzoate was not found in urban park (i.e., H/P) (Table A4.10 in the appendix). The I/O ratio less than 1 implied a stronger outdoor source of VOCs compared to indoor sources. But the comparison with background ambient sampling site like the park shows that there were also indoor sources that contributed to the levels of VOCs in the indoor environment.

For the industrial area, house indoor VOC level was compared with the level at the industrial ambient site (i.e., IH/IR) and with the industrial roadside (i.e., IH/IA). From Table 4.6 it can be seen that indoor samples, the I/O ratio for TVOCs and most of the groups except total terpenes, are less than or equal to 1 when the indoor sample is compared to the outdoor roadside site with a known immediate source of emission like the traffic site (i.e., IH/IR). When the urban indoor was compared to an outdoor industrial ambient sample with intermittent sources of emission, the I/O ratio of TVOC and most of the compound groups is greater than 1 except subgroup total alkanes, total aromatic compounds, total alcohols and total ketones (i.e., IH/IA).

Table 4.6: Mean concentration of TVOC groups and I/O ratios of the three sampling sites in industrial area of Dhaka city, Bangladesh

Industrial Area, Tejgaon, Dhaka					
	Mean concentration (µg/m^3)			I/O Ratio	
Compound Group	Indoor industrial house(IH)	Outdoor industrial roadside(IR)	Outdoor industrial ambient(IA)	IH/IR	IH/IA
Total Alkanes	13.67	17.32	15.58	0.79	0.88
Total Cyclo-Alkanes	5.87	6.62	5.81	0.89	1.01
Total (Cyclo)-Alkanes	19.54	23.94	21.39	0.82	0.91
Total Aromatic compounds	47.15	53.27	49.51	0.89	0.95
Total Aldehyde	4.18	5.07	2.24	0.83	1.87
Total Alcohols	0.95	1.78	1.15	0.54	0.83
Total ketones	1.56	1.68	1.65	0.93	0.94
Total Esters	8.14	8.77	3.47	0.93	2.34
Total Oxygenated compounds	14.83	17.30	8.51	0.86	1.74
Total Halogenated compounds	0.48	0.53	0.33	0.90	1.44
Total Terpenes	1.83	0.95	0.94	1.92	1.93
TVOCs	83.83	95.99	80.36	0.87	1.04

In Table A4.11 mean concentration of TVOC each compound and I/O ratios of the three sampling sites in industrial area of Dhaka city, Bangladesh is given in the appendix. From

Table A4.11 it can be found that the I/O ratio for each compounds and most of the compounds except p-isopropyltoluene, naphtalene, hexanal, 1,4-dichlorobenzene, alpha-pinene, beta-pinene and limoneneare less than or equal to 1 when the indoor sample is compared to the outdoor roadside site with a known immediate source of emission like the traffic site (i.e., IH/IR). When the industrial indoor was compared to an outdoor sample industrial ambient with intermittent sources of emission, the I/O ratio of compounds is less than 1 except octane, nonane, cyclohexane, p-isopropyltoluene, naphtalene, benzaldehyde, hexanal, heptanal, 3-pentanone, ethyl_acetate, 1,4-dichlorobenzene, 1,2,3-trichlorobenzene, beta-pinene and limonene (i.e., IH/IA). The I/O ratio less than 1 implied a stronger outdoor source of VOCs compared to indoor sources. But the comparison with industrial ambient sampling site shows that there were also indoor sources that contributed to the levels of VOCs in the indoor environment. The broad range of factors affecting the indoor air thus makes generalization of I/O ratio difficult. In this study, the indoor to outdoor ratio was seen to vary depending on the location where the house indoor level was compared. The I/O ratios of VOCs may not be as uniform as Do *et al.* (2013) pointed out and suggested that sampling region, specific indoor and outdoor location and type of pollutants should be considered in indoor and outdoor VOC comparisons. The significant effect or the extent of effect can be influenced by prevailing wind direction, ventilation type and the kind of indoor activity of the outdoor air pollution to the indoor air as described by Sarigiannis *et al*. (2011) and Srivastava *et al*. (2000).

4.9 Source Identification

Identification of all possible sources of VOCs becomes important to control effective emission and health risks assessment (Sanchez *et al*., 2008). In this section, use of diagnostic ratios and correlation coefficients to identify VOC sources are discussed for the aromatic compounds. Difference between the urban and industrial area in relation to the difference in diagnostic ratios and correlation coefficients will also be evaluated.

4.9.1 Diagnostic ratios

The Benzene-to-Toluene (B/T) ratios of the six sampling sites of Dhaka city can be observed in Table 4.7. From the Table 4.7 it can be observed that B/T ratios was 0.34 to 0.82 in urban indoor house with mean 0.55; 0.42 to 0.63 in outdoor urban street with mean 0.50 and 1.22 to 0.94 in outdoor urban park with mean 0.70. From the Table 4.7 it can be seen B/T ratios was 0.34 to 0.70 in indoor industrial house with mean 0.50, 0.25 to 0.87 in outdoor industrial street with mean 0.53 and 0.25 to 0.87outdoor industrial ambient with mean 0.49.

The B/T ratio frequently used the extent of the impact of vehicular emissions and other combustion sources upon atmospheric composition (Jeeranut *et al.*, 2012). In the study done by Jeeranut *et al.*, 2012 in Dhaka found that the B/T was 0.49 in Shabag junction road and 0.51 in Gulshan roadside where as 0.21 in Dhaka university area. Jeeranut *et al.*, 2012 mentioned the higher the B/T ratio, the more dominant the impact of traffic emission. According to Han and Naeher (2006), B/T ratios based upon ambient concentrations ranges from 0.3 to 0.8 in various urban roadside. Whereas B/T a range of 0.33 to 0.67 as the typical range of B/T ratio as an indicator of traffic dominated source of emission (Miller *et al*., 2011). But Buczynska *et al.* (2009) reported a lower range of 0.22 to 0.26 for areas with intensive street traffic.

Table 4.7: Toluene-to-Benzene (B/T) ratios of the six sampling sites of Dhaka city

Urban Area(Mirpur), Dhaka								
Sampling Date & Time	30/8/2013 weekend am	30/8/2013 weekend pm	1/9/2013 weekday am	1/9/2013 weekday pm	3/9/2013 weekday am	3/9/2013 weekday pm	Mean	Standard deviation
Indoor urban house	0.53	0.34	0.60	0.65	0.82	0.55	0.55	0.29
Outdoor urban street	0.63	0.53	0.54	0.46	0.52	0.42	0.50	0.39
Outdoor urban park	1.75	1.22	0.80	0.52	0.94	0.40	0.70	0.42
Industrial area(Tegjaon), Dhaka								
Sampling date & time	6/9/2013 weekend am	6/9/2013 weekend pm	9/9/2013 weekday am	9/9/2013 weekday pm	11/9/2013 weekday am	11/9/2013 weekday pm	Mean	Standard deviation
Indoor industrial house	0.50	0.52	0.49	0.34	0.70	0.59	0.50	0.32
Outdoor industrial street	0.87	0.67	0.71	0.25	0.47	0.35	0.53	0.66
Outdoor industrial ambient	0.53	0.87	0.72	0.25	0.49	0.45	0.49	0.49

On the other hand, Barletta *et al.* (2008) proposed a specific B/T ratio of less than 0.20 as an indicator of air samples strongly affected by industrial emissions. Do *et al.* (2013) mentioned that vehicle types, vehicle speed, fuel composition and other sources may explain the difference in the ratios. As traffic related emission plays an important role in controlling ambient concentration of VOC, the type of fuel used in the transport sector also have an influence on the ratio. So, the main source of benzene and toluene was most probably from vehicle emission.

4.9.2 Correlation coefficients of all aromatic compounds

Several studies have used correlation analysis of different VOCs for identification of prevailing emission sources (Brocco *et al.*, 1997; Wang *et al.*, 2002; Do *et al.*, 2013). Pearson's correlation of the concentrations of 14 aromatic compounds for the six sampling sites was then utilized to evaluate and assess the source of VOCs. The results of the correlation analysis (2 tailed) are summarized in Table 4.8 for urban areas and Table 4.9 for industrial areas where correlation was significant($r>0.81$) at the 0.05 level ($p<0.05$) has indicated as bold.

From Table 4.8 it can be observed that in urban street there was significant positive correlation coefficients ($r > 0.81$) among 13 aromatic compounds except naphthalene which indicate that their primary origin may be same and most probably from traffic. The poor correlation of naphthalene compared with other aromatic compounds suggested that measured naphthalene was from totally different source(s). In the urban house, significant positive correlation coefficients ($r > 0.81$) found between xylene, styrene, isopropylbenzene and p-isopropyltoluene which indicate the source of origin may be same. In the urban park significant positive correlation coefficients ($r > 0.81$) found also. This verifies the initial observations using diagnostic ratios that traffic is the main source of VOC exposure in the three urban environments monitored (Hoque *et al.*, 2008; Tiwari *et al.*, 2010).

Table 4.8: Pearson correlations(r) between aromatic compounds (14VOCs) in urban area

Urban house	B	T	EB	X1	X2	S	PB	TB1	PB	PT	N	TB2	SB
Benzene(B)	1.00												
Toluene(T)	0.13	1.00											
Ethylbenzene(EB)	**0.90**	0.32	1.00										
m-p-Xylene(X1)	0.43	0.11	0.61	1.00									
o-Xylene(X2)	0.51	0.35	0.73	**0.95**	1.00								
Styrene(S)	0.77	0.28	**0.86**	**0.89**	**0.93**	1.00							
Propylbenzene(PB)	0.49	0.52	0.74	**0.83**	**0.96**	**0.86**	1.00						
1-2-4-Trimethylbenzene(TB1)	0.43	0.51	0.68	**0.86**	**0.97**	**0.86**	**0.99**	1.00					
Isopropylbenzene(PT)	0.45	0.37	0.64	**0.91**	**0.98**	**0.89**	**0.96**	**0.98**	1.00				
p-Isopropyltoluene(PB)	0.41	0.34	0.68	**0.89**	**0.97**	**0.83**	**0.97**	**0.98**	**0.96**	1.00			
Naphtalene(N)	-0.62	0.12	-0.29	0.26	0.14	-0.11	0.08	0.14	0.10	0.17	1.00		
1-3-5-Trimethylbenzene(TB2)	0.48	0.42	0.67	**0.91**	**0.98**	**0.90**	**0.96**	**0.98**	**1.00**	**0.96**	0.09	1.00	
sec-Butylbenzene(SB)	-0.52	0.66	-0.43	-0.41	-0.32	-0.41	-0.20	-0.18	-0.28	-0.34	0.39	-0.25	1.00

Urban Street	B	T	EB	X1	X2	S	PB	TB1	PB	PT	N	TB2	SB
Benzene(B)	1.00												
Toluene(T)	**0.95**	1.00											
Ethylbenzene(EB)	**0.94**	**0.97**	1.00										
m-p-Xylene(X1)	**0.93**	**0.97**	**0.98**	1.00									
o-Xylene(X2)	**0.92**	**0.97**	**0.98**	**1.00**	1.00								
Styrene(S)	0.80	**0.88**	**0.92**	**0.95**	**0.96**	1.00							
Propylbenzene(PB)	**0.84**	**0.92**	**0.93**	**0.98**	**0.98**	**0.95**	1.00						
1-2-4-Trimethylbenzene(TB1)	**0.88**	**0.92**	**0.95**	**0.98**	**0.98**	**0.94**	**0.99**	1.00					
Isopropylbenzene(PT)	**0.90**	**0.95**	**0.97**	**0.99**	**1.00**	**0.94**	**0.99**	**0.99**	1.00				
p-Isopropyltoluene(PB)	**0.91**	**0.95**	**0.95**	**0.99**	**0.98**	**0.92**	**0.98**	**0.99**	**0.99**	1.00			
Naphtalene(N)	0.71	0.54	0.59	0.63	0.61	0.54	0.60	0.70	0.62	0.69	1.00		
1-3-5-Trimethylbenzene(TB2)	**0.88**	**0.93**	**0.95**	**0.99**	**0.99**	**0.96**	**0.99**	**1.00**	**0.99**	**0.99**	0.67	1.00	
sec-Butylbenzene(SB)	**0.83**	**0.90**	**0.92**	**0.95**	**0.95**	**0.88**	**0.97**	**0.97**	**0.98**	**0.97**	0.57	**0.96**	1.00

Urban park	B	T	EB	X1	X2	S	PB	TB1	PB	PT	N	TB2	SB
Benzene(B)	1.00												
Toluene(T)	0.63	1.00											
Ethylbenzene(EB)	0.67	**0.93**	1.00										
m-p-Xylene(X1)	0.71	**0.95**	**0.97**	1.00									
o-Xylene(X2)	0.73	**0.96**	**0.97**	**1.00**	1.00								
Styrene(S)	0.58	**0.86**	0.66	0.78	0.79	1.00							
Propylbenzene(PB)	**0.88**	**0.89**	**0.91**	**0.96**	**0.96**	0.78	1.00						
1-2-4-Trimethylbenzene(TB1)	0.77	**0.97**	**0.94**	**0.98**	**0.99**	**0.86**	**0.97**	1.00					
Isopropylbenzene(PT)	0.77	**0.94**	**0.94**	**0.99**	**0.99**	**0.83**	**0.98**	**0.99**	1.00				
p-Isopropyltoluene(PB)	**0.91**	**0.84**	**0.82**	**0.89**	**0.89**	0.74	**0.97**	**0.92**	**0.92**	1.00			
Naphtalene(N)	**0.98**	0.54	0.53	0.61	0.64	0.61	0.81	0.70	0.69	**0.86**	1.00		
1-3-5-Trimethylbenzene(TB2)	0.76	**0.94**	**0.93**	**0.99**	**0.99**	**0.84**	**0.98**	**0.99**	**1.00**	**0.91**	0.69	1.00	
sec-Butylbenzene(SB)	0.23	0.73	0.47	0.60	0.59	**0.93**	0.52	0.66	0.62	0.47	0.28	0.65	1.00

Correlation is significant($r>0.81$) at the 0.05 level ($p<0.05$) (2 tailed) has indicated as bold.

From Table 4.9 it can be observed that in industrial street there was significant positive correlation coefficients ($r > 0.81$) among all aromatic compounds which indicate that their primary origin may be same from traffic. High correlations in areas where traffic was the dominant source and poor correlations were noted in the vicinity of industrial sites (Dollard *et al.*, 2007). It is also noted low correlations associated with multiple emissions (Chan *et al.*, 2002; Barletta *et al.*, 2008). The poor correlation of industrial house and industrial ambient might probably indicate other source of aromatic compounds in the particular sampling site.

Table 4.9: Pearson correlations(r) between aromatic compounds (14VOCs) in industrial area

Industrial house	B	T	EB	X1	X2	S	PB	TB1	PB	PT	N	TB2	SB
Benzene(B)	1.00												
Toluene(T)	0.51	1.00											
Ethylbenzene(EB)	-0.37	0.44	1.00										
m-p-Xylene(X1)	0.80	0.60	-0.03	1.00									
o-Xylene(X2)	0.75	0.51	0.01	**0.99**	1.00								
Styrene(S)	0.42	**0.95**	0.49	0.68	0.61	1.00							
Propylbenzene(PB)	0.66	0.39	0.04	**0.95**	**0.99**	0.53	1.00						
1-2-4-Trimethylbenzene(TB1)	0.63	0.47	0.05	**0.96**	**0.98**	0.61	**0.98**	1.00					
Isopropylbenzene(PT)	0.60	0.50	0.23	**0.93**	**0.97**	0.63	**0.98**	**0.97**	1.00				
p-Isopropyltoluene(PB)	0.06	-0.55	-0.47	-0.05	0.05	-0.44	0.12	-0.01	-0.02	1.00			
Naphtalene(N)	0.17	-0.26	-0.39	0.32	0.38	-0.04	0.45	0.39	0.32	**0.85**	1.00		
1-3-5-Trimethylbenzene(TB2)	0.70	0.61	0.09	**0.99**	**0.98**	0.71	**0.95**	**0.98**	**0.96**	-0.13	0.28	1.00	
sec-Butylbenzene(SB)	0.63	0.58	0.18	**0.96**	**0.98**	0.70	**0.97**	**0.99**	**0.98**	-0.11	0.28	**0.99**	1.00

Industrial Street	B	T	EB	X1	X2	S	PB	TB1	PB	PT	N	TB2	SB
Benzene(B)	1.00												
Toluene(T)	0.60	1.00											
Ethylbenzene(EB)	**0.82**	**0.93**	1.00										
m-p-Xylene(X1)	**0.91**	0.74	**0.91**	1.00									
o-Xylene(X2)	**0.91**	0.78	**0.93**	**1.00**	1.00								
Styrene(S)	**0.87**	0.48	0.77	**0.85**	**0.86**	1.00							
Propylbenzene(PB)	**0.88**	**0.82**	**0.96**	**0.99**	**0.99**	**0.85**	1.00						
1-2-4-Trimethylbenzene(TB1)	**0.88**	0.79	**0.94**	**0.99**	**0.99**	**0.87**	**1.00**	1.00					
Isopropylbenzene(PT)	**0.91**	0.77	**0.94**	**0.98**	**0.99**	**0.91**	**0.99**	**0.99**	1.00				
p-Isopropyltoluene(PB)	**0.94**	0.68	**0.89**	**0.92**	**0.94**	**0.94**	**0.93**	**0.92**	**0.97**	1.00			
Naphtalene(N)	**0.92**	0.30	0.56	0.68	0.68	0.73	0.62	0.62	0.68	0.78	1.00		
1-3-5-Trimethylbenzene(TB2)	**0.90**	0.77	**0.94**	**0.98**	**0.99**	**0.91**	**0.99**	**0.99**	**1.00**	**0.95**	0.66	1.00	
sec-Butylbenzene(SB)	**0.89**	**0.85**	**0.98**	**0.93**	**0.95**	**0.87**	**0.97**	**0.96**	**0.97**	**0.96**	0.67	**0.97**	1.00

Industrial Ambient	B	T	EB	X1	X2	S	PB	TB1	PB	PT	N	TB2	SB
Benzene(B)	1.00												
Toluene(T)	0.57	1.00											
Ethylbenzene(EB)	0.69	0.68	1.00										
m-p-Xylene(X1)	0.73	0.65	**0.99**	1.00									
o-Xylene(X2)	0.70	0.58	**0.98**	**1.00**	1.00								
Styrene(S)	**0.98**	0.47	0.70	0.76	0.74	1.00							
Propylbenzene(PB)	0.64	0.51	**0.96**	**0.98**	**0.99**	0.71	1.00						
1-2-4-Trimethylbenzene(TB1)	0.64	0.53	**0.97**	**0.99**	**1.00**	0.69	**1.00**	1.00					
Isopropylbenzene(PT)	0.75	0.55	**0.97**	**0.99**	**1.00**	0.80	**0.99**	**0.99**	1.00				
p-Isopropyltoluene(PB)	0.81	0.44	**0.89**	**0.94**	**0.95**	**0.88**	**0.94**	**0.93**	**0.97**	1.00			
Naphtalene(N)	**0.86**	0.17	0.43	0.50	0.49	**0.84**	0.46	0.44	0.55	0.64	1.00		
1-3-5-Trimethylbenzene(TB2)	0.68	0.59	**0.98**	**1.00**	**1.00**	0.73	**0.99**	**1.00**	**0.99**	**0.94**	0.45	1.00	
sec-Butylbenzene(SB)	0.69	0.49	**0.95**	**0.98**	**0.99**	0.76	**1.00**	**0.99**	**1.00**	**0.97**	0.52	**0.99**	1.00

Correlation is significant(*r*>0.81) at the 0.05 level (*p*<0.05) (2 tailed) has indicated as bold.

4.10 Ozone Formation Potential

4.10.1 Total ozone formation potential

As mentioned before in this study, the contribution of VOC to O_3 formation is based on MIR provided by Carter 2010(Full version) and update MIR of aromatic compounds by Carter and Hoe, 2012. Among the measured 39 VOCs MIR (Carter 2010) is available for 33 VOCs. The combined mixture of m-Xylene and p-Xylene was separated as m-Xylene/p-Xylene equal to 2.33 according to Carla *et al.*, 2014 and Monod *et al.* 2001 because their MIR for O_3 production are not same. The total ozone formation potential (TOFP) of Dhaka city which is the sum of OFP of 33 VOCs is given in Figure 4.14. The highest TOFP was found in industrial street around 286.29μg/m^3 and the lowest was in the urban park 75.17μg/m^3 (Figure 4.14). In both urban and industrial area, roadside has the higher calculated TOFP been indicating that emissions from vehicles have the higher contribute to TOFP (urban roadside: 206.92μg/m^3 and industrial roadside: 286.29μg/m^3).

According to Bangladesh NAAQS, 2005, the threshold value for O_3 is 235µg/m^3 (0.12 ppm) for 1 hour (d) and 157µg/m^3 (0.08 ppm) which is 8 hours mean. The estimated TOFP were calculated which shows that 2 of the 4 outdoor sites exceed the the threshold value 235µg/m^3 (0.12 ppm) for 1 hour (d) of Bangladesh NAAQS, 2005 for ozone (O_3). The overall estimated mean TOFP was around 208µg/m_3 of the 4 sites which was within the limit of 1h average per day Bangladesh standard. The TOFP was found 267.2ppb O_3 in Dhaka city by Jeeranut *et al.* (2012). Jeeranut *et al.* (2012) found that 1h and 8h average of O_3 in Dhaka was 18.9ppb and 19.1ppb respectively. According to monthly report of August 2013 of DoE, the O_3 concentration was 9.15ppb (1h average) and 9.16ppb (8h average) based on CAMS at Bangladesh Agricultural Research Council (BARC), Farmgate at the sampling site industrial street (http://www.case-moef.gov.bd).

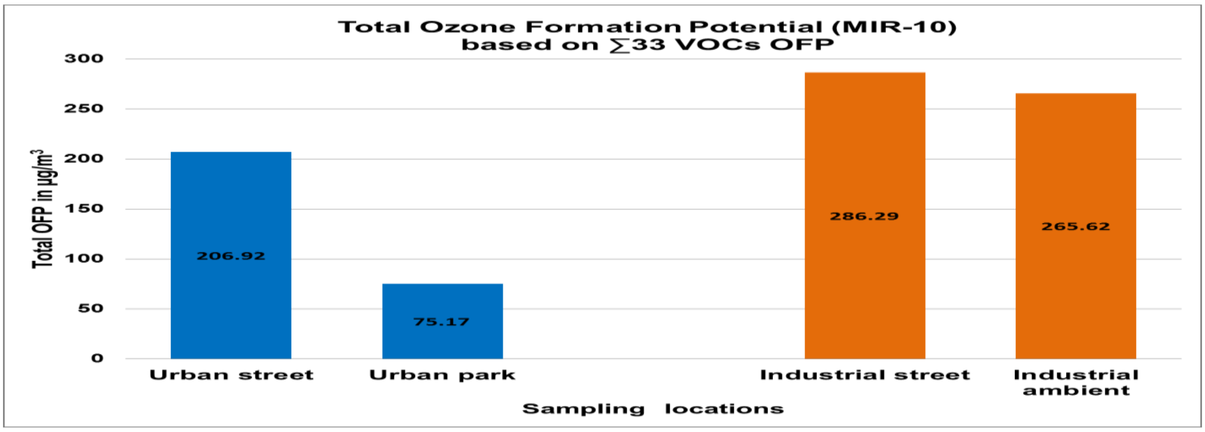


Figure 4.14: TOFP of the four outdoor ambient sampling sites

From the Figure 4.14 it can be observed that the exception of the urban park area, the all sampling sites exceeds the 8 hour threshold value of 100µg/m^3 set by WHO, 2005 (WHO, 2005). From the Figure 4.14 it can be observed that 3 out of 4 outdoor sites exceeded the WHO recommended level 100µg/m^3 and 157µg/m^3 (0.08 ppm) Bangladesh NAAQS, 2005 (8 hour average) of ozone but it worth noting that the sampling time was of 30 min in duration and sample size was limited. According to WHO, concentration equivalent to and above 240µg/m^3 already has significant health effects and substantial proportion of vulnerable populations are also affected. The TOFP was higher in industrial area compare to urban area (Figure 4.14). The high level at industrial sites as well as in the roadside environment poses great risks for people in these areas. The OFP (µg/m^3) is each compound at the 4 sites of Dhaka city is given in Table A4.9 in appendix. From the Table A4.9, it is clear that ozone formation from one VOC depends on both its concentration and MIR value.

4.10.2 Stacked column percentage (100%) contribution per group in TOFP

From the Figure 4.15 it can be observed the percentage contribution of each group to the TOFP. Total aromatic compounds had the highest contribution (64-87%) in TOFP where the highest contribution was found in industrial ambient and the lowest in urban park (Figure 4.15). Total (cyclo)-alkanes contribution was 8-10% where the highest contribution was found in both urban and industrial street and the lowest in urban park. Total oxygenated compounds had 3-26% contribution to TOFP where the highest contribution was found in urban park and the lowest in industrial ambient; Total terpenes contribution was 1-2% where the highest contribution was found in urban park and the lowest in the urban street.

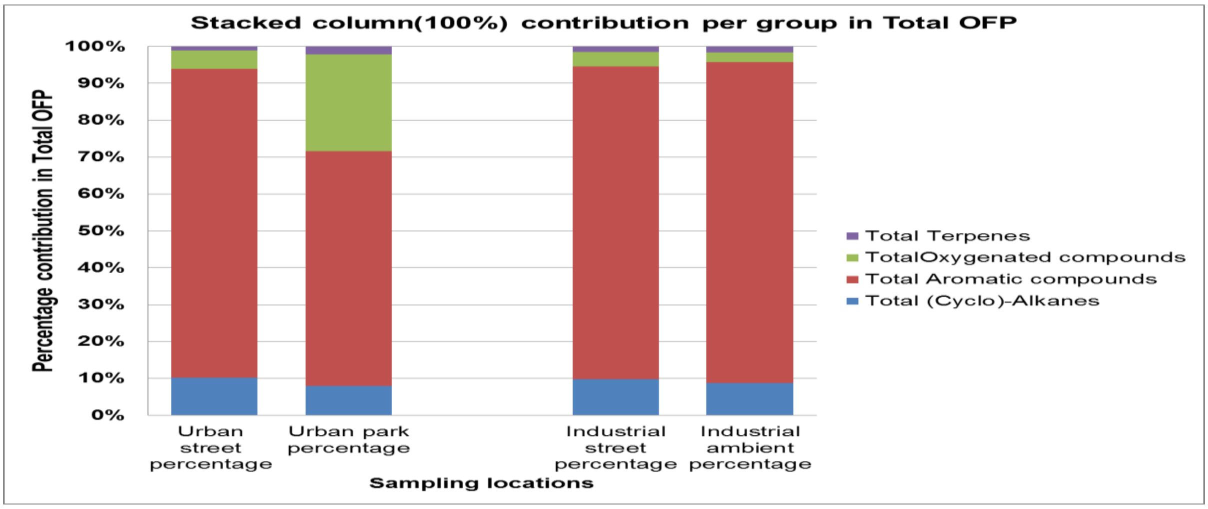


Figure 4.15: Stacked column percentage (100%) contribution per group in TOFP

4.10.3 Influence of update MIR in OFP

As aromatic compounds are the dominating groups and there is an update MIR, 2012(Carter and Hoe, 2012), so it is interesting to see the influence of update MIR, 2012 on aromatic compounds .Therefore, a comparison of update data used calculation of OFP using the update standard MIR-10(SAPRC-07) of Carter, 2010 and MIR-12(SAPRC-11) Carter and Hoe, 2012 for aromatic compounds.

4.10.3.1 Influence of update MIR in OFP (Urban Area)

From the Figure 4.16 it can be observed that all the aromatic compounds have higher contribution in ozone formation in urban street than in urban park. The OFP was calculated 59.46 µg/m^3 (MIR-10) and 78.79µg/m^3 (MIR-12) in urban street for toluene. Toluene has the highest contribution in OFP. The OFP level has increased 19µg/m^3 (33%) for industrial street and 6µg/m^3 (33%) for industrial park due to use update MIR-12 for toluene. Jeeranut *et al.* (2012) got also the highest calculated OFP for Dhaka city was toluene with 69.3ppb O_3 (1 ppb O_3 = 2µg/m^3 O_3) due to its high reactivity and high abundance. Only for 1,3,5-trimethylbenzene OFP is reduced in MIR-12 , all the rest compounds have increased value in MIR-12.

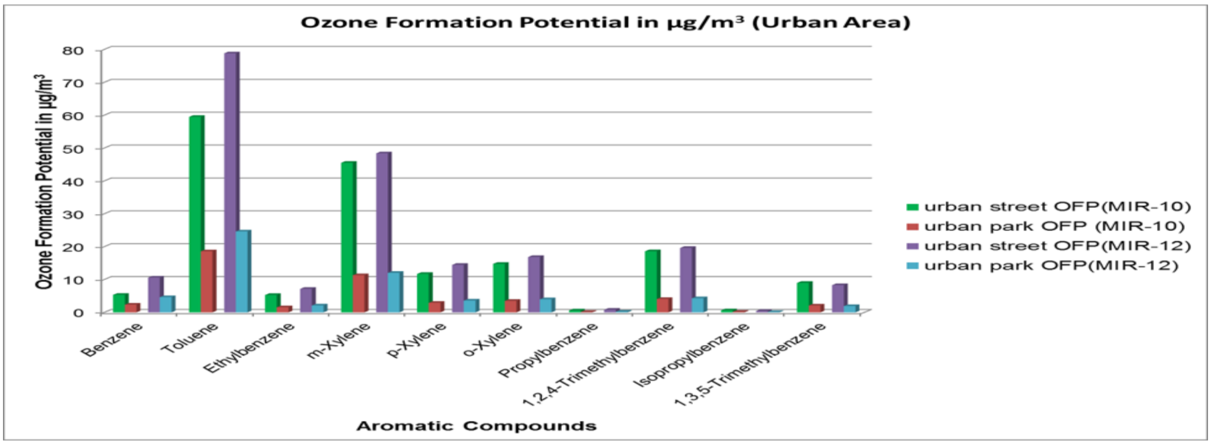


Figure 4.16: Comparison of ozone formation potential (urban area)

4.10.3.2 Influence of update MIR in OFP (Industrial Area)

From the Figure 4.17 it can be observed that the compounds benzene; toluene; m,p-xylene have higher contribution in industrial street than in industrial ambient but the compounds ethylbenzene, o-xylene have same contribution in both sites. Toluene has the highest contribution in OFP. The OFP was calculated 87.77µg/m^3 (MIR-10) and 116.30µg/m^3 (MIR-12) in industrial street for toluene. The OFP level has increased 29µg/m^3 (33%) for industrial street and 27µg/m^3 (33%) in industrial ambient due to use update MIR-12 for toluene. Only for 1,3,5-trimethylbenzene OFP is reduced in MIR-12 , all the rest compounds have increased value in MIR-12.

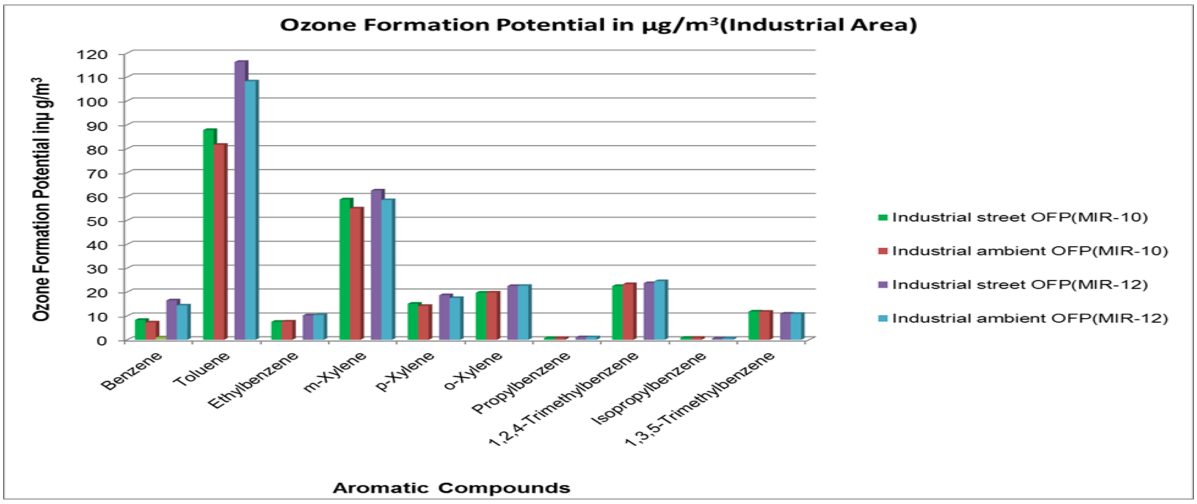


Figure 4.17: Comparison of Ozone Formation Potential (Industrial Area)

4.10.3.3 Influence of update MIR in TOFP for aromatic compounds

Figure 4.18 it can be noticed that for each site the OFP is higher due to use update MIR-12 than compare to the OFP of MIR-10 for aromatic compounds. Due to use of update MIR-12 the additional value added in O_3 formation compare to MIR-10 (MIR 12 - MIR 10) for urban street: 35µg/m^3(21%); urban park: 11µg/m^3(23%); industrial street: 50µg/m^3(21%) and industrial ambient: 46µg/m^3(21%). It is clear that ozone formation from VOC depends on both its concentration and MIR value.

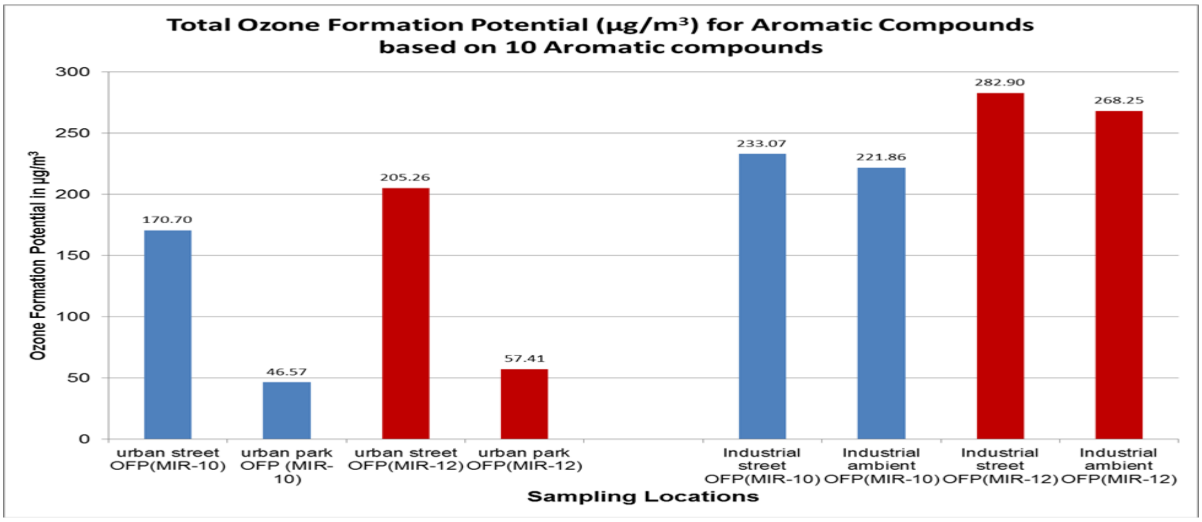


Figure 4.18: Comparison of ozone formation potential of the four ambient sampling sites

4.11 Country Level Comparison

There are some guidelines for indoor and ambient environments considering acute and long-term adverse health effects of VOCs and the guidelines vary from country to country. Reasonable comparison is challenging in the sense that the comparison is reasonable when comparison has done on the same type sampling environment, same sampling methods has used, there were same targets compounds and same sample size. In this section, a comparison at country level is discussed between this study and other studies in different cities from less developed region on BTEX and benzene level on urban environment.

4.11.1 Country level comparison for BTEX in urban area

The main reason to concentration on BTEX is due to their high level of volatilization, their toxicity to human and their role in the tropospheric chemistry (Franco *et al.*, 2012; Vyoma *et al*., 2012). Again among BTEX, Belgium and Vietnam had only one xylene compound (p-xylene), the data for the other two xylene compounds are not available (o- xylene and m-xylene). Therefore, the sum of m-xylene and p-xylene was separated as m-xylene/p-xylene equal to 2.33 according to Carla *et al*., 2014 and Monod *et al*., 2001 to make a fair comparison. That means m-xylene equal to 2.33×p-xylene and p-xylene equal to m,p-xylene/3.33 where m-xylene + p-xylene equal to m,p-xylene. Table A4.12 provides the calculated mean BTEX with maximum and minimum values at 3 sites for urban environment of 5 countries in the appendix.

Figure 4.19 provides a comparison of mean ∑BTEX at 3 sampling sites on urban environment among 5 countries namely Bangladesh, Belgium, Ethiopia, Philippines and Vietnam. The comparison is reasonable because they have the same target VOCs, same type sampling environment and the same sample size (N=6) and same sample analysis method. From the Figure 4.19, it can be observed that among the indoor houses, the highest mean ∑BTEX level was found in Vietnam (VT) and the concentration was around 38.32μg/m^3 and in Bangladesh (BD) was around 20.48μg/m^3; in Philippines (PH) 19.68μg/m^3; in Belgium (BE) 12.69μg/m^3 and the lowest was in Ethiopia (ET) 6.98μg/m^3.

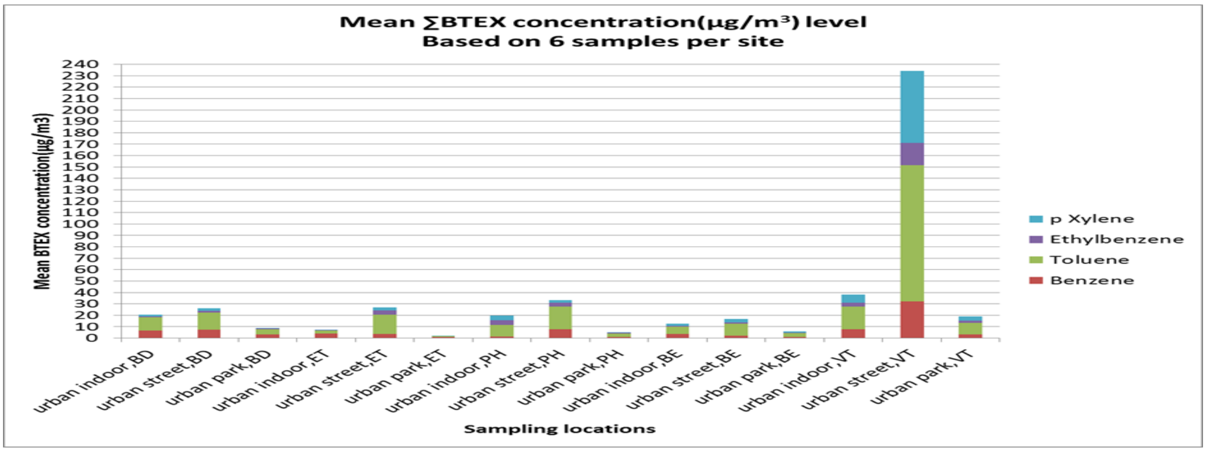


Figure 4.19:Comparison of mean ∑BTEX concentration (μg/m^3) level at 3 sites on urban area of Dhaka, Bangladesh and other studies' done on the urban area at Ghent, Belgium (BE) and Hanoi, Vietnam (VT) (Do *et al*., 2013);Manila, Philippines(PH)(Parao, 2012); Mekelle, Ethiopia(ET)(Amare, 2013).

From the Figure 4.19 it can be found that among the outdoor urban streets, the highest level mean ∑BTEX was found in Vietnam (VT) in the study done by Do *et al*., 2013 and the concentration was 234.22µg/m^3 whereas in Philippines (PH) 33.21µg/m^3; in Ethiopia (ET) 26.69µg/m^3; in Bangladesh (BD) 26.00µg/m^3 and the lowest was in Belgium (BE) 16.57µg/m^3. The main reason for the higher concentration of sums of BTEX in the road as discussed by Murena (2007) as well as Buczynska *et al*. (2009) is most probably the emissions from different vehicles. From the Figure 4.19 be observed that among the outdoor urban parks the highest level mean ∑BTEX was found in Vietnam (VT) in the study done by Do *et al*., 2013 and the concentration was 19.06µg/m^3. Whereas in Bangladesh (BD) mean ∑BTEX level was 8.84µg/m^3; in Belgium (BE) 5.81µg/m^3; in Philippines (PH) 5.22µg/m^3 and the lowest was in Ethiopia (ET) 1.90µg/m^3.

From Figure 4.20 it can be observed the comparison of urban mean ∑BTEX (µg/m^3) level between this study in Dhaka, Bangladesh and other countries studies. The comparison is reasonable because they have the same target VOCs, same environment and the same sample size (N=18). From the Figure 4.20 it can be observed the differences in the five countries with respect to ∑BTEX and represented that the highest ∑BTEX was measured in the urban area of Hanoi, Vietnam 97.20µg/m^3 which is a factor of 5 times higher than that measured at Dhaka city, Bangladesh 18.44µg/m^3 and in Manila, Philippines (PH) 19.37µg/m^3 besides a factor of 8 times higher compare to Mekelle, Ethiopia (ET) 11.86µg/m^3 and the lowest 11.69µg/m^3 at Ghent, Belgium.

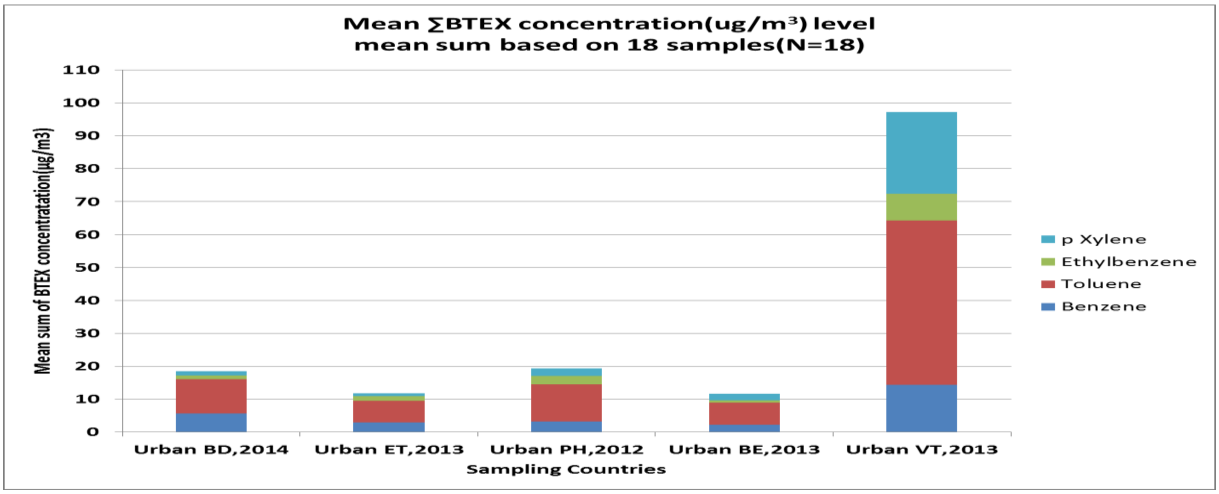


Figure 4.20 Comparison of ∑BTEX (µg/m^3) between Dhaka, BD and other countries study at Ghent, Belgium (BE) and Hanoi, Vietnam (VT) (Do *et al*., 2013); Manila, Philippines(PH)(Parao, 2012); Mekelle, Ethiopia(ET)(Amare, 2013).

4.11.2 Country level comparison for benzene in urban area

As mentioned before, the main reason to concentrate on benzene is that benzene can have acute and long-term adverse health effects such as cancer due to its toxic effects on the blood and marrow (Lan *et al*., 2004; IARC, 2013). As the result, there are some guidelines for benzene concentrations for both indoor and ambient environments. According to EU Directive/2008/50 the ambient air guideline for yearly average of benzene is 5µg/m³ and the

Flemish indoor air quality guidelines, 2007 long time average of benzene concentration is 2µg/m^3.

4.11.2.1 Country level comparison for benzene in indoor

From the Figure 4.21 it can be observed that the concentration level of benzene in the indoor of urban houses are above the guidelines of benzene concentration given by the Flemish indoor air quality guidelines, 2007 (benzene concentration: 2µg/m^3) except in Philippines (PH). The highest mean indoor benzene level was found in Hanoi, Vietnam (VT) 7.79µg/m^3. Whereas in Dhaka, Bangladesh (BD) mean indoor benzene level was 6.41µg/m^3; in the Mekelle, Ethiopia (ET) 4.02µg/m^3; in Ghent, Belgium 3.70µg/m^3 and the lowest was in the Manila, Philippines (PH) 1.24µg/m^3. The concentration of benzene level in Dhaka has reduced compare to previous study done Barai, 2012 (Figure 4.21). But as the guidelines for long-term average and the samples size (N=6) was limited and the sampling time was short and sample was taken in peak hours, so cautious should be exercised doing this type of comparison.

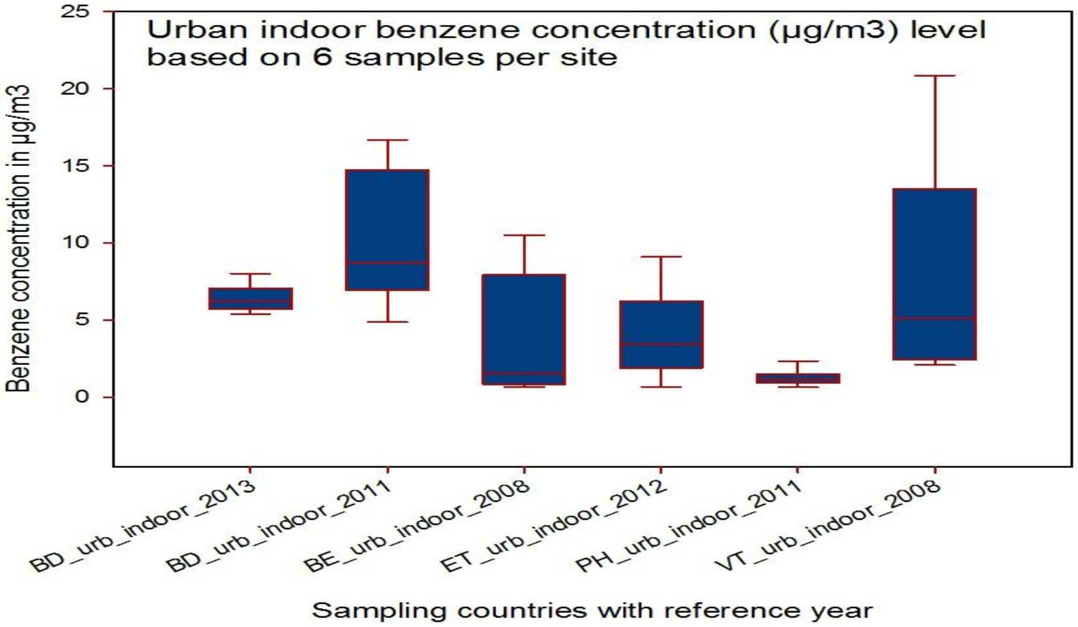


Figure 4.21:Comparison of indoor benzene (µg/m^3) between Dhaka, Bangladesh and other countries studies and other studies' done on the urban area at Ghent, Belgium (BE) and Hanoi, Vietnam (VT) (Do *et al.*, 2013);Manila, Philippines (PH)(Parao, 2012); Dhaka, Bangladesh (BD) (Barai, 2012) Mekelle, Ethiopia (ET) (Amare, 2013).

4.11.2.2 Country level comparison for benzene in outdoor

From the Figure 4.22 it can be observed that benzene concentration level in the outdoor of urban streets of Hanoi, Vietnam (32.18µg/m^3); Manila, Philippines (7.79µg/m^3); Dhaka, Bangladesh (7.40µg/m^3) are above the guidelines of benzene concentration given by EU Directive/2008/50 the ambient air guideline of benzene 5µg/m^3(yearly average). The highest level of mean outdoor benzene level was found in the street of Hanoi, Vietnam 32.18µg/m^3. Other urban streets (BE, ET) and all the urban parks are under that limit of benzene 5µg/m^3 yearly average. But again as the guidelines for yearly average and the samples size (N=6) was limited and the sampling time was short and sample was taken in peak hours, so cautions should be exercised doing this type of comparison.

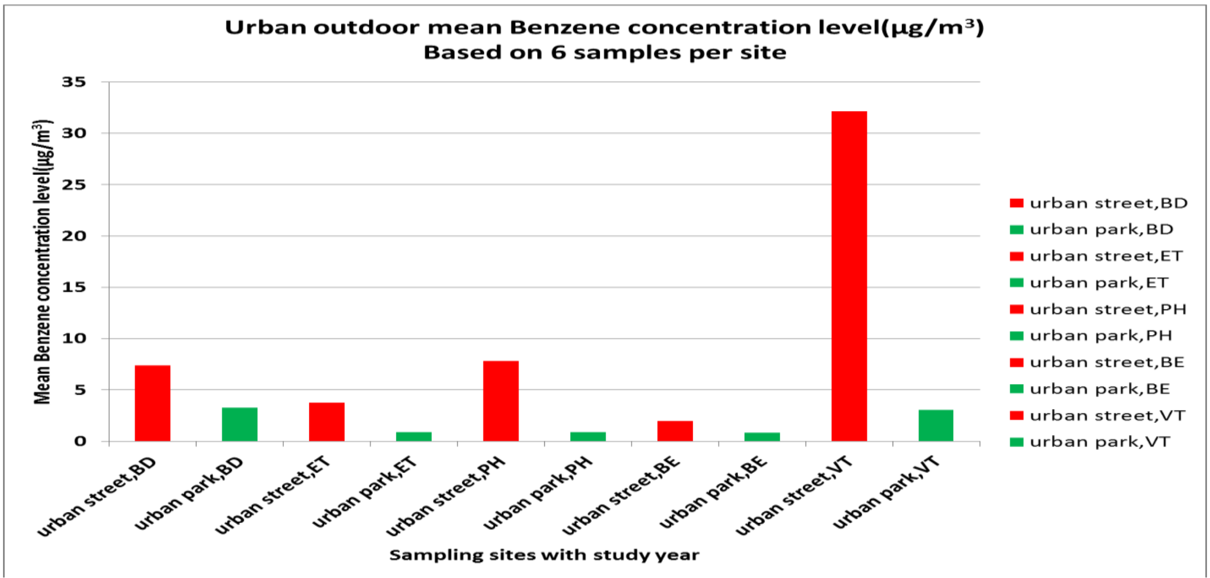


Figure 4.22: Comparison of outdoor benzene (µg/m^3) between Dhaka, Bangladesh and other countries studies done on the urban area at Ghent, Belgium (BE) and Hanoi, Vietnam (VT) (Do *et al.*, 2013); Manila, Philippines(PH) (Parao, 2012); Mekelle, Ethiopia (ET) (Amare, 2013).

CHAPTER FIVE: GENERAL CONCLUSIONS

Volatile organic compounds (VOCs) are of concern both as indoor and outdoor air polutants for their potential adverse impact on health of people who are exposed and ability to create photochemical smog under certain conditions. The presence and concentration levels of VOCs were investigated for urban and industrial areas Dhaka city, Bangladesh. For this purpose six places were selected in two areas (urban and industrial area) for sampling campaigns from 30 of August 2013 to 11 September 2013. Ambient/outdoor and indoor samples from both areas were obtained by means of active sampling using Tenax TA tubes as sorbent material during the sampling time.

Mirpur and Tejgaon were taken as urban and industrial sampling campaign respectively. Each sampling campaign has 3 locations both indoor and outdoor. Sample were taken each day two times in the morning and evening (7.00 am to 11.00 am and 4.30 to 8.30 pm) for three days where one weekend and two weekdays. During the sampling period the temperature was ranged between 28.1°C to 33.3°C and humidity was high (minimum: 92.1%).

Analysis and quantification were done by TD-GC-MS and internal standard calibration. A total set of 44 VOCs consisting of alkanes, aromatic compounds, halogenated compounds, oxygen containing compounds and terpenes were identified among the 84 target compounds from the six sampling sites. Considering safe sampling volume 5 compounds excluded. Data were interpreted in terms of TVOCs, subgroup of TVOCs, BETX level, benzene level, indoor to outdoor (I/O) ratio, source identification based on diagnostic ratios and correlations coefficient and OFP based on update MIR. Although the limited data set, the following conclusions can be drawn from the research.

The highest mean of TVOCs was measured in the roadside of the industrial street (mean: 96$\mu g/m^3$; maximum: around 151$\mu g/m^3$). The lowest mean of TVOCs was measured in the park of the urban area (mean: 28$\mu g/m^3$; minimum: around 14$\mu g/m^3$). All the sites of industrial area have higher level of TVOCs compare to urban areas. Total Aromatic compounds was observed to be the most abundant group in all sampling sites ranging from 42 to 61% of the TVOC in all the six sampling locations. The lowest percentage contribution (42%) of total aromatic compounds found in outdoor urban park and the highest percentage contribution (42%) of total aromatic compounds found in outdoor industrial ambient (62%).

The highest mean ΣBTEX were measured around 47$\mu g/m^3$ in the industrial ambient and the lowest mean around 10$\mu g/m^3$ in the urban park. Toluene has the highest concentration level among the 39 VOCs (mean around 5-22$\mu g/m^3$). However, evaluation of the detected VOCs shows that presence of VOCs varied from one site to another depending on the main source. There is an apparent improvement in terms of BTEX levels in Dhaka when the result of the study was compared to two other previous measurements done in 2012. Though, it seems that there is a significant reduction of VOCs in all the sites, more sampling campaigns should be done to validate this observation. Regular monitoring of significantly high emission sources of VOCs in sites should be considered.

Benzene concentration was 3.24-11.53µg/m^3. The highest mean concentration of benzene was found in industrial roadside (11.53µg/m^3) and the lowest in urban park (3.24µg/m^3). Among the 3 sites per area, the highest mean concentration of benzene level was found in roadside in both urban and industrial areas (urban road: 7.40µg/m^3 and industrial road: 11.53µg/m^3). Outdoor ambient benzene levels are above the EU Directive limit of 5µg/m^3 for 3 sampling sites except for the urban park which was below the level. According to WHO, there are no established safe levels for benzene.

The I/O ratio for TVOCs, some groups compound and as a specific compounds are not consistently higher than 1 as stated in this study. A number of possible factors can influence the I/O ratio like enhanced ventilation, the location of the outdoor ambient air site, presence of significant indoor sources.

This study shows that source identification can be done using diagnostic ratios and correlation analysis. Use of diagnostic ratios from the literature may prove to be problematic because of the observed site-specific BTEX patterns which imply different unique sources in different sites. Nevertheless, source identification by using specific values of diagnostic ratios becomes problematic at the presence of multiple point sources.

Diagnostic ratios that found in this study, B/T ratios was 0.34 to 0.82 in urban indoor house with mean 0.55; 0.42 to 0.63 in outdoor urban street with mean 0.50 and 1.22 to 0.94 in outdoor urban park with mean 0.70. Diagnostic ratio of B/T was 0.34 to 0.70 in indoor industrial house with mean 0.50, 0.25 to 0.87 in outdoor industrial street with mean 0.53 and 0.25 to 0.87 outdoor industrial ambient with mean 0.49. According to Han and Naeher, (2006), B/T ratios based upon ambient concentrations ranges from 0.3 to 0.8 in various urban roadside. Whereas B/T was in the range of 0.33 to 0.67 as the typical range of B/T ratio as an indicator of traffic dominated source of emission (Miller *et al*., 2011). Whereas Jeeranut *et al.*, 2012 mentioned the higher the B/T ratio, the more dominant the impact of traffic emission. But Buczynska *et al.* (2009) reported a lower range of 0.22 to 0.26 for areas with intensive street traffic.

Correlation analysis of aromatic compounds (14 VOCs) shows that the urban street, urban park and industrial street VOCs were highly correlated. This is indicative of a common source which is most probably the traffic emissions. On the other hand, industrial house, industrial ambient are characterized by poor correlation which indicates multiple and varied sources of emissions possibly because of the wide range of industries present in the sampling locations.

The highest TOFP was found in industrial street 286.29µg/m^3 and the lowest was in the urban park 75.17µg/m^3. In both urban and industrial area, roadside has the higher calculated TOFP been indicating that emissions from vehicles have the higher contribute to OFP (urban roadside: 206.92µg/m^3 and industrial roadside: 286.29µg/m^3). TOFP were calculated for industrial ambient was 265.62µg/m^3. This study shows that industrial activities can be a significant source of photochemical ground level ozone. It is thus imperative that, like traffic emission, careful attention and consideration should also be given to industrial emission sources. The estimated TOFP were calculated which shows that 2 of the 4 outdoor sites exceed the the threshold value 235µg/m^3 (0.12 ppm) for 1 hour (d) of Bangladesh NAAQS, 2005 for ozone and 3 out of 4 outdoor sites exceeded the WHO recommended level 100 µg/m^{3}and 157µg/m^3 (0.08 ppm) Bangladesh NAAQS, 2005 (8 hour average) of ozone but it worth nothing that caution should be exercised in making comparison because the sampling time was 30 minutes in duration and sample size was limited. The estimated overall ambient mean of 4 sites TOFP was around 208µg/m^3 which was under the threshold limit of Bangladesh NAAQS 2005 1h average per day for ozone.

So far the best of our knowledge, there is no specific guidelines for ambient levels of emissions of VOCs are provided in Bangladesh. According to the findings of this study, traffic and industries emit significant amount of VOCs that could cause substantial risks to health of population expose to be present in near the emission sources. It is recommended that VOCs be included in the list of criteria pollutants that are monitored and regulated. This study may provide helpful information in assessing current environmental policies for air quality and can serve as reference when hypothesising development programs, planning and implementing regulations and pollution reduction strategies.

RECOMMENDATIONS FOR FURTHER RESEARCH

Studies including more sites and including seasonal and temporal variations over a longer period of time are recommended as the sampling time was under the influence of monsoon considering the initial findings of this work and the reported spatial and temporal variability of VOC concentrations can be considered to further demonstrate and to have appropriate data set for human health risks assessment on the exposure to some toxic VOCs.

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Appendix

Table: 3.2 The 85(USEPA: 53, EnVOC: 31 & 1 IS) standard VOCs used for calibration of the TD-GC-MS are shown together with their characterizing ions, the loaded mass, the retention time and calculated RSRF (dimensionless) from the calibration (The loaded mass of internal standard Tol-d_8 for standard calibration was 69.9ng for Mix A of USEPA and 46.6 ng for Mix B of EnVOC).

Compound	Ion (SIM)	Mass (ng)	R.T (min)	RSRF
1,1-Dichloroethylene	61, 96, 98	50.0	3.48	0.192
Dichloromethane	49, 84, 86	50.0	3.60	0.540
trans-1,2-Dichloroethylene	61; 96; 98	50.0	4.49	0.262
1,1-Dichloroethane	63; 65	50.0	4.71	0.215
tert-Butyl methyl ether	73	37.0	4.75	0.147
2-Methylpentane	71	32.7	4.85	0.071
2-Butanone	43; 72	40.3	5.18	0.325
3-Methylpentane	41; 56; 57	33.2	5.35	0.358
cis-1,2-Dichloroethylene	61; 96; 98	50.0	5.79	0.335
n-Hexane	41; 71; 86	33.0	6.01	0.168
Bromochloromethane	128; 130; 132	50.0	6.07	0.182
Ethyl acetate	61; 70; 88	45.1	6.12	0.118
2,2-Dichloropropane	41; 77; 79	50.0	6.21	0.161
Chloroform	47; 83; 85	50.0	6.27	0.347
2-Methyl-1-propanol	31; 33; 43; 74	40.2	6.99	0.199
Methylcyclopentane	56; 69	37.4	7.41	0.328
1,2-Dichloroethane	62; 64; 98	50.0	7.49	0.208
1,1,1-Trichloroethane	61; 97; 99; 117	50.0	7.93	0.400
1,1-Dichloro-1-propene	75; 11; 112	50.0	8.61	0.293
Isopropyl acetate	43; 61; 87	43.6	8.95	0.411
Benzene	51; 77; 78	50.0	8.94	0.523
1-Butanol	31; 41; 56	40.5	9.20	0.242
Carbon_tetrachloride	117; 119; 121	50.0	9.30	0.523
Cyclohexane	56; 84	39.0	9.55	0.294
3-Pentanone	57; 86	40.7	11.08	0.374
1,2-Dichloropropane	27; 62; 63	50.0	11.16	0.176
Dibromomethane	93; 95; 172; 174	50.0	11.21	0.385
2,2,4-Trimethylpentane	56; 57	34.6	11.84	0.583
Bromodichloromethnae	47; 83; 85	50.0	11.90	0.261
Trichloroethylene	95; 97; 130; 132	50.0	11.90	0.573
n-Heptane	70; 71; 100	34.2	12.87	0.261
cis-1,3-Dichloropropene	39; 75; 77; 110	50.0	14.85	0.354
trans-1,3-Dichloropropene	39; 75; 77; 110	50.0	16.85	0.338
1,1,2-Trichloroethane	61; 97; 99; 132	50.0	17.35	0.305
Toluene-d_8^*	98; 100	46.6; 69.9	17.76	1.000
Toluene	65; 91; 92	50.0	18.14	1.052
1,3-Dichloropropane	41; 76; 78	50.0	18.46	0.307
Isobutyl acetate	43; 56; 73	43.4	18.75	0.464
2-Hexanone	43; 71; 85; 100	40.6	19.62	0.335
Dibromochloromethane	127; 129	50.0	19.88	0.350
Hexanal	44; 56; 72; 82	41.7	20.53	0.079
1,2-Dibromoethane	107; 109	50.0	20.67	0.441
n-Octane	71; 85; 114	35.2	22.53	0.285
Tetrachloroethylene	129; 164; 166; 168	50.0	22.58	0.551
Chlorobenzene	77; 112; 114	50.0	24.92	0.750
1,1,1,2-Tetrachloroethane	95; 117; 131; 133	50.0	24.96	0.443
Ethylbenzene	91; 106	50.0	26.04	0.922
m,p-xylene	91; 106	100.0	26.55	0.827
Styrene	51; 78; 194	50.0	27.43	0.232
Heptanal	44; 70; 96	42.5	27.61	0.140
o-Xylene	91; 106	50.0	27.63	0.912
1,1,2,2-Tetrachloroethane	83; 85; 131; 168	50.0	27.80	0.451
1,2,3-Trichloropropane	75; 99; 110; 112	50.0	28.05	0.466
n-Nonane	57; 85; 128	35.9	28.37	0.343
Isopropyl benzene	105; 120	50.0	29.00	0.905

Bromobenzene	156; 158	50.0	29.10	0.460
Alpha pinene	92; 93; 121; 136	42.9	29.76	0.566
Benzaldehyde	77; 105; 106	52.5	29.82	0.787
2-Chlorotoluene	126; 128	50.0	29.98	0.309
Propylbenzene	91; 120	50.0	30.12	1.461
4-Chlorotoluene	126; 128	50.0	30.15	0.293
1,3,5-Trimethylbenzene	105; 120	50.0	30.62	1.013
Beta-pinene	41; 69; 93	43.6	31.20	0.487
tert-Butylbenzene	91; 119; 134	50.0	31.43	1.289
1,2,4-Trimethylbenzene	105; 120	50.0	31.47	0.977
1,3-Dichlorobenzene	111; 146; 148	50.0	31.74	0.965
n-Decane	75; 85	36.5	31.80	0.089
1,4-Dichlorobenzene	111; 146; 148	50.0	31.90	1.062
sec-Butylbenzene	77; 91; 105; 134	50.0	32.01	1.331
2-Ethyl-1-hexanol	41; 43; 55; 57	41.7	32.34	0.385
p-Isopropyltoluene	119; 134	50.0	32.38	1.497
1,2-Dichlorobenzene	111; 146; 148	50.0	32.60	1.403
Limonene	68; 93; 107; 121; 136	42.1	32.67	0.558
n-Butylbenzene	91; 92; 134	50.0	33.27	2.225
1,2-Dibromo-3-chloropropane	75; 155; 157	50.0	33.59	0.643
Methylbenzoate	77; 105; 136	50.0	34.03	0.874
Linalool	71; 93; 121; 136	43.1	34.21	0.345
n-Undecane	57; 85	37.0	34.44	0.412
1,2,4-Trichlorobenzene	109; 145; 180; 182	50.0	36.34	0.575
Naphtalene	128	50.0	36.55	1.705
n-Dodecane	57; 85; 170	37.5	36.69	0.471
1,2,3-Trichlorobenzene	109; 145; 180; 182	50.0	37.11	1.365
Hexachloro-1,3-butadiene	118; 190; 225; 260	50.0	37.30	0.509
1,3,5-Triisopropylbenzene	91; 105; 161; 189; 204	42.7	38.89	1.100

Table A4.1 Excluded compounds in TVOCs with SSV

VOC Name	Scientific Instrument Services (SSV)	Marks International(SSV)	Lab/Paper
Dichloromethane			0.45(Duc *et al.*, 2013)
2-methylpentane			Not available
3-Methylpentane			Not available
Chloroform	1.9L	1.9L	
1,2-Dichloroethane	2.7L		

3-Methylpentane with the molecular formula C_6H_{14} is a branched-chain alkane. It is a structural isomer of hexane composed of a methyl group bonded to the third carbon atom in a pentane chain.. Molar mass**:** 86.18 g/mole (http://en.wikipedia.org).

2-Methylpentane with the molecular formula C_6H_{14} is also a branched-chain alkane. It is a structural isomer of hexane composed of a methyl group bonded to the second carbon atom in a pentane chain. Molar mass**:** 86.18 g/mole (http://en.wikipedia.org).

Although the above mentioned compounds have the same molar mass (86.18 g/mole) and molecular formula of Hexane ($C_6H_{14)}$ but considering the structural difference and volatility excluded from TVOCs calculation.

Appendix A VOC concentration - Urban Environment, Dhaka city, Bangladesh, 2013

Appendix A-1 Indoor VOC concentration (μg/m^3) measured at urban area- (Mukti housing, Taltala, Agargaon, south perirbag, Mirpur) (D= Detected, ND = Not Detected, TVOCs = Total Volatile Organic Compounds)

Sampling location	Indoor, 151/12/1Mukti Housing State, Taltala,Agargaon, Mirpur(Urban House)					
Sampling Date	30/8/2013 weekend	30/8/2013 weekend	1/9/2013 weekday	1/9/2013 weekday	3/9/2013 weekday	3/9/2013 weekday
Humidity	99.90%	99.90%	more than 100%	more than 100%	99.90%	99.90%
Temperature	31.6°C	30.4°C	30.6°C	29.6°C	29.0°C	30.0°C
Sample Time	7h19-7h49	20h02-20h32	7h16-7h46	19h31-20h01	07h01-07h31	19h41-20h11
Component Name	Final con (μg/m³)	Final con (μg/m³)	Final con (μg/m³)	Final con (μg/m³)	Final con (μg/m³)	Final con (μg/m³)
Hexane	0.79	0.95	1.42	1.09	1.33	1.33
Heptane	1.47	1.34	1.92	1.84	1.78	3.01
Octane	1.35	1.28	1.61	1.49	1.33	2.57
Nonane	1.06	1.59	1.27	1.86	0.95	2.88
Decane	0.91	1.50	0.76	2.00	0.78	2.31
Undecane	0.33	0.61	0.24	0.80	0.28	1.29
Dodecane	0.36	0.53	0.24	0.56	0.26	0.92
Total Alkanes	6.26	7.80	7.46	9.65	6.71	14.31
Cyclohexane	1.72	1.12	1.76	1.37	1.73	2.41
2,2,4-trimethylpentane	ND	0.08	0.04	0.19	0.07	0.34
Methylcyclopentane	1.98	1.60	2.44	2.04	2.50	2.95
Total Cyclo-alkanes	3.70	2.80	4.24	3.59	4.30	5.70
Total (Cyclo)-alkanes	9.96	10.60	11.70	13.24	11.01	20.02
Aromatic compounds						
Benzene	5.39	5.85	6.61	8.01	5.87	6.75
Toluene	10.26	17.05	11.02	12.31	7.16	12.22
Ethylbenzene	0.81	0.92	0.88	1.77	0.65	1.37
m,p-Xylene	4.34	3.63	4.30	4.64	3.36	6.32
o-Xylene	0.99	1.04	1.00	1.28	0.76	1.74
Total BTEX	21.79	28.49	23.81	28.02	17.81	28.39
Styrene	0.28	0.30	0.38	0.49	0.22	0.56
Propylbenzene	0.11	0.16	0.10	0.18	0.08	0.25
1,2,4-Trimethylbenzene	0.87	1.23	0.84	1.30	0.60	2.00
Isopropylbenzene	0.08	0.10	0.09	0.11	0.07	0.17
p-Isopropyltoluene	0.09	0.10	0.07	0.12	0.07	0.18
Naphtalene	6.16	3.48	2.68	1.49	1.79	4.06
1,3,5-Trimethylbenzene	0.33	0.44	0.39	0.49	0.27	0.76
sec-Butylbenzene	0.02	0.04	0.02	ND	0.01	0.05
Total Aromatic compounds	29.73	34.33	28.39	32.20	20.91	36.42
Oxygenated compound						
Aldehyde						
Benzaldehyde	1.78	1.65	2.52	2.07	1.43	4.20
Hexanal	2.69	0.90	0.90	0.72	2.21	1.40
Heptanal	0.90	ND	0.03	ND	1.22	0.17
Total Aldehyde	5.37	2.55	3.45	2.79	4.86	5.77
Alcohols						
2-Ethyl-1-hexanol	4.81	2.53	2.75	1.23	3.90	2.76
Total Alcohols	4.81	2.53	2.75	1.23	3.90	2.76
Ketones						
2-Butanone	0.54	1.23	0.93	0.80	0.44	0.55
3-Pentanone	0.06	0.04	0.03	0.03	0.02	0.02
Total ketones	0.60	1.27	0.96	0.84	0.46	0.57
Esters						
Methylbenzoate	0.35	0.14	ND	ND	ND	0.17
Ethyl_acetate	2.60	3.81	4.47	2.89	1.06	1.81
Total Esters	2.96	3.95	4.47	2.89	1.06	1.97
Total Oxygenated compounds	13.74	10.30	11.63	7.74	10.27	11.08
Halogenated compounds						
Carbon_tetrachloride	0.24	0.22	0.23	0.18	0.20	0.11
1,4-Dichlorobenzene	0.29	0.15	0.22	0.15	0.09	0.19
1,2-Dichlorobenzene	D	ND	0.01	0.00	0.00	ND
1,2,3-Trichlorobenzene	0.03	0.02	0.01	ND	0.02	0.02
Total Halogenated compounds	0.55	0.38	0.46	0.33	0.31	0.33
Terpenes						
Alpha_pinene	0.10	0.09	0.09	0.11	0.08	0.10
Beta-pinene	0.05	0.06	0.04	0.07	0.05	0.07
Limonene	0.37	0.39	0.36	0.32	0.31	0.73
Total Terpenes	0.52	0.54	0.49	0.50	0.44	0.91
Grand Total	54.49	56.15	52.68	54.02	42.94	68.75

Appendix A VOC concentration - Urban Environment, Dhaka city, Bangladesh, 2013

Appendix A-2 Outdoor VOC concentration (µg/m^3) measured at urban area- (Begum Rokeya Sarani, Mirpur-10) (D= Detected, ND = Not Detected, TVOCs = Total Volatile Organic Compounds)

Sampling location	Outdoor, street,Mirpur-10(Urban street)					
Sampling Date	30/8/2013 weekend	30/8/2013 weekend	1/9/2013 weekday	1/9/2013 weekday	3/9/2013 weekday	3/9/2013 weekday
Humidity	99.90%	99.90%	99.90%	99.90%	99.90%	99.90%
Temperature	31.6°C	30.9°C	32.6°C	30.0°C	29.4°C	30.2°C
Sample Time	8h39-9h09	18h44-19h14	8h14-8h44	16h31-17h01	9h45-10h15	17h44-18h14
Component Name	Final con (µg/m³)	Final con (µg/m³)	Final con (µg/m³)	Final con (µg/m³)	Final con (µg/m³)	Final con (µg/m³)
Hexane	1.57	3.53	1.35	4.49	2.02	2.66
Heptane	1.87	2.71	1.37	3.71	2.02	2.88
Octane	1.57	2.05	1.40	2.82	1.37	2.28
Nonane	2.29	2.34	1.99	3.57	1.67	3.19
Decane	2.48	2.29	1.68	3.21	1.53	3.26
Undecane	1.49	1.10	0.79	1.53	0.80	1.68
Dodecane	1.20	0.92	0.58	1.09	0.59	1.22
Total Alkanes	12.48	14.94	9.15	20.43	9.99	17.17
Cyclohexane	1.40	1.88	0.98	2.46	1.56	1.84
2,2,4-trimethylpentane	0.18	0.26	0.15	0.36	0.39	0.41
Methylcyclopentane	2.20	3.35	1.69	4.35	2.33	3.11
Total Cyclo-alkanes	3.78	5.49	2.81	7.18	4.28	5.36
Total (Cyclo)-alkanes	16.26	20.44	11.96	27.60	14.28	22.53
Aromatic compounds						
Benzene	6.10	9.12	4.56	10.85	6.31	7.46
Toluene	9.73	17.22	8.51	23.70	12.07	17.96
Ethylbenzene	1.00	2.29	0.90	3.31	0.80	2.10
m,p-Xylene	4.49	8.48	3.55	10.91	3.83	8.73
o-Xylene	1.25	2.44	1.04	3.23	1.04	2.58
Total BTEX	22.58	39.55	18.56	52.00	24.04	38.83
Styrene	0.22	0.49	0.28	0.53	0.20	0.51
Propylbenzene	0.21	0.33	0.16	0.41	0.16	0.40
1,2,4-Trimethylbenzene	1.74	2.62	1.16	3.15	1.12	2.79
Isopropylbenzene	0.13	0.20	0.10	0.26	0.10	0.22
p-Isopropyltoluene	0.10	0.14	0.07	0.17	0.08	0.15
Naphtalene	0.62	0.79	0.31	0.61	0.43	0.55
1,3,5-Trimethylbenzene	0.56	0.98	0.40	1.17	0.40	1.06
sec-Butylbenzene	0.05	0.06	0.03	0.09	0.03	0.08
Total Aromatic compounds	26.21	45.18	21.06	58.40	26.55	44.60
Oxygenated compound						
Aldehyde						
Benzaldehyde	2.54	2.04	2.42	2.89	2.62	2.34
Hexanal	0.67	0.20	0.86	0.47	0.34	0.37
Heptanal	ND	ND	0.25	ND	0.21	0.13
Total Aldehyde	3.20	2.25	3.53	3.37	3.18	2.84
Alcohols						
2-Ethyl-1-hexanol	1.40	1.90	2.05	1.54	6.91	1.29
Total Alcohols	1.40	1.90	2.05	1.54	6.91	1.29
Ketones						
2-Butanone	0.83	0.91	0.93	1.60	0.53	D
3-Pentanone	0.03	0.02	0.04	0.03	0.02	0.03
Total ketons	0.86	0.94	0.96	1.63	0.56	0.03
Esters						
Methylbenzoate	ND	ND	ND	0.12	ND	ND
Ethyl_acetate	3.01	3.04	3.78	8.15	1.79	2.91
Total Esters	3.01	3.04	3.78	8.28	1.79	2.91
Total Oxygenated compounds	8.47	8.12	10.32	14.82	12.43	7.06
Halogenated compounds						
Carbon_tetrachloride	0.19	0.20	0.21	0.20	0.17	0.16
1,4-Dichlorobenzene	0.13	0.13	0.08	0.16	0.10	0.12
1,2-Dichlorobenzene	0.00	0.00	0.00	ND	0.00	0.00
1,2,3-Trichlorobenzene	0.01	0.01	0.01	ND	0.01	ND
Total Halogenated compounds	0.34	0.34	0.30	0.37	0.28	0.29
Alpha_pinene	0.10	0.15	0.10	0.17	0.18	0.24
Beta-pinene	0.04	0.06	0.04	0.07	0.04	0.05
Limonene	0.28	0.47	0.17	0.58	0.15	0.31
Total Terpenes	0.42	0.67	0.31	0.82	0.37	0.60
Grand Total	51.71	74.76	43.95	102.01	53.91	75.09

Appendix A VOC concentration - Urban Environment, Dhaka city, Bangladesh, 2013

Appendix A-3 Outdoor VOC concentration (µg/m^3) measured at urban area- (National Botanical Garden, Mirpur) (D= Detected, ND = Not Detected, TVOCs = Total Volatile Organic Compounds)

Sampling location	Outdoor, National Botanical Garden, Urban Park					
Sampling Date	30/8/2013 weekend	30/8/2013 weekend	1/9/2013 weekday	1/9/2013 weekday	3/9/2013 weekday	3/9/2013 weekday
Humidity	99.90%	99.90%	99.90%	more than 100%	99.90%	99.90%
Temperature	31.2°C	30.5°C	31.9°C	33.3°C	30.1°C	28.8°C
Sample Time	9h52-10h22	16h53-17h23	8h51-9h21	16h37-17h07	9h36-10h06	17h41-18h11
Component Name	Final con (µg/m³)	Final con (µg/m³)	Final con (µg/m³)	Final con (µg/m³)	Final con (µg/m³)	Final con (µg/m³)
Hexane	ND	0.53	ND	0.70	ND	0.57
Heptane	0.26	1.00	0.43	0.81	0.28	1.06
Octane	0.39	1.34	0.35	0.79	0.49	0.99
Nonane	0.52	1.62	0.39	1.22	0.75	1.32
Decane	0.21	1.29	0.32	0.96	0.26	1.00
Undecane	0.03	0.45	0.09	0.27	0.04	0.36
Dodecane	0.12	0.44	0.10	0.20	0.09	0.31
Total Alkanes	1.54	6.67	1.67	4.97	1.90	5.62
Cyclohexane	D	0.72	0.24	0.63	D	0.82
2,2,4-trimethylpentane	0.10	0.13	ND	ND	ND	ND
Methylcyclopentane	0.21	1.03	0.49	1.11	0.18	1.32
Total Cyclo-alkanes	0.31	1.88	0.73	1.75	0.18	2.14
Total (Cyclo)-alkanes	1.85	8.55	2.41	6.71	2.08	7.76
Aromatic compounds						
Benzene	2.05	5.32	2.79	3.93	1.42	3.91
Toluene	1.18	4.36	3.47	7.59	1.50	9.75
Ethylbenzene	0.12	0.54	0.25	1.06	0.19	0.88
m,p-Xylene	0.48	1.93	0.96	2.70	0.99	2.88
o-Xylene	0.15	0.54	0.27	0.75	0.24	0.79
Total BTEX	3.98	12.69	7.74	16.04	4.34	18.19
Styrene	0.10	0.27	0.11	0.20	0.06	0.61
Propylbenzene	0.02	0.10	0.04	0.10	0.03	0.11
1,2,4-Trimethylbenzene	0.14	0.58	0.27	0.71	0.19	0.87
Isopropylbenzene	0.02	0.06	0.03	0.07	0.03	0.08
p-Isopropyltoluene	D	0.06	0.03	0.05	0.01	0.06
Naphtalene	0.16	0.47	0.21	0.26	0.08	0.33
1,3,5-Trimethylbenzene	0.04	0.23	0.08	0.27	0.09	0.33
sec-Butylbenzene	ND	ND	0.00	ND	ND	0.02
Total Aromatic compounds	4.46	14.46	8.50	17.71	4.82	20.60
Aldehyde						
Benzaldehyde	2.02	5.79	1.89	1.85	1.45	1.71
Hexanal	2.38	9.58	0.12	0.32	1.91	0.24
Heptanal	0.29	1.07	ND	ND	0.45	ND
Total Aldehyde	4.69	16.44	2.01	2.17	3.81	1.95
Alcohols						
2-Ethyl-1-hexanol	2.81	5.76	0.70	0.81	1.81	0.95
Total Alcohols	2.81	5.76	0.70	0.81	1.81	0.95
Ketones						
2-Butanone	0.85	2.41	D	D	D	D
3-Pentanone	D	0.06	0.02	D	0.02	D
Total ketons	0.85	2.47	0.02	0.00	0.02	0.00
Esters						
Methylbenzoate	ND	ND	ND	ND	ND	ND
Ethyl_acetate	1.24	2.83	2.80	4.10	0.75	5.72
Total Esters	1.24	2.83	2.80	4.10	0.75	5.72
Total Oxygenated compounds	9.60	27.50	5.53	7.07	6.37	8.61
Halogenated compounds						
Carbon_tetrachloride	0.19	0.37	0.18	0.23	0.26	0.20
1,4-Dichlorobenzene	D	0.04	0.04	0.07	D	0.09
1,2-Dichlorobenzene	0.00	ND	0.00	0.00	ND	ND
1,2,3-Trichlorobenzene	0.01	0.02	ND	ND	ND	0.00
Total Halogenated compounds	0.19	0.42	0.22	0.29	0.26	0.28
Terpenes						
Alpha_pinene	0.14	0.19	0.55	0.09	0.10	0.06
Beta-pinene	0.07	0.08	0.07	0.05	0.06	0.03
Limonene	0.06	0.24	0.08	0.12	0.04	0.17
Total Terpenes	0.27	0.51	0.71	0.27	0.20	0.26
Grand Total	16.37	51.44	17.37	32.06	13.74	37.52

Appendix B VOC concentration - Industrial Environment, Dhaka city, Bangladesh, 2013

Appendix B-1 Indoor VOC concentration (μg/m^3) measured at Industrial area- (540/1 Shahinbag, Nakhalpara, Tejgaon) (D= Detected, ND = Not Detected, TVOCs = Total Volatile Organic Compounds)

Sampling location	Indoor, 540/1 Shahinbag, Nakhalpara, house near Tejgaon industrial area					
Sampling Date	6/9/2013	6/9/2013	9/9/2013	9/9/2013	11/9/2013	11/9/2013
	weekend	weekend	weekday	weekday	weekday	weekday
Humidity	99.90%	99.90%	99.90%	99.90%	97.90%	94.90%
Temperature	30.6°C	30.3°C	29.2°C	29.5°C	30.0°C	30.9°C
Sample Time	10h51-11h21	17h37-18h07	10h04-10h34	18h04-18h34	10h09-10h39	17h24-5h54
Component Name	Final con (μg/m³)	Final con (μg/m³)	Final con (μg/m³)	Final con (μg/m³)	Final con (μg/m³)	Final con (μg/m³)
Hexane	1.19	3.82	2.03	2.18	2.02	2.01
Heptane	1.98	4.29	2.76	2.79	2.77	2.87
Octane	1.68	3.16	2.37	1.96	2.24	2.21
Nonane	1.90	3.14	3.45	2.55	3.08	1.95
Decane	1.12	2.63	3.00	2.31	2.30	1.43
Undecane	0.37	1.15	1.13	0.92	0.85	0.58
Dodecane	0.29	0.90	0.86	0.71	0.64	0.45
Total Alkanes	8.52	19.09	15.60	13.41	13.90	11.49
Cyclohexane	1.25	3.83	1.92	2.26	2.00	2.34
2,2,4-trimethylpentane	0.21	0.29	0.32	0.20	0.55	0.26
Methylcyclopentane	1.91	5.40	2.84	3.24	3.05	3.33
Total Cyclo-alkanes	3.38	9.53	5.08	5.70	5.60	5.93
Total (Cyclo)-alkanes	11.90	28.62	20.69	19.11	19.50	17.42
Benzene	5.98	11.16	8.18	8.74	9.29	8.98
Toluene	11.85	21.38	16.75	25.87	13.32	15.27
Ethylbenzene	2.63	2.28	2.75	2.89	1.88	1.56
m,p-Xylene	4.56	8.14	8.16	7.80	7.61	6.95
o-Xylene	1.31	2.41	2.50	2.23	2.32	1.94
Total BTEX	26.33	45.37	38.34	47.52	34.43	34.70
Styrene	0.26	0.46	0.45	0.65	0.36	0.35
Propylbenzene	0.14	0.32	0.37	0.29	0.33	0.24
1,2,4-Trimethylbenzene	0.96	2.19	2.64	2.17	2.21	1.83
Isopropylbenzene	0.11	0.21	0.24	0.20	0.20	0.15
p-Isopropyltoluene	0.48	0.34	0.27	0.17	1.33	0.33
Naphtalene	3.54	3.66	5.10	4.94	8.83	4.86
1,3,5-Trimethylbenzene	0.39	0.90	0.99	0.90	0.82	0.73
sec-Butylbenzene	ND	0.07	0.09	0.07	0.06	0.04
Total Aromatic compounds	32.21	53.52	48.50	56.91	48.57	43.22
Aldehyde						
Benzaldehyde	1.99	2.15	3.16	1.25	3.49	2.82
Hexanal	3.45	1.52	0.50	0.83	1.09	1.94
Heptanal	0.73	0.06	ND	ND	0.13	ND
Total Aldehyde	6.17	3.73	3.66	2.08	4.71	4.75
Alcohols						
2-Ethyl-1-hexanol	1.12	1.40	1.20	0.73	D	1.27
Total Alcohols	1.12	1.40	1.20	0.73	0.00	1.27
Ketones						
2-Butanone	1.62	1.39	1.44	2.09	1.68	0.95
3-Pentanone	0.04	ND	ND	0.02	0.07	0.04
Total ketons	1.66	1.39	1.44	2.11	1.75	0.99
Methylbenzoate	ND	ND	ND	ND	ND	ND
Ethyl_acetate	9.98	3.59	12.59	16.55	3.63	2.47
Total Esters	9.98	3.59	12.59	16.55	3.63	2.47
Total Oxygenated compounds	18.92	10.11	18.89	21.47	10.09	9.49
Halogenated compounds						
Carbon_tetrachloride	0.17	0.18	0.19	0.17	0.15	0.18
1,4-Dichlorobenzene	0.21	0.32	0.31	0.25	0.45	0.31
1,2-Dichlorobenzene	ND	ND	ND	ND	ND	ND
1,2,3-Trichlorobenzene	0.01	ND	ND	ND	0.01	0.00
Total Halogenated compounds	0.39	0.49	0.50	0.42	0.61	0.49
Alpha_pinene	0.28	0.26	0.24	0.20	0.31	0.14
Beta-pinene	0.54	0.23	0.14	0.09	0.89	0.13
Limonene	0.46	2.00	1.25	1.08	1.86	0.85
Total Terpenes	1.28	2.50	1.63	1.37	3.06	1.12
Grand Total	64.69	95.25	90.21	99.28	81.83	71.74

Appendix B VOC concentration - Industrial Environment, Dhaka city, Bangladesh, 2013

Appendix B-2 Outdoor VOC concentration ($\mu g/m^3$) measured at Industrial area- (Farmgate, Tejgaon) (D= Detected, ND = Not Detected, TVOCs = Total Volatile Organic Compounds)

Sampling location	Outdoor, Street, Farmgate					
Sampling Date	6/9/2013 weekend	6/9/2013 weekend	9/9/2013 weekday	9/9/2013 weekday	11/9/2013 weekday	11/9/2013 weekday
Humidity	more than 100%	more than 100%	99.90%	99.90%	99.90%	99.90%
Temperature	29.6°C	29.1°C	29.4°C	29.4°C	30.0°C	30.6°C
Sample Time	7h38-8h08	20h20-20h50	7h42-8h12	16h44-17h14	8h06-8h36	16h22-16h52
Component Name	Final con (µg/m³)	Final con (µg/m³)	Final con (µg/m³)	Final con (µg/m³)	Final con (µg/m³)	Final con (µg/m³)
Hexane	2.36	6.85	2.74	1.23	2.54	3.98
Heptane	3.20	6.28	2.68	1.62	3.04	2.95
Octane	3.11	4.43	2.05	1.43	2.13	2.81
Nonane	2.99	4.84	2.21	2.45	2.22	4.19
Decane	2.07	4.49	2.33	2.07	1.75	3.81
Undecane	0.98	2.49	0.99	0.64	0.80	1.41
Dodecane	0.83	2.15	0.80	0.43	0.61	0.96
Total Alkanes	15.55	31.52	13.80	9.85	13.07	20.11
Cyclohexane	2.34	5.02	1.82	1.15	2.19	1.98
2,2,4-trimethylpentane	0.30	0.54	0.34	0.14	0.43	0.47
Methylcyclopentane	3.22	8.00	3.08	1.68	3.56	3.44
Total Cyclo-alkanes	5.86	13.57	5.24	2.98	6.18	5.90
Total (Cyclo)-alkanes	21.41	45.08	19.04	12.83	19.25	26.01
Benzene	11.69	22.05	10.33	4.56	9.24	11.30
Toluene	13.38	32.94	14.52	18.45	19.64	32.72
Ethylbenzene	1.68	4.18	1.99	1.86	1.95	3.22
m,p-Xylene	5.86	14.67	8.79	4.92	8.12	9.32
o-Xylene	1.64	4.72	2.51	1.41	2.31	2.89
Total BTEX	34.24	78.56	38.14	31.20	41.27	59.44
Styrene	0.51	1.22	0.70	0.49	0.40	0.48
Propylbenzene	0.21	0.65	0.34	0.22	0.31	0.42
1,2,4-Trimethylbenzene	1.45	4.69	2.59	1.45	2.09	2.95
Isopropylbenzene	0.14	0.46	0.22	0.14	0.19	0.25
p-Isopropyltoluene	0.13	0.50	0.14	0.10	0.12	0.17
Naphtalene	1.48	1.84	0.93	0.46	0.91	0.89
1,3,5-Trimethylbenzene	0.57	2.01	1.00	0.58	0.75	1.12
sec-Butylbenzene	0.05	0.17	0.06	0.05	0.05	0.10
Total Aromatic compounds	38.79	90.11	44.13	34.67	46.08	65.83
Aldehyde						
Benzaldehyde	5.57	2.52	2.68	2.21	2.43	6.13
Hexanal	3.29	0.15	0.99	1.50	0.31	1.10
Heptanal	1.19	ND	ND	0.19	0.09	0.08
Total Aldehyde	10.05	2.67	3.67	3.90	2.83	7.30
Alcohols						
2-Ethyl-1-hexanol	2.56	0.37	2.91	1.43	2.06	1.34
Total Alcohols	2.56	0.37	2.91	1.43	2.06	1.34
Ketones						
2-Butanone	D	2.37	1.09	1.90	1.32	3.28
3-Pentanone	D	0.06	ND	0.02	0.06	D
Total ketons	0.00	2.42	1.09	1.92	1.38	3.28
Esters						
Methylbenzoate	ND	ND	ND	ND	ND	ND
Ethyl_acetate	3.55	7.25	5.54	12.72	5.94	17.63
Total Esters	3.55	7.25	5.54	12.72	5.94	17.63
Total Oxygenated compounds	16.16	12.71	13.20	19.97	12.21	29.56
Halogenated compounds						
Carbon_tetrachloride	0.37	0.19	0.17	0.17	0.15	0.41
1,4-Dichlorobenzene	0.31	0.43	0.22	0.12	0.40	0.26
1,2-Dichlorobenzene	0.01	ND	ND	ND	ND	0.01
1,2,3-Trichlorobenzene	0.01	0.04	ND	0.01	ND	ND
Total Halogenated compounds	0.68	0.62	0.39	0.29	0.55	0.67
Alpha_pinene	0.24	0.25	0.18	0.18	0.15	0.25
Beta-pinene	D	0.16	0.06	0.05	0.05	0.07
Limonene	0.61	1.71	0.42	0.46	0.24	0.64
Total Terpenes	0.86	2.12	0.65	0.69	0.44	0.96
Grand Total	77.90	150.65	77.41	68.45	78.54	123.03

Appendix B VOC concentration - Industrial Environment, Dhaka city, Bangladesh, 2013

Appendix B-3 Outdoor VOC concentration (µg/m^3) measured at Industrial area- (in front of BITAC (Bangladesh Industrial Technical Assistance Centre), Tejgaon industrial area of Dhaka) (D= Detected, ND = Not Detected, TVOCs = Total Volatile Organic Compounds)

Sampling location	Outdoor ambient, Industrial area					
Sampling Date	6/9/2013 weekend	6/9/2013 weekend	9/9/2013 weekday	9/9/2013 weekday	11/9/2013 weekday	11/9/2013 weekday
Humidity	99.90%	99.90%	99.90%	99.90%	92.10%	99.90%
Temperature	31.4°C	29.4°C	28.6°C	28.1°C	31.1°C	29.7°C
Sample Time	9h21-9h51	19h19- 19h49	8h42-9h12	19h06-19h36	9h10-9h40	18h38-19h08
Component Name	Final con (µg/m³)	Final con (µg/m³)	Final con (µg/m³)	Final con (µg/m³)	Final con (µg/m³)	Final con (µg/m³)
Hexane	D	8.43	0.48	8.21	1.47	5.32
Heptane	0.80	5.39	1.32	3.59	1.85	4.59
Octane	0.70	3.90	1.24	1.83	1.22	4.22
Nonane	0.81	3.98	1.44	2.04	1.55	5.35
Decane	0.66	3.53	1.23	1.91	1.43	4.57
Undecane	0.20	1.77	0.45	0.85	0.57	2.18
Dodecane	0.23	1.40	D	0.63	0.45	1.68
Total Alkanes	3.40	28.40	6.15	19.06	8.54	27.92
Cyclohexane	0.55	4.95	0.91	2.24	1.15	2.01
2,2,4-trimethylpentane	ND	0.43	0.17	0.20	0.24	0.68
Methylcyclopentane	0.91	7.85	1.23	4.17	2.22	4.97
Total Cyclo-alkanes	1.47	13.24	2.30	6.61	3.61	7.66
Total Hydrocarbons	4.87	41.64	8.46	25.67	12.15	35.58
Benzene	3.79	22.45	4.70	10.84	6.56	11.90
Toluene	7.21	25.87	6.55	42.90	13.46	26.44
Ethylbenzene	1.31	3.52	0.75	2.92	1.61	4.94
m,p-Xylene	2.80	12.11	3.27	8.73	5.23	16.20
o-Xylene	0.77	3.95	0.95	2.52	1.66	5.65
Total BTEX	15.89	67.90	16.21	67.91	28.53	65.13
Styrene	0.12	1.03	0.30	0.40	0.24	0.61
Propylbenzene	0.09	0.54	0.14	0.31	0.22	0.86
1,2,4-Trimethylbenzene	0.62	3.85	0.98	2.38	1.64	6.27
Isopropylbenzene	0.06	0.39	0.09	0.21	0.13	0.51
p-Isopropyltoluene	0.05	0.39	0.11	0.14	0.08	0.42
Naphtalene	0.44	2.30	0.49	0.49	1.21	0.97
1,3,5-Trimethylbenzene	0.22	1.52	0.37	1.01	0.55	2.30
sec-Butylbenzene	0.01	0.13	0.03	0.06	0.04	0.19
Total Aromatic compounds	17.51	78.05	18.72	72.90	32.62	77.25
Aldehyde						
Benzaldehyde	1.72	2.49	2.39	1.76	1.95	1.58
Hexanal	0.48	ND	0.43	0.29	ND	ND
Heptanal	0.15	ND	ND	ND	0.19	ND
Total Aldehyde	2.36	2.49	2.83	2.04	2.15	1.58
Alcohols						
2-Ethyl-1-hexanol	D	0.64	1.80	0.12	4.01	0.31
Total Alcohols	0.00	0.64	1.80	0.12	4.01	0.31
Ketones						
2-Butanone	0.78	2.63	D	4.49	1.06	0.92
3-Pentanone	D	ND	0.02	ND	D	0.03
Total ketons	0.78	2.63	0.02	4.49	1.06	0.95
Esters						
Methylbenzoate	ND	ND	ND	ND	ND	ND
Ethyl_acetate	4.26	2.49	0.99	7.61	3.19	2.28
Total Esters	4.26	2.49	0.99	7.61	3.19	2.28
Total Oxygenated compounds	7.40	8.25	5.64	14.26	10.40	5.13
Halogenated compounds						
Carbon_tetrachloride	0.21	0.22	0.17	0.20	0.19	0.18
1,4-Dichlorobenzene	0.05	0.37	0.08	0.08	0.15	0.11
1,2-Dichlorobenzene	0.00	ND	ND	ND	ND	ND
1,2,3-Trichlorobenzene	ND	ND	0.00	ND	ND	ND
Total Halogenated compounds	0.26	0.59	0.24	0.28	0.34	0.29
Alpha_pinene	0.16	0.25	0.12	0.09	0.10	0.98
Beta-pinene	0.09	0.20	0.06	0.07	0.06	0.17
Limonene	0.19	1.40	0.52	0.47	0.19	0.55
Total Terpenes	0.44	1.85	0.70	0.63	0.34	1.70
Grand Total	30.47	130.39	33.76	113.73	55.86	119.95

Table A4.2: Summary of VOCs concentration (µg/m^3) measured in the urban indoor house

Sampling location	**Indoor, Mukti Housing State, (Urban House)**			
Component Name	**Mean**	**Standard Deviation**	**Minimum**	**Maximum**
Total (Cyclo)-alkanes				
Alkanes				
Hexane	1.15	0.25	0.79	1.42
Heptane	1.89	0.59	1.34	3.01
Octane	1.60	0.49	1.28	2.57
Nonane	1.60	0.71	0.95	2.88
Decane	1.38	0.67	0.76	2.31
Undecane	0.59	0.41	0.24	1.29
Dodecane	0.48	0.26	0.24	0.92
Total Alkanes	8.70	2.99	6.26	14.31
Cyclo-alkanes				
Cyclohexane	1.69	0.44	1.12	2.41
2,2,4-trimethylpentane	0.14	0.12	0.04	0.34
Methylcyclopentane	2.25	0.48	1.60	2.95
Total Cyclo-alkanes	4.06	0.97	2.80	5.70
Total (Cyclo)-alkanes	12.76	3.73	9.96	20.02
Aromatic compounds				
Benzene	6.41	0.93	5.39	8.01
Toluene	11.67	3.24	7.16	17.05
Ethylbenzene	1.07	0.42	0.65	1.77
m,p-Xylene	4.43	1.04	3.36	6.32
o-Xylene	1.14	0.34	0.76	1.74
Total BTEX	24.72	4.38	17.81	28.49
Styrene	0.37	0.13	0.22	0.56
Propylbenzene	0.15	0.06	0.08	0.25
1,2,4-Trimethylbenzene	1.14	0.49	0.60	2.00
Isopropylbenzene	0.10	0.04	0.07	0.17
p-Isopropyltoluene	0.10	0.04	0.07	0.18
Naphtalene	3.28	1.71	1.49	6.16
1,3,5-Trimethylbenzene	0.45	0.17	0.27	0.76
sec-Butylbenzene	0.03	0.01	0.01	0.05
Total Aromatic compounds	30.33	5.47	20.91	36.42
Oxygenated compound				
Aldehyde				
Benzaldehyde	2.27	1.02	1.43	4.20
Hexanal	1.47	0.81	0.72	2.69
Heptanal	0.58	0.57	0.03	1.22
Total Aldehyde	4.13	1.38	2.55	5.77
Alcohols				
2-Ethyl-1-hexanol	3.00	1.23	1.23	4.81
Total Alcohols	3.00	1.23	1.23	4.81
Ketones				
2-Butanone	0.75	0.30	0.44	1.23
3-Pentanone	0.03	0.02	0.02	0.06
Total ketones	0.78	0.30	0.46	1.27
Esters				
Methylbenzoate	0.22	0.11	0.14	0.35
Ethyl_acetate	2.77	1.25	1.06	4.47
Total Esters	2.88	1.25	1.06	4.47
Total Oxygenated compounds	10.79	1.96	7.74	13.74
Halogenated compounds				
Carbon_tetrachloride or tetrachloromethane	0.19	0.05	0.11	0.24
1,4-Dichlorobenzene	0.18	0.07	0.09	0.29
1,2-Dichlorobenzene	0.00	0.00	0.00	0.01
1,2,3-Trichlorobenzene	0.02	0.01	0.01	0.03
Total Halogenated compounds	0.39	0.09	0.31	0.55
Terpenes				
Alpha_pinene	0.09	0.01	0.08	0.11
Beta-pinene	0.06	0.01	0.04	0.07
Limonene	0.41	0.16	0.31	0.73
Total Terpenes	0.57	0.17	0.44	0.91
Grand Total	54.84	8.27	42.94	68.75

Table A4.3: Summary of VOCs concentration (µg/m^3) measured in the urban outdoor roadside

Sampling location	**Outdoor, street, Mirpur-10(Urban street)**			
Component Name	**Mean**	**Standard Deviation**	**Minimum**	**Maximum**
Total (Cyclo)-alkanes				
Alkanes				
Hexane	2.60	1.22	1.35	4.49
Heptane	2.43	0.84	1.37	3.71
Octane	1.92	0.57	1.37	2.82
Nonane	2.51	0.73	1.67	3.57
Decane	2.41	0.74	1.53	3.26
Undecane	1.23	0.39	0.79	1.68
Dodecane	0.93	0.29	0.58	1.22
Total Alkanes	14.03	4.34	9.15	20.43
Cyclo-alkanes				
Cyclohexane	1.69	0.50	0.98	2.46
2,2,4-trimethylpentane	0.29	0.11	0.15	0.41
Methylcyclopentane	2.84	0.96	1.69	4.35
Total Cyclo-alkanes	4.82	1.53	2.81	7.18
Total (Cyclo)-alkanes	18.84	5.79	11.96	27.60
Aromatic compounds				
Benzene	7.40	2.27	4.56	10.85
Toluene	14.87	5.79	8.51	23.70
Ethylbenzene	1.73	1.01	0.80	3.31
m,p-Xylene	6.67	3.10	3.55	10.91
o-Xylene	1.93	0.94	1.04	3.23
Total BTEX	32.59	12.92	18.56	52.00
Styrene	0.37	0.16	0.20	0.53
Propylbenzene	0.28	0.12	0.16	0.41
1,2,4-Trimethylbenzene	2.09	0.87	1.12	3.15
Isopropylbenzene	0.17	0.07	0.10	0.26
p-Isopropyltoluene	0.12	0.04	0.07	0.17
Naphtalene	0.55	0.17	0.31	0.79
1,3,5-Trimethylbenzene	0.76	0.35	0.40	1.17
sec-Butylbenzene	0.06	0.02	0.03	0.09
Total Aromatic compounds	37.00	14.58	21.06	58.40
Oxygenated compound				
Aldehyde				
Benzaldehyde	2.48	0.29	2.04	2.89
Hexanal	0.49	0.24	0.20	0.86
Heptanal	0.20	0.06	0.13	0.25
Total Aldehyde	3.06	0.46	2.25	3.53
Alcohols				
2-Ethyl-1-hexanol	2.52	2.17	1.29	6.91
Total Alcohols	2.52	2.17	1.29	6.91
Ketones				
2-Butanone	0.96	0.39	0.53	1.60
3-Pentanone	0.03	0.00	0.02	0.04
Total ketones	0.83	0.53	0.03	1.63
Esters				
Methylbenzoate	0.12	0.00	0.12	0.12
Ethyl_acetate	3.78	2.24	1.79	8.15
Total Esters	3.80	2.28	1.79	8.28
Total Oxygenated compounds	10.21	2.95	7.06	14.82
Halogenated compounds				
Carbon_tetrachloride or tetrachloromethane	0.19	0.02	0.16	0.21
1,4-Dichlorobenzene	0.12	0.03	0.08	0.16
1,2-Dichlorobenzene	0.00	0.00	0.00	0.00
1,2,3-Trichlorobenzene	0.01	0.00	0.01	0.01
Total Halogenated compounds	0.32	0.04	0.28	0.37
Terpenes				
Alpha_pinene	0.16	0.06	0.10	0.24
Beta-pinene	0.05	0.01	0.04	0.07
Limonene	0.33	0.17	0.15	0.58
Total Terpenes	0.53	0.20	0.31	0.82
Grand Total	66.90	21.39	43.95	102.01

Table A4.4: Summary of VOCs concentration (µg/m^3) measured in the urban outdoor park

Sampling location	**Outdoor, National Botanical Garden, Urban Park**			
Component Name	**Mean**	**Standard Deviation**	**Minimum**	**Maximum**
Total (Cyclo)-alkanes				
Alkanes				
Hexane	0.60	0.09	0.53	0.70
Heptane	0.64	0.36	0.26	1.06
Octane	0.73	0.39	0.35	1.34
Nonane	0.97	0.49	0.39	1.62
Decane	0.67	0.46	0.21	1.29
Undecane	0.21	0.18	0.03	0.45
Dodecane	0.21	0.14	0.09	0.44
Total Alkanes	3.73	2.28	1.54	6.67
Cyclo-alkanes				
Cyclohexane	0.60	0.25	0.24	0.82
2,2,4-trimethylpentane	0.12	0.02	0.10	0.13
Methylcyclopentane	0.72	0.49	0.18	1.32
Total Cyclo-alkanes	1.17	0.86	0.18	2.14
Total (Cyclo)-alkanes	4.89	3.11	1.85	8.55
Aromatic compounds				
Benzene	3.24	1.43	1.42	5.32
Toluene	4.64	3.41	1.18	9.75
Ethylbenzene	0.51	0.39	0.12	1.06
m,p-Xylene	1.66	1.00	0.48	2.88
o-Xylene	0.46	0.27	0.15	0.79
Total BTEX	10.50	6.05	3.98	18.19
Styrene	0.22	0.20	0.06	0.61
Propylbenzene	0.07	0.04	0.02	0.11
1,2,4-Trimethylbenzene	0.46	0.30	0.14	0.87
Isopropylbenzene	0.05	0.03	0.02	0.08
p-Isopropyltoluene	0.05	0.02	0.01	0.06
Naphtalene	0.25	0.14	0.08	0.47
1,3,5-Trimethylbenzene	0.18	0.12	0.04	0.33
sec-Butylbenzene	0.01	0.02	0.00	0.02
Total Aromatic compounds	11.76	6.83	4.46	20.60
Oxygenated compound				
Aldehyde				
Benzaldehyde	2.45	1.65	1.45	5.79
Hexanal	2.43	3.63	0.12	9.58
Heptanal	0.60	0.41	0.29	1.07
Total Aldehyde	5.18	5.63	1.95	16.44
Alcohols				
2-Ethyl-1-hexanol	2.14	1.95	0.70	5.76
Total Alcohols	2.14	1.95	0.70	5.76
Ketones				
2-Butanone	1.63	1.10	0.85	2.41
3-Pentanone	0.03	0.02	0.02	0.06
Total ketones	0.56	0.99	0.00	2.47
Esters				
Methylbenzoate	ND	ND	ND	ND
Ethyl_acetate	2.91	1.83	0.75	5.72
Total Esters	2.91	1.83	0.75	5.72
Total Oxygenated compounds	10.78	8.32	5.53	27.50
Halogenated compounds				
Carbon_tetrachloride or tetrachloromethane	0.24	0.07	0.18	0.37
1,4-Dichlorobenzene	0.06	0.02	0.04	0.09
1,2-Dichlorobenzene	0.00	0.00	0.00	0.00
1,2,3-Trichlorobenzene	0.01	0.01	0.00	0.02
Total Halogenated compounds	0.28	0.08	0.19	0.42
Terpenes				
Alpha_pinene	0.19	0.18	0.06	0.55
Beta-pinene	0.06	0.02	0.03	0.08
Limonene	0.12	0.07	0.04	0.24
Total Terpenes	0.37	0.20	0.20	0.71
Grand Total	28.08	14.89	13.74	51.44

Table A4.5: Summary of VOCs concentration (µg/m^3) measured in the indoor house industrial area

Sampling location	**Indoor, Nakhalpara, house near industrial area**			
Component Name	**Mean**	**Standard Deviation**	**Minimum**	**Maximum**
Total (Cyclo)-alkanes				
Alkanes				
Hexane	2.21	0.87	1.19	3.82
Heptane	2.91	0.75	1.98	4.29
Octane	2.27	0.50	1.68	3.16
Nonane	2.68	0.65	1.90	3.45
Decane	2.13	0.72	1.12	3.00
Undecane	0.83	0.31	0.37	1.15
Dodecane	0.64	0.24	0.29	0.90
Total Alkanes	13.67	3.59	8.52	19.09
Cyclo-alkanes				
Cyclohexane	2.27	0.86	1.25	3.83
2,2,4-trimethylpentane	0.31	0.13	0.20	0.55
Methylcyclopentane	3.30	1.15	1.91	5.40
Total Cyclo-alkanes	5.87	2.01	3.38	9.53
Total (Cyclo)-alkanes	19.54	5.42	11.90	28.62
Aromatic compounds				
Benzene	8.72	1.68	5.98	11.16
Toluene	17.41	5.29	11.85	25.87
Ethylbenzene	2.33	0.52	1.56	2.89
m,p-Xylene	7.20	1.37	4.56	8.16
o-Xylene	2.12	0.44	1.31	2.50
Total BTEX	37.78	7.81	26.33	47.52
Styrene	0.42	0.13	0.26	0.65
Propylbenzene	0.28	0.08	0.14	0.37
1,2,4-Trimethylbenzene	2.00	0.57	0.96	2.64
Isopropylbenzene	0.18	0.05	0.11	0.24
p-Isopropyltoluene	0.49	0.43	0.17	1.33
Naphtalene	5.15	1.92	3.54	8.83
1,3,5-Trimethylbenzene	0.79	0.21	0.39	0.99
sec-Butylbenzene	0.06	0.02	0.04	0.09
Total Aromatic compounds	47.15	8.70	32.21	56.91
Oxygenated compound				
Aldehyde				
Benzaldehyde	2.48	0.83	1.25	3.49
Hexanal	1.55	1.06	0.50	3.45
Heptanal	0.31	0.37	0.06	0.73
Total Aldehyde	4.18	1.37	2.08	6.17
Alcohols				
2-Ethyl-1-hexanol	1.14	0.25	0.73	1.40
Total Alcohols	0.95	0.52	0.00	1.40
Ketones				
2-Butanone	1.53	0.38	0.95	2.09
3-Pentanone	0.04	0.02	0.02	0.07
Total ketons	1.56	0.38	0.99	2.11
Esters				
Methylbenzoate	ND	ND	ND	ND
Ethyl_acetate	8.14	5.78	2.47	16.55
Total Esters	8.14	5.78	2.47	16.55
Total Oxygenated compounds	14.83	5.49	9.49	21.47
Halogenated compounds				
Carbon_tetrachloride or tetrachloromethane	0.17	0.01	0.15	0.19
1,4-Dichlorobenzene	0.31	0.08	0.21	0.45
1,2-Dichlorobenzene	ND	ND	ND	ND
1,2,3-Trichlorobenzene	0.01	0.00	0.00	0.01
Total Halogenated compounds	0.48	0.08	0.39	0.61
Terpenes				
Alpha_pinene	0.24	0.06	0.14	0.31
Beta-pinene	0.34	0.31	0.09	0.89
Limonene	1.25	0.59	0.46	2.00
Total Terpenes	1.83	0.77	1.12	3.06
Grand Total	83.83	13.61	64.69	99.28

Table A4.6: Summary of VOCs concentration (µg/m^3) measured in the outdoor street industrial area

Sampling location	**Outdoor, Street, Farmgate**			
Component Name	**Mean**	**Standard Deviation**	**Minimum**	**Maximum**
Total (Cyclo)-alkanes				
Alkanes				
Hexane	3.28	1.96	1.23	6.85
Heptane	3.30	1.57	1.62	6.28
Octane	2.66	1.05	1.43	4.43
Nonane	3.15	1.11	2.21	4.84
Decane	2.75	1.12	1.75	4.49
Undecane	1.22	0.67	0.64	2.49
Dodecane	0.96	0.61	0.43	2.15
Total Alkanes	17.32	7.73	9.85	31.52
Cyclo-alkanes				
Cyclohexane	2.42	1.34	1.15	5.02
2,2,4-trimethylpentane	0.37	0.14	0.14	0.54
Methylcyclopentane	3.83	2.16	1.68	8.00
Total Cyclo-alkanes	6.62	3.60	2.98	13.57
Total (Cyclo)-alkanes	23.94	11.20	12.83	45.08
Aromatic compounds				
Benzene	11.53	5.76	4.56	22.05
Toluene	21.94	8.75	13.38	32.94
Ethylbenzene	2.48	1.00	1.68	4.18
m,p-Xylene	8.61	3.42	4.92	14.67
o-Xylene	2.58	1.18	1.41	4.72
Total BTEX	47.14	18.30	31.20	78.56
Styrene	0.64	0.30	0.40	1.22
Propylbenzene	0.36	0.16	0.21	0.65
1,2,4-Trimethylbenzene	2.54	1.22	1.45	4.69
Isopropylbenzene	0.23	0.12	0.14	0.46
p-Isopropyltoluene	0.19	0.15	0.10	0.50
Naphtalene	1.09	0.49	0.46	1.84
1,3,5-Trimethylbenzene	1.01	0.54	0.57	2.01
sec-Butylbenzene	0.08	0.05	0.05	0.17
Total Aromatic compounds	53.27	21.01	34.67	90.11
Oxygenated compound				
Aldehyde				
Benzaldehyde	3.59	1.77	2.21	6.13
Hexanal	1.22	1.13	0.15	3.29
Heptanal	0.39	0.54	0.08	1.19
Total Aldehyde	5.07	2.96	2.67	10.05
Alcohols				
2-Ethyl-1-hexanol	1.78	0.92	0.37	2.91
Total Alcohols	1.78	0.92	0.37	2.91
Ketones				
2-Butanone	1.99	0.88	1.09	3.28
3-Pentanone	0.04	0.02	0.02	0.06
Total ketones	1.68	1.13	0.00	3.28
Esters				
Methylbenzoate	ND	ND	ND	ND
Ethyl_acetate	8.77	5.33	3.55	17.63
Total Esters	8.77	5.33	3.55	17.63
Total Oxygenated compounds	17.30	6.67	12.21	29.56
Halogenated compounds				
Carbon_tetrachloride or tetrachloromethane	0.24	0.11	0.15	0.41
1,4-Dichlorobenzene	0.29	0.11	0.12	0.43
1,2-Dichlorobenzene	0.01	0.00	0.01	0.01
1,2,3-Trichlorobenzene	0.02	0.02	0.01	0.04
Total Halogenated compounds	0.53	0.16	0.29	0.68
Terpenes				
Alpha_pinene	0.21	0.04	0.15	0.25
Beta-pinene	0.08	0.05	0.05	0.16
Limonene	0.68	0.52	0.24	1.71
Total Terpenes	0.95	0.60	0.44	2.12
Grand Total	95.99	33.03	68.45	150.65

Table A4.7: Summary of VOCs concentration (µg/m^3) measured in the outdoor ambient industrial area

Sampling location	**Outdoor, Industrial area, ambient**			
Component Name	**Mean**	**Standard Deviation**	**Minimum**	**Maximum**
(Cyclo)-alkanes				
Alkanes				
Hexane	4.78	3.70	0.48	8.43
Heptane	2.93	1.87	0.80	5.39
Octane	2.19	1.50	0.70	4.22
Nonane	2.53	1.76	0.81	5.35
Decane	2.22	1.51	0.66	4.57
Undecane	1.00	0.79	0.20	2.18
Dodecane	0.88	0.63	0.23	1.68
Total Alkanes	15.58	11.09	3.40	28.40
Cyclo-alkanes				
Cyclohexane	1.97	1.60	0.55	4.95
2,2,4-trimethylpentane	0.34	0.21	0.17	0.68
Methylcyclopentane	3.56	2.65	0.91	7.85
Total Cyclo-alkanes	5.81	4.36	1.47	13.24
Total (Cyclo)-alkanes	21.39	15.20	4.87	41.64
Aromatic compounds				
Benzene	10.04	6.90	3.79	22.45
Toluene	20.41	14.05	6.55	42.90
Ethylbenzene	2.51	1.58	0.75	4.94
m,p-Xylene	8.06	5.32	2.80	16.20
o-Xylene	2.58	1.90	0.77	5.65
Total BTEX	43.59	26.04	15.89	67.91
Styrene	0.45	0.33	0.12	1.03
Propylbenzene	0.36	0.29	0.09	0.86
1,2,4-Trimethylbenzene	2.62	2.12	0.62	6.27
Isopropylbenzene	0.23	0.18	0.06	0.51
p-Isopropyltoluene	0.20	0.16	0.05	0.42
Naphtalene	0.98	0.72	0.44	2.30
1,3,5-Trimethylbenzene	1.00	0.80	0.22	2.30
sec-Butylbenzene	0.08	0.07	0.01	0.19
Total Aromatic compounds	49.51	29.63	17.51	78.05
Oxygenated compound				
Aldehyde				
Benzaldehyde	1.98	0.38	1.58	2.49
Hexanal	0.40	0.10	0.29	0.48
Heptanal	0.17	0.03	0.15	0.19
Total Aldehyde	2.24	0.42	1.58	2.83
Alcohols				
2-Ethyl-1-hexanol	1.38	1.61	0.12	4.01
Total Alcohols	1.15	1.54	0.00	4.01
Ketones				
2-Butanone	1.98	1.59	0.78	4.49
3-Pentanone	0.03	0.01	0.02	0.03
Total ketones	1.65	1.63	0.02	4.49
Esters				
Methylbenzoate	ND	ND	ND	ND
Ethyl_acetate	3.47	2.30	0.99	7.61
Total Esters	3.47	2.30	0.99	7.61
Total Oxygenated compounds	8.51	3.39	5.13	14.26
Halogenated compounds				
Carbon_tetrachloride or tetrachloromethane	0.19	0.02	0.17	0.22
1,4-Dichlorobenzene	0.14	0.12	0.05	0.37
1,2-Dichlorobenzene	ND	ND	ND	ND
1,2,3-Trichlorobenzene	ND	ND	ND	ND
Total Halogenated compounds	0.33	0.13	0.24	0.59
Terpenes				
Alpha_pinene	0.28	0.35	0.09	0.98
Beta-pinene	0.11	0.06	0.06	0.20
Limonene	0.55	0.44	0.19	1.40
Total Terpenes	0.94	0.66	0.34	1.85
Grand Total	80.36	45.70	30.47	130.39

Table A4.8: Summary of Statistics of the six sampling sites based on six samples

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•         ***  Summary Statistics for data in:   SDF62 ***

•           urb.house urb.street   urb.park  ind.house ind.street ind.ambient
•       Min: 42.940000  43.950000  13.740000  64.700000   68.45000    30.47000
•   1st Qu.: 53.015000  52.260000  16.627500  74.265000   77.53750    39.29250
•      Mean: 54.838333  66.905000  28.088333  83.836667   96.00667    80.69500
•    Median: 54.255000  64.335000  24.715000  86.025000   78.23000    84.79500
•   3rd Qu.: 55.735000  75.007500  36.155000  93.990000  111.90750   118.39500
•       Max: 68.750000 102.010000  51.460000  99.280000  150.69000   130.39000
•   Total N:  6.000000   6.000000   6.000000   6.000000    6.00000     6.00000
•     NA's :  0.000000   0.000000   0.000000   0.000000    0.00000     0.00000
•  Variance: 68.454937 457.549270 221.761537 185.181627 1091.58907  2088.62855
•  Std Dev.:  8.273750  21.390401  14.891660  13.608146   33.03920    45.70152
•   SE Mean:  3.377744   8.732595   6.079495   5.555502   13.48820    18.65757
•  LCL Mean: 46.155565  44.457150  12.460495  69.555794   61.33415    32.73420
•  UCL Mean: 63.521101  89.352850  43.716172  98.117540  130.67919   128.65580
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Table A4.9: OFP of each compound in the four outdoor ambient sampling site of Dhaka city, Bangladesh(OFP (µg/m³) = concentration of VOC (µg/m³) × MIR)

Component Name	Mean concentration(µg/m^3)				MIR-10	Total OFP((µg/m^3)			
Alkanes									
Hexane	2.60	0.60	3.28	4.78	1.24	3.23	0.75	4.07	5.93
Heptane	2.43	0.64	3.30	2.93	1.07	2.60	0.68	3.53	3.13
Octane	1.92	0.73	2.66	2.19	0.90	1.72	0.65	2.39	1.97
Nonane	2.51	0.97	3.15	2.53	0.78	1.96	0.76	2.46	1.97
Decane	2.41	0.67	2.75	2.22	0.68	1.64	0.46	1.87	1.51
Undecane	1.23	0.21	1.22	1.00	0.61	0.75	0.13	0.74	0.61
Dodecane	0.93	0.21	0.96	0.88	0.55	0.51	0.12	0.53	0.48
Cyclo-alkanes									
Cyclohexane	1.69	0.60	2.42	1.97	1.25	2.11	0.76	3.02	2.46
2,2,4-trimethylpentane	0.29	0.12	0.37	0.34	1.26	0.37	0.15	0.47	0.43
Methylcyclopentane	2.84	0.72	3.83	3.56	2.19	6.21	1.59	8.39	7.79
Aromatic compounds									
Benzene	7.40	3.24	11.53	10.04	0.72	5.33	2.33	8.30	7.23
Toluene	14.87	4.64	21.94	20.41	4.00	59.46	18.57	87.77	81.62
Ethylbenzene	1.73	0.51	2.48	2.51	3.04	5.27	1.54	7.53	7.62
m-Xylene	4.66	1.16	6.03	5.64	9.75	45.48	11.30	58.75	54.96
p-Xylene	2.00	0.50	2.59	2.42	5.84	11.69	2.90	15.10	14.13
o-Xylene	1.93	0.46	2.58	2.58	7.64	14.74	3.49	19.71	19.74
Styrene	0.37	0.22	0.64	0.45	1.73	0.65	0.39	1.10	0.78
Propylbenzene	0.28	0.07	0.36	0.36	2.03	0.57	0.14	0.73	0.73
1,2,4-Trimethylbenzene	2.09	0.46	2.54	2.62	8.87	18.58	4.07	22.50	23.27
Isopropylbenzene	0.17	0.05	0.23	0.23	3.63	0.61	0.17	0.84	0.84
p-Isopropyltoluene	0.12	0.05	0.19	0.20		0.00	0.00	0.00	0.00
Naphtalene	0.55	0.25	1.09	0.98	3.34	1.84	0.83	3.63	3.29
1,3,5-Trimethylbenzene	0.76	0.18	1.01	1.00	11.76	8.96	2.07	11.83	11.72
sec-Butylbenzene	0.06	0.01	0.08	0.08	3.36	0.20	0.04	0.27	0.26
Oxygenated compound									
Aldehyde									
Benzaldehyde	2.48	2.45	3.59	1.98	-0.67	-1.66	-1.64	-2.40	-1.33
Hexanal	0.49	2.43	1.22	0.40	4.35	2.11	10.55	5.32	1.75
Heptanal	0.20	0.60	0.39	0.17	3.69	0.73	2.22	1.43	0.63
Alcohols									
2-Ethyl-1-hexanol	2.52	2.14	1.78	1.38	2.00	5.03	4.28	3.56	2.75
Ketones									
2-Butanone	0.96	1.63	1.99	1.98	1.48	1.42	2.41	2.94	2.92
3-Pentanone	0.03	0.03	0.04	0.03	1.24	0.04	0.04	0.05	0.03
Esters									
Methylbenzoate	0.12	ND	ND	ND		0.00			
Ethyl_acetate	3.78	2.91	8.77	3.47	0.63	2.38	1.83	5.53	2.19
Halogenated compounds									
Carbon_tetrachloride	0.19	0.24	0.24	0.19	NA				
1,4-Dichlorobenzene	0.12	0.06	0.29	0.14	NA				
1,2-Dichlorobenzene	0.00	0.00	0.01	0.00	NA				
1,2,3-Trichlorobenzene	0.01	0.01	0.02	0.00	NA				
Terpenes									
Alpha_pinene	0.16	0.19	0.21	0.28	4.51	0.71	0.86	0.94	1.27
Beta-pinene	0.05	0.06	0.08	0.11	3.52	0.17	0.22	0.27	0.39
Limonene	0.33	0.12	0.68	0.55	4.60	1.50	0.55	3.13	2.54
TOFP(sum)						206.92	75.17	286.29	265.62

Table A4.10: Mean concentration of TVOC of each compound and I/O ratios of the three sampling sites in urban area of Dhaka city, Bangladesh

	Urban Area, Mirpur, Dhaka city				
	Mean concentration($\mu g/m^3$)			I/O Ratio	I/O Ratio
Component Name	Urban house(H)	Urban Roadside(S)	Urban Park(P)	Ratio H/S	Ratio H/P
(Cyclo)-alkanes					
Alkanes					
Hexane	1.15	2.60	0.60	0.44	1.91
Heptane	1.89	2.43	0.64	0.78	2.96
Octane	1.60	1.92	0.73	0.84	2.21
Nonane	1.60	2.51	0.97	0.64	1.65
Decane	1.38	2.41	0.67	0.57	2.05
Undecane	0.59	1.23	0.21	0.48	2.88
Dodecane	0.48	0.93	0.21	0.51	2.25
Total Alkanes	8.70	14.03	3.73	0.62	2.33
Cyclo-alkanes					
Cyclohexane	1.69	1.69	0.60	1.00	2.79
2,2,4-trimethylpentane	0.14	0.29	0.12	0.49	1.25
Methylcyclopentane	2.25	2.84	0.72	0.79	3.11
Total Cyclo-alkanes	4.06	4.82	1.17	0.84	3.48
Total Hydrocarbons	12.76	18.84	4.89	0.68	2.61
Aromatic compounds					
Benzene	6.41	7.40	3.24	0.87	1.98
Toluene	11.67	14.87	4.64	0.79	2.51
Ethylbenzene	1.07	1.73	0.51	0.62	2.11
m,p-Xylene	4.43	6.67	1.66	0.66	2.68
o-Xylene	1.14	1.93	0.46	0.59	2.49
Total BTEX	24.72	32.59	10.50	0.76	2.35
Styrene	0.37	0.37	0.22	0.99	1.65
Propylbenzene	0.15	0.28	0.07	0.53	2.18
1,2,4-Trimethylbenzene	1.14	2.09	0.46	0.54	2.49
Isopropylbenzene	0.10	0.17	0.05	0.60	2.16
p-Isopropyltoluene	0.10	0.12	0.05	0.89	2.30
Naphtalene	3.28	0.55	0.25	5.95	13.15
1,3,5-Trimethylbenzene	0.45	0.76	0.18	0.59	2.53
sec-Butylbenzene	0.03	0.06	0.01	0.50	2.37
Total Aromatic compounds	30.33	37.00	11.76	0.82	2.58
Oxygenated compound					
Aldehyde					
Benzaldehyde	2.27	2.48	2.45	0.92	0.93
Hexanal	1.47	0.49	2.43	3.02	0.61
Heptanal	0.58	0.20	0.60	2.92	0.97
Total Aldehyde	4.13	3.06	5.18	1.35	0.80
Alcohols					
2-Ethyl-1-hexanol	3.00	2.52	2.14	1.19	1.40
Total Alcohols	3.00	2.52	2.14	1.19	1.40
Ketones					
2-Butanone	0.75	0.96	1.63	0.78	0.46
3-Pentanone	0.03	0.03	0.03	1.16	1.02
Total ketons	0.78	0.83	0.56	0.94	1.40
Esters					
Methylbenzoate	0.22	0.12	ND	1.78	ND
Ethyl_acetate	2.77	3.78	2.91	0.73	0.95
Total Esters	2.88	3.80	2.91	0.76	0.99
Total Oxygenated compounds	10.79	10.21	10.78	1.06	1.00
Halogenated compounds					
Carbon_tetrachloride or tetrachloromethane	0.19	0.19	0.24	1.03	0.82
1,4-Dichlorobenzene	0.18	0.12	0.06	1.49	3.03
1,2-Dichlorobenzene	0.00	0.00	0.00	1.26	3.01
1,2,3-Trichlorobenzene	0.02	0.01	0.01	1.84	1.75
Total Halogenated compounds	0.39	0.32	0.28	1.23	1.42
Terpenes					
Alpha_pinene	0.09	0.16	0.19	0.60	0.50
Beta-pinene	0.06	0.05	0.06	1.20	0.95
Limonene	0.41	0.33	0.12	1.27	3.47
Total Terpenes	0.57	0.53	0.37	1.07	1.53
Grand Total	54.84	66.90	28.08	0.82	1.95

Table A4.11: Mean concentration of TVOC each compound and I/O ratios of the three sampling sites in industrial area of Dhaka city, Bangladesh

	Industrial Area,Tejgaon, Dhaka				
	Mean concentration (µg/m^3)			Ratio I/O	Ratio I/O
Component Name	Outdoor Industrial House (IH)	Outdoor Industrial Roadside (IR)	Outdoor Industrial Ambient (IA)	IH/IR	IH/IA
(Cyclo)-alkanes					
Alkanes					
Hexane	2.21	3.28	4.78	0.67	0.46
Heptane	2.91	3.30	2.93	0.88	0.99
Octane	2.27	2.66	2.19	0.85	1.04
Nonane	2.68	3.15	2.53	0.85	1.06
Decane	2.13	2.75	2.22	0.77	0.96
Undecane	0.83	1.22	1.00	0.69	0.83
Dodecane	0.64	0.96	0.88	0.67	0.73
Total Alkanes	13.67	17.32	15.58	0.79	0.88
Cyclo-alkanes					
Cyclohexane	2.27	2.42	1.97	0.94	1.15
2,2,4-trimethylpentane	0.31	0.37	0.34	0.82	0.89
Methylcyclopentane	3.30	3.83	3.56	0.86	0.93
Total Cyclo-alkanes	5.87	6.62	5.81	0.89	1.01
Total Hydrocarbons	19.54	23.94	21.39	0.82	0.91
Aromatic compounds					
Benzene	8.72	11.53	10.04	0.76	0.87
Toluene	17.41	21.94	20.41	0.79	0.85
Ethylbenzene	2.33	2.48	2.51	0.94	0.93
m,p-Xylene	7.20	8.61	8.06	0.84	0.89
o-Xylene	2.12	2.58	2.58	0.82	0.82
Total BTEX	37.78	47.14	43.59	0.80	0.87
Styrene	0.42	0.64	0.45	0.67	0.94
Propylbenzene	0.28	0.36	0.36	0.79	0.79
1,2,4-Trimethylbenzene	2.00	2.54	2.62	0.79	0.76
Isopropylbenzene	0.18	0.23	0.23	0.79	0.80
p-Isopropyltoluene	0.49	0.19	0.20	2.52	2.48
Naphtalene	5.15	1.09	0.98	4.75	5.24
1,3,5-Trimethylbenzene	0.79	1.01	1.00	0.78	0.79
sec-Butylbenzene	0.06	0.08	0.08	0.80	0.85
Total Aromatic compounds	47.15	53.27	49.51	0.89	0.95
Oxygenated compound					
Aldehyde					
Benzaldehyde	2.48	3.59	1.98	0.69	1.25
Hexanal	1.55	1.22	0.40	1.27	3.87
Heptanal	0.31	0.39	0.17	0.79	1.79
Total Aldehyde	4.18	5.07	2.24	0.83	1.87
Alcohols					
2-Ethyl-1-hexanol	1.14	1.78	1.38	0.64	0.83
Total Alcohols	0.95	1.78	1.15	0.54	0.83
Ketones					
2-Butanone	1.53	1.99	1.98	0.77	0.77
3-Pentanone	0.04	0.04	0.03	0.98	1.73
Total ketons	1.56	1.68	1.65	0.93	0.94
Esters					
Methylbenzoate	ND	ND	ND	ND	ND
Ethyl_acetate	8.14	8.77	3.47	0.93	2.34
Total Esters	8.14	8.77	3.47	0.93	2.34
Total Oxygenated compounds	14.83	17.30	8.51	0.86	1.74
Halogenated compounds					
Carbon_tetrachloride or tetrachloromethane	0.17	0.24	0.19	0.72	0.90
1,4-Dichlorobenzene	0.31	0.29	0.14	1.07	2.21
1,2-Dichlorobenzene	ND	0.01	0.00	ND	ND
1,2,3-Trichlorobenzene	0.01	0.02	0.00	0.29	2.82
Total Halogenated compounds	0.48	0.53	0.33	0.90	1.44
Terpenes					
Alpha_pinene	0.24	0.21	0.28	1.15	0.85
Beta-pinene	0.34	0.08	0.11	4.41	3.07
Limonene	1.25	0.68	0.55	1.84	2.26
Total Terpenes	1.83	0.95	0.94	1.92	1.93
Grand Total	83.83	95.99	80.36	0.87	1.04

Table A4.12 shows calculated mean BTEX with maximum and minimum values for urban environment

Sampling Country		urban indoor			urban street			urban park		
		Mean	Maximum	Minimum	Mean	Maximum	Minimum	Mean	Maximum	Minimum
Bangladesh 2014										
This study	Benzene	6.41	8.01	5.39	7.40	10.85	4.56	3.24	5.32	1.42
	Toluene	11.67	17.05	7.16	14.87	23.70	8.51	4.64	9.75	1.18
	Ethylbenzene	1.07	1.77	0.65	1.73	3.31	0.80	0.51	1.06	0.12
	p Xylene	1.33	1.90	1.01	2.00	3.28	1.07	0.46	0.79	0.15
	m- Xylene	3.10	4.42	2.35	4.66	7.64	2.48	0.14	0.24	0.04
	o-Xylene	1.14	1.74	0.76	1.93	3.23	1.04	0.32	0.55	0.10
Bangladesh 2012										
Barai, 2012	Benzene	10.12	16.69	4.86	12.99	24.86	8.32	3.50	5.51	1.78
	Toluene	49.38	81.25	28.46	88.48	197.60	39.87	16.46	36.29	6.11
	Ethylbenzene	11.53	21.05	5.67	24.99	50.11	9.86	3.62	7.09	1.45
	p Xylene	13.32	21.93	8.03	27.81	50.65	12.72	3.29	5.22	1.35
	m- Xylene	15.80	22.88	9.55	31.03	51.10	18.70	7.66	12.16	3.14
	o-Xylene	2.35	4.90	1.15	15.80	22.88	9.55	4.10	7.14	1.81
Ethiopia 2013										
Amare, 2013	Benzene	4.02	9.11	0.66	3.73	5.59	1.87	0.87	2.30	0.24
	Toluene	2.51	4.28	1.34	16.75	50.67	7.64	0.82	2.04	0.28
	Ethylbenzene	0.25	0.42	0.10	3.59	8.74	1.72	0.11	0.27	0.05
	p Xylene	0.20	0.34	0.10	2.62	4.99	1.60	0.10	0.21	0.03
	m- Xylene	0.46	0.79	0.24	6.10	11.62	3.72	0.23	0.49	0.06
	o-Xylene	0.25	0.40	0.15	3.24	4.30	2.13	0.13	0.28	0.03
Philippines 2012										
Parao, 2012	Benzene	1.24	2.34	0.63	7.79	20.87	2.08	0.85	1.62	0.49
	Toluene	10.39	15.73	5.30	19.93	47.96	4.65	3.17	5.72	1.52
	Ethylbenzene	4.07	9.12	1.05	3.31	7.72	0.79	0.63	1.05	0.35
	p Xylene	3.98	9.84	0.87	2.18	5.61	0.19	0.56	1.02	0.34
	m- Xylene	9.27	22.93	2.02	0.40	0.94	0.11	1.31	2.38	0.78
	o-Xylene	8.33	22.42	1.52	2.76	6.27	0.73	0.98	1.75	0.58
Belgium 2008										
Do *et al*, 2013	Benzene	3.70	10.52	0.63	1.96	3.62	0.95	0.83	1.91	0.37
	Toluene	6.09	12.82	1.56	10.67	21.47	3.22	3.61	13.55	0.38
	Ethylbenzene	0.86	1.67	0.37	0.95	2.09	0.38	0.31	0.94	0.06
	p Xylene	2.04	4.37	0.79	2.99	6.65	1.16	1.06	3.39	0.17
	m- Xylene	NA	NA	NA	NA	NA	NA	NA	NA	NA
	o-Xylene	NA	NA	NA	NA	NA	NA	NA	NA	NA
Vietnam 2008										
Do *et al*, 2013	Benzene	7.79	20.87	2.08	32.18	49.40	19.86	3.04	3.57	2.45
	Toluene	19.93	47.96	4.65	119.32	163.25	78.82	10.44	16.16	7.32
	Ethylbenzene	3.31	7.72	0.79	19.54	27.81	12.93	1.89	2.90	0.86
	p Xylene	7.29	18.87	1.86	63.18	89.76	43.96	3.69	6.55	1.96
	m- Xylene	NA	NA	NA	NA	NA	NA	NA	NA	NA
	o-Xylene	NA	NA	NA	NA	NA	NA	NA	NA	NA

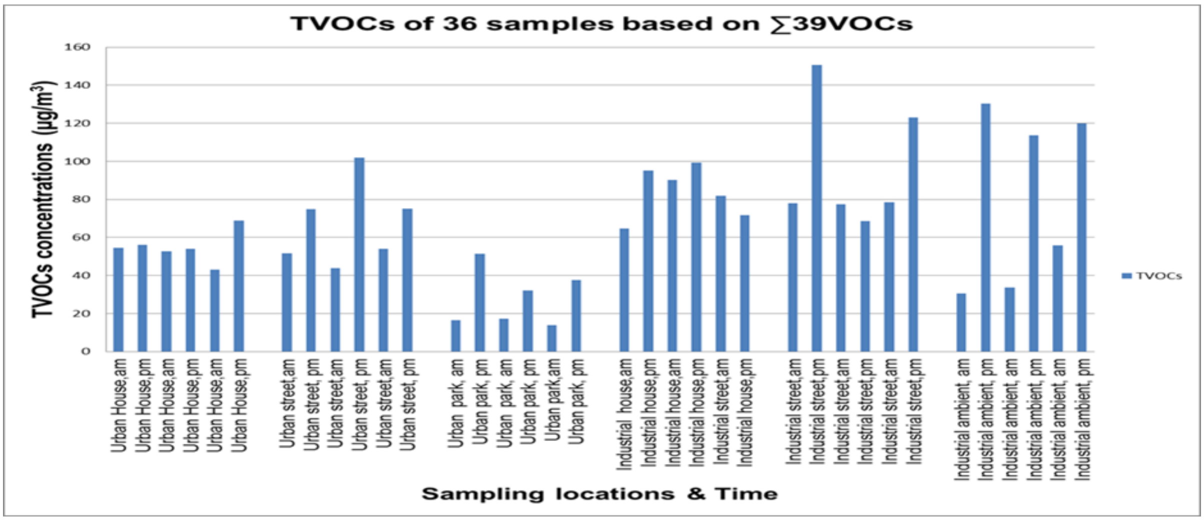

Figure A1: TVOCs of 36 samples based on sum of 39VOCs

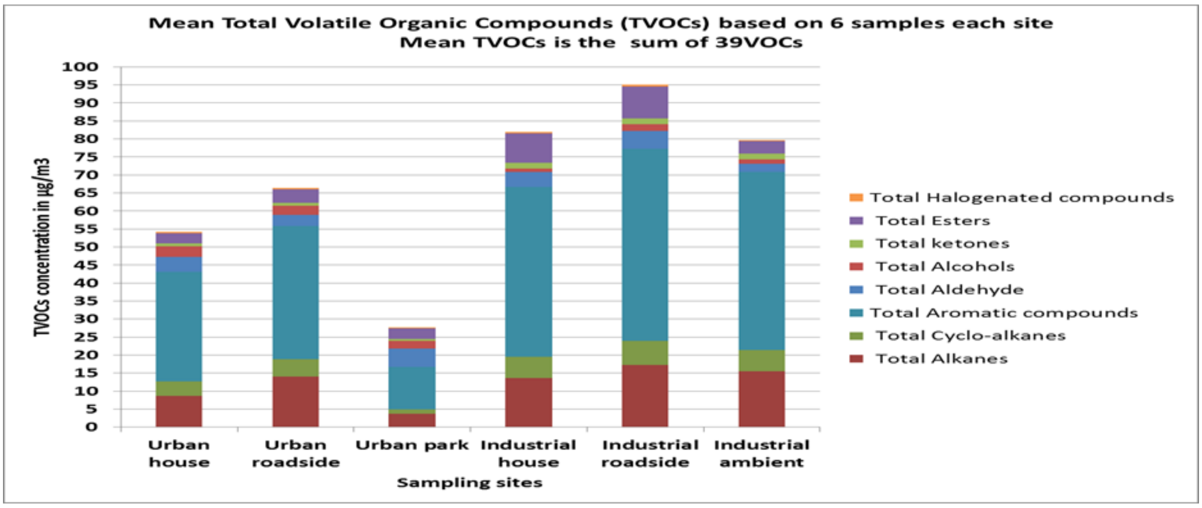

Figure A2: Contribution of each group to mean TVOCs (5 main groups)

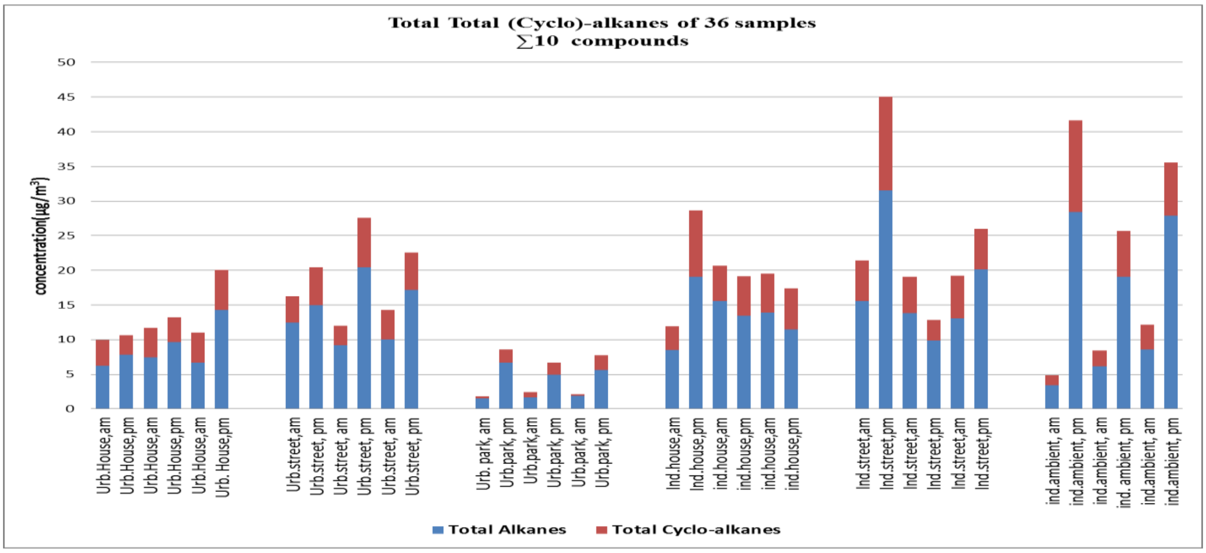

Figure A3: Total (cyclo)-alkanes of 36 samples

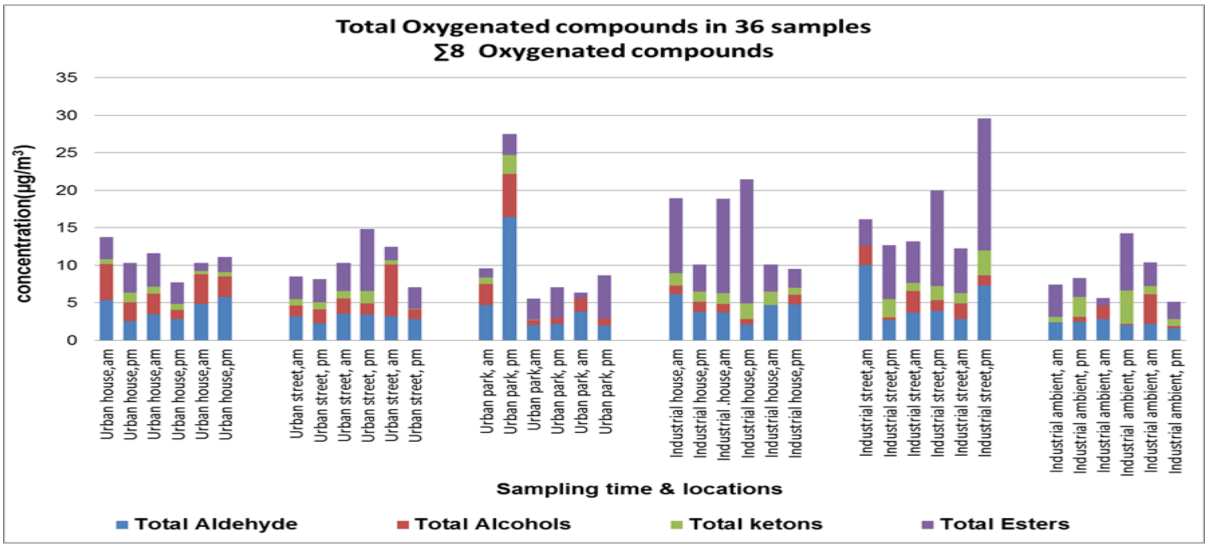

Figure A4: Total Oxygenated compounds in 36 samples