NUMERICAL ANALYSIS OF VOLATILE ORGANIC COMPOUNDS CONCENTRATION AND EVALUATION OF HAZARD INDEX IN BANGKOK, THAILAND

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NUMERICAL ANALYSIS OF VOLATILE ORGANIC COMPOUNDS CONCENTRATION AND EVALUATION OF HAZARD INDEX IN BANGKOK, THAILAND

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ABSTRACT

Monitoring data of conventional air pollutants, measured from 2008 to 2013 in Bangkok, were used to formulate an equation for predicting BTEX and 1,3-butadiene concentrations. It was found that the model performed well and predicted the overall concentration of all air toxic compounds except 1,3-butadiene. Three different spatial interpolation techniques namely, ordinary kriging, the inverse distance weighted (IDW), and spline were tested in order to find the most appropriate scheme to provide the best interpolated results for this study. A cross validation and several statistical parameters were employed for selection. Results indicated that in general, IDW performs much better than the other techniques. The impact zone was defined as an area having annual average concentration of benzene higher than the Thai ambient air quality standard for benzene (1.7 µg/m^3), which had decreased from the year 2008 to 2013. The calculated results of hazard quotient (HQ) and hazard index (HI) for the year 2008 to 2013 were less than 1. The decreasing tendency of the area having HI > 0.25 from the year 2008 to 2013 was also illustrated.

This could be explained by a success of mitigation measures for VOCs management policy such as the implementation of EURO IV standards. These findings elucidate the effectiveness of changing of fuel quality on the reduction of air toxic concentration in the Bangkok environment.

KEY WORDS: AIR TOXIC / VOLATILE ORGANIC COMPOUNDS / BTEX
POLLUTION MAP / HAZARD INDEX

153 pages

การวิเคราะห์ข้อมูลเชิงตัวเลขของความเข้มข้นของสารประกอบอินทรีย์ระเหยง่ายและการประเมิน Hazard Index ในกรุงเทพมหานคร ประเทศไทย

NUMERICAL ANALYSIS OF VOLATILE ORGANIC COMPOUNDS CONCENTRATION AND EVALUATION OF HAZARD INDEX IN BANGKOK, THAILAND

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บทคัดย่อ

การสร้างสมการเพื่อใช้ทำนายค่าความเข้มข้นของ BTEX และ 1,3-butadiene ใช้ข้อมูลจากการตรวจวัดคุณภาพอากาศในเขตกรุงเทพมหานครระหว่างปี พ.ศ. 2551 ถึง พ.ศ. 2556 พบว่าสมการมีประสิทธิภาพดีในการใช้ทำนายสารมลพิษทางอากาศ ยกเว้นสาร 1,3-butadiene การศึกษานี้ได้ทำการประเมินค่าความเข้มข้นของสารมลพิษเชิงพื้นที่ โดยทำการเปรียบเทียบกัน 3 วิธีคือ ordinary kriging, the inverse distance weighted (IDW), and spline เพื่อหาวิธีที่เหมาะสมที่สุด การทำ cross validation และการทดสอบทางสถิติโดยรวมแสดงให้เห็นว่า IDW เป็นวิธีการที่เหมาะสมที่สุด นอกจากนี้ยังพบว่าพื้นที่ที่ได้รับผลกระทบจากสารเบนซีนที่มีค่าความเข้มข้นเฉลี่ยรายปีเกินค่ามาตรฐานคุณภาพอากาศของประเทศไทยที่ 1.7 ไมโครกรัมต่อลูกบาศก์เมตรมีแนวโน้มลดลง และผลจากการคำนวณค่า hazard quotient (HQ) และ hazard index (HI) มีค่าน้อยกว่า 1 โดยพื้นที่ที่ได้รับผลกระทบที่ค่า HI > 0.25 มีแนวโน้มลดลงเช่นเดียวกัน

การที่มีมาตรการการลดผลกระทบ โดยใช้นโยบายการบริหารจัดการสารประกอบอินทรีย์ระเหยง่าย ด้วยการประกาศให้ใช้น้ำมันเชื้อเพลิงมาตรฐาน EURO IV นั้นทำให้ความเข้มข้นของสารมลพิษในอากาศในเขตกรุงเทพมหานครลดลง

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LIST OF ABBREVIATIONS

BMA	Bangkok Metropolitan Administration
BTEX	Benzene, Toluene, Ethylbenzene, and Xylene
CBD	Central Business Districts
$\mathbf{F_b}$	Fraction Bias
$\mathbf{F_s}$	Fraction Variance
HI	Hazard Index
HQ	Hazard Quotient
IDW	Inverse Distance Weighted
IOA	Index of Agreement
NAAQS	National Ambient Air Quality Standards
$\mathbf{O_{mean}}$	Observed Mean
$\mathbf{O_{std}}$	Observed Standard Deviation/Sigma
PCD	Pollution Control Department
$\mathbf{P_{mean}}$	Predicted/Modeled Mean
ppb	Part per billion
ppm	Part per million
$\mathbf{P_{std}}$	Predicted/Modeled Standard Deviation/Sigma
$\mathbf{r^2}$	Pearson Correlation Coefficient
RfC	Reference Concentration
RHC	Robust Highest Concentration
RMSE	Root Mean Square Error
SPSS	Statistical Package for Social Science
US EPA	United States Environmental Protection Agency
VOCs	Volatile Organic Compounds
WHO	World Health Organization

CHAPTER I

INTRODUCTION

1.1 Statement of the Problem

Air pollution is contamination of the outdoor or indoor environment by any physical, biological or chemical agent that modifies the natural characteristics of the atmosphere. Air pollution causes damage to crops, animals, forests, and aquatic environment. Another negative effect of air pollution is the formation of acid rain, which causes harm to the environment such as trees, soils, rivers, and wildlife. Some of the other environmental effects of air pollution are haze, eutrophication, and global climate change. Common sources of air pollution are household combustion devices, motor vehicles, industrial facilities and forest fires. In densely populated urban and industrial areas air pollution can create serious problems. Air pollution can cause acute and chronic health effects. It has been found that the elderly and young children are more affected by air pollution. Acute health effects include eye, nose, and throat irritation, headaches, allergic reactions, and upper respiratory tract infections. Some chronic health effects include damage to the lungs, as well as brain and kidneys, heart and respiratory diseases.

Volatile Organic Compounds (VOCs) include any compound of carbon, excluding carbon oxides (i.e., monoxide and dioxide), carbonic acid, metallic carbides and carbonates, which participate in atmospheric photochemical reactions. VOCs are emitted as gases from certain solids or liquids such as paints, lacquers, cleaning supplies, pesticides, building materials, furnishings, office equipment, correction fluids, carbonless copy paper, graphics, craft materials, permanent markers, and photographic solutions. VOCs include a variety of chemicals, some of which may have adverse health effects. VOCs are toxic substances which are of high concern to the public. Mobile (i.e., cars, trucks, motorcycles and airplanes) and stationary (i.e., industry, power plants and sewage treatment) sources emit large amounts of VOCs Household products contain a variety of organic chemicals. For example, paints, varnishes, and wax all contain organic solvents, as do many cleaning, disinfecting, cosmetic, degreasing, and hobby products. In addition, fuels consist of organic chemicals. All of these products can release organic compounds during use and to a lesser degree, when they are stored (US.EPA, 2012a).

Thailand is facing serious air pollution problems, due to rapid urbanization, industrialization, and motorization. The government designated the National Ambient Air Quality Standards (NAAQS) and implemented countermeasures for criteria air pollutants such as dust, suspended particulate matters (PM_{10} and $PM_{2.5}$), sulfur dioxide (SO_2), carbon monoxide (CO), nitrogen dioxide (NO_2) and ground level ozone (O_3). The above substances are commonly referred as “conventional” air pollutants. Currently, the air quality has gradually improved to a certain level for these substances. However, ozone and particulate matter are occasionally reported as exceeding the NAAQS at many of the monitoring locations.

An emerging air pollution problem in Thailand is the emission of toxic compounds from transportation and industrial activities. Such toxic compounds are normally known as “air toxic”. The average levels of selected VOCs measured at outdoor sites in Bangkok were found to significantly vary, even over the relatively short period monitored. Typical emission sources of air toxic pollutants include automobiles, gas stations, storage tanks, petrochemical industries, oil refineries, chemical based factories, construction sites, forest fires, and the open burning of solid wastes. In the transportation sector, two-stroke motorcycles, diesel trucks and aging buses contribute largely to air toxics pollution in urban areas. In the industrial sector, different business activities may contribute air toxics to atmosphere at different levels.

Industries and vehicles are a major source of VOCs that contribute to photochemical reactions resulting in tropospheric ozone formation. Moreover, some VOCs are hazardous air pollutants, which cause various acute health problems as well as can be carcinogenic. They also contribute to secondary formation of suspended particulate matter. Therefore, the Thai government decided to control VOCs by setting environmental and emission standards as an initial environmental control policy. The implementation of pollution control measures by regulation alone can be inadequate, therefore the government incorporated pollution control elements into the industrial and transportation policy.

The Thai government designated national ambient air quality standards for VOCs. The following nine compounds, verified as carcinogenic substances; Benzene, Vinyl Chloride, Chloroform, 1, 2 - Dichloroethane, Trichloroethylene, Dichloroethane, 1, 2 - Dichloropropane, Tetrachloroethylene, and 1, 3-Butadiene were set for their ambient air standard on an annual basis (PCD, 2009).

Benzene, toluene, ethylbenzene, and xylene (BTEX) generally found in petroleum products, such as gasoline and diesel fuel (USGS, 2014). The increasing numbers of motor vehicles are the major cause of the high roadside BTEX levels along the busy road (Truc and Oanh, 2007). Motor vehicle exhaust is a constant source of 1, 3-butadiene emission. However 1, 3-butadiene breaks down quickly in the atmosphere and it is generally found in ambient air at relatively low levels in both urban and suburban areas (US.EPA, 2014). Traffic related VOC pollution has often been observed to be a more serious problem in developing countries as indicated by the VOC data obtained in Thailand, India, Pakistan and Egypt compared to the United States and Europe (Borgie et al, 2014).

The concept of this study is utilizing the data obtained from current conventional air monitoring stations to estimate concentration of air toxic compounds in the urban area.

1.2 Research Objectives

1.2.1 To formulate a mathematical equation for predicting BTEX and 1, 3-butadiene concentration by using existing conventional air pollution monitoring data.

1.2.2 To evaluate the hazard index caused by BTEX and 1, 3-butadiene exposure in Bangkok, Thailand.

1.3 Scope of the Study

Air monitoring data used in this study were from January 2008 to December 2013. The monitoring sites were located in the Bangkok Metropolitan Area and were operated by The Pollution Control Department of Thailand.

1.4 Definition of Keywords

Air Toxics: Toxic air pollutants or hazardous air pollutants are those pollutants known to or suspected of causing cancer or other serious health problems. Health concerns could be associated with both short and long term exposures to these pollutants. Many are known to have respiratory, neurological, immune or reproductive effects, particularly for more susceptible or sensitive populations such as children (US.EPA, 2012b).

Volatile Organic Compounds (VOCs): Any organic compound which evaporates readily to the atmosphere. VOCs contribute significantly to photochemical smog production and certain health problems.

BTEX: The term used for benzene, toluene, ethylbenzene, and xylene presented in coal tar, petroleum products, and various organic chemical product formulations.

1, 3-butadiene: Motor vehicle exhaust, manufacturing and processing facilities, forest fires or other combustion, and cigarette smoke are a major sources of 1, 3-butadiene released into the air and breaks down quickly in the atmosphere, it is usually found in ambient air at low levels in urban and suburban areas.

Carcinogen: A chemical or physical agent capable of causing cancer.

Inhalation: Breathing. Once inhaled, contaminants can be deposited in the lungs, taken into the blood, or both.

Hazard Quotient (HQ): The ratio of the potential exposure to the substance and the level at which no adverse effects are expected. If the HQ is calculated to be equal to or less than 1, then no adverse health effects are expected as a result of exposure. If the HQ is greater than 1, then adverse health effects are possible.

Hazard Index (HI): The sum of hazard quotients (HQs) for substances that affect the same target organ or organ system. Because different pollutants can cause similar adverse health effects, it is often appropriate to combine HQs associated with different substances.

1.5 Conceptual Framework

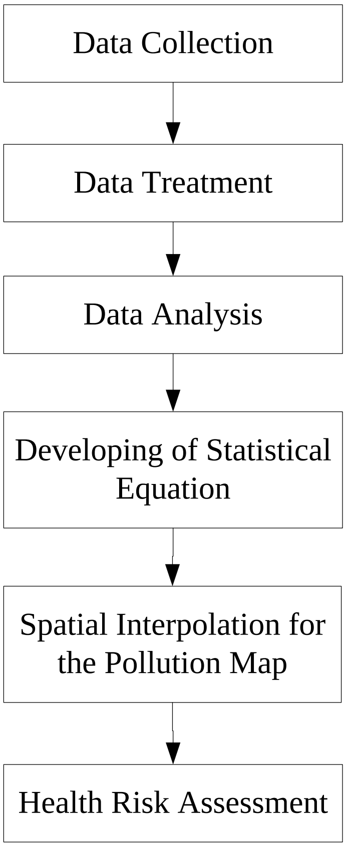


Figure 1.1 Conceptual framework

CHAPTER II
LITERATURE REVIEW

2.1 Introduction of Air Pollution

Ambient (outdoor) air pollution is a major environmental health problem affecting everyone in developed and developing countries. WHO estimates that 80% of ambient air pollution related premature deaths were due to ischaemic heart disease and strokes. Deaths due to chronic obstructive pulmonary disease or acute lower respiratory infections were 14%, and lung cancer was 6%. Some deaths may be attributed to more than one risk factor at the same time. For example, both smoking and ambient air pollution affect lung cancer. The improvement of ambient air quality or reducing smoking of tobacco may reduce deaths due to lung cancer.

In the year 2013 an assessment by WHO's International Agency for Research on Cancer (IARC) concluded that outdoor air pollution is carcinogenic to humans. The particulate matter component of air pollution was most closely associated with increased cancer incidence, especially lung cancer. An association has been observed between outdoor air pollution and an increase in cancer of the urinary tract. Ambient air pollution in both cities and rural areas was estimated to cause 3.7 million premature deaths worldwide in 2012. The death rate is due to exposure to small particulate matter of 10 microns or less in diameter (PM_{10}), which causes cardiovascular and respiratory disease, and cancers.

People living in low and middle income countries disproportionately experience the burden of outdoor air pollution with 88% (of the 3.7 million premature deaths), and the greatest number of deaths are in the Western Pacific and South-East Asia regions. The latest burden estimates reflect the very significant role air pollution plays in cardiovascular illness and premature deaths. These estimates are much greater than previously understood by scientists.

Most sources of outdoor air pollution are beyond the control of individuals and demand action by cities, as well as national and international policymakers in the areas of transport, energy, waste management, buildings and agriculture (WHO, 2014).

2.2 Sources of Air Pollution

2.2.1 Point sources or stationary sources

The point source emissions are generated from stack emission, for example power plants, industrial boilers, petroleum refineries, industrial surface coatings and chemical manufacturing industries.

2.2.2 Line sources or mobile sources

Mobile sources are categorized for highway and off-highway sources. The highway sources include automobiles, buses, trucks and other vehicles traveling on local and highway roads. The emission from highway vehicles represents one third of the VOCs and 40 percent of the nitric oxide (NO_x) emissions. Off-highway sources are any mobile combustion sources such as railroads, marine vessel, off-road motorcycle, snowmobiles, farm, construction, industrial, and lawn and garden equipment.

2.2.3 Area sources

Area sources activities are those emissions that are too small to be treated as point sources and all sources emissions information is combined and maintained. Area sources emissions can be generated from solvents used for surface coating operation, degreasing, graphic arts, dry cleaning and gasoline station (tank truck unloading and refueling) (US.EPA, 2014b).

2.3 Volatile Organic Compounds (VOCs)

VOCs include any compound of carbon, excluding carbon oxides (i.e., monoxide and dioxide), carbonic acid, metallic carbides and carbonates, which participate in atmospheric photochemical reactions, except those designated by EPA as having negligible photochemical reactivity. VOCs are organic chemical compounds whose composition makes it possible for them to evaporate under normal indoor atmospheric conditions of temperature and pressure. The general definition of VOCs is consistent with the definition used for indoor air quality. The volatility of a compound is generally higher the lower its boiling point temperature, the volatility of organic compounds is sometimes classified by their boiling points. A VOC is any organic compound having an initial boiling point less than or equal to 250° C measured at a standard atmospheric pressure of 101.3 kPa.

VOCs are sometimes classified by the ease they will be emitted. The World Health Organization (WHO) classifies indoor organic pollutants as very volatile, volatile, and semi-volatile. The higher the volatility (lower the boiling point), the more likely the compound will be released from a product or surface into the air. Very volatile organic compounds (VVOCs) are so volatile that they are difficult to measure and are found almost entirely as gases in the air rather than in materials or on surfaces. The semi volatile compounds (SVOCs) present in air compose a far smaller amount of the total present indoors while the majority will be in solids or liquids that contain them or on surfaces including dust, furnishings, and building materials (US.EPA, 2012a).

2.3.1 Health Effects

Many organic compounds can cause cancer in animals and humans. Key symptoms linked with exposure to VOCs include conjunctival irritation, nose and throat discomfort, headache, allergic skin reaction, dyspnea, declines in serum cholinesterase levels, nausea, emesis, epistaxis, fatigue, and dizziness. The capability of organic chemicals to cause health effects may vary greatly from those that are highly toxic, to no known effects on human health. Health effects from other pollutants will depend on many factors including level of exposure and length of time exposed. Eye and respiratory tract irritation, headaches, dizziness, visual disorders, and memory impairment are among the immediate symptoms that some people have experienced soon after exposure to some organics. Generally, little is known about what health effects occur from the levels of organics usually found in homes.

2.4 Health Impact

Health risk assessment is a scientific tool designed to help answer questions. Risk assessments help government agency determine which potential hazards are the most significant. Risk assessments can also guide regulators in reducing environmental hazards. The risk assessment process typically consists of four basic steps: hazard identification, exposure assessment, dose-response assessment, and risk characterization (California Environmental Protection Agency, 2001).

2.4.1 Hazard Identification

In hazard identification, scientists determine the types of health problems chemicals could cause by reviewing studies of its effects in humans and laboratory animals. These health effects may include short-term ailments, such as headaches; nausea; and eye, nose, and throat irritation; or chronic diseases, such as cancer. Effects on sensitive populations, (i.e., pregnant women and their developing fetuses, the elderly, or those with health problems), are a concern. Reactions to toxic chemicals will vary depending on the amount and length of exposure. Short-term exposure to low levels of chemicals may result in no noticeable effect, but continued exposure to the same levels of chemicals over a long period of time may ultimately cause harm. An important step in hazard identification is the selection of key research studies that can provide accurate, timely information on the hazards posed to humans by a specific chemical. Both humans and laboratory animals are used in studies that have been exposed to chemicals. Human data frequently are useful in evaluating human health risks associated with chemical exposures. Human epidemiologic studies usually expose the effects of varying concentrations of chemical exposure on a large number of people, such as employees in the workplace. Many of these exposures took place prior to implementing modern employee safeguards.

2.4.2 Dose-Response Assessment

In dose-response assessment, scientists assess the information obtained during the hazard identification step to estimate the amount of a chemical that is prone to result in a particular health effect in humans. Scientists perform a dose-response assessment to estimate how different levels of exposure to a chemical can impact the likelihood and severity of health effects. The dose-response relationship is often different for many chemicals that cause cancer than it is for those that cause other kinds of health problems.

2.4.2.1 Cancer Effects

For chemicals that cause cancer, the general assumption in risk assessment has been that there are no exposures that have “zero risk” unless there is clear evidence otherwise. Cancer may develop after a very low exposure to a chemical, if the chemical alters the normal functions of the cells. The risk of cancer, no matter how small, may increase upon a very low exposure to carcinogens. Several factors make it difficult to estimate the risk of cancer. Cancer appears to be a progressive disease because a series of cellular transformations is thought to occur before cancer develops. Chemicals may cause cancer, years after being exposed. The data of cancer causing chemicals is often from exposing laboratory animals to extremely high doses of chemicals. This exposure concentration is much greater than in the normal human life. However, scientists use calculations based on research animals exposed to high levels of a chemical to calculate the chances of cancer developing in a varied human populace exposed to much lower levels.

2.4.2.2 Non-cancer Effects

Non-cancer health effects (such as asthma, nervous system disorders, birth defects, and developmental problems in children) usually become more severe as exposure to a chemical increases. One objective of dose-response assessment is to calculate levels of exposure that pose only a low risk for non-cancer health effects. Scientists analyze studies of the health effects of a chemical to develop this calculation. They take into account such factors as the quality of the scientific studies, whether humans or laboratory animals were studied, and the degree to which some people may be more sensitive to the chemical than others. The calculated level of exposure that poses no significant health risks can be decreased to reflect these factors.

2.4.3 Exposure Assessment

In exposure assessment, scientists research how long and how much people were exposed to a chemical; if the exposure was continuous or intermittent; and how people were exposed through eating, drinking water and other liquids, breathing, or skin contact. All of this information is combined with factors such as breathing rates, water consumption, and daily routine to calculate the amount of the chemical taken into the bodies of those exposed. People can be exposed to toxic chemicals in several ways. These chemicals can enter the body through air, food, and water. Some chemicals may be both inhaled and ingested. For example, airborne chemicals can settle on the surface of water, soil, leaves, fruits, vegetables, and forage crops used as animal feed. Chemicals can be absorbed through the skin, so infants and children can be exposed simply by crawling or playing in contaminated dirt. They can also ingest chemicals if they put their fingers or toys in their mouths after playing in contaminated dirt. Nursing mothers can pass on chemicals to their children through breast milk (US.EPA, 2012c).

2.4.4 Risk Characterization

The last step in risk assessment brings together the information developed in the previous three steps to estimate the risk of health effects in an exposed population. In the risk characterization step, scientists analyze the information developed during the exposure and dose response assessments to describe the resulting health risks that are expected to occur in the exposed population. This information is presented in different ways for cancer and non-cancer health effects, as explained below.

2.4.4.1 Cancer Risk

Cancer risk is stated as the maximum number of new cases of cancer estimated to occur in a population of one million people due to exposure to the cancer-causing substance over a 70-year lifetime. For example, a cancer risk of one in one million means that in a population of one million people, not more than one additional person would be expected to develop cancer as the result of the exposure to the substance causing that risk. An individual's actual risk of contracting cancer from exposure to a chemical is often less than the theoretical risk to the entire population estimated in the risk assessment. For example, the risk assessment for a drinking-water contaminant may be based on the health-protective assumption that the individual drinks two liters of water from a contaminated source daily over a 70-year lifetime. However, an individual's actual exposure to that contaminant would depend on the length of residence in the area. Moreover, an individual's risk not only depends on the individual's exposure to a specific chemical but also on his or her genetic background, health, diet, and lifestyle choices.

2.4.4.2 Non-cancer Risk

Non-cancer risk is normally defined by comparing the actual level of exposure to a chemical to the level of exposure that is not expected to cause any adverse effects, even in the most susceptible people. Levels of exposure at which no adverse health effects are expected are called "health reference levels," and they generally are based on the results of animal studies. Scientists usually set health reference levels much lower than the levels of exposure that were found to have no adverse effects in the animals tested. This approach helps to ensure that real health risks are not underestimated by adjusting for possible differences in a chemical's effects on laboratory animals and humans; the possibility that some humans, such as children and the elderly may be particularly sensitive to chemical; and possible deficiencies in data from the animal studies. Depending on the amount of uncertainty in the data, scientists may set a health reference level 100 to 10,000 times lower than the levels of exposure observed to have no adverse effects in animal studies. Exposures above the health reference level are not necessarily hazardous, but the risk of toxic effects increases as the dose increases. If an assessment determines that human exposure to a chemical exceeds the health reference level, additional study is justified.

$$\text{Hazard Quotient (HQ)} \quad = \quad \frac{\text{Intake}\left(\frac{\mu g}{m^3}\right)}{\text{RfC}\left(\frac{\mu g}{m^3}\right)}$$

$$\text{Hazard Index (HI)} \quad = \quad \sum \text{HQ}_1 + \text{HQ}_2 + \ldots \text{HQ}_n$$

2.5 Geographic Information System (GIS)

A geographic information system (GIS) is a program used for the capturing, maintaining, and analyzing all types of spatial and geographical information. The objective of GIS is to create, share, and apply effective information from maps to create and manage the supporting geographic information. Maps interpret logical collections of geographic data as map layers. Interactive GIS maps provide the principal user interface for using geographic information (ArcGIS Resource Center, 2013).

A GIS map is an interactive window into all geographic information and descriptive data, and into rich spatial analysis models created by GIS professionals. Maps relate and transfer large amounts of information in a standardized way. Humans, as spatial thinkers, are able to view a map, associate map locations with real-world phenomena, and interpret and grasp critical information from the sea of detailed content that is contained within each map display.

Maps are used to explore and examine patterns such as the aspects of a population across a city or the movement of animals on seasonal migrations. In GIS, interactive, online maps are used to analyze data reports for multiple features and how phenomena evolve through time. GIS maps supply interactive data of the material behind the map, not only a list of attributes but also charts, reports, photos, and any relevant content. Surface interpolation tools create a continuous surface from sampled point values. Visiting every location in a study area to measure the height, concentration, or magnitude of a phenomenon is usually difficult or expensive. The measurement of samples from strategically dispersed locations can predict and assign values to the other locations. A sampling scheme may contain either randomly or regularly spaced input points. The continuous surface representation of a raster dataset represents some measure, such as the height, concentration, or magnitude.

Surface interpolation tools are used to forecast from sets of known data for all locations in an output raster dataset, whether or not a measurement has been taken at the location. There are various ways to develop a prediction for each location; each method is referred to as a model. With each model, there are different approaches made of the data, and certain models are more applicable for specific data for example, one model may account for local variation better than another. Each model produces predictions using different calculations. The interpolation tools are generally divided into deterministic and geostatistical methods.

- The deterministic interpolation methods assign values to locations based on the surrounding measured values and on specified mathematical formulas that determine the smoothness of the resulting surface. The deterministic methods include IDW (inverse distance weighted), Natural Neighbor, Trend, and Spline.
- The geostatistical methods are based on statistical models that include autocorrelation (the statistical relationship among the measured points). Because of this, geostatistical techniques not only have the capability of producing a prediction surface but also provide some measure of the certainty or accuracy of the predictions. Kriging is a geostatistical method of interpolation.

The remaining interpolation tools, Topo to Raster and Topo to Raster by File, use an interpolation method specifically designed for creating continuous surfaces from contour lines, and the methods also contain properties favorable for creating surfaces for hydrologic analysis.

Interpolation predicts values for cells in a raster from a limited number of sample data points. The predicting of unknown values through interpolation can be used on any geographic point data, such as elevation, rainfall, chemical concentrations, and noise levels. The available interpolation methods are listed below.

The IDW (Inverse Distance Weighted) tool uses a method of interpolation that estimates cell values by averaging the values of sample data points in the neighborhood of each processing cell. The closer a point is to the center of the cell being estimated, the more significance it has in the averaging process.

Kriging is an advanced geostatistical procedure that generates an estimated surface from a scattered set of points with z-values. A thorough investigation of the spatial behavior of the phenomenon represented by the z-values should be done before the selection of the best estimation method for generating the output surface.

The Spline tool uses an interpolation method that estimates values using a mathematical function that minimizes overall surface curvature, resulting in a smooth surface that passes exactly through the input points.

2.6 Related Research

Kajihara et al. (2000) studied population risk assessment of ambient benzene and evaluation of benzene regulation in gasoline in Japan. The result showed the exposure assessment to ambient benzene in Japan, by using NO_x monitored data from air monitoring stations across the country to predict benzene concentrations. The data resulted in a high correlation between the levels of benzene and NO_x after eighteen months of monitoring. The benzene level distribution throughout Japan was calculated using the relationship between the benzene and NO_x levels. Population distribution of exposure to benzene was estimated for the roadside population and the total population. The distribution of excess cancer risk due to exposure to benzene was established according to the US EPA cancer unit risk. The total population risk for all of Japan was estimated to be 29.6 cancer deaths annually. The cost of benzene regulation in gasoline was estimated to be 25.6 billion yen, which correspondingly was calculated to prevent 8.8 cancer deaths annually, corresponding to 27% of the total number of cancer deaths before regulation was introduced. In addition, benzene regulation in gasoline was estimated to be 2.9 billion yen per life saved.

Vlachokostas et al. (2012) investigated the prediction of toluene concentration levels in European cities. The exposure to toxic chemicals may affect the health of humans in many ways. The respective contributions of a number of factors to every health outcome have to be assessed. However, the majority of urban areas are characterized by the absence of monitoring infrastructure, especially regarding uncommon air pollutants such as TEX, PAHs (BaP) or heavy metals. In the same study, statistical analysis was used to predict the air pollution levels related to traffic in urban areas, specifically toluene levels by using two linear statistical relationships, that is, toluene = f (benzene) and toluene = f (CO). The available toluene data from monitoring stations located in the European Union used to validate these two linear statistical equations. These validated models are adequate for the prediction of similar studies (Apart from the strong linear relationship that is obvious, the better fit of the single pollutant linear model over more complicated models is justified by the simplicity as well as the flexibility it offers).

Thepanondh and Toruksa (2011) studied the proximity analysis of air pollution exposure and its potential risk. This work evaluated approaches for estimating the spatial variability in ambient air pollution concentrations in the Mabtaphud district, Thailand. The nitrogen dioxide concentrations measured at 11 ambient air quality monitoring stations was used to carry out. Spatial interpolation using the following three separate techniques: the ordinary kriging, the inverse distance weighted (IDW), and the spline. Based on a cross-validation procedure the ordinary kriging technique produced better results. Specifically, the ordinary kriging created a nitrogen dioxide concentration map. The results indicated a small variation of its concentration over the study domain. However, spatial interpolation allowed the analysis of areas having high concentrations to pollutants (commonly referred as “hot spots”) which were in downwind locations of the industrial complex. It was suggested that for further study, air pollution mapping it is imperative to compare several integrating and interpolating techniques of secondary data prior to applying the best spatial interpolation technique. Mobile source emission also played a critical role in increasing the ambient nitrogen dioxide concentration in the study area.

Wu et al. (2012) studied the exposure to VOCs and associated health risks of a socio-economically disadvantaged population in Camden, New Jersey. They estimated personal and ambient concentrations of VOCs in a suspected hot spot of air pollution in the Village of Waterfront South (WFS), and an urban reference community, the Copewood and Davis Streets (CDS) area in Camden, New Jersey. Both are minority dominant, impoverished communities. This involved the collection of 24-h integrated personal air samples from 54 WFS and 53 CDS residents, with one sample on a weekday and one on a weekend day during the summer and winter seasons of 2004-2006. Moreover, ambient air samples from the center of each community were also collected simultaneously during personal air sampling. It was found that toluene, ethylbenzene, and xylenes (TEX) presented higher ($p < 0.05$) ambient levels in WFS than in CDS, particularly during weekdays. A stronger association between personal and ambient concentrations of MTBE and TEX was observed in WFS than in CDS. Local outdoor air pollution accounted for fourteen to forty-two percent of the variation in personal MTBE, hexane, benzene, and TEX. These results suggested that local sources impacted the community air pollution and personal exposure in WFS. The estimated cancer risk resulting from two locally emitted VOCs, benzene and ethylbenzene, and non-cancer neurological and respiratory effects resulting from hexane, benzene, toluene, and xylenes exceeded the corresponding US EPA risk benchmarks in both communities. It has been found that the health risks related to ambient air pollution for the socio-economically disadvantaged groups need proper attention.

Zhou et al. (2011) studied the health risk assessment of personal inhalation exposure to VOCs in Tianjin, China. In this study, 12 participants were exposure to a residential indoor and outdoor, workplace and to vehicle VOC concentrations simultaneously in Tianjin, China. Five days of VOC samples were collected using passive sampling. Inhalation Unit Risks from U.S. EPA were used to calculate the inhalation cancer health risk. It was observed that modeled and measured concentrations were statistically linearly correlated for all VOCs ($P<0.01$) except chloroform, which confirms that personal exposure using a time-weighted model can provide a reasonable estimate of personal inhalation exposure to VOCs. Based on the time-activity pattern and factor analysis indoor smoking and recent renovation were identified as two crucial factors affecting personal exposure. According to the cancer risk analysis of personal exposure, benzene, chloroform, carbon tetrachloride and 1,3-butadiene had median upper-bound lifetime cancer risks that exceeded the U.S. EPA benchmark of 1 per one million, while benzene presented the highest median risks at about 22 per one million population. The median cumulative cancer risk of personal exposure to 5 VOCs was approximately 44 per million, followed by indoor exposure (37 per million) and in vehicle exposure (36 per million).

Gulliver et al. (2011) studied the comparative assessment of GIS-based methods and metrics for estimating long-term exposure to air pollution. They compared the performance of ten different methods and metrics in terms of their ability to predict mean annual PM10 concentrations across 52 monitoring sites in London, UK. Metrics analyzed include the following indicators: distance to nearest road, traffic volume on nearest road, heavy duty vehicle (HDV) volume on nearest road, road density within 150 meters, traffic volume within 150 meters and HDV volume within 150 meters. Four modeling approaches were also applied: based on the nearest monitoring site, kriging, dispersion modeling and land use regression (LUR). Measures were calculated in a GIS, and resulting metrics calibrated and validated against monitoring data using a form of grouped jack-knife analysis. The results show that PM10 concentrations across London exhibit little spatial variation. As a consequence, most methods can predict the average without serious bias. However, few of the approaches show good correlations with monitored PM10 concentrations, and most predict no better than a simple classification based on site type. It was observed that only land use regression reaches acceptable levels of correlation (R2<0.47), though this can be improved by also including information on site type.

Eldrandaly and Abu-Zaid (2011) studied the comparison of six GIS-based spatial interpolation methods for estimating air temperature in Western Saudi Arabia. This research were compared the suitability of the interpolation method for estimating mean monthly air temperature (MMAT) surfaces. The interpolation techniques applied four deterministic methods including Inverse Distance Weighted (IDW), Global Polynomial, Local Polynomial, and Radial Basis Function (Thin-Plate Spline) and two geostatistical methods including Ordinary Kriging, and Universal Kriging. Cross-validation was used to compare the various interpolation methods. Diagnostic statistics indicated that Ordinary and Universal Kriging had the smallest Root Mean Square Error (RMSE) and thus they are considered the optimal methods for interpolating air temperature in this region.

CHAPTER III

METHODOLOGY

In this chapter, data collection, treatment and analysis are presented. The statistical analysis used for developing and validating an equation of BTEX and 1, 3-butadiene are described. The hazard quotient (HQ) and hazard index (HI) used in health effects to the population in the study area. A research design presented in this chapter is as shown in Figure 3.1.

3.1 Data Collection and Analysis

The air monitoring data used in this study were from January 2008 to December 2013. BTEX and 1, 3-butadiene were monitored at three monitoring sites in Bangkok Metropolitan area namely Din Dang, Chokchai 4, and Bansomdaj. The monitoring sites are operated by Pollution Control Department (PCD). The available conventional air monitoring data include Carbon Monoxide (CO), Nitric Oxide (NO), Nitrogen Dioxide (NO_2) and Oxide of Nitrogen (NO_x). These conventional air pollutants except CO which is reported in a unit of part per million (ppm) (NO, NO_2 and NO_x) are reported in a unit of part per billion (ppb). These units were converted to milligram per cubic meter (mg/m^3) and microgram per cubic meter ($\mu g/m^3$) as follow;

$$mg/m^3 = \left(\frac{ppm \times MW}{24.45}\right)$$

$$\mu g/m^3 = \left(\frac{ppb \times MW}{24,450}\right) \times 1,000$$

Where, MW = Molecular weight of compound

Daily average (24 hours average) of BTEX, 1, 3-butadiene and conventional air monitoring data were used in the correlation analysis. To developing an equation will obtain by using linear regression analysis.

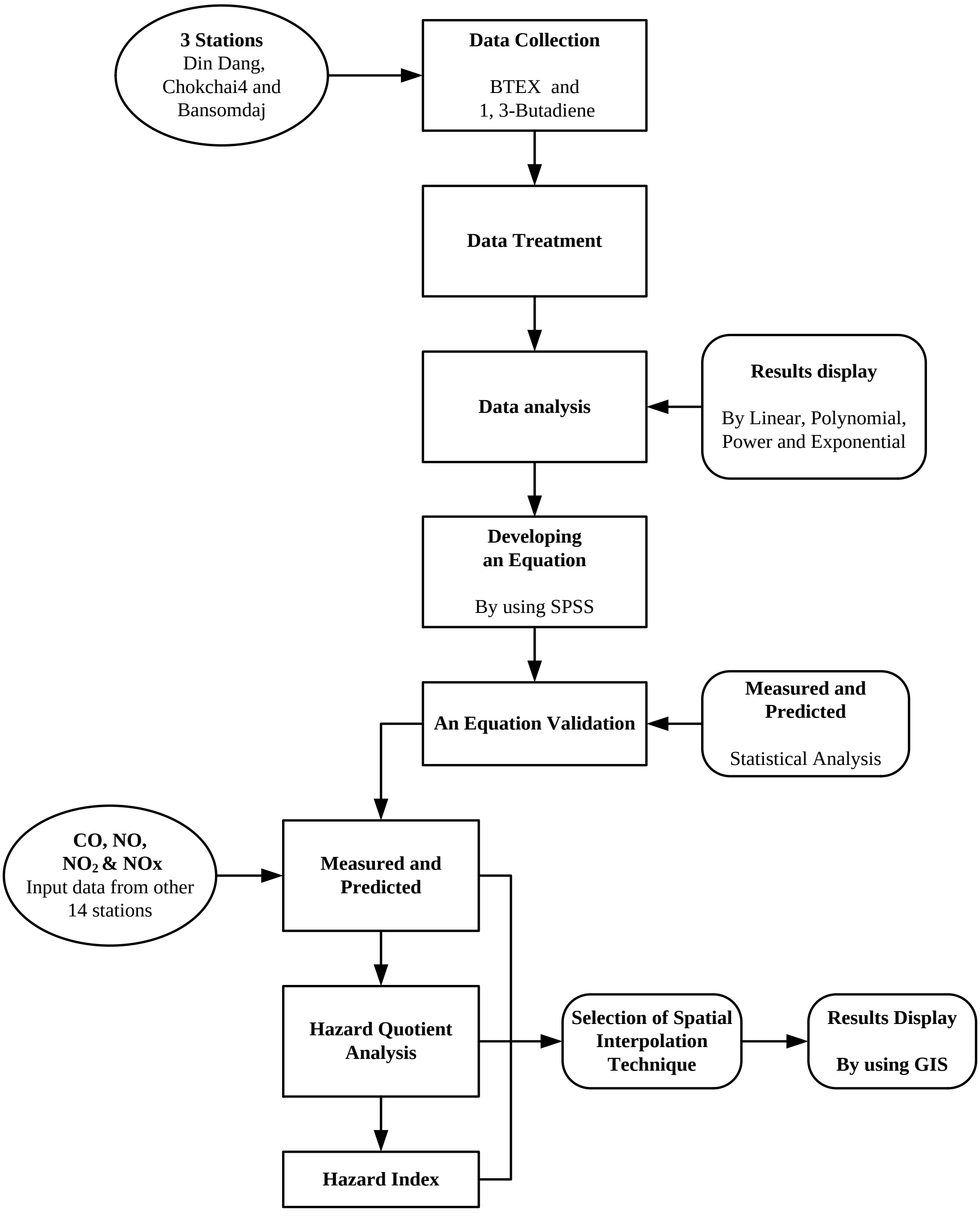


Figure 3.1 Research design

3.2 Data Treatment

The daily average BTEX, 1, 3-butadiene and hourly average available conventional air monitoring data from PCD were treated as follow:

For BTEX and 1, 3-butadiene, zero value was used to replace non-available data. For cases that data values were less than mark (<), half of values of those data were used.

As for conventional air quality data, missing data were replaced prior calculation of daily average concentration. In case of missing data of one hour, data before and after of missing values were averaged and were used to replace missing data.

As for 2-3 hours of missing data, treatment of data were carried out by interpolation technique or by using data from previous day as appropriate.

3.3 Data Analysis

After data treatment process for this study was used correlation technique to analyze BTEX and 1, 3-butadiene with available conventional air pollutants (CO, NO, NO_2 and NO_x) from 5 to 95 percentile and the results displayed by 4 best fit of different regression types included Exponential, Linear, Polynomial and Power respectively. To develop an equation for predicting BTEX and 1, 3-butadiene concentration by using existed conventional air pollution monitoring data was used linear regression by the Statistical Package for Social Science (SPSS) then each selected BTEX and 1, 3-butadiene will generate a different equation that was related to available conventional air pollutants. For an equation validation was used statistical numerical equation to measure model performance. To validate a measured and predicted selected BTEX and 1, 3-butadiene was used an existed conventional air pollution monitoring data from other 14 stations. Spatial distributions of 17 air monitoring stations as shown in Figure 3.2.

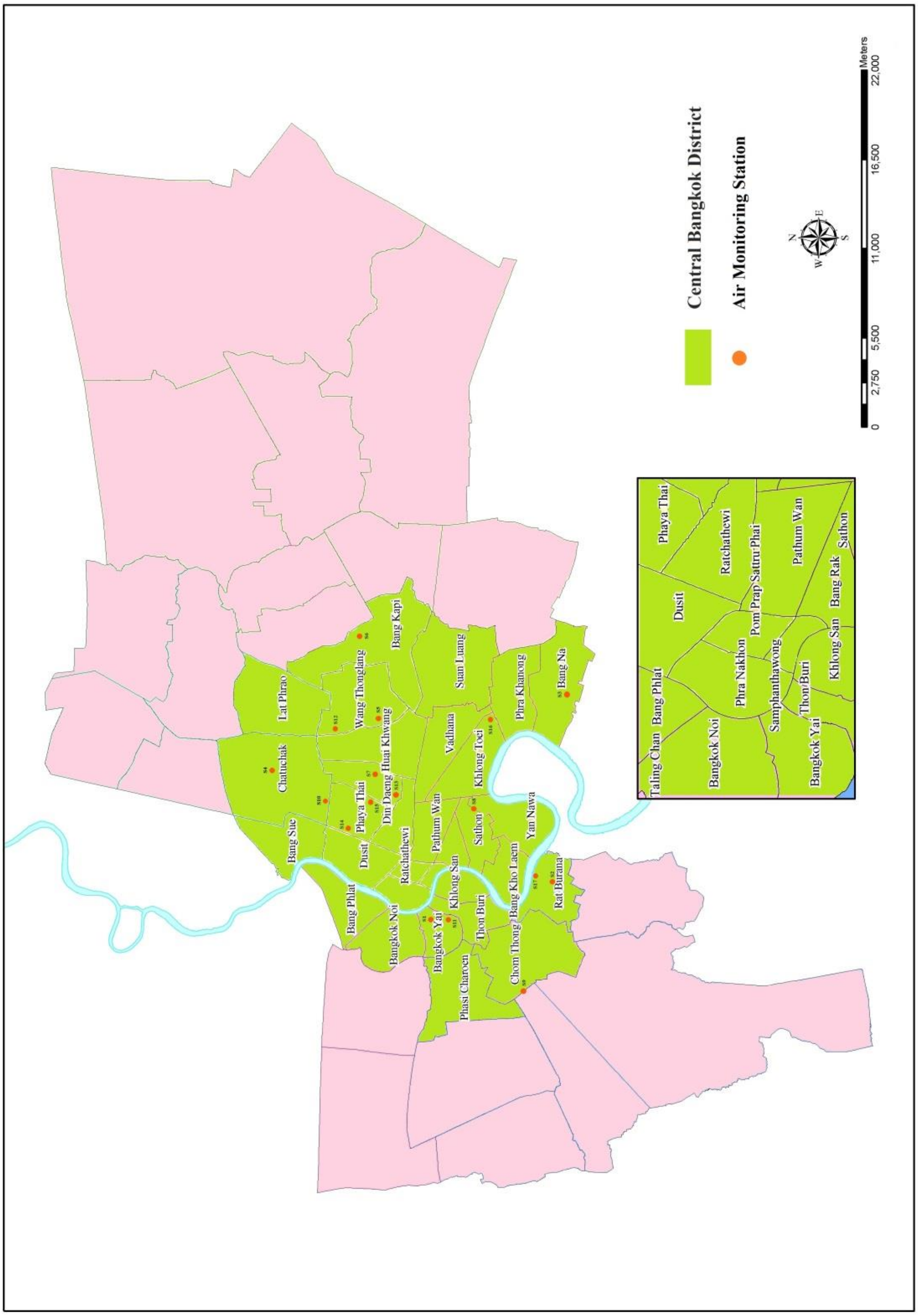


Figure 3.2 Spatial distributions of 17 air monitoring stations

3.4 Study area

The study area were Central Business Districts (CBD) included 31 districts and number of population from the year 2013 (BMA, 2014) as shown in Table 3.1

Table 3.1 Central Bangkok Districts and number of population

No.	Districts	Population
1	Bang Sue	130,511
2	Chatuchak	160,948
3	Lat Phrao	122,441
4	Bang Kapi	149,056
5	Wang Thonglang	114,805
6	Huai Khwang	78,943
7	Din Daeng	128,838
8	Phaya Thai	72,495
9	Dusit	106,811
10	Ratchathewi	73,550
11	Phra Nakhon	56,684
12	Pom Prap Sattru Phai	50,092
13	Samphanthawong	26,932
14	Bang Phlat	98,113
15	Bangkok Noi	117,503
16	Bangkok Yai	71,087
17	Phasi Charoen	129,559
18	Chom Thong	157,156
19	Thon Buri	117,536
20	Khlong San	75,765
21	Rat Burana	85,825
22	Bang Kho Laem	93,508
23	Yan Nawa	81,162
24	Sathon	83,898
25	Bang Rak	46,114
26	Pathum Wan	52,613
27	Khlong Toei	108,066
28	Vadhana	82,637
29	Suan Luang	116,688
30	Phra Khanong	92,774
31	Bang Na	95,204

3.5 Statistical Numerical Equation of VOCs Concentration

The statistics uses to measure model performance in this study were described as follow.

Observed Mean (O_{mean}) value averaged over all monitored days in the year 2008 to 2011 and 2012 to 2013.

$$O_{mean} = \frac{1}{N}\sum_{i=1}^{N} O_i$$

Predicted/Modeled Mean (P_{mean}) value paired in time and space with the observations in the year 2008 to 2011 and 2012 to 2013.

$$P_{mean} \frac{1}{N}\sum_{i=1}^{N} P_i$$

Observed Standard Deviation/Sigma (O_{std})

$$O_{std} \sqrt{\frac{1}{N-1}\sum_{i=1}^{N}(O_i - O_{mean})^2}$$

Predicted/Modeled Standard Deviation/Sigma (P_{std})

$$P_{std} = \sqrt{\frac{1}{N-1}\sum_{i=1}^{N}(P_i - P_{mean})^2}$$

Pearson Correlation Coefficient (r^2), the value of correlation close to 1 indicates perfect correlation between the observed and the predicted values that is a sign of good model performance.

$$r^2 = \frac{N(\sum_{i=1}^{N} O_i P_i) - (\sum_{i=1}^{N} O_i)(\sum_{i=1}^{N} P_i)}{\sqrt{[N(\sum_{i=1}^{N} O_i^2) - (\sum_{i=1}^{N} O_i)^2][N(\sum_{i=1}^{N} P_i^2) - (\sum_{i=1}^{N} P_i)^2]}}$$

Root Mean Square Error (RMSE) ranges from zero (for the ideal model) to positive infinity (worst model). RMSE is biased toward peak flows.

$$\text{RMSE} = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(P_i - O_i)^2}$$

Index of Agreement (IOA) was developed by Willmott as a standardized measure of the degree of model prediction error and varies between 0 and 1. A computed value of 1 indicates a perfect agreement between the measured and predicted values, and 0 indicates no agreement at all. IOA determines the degree to which magnitudes and signs of the observed value about mean observed value are related to the predicted deviation about mean predicted value, and allows for sensitivity toward difference in observed and predicted values as well as proportionality changes (Elbir, T., 2003).

$$\text{IOA} = 1 - \frac{\sum_{i=1}^{N}(P_i - O_i)^2}{\sum_{i=1}^{N}(|P_i - O_{mean}| + |O_i - O_{mean}|)^2}$$

Fraction Bias (F_b) indicates how well the computation produces the average values around the average values of observed variable.

$$F_b = 2\frac{(O_{mean} - P_{mean})}{(O_{mean} + P_{mean})}$$

Fraction Variance (F_s)

$$F_s = 2\frac{(O_{std} - P_{std})}{(O_{std} + P_{std})}$$

Robust Highest Concentration (RHC) is preferred to the actual peak value because it mitigates the undesirable influence of unusual events, while still representing the magnitude of the maximum concentration (Peter *et. al*, 2003).

$$\text{RHC} = C(R) + (\bar{C} - C(R)\ln(\frac{(3R-1)}{2}$$

Where:

Oi = Observed data

Pi = Predicted/Modeled data

C(R) = The R^{th} highest concentration

$\bar{C}$ = The mean of the top R-1 concentration

3.6 Hazard Index

Health risk associated with VOCs exposure were estimated based on ambient VOCs concentrations for both cancer and non-cancer endpoints, using the conventional approaches developed by the US.EPA. Hazard Quotient (HQ) and Hazard Index (HI) of BTEX and 1, 3-butadiene will illustrate in this study. The HQ of benzene was used to create a pollution map and the summation of HQ was used to create the thematic map of HI. If HQ and HI are greater than 1, then it can be interpreted that there are adverse health effects and if HQ and HI less than 1, then there are no adverse health effects to the population in the study area. The reference concentration of BTEX and 1, 3-butadiene (IRIS, 2013) as shown in Table 3.2

Table 3.2 The reference concentration of BTEX and 1, 3-butadiene

VOCs	**RfC (mg/m^3)**
Benzene	$3x10^{-2}$
Toluene	5
Ethylbenzene	1
Xylene	0.1
1,3-Butadiene	$2x10^{-3}$

3.7 GIS for Pollution Map

The result of health affect was illustrated by using selection of interpolation technique of GIS. The spatial interpolation of BTEX and 1, 3-butadiene in this study was performed using three separate spatial interpolation schemes. The spatial interpolation methods used in this study were the Ordinary Kriging, the Inverse Distance Weighted (IDW) and the Spline.

The inverse distance weighted (IDW) interpolation technique weights the contribution of each of the input (control) points by a normalized inverse of the distance from the control point to the interpolated point. IDW assumes that each input point has a local influence that diminishes with distance. It weights the points closer to the processing points greater than those farther away. A specified number of points or all the points within a specified radius are used to determine the output value for each location. The power parameter in the IDW interpolator controls the significance of the surrounding points upon the interpolated value. A higher power results in less influence from distant points. In this study, the power was set as 1.

As for kriging, the weighting rule and the resulting map are directly determined by the spatial behavior of the mapped pollutant. The variogram calculated from the values observed at the monitoring sites makes it possible to quantify the pollutant’s spatial continuity. A mathematical function is then fitted to the experimental variograms to get a model which characterizes the spatial variability for any distance and any direction. The ordinary kriging predictions are, like IDW predictions, weighted averages of the available data. The sum of the weights in the ordinary kriging is equal to one, which allows the construction of an unbiased estimator that does not require prior knowledge of the stationary mean of the observed values.

The spline technique fits a minimum curvature surface through the input points. This method is best for gently varying surfaces where the physiographic changes or changes in other phenomenon are not abrupt. It is not appropriate if there are large changes in the surface within a short horizontal distance because it can overshoot the estimated values. The normalized method yields a smooth surface as the weight parameters define the weight of the third derivative of the surface in the curvature minimization expression.

Cross-Validation was used to assess the performance of each interpolation method. It is one of the most commonly used statistical techniques for comparing interpolation methods. Cross-Validation compares the interpolation methods by repeating the following procedure for each interpolation method to be compared.

- Remove a known point from the data set.
- Use the remaining points to estimate the value at the point previously removed, and
- Calculate the predicted error of the estimation by comparing the estimated with the known value.

Upon finalizing the procedure for each known point, two common diagnostic statistics, Root Mean Square Error (RMSE) and the standardized RMSE, are calculated to assess the accuracy of the interpolation method.

CHAPTER IV

RESULTS AND DISCUSSION

This chapter describes results and discussion of data collection, treatment and analysis. Data used in this study were from January 2008 to December 2013. The hazard quotient (HQ) and hazard index (HI) for benzene, toluene, ethylbenzene, xylene (BTEX) and 1, 3-butadiene were also assessed.

4.1 Numerical analysis (Air pollution monitoring data from 2008 – 2011)

Conventional air pollutants, BTEX and 1, 3-butadiene monitoring data were treated as described in Chapter 3. The 5th and 95th percentiles of BTEX, 1, 3-butadiene and conventional air monitoring data (CO, NO, NO_2 and NO_x) from 2008 – 2011 were shown in Tables 4.1 to 4.5. These data were used to evaluate relationship between pair of air pollutants. The best fit plots between two pollutants were chosen taking into consideration, obtained from each numerical equation. Results as shown in Figure 4.1 to 4.20 respectively.

Table 4.1 Statistical analysis for the 5th - 95th percentiles of benzene and conventional air monitoring data

Statistics

		Benzene	**CO**	**NO**	**NO_2**	**NO_x**
N	Valid	127	127	127	127	127
	Missing	0	0	0	0	0
Percentiles	5	2.08	147.19	5.83	21.84	32.79
	95	9.02	2807.26	275.04	130.78	385.25

Remark: N = number of data

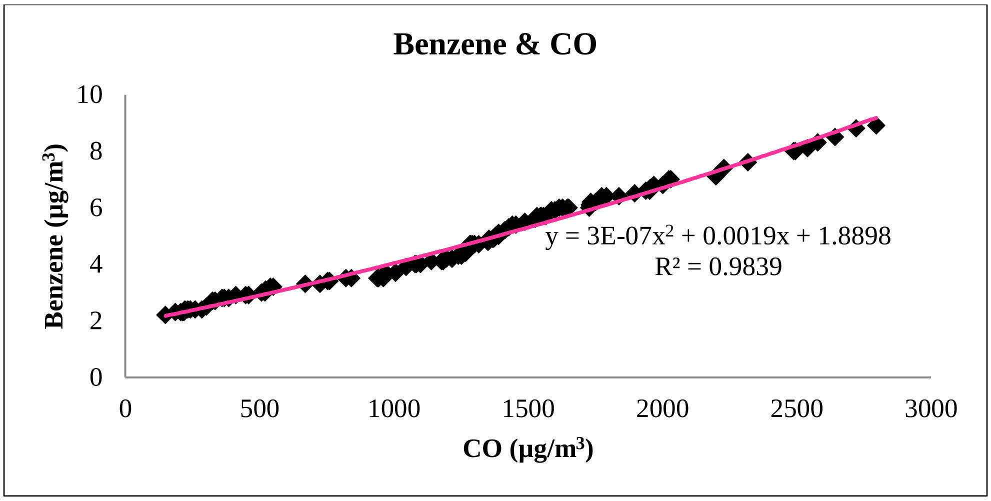


Figure 4.1 Best fit plot between benzene and CO concentrations from 2008 – 2011

Figure 4.1 shows the correlation between benzene and CO. The best fit equation was in the form of polynomial equation as $y = 3E - 07x^2 + 0.0019x + 1.8898$ with R^2 of 0.9839 (Appendix A).

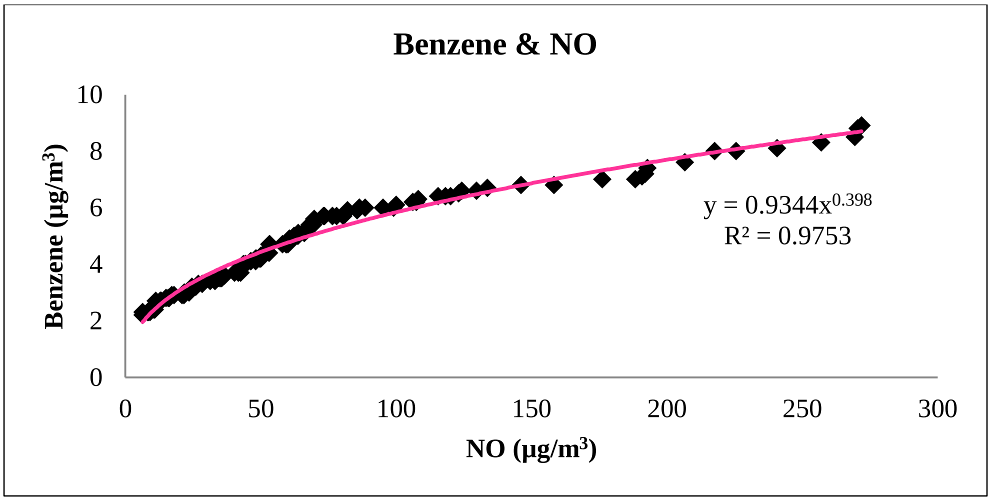


Figure 4.2 Best fit plot between benzene and NO concentrations from 2008 – 2011

Figure 4.2 shows the correlation between benzene and NO. The best fit equation was in the form of power equation as $y = 0.9344x^{0.398}$ with R^2 of 0.9753 (Appendix A).

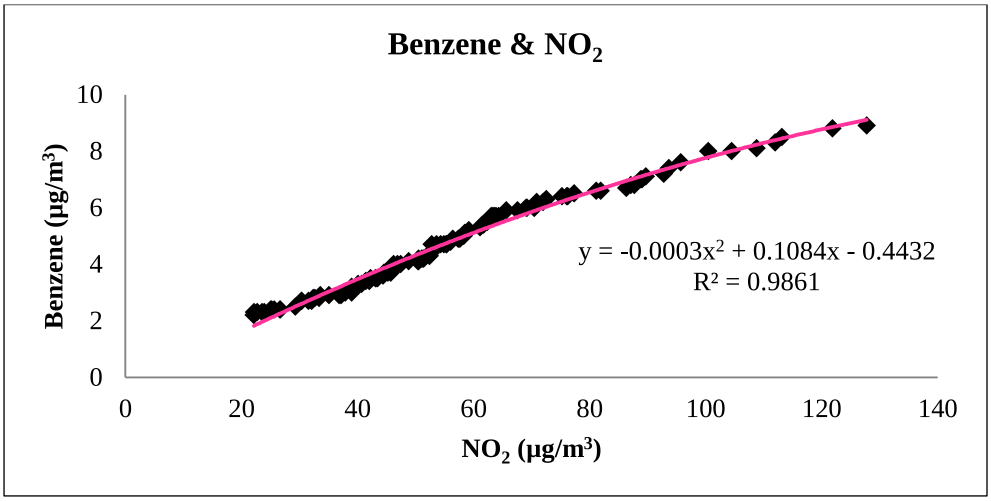


Figure 4.3 Best fit plot between benzene and NO_2 concentrations from 2008 – 2011

Figure 4.3 shows the correlation between benzene and NO_2. The best fit equation was in the form of polynomial equation as $y = -3E-04x^2 + 0.1084x - 0.4432$ with R^2 of 0.9861 (Appendix A).

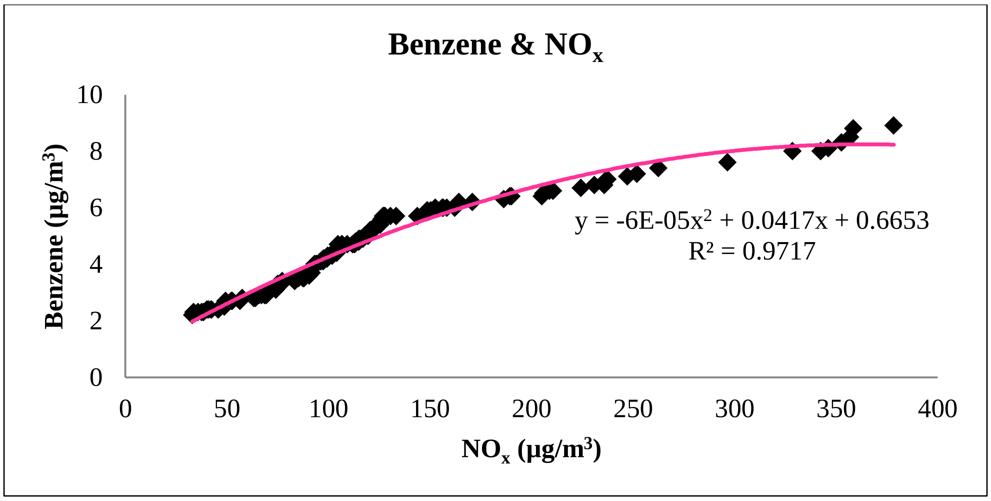


Figure 4.4 Best fit plot between benzene and NO_x concentrations from 2008 – 2011

Figure 4.4 shows the correlation between benzene and NO_x. The best fit equation was in the form of polynomial equation as $y = -6E-05x^2 + 0.0417x + 0.6653$ with R^2 of 0.9717 (Appendix A).

Table 4.2 Statistical analysis for the 5th - 95th percentiles of toluene and conventional air monitoring data

Statistics

		Toluene	**CO**	**NO**	**NO_2**	**NO_x**
N	Valid	130	130	130	130	130
	Missing	0	0	0	0	0
Percentiles	5	14.55	147.84	5.97	21.92	32.61
	95	90.80	2804.57	274.27	124.54	367.47

Remark: N = number of data

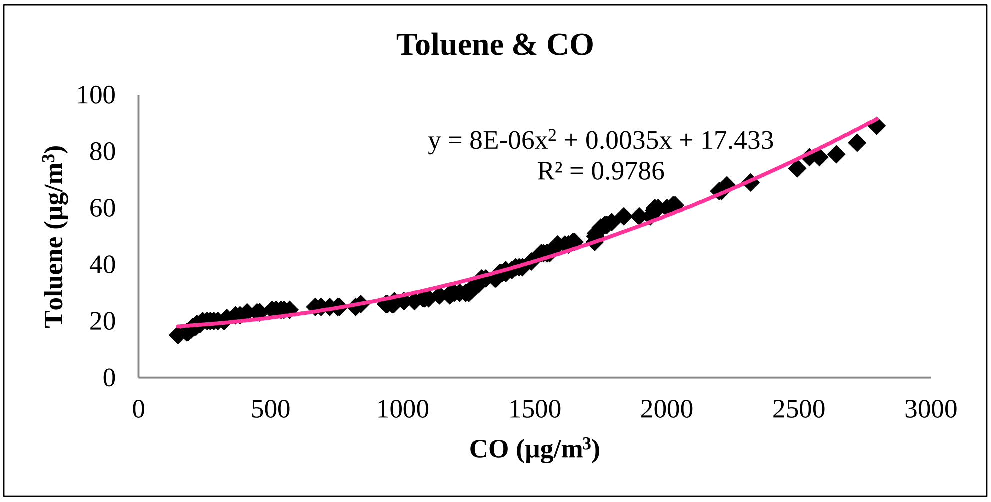


Figure 4.5 Best fit plot between Toluene and CO concentrations from 2008 – 2011

Figure 4.5 shows the correlation between toluene and CO. The best fit equation was in the form of polynomial equation as $y = 8E - 06x^2 + 0.0035x + 17.433$ with R^2 of 0.9786 (Appendix A).

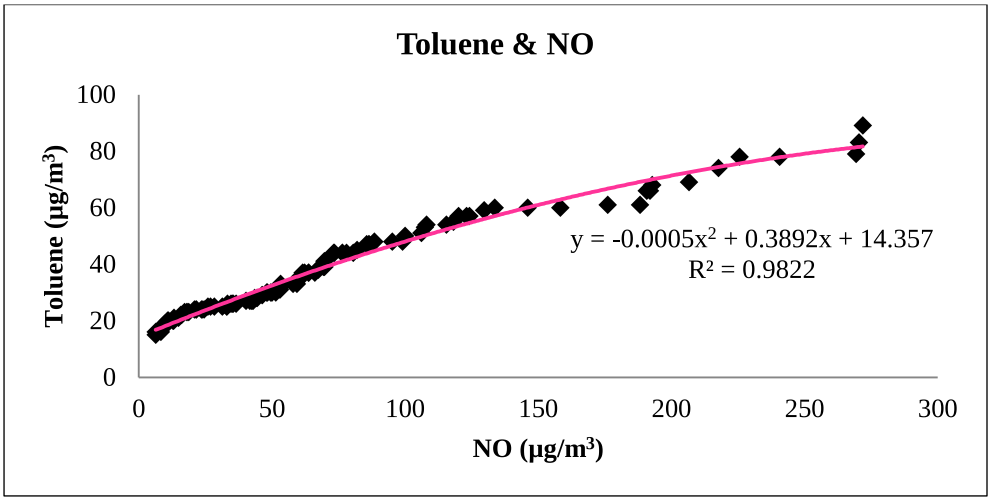


Figure 4.6 Best fit plot between Toluene and NO concentrations from 2008 – 2011

Figure 4.6 shows the correlation between toluene and NO. The best fit equation was in the form of polynomial equation as $y = -5E - 04x^2 + 0.3892x + 14.357$ with R^2 of 0.9822 (Appendix A).

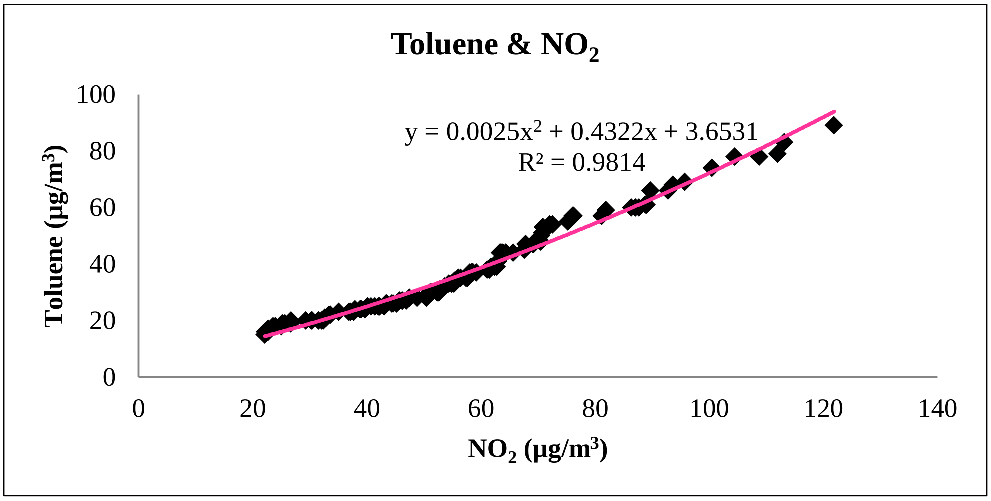


Figure 4.7 Best fit plot between Toluene and NO_2 concentrations from 2008 – 2011

Figure 4.7 shows the correlation between toluene and NO_2. The best fit equation was in the form of polynomial equation as $y = 2.5E - 03x^2 + 0.4322x + 3.6531$ with R^2 of 0.9814 (Appendix A).

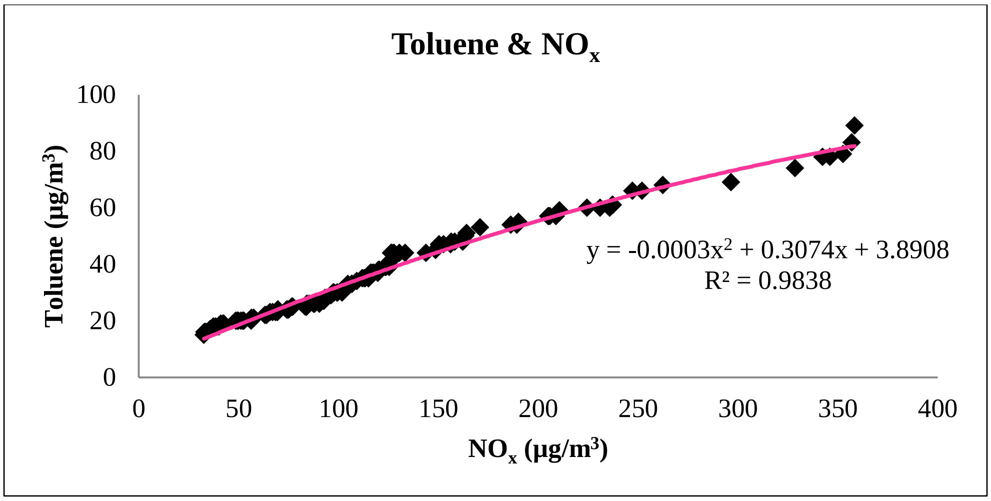


Figure 4.8 Best fit plot between Toluene and NO$_x$ concentrations from 2008 – 2011

Figure 4.8 shows the correlation between toluene and NO$_x$. The best fit equation was in the form of polynomial equation as $y = -3E - 04x^2 + 0.3074x + 3.8908$ with R^2 of 0.9838 (Appendix A).

Table 4.3 Statistical analysis for the 5th - 95th percentiles of ethylbenzene and conventional air monitoring data

Statistics

		Ethyl benzene	**CO**	**NO**	**NO$_2$**	**NO$_x$**
N	Valid	121	121	121	121	121
	Missing	0	0	0	0	0
Percentiles	5	1.20	145.88	5.56	21.69	32.72
	95	7.28	2789.10	271.81	132.28	376.44

Remark: N = number of data

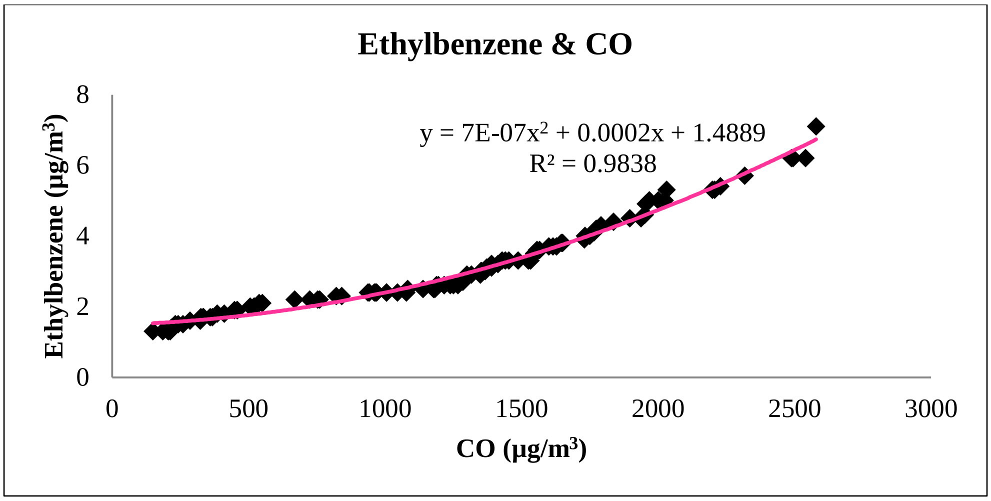


Figure 4.9 Best fit plot between Ethylbenzene and CO concentrations from 2008 – 2011

Figure 4.9 shows the correlation between ethylbenzene and CO. The best fit equation was in the form of polynomial equation as $y = 7E - 07x^2 + 0.0002x + 1.4889$ with R^2 of 0.9838 (Appendix A).

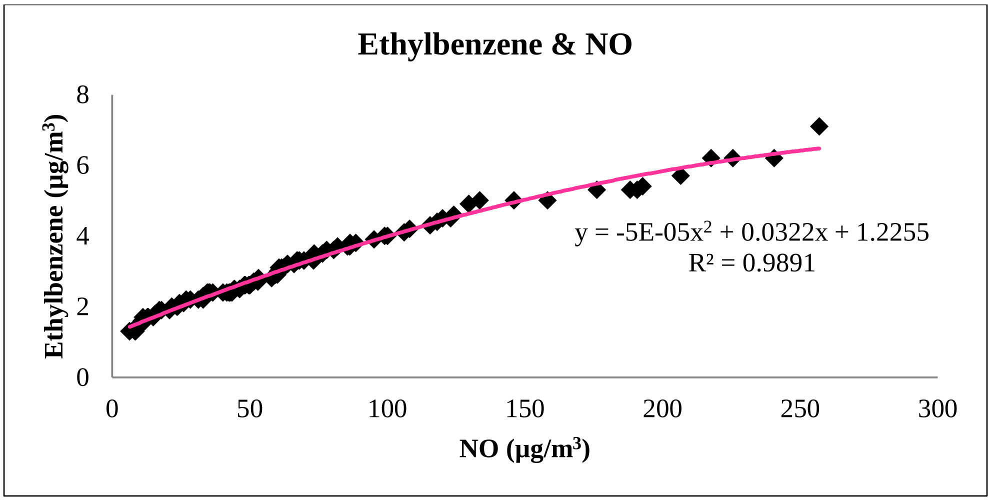


Figure 4.10 Best fit plot between Ethylbenzene and NO concentrations from 2008 – 2011

Figure 4.10 shows the correlation between ethylbenzene and NO. The best fit equation was in the form of polynomial equation as $y = -5E - 05x^2 + 0.0322x + 1.2255$ with R^2 of 0.9891 (Appendix A).

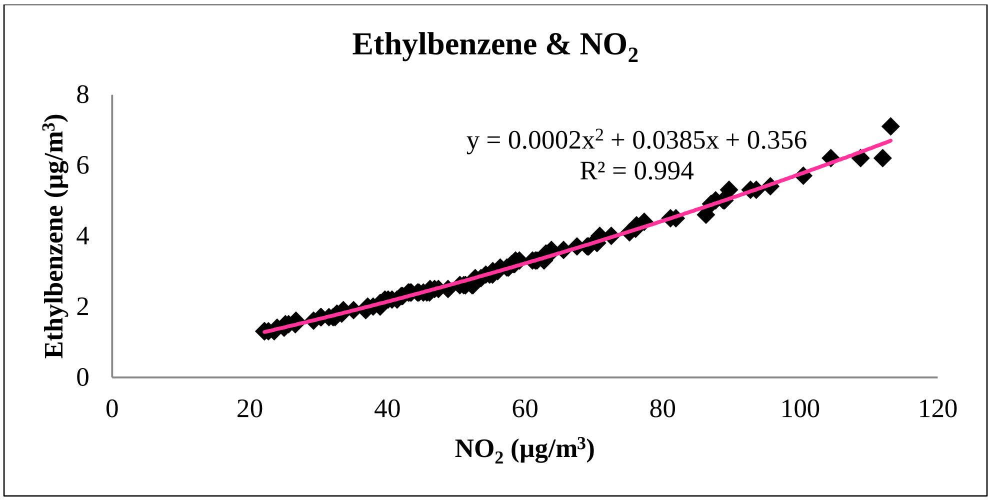


Figure 4.11 Best fit plot between Ethylbenzene and NO_2 concentrations from 2008 – 2011

Figure 4.11 shows the correlation between ethylbenzene and NO_2. The best fit equation was in the form of polynomial equation as

$y = 2E - 04x^2 + 0.0385x + 0.356$ with R^2 of 0.994 (Appendix A).

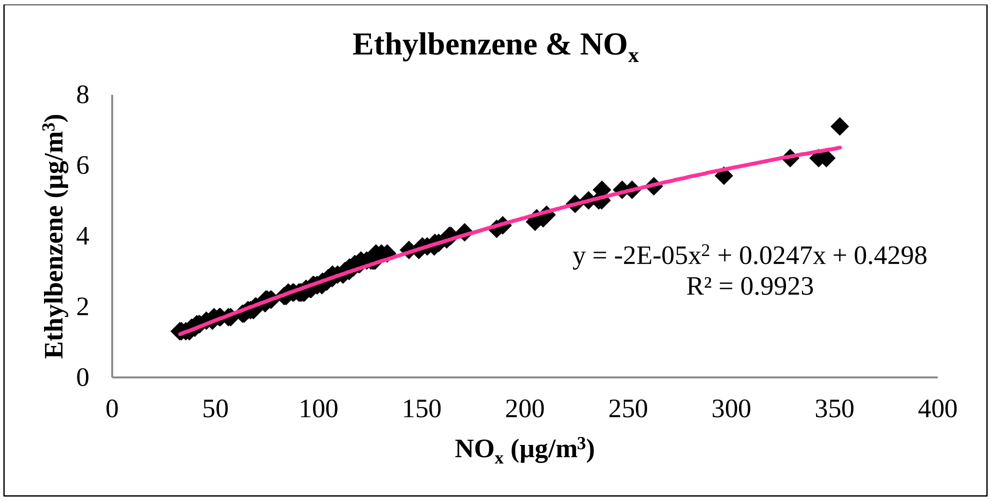


Figure 4.12 Best fit plot between Ethylbenzene and NO_x concentrations from 2008 – 2011

Figure 4.12 shows the correlation between ethylbenzene and NO_x. The best fit equation was in the form of polynomial equation as

$y = -2E - 05x^2 + 0.0247x + 0.4298$ with R^2 of 0.9923 (Appendix A).

Table 4.4 Statistical analysis for the 5th - 95th percentiles of xylene and conventional air monitoring data

Statistics

		Xylene	CO	NO	NO_2	NO_x
N	Valid	123	123	123	123	123
	Missing	0	0	0	0	0
Percentiles	5	3.34	146.32	5.65	21.74	32.74
	95	22.60	2781.69	271.67	131.78	374.45

Remark: N = number of data

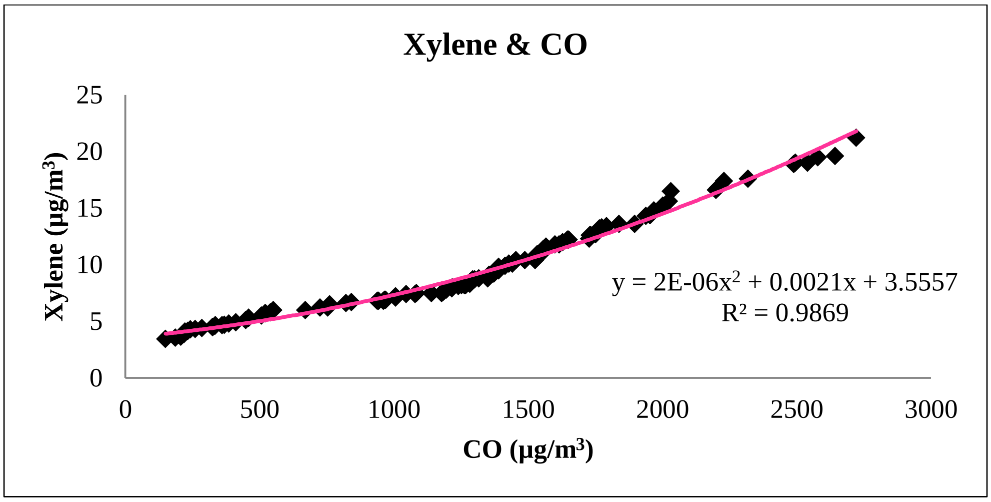


Figure 4.13 Best fit plot between Xylene and CO concentrations from 2008 – 2011

Figure 4.13 shows the correlation between xylene and CO. The best fit equation was in the form of polynomial equation as $y = 2E - 06x^2 + 0.0021x + 3.5557$ with R^2 of 0.9869 (Appendix A).

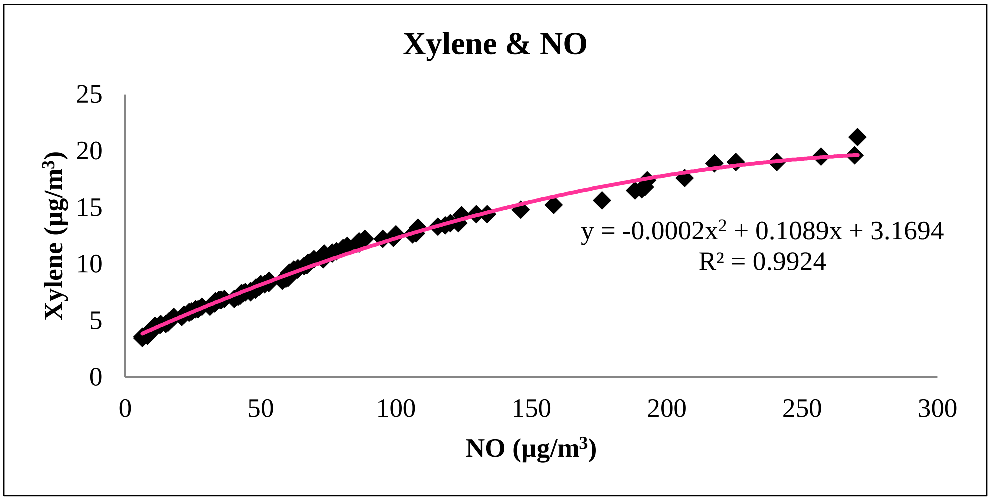


Figure 4.14 Best fit plot between Xylene and NO concentrations from 2008 – 2011

Figure 4.14 shows the correlation between xylene and NO. The best fit equation was in the form of polynomial equation as $y = -2E - 04x^2 + 0.1089x + 3.1694$ with R^2 of 0.9924 (Appendix A).

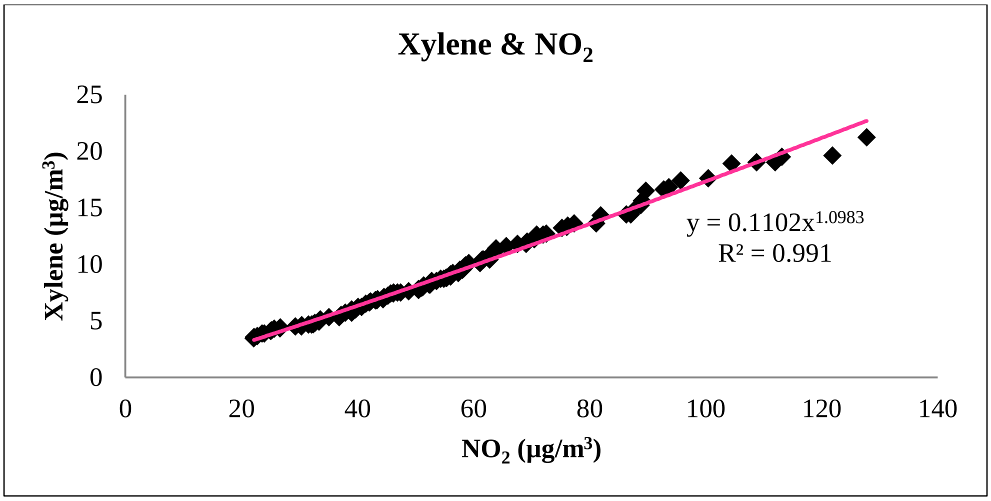


Figure 4.15 Best fit plot between Xylene and NO_2 concentrations from 2008 – 2011

Figure 4.15 shows the correlation between xylene and NO_2. The best fit equation was in the form of power equation as $y = 0.1102x^{1.0983}$ with R^2 of 0.991 (Appendix A).

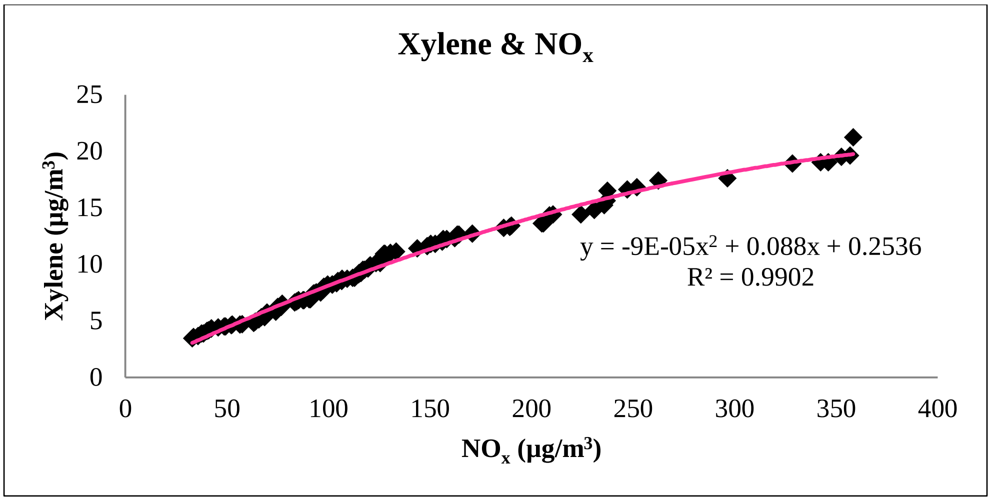


Figure 4.16 Best fit plot between Xylene and NO$_x$ concentrations from 2008 – 2011

Figure 4.16 shows the correlation between xylene and NO$_x$. The best fit equation was in the form of polynomial equation as $y = -9E - 05x^2 + 0.088x + 0.2536$ with R^2 of 0.9902 (Appendix A).

Table 4.5 Statistical analysis for the 5th - 95th percentiles of 1, 3-butadiene and conventional air monitoring data

Statistics

		1, 3-butadiene	**CO**	**NO**	**NO$_2$**	**NO$_x$**
N	Valid	127	127	127	127	127
	Missing	0	0	0	0	0
Percentiles	5	0.005	147.19	5.83	21.84	32.79
	95	1.260	2807.26	275.04	130.78	385.25

Remark: N = number of data

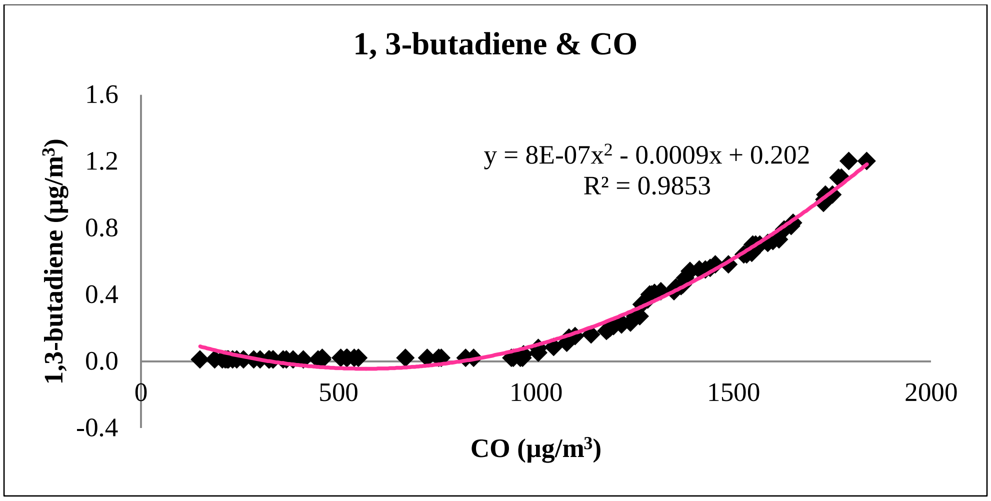


Figure 4.17 Best fit plot between 1, 3-butadiene and CO concentrations from 2008 – 2011

Figure 4.17 shows the correlation between 1, 3-butadiene and CO. The best fit equation was in the form of polynomial equation as $y = 8E - 07x^2 - 0.0009x + 0.202$ with R^2 of 0.9853 (Appendix A).

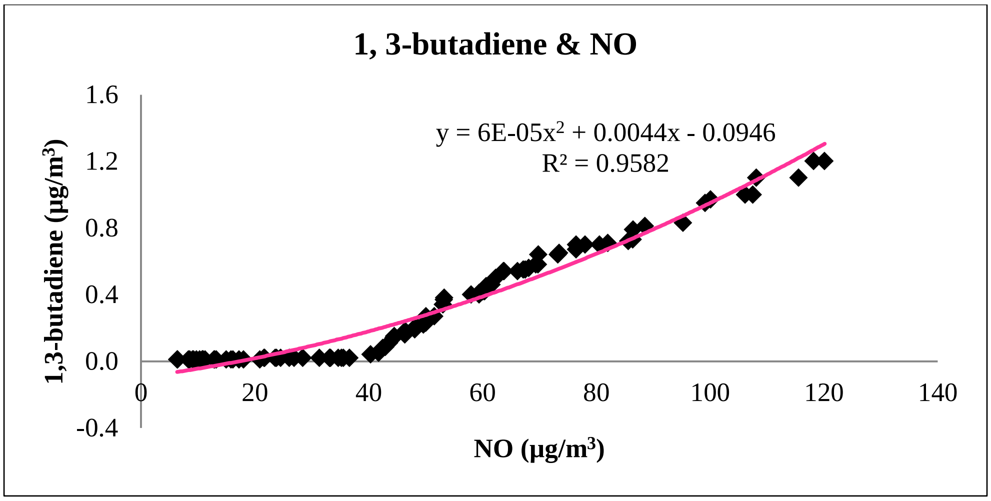


Figure 4.18 Best fit plot between 1, 3-butadiene and NO concentrations from 2008 – 2011

Figure 4.18 shows the correlation between 1, 3-butadiene and NO. The best fit equation was in the form of polynomial equation as $y = 6E - 05x^2 + 0.0044x - 0.0946$ with R^2 of 0.9582 (Appendix A).

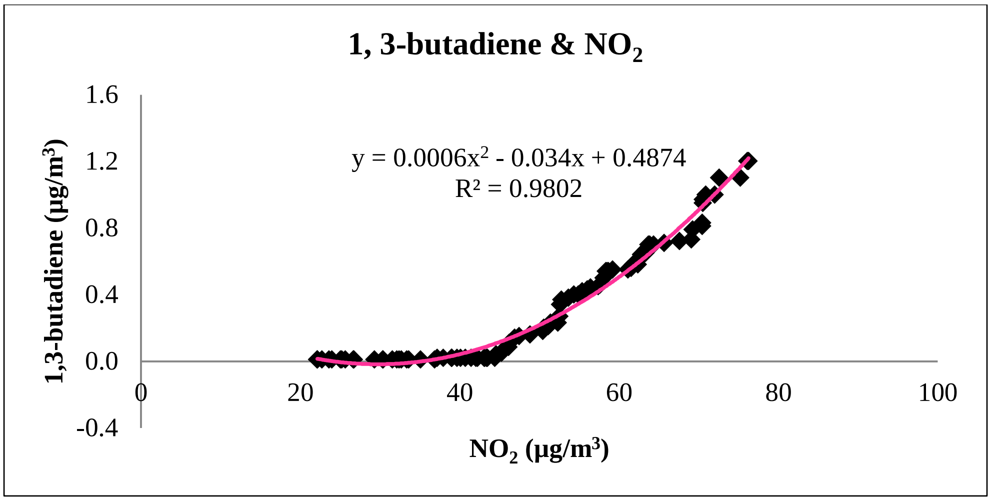


Figure 4.19 Best fit plot between 1, 3-butadiene and NO_2 concentrations from 2008 – 2011

Figure 4.19 shows the correlation between 1, 3-butadiene and NO_2. The best fit equation was in the form of polynomial equation as $y = 6E-04x^2 - 0.034x + 0.4874$ with R^2 of 0.9582 (Appendix A).

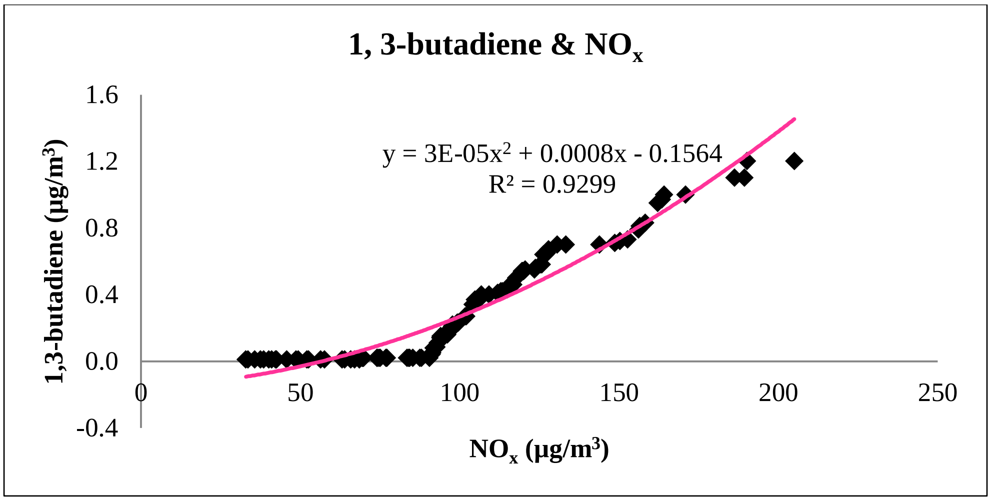


Figure 4.20 Best fit plot between 1, 3-butadiene and NO_x concentrations from 2008 – 2011

Figure 4.20 shows the correlation between 1, 3-butadiene and NO_x. The best fit equation was in the form of polynomial equation as $y = 3E-05x^2 + 0.0008x - 0.1564$ with R^2 of 0.9299 (Appendix A).

It was found that mostly of the best relationship can be described by polynomial equation except the relationship between benzene versus NO and xylene versus NO_2, which the best numerical equation could be described by power equation as shown in Table 4.6.

Table 4.6 Summary of equation used for numerical calculation of VOCs concentration for 2008 - 2011

No.	Air Pollutant	Regression Type (R-Square)	Equation
1	Benzene & CO	Polynomial (R^2 = 0.9839)	$y = 3E-07x^2 + 0.0019x + 1.8898$
2	Benzene & NO	Power (R^2 = 0.9753)	$y = 0.9344x^{0.398}$
3	Benzene & NO_2	Polynomial (R^2 = 0.9861)	$y = -3E-04x^2 + 0.1084x - 0.4432$
4	Benzene & NO_x	Polynomial (R^2 = 0.9717)	$y = -6E-05x^2 + 0.0417x + 0.6653$
5	1, 3-Butadiene & CO	Polynomial (R^2 = 0.9853)	$y = 8E-07x^2 - 0.0009x + 0.202$
6	1, 3-Butadiene & NO	Polynomial (R^2 = 0.9582)	$y = 6E-05x^2 + 0.0044x - 0.0946$
7	1, 3-Butadiene & NO_2	Polynomial (R^2 = 0.9802)	$y = 6E-04x^2 - 0.034x + 0.4874$
8	1, 3-Butadiene & NO_x	Polynomial (R^2 = 0.9299)	$y = 3E-05x^2 + 0.0008x - 0.1564$
9	Toluene & CO	Polynomial (R^2 = 0.9786)	$y = 8E-06x^2 + 0.0035x + 17.433$
10	Toluene & NO	Polynomial (R^2 = 0.9822)	$y = -5E-04x^2 + 0.3892x + 14.357$
11	Toluene & NO_2	Polynomial (R^2 = 0.9814)	$y = 2.5E-03x^2 + 0.4322x + 3.6531$
12	Toluene & NO_x	Polynomial (R^2 = 0.9838)	$y = -3E-04x^2 + 0.3074x + 3.8908$

Table 4.6 Summary of equation used for numerical calculation of VOCs concentration for 2008 – 2011 (Cont.)

No.	Air Pollutant	Regression Type (R-Square)	Equation
13	Ethylbenzene & CO	Polynomial ($R^2 = 0.9838$)	$y = 7E - 07x^2 + 0.0002x + 1.4889$
14	Ethylbenzene & NO	Polynomial ($R^2 = 0.9891$)	$y = -5E - 05x^2 + 0.0322x + 1.2255$
15	Ethylbenzene & NO_2	Polynomial ($R^2 = 0.9940$)	$y = 2E - 04x^2 + 0.0385x + 0.356$
16	Ethylbenzene & NO_x	Polynomial ($R^2 = 0.9923$)	$y = -2E - 05x^2 + 0.0247x + 0.4298$
17	Xylene & CO	Polynomial ($R^2 = 0.9869$)	$y = 2E - 06x^2 + 0.0021x + 3.5557$
18	Xylene & NO	Polynomial ($R^2 = 0.9924$)	$y = -2E - 04x^2 + 0.1089x + 3.1694$
19	Xylene & NO_2	Power ($R^2 = 0.9910$)	$y = 0.1102x^{1.0983}$
20	Xylene & NO_x	Polynomial ($R^2 = 0.9902$)	$y = -9E - 05x^2 + 0.088x + 0.2536$

4.2 Statistical analysis to formulate an equation for predicting BTEX and 1, 3-butadiene from 2008 - 2011

The 5th - 95th percentile of benzene and conventional air pollutants data from 2008 – 2011 were used to formulate an equation by using the Statistical Package for Social Science (SPSS) version 18. Results were as shown in Table 4.7. It was found that model 3 in which NO_2, CO and NO were used in calculation could provide the best fit regression equation.

Table 4.7 Regression of benzene and conventional air monitoring data

Model		Unstandardized Coefficients B	Unstandardized Coefficients Std. Error	Standardized Coefficients Beta	t	Sig.
1	(Constant)	-0.171	0.059		-2.88	0.005
	NO_2	1.067	0.012	0.993	87.62	0.000
2	(Constant)	-0.057	0.057		-0.99	0.320
	NO_2	0.597	0.088	0.555	6.78	0.000
	CO	0.424	0.079	0.441	5.39	0.000
3	(Constant)	-0.053	0.056		-0.94	0.346
	NO_2	0.792	0.112	0.737	7.06	0.000
	CO	0.550	0.090	0.572	6.13	0.000
	NO	-0.320	0.119	-0.313	-2.69	0.008

Coefficients[a]

a. Dependent Variable: Benzene

From this table, an equation for predicting benzene concentration can be written as;

$$Benzene = -0.053 + 0.792NO_2 + 0.550CO - 0.320NO$$

Substituted NO_2, CO and NO by using the data from Table 4.6; therefore

$$\begin{aligned} Benzene = {} & -0.053 + [0.792(-3E-04x^2) + (0.1084x) - 0.4432] + \\ & [0.550(3E-07x^2) + (0.0019x) + 1.8898] - [0.320(0.9344x^{0.398})] \end{aligned}$$

$$\begin{aligned} Benzene = {} & (-2.376E-04x^2 + 0.0858x - 0.298) + \\ & (1.65E-07x^2 + 1.045E-03x + 0.986) - (0.299x^{0.398}) \end{aligned}$$

The final equation, used to predict benzene concentration was expressed as

$$\begin{aligned} Benzene = {} & [-2.376E-04(NO_2)^2 + 0.0858(NO_2) - 0.298] + \\ & [1.65E-07(CO)^2 + 1.045E-03(CO) + 0.986] - [0.299(NO)^{0.398}] \end{aligned}$$

Where: concentration used in calculation is in µg/m^3

From this equation, a Quantile-Quantile plot (Q-Q plot) of observed and predicted benzene concentration was illustrated in Figure 4.21. It was found that predicted data were well agree with those observed data (R^2 = 0.9896).

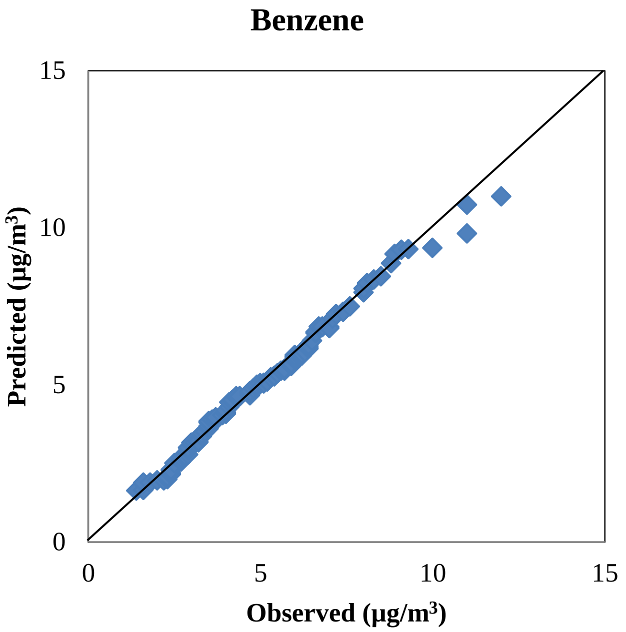


Figure 4.21 Comparison between observed and predicted benzene data from 2008 – 2011

The 5th - 95th percentile of toluene and conventional air pollutants data from 2008 – 2011 were used to formulate an equation by using the SPSS version 18. Results were as shown in Table 4.8. It was found that model 2 in which NO_x and CO were used in calculation could provide the best fit regression equation.

Table 4.8 Regression of toluene and conventional air monitoring data

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-1.936	0.522		-3.71	0.000
	NO_x	1.084	0.013	0.991	81.10	0.000
2	(Constant)	-1.575	0.447		-3.52	0.001
	NO_x	0.627	0.069	0.574	9.11	0.000
	CO	0.438	0.065	0.423	6.72	0.000

Coefficients[a]

a. Dependent Variable: Toluene

From this table, an equation for predicting toluene concentration can be written as;

$$Toluene = -1.575 + 0.627NO_x + 0.438CO$$

Substituted NO_x and CO by using the data from Table 4.6; therefore

$$\begin{aligned} Toluene = -1.575 + [0.627(-3E-04x^2) + (0.3074x) + 3.8908] + \\ [0.438(8E-06x^2) + (0.0035x) + 17.433] \end{aligned}$$

$$\begin{aligned} Toluene = -1.575 + (-1.881E-04x^2 + 0.1927x + 2.4395) + \\ (3.504E-06x^2 + 1.533E-03x + 7.6356) \end{aligned}$$

The final equation, used to predict toluene concentration was expressed as

$$\begin{aligned} Toluene = [-1.881E-04(NO_x)^2 + 0.1927(NO_x) + 0.8645] + \\ [3.504E-06(CO)^2 + 1.533E-03(CO) + 6.0606] \end{aligned}$$

Where: concentration used in calculation is in µg/m^3

From this equation, a Q-Q plot of observed and predicted toluene concentration was illustrated in Figure 4.22. It was found that predicted data were well agree with those observed data (R^2 = 0.9499). At high concentration model provide under predicted data.

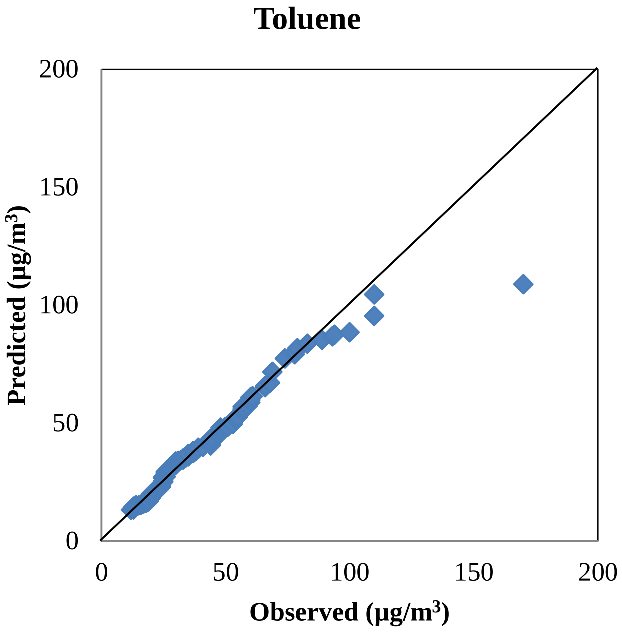


Figure 4.22 Comparison between observed and predicted toluene data from 2008 – 2011

The 5th - 95th percentile of ethylbenzene and conventional air pollutants data from 2008 – 2011 were used to formulate an equation by using the SPSS version 18. Results were as shown in Table 4.9. It was found that model 3 in which NO_2, NO and NO_x were used in calculation could provide the best fit regression equation.

Table 4.9 Regression of ethylbenzene and conventional air monitoring data

Coefficients[a]						
Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	0.129	0.024		5.30	0.000
	NO_2	0.910	0.007	0.997	130.54	0.000
2	(Constant)	0.071	0.029		2.45	0.016
	NO_2	0.690	0.067	0.756	10.36	0.000
	NO	0.253	0.076	0.242	3.32	0.001
3	(Constant)	0.057	0.029		1.96	0.053
	NO_2	0.492	0.103	0.539	4.78	0.000
	NO	0.209	0.076	0.200	2.73	0.007
	NO_x	0.254	0.103	0.259	2.47	0.015

a. Dependent Variable: Ethylbenzene

From this table, an equation for predicting ethylbenzene concentration can be written as;

$$Ethylbenzene = 0.057 + 0.492NO_2 + 0.209NO + 0.254NO_x$$

Substituted NO_2, NO and NO_x by using the data from Table 4.6; therefore

$$\begin{aligned} Ethylbenzene = 0.057 &+ [0.492(2E-04x^2) + (0.0385x) + 0.356] + \\ &[0.209(-5E-05x^2) + (0.0322x) + 1.2255] + \\ &[0.254(-2E-05x^2) + (0.0247x) + 0.4298 \end{aligned}$$

$$\begin{aligned} Ethylbenzene = 0.057 + (9.84E-05x^2 + 0.0189x + 0.1751) - \\ (1.045E-05x^2 + 6.7298E-03x + 0.2561) - \\ (5.08E-06x^2 + 6.273E-03x + 0.1091) \end{aligned}$$

The final equation, used to predict ethylbenzene concentration was expressed as

$$\begin{aligned} Ethylbenzene = [9.84E-05(NO_2)^2 + 0.0189(NO_2) + 0.2321] - \\ [1.045E-05(NO)^2 + 16.7298E-03(NO) + 0.3131] - \\ [5.08E-06(NO_x)^2 + 6.2738E-03(NO_x) + 0.1661] \end{aligned}$$

Where: concentration used in calculation is in µg/m^3

From this equation, a Q-Q plot of observed and predicted ethylbenzene concentration was illustrated in Figure 4.23. It was found that predicted data were well agree with those observed data ($R^2 = 0.9917$).

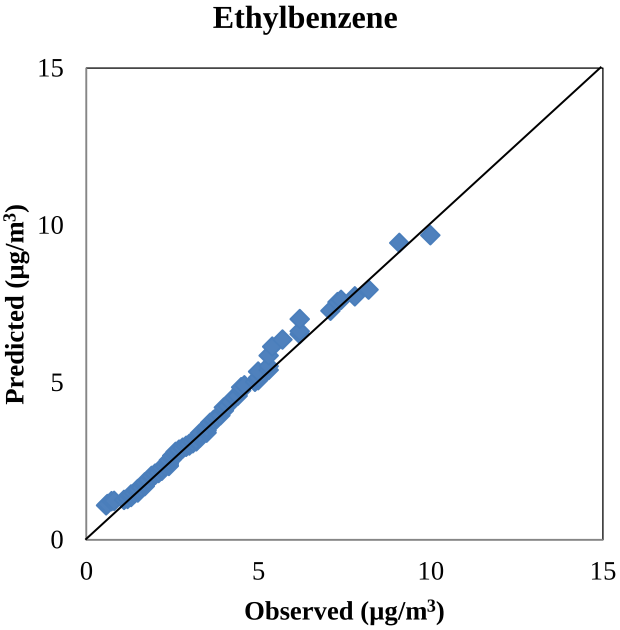


Figure 4.23 Comparison between observed and predicted ethylbenzene data from 2008 – 2011

The 5th - 95th percentile of xylene and conventional air pollutants data from 2008 – 2011 were used to formulate an equation by using the SPSS version 18. Results were as shown in Table 4.10. It was found that model 3 in which NO, NO_2 and CO were used in calculation could provide the best fit regression equation.

Table 4.10 Regression of xylene and conventional air monitoring data

Coefficients[a]						
Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-0.495	0.101		-4.89	0.000
	NO	1.076	0.010	0.995	106.84	0.000
2	(Constant)	-0.315	0.067		-4.69	0.000
	NO	0.562	0.042	0.519	13.26	0.000
	NO_2	0.485	0.039	0.482	12.30	0.000
3	(Constant)	-0.230	0.074		-3.12	0.002
	NO	0.531	0.043	0.491	12.30	0.000
	NO_2	0.360	0.063	0.357	5.72	0.000
	CO	0.137	0.055	0.153	2.51	0.013

a. Dependent Variable: Xylene

From this table, an equation for predicting xylene concentration can be written as;

$$Xylene = -0.230 + 0.531NO + 0.360NO_2 + 0.137CO$$

Substituted NO, NO_2 and CO by using the data from Table 4.6; therefore

$$\begin{aligned} Xylene = {} & -0.23 + [0.531(2E-04x^2) + (0.1089x) + 3.1694] + \\ & [0.36(0.1102)x^{1.0983}] + [0.137(2E-06x^2) + (0.0021x) + 3.5557] \end{aligned}$$

$$\begin{aligned} Xylene = {} & -0.23 + (1.062E-04x^2 + 0.0578x + 1.6829) + \\ & (0.0396x^{1.0983}) + (2.74E-07x^2 + 2.877E-04x + 0.4871) \end{aligned}$$

The final equation, used to predict xylene concentration was expressed as

$$Xylene = [1.062E-04(NO)^2 + 0.0578(NO) + 1.4529] + \\ [0.0396(NO_2)^{1.0983}] + [2.74E-07(CO)^2 + 2.877E-04(CO) + 0.2571]$$

Where: concentration used in calculation is in µg/m^3

From this equation, a Q-Q plot of observed and predicted xylene concentration was illustrated in Figure 4.24. It was found that predicted data were well agree with those observed data ($R^2 = 0.9344$). At high concentration model provide under predicted data.

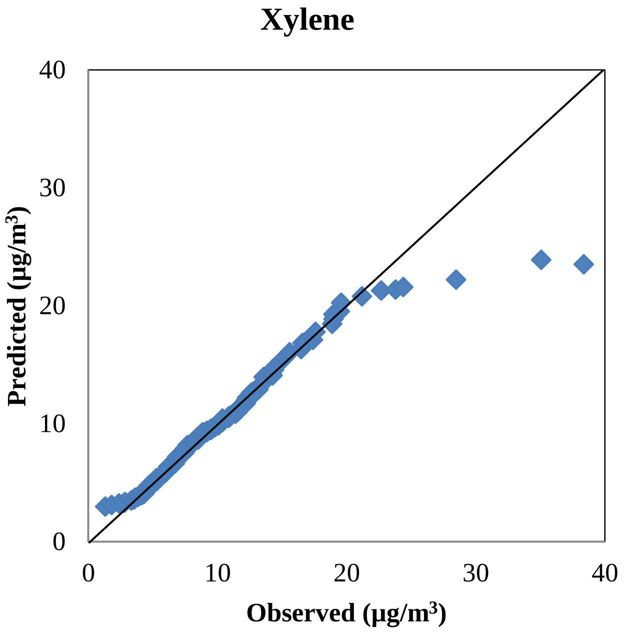


Figure 4.24 Comparison between observed and predicted xylene data from 2008 – 2011

The 5th - 95th percentile of 1, 3-butadiene and conventional air pollutants data from 2008 – 2011 were used to formulate an equation by using the SPSS version 18. Results were as shown in Table 4.11. It was found that model 2 in which CO and NO_X were used in calculation could provide the best fit regression equation.

Table 4.11 Regression of 1, 3-butadiene and conventional air monitoring data

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	0.004	0.006		0.63	0.525
	CO	0.939	0.012	0.993	79.12	0.000
2	(Constant)	-0.054	0.017		-3.25	0.002
	CO	0.800	0.039	0.845	20.25	0.000
	NO_x	0.181	0.049	0.154	3.68	0.000

a. Dependent Variable: 1, 3-butadiene

From this table, an equation for predicting 1, 3-butadiene concentration can be written as;

$$1,3-Butadiene = -0.054 + 0.800CO + 0.181NO_x$$

Substituted CO and NO_x by using the data from Table 4.6; therefore

$$\begin{aligned}1,3-Butadiene = {} & -0.054 + [0.80(8E-07x^2) - (0.0009x) + 0.202] + \\ & [0.181(3E-05x^2) + (0.0008x) - 0.1564]\end{aligned}$$

$$\begin{aligned}1,3-Butadiene = {} & -0.054 + (6.4E-07x^2 - 7.2E-04x + 0.1616) + \\ & (5.43E-06x^2 + 0.1818x - 0.0283)\end{aligned}$$

The final equation, used to predict 1, 3-butadiene concentration was expressed as

$$\begin{aligned}1,3-Butadiene = {} & [6.4E-07(CO)^2 - 7.2E-04(CO) + 0.1076] + \\ & [5.43E-06(NO_x)^2 + 0.1818(NO_x) - 0.0823]\end{aligned}$$

Where: concentration used in calculation is in µg/m^3

From this equation, a Q-Q plot of observed and predicted 1, 3-butadiene concentration was illustrated in Figure 4.25. It was found that the model provided over-estimation results as comparing with those observed data. These results could be described by low concentration of observed 1, 3-butadiene data which made it difficult to evaluate relationship of this compound with other pollutants.

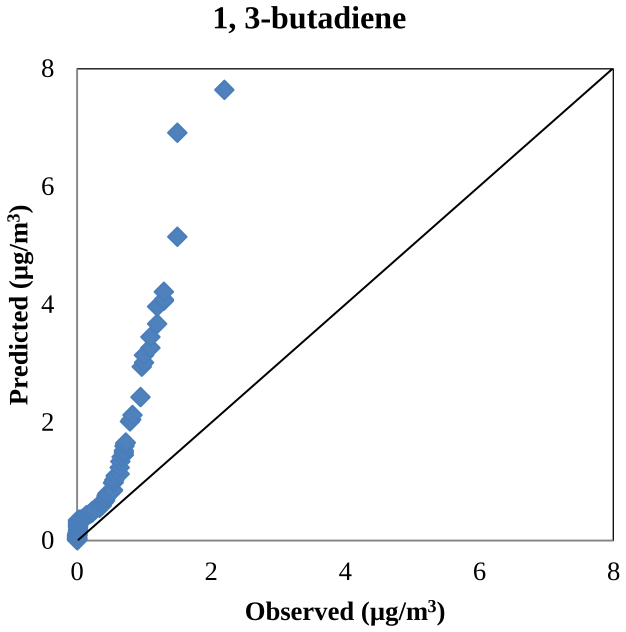


Figure 4.25 Comparison between observed and predicted 1, 3-butadiene data from 2008 – 2011

4.3 Numerical analysis (Air pollution monitoring data from 2012 – 2013)

Conventional air pollutants BTEX and 1, 3-butadiene monitoring data were treated as described in Chapter 3. The 5th - 95th percentiles of BTEX, 1, 3-butadiene and conventional air monitoring data (CO, NO, NO_2 and NO_x) from 2012 – 2013 were shown in Tables 4.12 to 4.16. These data were used to evaluate relationship between pair of air pollutants. The best fit plots between two pollutants were chosen taking into consideration highest value of correlation, obtained from each numerical equation. Results as shown in Figure 4.26 to 4.41, respectively.

Table 4.12 Statistical analysis for the 5th - 95th percentiles of benzene and conventional air monitoring data

Statistics

		Benzene	**CO**	**NO**	**NO_2**	**NO_x**
N	Valid	48	48	48	48	48
	Missing	0	0	0	0	0
Percentiles	5	1.19	136.43	2.57	12.04	17.11
	95	8.40	2509.20	303.33	149.83	454.25

Remark: N = number of data

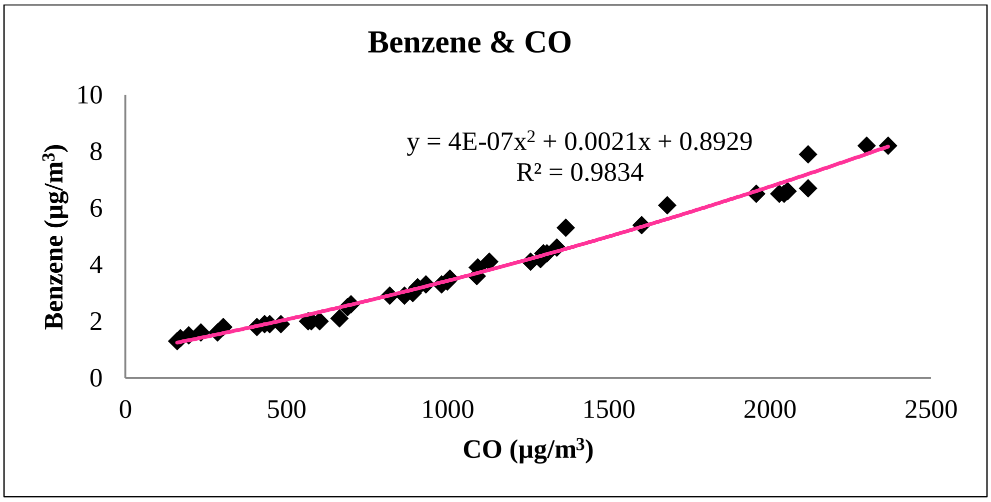


Figure 4.26 Best fit plot between Benzene and CO concentrations from 2012 – 2013

Figure 4.26 shows the correlation between benzene and CO. The best fit equation was in the form of polynomial equation as $y = 4E - 07x^2 + 0.0021x + 0.8929$ with R^2 of 0.9834 (Appendix B).

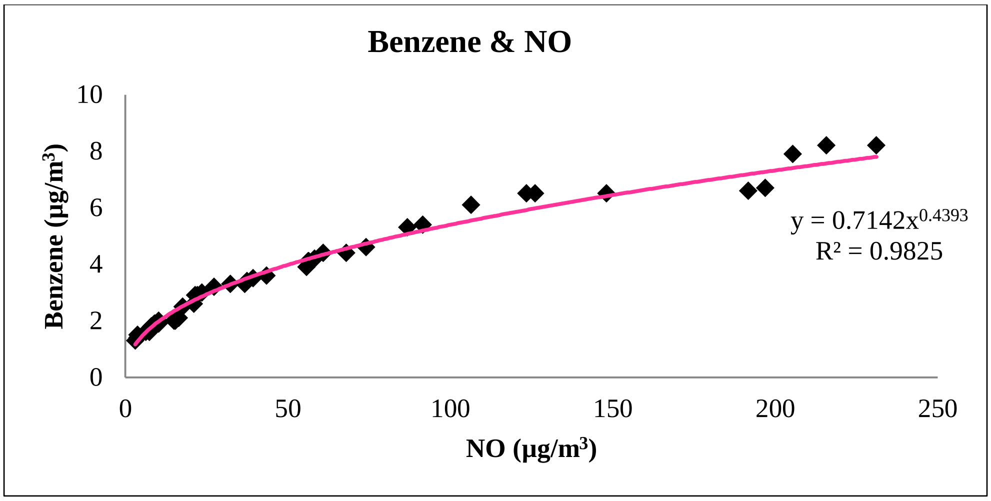


Figure 4.27 Best fit plot between Benzene and NO concentrations from 2012 – 2013

Figure 4.27 shows the correlation between benzene and NO. The best fit equation was in the form of power equation as $y = 0.7142x^{0.4393}$ with R^2 of 0.9825 (Appendix B).

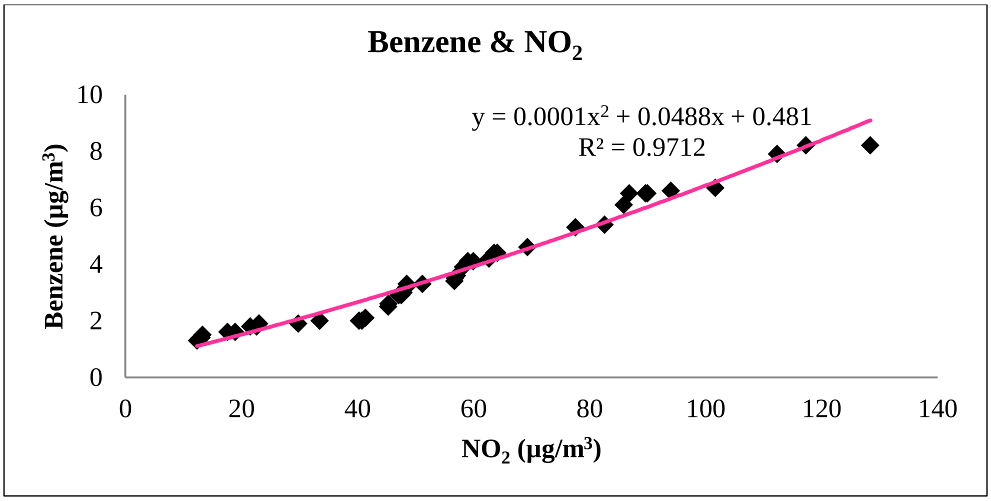


Figure 4.28 Best fit plot between Benzene and NO_2 concentrations from 2012 – 2013

Figure 4.28 shows the correlation between benzene and NO_2. The best fit equation was in the form of polynomial equation as $y = 1E - 04x^2 + 0.0488x + 0.481$ with R^2 of 0.9712 (Appendix B).

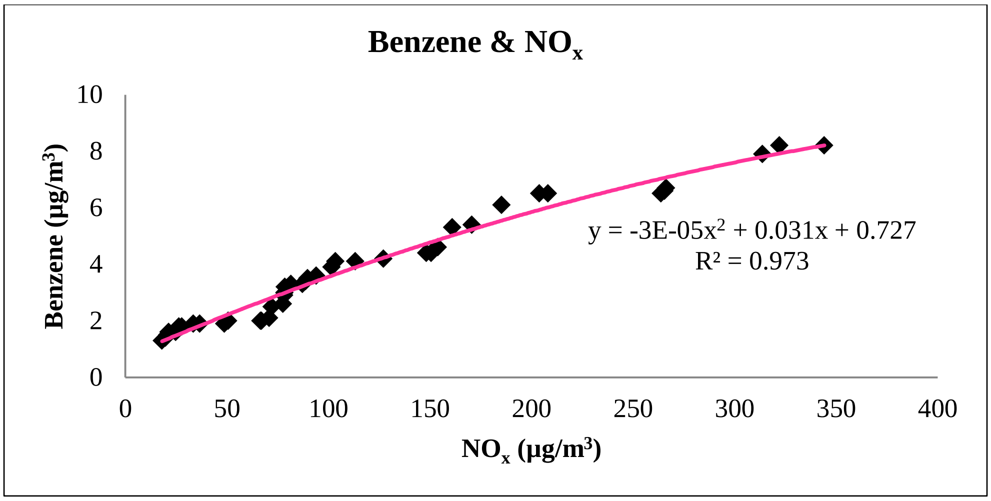


Figure 4.29 Best fit plot between Benzene and NO$_x$ concentrations from 2012 – 2013

Figure 4.29 shows the correlation between benzene and NO$_x$. The best fit equation was in the form of polynomial equation as $y = -3E - 05x^2 + 0.031x + 0.727$ with R^2 of 0.973 (Appendix B).

Table 4.13 Statistical analysis for the 5th - 95th percentiles of toluene and conventional air monitoring data

Statistics

		Toluene	**CO**	**NO**	**NO$_2$**	**NO$_x$**
N	Valid	47	47	47	47	47
	Missing	0	0	0	0	0
Percentiles	5	18.00	134.20	2.53	12.02	17.02
	95	98.00	2513.29	305.18	151.61	454.71

Remark: N = number of data

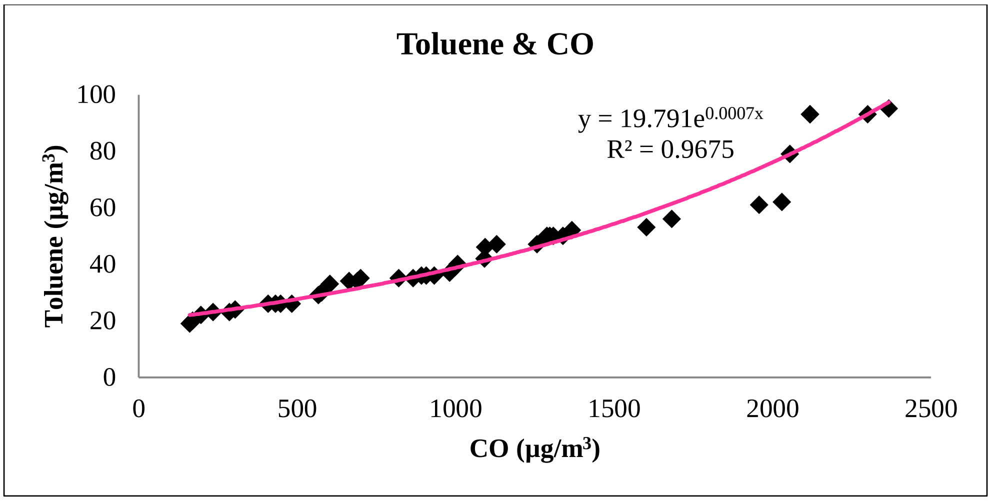


Figure 4.30 Best fit plot between Toluene and CO concentrations from 2012 – 2013

Figure 4.30 shows the correlation between toluene and CO. The best fit equation was in the form of exponential equation as $y = 19.791e^{0.0007x}$ with R^2 of 0.9675 (Appendix B).

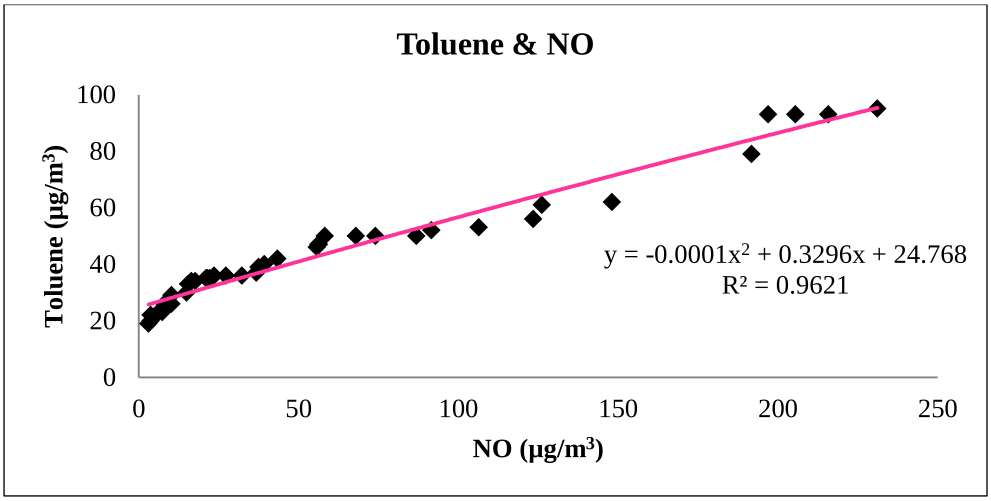


Figure 4.31 Best fit plot between Toluene and NO concentrations from 2012 – 2013

Figure 4.31 shows the correlation between toluene and NO. The best fit equation was in the form of polynomial equation as

$y = -1E - 04x^2 + 0.3296x + 24.768$ with R^2 of 0.9621 (Appendix B).

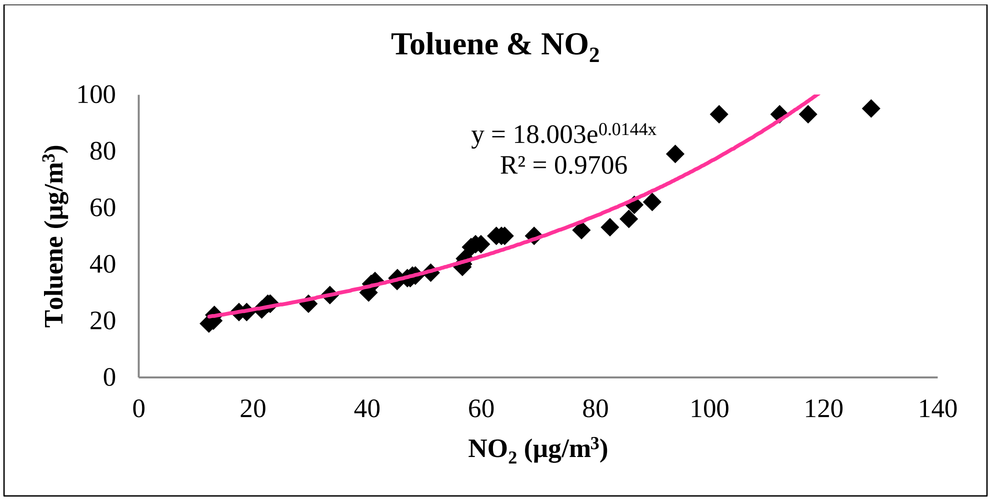


Figure 4.32 Best fit plot between Toluene and NO_2 concentrations from 2012 – 2013

Figure 4.32 shows the correlation between toluene and NO_2. The best fit equation was in the form of exponential equation as $y = 18.003e^{0.0144x}$ with R^2 of 0.9706 (Appendix B).

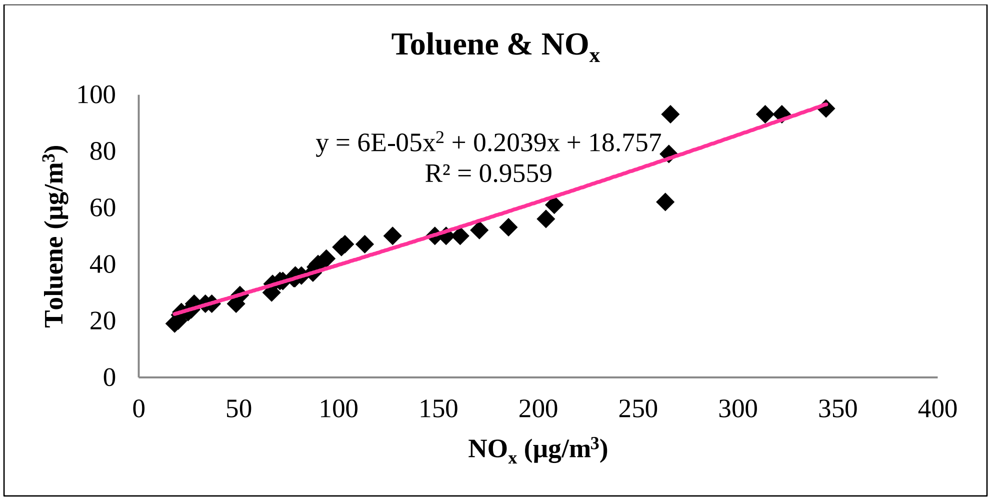


Figure 4.33 Best fit plot between Toluene and NO_x concentrations from 2012 – 2013

Figure 4.33 shows the correlation between toluene and NO_x. The best fit equation was in the form of polynomial equation as $y = 6E - 05x^2 + 0.2039x + 18.757$ with R^2 of 0.9559 (Appendix B).

Table 4.14 Statistical analysis for the 5th - 95th percentiles of ethylbenzene and conventional air monitoring data

Statistics

		Ethyl benzene	**CO**	**NO**	**NO_2**	**NO_x**
N	Valid	45	45	45	45	45
	Missing	0	0	0	0	0
Percentiles	5	1.59	129.72	2.44	11.96	16.85
	95	10.70	2521.47	308.88	155.15	455.64

Remark: N = number of data

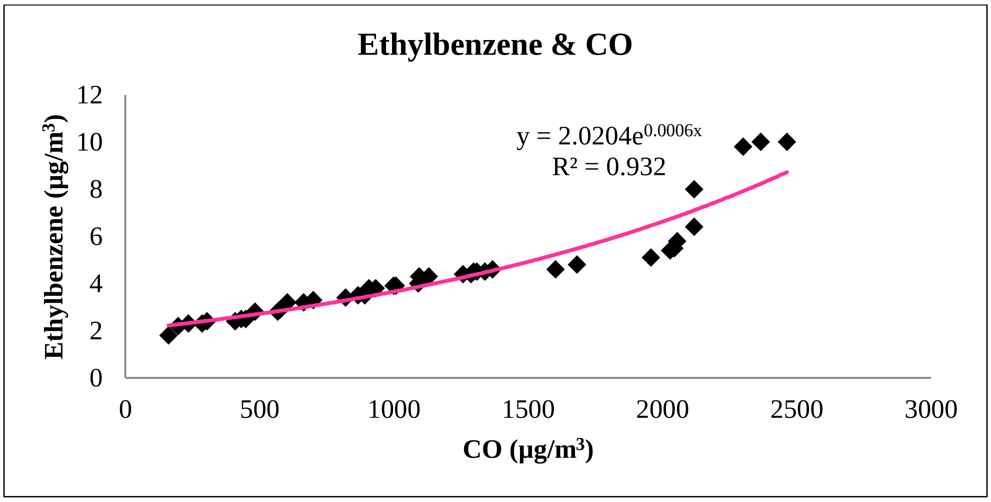


Figure 4.34 Best fit plot between Ethylbenzene and CO concentrations from 2012 – 2013

Figure 4.34 shows the correlation between ethylbenzene and CO. The best fit equation was in the form of exponential equation as $y = 2.0204e^{0.0006x}$ with R^2 of 0.932 (Appendix B).

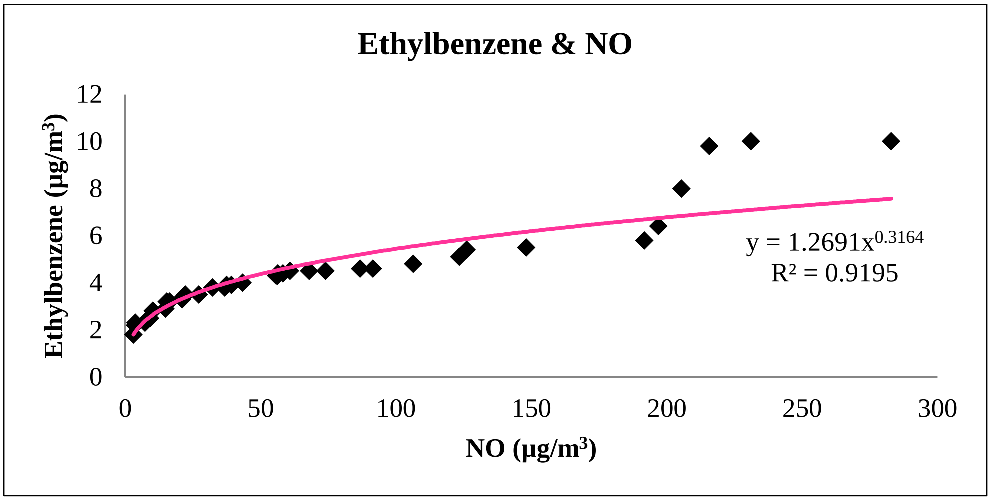


Figure 4.35 Best fit plot between Ethylbenzene and NO concentrations from 2012 – 2013

Figure 4.35 shows the correlation between ethylbenzene and NO. The best fit equation was in the form of power equation as $y = 0.1102x^{1.0983}$ with R^2 of 0.9195 (Appendix B).

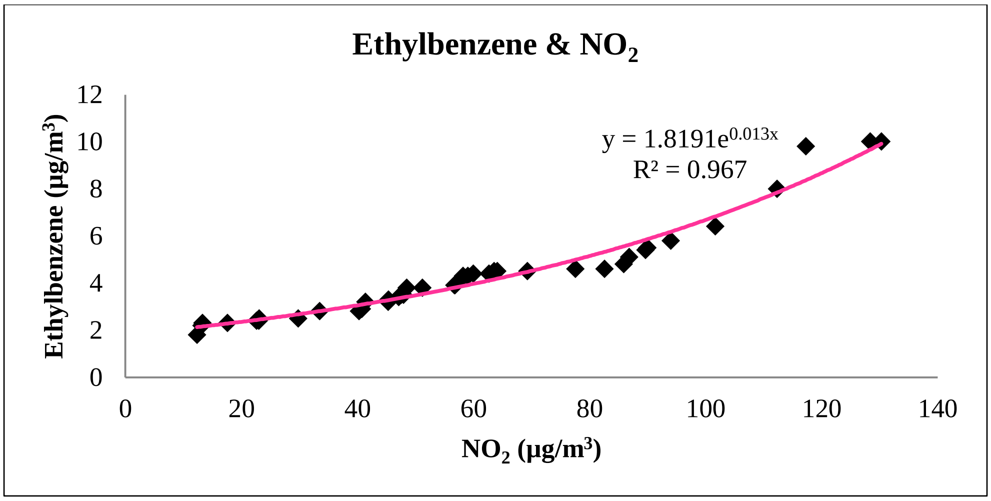


Figure 4.36 Best fit plot between Ethylbenzene and NO_2 concentrations from 2012 – 2013

Figure 4.36 shows the correlation between ethylbenzene and NO_2. The best fit equation was in the form of exponential equation as $y = 1.8191e^{0.013x}$ with R^2 of 0.967 (Appendix B).

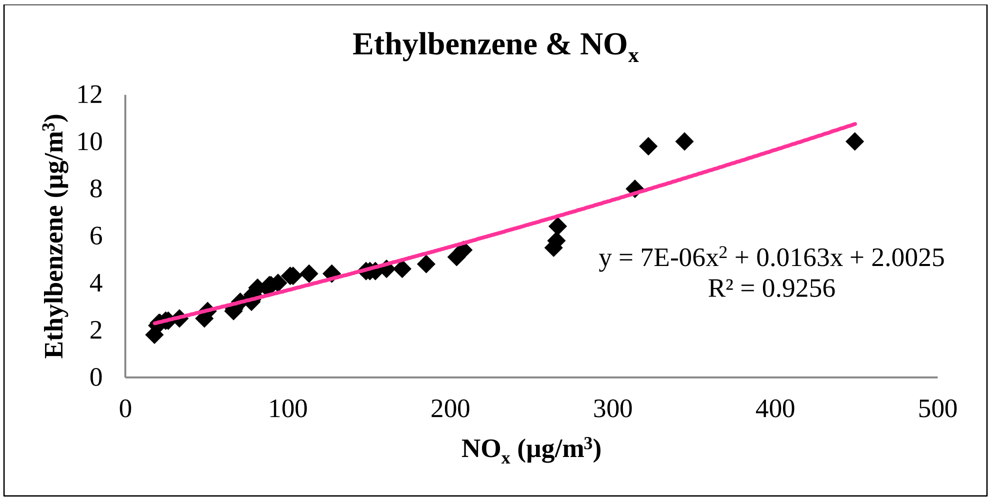


Figure 4.37 Best fit plot between Ethylbenzene and NO$_x$ concentrations from 2012 – 2013

Figure 4.37 shows the correlation between ethylbenzene and NO$_x$. The best fit equation was in the form of polynomial equation as $y = 7E - 06x^2 + 0.0163x + 2.0025$ with R^2 of 0.9256 (Appendix B).

Table 4.15 Statistical analysis for the 5th - 95th percentiles of Xylene and conventional air monitoring data

Statistics

		Xylene	**CO**	**NO**	**NO$_2$**	**NO$_x$**
N	Valid	48	48	48	48	48
	Missing	0	0	0	0	0
Percentiles	5	3.10	136.43	2.57	12.04	17.11
	95	19.84	2509.20	303.33	149.83	454.25

Remark: N = number of data

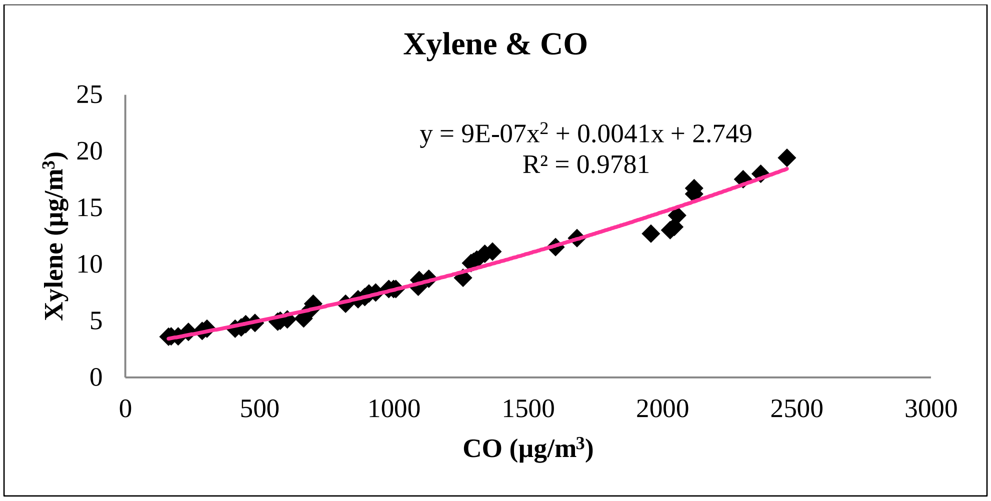


Figure 4.38 Best fit plot between Xylene and CO concentrations from 2012 – 2013

Figure 4.38 shows the correlation between xylene and CO. The best fit equation was in the form of polynomial equation as $y = 9E - 07x^2 + 0.0041x + 2.749$ with R^2 of 0.9781 (Appendix B).

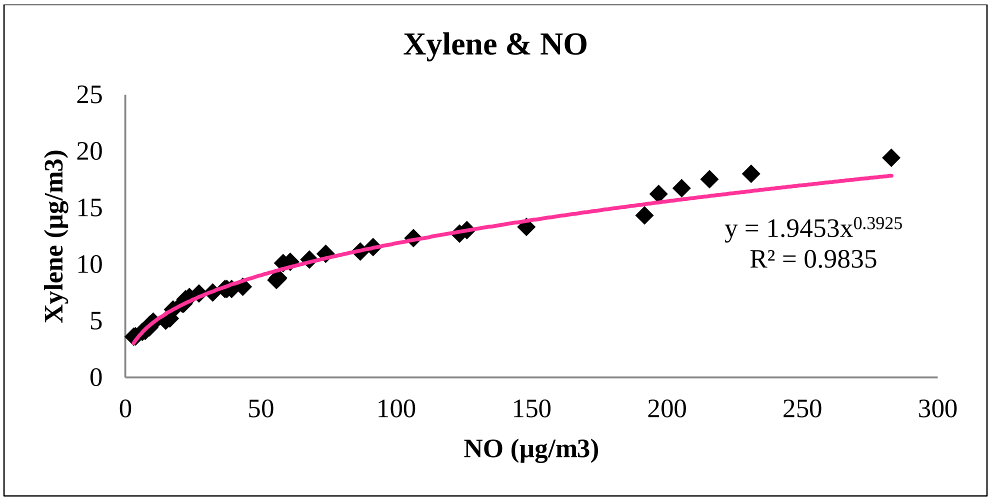


Figure 4.39 Best fit plot between Xylene and NO concentrations from 2012 – 2013

Figure 4.39 shows the correlation between xylene and NO. The best fit equation was in the form of power equation as $y = 0.1102x^{1.0983}$ with R^2 of 0.9835 (Appendix B).

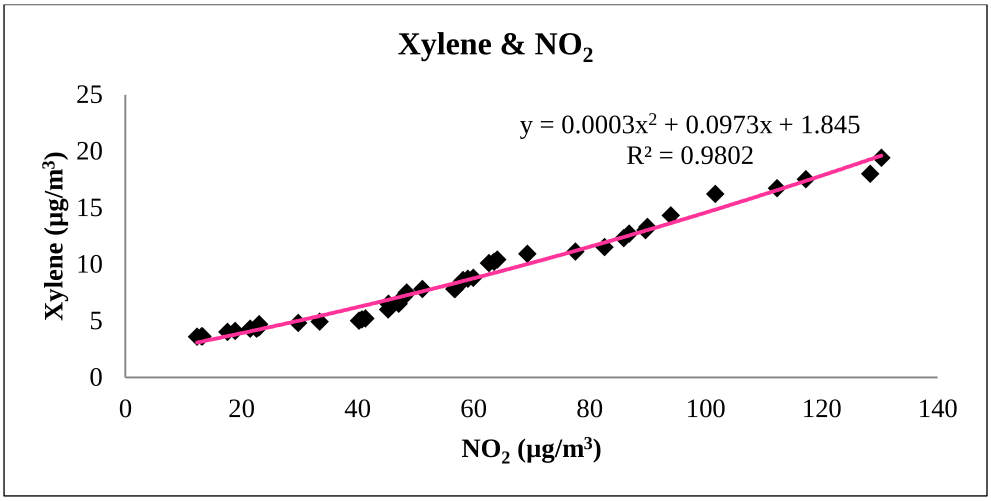


Figure 4.40 Best fit plot between Xylene and NO_2 concentrations from 2012 – 2013

Figure 4.40 shows the correlation between xylene and NO_2. The best fit equation was in the form of polynomial equation as $y = 3E - 04x^2 + 0.0973x + 1.845$ with R^2 of 0.9802 (Appendix B).

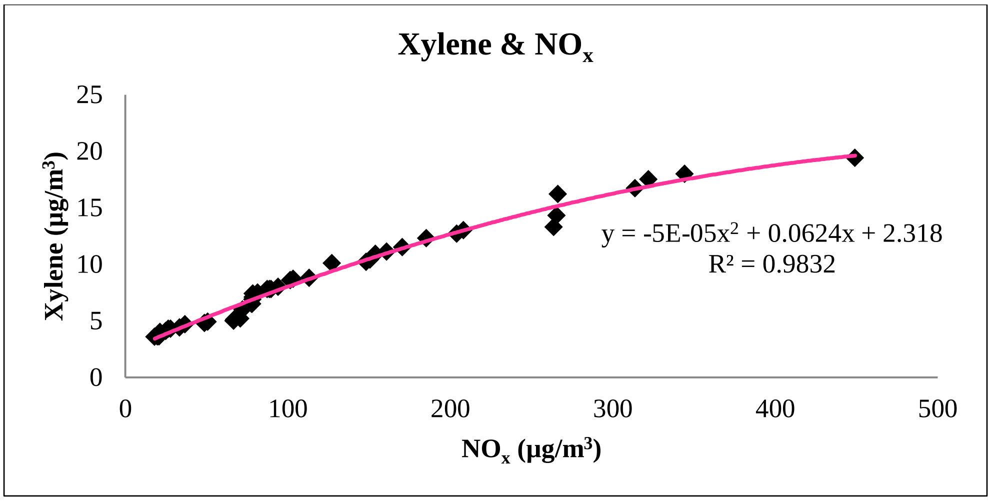


Figure 4.41 Best fit plot between Xylene and NO_x concentrations from 2012 – 2013

Figure 4.41 shows the correlation between xylene and NO_x. The best fit equation was in the form of polynomial equation as $y = -5E - 05x^2 + 0.0624x + 2.318$ with R^2 of 0.9832 (Appendix B).

Table 4.16 Statistical analysis for 5th - 95th percentiles of 1, 3-butadiene and conventional air monitoring data

Statistics

		1, 3-butadiene	**CO**	**NO**	**NO_2**	**NO_x**
N	Valid	48	48	48	48	48
	Missing	0	0	0	0	0
Percentiles	5	0.005	136.48	2.57	12.04	17.11
	95	0.015	2509.20	303.33	149.83	454.25

Remark: N = number of data

It was found that mostly of the best relationship can be described by polynomial and exponential equation except the relationship between benzene versus NO, ethylbenzene versus NO and xylene versus NO which the best numerical equation could be described by power equation as shown in Table 4.17.

Table 4.17 Summary of equation used for numerical calculation of VOCs concentration for 2012 – 2013

No.	**Air Pollutant**	**Regression Type (R-Square)**	**Equation**
1	Benzene & CO	Polynomial (R^2 = 0.9834)	$y = 4E - 07x^2 + 0.0021x + 0.8929$
2	Benzene & NO	Power (R^2 = 0.9825)	$y = 0.7142x^{0.4393}$
3	Benzene & NO_2	Polynomial (R^2 = 0.9712)	$y = 1E - 04x^2 + 0.0488x + 0.481$
4	Benzene & NO_x	Polynomial (R^2 = 0.9730)	$y = -3E - 05x^2 + 0.031x + 0.727$
5	Toluene & CO	Exponential (R^2 = 0.9675)	$y = 19.791e^{0.0007x}$

Table 4.17 Summary of equation used for numerical calculation of VOCs concentration for 2012 – 2013 (Cont.)

No.	**Air Pollutant**	**Regression Type (R-Square)**	**Equation**
6	Toluene & NO	Polynomial (R^2 = 0.9621)	$y = -1E - 04x^2 + 0.3296x + 24.768$
7	Toluene & NO_2	Exponential (R^2 = 0.9706)	$y = 18.003e^{0.0144x}$
8	Toluene & NO_x	Polynomial (R^2 = 0.9559)	$y = 6E - 05x^2 + 0.2039x + 18.757$
9	Ethylbenzene & CO	Exponential (R^2 = 0.9320)	$y = 2.0204e^{0.0006x}$
10	Ethylbenzene & NO	Power (R^2 = 0.9195)	$y = 0.1102x^{1.0983}$
11	Ethylbenzene & NO_2	Exponential (R^2 = 0.9670)	$y = 1.8191e^{0.013x}$
12	Ethylbenzene & NO_x	Polynomial (R^2 = 0.9256)	$y = 7E - 06x^2 + 0.0163x + 2.0025$
13	Xylene & CO	Polynomial (R^2 = 0.9781)	$y = 9E - 07x^2 + 0.0041x + 2.749$
14	Xylene & NO	Power (R^2 = 0.9835)	$y = 0.1102x^{1.0983}$
15	Xylene & NO_2	Polynomial (R^2 = 0.9802)	$y = 3E - 04x^2 + 0.0973x + 1.845$
16	Xylene & NO_x	Polynomial (R^2 = 0.9832)	$y = -5E - 05x^2 + 0.0624x + 2.318$

4.4 Statistical analysis to formulate an equation for predicting BTEX and 1, 3-butadiene from 2012 - 2013

The 5th - 95th percentile of benzene and conventional air pollutants data from 2012 – 2013 were used to formulate an equation by using the SPSS version 18. Results were as shown in Table 4.18. It was found that model 2 in which CO and NO were used in calculation could provide the best fit regression equation.

Table 4.18 Regression of benzene and conventional air monitoring data

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	0.003	0.087		0.031	0.976
	CO	1.009	0.020	0.992	49.266	0.000
2	(Constant)	-0.070	0.080		-0.876	0.386
	CO	0.542	0.139	0.532	3.913	0.000
	NO	0.485	0.142	0.463	3.404	0.002

a. Dependent Variable: Benzene

From this table, an equation for predicting benzene concentration can be written as;

$$Benzene = -0.070 + 0.542CO + 0.485NO$$

Substituted CO and NO by using the data from Table 4.17; therefore

$$Benzene = -0.07 + [0.542(4E - 07x^2) + (0.0021x) + 0.8929] \\ + [0.485(0.7142x^{0.4393})]$$

$$Benzene = -0.07 + (2.168E - 07x^2 + 1.1382E - 03x + 0.4839) \\ + (0.3463x^{0.4393})$$

The final equation, used to predict benzene concentration was expressed as

$$Benzene = [2.168E - 07(CO)^2 + 1.1382E - 03(CO) + 0.4139] \\ + [0.3463(NO)^{0.4393})]$$

Where: concentration used in calculation is in µg/m^3

From this equation, a Q-Q plot of observed and predicted benzene concentration was illustrated in Figure 4.42. It was found that predicted data were well agree with those observed data ($R^2 = 0.9875$).

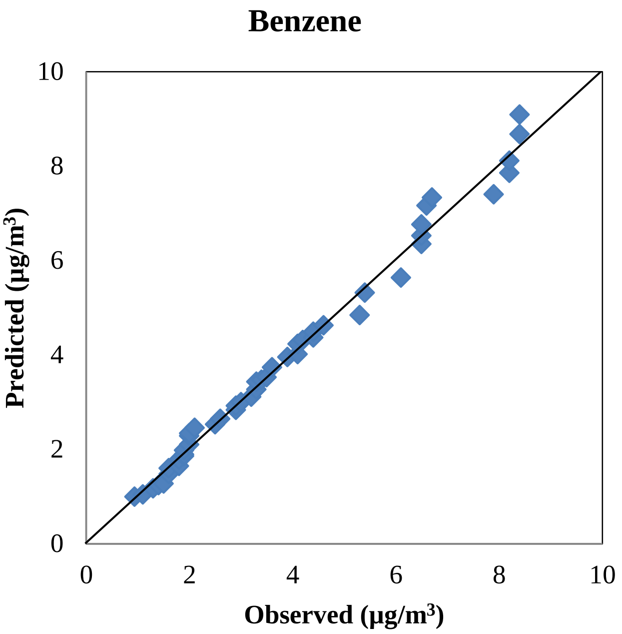


Figure 4.42 Comparison between observed and predicted benzene data from 2012 - 2013

The 5th - 95th percentile of toluene and conventional air pollutants data from 2012 – 2013 were used to formulate an equation by using the SPSS version 18. Results were as shown in Table 4.19. It was found that model 2 in which NO and NO_2 were used in calculation could provide the best fit regression equation.

Table 4.19 Regression of toluene and conventional air monitoring data

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	0.106	1.513		0.070	0.945
	NO	0.997	0.031	0.981	31.843	0.000
2	(Constant)	0.395	1.402		0.282	0.780
	NO	0.652	0.127	0.641	5.131	0.000
	NO_2	0.339	0.122	0.349	2.791	0.008

a. Dependent Variable: Toluene

From this table, an equation for predicting toluene concentration can be written as;

$$Toluene = 0.395 + 0.652NO + 0.339NO_2$$

Substituted NO and NO_2 by using the data from Table 4.17; therefore

$$\begin{aligned} Toluene = 0.395 &+ [0.652(-1E-04x^2) + (0.3296x) + 24.768] \\ &+ [0.339(18.003e^{0.0144x})] \end{aligned}$$

$$Toluene = 0.395 + (6.52E-05x^2 + 0.2148x + 16.1487) + (6.103e^{0.0144x})$$

The final equation, used to predict toluene concentration was expressed as

$$Toluene = [6.52E-05(NO)^2 + 0.2148(NO) + 16.5437] + [6.103e^{0.0144(NO_2)}]$$

Where: concentration used in calculation is in µg/m^3

From this equation, a Q-Q plot of observed and predicted toluene concentration was illustrated in Figure 4.43. It was found that predicted data were well agree with those observed data (R^2 = 0.9258).

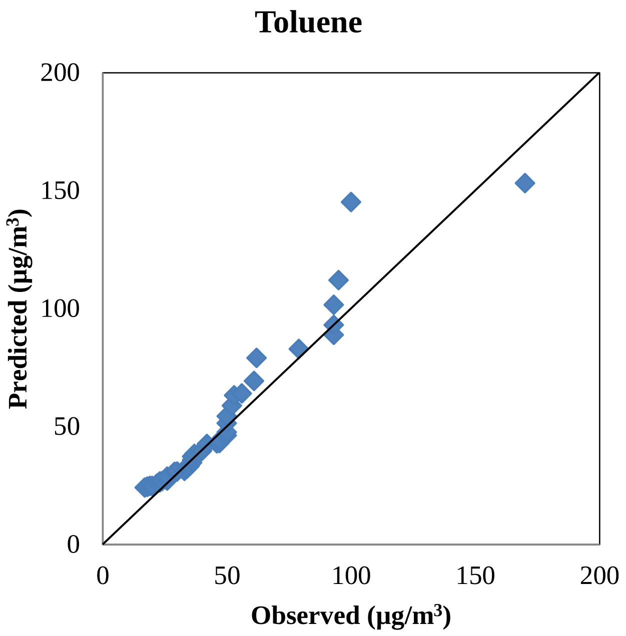


Figure 4.43 Comparison between observed and predicted toluene data from 2012 - 2013

The 5th - 95th percentile of ethylbenzene and conventional air pollutants data from 2012 – 2013 were used to formulate an equation by using the SPSS version 18. Results were as shown in Table 4.20. It was found that model 1 in which NO_2 was used in calculation could provide the best fit regression equation.

Table 4.20 Regression of ethylbenzene and conventional air monitoring data

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-0.062	0.146		-0.42	0.674
	NO_2	1.018	0.031	0.982	32.84	0.000

a. Dependent Variable: Ethylbenzene

From this table, an equation for predicting ethylbenzene concentration can be written as;

$$Ethylbenzene = -0.062 + 1.018NO_2$$

Substituted NO_2 by using the data from Table 4.17; therefore

$$Ethylbenzene = -0.062 + [1.018(1.8191e^{0.013x})]$$

$$Ethylbenzene = (1.8518e^{0.013x} - 0.062)$$

The final equation, used to predict ethylbenzene concentration was expressed as

$$Ethylbenzene = [1.8518e^{0.013(NO_2)} - 0.062]$$

Where: concentration used in calculation is in µg/m^3

From this equation, a Q-Q plot of observed and predicted ethylbenzene concentration was illustrated in Figure 4.44. It was found that predicted data were well agree with those observed data (R^2 = 0.9182). At high concentration model provide over predicted data.

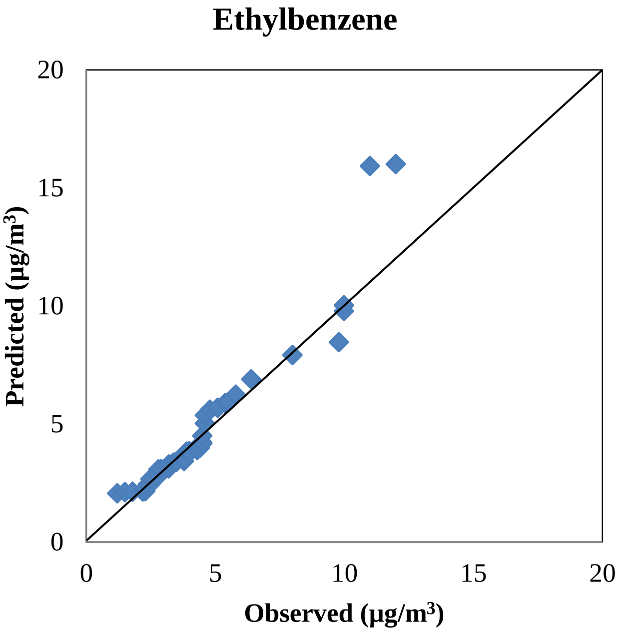


Figure 4.44 Comparison between observed and predicted ethylbenzene data from 2012 - 2013

The 5th - 95th percentile of xylene and conventional air pollutants data from 2012 – 2013 were used to formulate an equation by using the SPSS version 18. Results were as shown in Table 4.21. It was found that model 3 in which NO_x, NO and NO_2 were used in calculation could provide the best fit regression equation.

Table 4.21 Regression of xylene and conventional air monitoring data

Coefficients^{a}						
Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	0.151	0.195		0.77	0.443
	NO_x	0.974	0.020	0.991	49.29	0.000
2	(Constant)	-0.979	0.322		-3.03	0.004
	NO_x	0.588	0.096	0.599	6.14	0.000
	NO	1.086	0.266	0.398	4.08	0.000
3	(Constant)	-0.852	0.301		-2.83	0.007
	NO_x	0.346	0.123	0.353	2.82	0.007
	NO	0.885	0.255	0.325	3.46	0.001
	NO_2	0.326	0.115	0.323	2.84	0.007

a. Dependent Variable: Xylene

From this table, an equation for predicting xylene concentration can be written as;

$$Xylene = -0.852 + 0.346NO_x + 0.885NO + 0.326NO_2$$

Substituted NO_x, NO and NO_2 by using the data from Table 4.17; therefore

$$\begin{aligned} Xylene = {} & -0.852 + [0.346(-5E-05x^2) + (0.0624x) + 2.318] + \\ & [0.885(0.1102x^{1.0983})] + [0.326(3E-04x^2) + (0.0973x) + 1.845] \end{aligned}$$

$$\begin{aligned} Xylene = {} & -0.852 + (-1.73E-05x^2 + 0.0215x + 0.802) + \\ & (0.0975x^{1.0983}) + (9.78E-05x^2 + 0.0317x + 0.6014] \end{aligned}$$

The final equation, used to predict xylene concentration was expressed as

$$Xylene = [-1.73E-05(NO_x)^2 + 0.0215(NO_x) - 0.05] + [0.0975(NO)^{1.0983} + (9.78E-05(NO_2)^2 + 0.0317(NO_2) + 0.25]$$

Where: concentration used in calculation is in µg/m^3

From this equation, a Q-Q plot of observed and predicted xylene concentration was illustrated in Figure 4.45. It was found that predicted data were well agree with those observed data ($R^2 = 0.9833$).

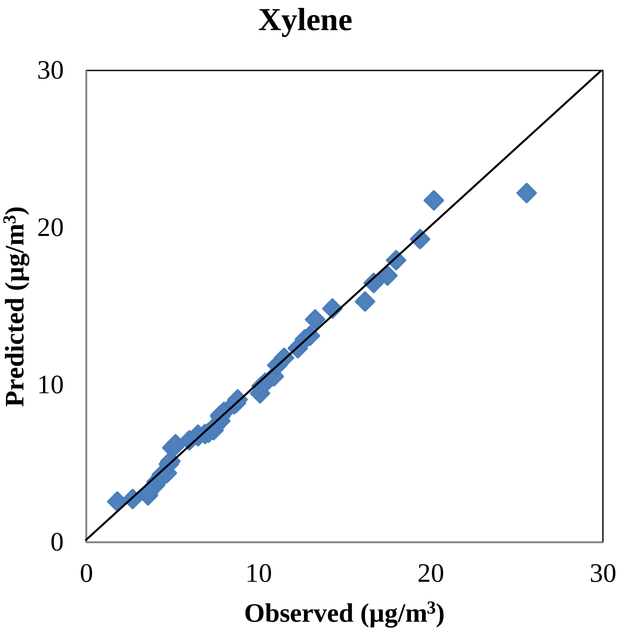


Figure 4.45 Comparison between observed and predicted xylene data from 2012 - 2013

1, 3-Butadiene cannot create the equation by those data since most of observed data were reported as lower than detection limit.

4.5 Statistical analysis for model performance evaluation

4.5.1 Data from 2008 - 2011

The statistics used to measure model performance in this study were Observed Mean (O_{mean}), Predicted/Modeled Mean (P_{mean}), Observed Standard Deviation/Sigma (O_{std}), Predicted/Modeled Standard Deviation/Sigma (P_{std}), Pearson Correlation Coefficient (r^2), Root Mean Square Error (RMSE), Index of Agreement (IOA), Fraction Bias (F_b), Fraction Variance (F_s), Robust Highest Concentration (RHC_o) for observed concentration and Robust Highest Concentration (RHC_p) for predicted concentration. Results of statistical analysis were as shown in Table 4.22.

Table 4.22 Model performance evaluation for VOC concentrations from 2008 - 2011

Parameter	**Benzene**	**1, 3-Butadiene**	**Toluene**	**Ethyl benzene**	**Xylene**
O_{mean}	4.88	0.32	39.35	3.17	10.05
P_{mean}	4.86	0.85	38.56	3.28	9.77
O_{std}	2.15	0.43	24.06	1.77	6.22
P_{std}	2.07	1.35	20.92	1.80	5.13
r^2	0.99	0.95	0.97	0.99	0.96
RMSE	0.23	1.09	5.98	0.20	1.83
IOA	1.00	0.65	0.98	0.99	0.97
F_b	0.004	-0.91	0.02	-0.04	0.03
F_s	0.04	-1.04	0.14	-0.02	0.19
RHC_o	10.86	1.64	117.16	8.91	29.78
RHC_p	10.31	5.74	98.19	8.75	23.20

The fractional bias (F_b) and fraction variance (F_s) were calculated as negative value for 1, 3-butadiene and ethylbenzene indicating over-prediction of the model. Generally, it was found that the model can perform well in predicting overall concentration of VOCs as determined by r^2 and IOA (>0.5). Differences between observed and predicted concentration were also within an acceptable range ($F_b < \pm 2$).

IOA which is designed to better handling differences in predicted and observed means and variances (Almaza *et. al*, 2014). For 1, 3-butadiene and BTEX concentration were between 0.65 – 1.00, indicated high abilities for 1, 3-butadiene and BTEX concentration predictions. The robust highest concentration (RHC) is preferred to the actual peak value because it mitigates the undesirable of the maximum concentration. Results from RHC indicated a good performance of the model in predicting extreme high end concentration of benzene, ethylbenzene, xylene and toluene respectively. As for 1, 3-butadiene, RHC_p was slightly higher than RHC_o, this finding indicated over estimation of this compound in this numerical simulation.

4.5.2 Data from 2012 - 2013

The statistics used to measure model performance in this study were shown in Table 4.23. As for 1, 3-butadiene no data for those parameters, fractional bias (F_b) and fraction variance (F_s) were calculated as negative value for benzene, toluene and ethylbenzene indicating over-prediction of the model. Generally, it was found that the model can perform well in predicting overall concentration of VOCs as determined by r^2 and IOA (>0.5). For BTEX concentrations were between 0.96 – 1.00, indicated high abilities for BTEX concentration predictions. Results from RHC indicated a good performance of the model in predicting extreme high end concentration of xylene. As for benzene, toluene and ethlybenzene, RHC_p was slightly higher than RHC_o, this finding indicated over estimation of these compounds in this numerical simulation.

Table 4.23 Model performance evaluation for VOC concentrations from 2012 - 2013

Parameter	Benzene	1, 3-Butadiene	Toluene	Ethyl benzene	Xylene
O_{mean}	3.97	-	46.09	4.51	9.06
P_{mean}	4.01	-	48.96	4.74	9.04
O_{std}	2.33	-	28.94	2.54	5.28
P_{std}	2.41	-	30.73	3.13	5.11
r^2	0.99	-	0.96	0.96	0.99

Table 4.23 Model performance evaluation for VOC concentrations from 2012 – 2013 (Cont.)

Parameter	Benzene	1, 3-Butadiene	Toluene	Ethyl benzene	Xylene
RMSE	0.28	-	8.79	1.02	0.69
IOA	1.00	-	0.98	0.96	0.99
F_b	-0.01	-	-0.06	-0.05	0.002
F_s	-0.03	-	-0.06	-0.21	0.033
RHC_o	8.51	-	117.46	10.80	20.88
RHC_p	9.05	-	124.99	11.96	20.34

4.5.3 Model validation of data for the year 2014

Data from the year 2014 were used to validate BTEX equation. A Q-Q plot of observed and predicted BTEX concentration was illustrated in Appendix C. It was found that predicted data were well agreed with those observed data. The statistics used to validate model performance in this study were shown in Table 4.24. Generally, it was found that the model can perform well in predicting overall concentration of BTEX as determined by r^2 and IOA (>0.5).Results from RHC indicated a good performance of the model in predicting extreme end of concentration distributions. RHC_p was slightly lower than RHC_o. This finding indicated that the model provided under estimation of those compounds in this numerical simulation.

Table 4.24 Model validation for BTEX concentrations of 2014

Parameter	**Benzene**	**Toluene**	**Ethyl benzene**	**Xylene**
O_{mean}	2.53	32.67	3.37	7.59
P_{mean}	2.82	33.28	3.30	6.10
O_{std}	1.67	18.77	2.24	4.48
P_{std}	0.91	7.59	0.91	2.24
r^2	0.96	0.97	0.98	0.98
RMSE	0.87	11.29	1.40	2.71
IOA	0.88	0.81	0.80	0.83
F_b	-0.11	-0.02	0.13	0.22
F_s	0.59	0.85	0.84	0.67
RHC_o	5.48	62.48	7.35	14.83
RHC_p	4.36	46.54	4.79	9.46

4.6 Pollution Map

Spatial and temporal evaluations were conducted by interpolation of pollution map. The pollution maps were drawn by using Geological Information System (GIS) techniques. Three difference spatial interpolation techniques were tested in order to determine the best interpolation scheme which most fit for this study. They were the Ordinary Kriging, the Inverse Distance Weighted (IDW) and the Spline. Cross-validation was used to assess the relative performance of the techniques applied. In this analysis, 17 conventional air monitoring stations (S1 – S17) located in Central Business District (CBD) of Bangkok were chosen for a living-one-cut analysis. Benzene concentrations from 2008 – 2011 were calculated by equation below:

$$
\begin{aligned}
Benzene = {} & [-2.376E-04(NO_2)^2 + 0.0858(NO_2) - 0.298] + \\
& [1.65E-07(CO)^2 + 1.045E-03(CO) + 0.986] - [0.299(NO)^{0.398}]
\end{aligned}
$$

While the year 2012 - 2013 were calculated by following equation;

$$Benzene = [2.168E-07(CO)^{2} + 1.1382E-03(CO) + 0.4139] \\ + [0.3463(NO)^{0.4393})]$$

Annual average concentration of benzene from numerical analysis was as summarized in Table 4.25.

Table 4.25 Annual average of benzene concentration of 2008 – 2013 (Unit: µg/m^3)

Code	Stations	Location	Coordinate		Year					
			X	Y	2008	2009	2010	2011	2012	2013
S1	Ban Somdej	47P	660676	1518679	3.33	3.24	2.95	-	-	-
S2	Rat Burana Post	47N	662848	1511579	3.73	4.20	2.93	2.93	2.13	2.14
S3	Met_Bang Na	47N	673672	1511384	2.90	4.47	3.44	-	3.07	3.22
S4	Chandrakasem	47P	670334	1528374	4.22	-	4.25	3.49	-	2.82
S5	Bodindecha	47N	672749	1522825	4.19	4.85	3.82	-	-	3.28
S6	Khlong Chan	47N	678005	1523487	3.88	4.23	3.67	-	-	-
S7	Huai Khwang	47P	669612	1523437	5.54	5.44	4.96	-	4.82	3.92
S8	Nonsi Witthaya	47P	667326	1515973	4.10	4.43	3.42	-	-	2.71
S9	Singharat	47P	656379	1513271	3.83	2.97	2.61	-	-	2.44
S10	Land Trans	47P	668039	1525611	-	6.14	4.90	-	-	-
S11	Intharaphithak	47N	660741	1518098	5.16	5.18	4.30	-	4.33	3.53
S12	Chok Chai 4	47P	672535	1525366	5.21	5.26	4.93	4.44	-	3.41
S13	Din Daeng	47N	667907	1521979	6.61	6.52	5.48	5.09	4.88	4.96
S14	Gov Pub Re	47N	666536	1524275	3.49	4.21	3.47	-	1.84	1.77
S15	Din Dang BMA	47P	667921	1523127	5.09	6.86	4.30	5.89	4.74	5.25
S16	Phra Khanong BMA	47P	673253	1515382	5.69	5.66	4.99	7.24	5.85	-
S17	Rat Burana BMA	47N	662865	1513090	4.40	4.12	3.11	4.04	4.13	4.35

The year 2010 was selected for cross validation analysis due to its completeness of data (100%). Analysis results for each interpolation technique were as follow:

4.6.1 Ordinary Kriging

Table 4.26 Comparison of measured and predicted by Kriging

Station	**Benzene_O_i (μg/m^3)**	**Benzene_P_i (μg/m^3)**	**$(O_i - O_{mean})$^2**	**$(P_i - P_{mean})$^2**	**$(P_i - O_i)$^2**
Ban Somdej	2.95	3.89	1.04	0.07	0.89
Rat Burana Post	2.93	3.06	1.08	1.19	0.02
Met_Bang Na	3.44	4.37	0.28	0.05	0.86
Chandrakasem	4.25	4.92	0.08	0.60	0.45
Bodindecha	3.82	4.83	0.02	0.46	1.01
Khlong Chan	3.67	4.36	0.09	0.05	0.48
Huai Khwang	4.96	4.88	0.98	0.54	0.01
Nonsi Witthaya	3.42	4.41	0.30	0.07	0.97
Singharat	2.61	3.53	1.85	0.38	0.85
Land Trans	4.90	4.19	0.86	0.00	0.50
Intharaphithak	4.30	2.94	0.11	1.47	1.86
Chok Chai 4	4.93	4.27	0.92	0.01	0.44
Din Daeng	5.48	4.31	2.28	0.03	1.37
Gov Pub Re	3.47	4.78	0.25	0.40	1.72
Din Dang BMA	4.30	4.67	0.11	0.27	0.14
Phra Khanong BMA	4.99	3.54	1.04	0.38	2.11
Rat Burana BMA	3.11	3.36	0.74	0.62	0.06
SUM	67.53	70.31	12.04	6.56	13.74
				O_{mean}	3.97
				P_{mean}	4.14
				RMSE	**0.90**
				IOA	**0.57**

4.6.2 Inverse Distance Weighted (IDW)

Table 4.27 Comparison of measured and predicted by IDW

Station	**Benzene_O_i (µg/m^3)**	**Benzene_P_i (µg/m^3)**	**$(Oi - O_{mean})$^2**	**$(P_i - P_{mean})$^2**	**$(P_i - O_i)$^2**
Ban Somdej	2.95	4.28	1.04	0.02	1.76
Rat Burana Post	2.93	3.10	1.08	1.10	0.03
Met_Bang Na	3.44	4.49	0.28	0.12	1.11
Chandrakasem	4.25	4.92	0.08	0.60	0.45
Bodindecha	3.82	4.85	0.02	0.49	1.06
Khlong Chan	3.67	4.44	0.09	0.08	0.59
Huai Khwang	4.96	4.77	0.98	0.38	0.04
Nonsi Witthaya	3.42	4.41	0.30	0.07	0.97
Singharat	2.61	3.45	1.85	0.48	0.71
Land Trans	4.90	4.10	0.86	0.00	0.65
Intharaphithak	4.30	2.95	0.11	1.44	1.83
Chok Chai 4	4.93	4.22	0.92	0.01	0.50
Din Daeng	5.48	4.31	2.28	0.03	1.36
Gov Pub Re	3.47	4.75	0.25	0.36	1.64
Din Dang BMA	4.30	4.91	0.11	0.58	0.38
Phra Khanong BMA	4.99	3.50	1.04	0.43	2.23
Rat Burana BMA	3.11	3.06	0.74	1.20	0.00
SUM	67.53	70.51	12.04	7.38	15.30
				O_{mean}	3.97
				P_{mean}	4.15
				RMSE	**0.95**
				IOA	**0.55**

4.6.3 Spline

Table 4.28 Comparison of measured and predicted by spline

Station	Benzene_O_i (μg/m^3)	Benzene_P_i (μg/m^3)	(Oi - O_{mean})^2	(P_i - P_{mean})^2	(P_i - O_i)^2
Ban Somdej	2.95	4.35	1.04	0.04	1.95
Rat Burana Post	2.93	1.31	1.08	8.09	2.64
Met_Bang Na	3.44	4.02	0.28	0.02	0.34
Chandrakasem	4.25	7.54	0.08	11.51	10.84
Bodindecha	3.82	5.67	0.02	2.32	3.43
Khlong Chan	3.67	0.09	0.09	16.46	12.79
Huai Khwang	4.96	4.61	0.98	0.21	0.12
Nonsi Witthaya	3.42	6.15	0.30	4.02	7.47
Singharat	2.61	7.72	1.85	12.73	26.09
Land Trans	4.90	3.54	0.86	0.37	1.84
Intharaphithak	4.30	2.99	0.11	1.36	1.73
Chok Chai 4	4.93	3.29	0.92	0.74	2.68
Din Daeng	5.48	4.03	2.28	0.01	2.09
Gov Pub Re	3.47	3.54	0.25	0.37	0.01
Din Dang BMA	4.30	4.95	0.11	0.63	0.42
Phra Khanong BMA	4.99	4.15	1.04	0.00	0.71
Rat Burana BMA	3.11	4.63	0.74	0.23	2.32
SUM	67.53	72.58	12.04	59.10	77.49
				O_{mean}	3.97
				P_{mean}	4.27
				RMSE	**2.13**
				IOA	**0.25**

Results of cross-validation with the ordinary Kriging, IDW and the spline are presented in Table 4.26, 4.27 and 4.28, respectively. Model performance indicators were as shown in Table 4.29. It was found that ordinary Kriging and IDW had similar value for the RMSE while the spline shown the highest value (RMSE = 0.90, 0.95 and 2.3; IOA = 0.57, 0.55 and 0.25 respectively). Results from cross validation indicated that in general, IDW perform much better than other techniques. Therefore, interpolation of benzene map was drawn using the IDW method.

Table 4.29 Model performance indicators

Statistical measure	**Interpolation techniques**		
	Ordinary kriging	**IDW**	**Spline**
Number of observation	17	17	17
Fraction bias (Fb)	-0.04	-0.04	-0.07
Fraction variance (Fs)	0.30	0.24	-0.75
Index of agreement (IOA)	0.57	0.55	0.25
Root mean square error (RMSE)	0.90	0.95	2.13

Mapping benzene concentration from the set of prediction data was performed using ArcGIS 9.3. The other advantage of choosing IDW in this study was the smooth surface of data in the simulation of IDW. A raster map from spatial interpolation depicting the distribution of benzene concentration of the year 2008 to 2013 was produced by performing the IDW method. Levels of benzene concentration were classified into 4 classes as shown in Figure 4.46 to 4.51. The ambient air monitoring stations were located in the predicted area, having high concentration of air pollutants or were situated close to the main road. The interpolation technique assisted in determining the hotspot area (> 1.7 µg/m^3) where high concentration of benzene was detected (Thepanondh et al, 2011).

In 2008 and 2009, interpolated results illustrated that high concentrations of benzene were found in almost every districts of the study area except in the dark green area where annual average benzene concentration was lower than the Thai ambient concentration standard for benzene (< 1.7 µg/m^3) as shown in Figure 4.46 and 4.47. In 2010 it was found that almost every districts having annual concentrations greater than standard (> 1.7 µg/m^3) as shown in Figure 4.48. In 2011, 2012 and 2013, there were some districts of the study area having annual concentrations less than standard (< 1.7 µg/m^3) as shown in Figure 4.49, 4.50 and 4.51, respectively.

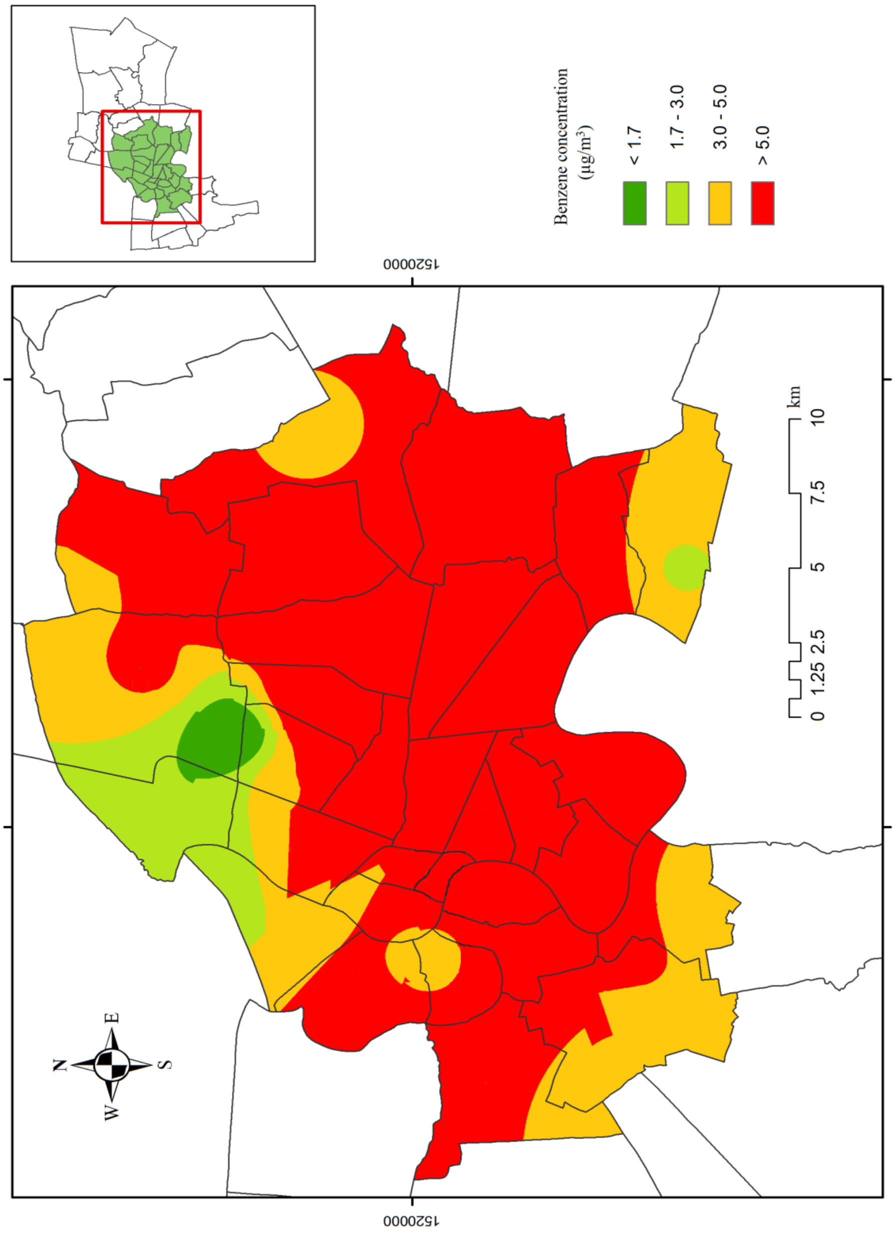


Figure 4.46 Benzene concentration map for the year 2008

Benzene concentration map for the year 2008 indicated that most of the populations in the study area were defined as impact zone (annual average of benzene greater than 1.7 µg/m^3). The zone of impact covering 404.29 km^2 of the total area (31 districts) where they were 2,937,588 people living in this zone.

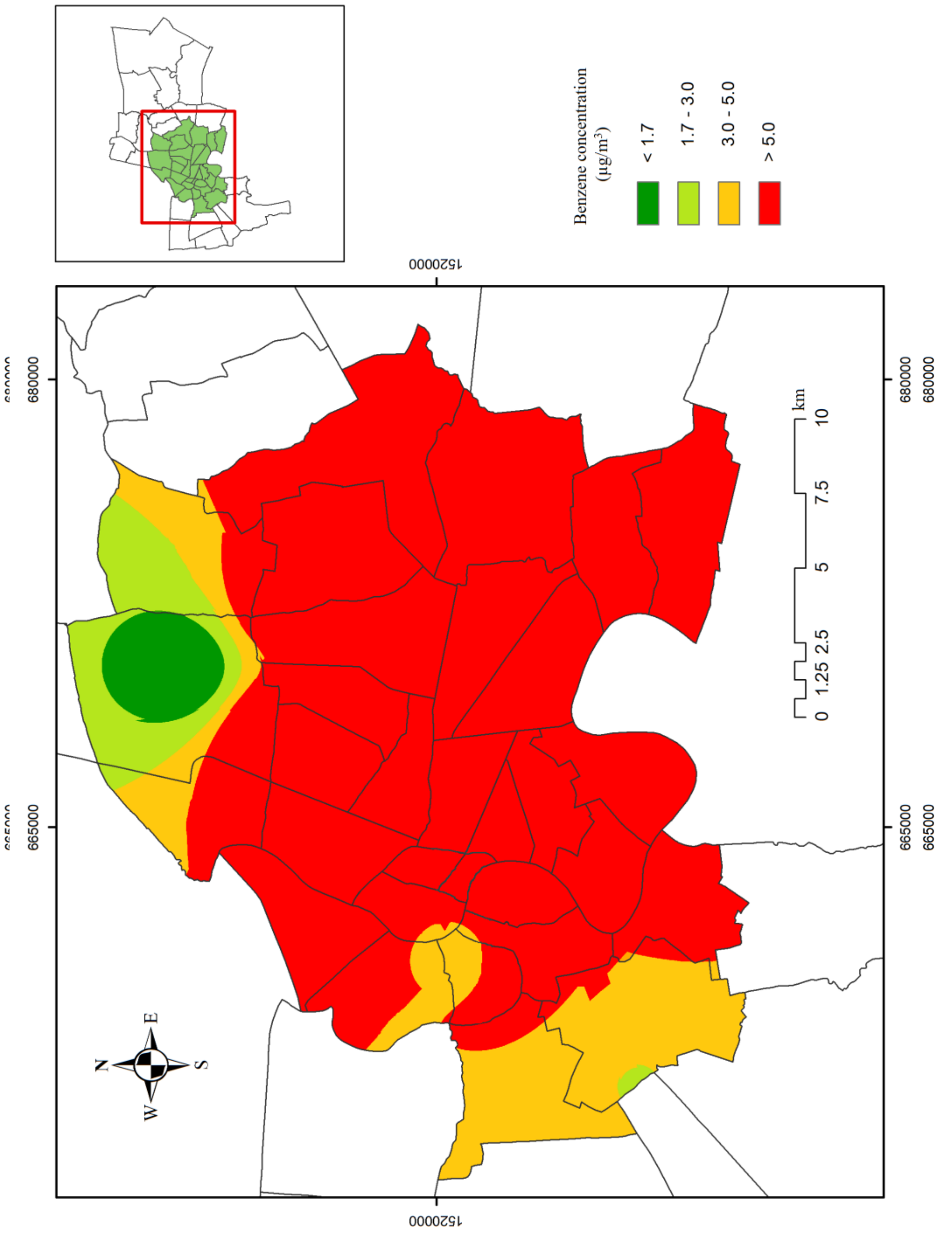


Figure 4.47 Benzene concentration map for the year 2009

Benzene concentration map for the year 2009 indicated that most of the populations in the study area were defined as impact zone (annual average of benzene greater than 1.7 µg/m^3). The zone of impact covering 379.06 km^2 of the total area (31 districts) where they were 2,905,373 people living in this zone.

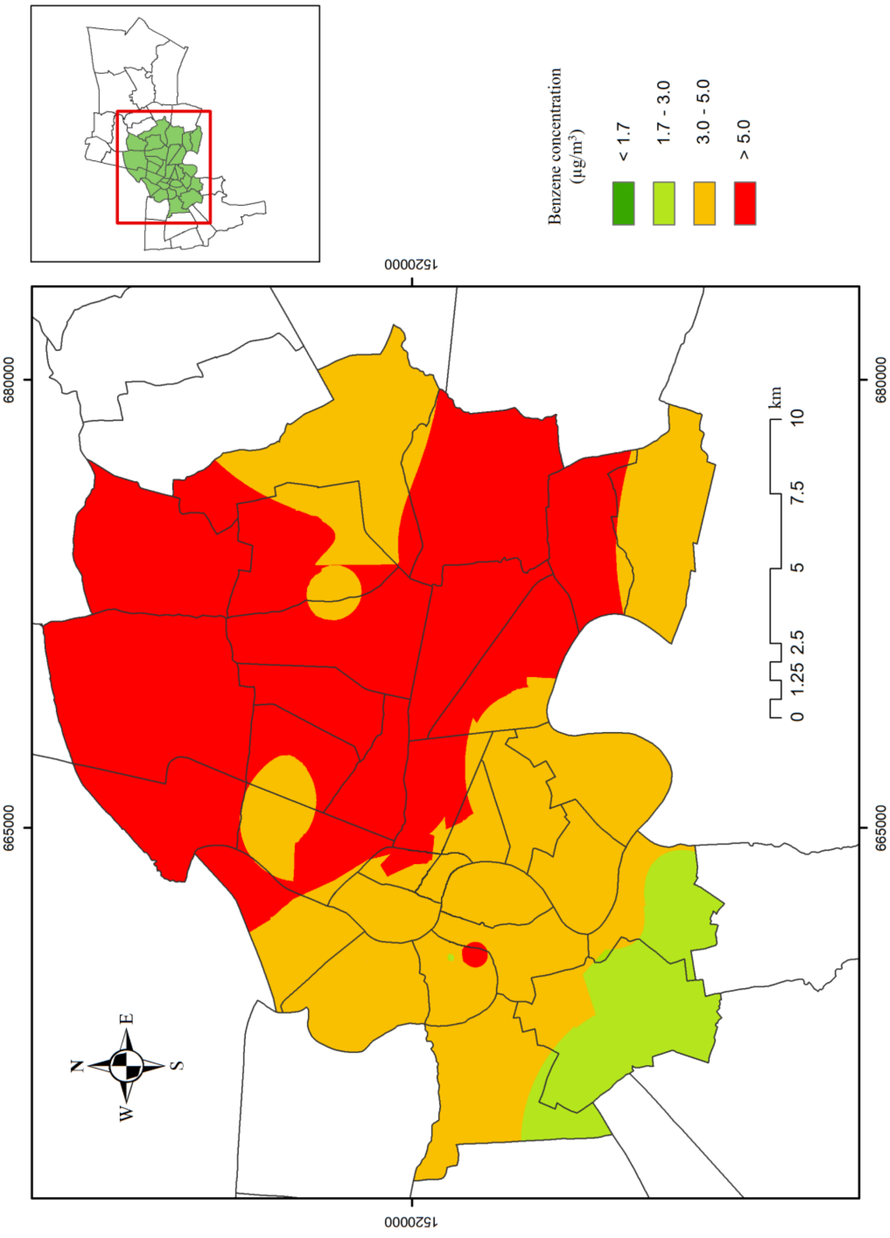


Figure 4.48 Benzene concentration map for the year 2010

Benzene concentration map for the year 2010 indicated that most of the populations in the study area were defined as impact zone (annual average of benzene greater than 1.7 µg/m^3). The zone of impact covering 408.92 km^2 of the total area (31 districts) where they were 2,977,314 people living in this zone.

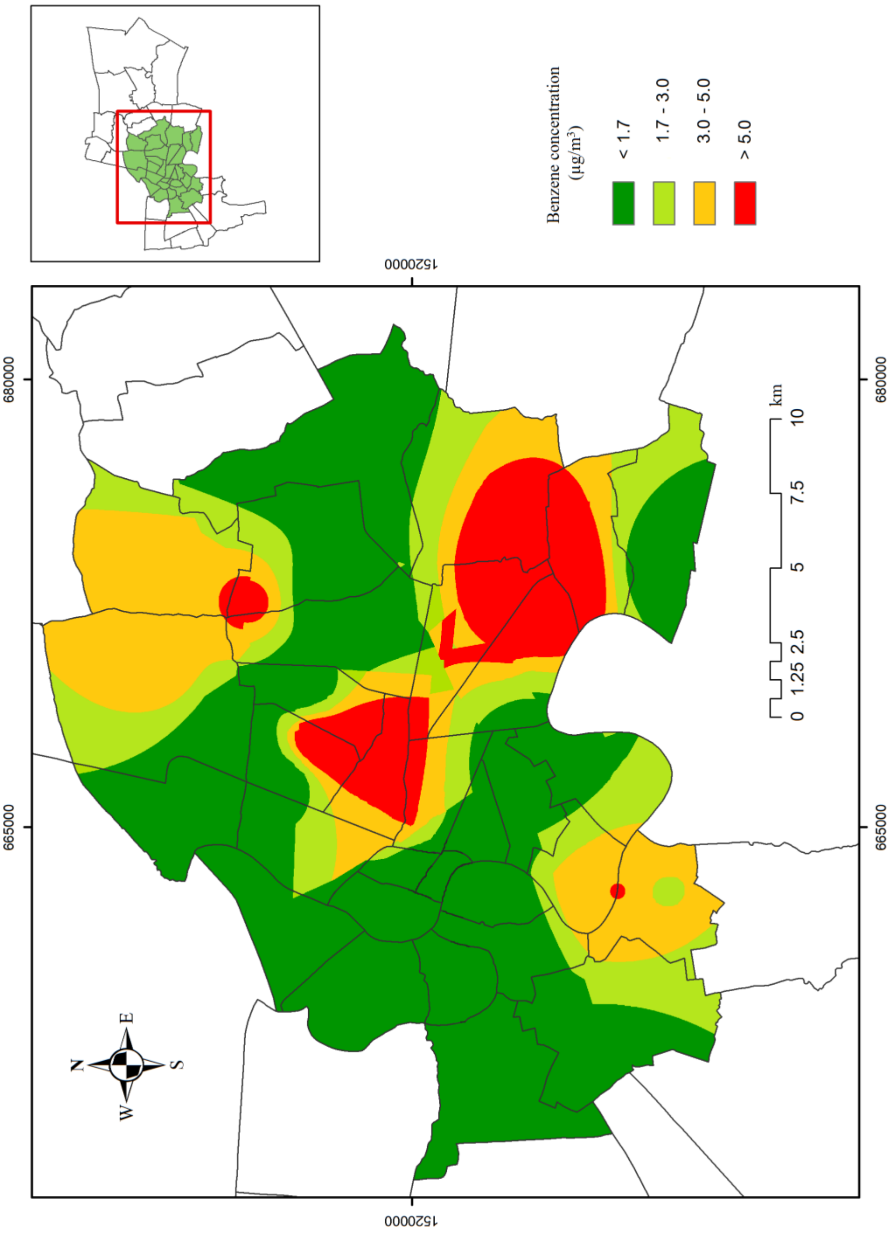


Figure 4.49 Benzene concentration map for the year 2011

Benzene concentration map for the year 2011 indicated that some of the populations in the study area were defined as impact zone (annual average of benzene greater than 1.7 µg/m^3). The zone of impact covering 189.06 km^2 of the total area (26 districts) where they were 1,233,787 people living in this zone.

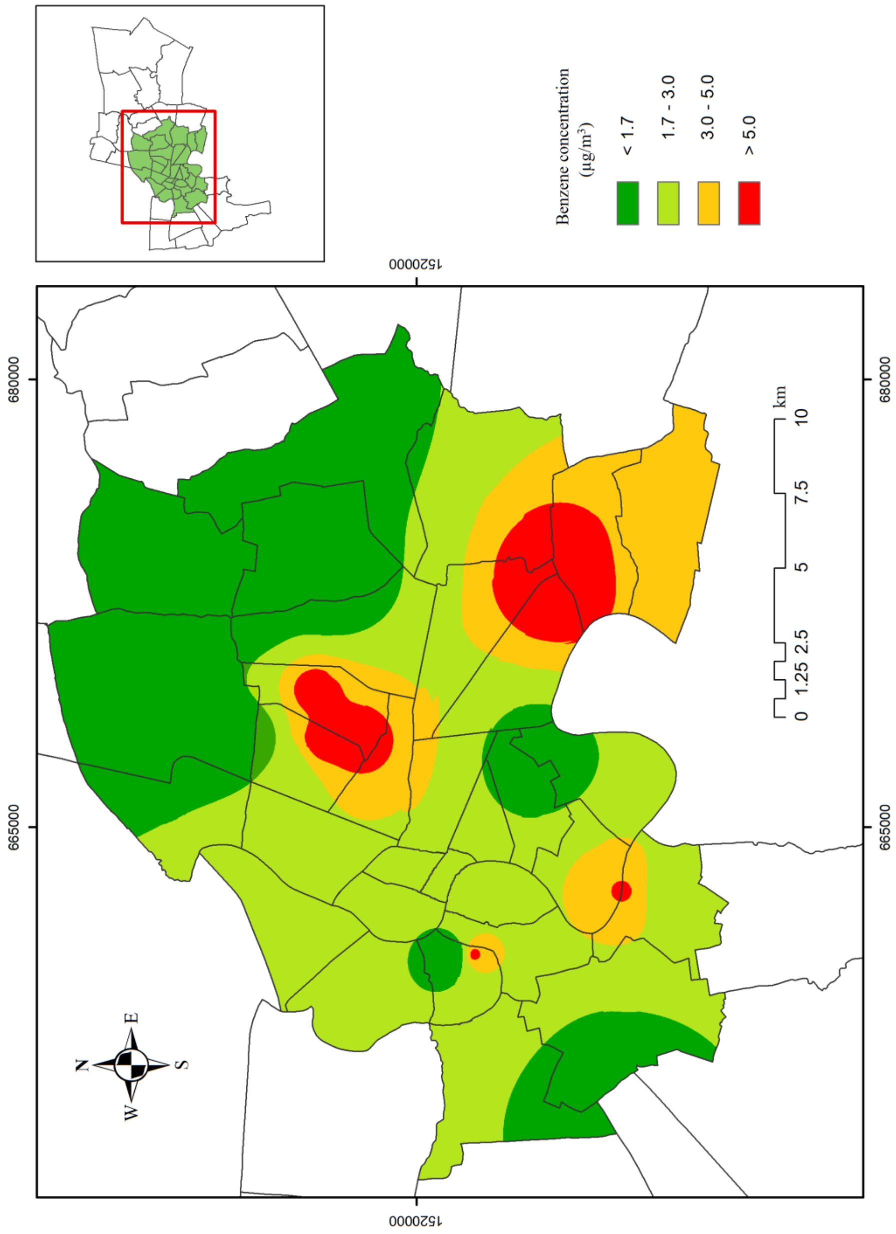


Figure 4.50 Benzene concentration map for the year 2012

Benzene concentration map for the year 2012 indicated that some of the populations in the study area were defined as impact zone (annual average of benzene greater than 1.7 µg/m^3). The zone of impact covering 253.36 km^2 of the total area (28 districts) where they were 2,021,867 people living in this zone.

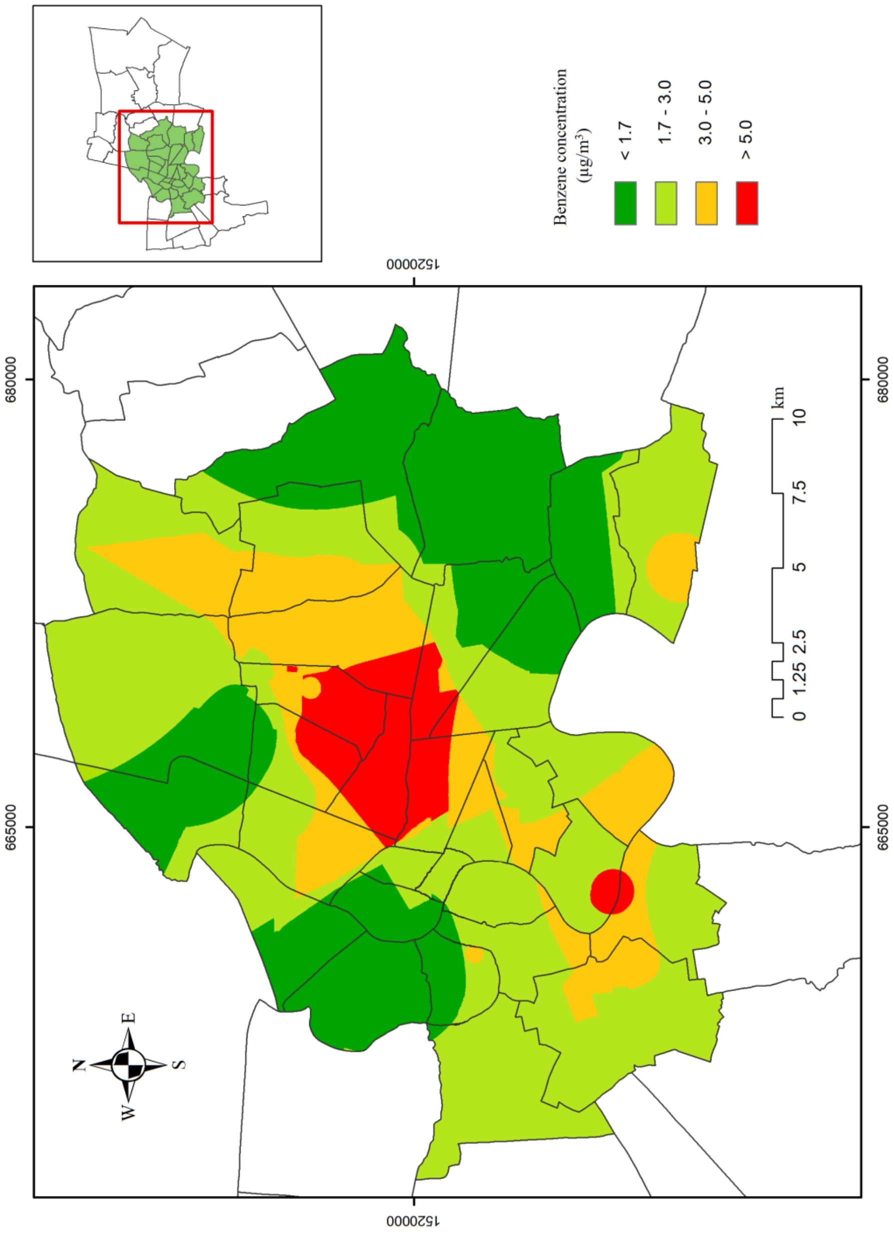


Figure 4.51 Benzene concentration map for the year 2013

Benzene concentration map for the year 2013 indicated that some of the populations in the study area were defined as impact zone (annual average of benzene greater than 1.7 µg/m^3). The zone of impact covering 290.53 km^2 of the total area (31 districts) where they were 2,122,887 people living in this zone.

The populations living in impact zone were as shown Table 4.30. Spatial distribution map illustrated that benzene concentrations had decreasing tendency from the year 2008 to 2013. The impact zone was dramatically decrease in the year 2011 which could be explained by uncertainty of data analysis due to large number of missing value caused by flooding in that year.

Table 4.30 Summary of benzene impact zone

Year	**Impact zone (km^2)**	**Population (person)**
2008	404.29	2,937,588
2009	397.06	2,905,373
2010	408.92	2,977,314
2011	189.06	1,233,787
2012	253.36	2,021,867
2013	290.53	2,122,887

4.7 Hazard Index

The potential risk impact from inhalation of BTEX and 1, 3-butadiene in this study area was evaluated. Evaluation of health impact was based on the assumption that BTEX and 1, 3-butadiene remains as gases when emitted into the air, human exposure did not occur to any appreciable extent via ingestion or dermal exposure. Significant exposure to these pollutants only occurred through the inhalation pathway. The concept of hazard quotient (HQ) and hazard index (HI) were applied in this study. HQ of each compound is calculated by using annual average concentration divided by reference concentration (RfC). HI is the sum of the HQs from toxic air pollutants that affect the same organ systems. Calculated results of HQ for the year 2008 to 2013 were as shown in Table 4.31 – 4.34. HI was calculated using summation of BTEX. Results were as shown in Table 4.35 and HI map were as shown in Figure

4.52 to 4.57. As for interpretation of results, those HQ and HI of less than 1 are considered as there are no adverse health effects to the population in the study area.

Table 4.31 Hazard quotient for benzene

Stations	**Benzene**					
	2008	**2009**	**2010**	**2011**	**2012**	**2013**
Ban Somdaj	0.111	0.108	0.098	-	-	-
Ratburana_Post	0.124	0.140	0.098	0.098	0.071	0.071
Met_Bangna	0.097	0.149	0.115	-	0.102	0.107
Chankasame	0.141	-	0.142	0.116	-	0.094
Bodindecha	0.140	0.162	0.127	-	-	0.109
Klong Chan	0.129	0.141	0.122	-	-	-
Huay Kwang	0.185	0.181	0.165	-	0.161	0.131
Nonthree	0.137	0.148	0.114	-	-	0.090
Singharat	0.128	0.099	0.087	-	-	0.081
Land_Trans	-	0.205	0.163	-	-	-
Intarapithug	0.172	0.173	0.143	-	0.144	0.118
Chok Chai 4	0.174	0.175	0.164	0.148	-	0.114
Din Dang	0.220	0.217	0.183	0.170	0.163	0.165
Gov_Pub_Re	0.116	0.140	0.116	-	0.061	0.059
Din Dang_BMA	0.170	0.229	0.143	0.196	0.158	0.175
Phakanong_BMA	0.190	0.189	0.166	0.241	0.195	-
Ratburana_BMA	0.147	0.137	0.104	0.135	0.138	0.145

As for benzene, the highest HQ which were calculated in the year 2008 to 2013 were at Din Dang = 0.220, Din Dang_BMA = 0.229, Din Dang = 0.183, Phakanong_BMA = 0.241, Phakanong_BMA = 0.195 and Din Dang_BMA station = 0.175, respectively. However, calculated HQ for benzene was much lower than 1, indicated that benzene concentrations were lower than its reference value (3.00E+01 µg/m^3).

Table 4.32 Hazard quotient for toluene

Station	**Toluene**					
	2008	**2009**	**2010**	**2011**	**2012**	**2013**
Ban Somdaj	0.004	0.004	0.004	-	-	-
Ratburana_Post	0.005	0.005	0.004	0.004	0.007	0.007
Met_Bangna	0.004	0.006	0.005	-	0.006	0.007
Chankasame	0.006	-	0.005	0.005	-	0.008
Bodindecha	0.006	0.007	0.005	-	-	0.007
Klong Chan	0.005	0.006	0.005	-	-	-
Huay Kwang	0.008	0.007	0.006	-	0.009	0.008
Nonthree	0.006	0.005	0.005	-	-	0.007
Singharat	0.006	0.004	0.004	-	-	0.006
Land_Trans	-	0.011	0.008	-	-	-
Intarapithug	0.008	0.007	0.006	-	0.008	0.008
Chok Chai 4	0.008	0.008	0.007	0.007	-	0.008
Din Dang	0.013	0.012	0.010	0.010	0.0111	0.013
Gov_Pub_Re	0.005	0.004	0.004	-	0.007	0.007
Din Dang_BMA	0.012	0.010	0.008	0.010	0.009	0.010
Phakanong_BMA	0.013	0.011	0.011	0.012	0.0108	-
Ratburana_BMA	0.007	0.008	0.006	0.006	0.009	0.009

As for toluene, the highest HQ which were calculated in the year 2008 to 2013 were at Phakanong_BMA = 0.013, Din Dang = 0.012, Phakanong_BMA = 0.011, Phakanong_BMA = 0.012, Din Dang = 0.0111 and Din Dang station = 0.013, respectively. However, calculated HQ for toluene was much lower than 1, indicated that toluene concentrations were lower than its reference value (5.00E+03 µg/m^3).

Table 4.33 Hazard quotient for ethylbenzene

Station	**Ethylbenzene**					
	2008	**2009**	**2010**	**2011**	**2012**	**2013**
Ban Somdaj	0.002	0.002	0.002	-	-	-
Ratburana_Post	0.002	0.003	0.002	0.002	0.003	0.004
Met_Bangna	0.002	0.002	0.002	-	0.003	0.003
Chankasame	0.002	-	0.002	0.002	-	0.005
Bodindecha	0.002	0.002	0.002	-	-	0.004
Klong Chan	0.002	0.002	0.002	-	-	-
Huay Kwang	0.003	0.003	0.003	-	0.004	0.005
Nonthree	0.003	0.003	0.002	-	-	0.004
Singharat	0.002	0.001	0.001	-	-	0.003
Land_Trans	-	0.0046	0.003	-	-	-
Intarapithug	0.003	0.003	0.003	-	0.004	0.004
Chok Chai 4	0.003	0.003	0.003	0.003	-	0.004
Din Dang	0.005	0.0051	0.004	0.004	0.0048	0.006
Gov_Pub_Re	0.002	0.003	0.002	-	0.003	0.004
Din Dang_BMA	0.004	0.004	0.003	0.004	0.004	0.003
Phakanong_BMA	0.003	0.003	0.003	0.006	0.0049	-
Ratburana_BMA	0.003	0.003	0.002	0.003	0.004	0.004

As for ethylbenzene, the highest HQ which were calculated in the year 2008 to 2013 were at Din Dang = 0.005, Din Dang = 0.0051, Din Dang = 0.004, Phakanong_BMA = 0.006, Phakanong_BMA = 0.0049 and Din Dang station = 0.006, respectively. However, calculated HQ for ethylbenzene was much lower than 1, indicated that ethylbenzene concentrations were lower than its reference value (1.00E+03 µg/m^3).

Table 4.34 Hazard quotient for xylene

Station	**Xylene**					
	2008	**2009**	**2010**	**2011**	**2012**	**2013**
Ban Somdaj	0.059	0.056	0.048	-	-	-
Ratburana_Post	0.067	0.068	0.051	0.050	0.057	0.060
Met_Bangna	0.052	0.069	0.054	-	0.058	0.065
Chankasame	0.069	-	0.059	0.058	-	0.077
Bodindecha	0.069	0.076	0.056	-	-	0.066
Klong Chan	0.063	0.067	0.056	-	-	-
Huay Kwang	0.097	0.088	0.085	-	0.093	0.084
Nonthree	0.073	0.070	0.064	-	-	0.067
Singharat	0.061	0.046	0.046	-	-	0.049
Land_Trans	-	0.141	0.099	-	-	-
Intarapithug	0.093	0.090	0.078	-	0.084	0.081
Chok Chai 4	0.099	0.100	0.092	0.085	-	0.073
Din Dang	0.145	0.143	0.118	0.128	0.105	0.120
Gov_Pub_Re	0.060	0.065	0.051	-	0.060	0.064
Din Dang_BMA	0.126	0.152	0.092	0.124	0.093	0.096
Phakanong_BMA	0.129	0.118	0.113	0.155	0.110	-
Ratburana_BMA	0.090	0.091	0.071	0.080	0.092	0.089

As for xylene, the highest HQ which were calculated in the year 2008 to 2013 were at Din Dang = 0.145, Din Dang_BMA = 0.152, Din Dang = 0.118, Phakanong_BMA = 0.155, Phakanong_BMA = 0.110 and Din Dang station = 0.120, respectively. However, calculated HQ for xylene was much lower than 1, indicated that xylene concentrations were lower than its reference value (1.00E+02 µg/m^3).

HQs less than 1 are considered to be of minimal risk for adverse health effects arising from exposure. The higher the HQ is from a value of 1, the greater the risk (California Environmental Agency, 2003). HI was calculated using summation of BTEX for the year 2008 to 2013 it was found that at Din Dang = 0.38, Din Dang_BMA = 0.40, Din Dang = 0.31, Phakanong_BMA = 0.41, Phakanong_BMA = 0.32 and Din Dang station = 0.31 respectively. However, HI values was much lower than 1 there is considered as non-cancer risk originated from exposure of BTEX in the study area was less as shown in Table 4.34.

Table 4.35 Hazard Index

Code	Stations	Location	Coordinate		Year					
			X	Y	2008	2009	2010	2011	2012	2013
S1	Ban Somdej	47P	660676	1518679	3.33	3.24	2.95	-	-	-
S2	Rat Burana Post	47N	662848	1511579	3.73	4.20	2.93	2.93	2.13	2.14
S3	Met_Bang Na	47N	673672	1511384	2.90	4.47	3.44	-	3.07	3.22
S4	Chandrakasem	47P	670334	1528374	4.22	-	4.25	3.49	-	2.82
S5	Bodindecha	47N	672749	1522825	4.19	4.85	3.82	-	-	3.28
S6	Khlong Chan	47N	678005	1523487	3.88	4.23	3.67	-	-	-
S7	Huai Khwang	47P	669612	1523437	5.54	5.44	4.96	-	4.82	3.92
S8	Nonsi Witthaya	47P	667326	1515973	4.10	4.43	3.42	-	-	2.71
S9	Singharat	47P	656379	1513271	3.83	2.97	2.61	-	-	2.44
S10	Land Trans	47P	668039	1525611	-	6.14	4.90	-	-	-
S11	Intharaphithak	47N	660741	1518098	5.16	5.18	4.30	-	4.33	3.53
S12	Chok Chai 4	47P	672535	1525366	5.21	5.26	4.93	4.44	-	3.41
S13	Din Daeng	47N	667907	1521979	6.61	6.52	5.48	5.09	4.88	4.96
S14	Gov Pub Re	47N	666536	1524275	3.49	4.21	3.47	-	1.84	1.77
S15	Din Dang BMA	47P	667921	1523127	5.09	6.86	4.30	5.89	4.74	5.25

Table 4.35 Hazard Index (Cont.)

Code	Stations	Location	Coordinate		Year					
			X	Y	2008	2009	2010	2011	2012	2013
S16	Phra Khanong BMA	47P	673253	1515382	5.69	5.66	4.99	7.24	5.85	-
S17	Rat Burana BMA	47N	662865	1513090	4.40	4.12	3.11	4.04	4.13	4.35

HI map from the year 2008 to 2013 were also drawn in order to illustrate tendency of health impact, caused by exposure of BTEX in CBD of Bangkok. Temporal difference of HI can be explained by difference in variation of benzene concentration which was greatly affected to calculated HI value. Results were as shown in Figure 4.52 – 4.57.

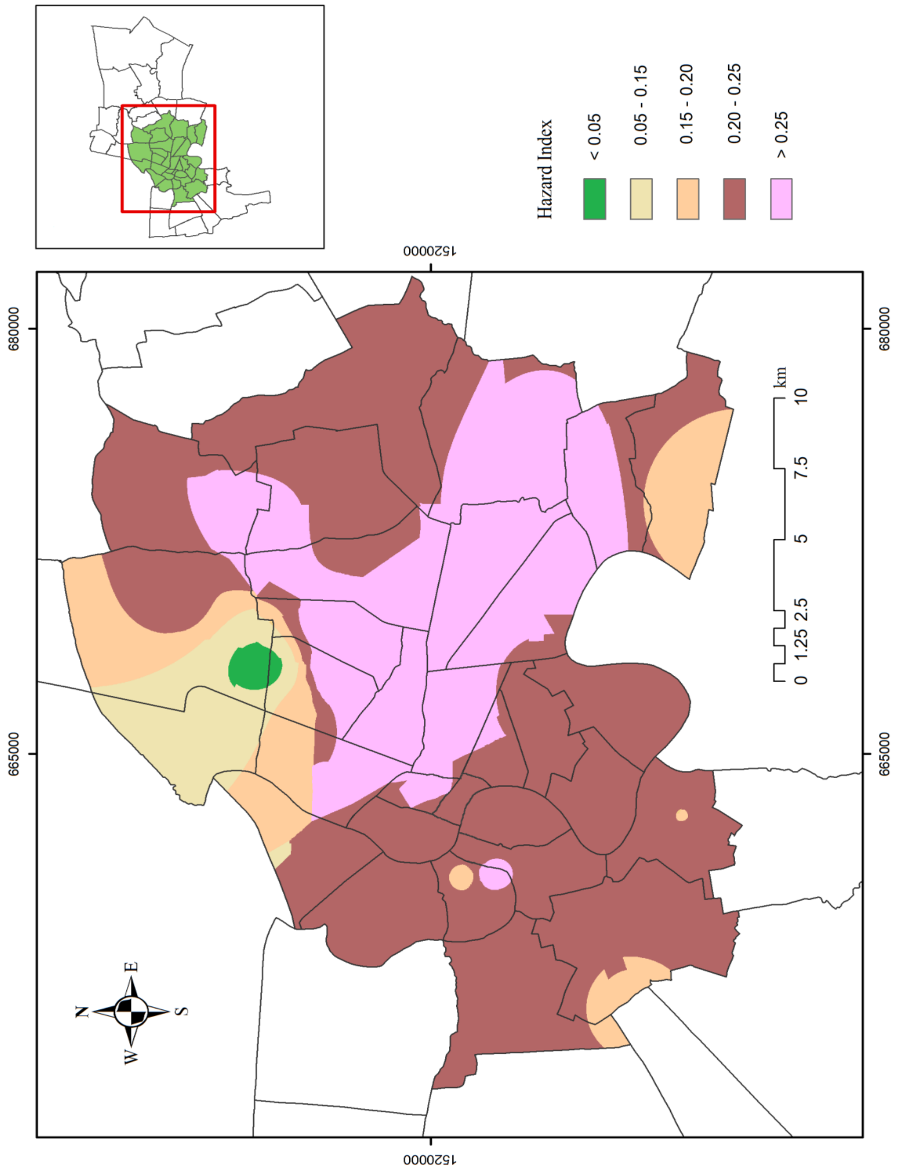


Figure 4.52 Hazard Index map for the year 2008

Calculated HI was found lower than 1 at every year. Therefore, the HI value of more than 0.25 (>0.25) was used in this analysis. It was found than in the year 2008, an area having HI > 0.25 covering 106.78 km^2 of the total area (19 districts) where they were 807,107 people living in this zone.

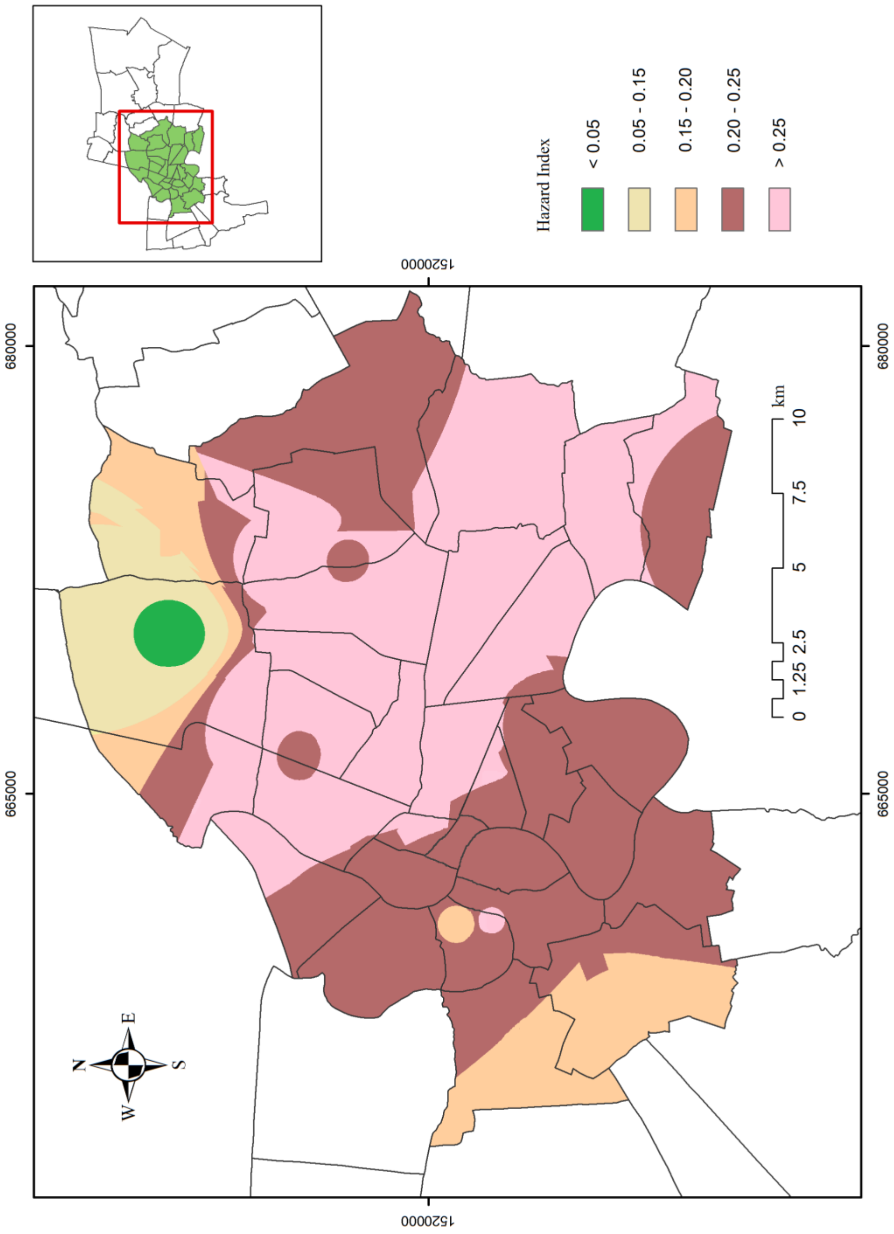


Figure 4.53 Hazard Index map for the year 2009

Calculated HI was found lower than 1. Therefore, the HI value of more than 0.25 (>0.25) was used in this analysis. It was found than in the year 2009, an area having HI > 0.25 covering 147.94 km^2 of the total area (22 districts) where they were 1,090,295 people living in this zone.

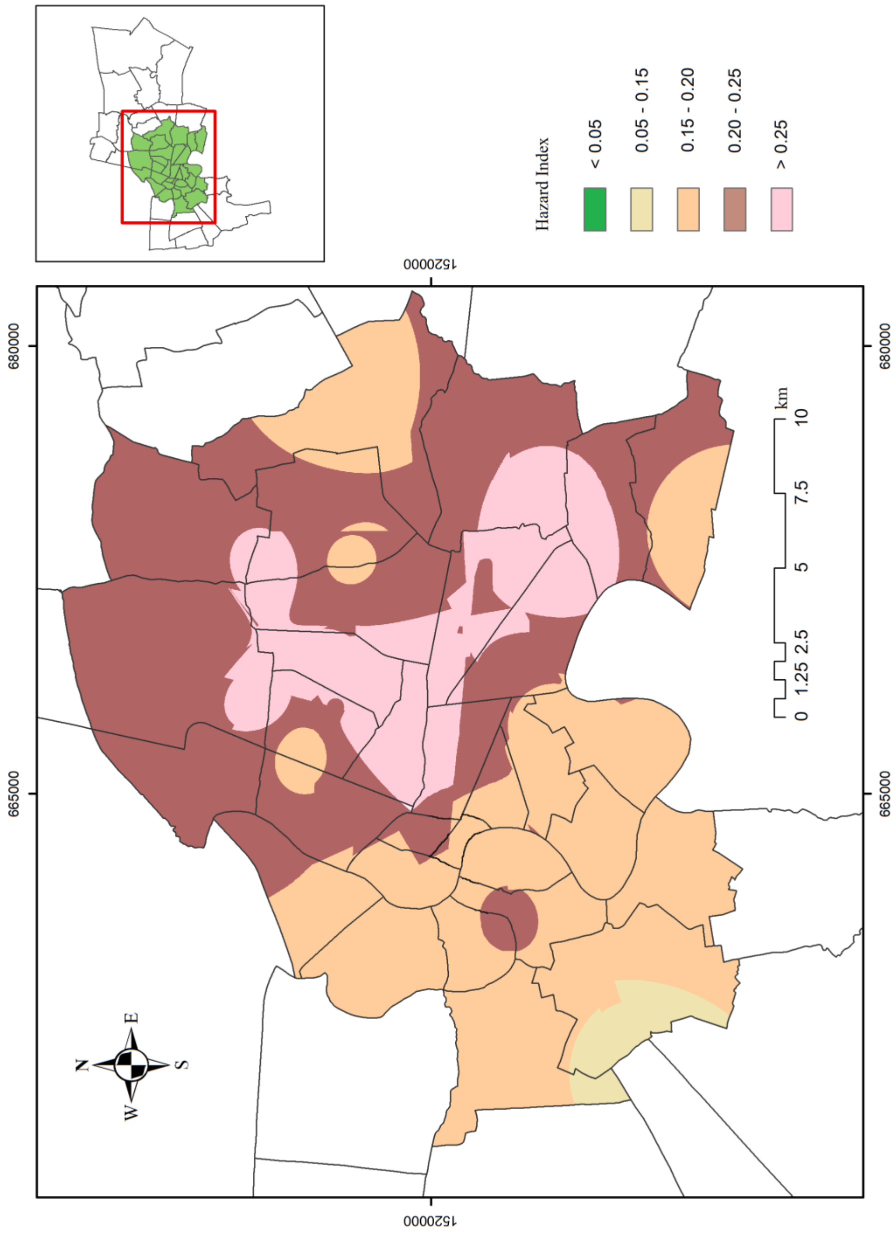


Figure 4.54 Hazard Index map for the year 2010

Calculated HI was found lower than 1. Therefore, the HI value of more than 0.25 (>0.25) was used in this analysis. It was found than in the year 2010, an area having HI > 0.25 covering 63.46 km^2 of the total area (13 districts) where they were 498,918 people living in this zone.

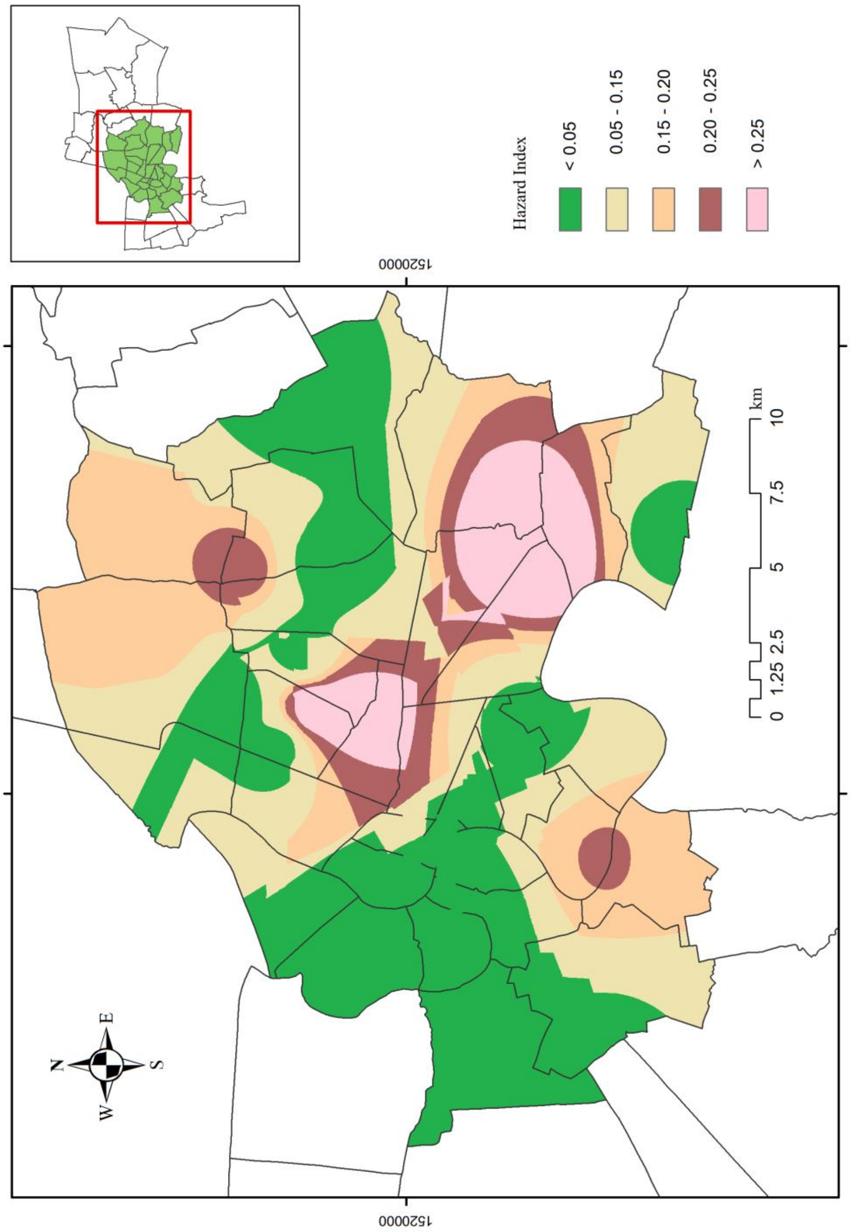


Figure 4.55 Hazard Index map for the year 2011

Calculated HI was found lower than 1. Therefore, the HI value of more than 0.25 (>0.25) was used in this analysis. It was found than in the year 2011, an area having HI > 0.25 covering 33.06 km^2 of the total area (8 districts) where they were 251,000 people living in this zone.

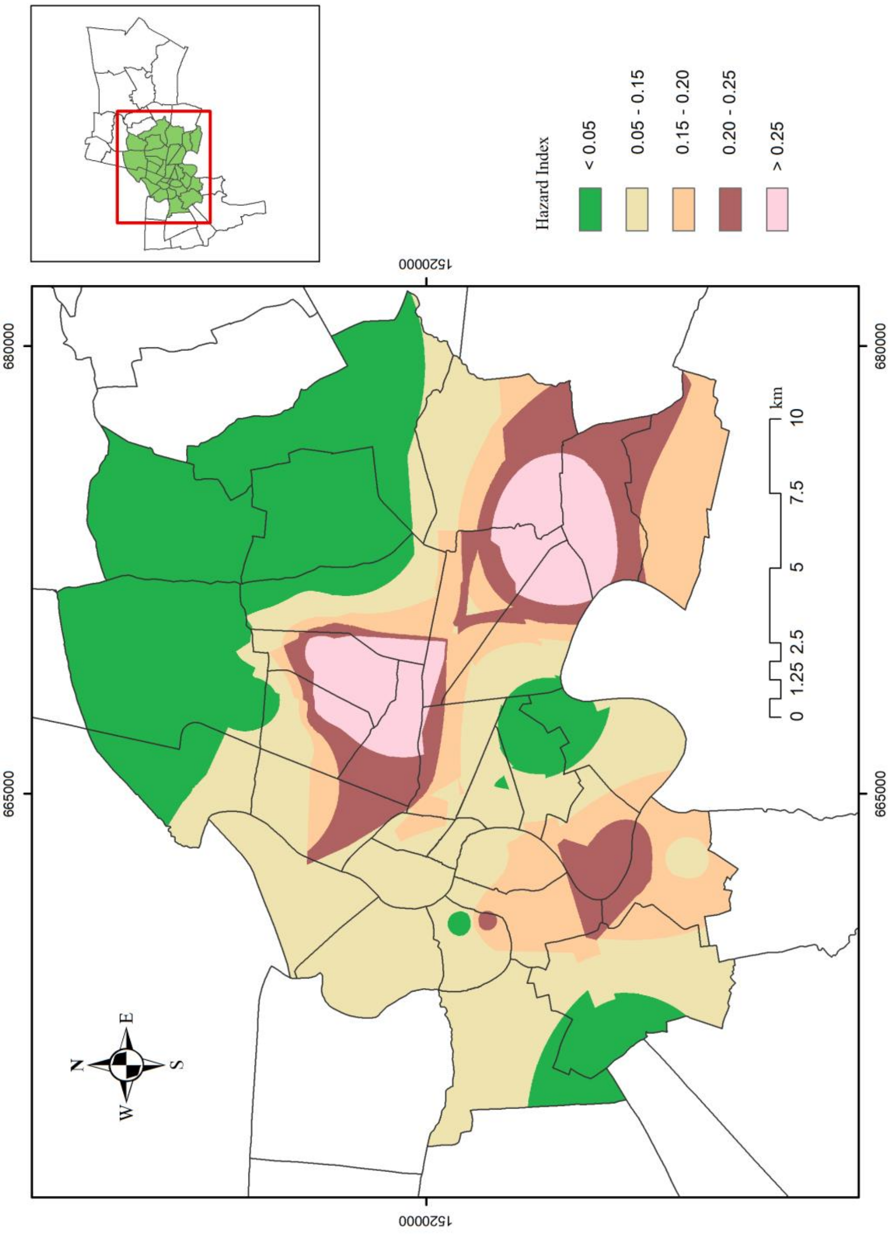


Figure 4.56 Hazard Index map for the year 2012

Calculated HI was found lower than 1. Therefore, the HI value of more than 0.25 (>0.25) was used in this analysis. It was found than in the year 2012, an area having HI > 0.25 covering 31.10 km^2 of the total area (9 districts) where they were 268,978 people living in this zone.

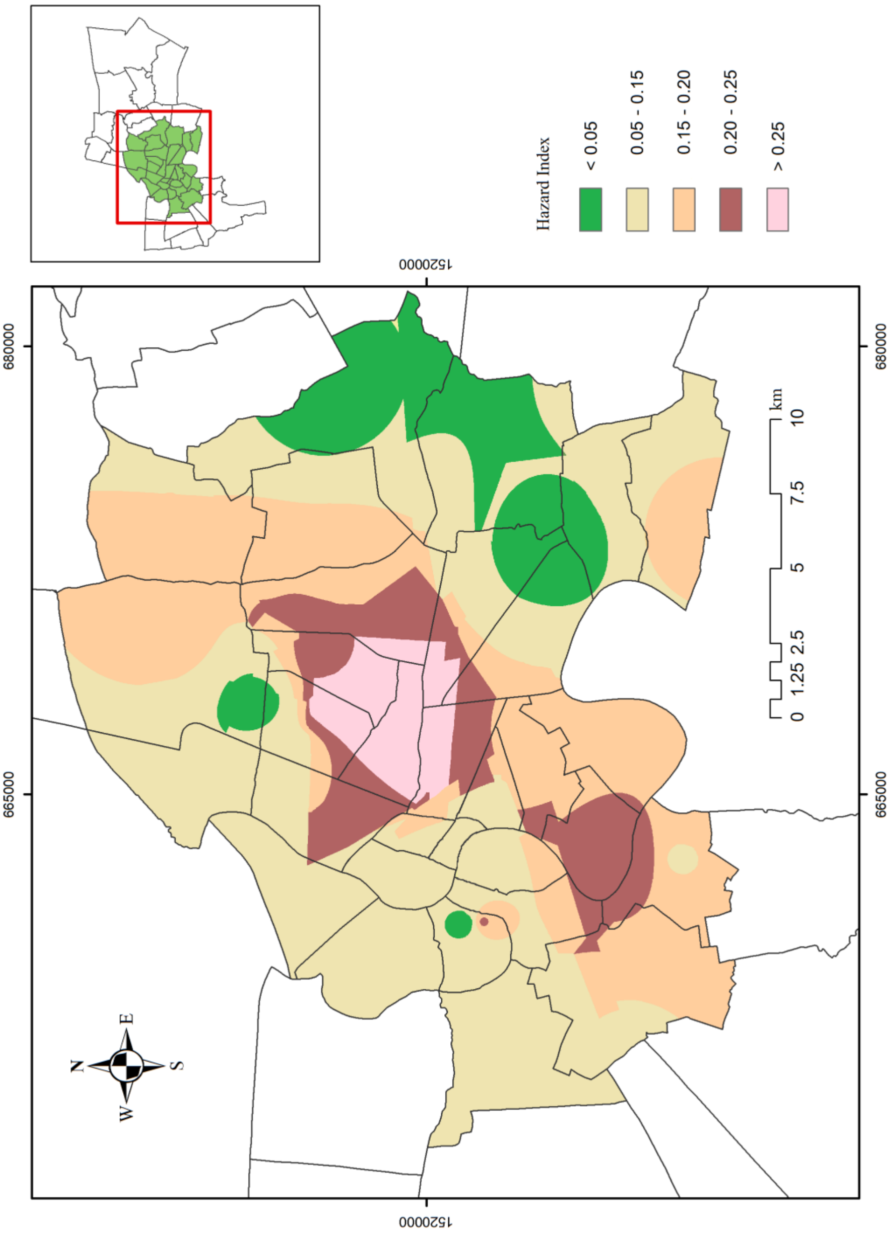


Figure 4.57 Hazard Index map for the year 2013

Calculated HI was found lower than 1. Therefore, the HI value of more than 0.25 (>0.25) was used in this analysis. It was found than in the year 2013, an area having HI > 0.25 covering 19.17 km^2 of the total area (7 districts) where they were 183,994 people living in this zone.

The populations living in an area having HI > 0.25 were as shown Table 4.36. Decreasing tendency of impact zone and number of exposed population was found in the central business district of Bangkok. This result could be explained by successful mitigation for VOCs controlling and management particularly those measures related to mobile source emission control.

Table 4.36 Summary of HI impact zone

Year	**Impact zone (km^2)**	**Population (person)**
2008	106.78	807,107
2009	147.94	1,090,295
2010	63.46	498,918
2011	33.06	251,000
2012	31.10	268,978
2013	19.17	183,994

CHAPTER V
CONCLUSION AND RECOMMENDATION

The overall results and findings from this study are summarized in this chapter. Conclusions with respect to the objectives of the study are presented. The mathematical equation and hazard index of BTEX and 1, 3-butadiene in the study area are illustrated, it also provides recommendation.

5.1 Conclusion

5.1.1 Numerical equation for predicting BTEX and 1, 3-butadiene

Daily average (24 hour average) of BTEX, 1, 3-butadiene and conventional air monitoring data (including CO, NO, NO_2 and NO_x) were used in the correlation analysis. Even though monitor data of each compound were not derived from the same period during the day, efforts were paid to compare the most similar period of the day for each data set. The existing conventional air pollution monitoring data was substituted in the equation. The equations were created by best fit plot with BTEX and 1, 3-butadiene. Measured data within the range of 5^{th} - 95^{th} percentile concentrations from 2008 to 2011 were used to formulate an equation. The equation for predicting BTEX and 1, 3-butadiene concentration can be written as;

$$\begin{aligned} Benzene = {} & [-2.376E-04(NO_2)^2 + 0.0858(NO_2) - 0.298] + \\ & [1.65E-07(CO)^2 + 1.045E-03(CO) + 0.986] - [0.299(NO)^{0.398}] \end{aligned}$$

$$\begin{aligned} Toluene = {} & [-1.881E-04(NO_x)^2 + 0.1927(NO_x) + 0.8645] + \\ & [3.504E-06(CO)^2 + 1.533E-03(CO) + 6.0606] \end{aligned}$$

$$
\begin{aligned}
Ethylbenzene = {} & [9.84E-05(NO_2)^2 + 0.0189(NO_2) + 0.2321] - \\
& [1.045E-05(NO)^2 + 16.7298E-03(NO) + 0.3131] - \\
& [5.08E-06(NO_x)^2 + 6.2738E-03(NO_x) + 0.1661]
\end{aligned}
$$

$$
\begin{aligned}
Xylene = {} & [1.062E-04(NO)^2 + 0.0578(NO) + 1.4529] + \\
& [0.0396(NO_2)^{1.0983}] + [2.74E-07(CO)^2 + 2.877E-04(CO) + 0.2571]
\end{aligned}
$$

$$
\begin{aligned}
1,3-Butadiene = {} & [6.4E-07(CO)^2 - 7.2E-04(CO) + 0.1076] + \\
& [5.43E-06(NO_x)^2 + 0.1818(NO_x) - 0.0823]
\end{aligned}
$$

Statistical analysis is employed to evaluate performance of the equation by comparing of modeled and measured data. Generally, it was found the model performance well in predicting overall concentration of every air toxic compounds except for 1, 3-butadiene. Results from RHC indicated a good performance of the model in predicting extreme high end concentration of benzene, ethylbenzene, xylene and toluene respectively. As for 1, 3-butadiene, RHC_p was slightly higher than RHC_o. This finding indicated over estimation of this compound from numerical simulation. The equation for predicting BTEX concentration for the year 2012 to 2013 can be written as;

$$
\begin{aligned}
Benzene = {} & [2.168E-07(CO)^2 + 1.1382E-03(CO) + 0.4139] \\
& + [0.3463(NO)^{0.4393})]
\end{aligned}
$$

$$
Toluene = [6.52E-05(NO)^2 + 0.2148(NO) + 16.5437] + [6.103e^{0.0144(NO_2)}]
$$

$$
Ethylbenzene = [1.8518e^{0.013(NO_2)} - 0.062]
$$

$$
\begin{aligned}
Xylene = {} & [-1.73E-05(NO_x)^2 + 0.0215(NO_x) - 0.05] + \\
& [0.0975(NO)^{1.0983} + (9.78E-05(NO_2)^2 + 0.0317(NO_2) + 0.25]
\end{aligned}
$$

Statistical analysis is employed to evaluate performance of the equation by comparing of modeled and measured data. Generally, it was found the model performance well in predicting overall concentration of every air toxic compounds. Results from RHC indicated a good performance of the model in predicting extreme high end concentration of xylene. As for benzene, toluene and ethlybenzene, RHC_p was slightly higher than RHC_o. This finding indicated over estimation of these compounds from numerical simulation.

5.1.2 Pollution map

The pollution maps were drawn by using Geological Information System (GIS) techniques. Three difference spatial interpolation techniques were tested in order to determine the best interpolation scheme which most fit for this study. They were the Ordinary Kriging, the Inverse Distance Weighted (IDW) and the Spline. Results from cross validation indicated that in general, IDW perform much better than other techniques. Therefore, interpolation of benzene map was drawn using the IDW method. The impact zone was defined as an area having annual average concentration of benzene higher than the Thai ambient air quality standard for benzene (1.7 $\mu g/m^3$) had decreasing tendency from the year 2008 to 2013. This could be explained by a success of mitigation measure for VOCs management policy such as implementation of EURO IV standard which has been commenced since January 1, 2012. Spatial distribution map illustrated that benzene concentrations had decreasing tendency from the year 2008 to 2013. These finding elucidated the effectiveness of changing of fuel quality to the reduction of airborne air toxic concentration in Bangkok environment (Thongkum and Thepanondh, 2014).

In order to evaluate a chronic non-cancer effect from VOCs, the concept of hazard quotient (HQ) and hazard index (HI) were applied in this study. HQ of each compound was calculated by using annual average concentration divided by reference concentration (RfC). HI is the sum of the HQs from toxic air pollutants that affect the same organ systems. Calculated results of HQ and HI for the year 2008 to 2013 were less than 1, indicated that there were no adverse health effects to the population in the study area. It was also found that tendency of area having HI > 0.25 was decreased from the year 2008 to 2013. The population in impact zone of benzene and HI were as shown in Table 5.1.

Table 5.1 Summary of benzene and HI impact zone

Year	**Benzene conc. ≥ 1.7 μg/m^3**		**HI ≥ 0.25**	
	Impact zone (km^2)	**Population (person)**	**Impact zone (km^2)**	**Population (person)**
2008	404.29	2,937,588	106.78	807,107
2009	397.06	2,905,373	147.94	1,090,295
2010	408.92	2,977,314	63.46	498,918
2011	189.06	1,233,787	33.06	251,000
2012	253.36	2,021,867	31.10	268,978
2013	290.53	2,122,887	19.17	183,994

5.2 Recommendation

- Representativeness of monitoring site is crucial parameter in developing and accessing air pollution situation particularly when health impact is needed to be evaluated.
- Spatial distribution of air monitoring station should be sparsely covered the entire Bangkok area.

REFERENCES

Almaza, V. H., Batyrshin, I., and Sosa, G. (2014). Multi-criteria selection of an Air Quality Model configuration based on quantitative and linguistic evaluations. *Journal of Expert Systems with Applications, 41,* pp. 869-876.

ArcGIS Resource Center. (2013). *Welcome to the ArcGIS Help Library*. http://help.arcgis.com/en/arcgisdesktop/10.0/help. Access: 9 January 2013.

BMA. (2014). *Population in Bangkok metropolis.* http://www.bangkok.go.th/info/ Access: 24 May, 2014.

Borgir, M., Garat, A., Cazier, F., Delbende, A., Allorge, D., Ledoux, F., Courcot, D., Shirali, P., and Dagher, Z. (2014). Traffic-related air pollution. A pilot exposure assessment in Beirut, Lebanon. *Chemosphere, 96,* pp.122-128.

California Environmental Protection Agency. (2001). *A Guide to Health Risk Assessment*. Office of Environmental Health Hazard Assessment, California.

California Environmental Agency. (2003). *The air toxics hotspots program guidance manual for preparation of health risk assessments.* http://oehha.ca.gov/air/hot_spots/hraguidefinal.html. Access: 10 June 2014.

Elbir, T. (2003). Comparison of model predictions with the data of an urban air quality monitoring network in Izmir, Turkey. *Atmospheric Environment, 37*, pp. 2149-2157.

Eldrandaly, K. A., and Abu-Zaid, M. S. (2011). Comparison of six GIS-based spatial interpolation methods for estimating air temperature in Western Saudi Arabia. *Journal of Environmental Informatics, 18(1),* pp.38-45.

Gulliver, J., Hoogh, K.D., Fecht, D., Vienneau, D., and Briggs, D. (2011). Comparative assessment of GIS-based methods and metrics for estimating long-term exposures to air pollution. *Atmospheric Environment, 45*, pp. 7072-7080.

IRIS. (2013). *Integrated Risk Information System (IRIS).* http://cfpub.epa.gov/ncea/iris/index.cfm?fuseaction=iris.showSubstanceList. Access: 8 October, 2013.

Kajihara, H., Ishizuka, S., Fushimi, A., Masuda, A., and Nakanishi, J. (2000). Population risk assessment of ambient benzene and evaluation of benzene regulation in gasoline in Japan, *Environmental Engineering and Policy 2*(1), pp.1-9.

PCD. (2009). *Development of Environmental and Emission Standard of Volatile Organic Compounds (VOCs) in Thailand.* PCD, Bangkok, Thailand, August 2009.

Robinson, T. P., and Metternicht, G., (2006). Testing the performance of spatial interpolation techniques for mapping soil properties. *Computer and electronics in agriculture, 50*, pp.97-108.

Thepanondh, S., and Toruksa, W. (2011). Proximity analysis of air pollution exposure and its potential risk. *Journal of Environmental Monitoring, 13,* pp.1264-1270.

Thepanondh, S.,Varoonphan, J., Sarutichart, P., and Makkasap, T. (2011). Airborne volatile organic compounds and their potential health impact on the vicinity of petrochemical industrial complex. *Water Air Soil Pollution, 214,* pp.83-92.

Thongkum, W., and Thepanondh, S. (2014). Impact of fuel switching to the level of air toxic and its potential health impact in Bangkok, Thaialnd. *Advanced Material Research, 931-932*, pp. 671-675.

Truc, V. T. Q., and Oanh, N. T. K. (2007). Roadside BTEX and other gaseous air pollutants in relation to emission sources. *Atmospheric Environment, 41,* pp.7685-7697.

US.EPA. (2012a). *Volatile Organic Compounds (VOCs).* http://www.epa.gov/iaq/voc2.html. Access: 8 November, 2012.

US.EPA. (2012b). *Glossary of Key Terms.* http://www.epa.gov/nata/gloss1.html. Access: 8 November, 2012.

US.EPA. (2012c). Case Study: Site-specific Human Health Risk Assessment for a Metal Smelter. *Training Course on Risk Assessment Training and Experience (RATE) Principles and Understanding of Risk Assessments* 8–9 September 2012. Bangkok, Thailand.

US. EPA. (2014a). *1, 3-butadiene.* http://www.epa.gov/ttn/atw/hlthef/butadien.html. Access: 20 January, 2014.

US.EPA. (2014b). *Region 5 Air and radiation.* http://www.epa.gov/reg5oair/naaqs/definitions.html. Access: 20 January, 2014.

USGS. (2014). *Environmental health-toxic substances.* http://toxics.usgs.gov/definitions/btex.html. Access: 15 April, 2014.

Vlachokostas, Ch., Chourdakis, E., Michalidou, A.V., Moussiopoulos, N., Kelessis, A., and Petrakakis, M. (2012). Establishing relationships between chemical health stressors in urban traffic environments: Prediction of toluene concentration levels in European cities. *Atmospheric Environment, 55*, pp.299-310.

WHO. (2014). *Ambient (outdoor) air quality and health.* http://www.who.int/mediacentre/factsheets/fs313/en/ Access: 15 April, 2014

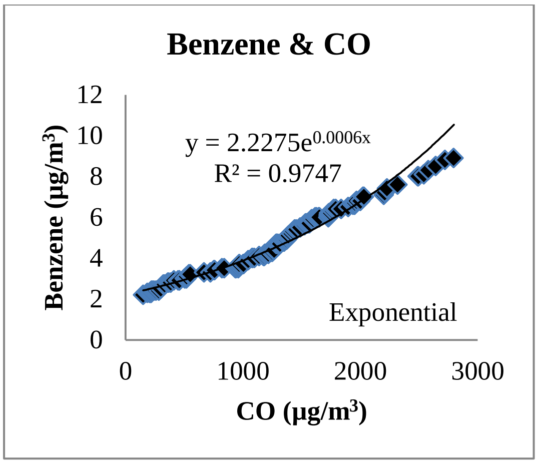
Wu, X.M., Fan, Z.T., Zhu, X. Jung, K.H., Ohman-Strickland, P., Weisel, C.P., and Lioy, P.J. (2012). Exposures to volatile organic compounds (VOCs) and associated health risks of socio-economically disadvantaged population in a “hot spot” in Camden, New Jersey. *Atmospheric Environment, 57*, pp.72-79.

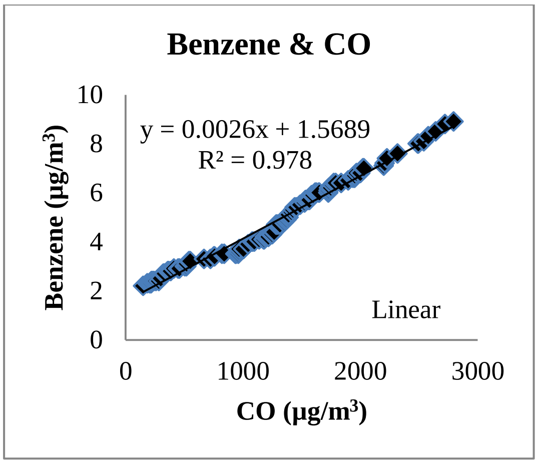
Zhou, J., You, Y., Bai, Z., Hu, Y., Zhang, J., and Zhang, N. (2011). Health risk assessment of personal inhalation exposure to volatile organic compounds in Tianjin, China. *Science of the Total Environment, 409*, pp.452–459.

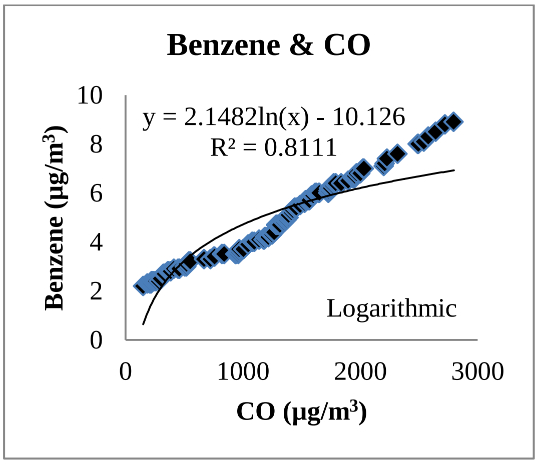
APPENDICES

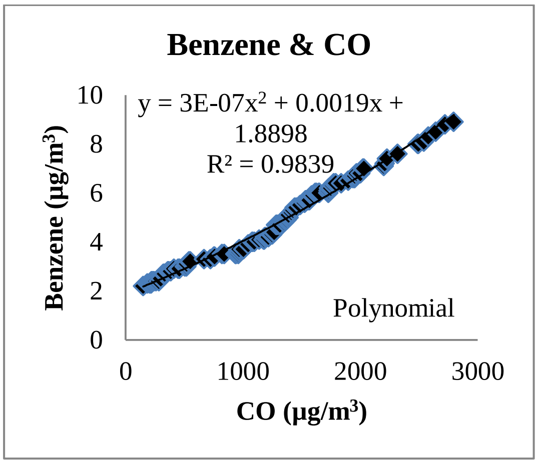
APPENDIX A

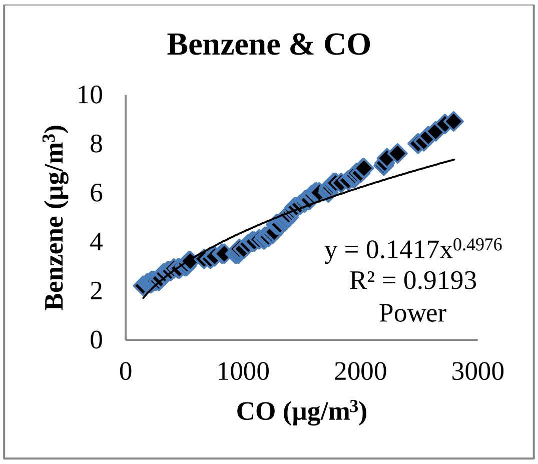
A SELECTION OF BEST FIT PLOT OF DATA FROM 2008 -2011

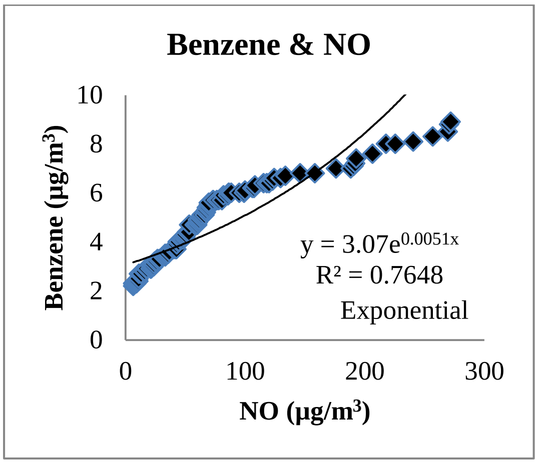


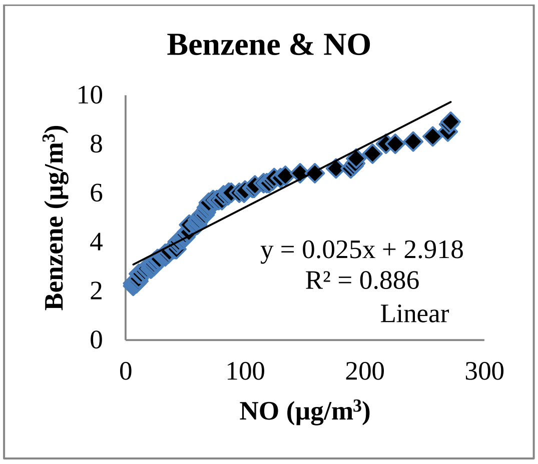


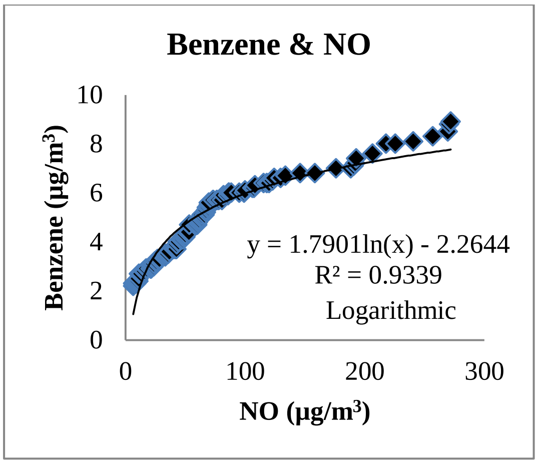


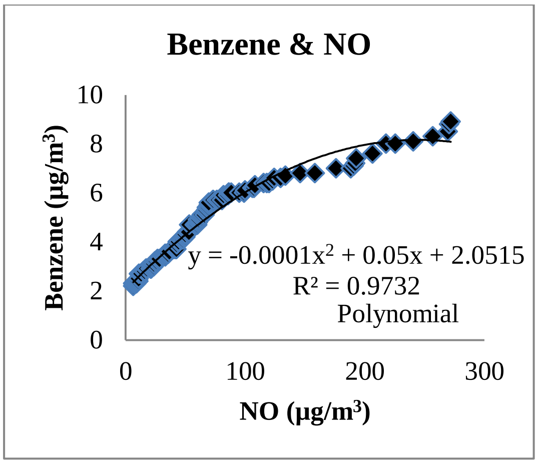


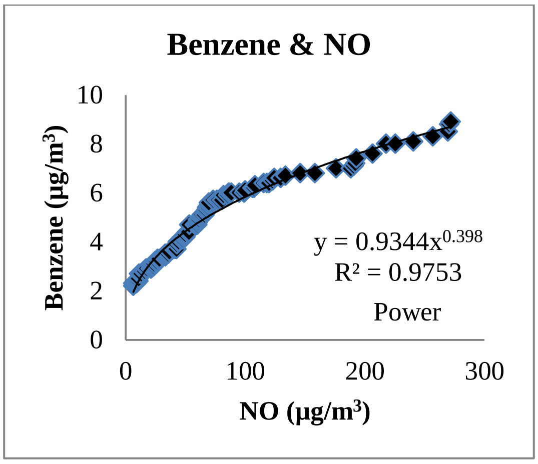


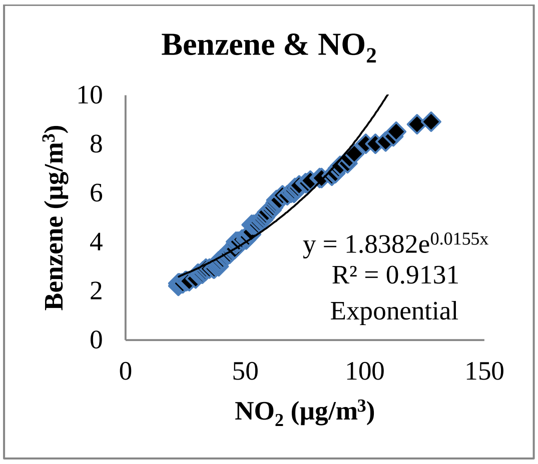

Benzene & NO
Benzene (µg/m³)
10
8
6
4
2
0
0
100
200
300
NO (µg/m³)
y = 3.07e^0.0051x
R² = 0.7648
Exponential

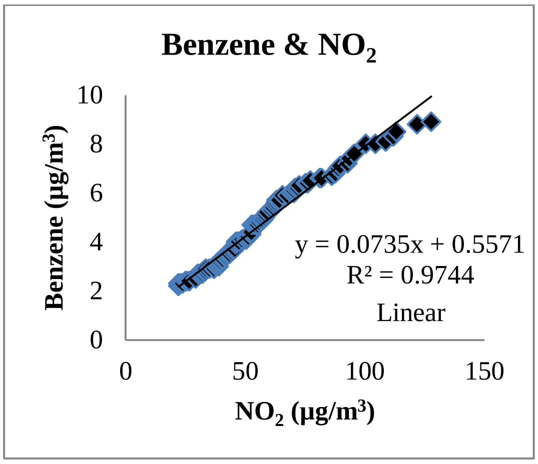

Benzene & NO
Benzene (µg/m³)
10
8
6
4
2
0
0
100
200
300
NO (µg/m³)
y = 0.025x + 2.918
R² = 0.886
Linear

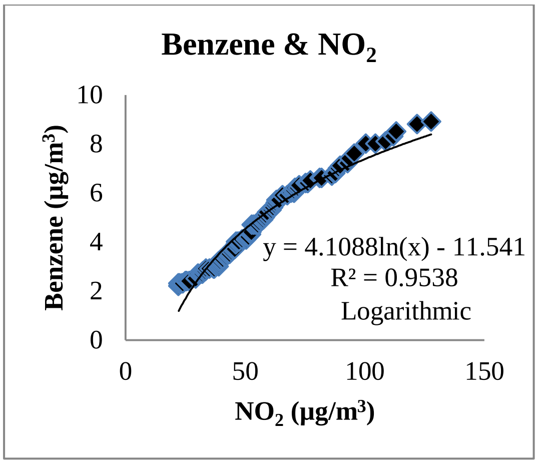

Benzene & NO
Benzene (µg/m³)
10
8
6
4
2
0
0
100
200
300
NO (µg/m³)
y = 1.7901ln(x) - 2.2644
R² = 0.9339
Logarithmic

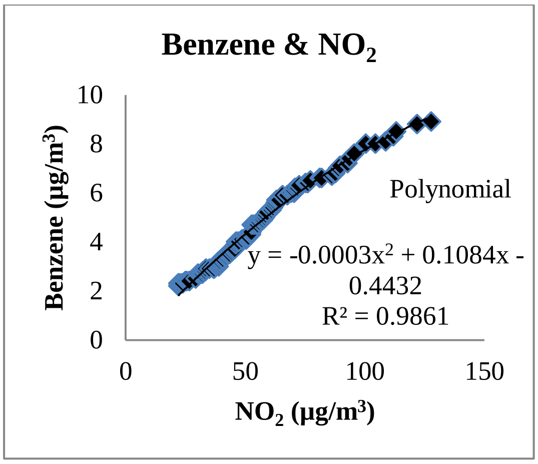

Benzene & NO
Benzene (µg/m³)
10
8
6
4
2
0
0
100
200
300
NO (µg/m³)
y = -0.0001x² + 0.05x + 2.0515
R² = 0.9732
Polynomial

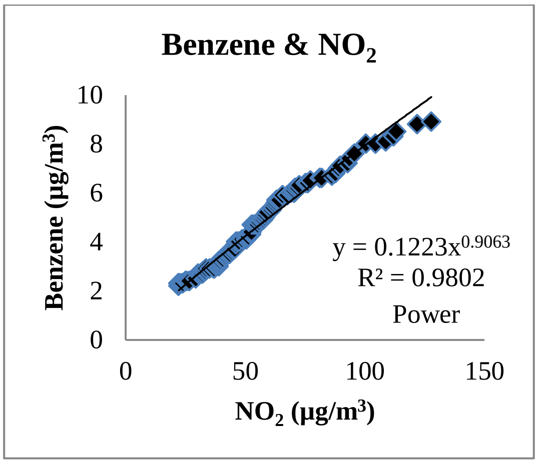

Benzene & NO
Benzene (µg/m³)
10
8
6
4
2
0
0
100
200
300
NO (µg/m³)
y = 0.9344x^0.398
R² = 0.9753
Power

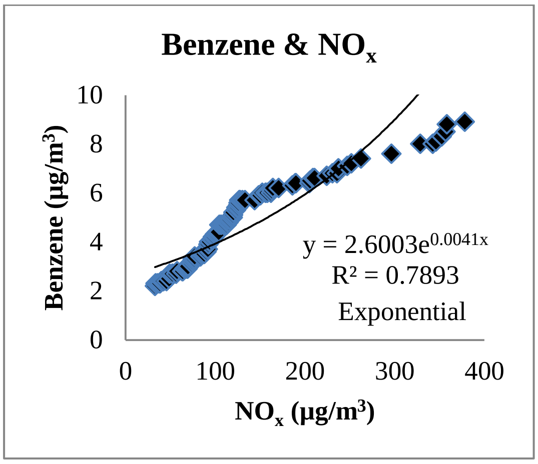

Benzene & NO_2
Benzene (µg/m^3)
10
8
6
4
2
0
0
50
100
150
NO_2 (µg/m^3)
$y = 1.8382e^{0.0155x}$
$R^2 = 0.9131$
Exponential

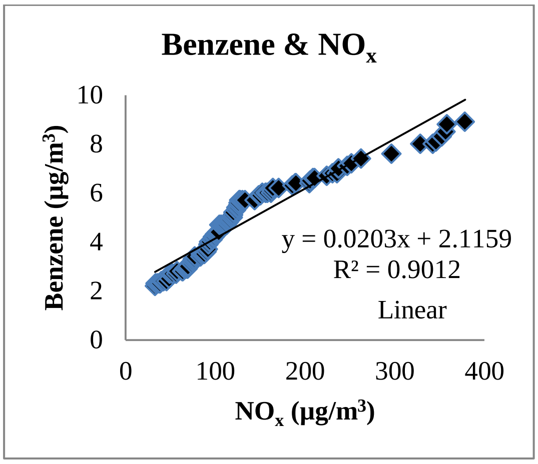

Benzene & NO_2
Benzene (µg/m^3)
10
8
6
4
2
0
0
50
100
150
NO_2 (µg/m^3)
$y = 0.0735x + 0.5571$
$R^2 = 0.9744$
Linear

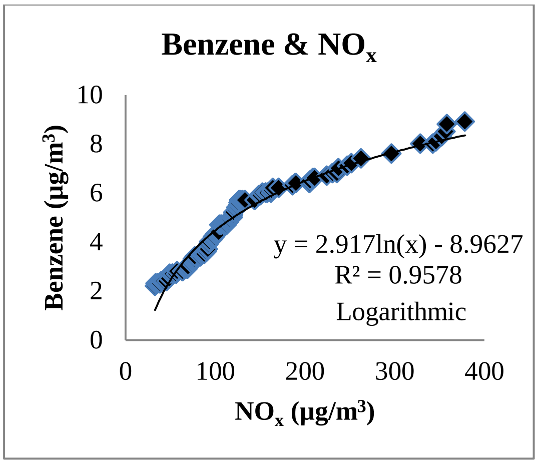

Benzene & NO_2
Benzene (µg/m^3)
10
8
6
4
2
0
0
50
100
150
NO_2 (µg/m^3)
$y = 4.1088\ln(x) - 11.541$
$R^2 = 0.9538$
Logarithmic

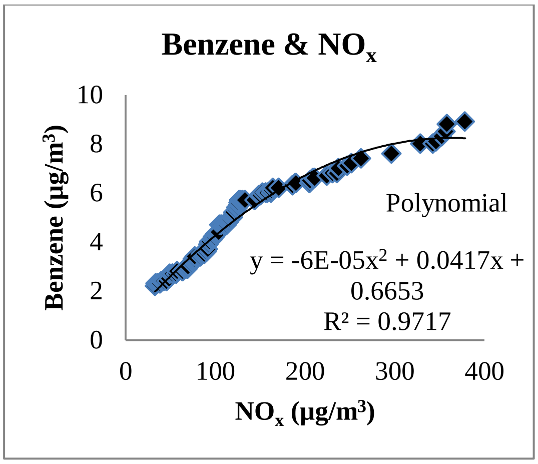

Benzene & NO_2
Benzene (µg/m^3)
10
8
6
4
2
0
0
50
100
150
NO_2 (µg/m^3)
Polynomial
$y = -0.0003x^2 + 0.1084x - 0.4432$
$R^2 = 0.9861$

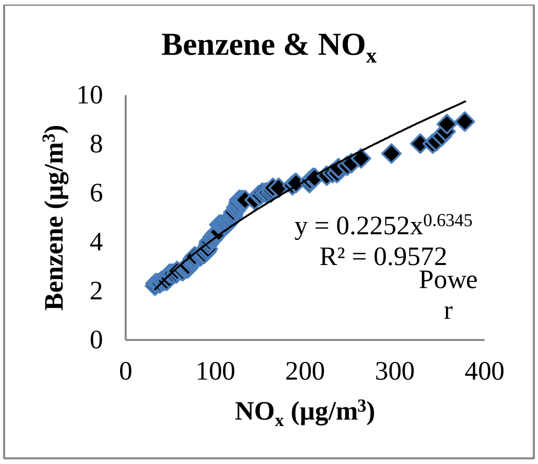

Benzene & NO_2
Benzene (µg/m^3)
10
8
6
4
2
0
0
50
100
150
NO_2 (µg/m^3)
$y = 0.1223x^{0.9063}$
$R^2 = 0.9802$
Power

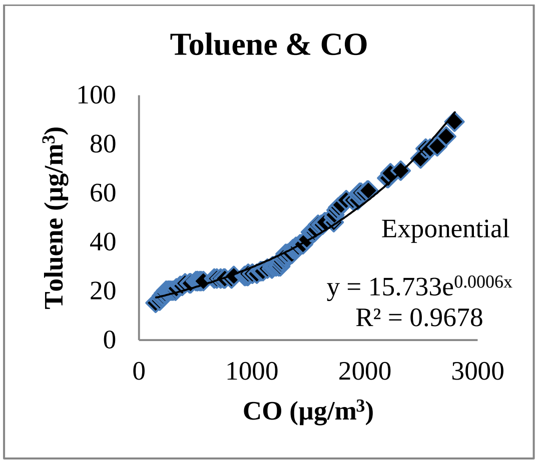

Benzene & NO_x
Benzene (µg/m^3)
10
8
6
4
2
0
0
100
200
300
400
NO_x (µg/m^3)
$y = 2.6003e^{0.0041x}$
$R^2 = 0.7893$
Exponential

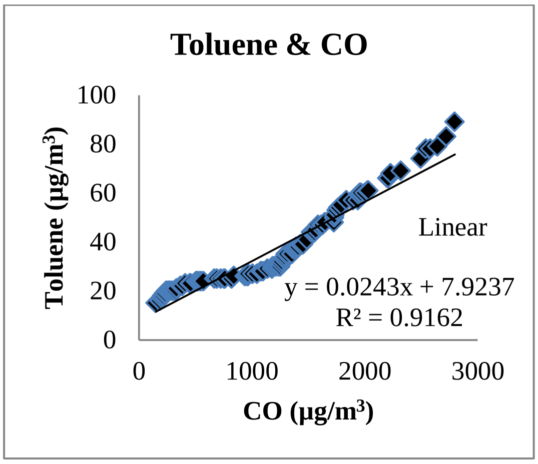

Benzene & NO_x
Benzene (µg/m^3)
10
8
6
4
2
0
0
100
200
300
400
NO_x (µg/m^3)
$y = 0.0203x + 2.1159$
$R^2 = 0.9012$
Linear

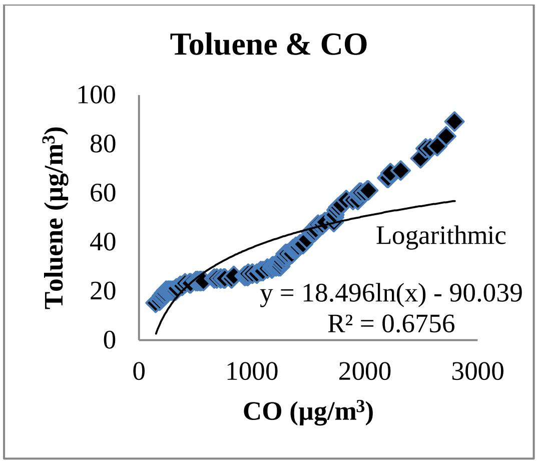

Benzene & NO_x
Benzene (µg/m^3)
10
8
6
4
2
0
0
100
200
300
400
NO_x (µg/m^3)
$y = 2.917\ln(x) - 8.9627$
$R^2 = 0.9578$
Logarithmic

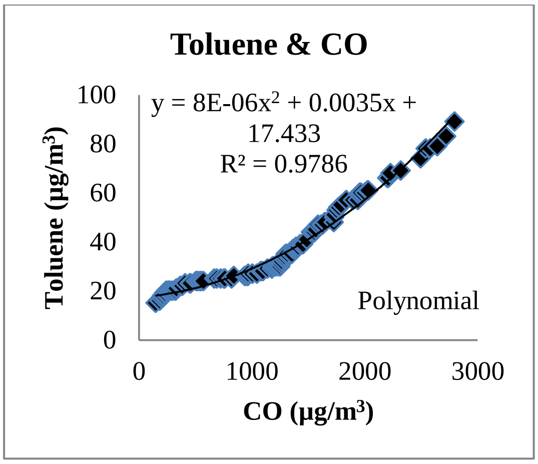

Benzene & NO_x
Benzene (µg/m^3)
10
8
6
4
2
0
0
100
200
300
400
NO_x (µg/m^3)
Polynomial
$y = -6E-05x^2 + 0.0417x + 0.6653$
$R^2 = 0.9717$

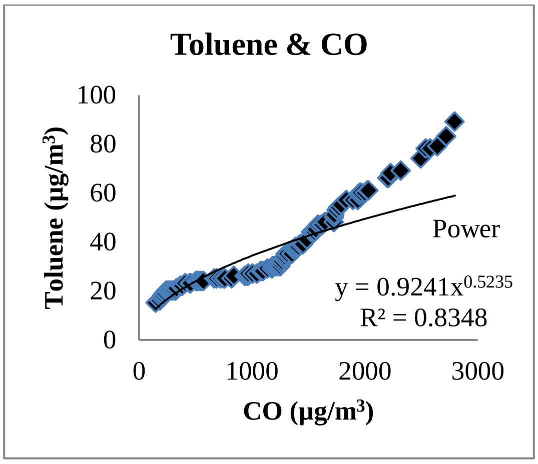

Benzene & NO_x
Benzene (µg/m^3)
10
8
6
4
2
0
0
100
200
300
400
NO_x (µg/m^3)
$y = 0.2252x^{0.6345}$
$R^2 = 0.9572$
Powe
r

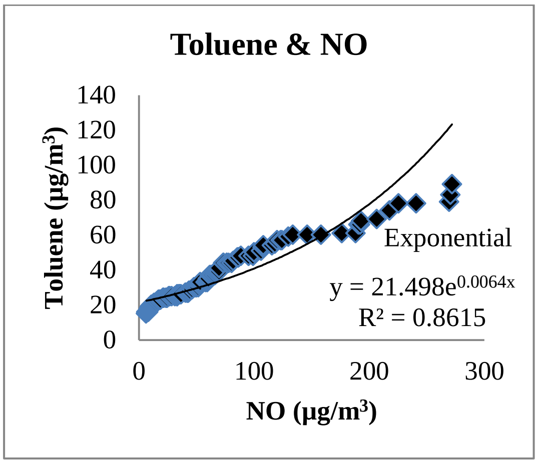

Toluene & CO
Toluene (µg/m³)
100
80
60
40
20
0
0
1000
2000
3000
CO (µg/m³)
Exponential
y = 15.733e^0.0006x
R² = 0.9678

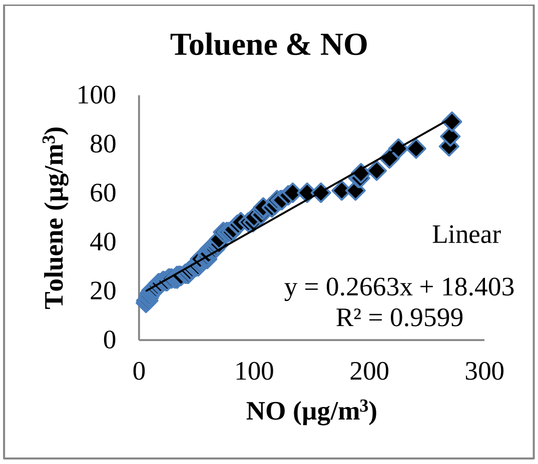

Toluene & CO
Toluene (µg/m³)
100
80
60
40
20
0
0
1000
2000
3000
CO (µg/m³)
Linear
y = 0.0243x + 7.9237
R² = 0.9162

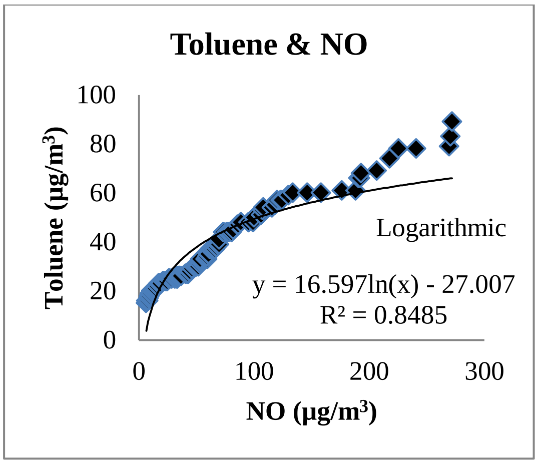

Toluene & CO
Toluene (µg/m³)
100
80
60
40
20
0
0
1000
2000
3000
CO (µg/m³)
Logarithmic
y = 18.496ln(x) - 90.039
R² = 0.6756

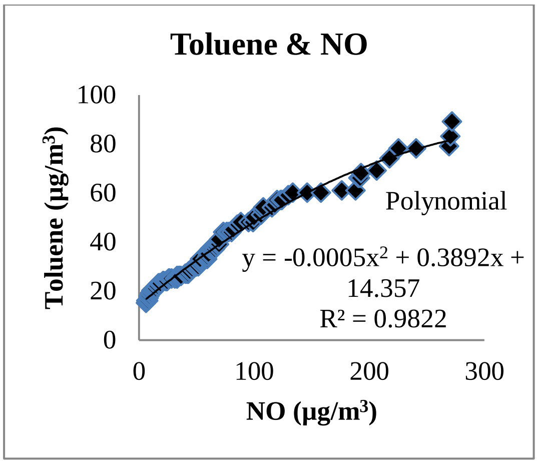

Toluene & CO
Toluene (µg/m³)
100
80
60
40
20
0
0
1000
2000
3000
CO (µg/m³)
y = 8E-06x² + 0.0035x + 17.433
R² = 0.9786
Polynomial

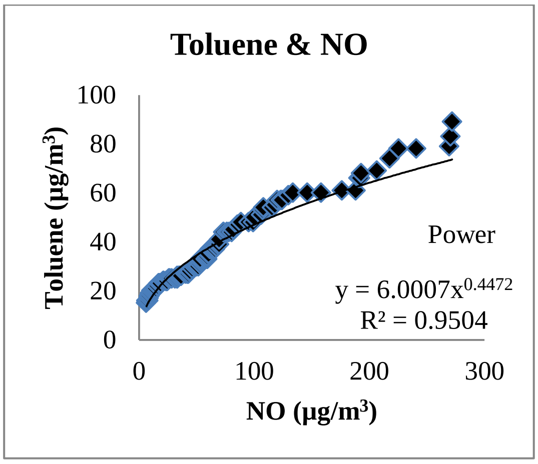

Toluene & CO
Toluene (µg/m³)
100
80
60
40
20
0
0
1000
2000
3000
CO (µg/m³)
Power
y = 0.9241x^0.5235
R² = 0.8348

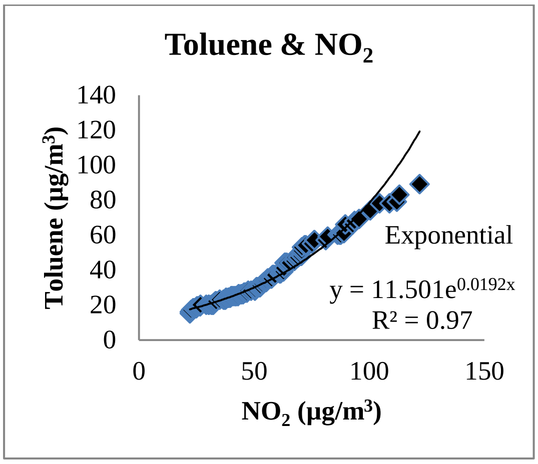

Toluene & NO
Toluene (μg/m^3)
0
20
40
60
80
100
120
140
NO (μg/m^3)
0
100
200
300
Exponential
y = 21.498e$^{0.0064x}$
R² = 0.8615

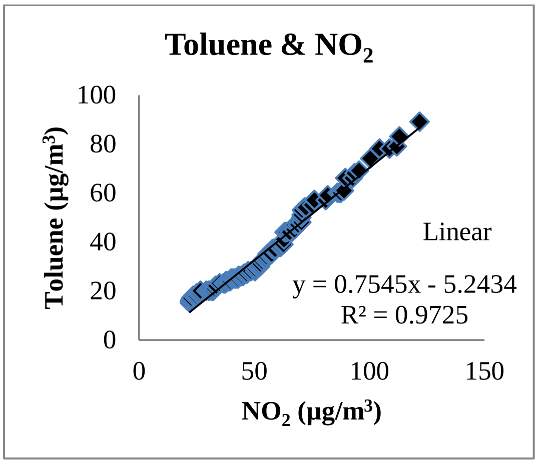

Toluene & NO
Toluene (μg/m^3)
0
20
40
60
80
100
NO (μg/m^3)
0
100
200
300
Linear
y = 0.2663x + 18.403
R² = 0.9599

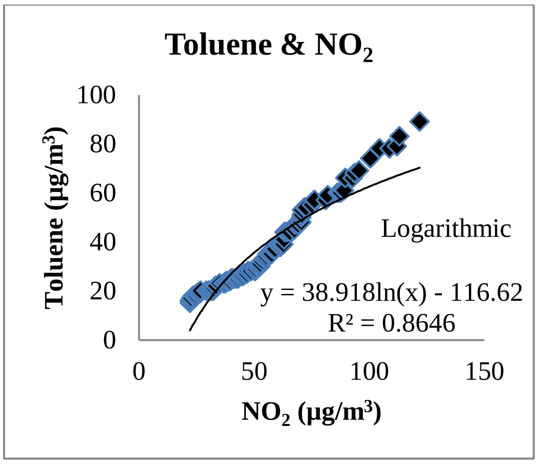

Toluene & NO
Toluene (μg/m^3)
0
20
40
60
80
100
NO (μg/m^3)
0
100
200
300
Logarithmic
y = 16.597ln(x) - 27.007
R² = 0.8485

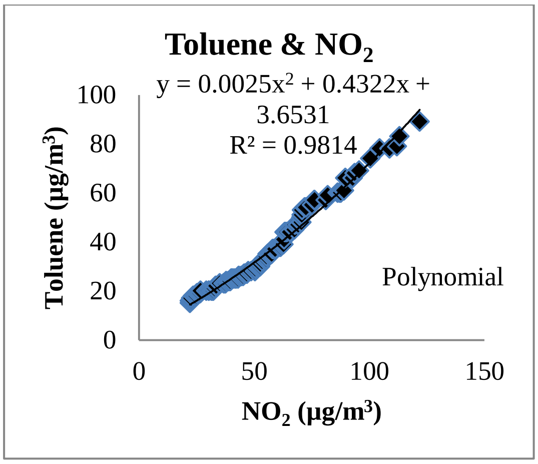

Toluene & NO
Toluene (μg/m^3)
0
20
40
60
80
100
NO (μg/m^3)
0
100
200
300
Polynomial
y = -0.0005x^2 + 0.3892x + 14.357
R² = 0.9822

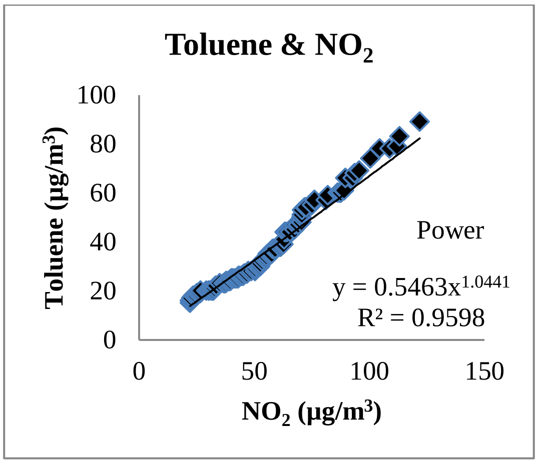

Toluene & NO
Toluene (μg/m^3)
0
20
40
60
80
100
NO (μg/m^3)
0
100
200
300
Power
y = 6.0007x$^{0.4472}$
R² = 0.9504

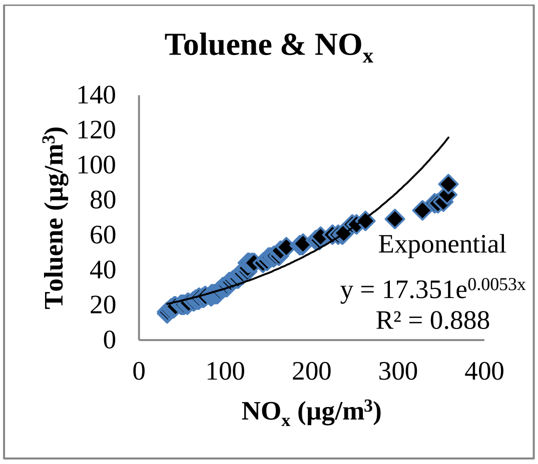

Toluene & NO$_2$
Toluene (µg/m^3)
140
120
100
80
60
40
20
0
0
50
100
150
NO$_2$ (µg/m^3)
Exponential
y = 11.501e$^{0.0192x}$
R² = 0.97

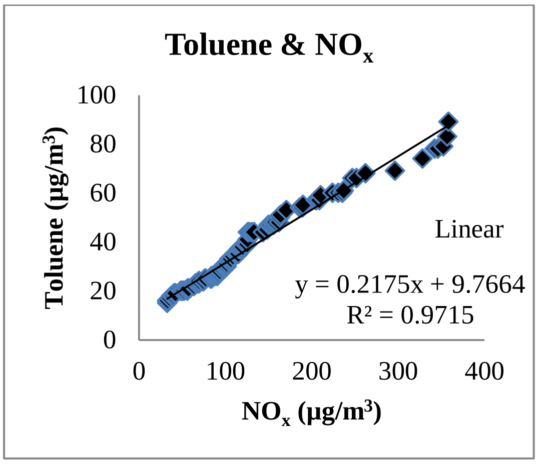

Toluene & NO$_2$
Toluene (µg/m^3)
100
80
60
40
20
0
0
50
100
150
NO$_2$ (µg/m^3)
Linear
y = 0.7545x - 5.2434
R² = 0.9725

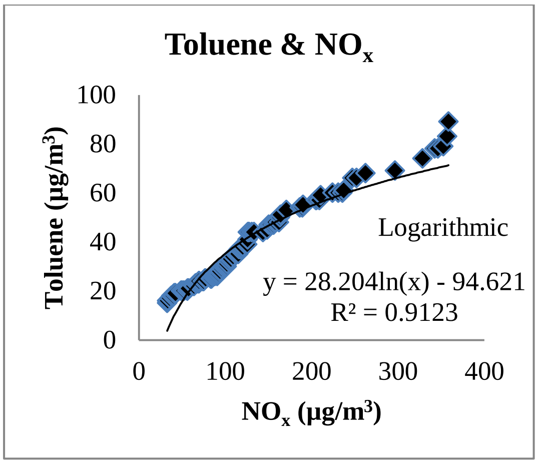

Toluene & NO$_2$
Toluene (µg/m^3)
100
80
60
40
20
0
0
50
100
150
NO$_2$ (µg/m^3)
Logarithmic
y = 38.918ln(x) - 116.62
R² = 0.8646

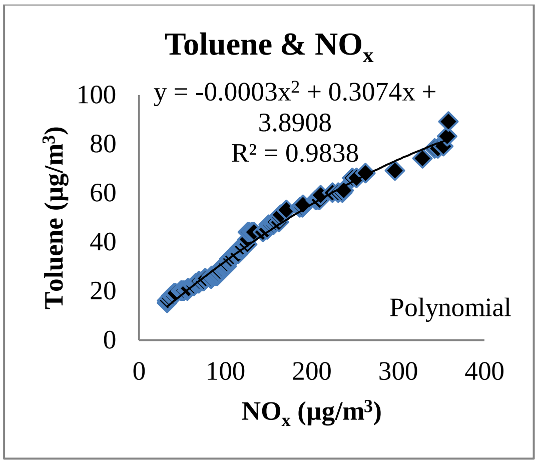

Toluene & NO$_2$
y = 0.0025x^2 + 0.4322x + 3.6531
R² = 0.9814
Toluene (µg/m^3)
100
80
60
40
20
0
0
50
100
150
NO$_2$ (µg/m^3)
Polynomial

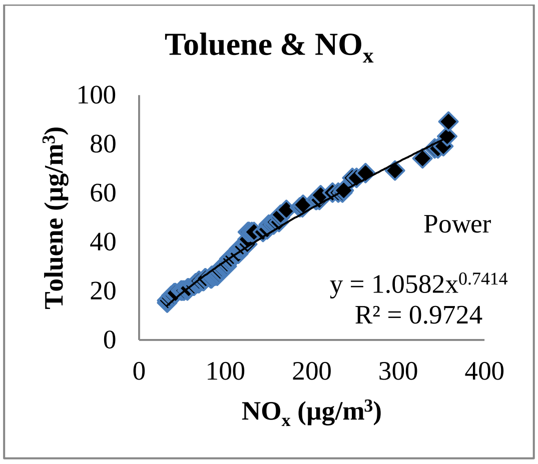

Toluene & NO$_2$
Toluene (µg/m^3)
100
80
60
40
20
0
0
50
100
150
NO$_2$ (µg/m^3)
Power
y = 0.5463x$^{1.0441}$
R² = 0.9598

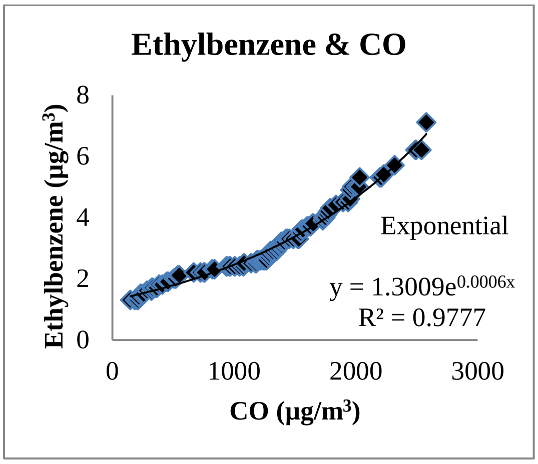

Toluene & NO_x
Toluene (µg/m^3)
0
20
40
60
80
100
120
140
0
100
200
300
400
NO_x (µg/m^3)
Exponential
$y = 17.351e^{0.0053x}$
$R^2 = 0.888$

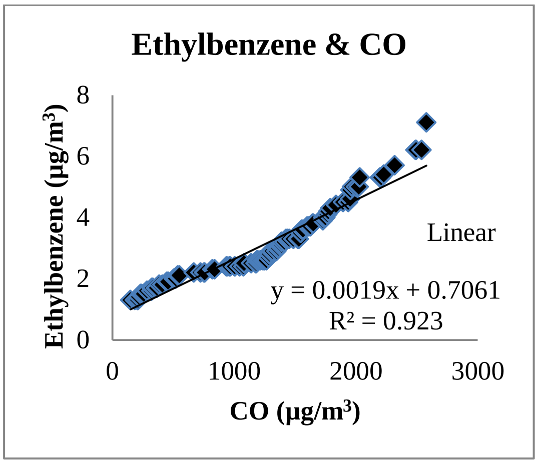

Toluene & NO_x
Toluene (µg/m^3)
0
20
40
60
80
100
0
100
200
300
400
NO_x (µg/m^3)
Linear
$y = 0.2175x + 9.7664$
$R^2 = 0.9715$

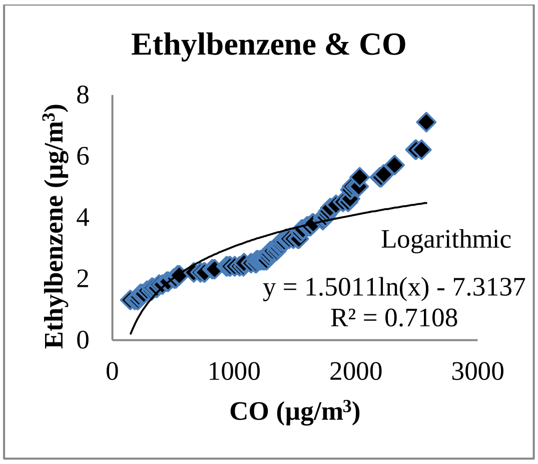

Toluene & NO_x
Toluene (µg/m^3)
0
20
40
60
80
100
0
100
200
300
400
NO_x (µg/m^3)
Logarithmic
$y = 28.204\ln(x) - 94.621$
$R^2 = 0.9123$

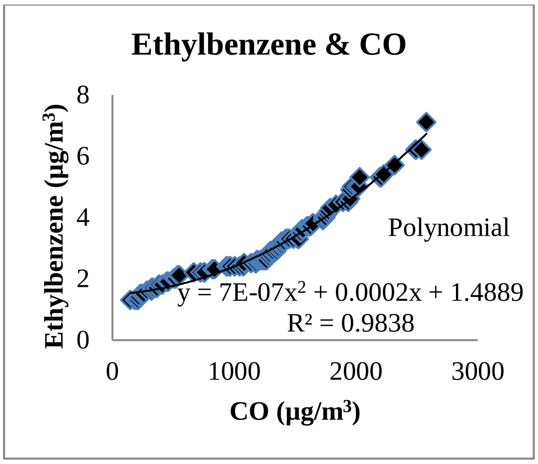

Toluene & NO_x
Toluene (µg/m^3)
0
20
40
60
80
100
0
100
200
300
400
NO_x (µg/m^3)
$y = -0.0003x^2 + 0.3074x + 3.8908$
$R^2 = 0.9838$
Polynomial

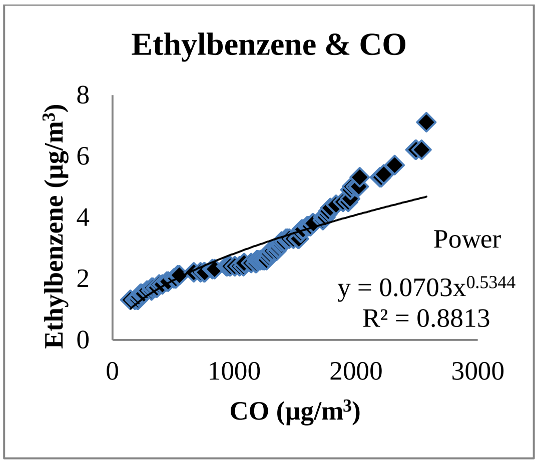

Toluene & NO_x
Toluene (µg/m^3)
0
20
40
60
80
100
0
100
200
300
400
NO_x (µg/m^3)
Power
$y = 1.0582x^{0.7414}$
$R^2 = 0.9724$

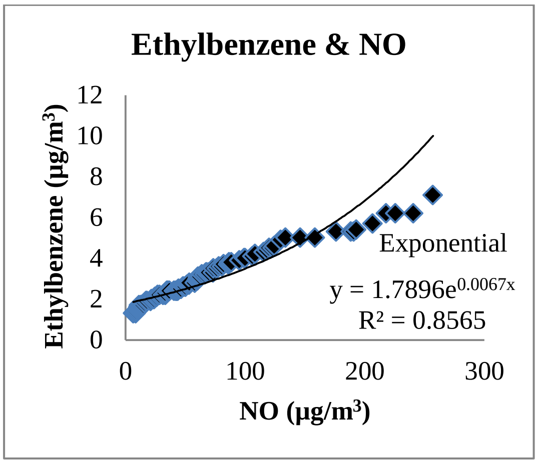

Ethylbenzene & CO
Ethylbenzene (μg/m^3)
8
6
4
2
0
0
1000
2000
3000
CO (μg/m^3)
Exponential
$y = 1.3009e^{0.0006x}$
$R^2 = 0.9777$

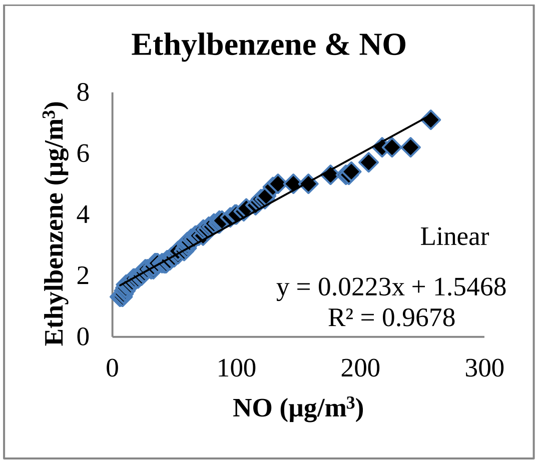

Ethylbenzene & CO
Ethylbenzene (μg/m^3)
8
6
4
2
0
0
1000
2000
3000
CO (μg/m^3)
Linear
$y = 0.0019x + 0.7061$
$R^2 = 0.923$

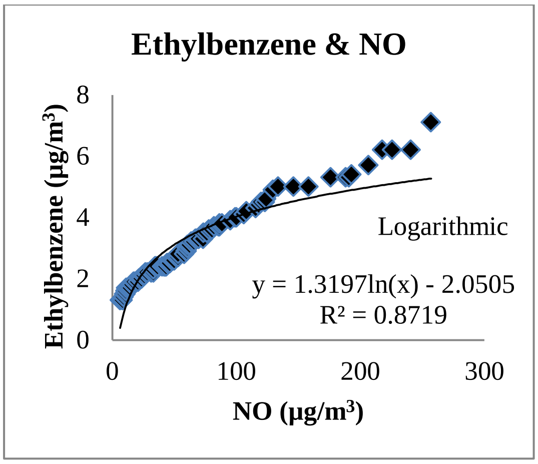

Ethylbenzene & CO
Ethylbenzene (μg/m^3)
8
6
4
2
0
0
1000
2000
3000
CO (μg/m^3)
Logarithmic
$y = 1.5011\ln(x) - 7.3137$
$R^2 = 0.7108$

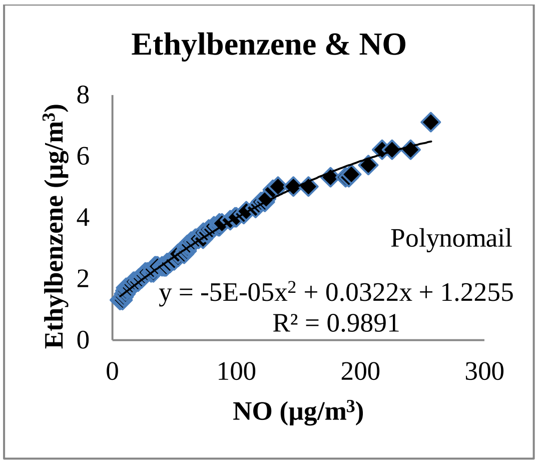

Ethylbenzene & CO
Ethylbenzene (μg/m^3)
8
6
4
2
0
0
1000
2000
3000
CO (μg/m^3)
Polynomial
$y = 7E\text{-}07x^2 + 0.0002x + 1.4889$
$R^2 = 0.9838$

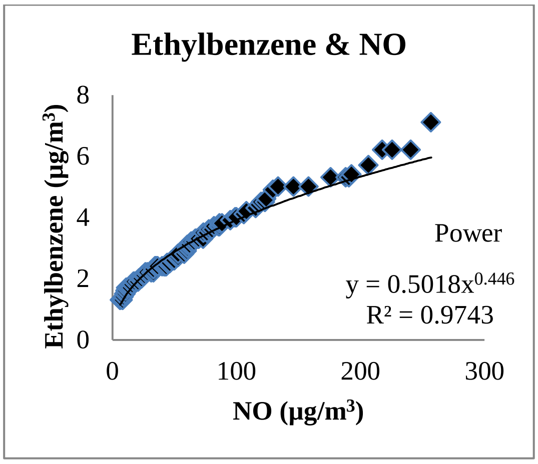

Ethylbenzene & CO
Ethylbenzene (μg/m^3)
8
6
4
2
0
0
1000
2000
3000
CO (μg/m^3)
Power
$y = 0.0703x^{0.5344}$
$R^2 = 0.8813$

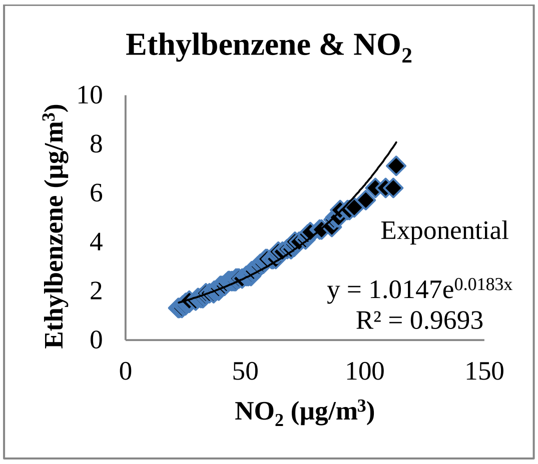

Ethylbenzene & NO
Ethylbenzene (µg/m³)
12
10
8
6
4
2
0
0
100
200
300
NO (µg/m³)
Exponential
y = 1.7896e^0.0067x
R² = 0.8565

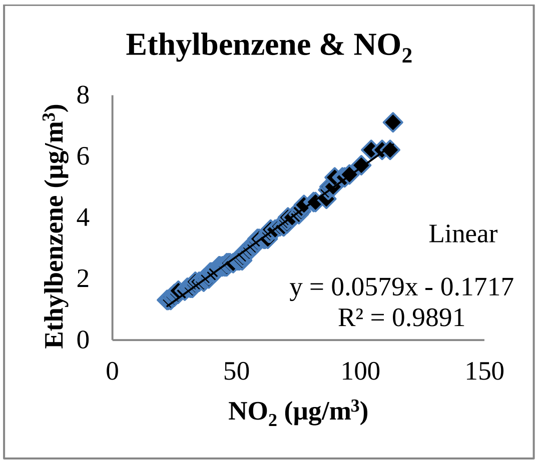

Ethylbenzene & NO
Ethylbenzene (µg/m³)
8
6
4
2
0
0
100
200
300
NO (µg/m³)
Linear
y = 0.0223x + 1.5468
R² = 0.9678

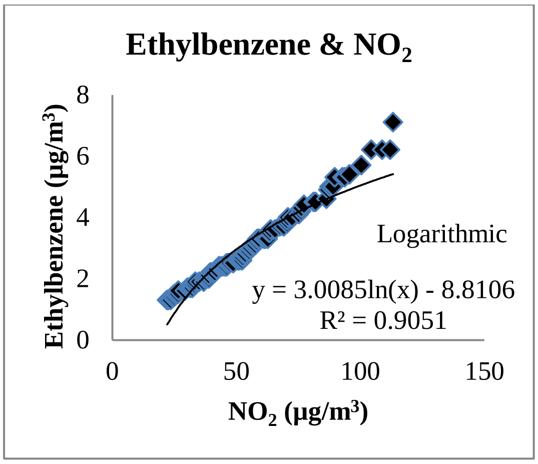

Ethylbenzene & NO
Ethylbenzene (µg/m³)
8
6
4
2
0
0
100
200
300
NO (µg/m³)
Logarithmic
y = 1.3197ln(x) - 2.0505
R² = 0.8719

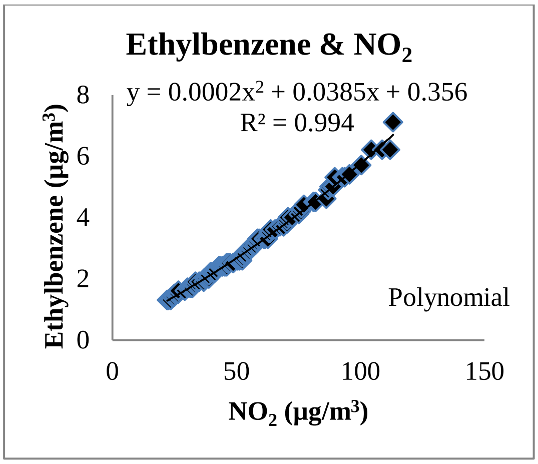

Ethylbenzene & NO
Ethylbenzene (µg/m³)
8
6
4
2
0
0
100
200
300
NO (µg/m³)
Polynomail
y = -5E-05x² + 0.0322x + 1.2255
R² = 0.9891

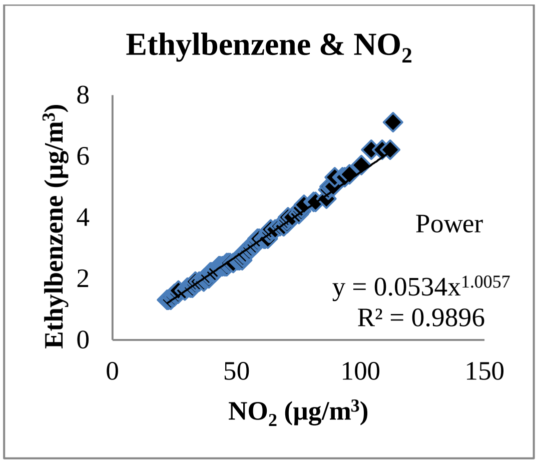

Ethylbenzene & NO
Ethylbenzene (µg/m³)
8
6
4
2
0
0
100
200
300
NO (µg/m³)
Power
y = 0.5018x^0.446
R² = 0.9743

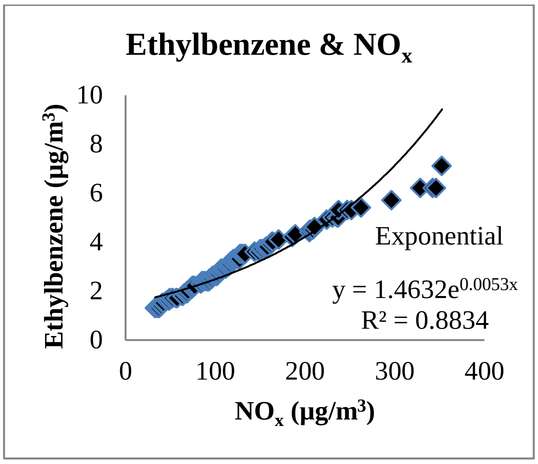

Ethylbenzene & NO$_2$
Ethylbenzene (µg/m^3)
10
8
6
4
2
0
0
50
100
150
NO$_2$ (µg/m^3)
Exponential
y = 1.0147e$^{0.0183x}$
R² = 0.9693

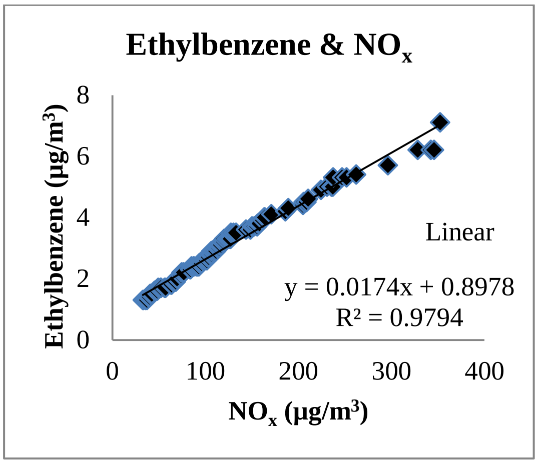

Ethylbenzene & NO$_2$
Ethylbenzene (µg/m^3)
8
6
4
2
0
0
50
100
150
NO$_2$ (µg/m^3)
Linear
y = 0.0579x - 0.1717
R² = 0.9891

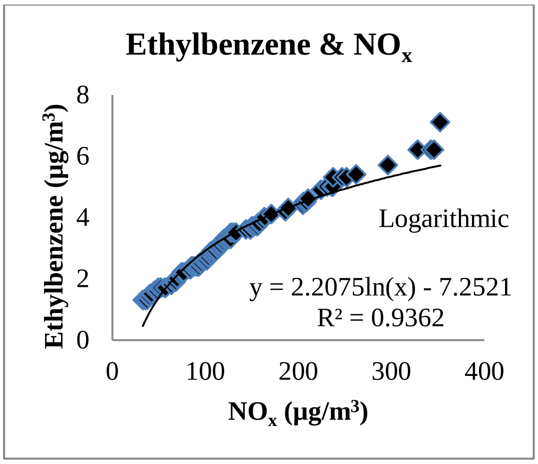

Ethylbenzene & NO$_2$
Ethylbenzene (µg/m^3)
8
6
4
2
0
0
50
100
150
NO$_2$ (µg/m^3)
Logarithmic
y = 3.0085ln(x) - 8.8106
R² = 0.9051

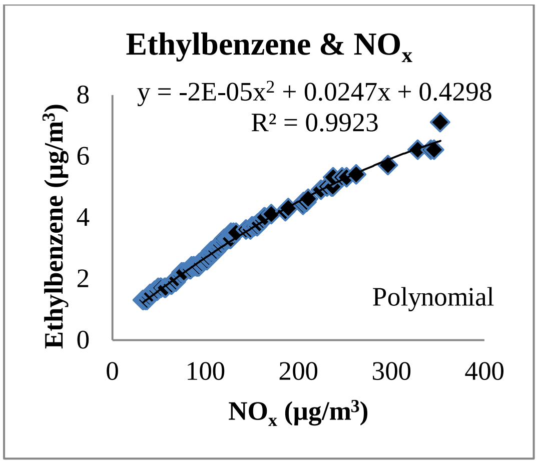

Ethylbenzene & NO$_2$
Ethylbenzene (µg/m^3)
y = 0.0002x² + 0.0385x + 0.356
R² = 0.994
8
6
4
2
0
0
50
100
150
NO$_2$ (µg/m^3)
Polynomial

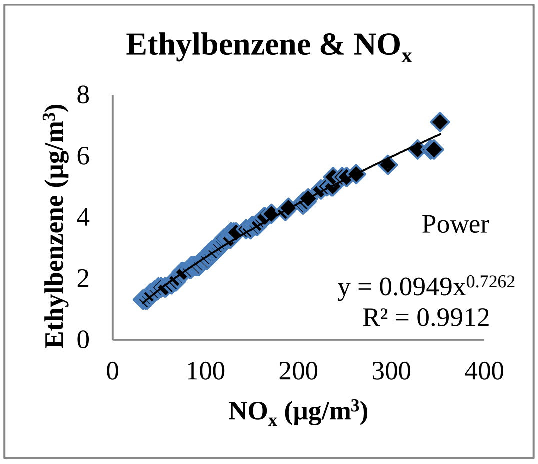

Ethylbenzene & NO$_2$
Ethylbenzene (µg/m^3)
8
6
4
2
0
0
50
100
150
NO$_2$ (µg/m^3)
Power
y = 0.0534x$^{1.0057}$
R² = 0.9896

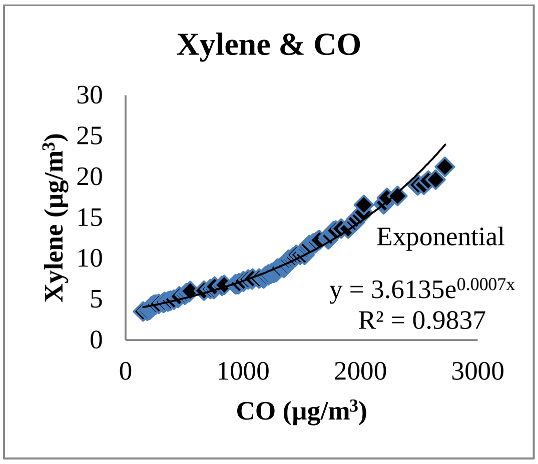

Ethylbenzene & NO_x
Ethylbenzene ($\mu g/m^3$)
10
8
6
4
2
0
0
100
200
300
400
NO_x ($\mu g/m^3$)
Exponential
$y = 1.4632e^{0.0053x}$
$R^2 = 0.8834$

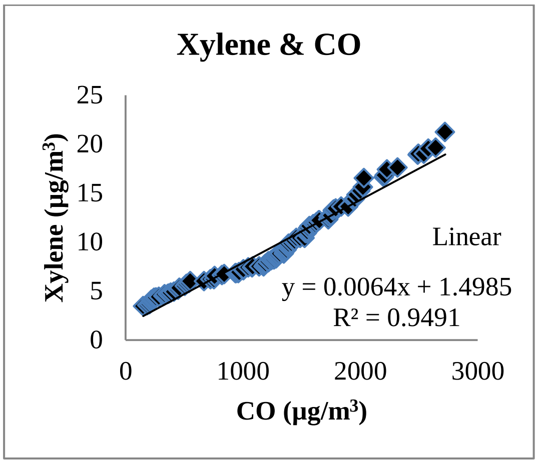

Ethylbenzene & NO_x
Ethylbenzene ($\mu g/m^3$)
8
6
4
2
0
0
100
200
300
400
NO_x ($\mu g/m^3$)
Linear
$y = 0.0174x + 0.8978$
$R^2 = 0.9794$

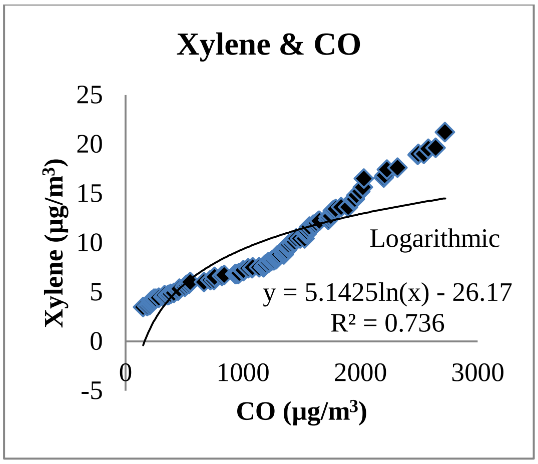

Ethylbenzene & NO_x
Ethylbenzene ($\mu g/m^3$)
8
6
4
2
0
0
100
200
300
400
NO_x ($\mu g/m^3$)
Logarithmic
$y = 2.2075\ln(x) - 7.2521$
$R^2 = 0.9362$

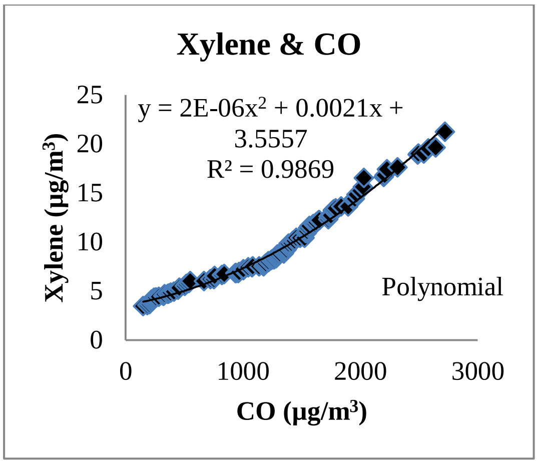

Ethylbenzene & NO_x
Ethylbenzene ($\mu g/m^3$)
$y = -2E\text{-}05x^2 + 0.0247x + 0.4298$
$R^2 = 0.9923$
8
6
4
2
0
0
100
200
300
400
NO_x ($\mu g/m^3$)
Polynomial

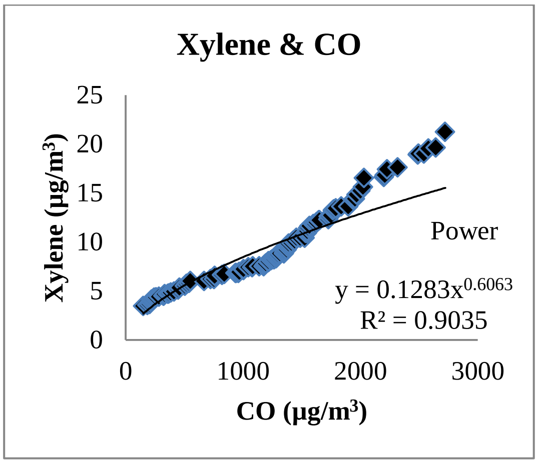

Ethylbenzene & NO_x
Ethylbenzene ($\mu g/m^3$)
8
6
4
2
0
0
100
200
300
400
NO_x ($\mu g/m^3$)
Power
$y = 0.0949x^{0.7262}$
$R^2 = 0.9912$

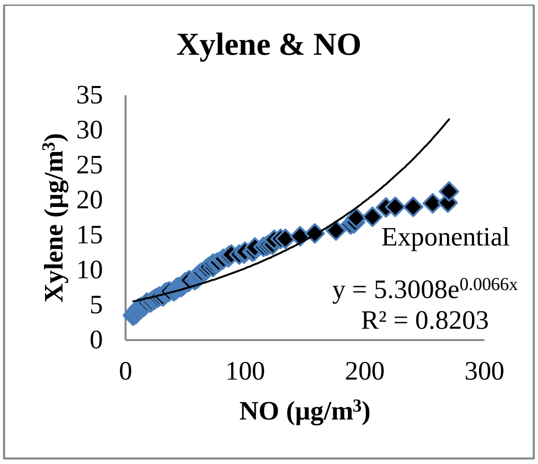

Xylene & CO
Xylene (µg/m³)
CO (µg/m³)
30
25
20
15
10
5
0
0
1000
2000
3000
Exponential
y = 3.6135e^0.0007x
R² = 0.9837

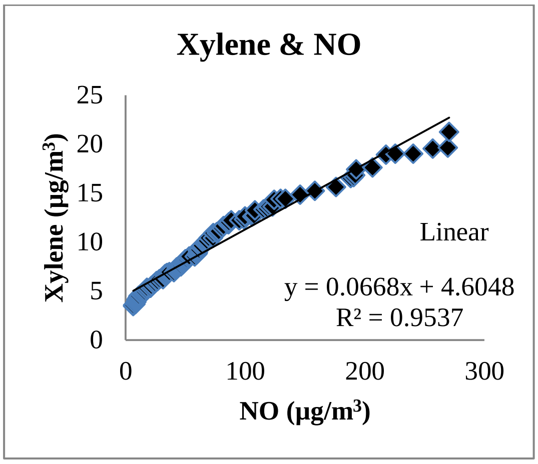

Xylene & CO
Xylene (µg/m³)
CO (µg/m³)
25
20
15
10
5
0
0
1000
2000
3000
Linear
y = 0.0064x + 1.4985
R² = 0.9491

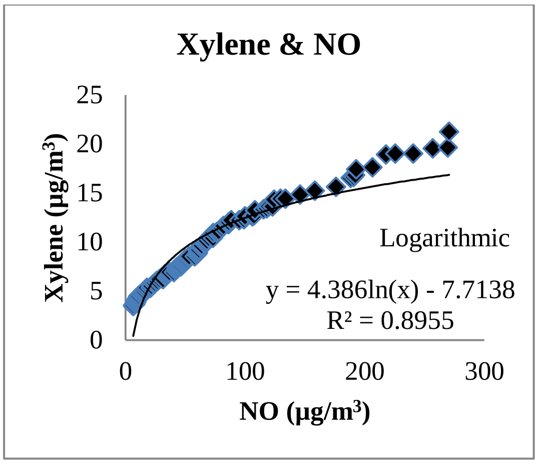

Xylene & CO
Xylene (µg/m³)
CO (µg/m³)
25
20
15
10
5
0
-5
0
1000
2000
3000
Logarithmic
y = 5.1425ln(x) - 26.17
R² = 0.736

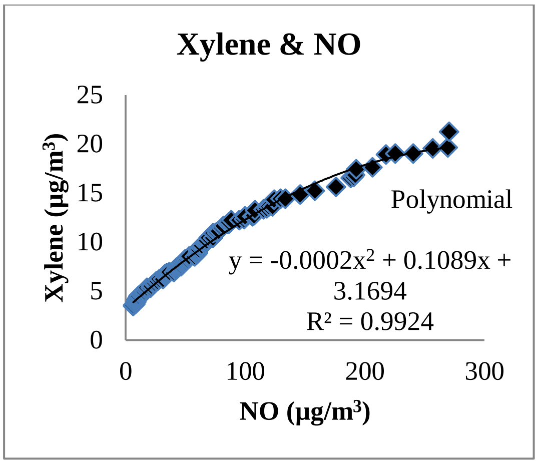

Xylene & CO
Xylene (µg/m³)
CO (µg/m³)
25
20
15
10
5
0
0
1000
2000
3000
y = 2E-06x² + 0.0021x + 3.5557
R² = 0.9869
Polynomial

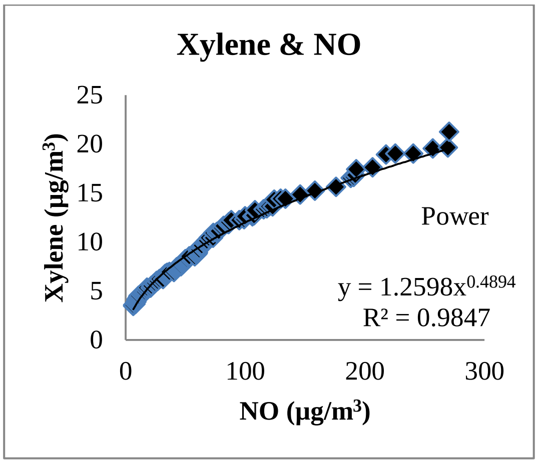

Xylene & CO
Xylene (µg/m³)
CO (µg/m³)
25
20
15
10
5
0
0
1000
2000
3000
Power
y = 0.1283x^0.6063
R² = 0.9035

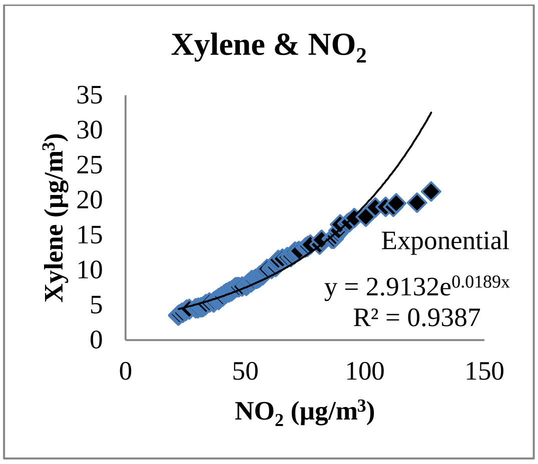

Xylene & NO
Xylene (µg/m³)
35
30
25
20
15
10
5
0
0
100
200
300
NO (µg/m³)
Exponential
y = 5.3008e^0.0066x
R² = 0.8203

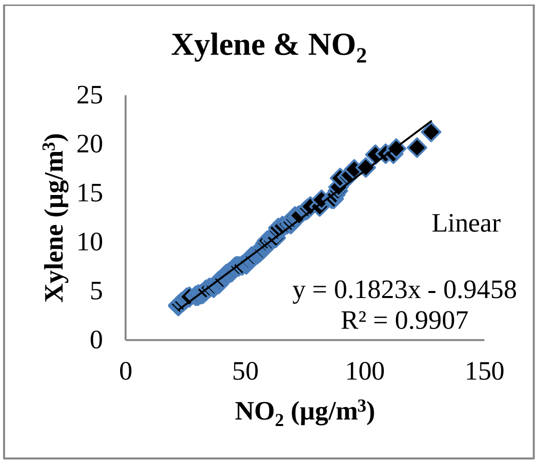

Xylene & NO
Xylene (µg/m³)
25
20
15
10
5
0
0
100
200
300
NO (µg/m³)
Linear
y = 0.0668x + 4.6048
R² = 0.9537

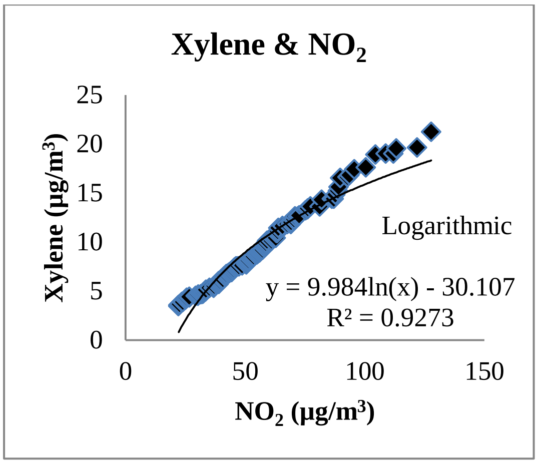

Xylene & NO
Xylene (µg/m³)
25
20
15
10
5
0
0
100
200
300
NO (µg/m³)
Logarithmic
y = 4.386ln(x) - 7.7138
R² = 0.8955

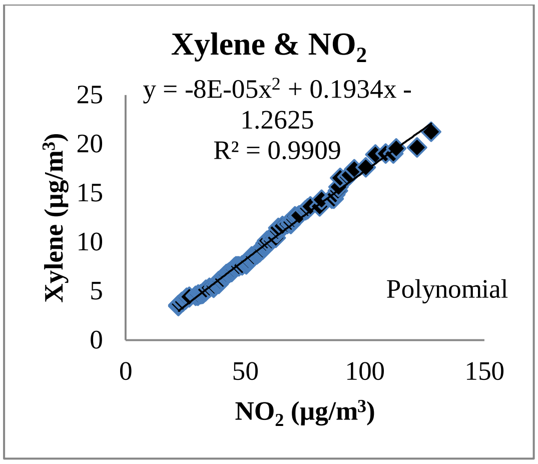

Xylene & NO
Xylene (µg/m³)
25
20
15
10
5
0
0
100
200
300
NO (µg/m³)
Polynomial
y = -0.0002x² + 0.1089x + 3.1694
R² = 0.9924

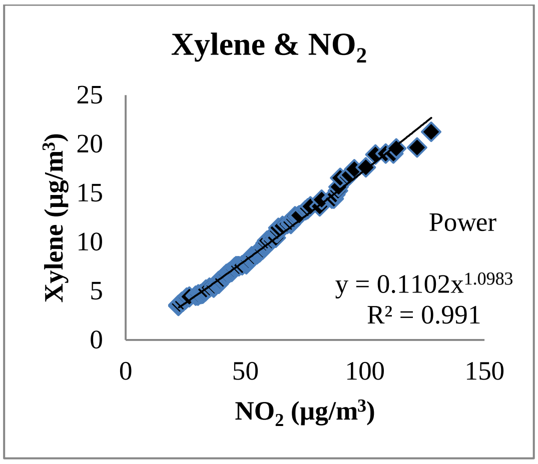

Xylene & NO
Xylene (µg/m³)
25
20
15
10
5
0
0
100
200
300
NO (µg/m³)
Power
y = 1.2598x^0.4894
R² = 0.9847

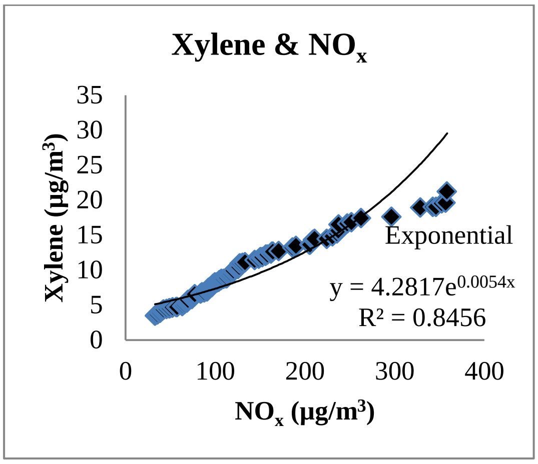

Xylene & NO_2
Xylene ($\mu g/m^3$)
35
30
25
20
15
10
5
0
0
50
100
150
NO_2 ($\mu g/m^3$)
Exponential
$y = 2.9132e^{0.0189x}$
$R^2 = 0.9387$

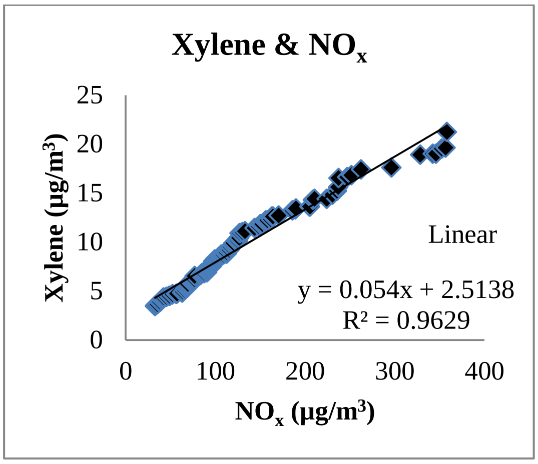

Xylene & NO_2
Xylene ($\mu g/m^3$)
25
20
15
10
5
0
0
50
100
150
NO_2 ($\mu g/m^3$)
Linear
$y = 0.1823x - 0.9458$
$R^2 = 0.9907$

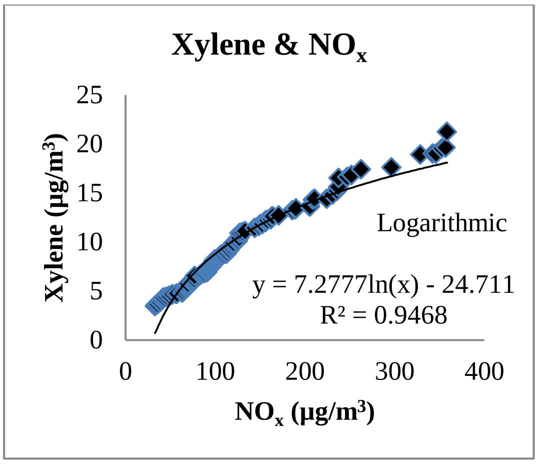

Xylene & NO_2
Xylene ($\mu g/m^3$)
25
20
15
10
5
0
0
50
100
150
NO_2 ($\mu g/m^3$)
Logarithmic
$y = 9.984\ln(x) - 30.107$
$R^2 = 0.9273$

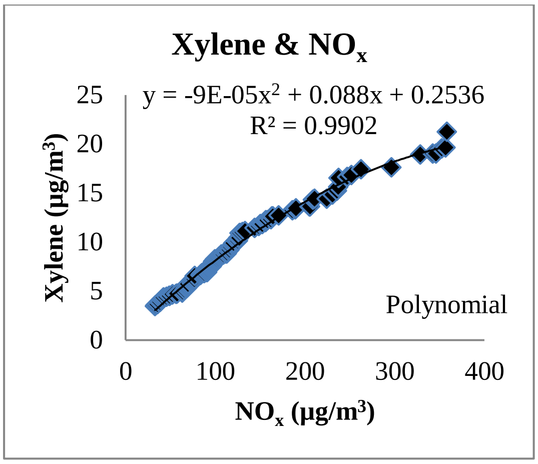

Xylene & NO_2
Xylene ($\mu g/m^3$)
25
20
15
10
5
0
0
50
100
150
NO_2 ($\mu g/m^3$)
$y = -8E-05x^2 + 0.1934x - 1.2625$
$R^2 = 0.9909$
Polynomial

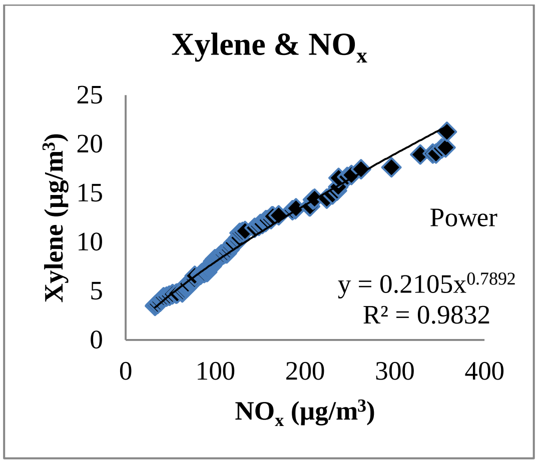

Xylene & NO_2
Xylene ($\mu g/m^3$)
25
20
15
10
5
0
0
50
100
150
NO_2 ($\mu g/m^3$)
Power
$y = 0.1102x^{1.0983}$
$R^2 = 0.991$

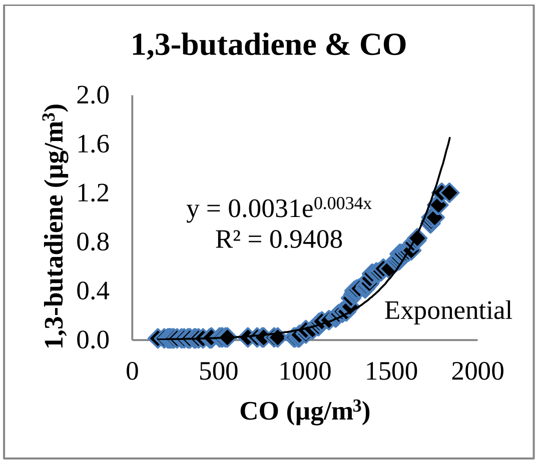

Xylene & NO_x
Xylene (μg/m³)
35
30
25
20
15
10
5
0
0
100
200
300
400
NO_x (μg/m³)
Exponential
y = 4.2817e^0.0054x
R² = 0.8456

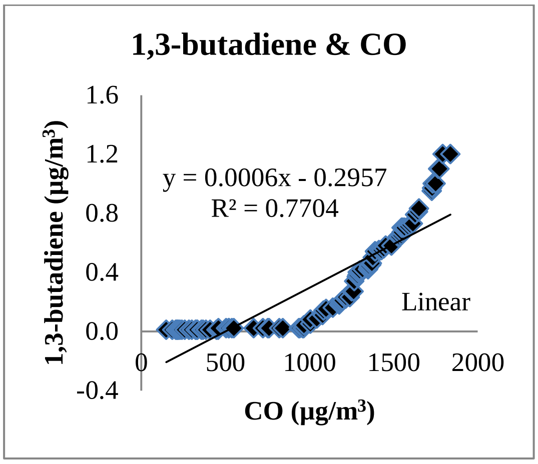

Xylene & NO_x
Xylene (μg/m³)
25
20
15
10
5
0
0
100
200
300
400
NO_x (μg/m³)
Linear
y = 0.054x + 2.5138
R² = 0.9629

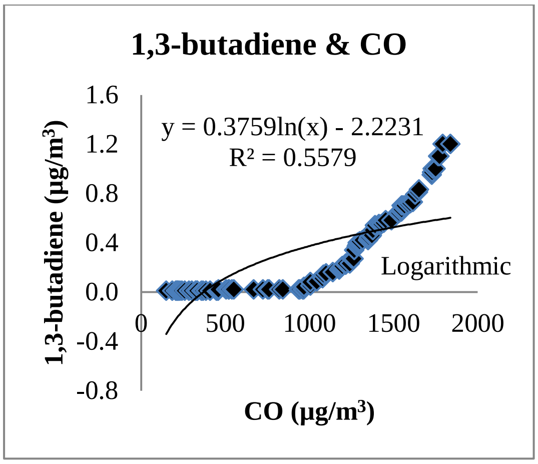

Xylene & NO_x
Xylene (μg/m³)
25
20
15
10
5
0
0
100
200
300
400
NO_x (μg/m³)
Logarithmic
y = 7.2777ln(x) - 24.711
R² = 0.9468

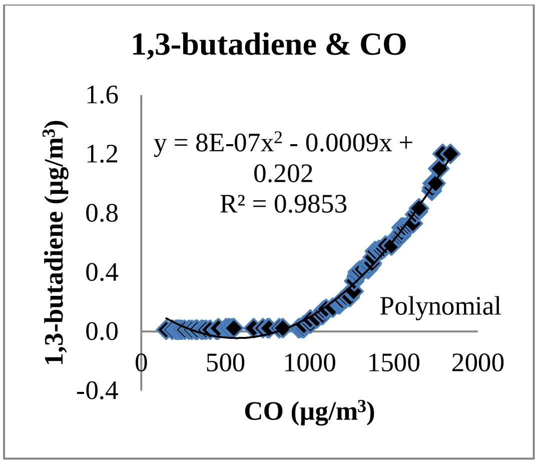

Xylene & NO_x
Xylene (μg/m³)
y = -9E-05x² + 0.088x + 0.2536
R² = 0.9902
25
20
15
10
5
0
0
100
200
300
400
NO_x (μg/m³)
Polynomial

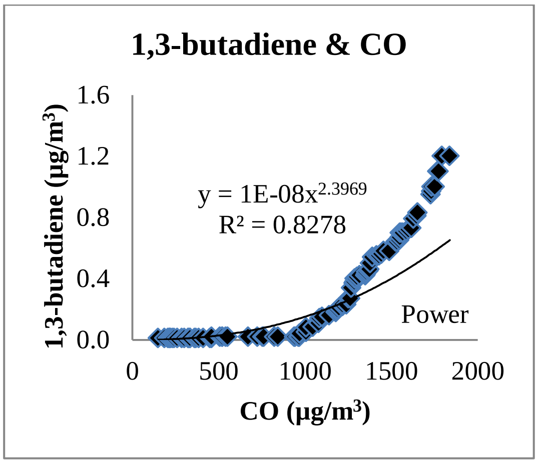

Xylene & NO_x
Xylene (μg/m³)
25
20
15
10
5
0
0
100
200
300
400
NO_x (μg/m³)
Power
y = 0.2105x^0.7892
R² = 0.9832

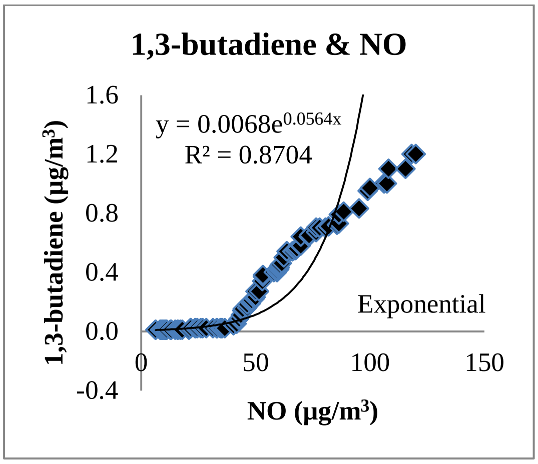

1,3-butadiene & CO
1,3-butadiene (µg/m³)
2.0
1.6
1.2
0.8
0.4
0.0
0
500
1000
1500
2000
CO (µg/m³)
y = 0.0031e^0.0034x
R² = 0.9408
Exponential

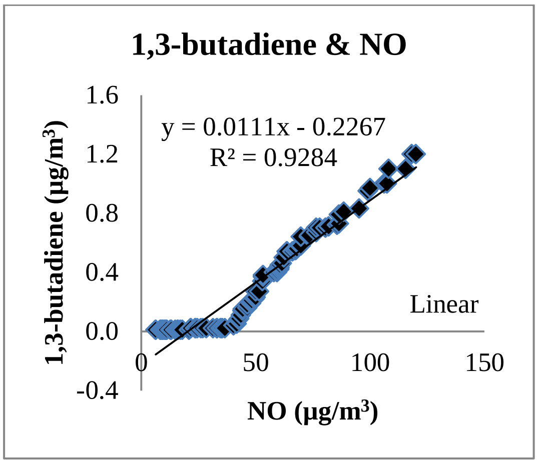

1,3-butadiene & CO
1,3-butadiene (µg/m³)
1.6
1.2
0.8
0.4
0.0
-0.4
0
500
1000
1500
2000
CO (µg/m³)
y = 0.0006x - 0.2957
R² = 0.7704
Linear

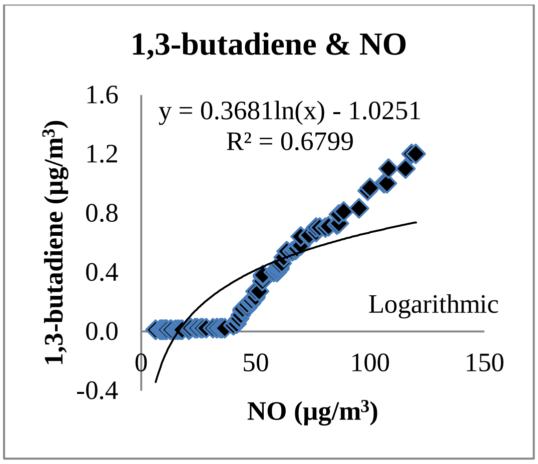

1,3-butadiene & CO
1,3-butadiene (µg/m³)
1.6
1.2
0.8
0.4
0.0
-0.4
-0.8
0
500
1000
1500
2000
CO (µg/m³)
y = 0.3759ln(x) - 2.2231
R² = 0.5579
Logarithmic

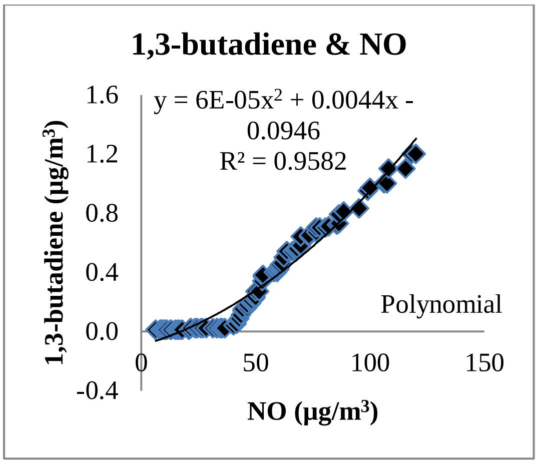

1,3-butadiene & CO
1,3-butadiene (µg/m³)
1.6
1.2
0.8
0.4
0.0
-0.4
0
500
1000
1500
2000
CO (µg/m³)
y = 8E-07x² - 0.0009x + 0.202
R² = 0.9853
Polynomial

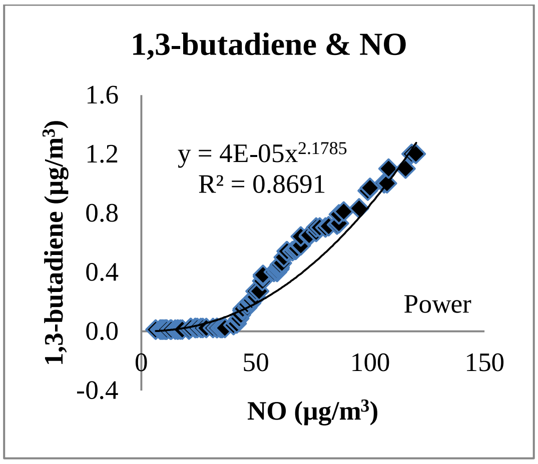

1,3-butadiene & CO
1,3-butadiene (µg/m³)
1.6
1.2
0.8
0.4
0.0
0
500
1000
1500
2000
CO (µg/m³)
y = 1E-08x^2.3969
R² = 0.8278
Power

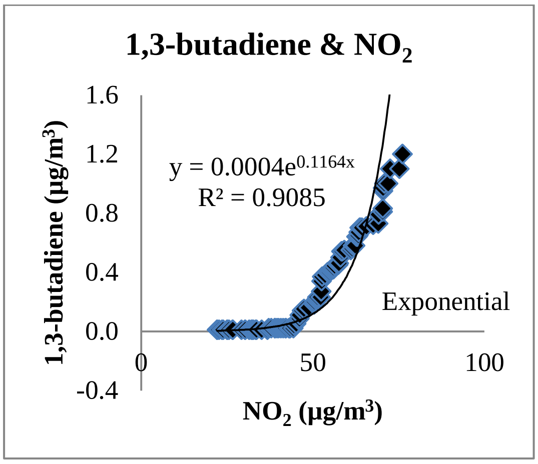

1,3-butadiene & NO
$y = 0.0068e^{0.0564x}$
$R^2 = 0.8704$
Exponential
1,3-butadiene (µg/m³)
1.6
1.2
0.8
0.4
0.0
-0.4
0
50
100
150
NO (µg/m³)

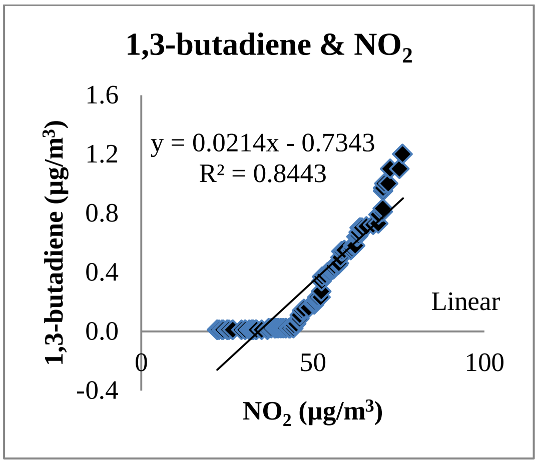

1,3-butadiene & NO
$y = 0.0111x - 0.2267$
$R^2 = 0.9284$
Linear
1,3-butadiene (µg/m³)
1.6
1.2
0.8
0.4
0.0
-0.4
0
50
100
150
NO (µg/m³)

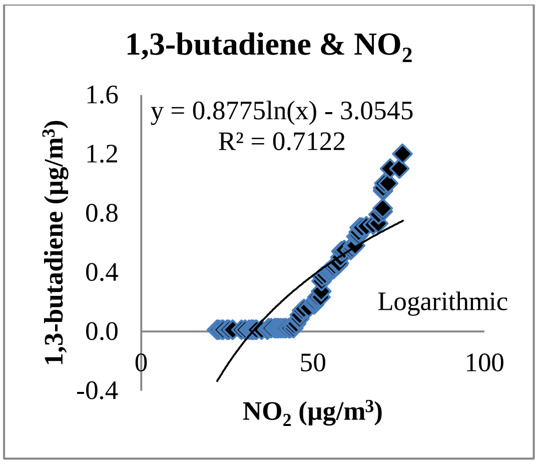

1,3-butadiene & NO
$y = 0.3681\ln(x) - 1.0251$
$R^2 = 0.6799$
Logarithmic
1,3-butadiene (µg/m³)
1.6
1.2
0.8
0.4
0.0
-0.4
0
50
100
150
NO (µg/m³)

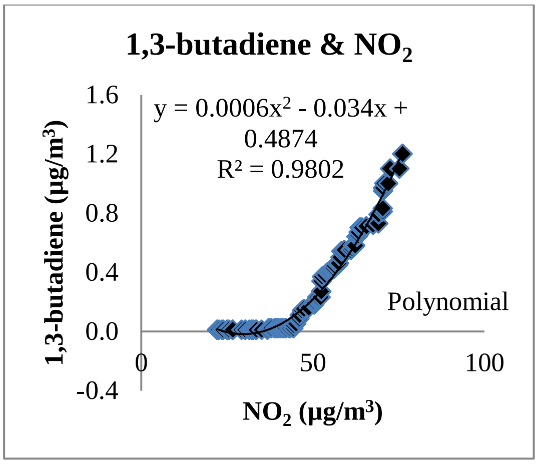

1,3-butadiene & NO
$y = 6E\text{-}05x^2 + 0.0044x - 0.0946$
$R^2 = 0.9582$
Polynomial
1,3-butadiene (µg/m³)
1.6
1.2
0.8
0.4
0.0
-0.4
0
50
100
150
NO (µg/m³)

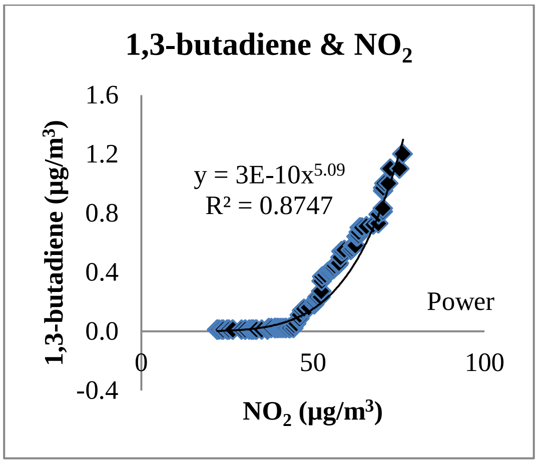

1,3-butadiene & NO
$y = 4E\text{-}05x^{2.1785}$
$R^2 = 0.8691$
Power
1,3-butadiene (µg/m³)
1.6
1.2
0.8
0.4
0.0
-0.4
0
50
100
150
NO (µg/m³)

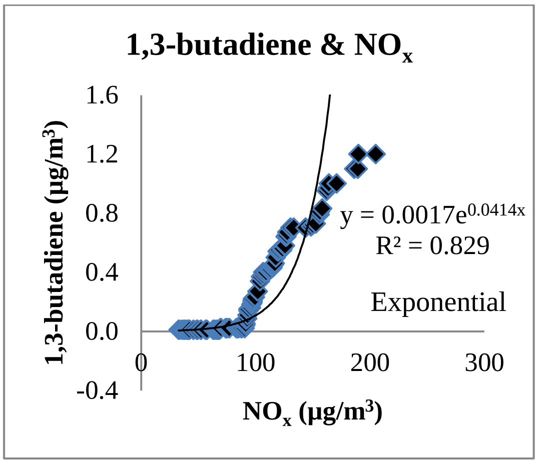

1,3-butadiene & NO2
y = 0.0004e0.1164x
R² = 0.9085
Exponential
1.6
1.2
0.8
0.4
0.0
-0.4
0
50
100
1,3-butadiene (µg/m3)
NO2 (µg/m3)

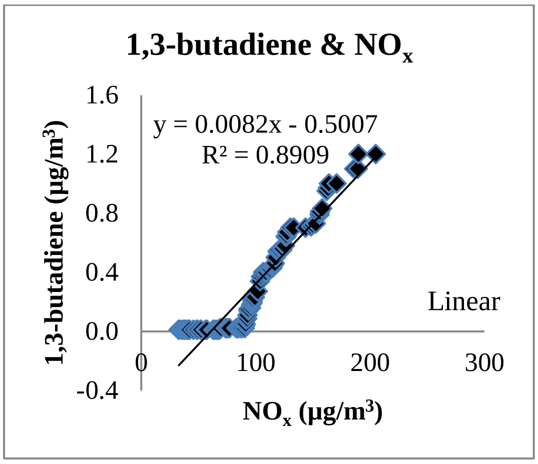

1,3-butadiene & NO2
y = 0.0214x - 0.7343
R² = 0.8443
Linear
1.6
1.2
0.8
0.4
0.0
-0.4
0
50
100
1,3-butadiene (µg/m3)
NO2 (µg/m3)

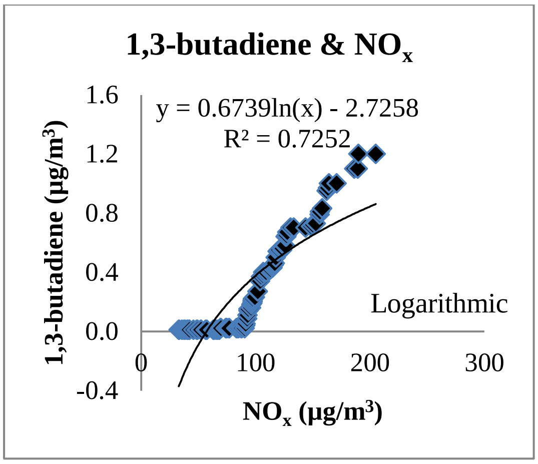

1,3-butadiene & NO2
y = 0.8775ln(x) - 3.0545
R² = 0.7122
Logarithmic
1.6
1.2
0.8
0.4
0.0
-0.4
0
50
100
1,3-butadiene (µg/m3)
NO2 (µg/m3)

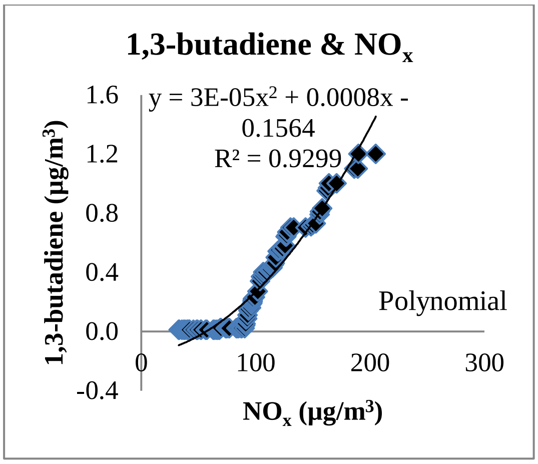

1,3-butadiene & NO2
y = 0.0006x² - 0.034x + 0.4874
R² = 0.9802
Polynomial
1.6
1.2
0.8
0.4
0.0
-0.4
0
50
100
1,3-butadiene (µg/m3)
NO2 (µg/m3)

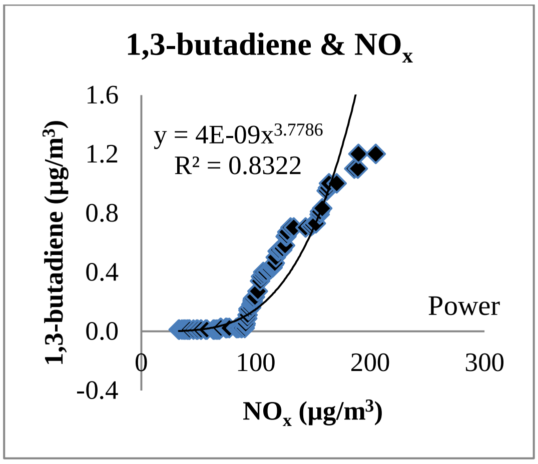

1,3-butadiene & NO2
y = 3E-10x5.09
R² = 0.8747
Power
1.6
1.2
0.8
0.4
0.0
-0.4
0
50
100
1,3-butadiene (µg/m3)
NO2 (µg/m3)


1,3-butadiene & NO$_x$
1,3-butadiene (µg/m^3)
1.6
1.2
0.8
0.4
0.0
-0.4
0
100
200
300
NO$_x$ (µg/m^3)
y = 0.0017e$^{0.0414x}$
R² = 0.829
Exponential


1,3-butadiene & NO$_x$
1,3-butadiene (µg/m^3)
1.6
1.2
0.8
0.4
0.0
-0.4
0
100
200
300
NO$_x$ (µg/m^3)
y = 0.0082x - 0.5007
R² = 0.8909
Linear

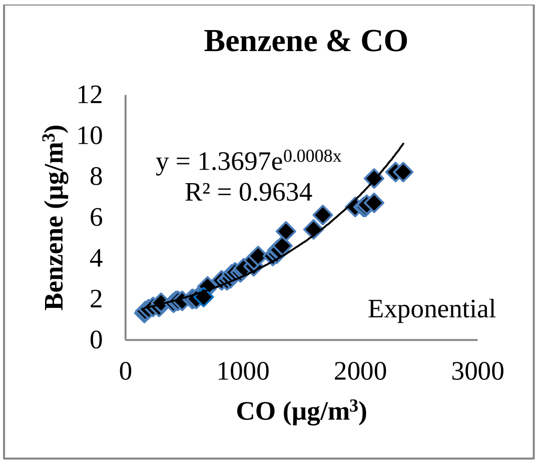

1,3-butadiene & NO$_x$
1,3-butadiene (µg/m^3)
1.6
1.2
0.8
0.4
0.0
-0.4
0
100
200
300
NO$_x$ (µg/m^3)
y = 0.6739ln(x) - 2.7258
R² = 0.7252
Logarithmic

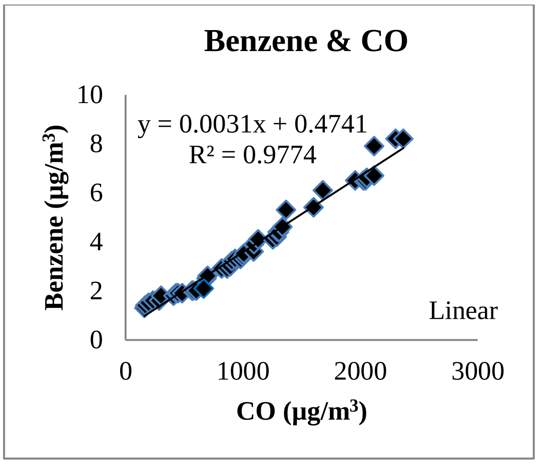

1,3-butadiene & NO$_x$
1,3-butadiene (µg/m^3)
1.6
1.2
0.8
0.4
0.0
-0.4
0
100
200
300
NO$_x$ (µg/m^3)
y = 3E-05x² + 0.0008x - 0.1564
R² = 0.9299
Polynomial

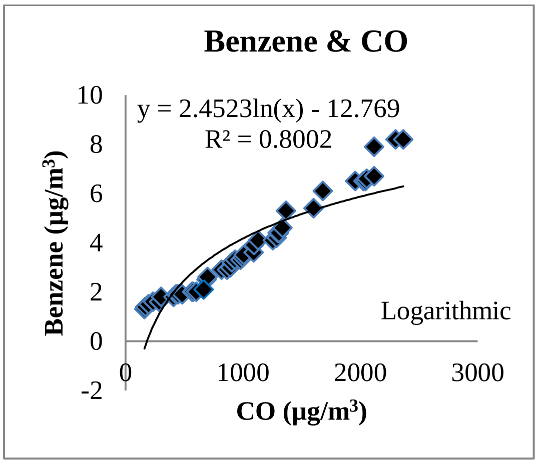

1,3-butadiene & NO$_x$
1,3-butadiene (µg/m^3)
1.6
1.2
0.8
0.4
0.0
-0.4
0
100
200
300
NO$_x$ (µg/m^3)
y = 4E-09x$^{3.7786}$
R² = 0.8322
Power

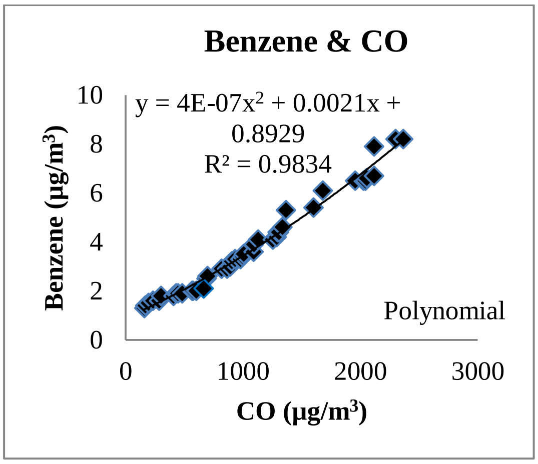
APPENDIX B

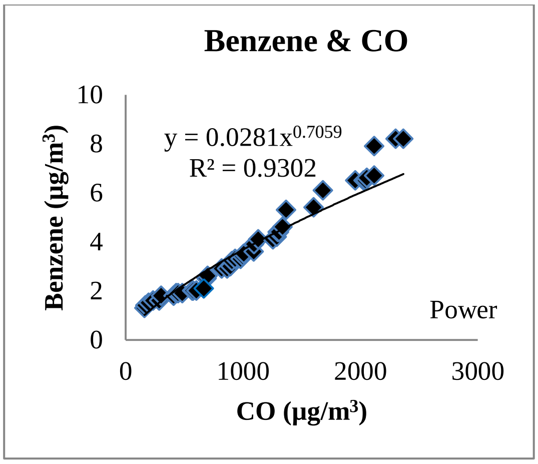
A SELECTION OF BEST FIT PLOT OF DATA FROM 2012 -2013

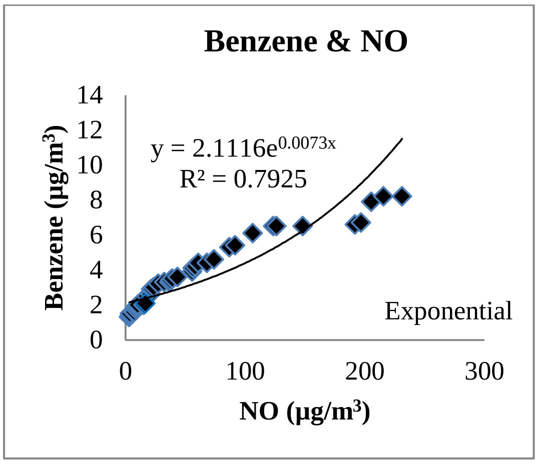


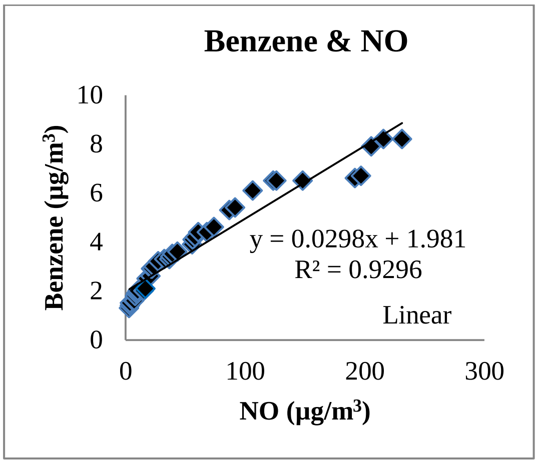


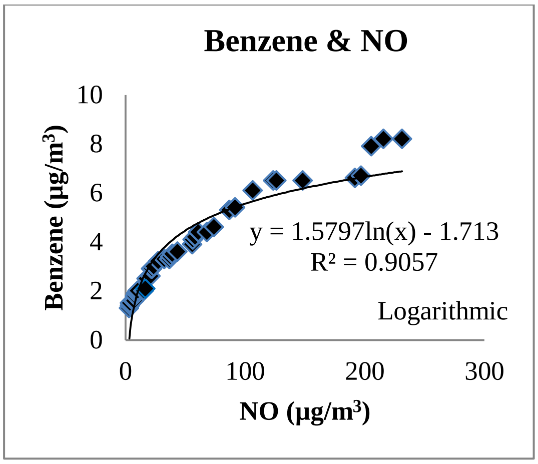


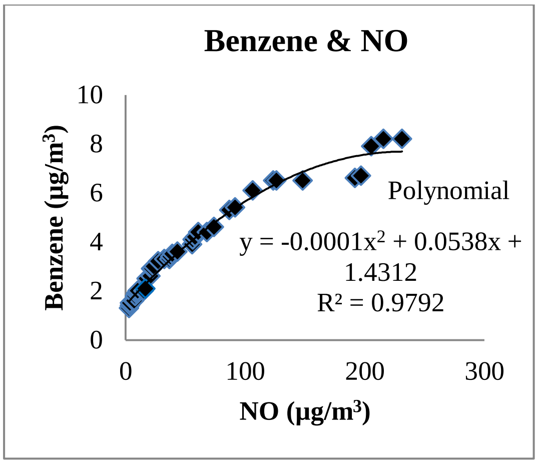


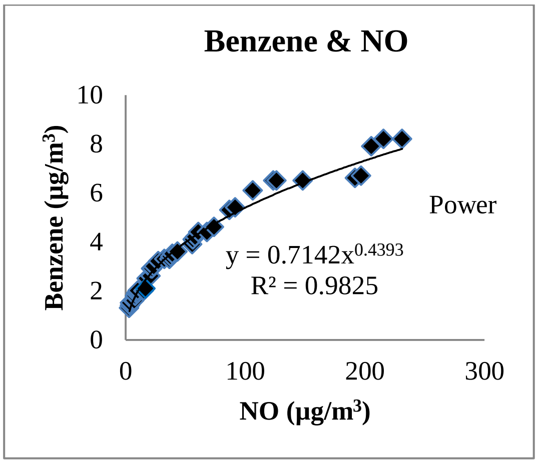


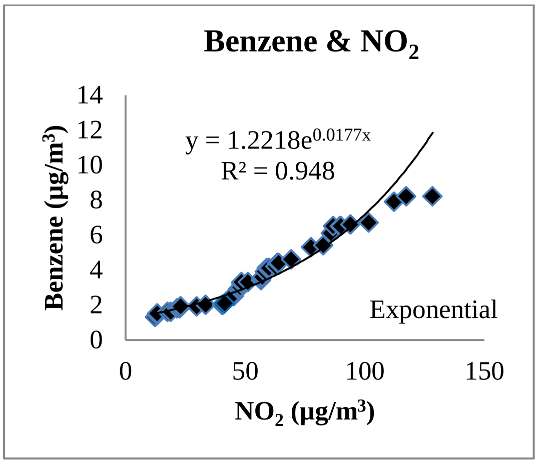

Benzene & NO
Benzene (µg/m³)
14
12
10
8
6
4
2
0
y = 2.1116e^0.0073x
R² = 0.7925
Exponential
0
100
200
300
NO (µg/m³)

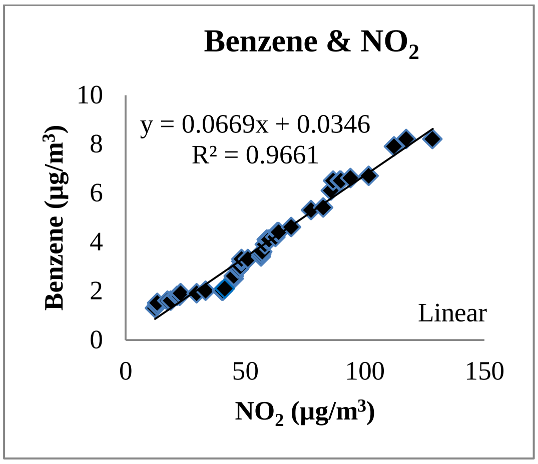

Benzene & NO
Benzene (µg/m³)
10
8
6
4
2
0
y = 0.0298x + 1.981
R² = 0.9296
Linear
0
100
200
300
NO (µg/m³)

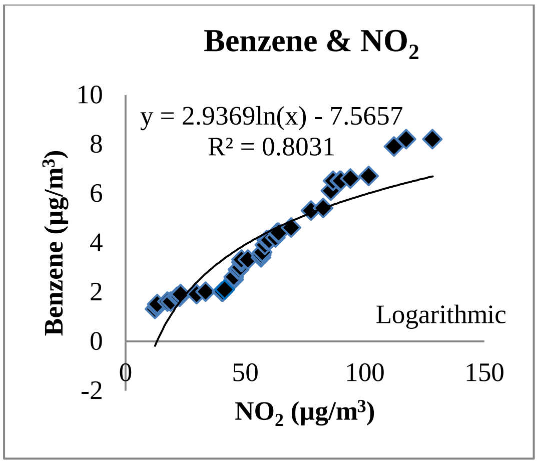

Benzene & NO
Benzene (µg/m³)
10
8
6
4
2
0
y = 1.5797ln(x) - 1.713
R² = 0.9057
Logarithmic
0
100
200
300
NO (µg/m³)

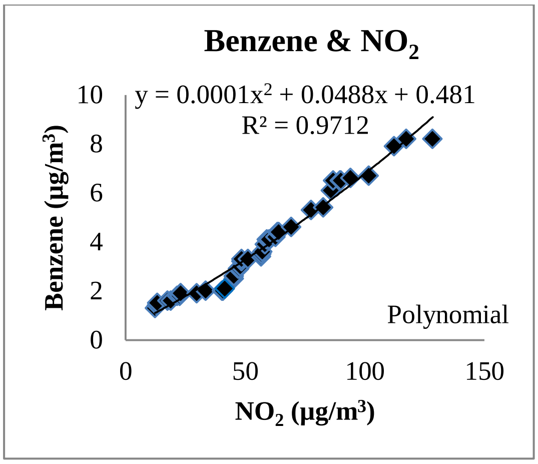

Benzene & NO
Benzene (µg/m³)
10
8
6
4
2
0
Polynomial
y = -0.0001x² + 0.0538x + 1.4312
R² = 0.9792
0
100
200
300
NO (µg/m³)

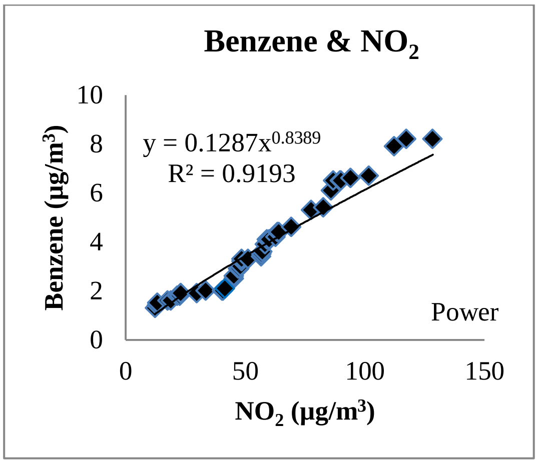

Benzene & NO
Benzene (µg/m³)
10
8
6
4
2
0
Power
y = 0.7142x^0.4393
R² = 0.9825
0
100
200
300
NO (µg/m³)

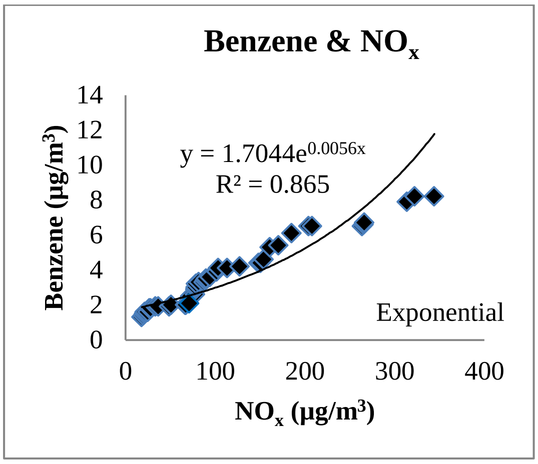

Benzene & NO2
Benzene (µg/m3)
NO2 (µg/m3)
y = 1.2218e0.0177x
R² = 0.948
Exponential
14
12
10
8
6
4
2
0
0
50
100
150

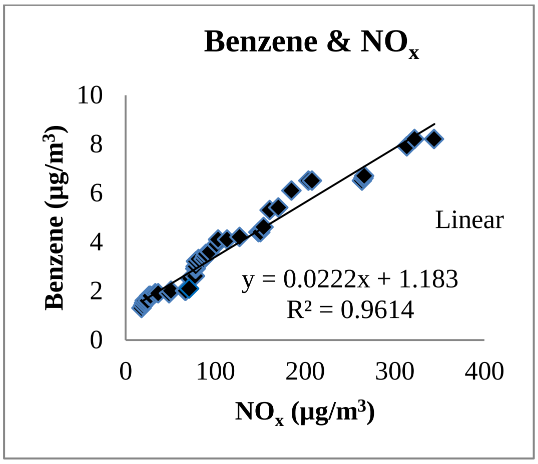

Benzene & NO2
Benzene (µg/m3)
NO2 (µg/m3)
y = 0.0669x + 0.0346
R² = 0.9661
Linear
10
8
6
4
2
0
0
50
100
150

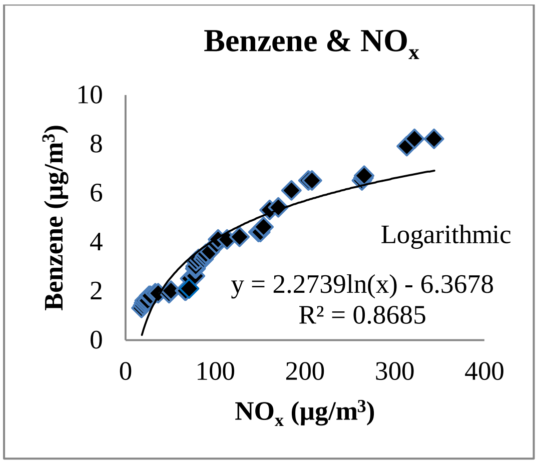

Benzene & NO2
Benzene (µg/m3)
NO2 (µg/m3)
y = 2.9369ln(x) - 7.5657
R² = 0.8031
Logarithmic
10
8
6
4
2
0
-2
0
50
100
150

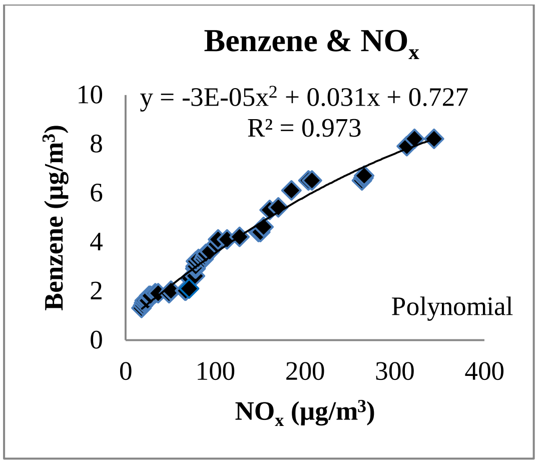

Benzene & NO2
Benzene (µg/m3)
NO2 (µg/m3)
y = 0.0001x² + 0.0488x + 0.481
R² = 0.9712
Polynomial
10
8
6
4
2
0
0
50
100
150

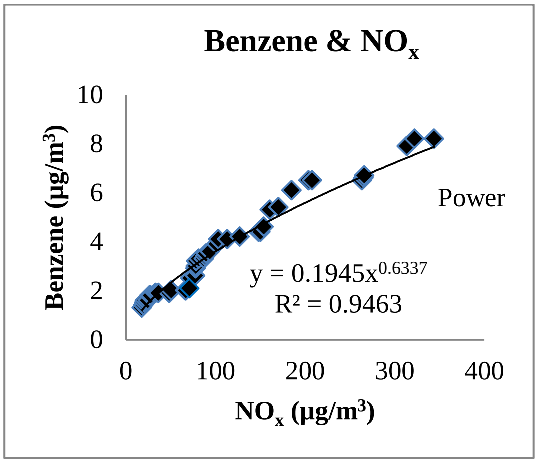

Benzene & NO2
Benzene (µg/m3)
NO2 (µg/m3)
y = 0.1287x0.8389
R² = 0.9193
Power
10
8
6
4
2
0
0
50
100
150

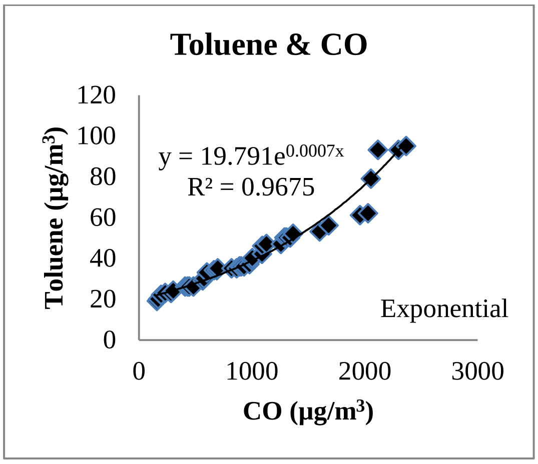

Benzene & NOx
y = 1.7044e^0.0056x
R² = 0.865
Exponential
Benzene (µg/m³)
14
12
10
8
6
4
2
0
0
100
200
300
400
NOx (µg/m³)

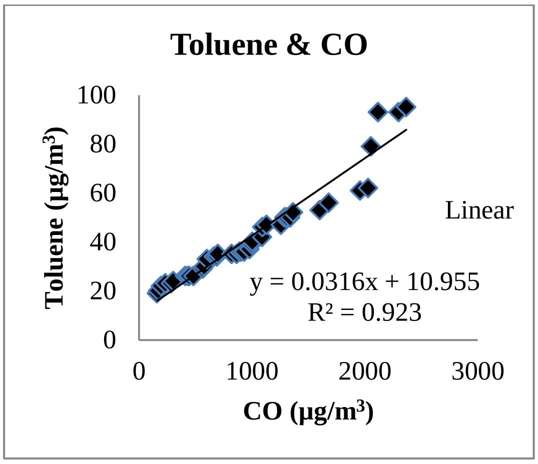

Benzene & NOx
Linear
y = 0.0222x + 1.183
R² = 0.9614
Benzene (µg/m³)
10
8
6
4
2
0
0
100
200
300
400
NOx (µg/m³)

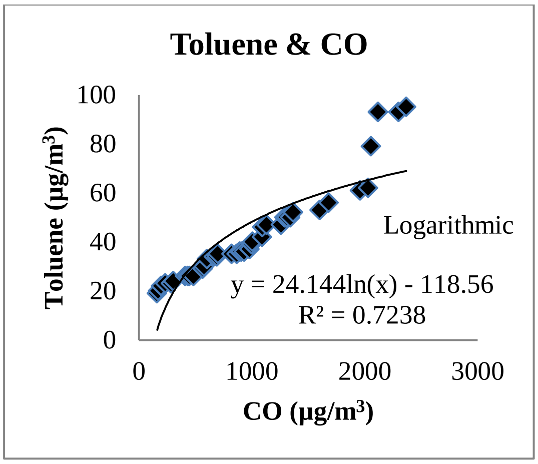

Benzene & NOx
Logarithmic
y = 2.2739ln(x) - 6.3678
R² = 0.8685
Benzene (µg/m³)
10
8
6
4
2
0
0
100
200
300
400
NOx (µg/m³)

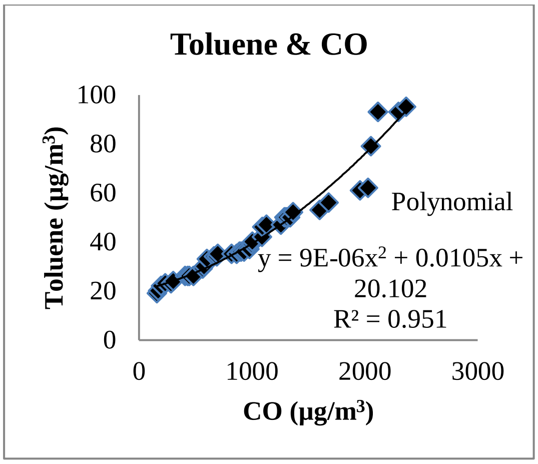

Benzene & NOx
y = -3E-05x² + 0.031x + 0.727
R² = 0.973
Polynomial
Benzene (µg/m³)
10
8
6
4
2
0
0
100
200
300
400
NOx (µg/m³)

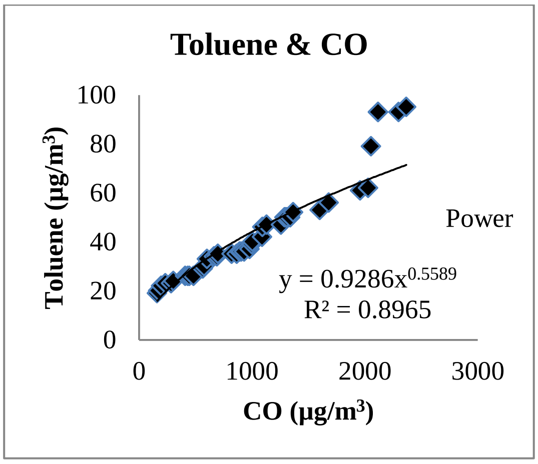

Benzene & NOx
Power
y = 0.1945x^0.6337
R² = 0.9463
Benzene (µg/m³)
10
8
6
4
2
0
0
100
200
300
400
NOx (µg/m³)

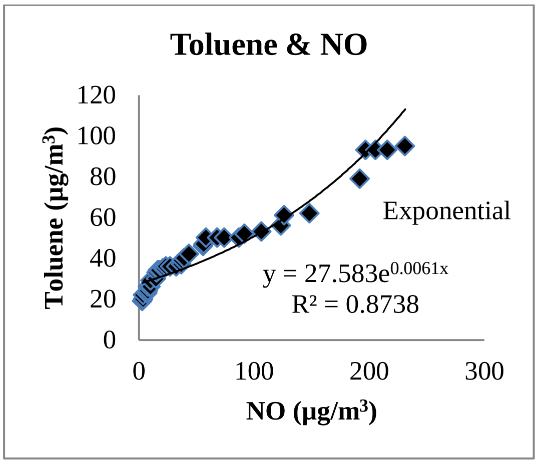

Toluene & CO
Toluene (µg/m³)
CO (µg/m³)
120
100
80
60
40
20
0
0
1000
2000
3000
y = 19.791e^0.0007x
R² = 0.9675
Exponential

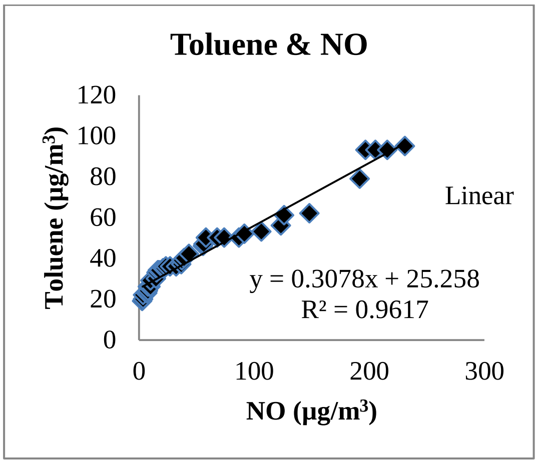

Toluene & CO
Toluene (µg/m³)
CO (µg/m³)
100
80
60
40
20
0
0
1000
2000
3000
Linear
y = 0.0316x + 10.955
R² = 0.923

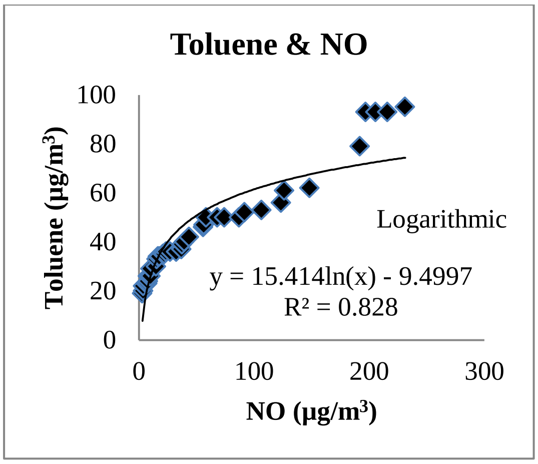

Toluene & CO
Toluene (µg/m³)
CO (µg/m³)
100
80
60
40
20
0
0
1000
2000
3000
Logarithmic
y = 24.144ln(x) - 118.56
R² = 0.7238

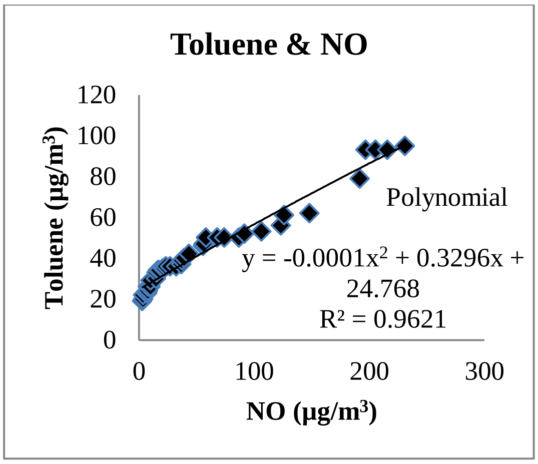

Toluene & CO
Toluene (µg/m³)
CO (µg/m³)
100
80
60
40
20
0
0
1000
2000
3000
Polynomial
y = 9E-06x² + 0.0105x + 20.102
R² = 0.951

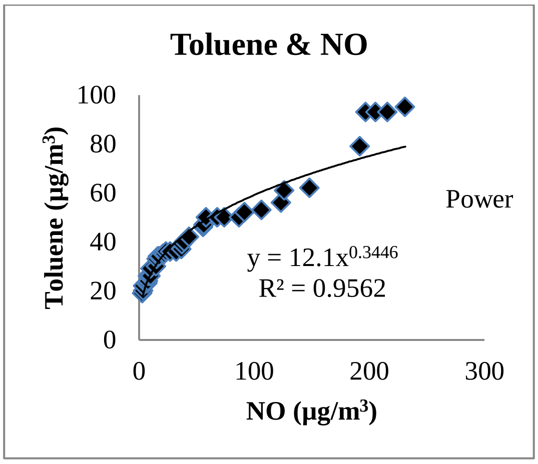

Toluene & CO
Toluene (µg/m³)
CO (µg/m³)
100
80
60
40
20
0
0
1000
2000
3000
Power
y = 0.9286x^0.5589
R² = 0.8965

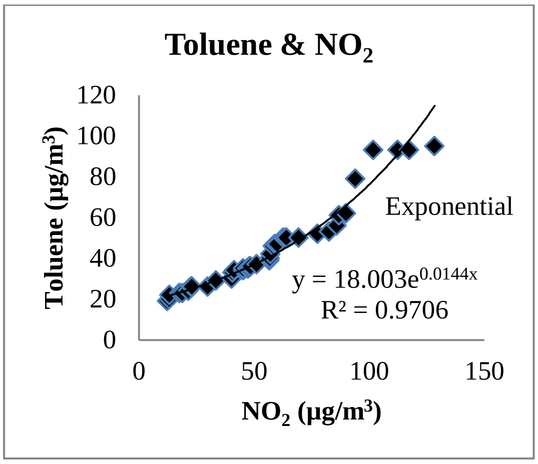

Toluene & NO
Toluene (µg/m³)
120
100
80
60
40
20
0
0
100
200
300
NO (µg/m³)
Exponential
y = 27.583e^0.0061x
R² = 0.8738

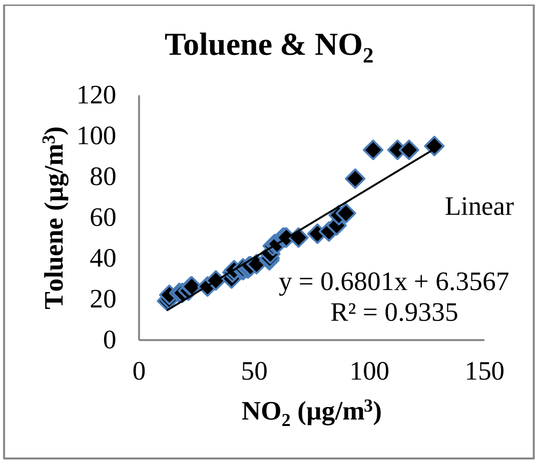

Toluene & NO
Toluene (µg/m³)
120
100
80
60
40
20
0
0
100
200
300
NO (µg/m³)
Linear
y = 0.3078x + 25.258
R² = 0.9617

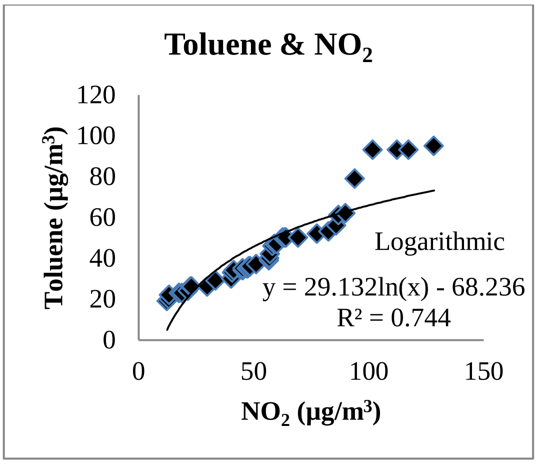

Toluene & NO
Toluene (µg/m³)
100
80
60
40
20
0
0
100
200
300
NO (µg/m³)
Logarithmic
y = 15.414ln(x) - 9.4997
R² = 0.828

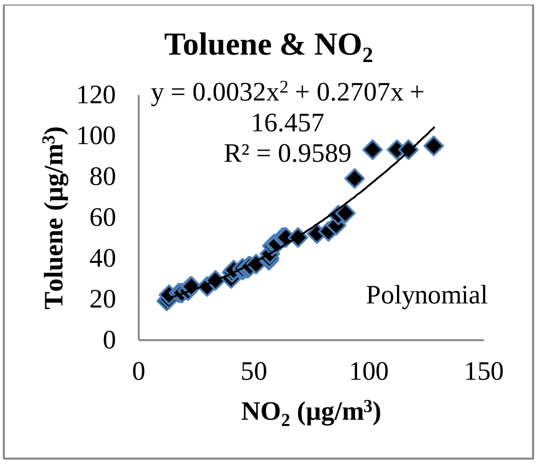

Toluene & NO
Toluene (µg/m³)
120
100
80
60
40
20
0
0
100
200
300
NO (µg/m³)
Polynomial
y = -0.0001x² + 0.3296x + 24.768
R² = 0.9621

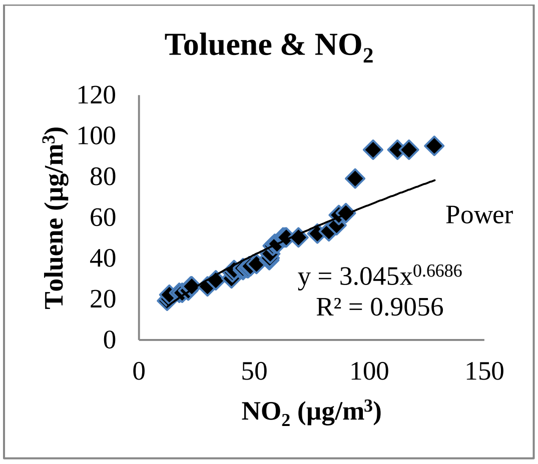

Toluene & NO
Toluene (µg/m³)
100
80
60
40
20
0
0
100
200
300
NO (µg/m³)
Power
y = 12.1x^0.3446
R² = 0.9562

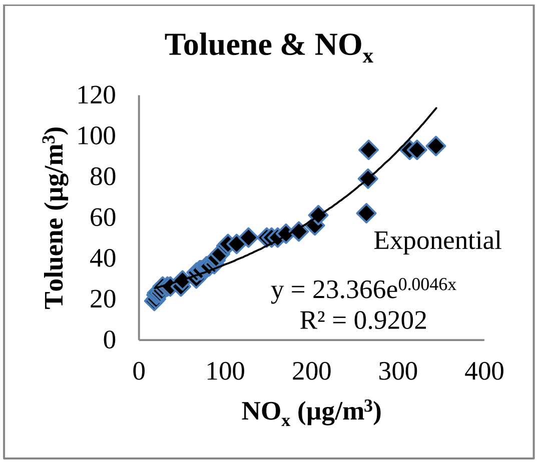

Toluene & NO_2
Toluene (µg/m^3)
120
100
80
60
40
20
0
0
50
100
150
NO_2 (µg/m^3)
Exponential
$y = 18.003e^{0.0144x}$
$R^2 = 0.9706$

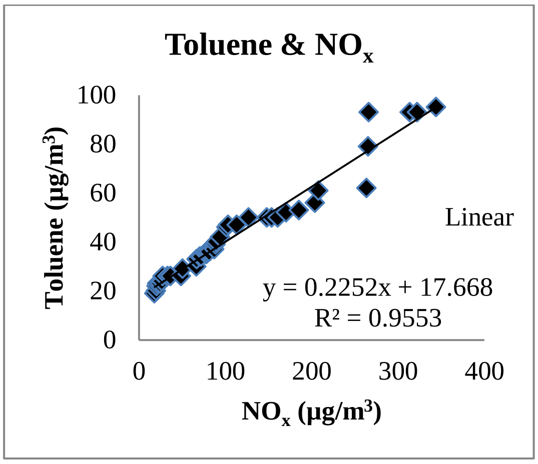

Toluene & NO_2
Toluene (µg/m^3)
120
100
80
60
40
20
0
0
50
100
150
NO_2 (µg/m^3)
Linear
$y = 0.6801x + 6.3567$
$R^2 = 0.9335$

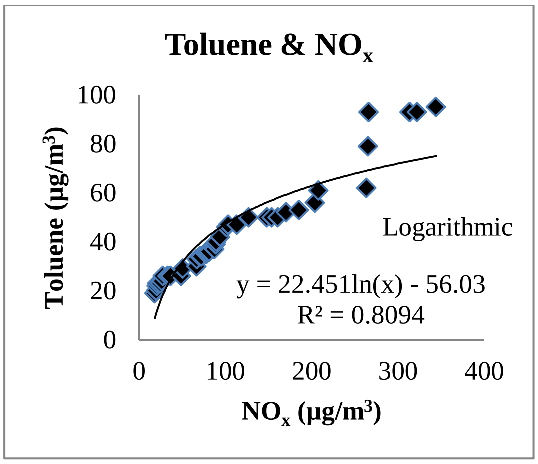

Toluene & NO_2
Toluene (µg/m^3)
120
100
80
60
40
20
0
0
50
100
150
NO_2 (µg/m^3)
Logarithmic
$y = 29.132\ln(x) - 68.236$
$R^2 = 0.744$

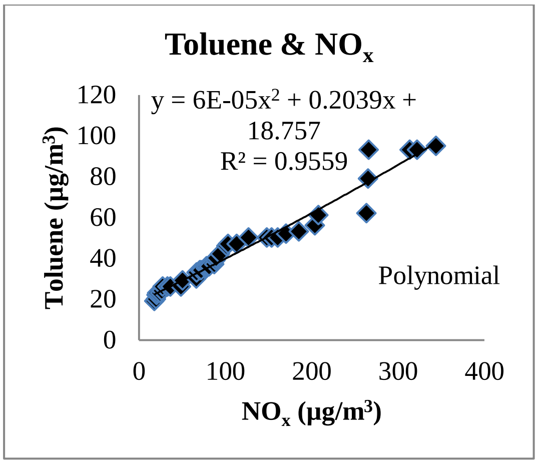

Toluene & NO_2
Toluene (µg/m^3)
120
100
80
60
40
20
0
0
50
100
150
NO_2 (µg/m^3)
$y = 0.0032x^2 + 0.2707x + 16.457$
$R^2 = 0.9589$
Polynomial

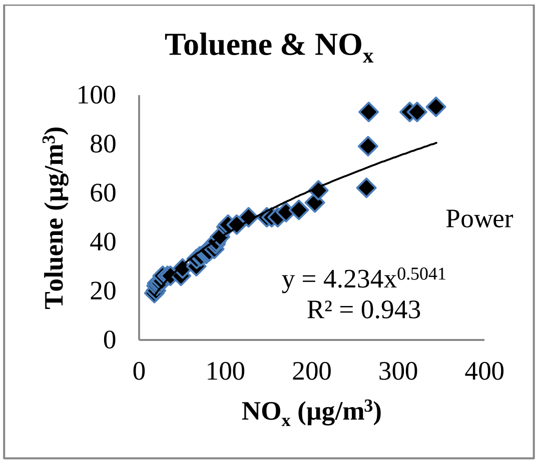

Toluene & NO_2
Toluene (µg/m^3)
120
100
80
60
40
20
0
0
50
100
150
NO_2 (µg/m^3)
Power
$y = 3.045x^{0.6686}$
$R^2 = 0.9056$

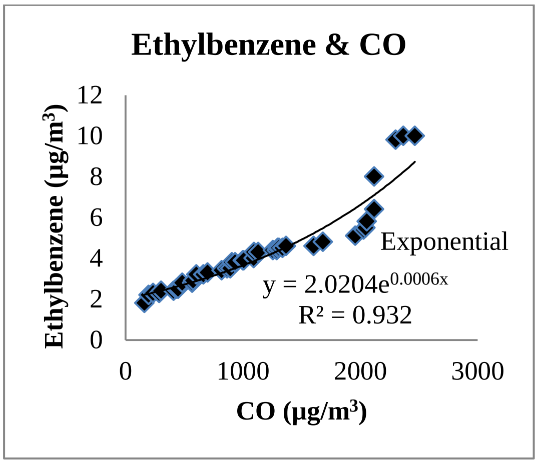

Toluene & NOx
Toluene (µg/m³)
120
100
80
60
40
20
0
0
100
200
300
400
NOx (µg/m³)
Exponential
y = 23.366e^0.0046x
R² = 0.9202

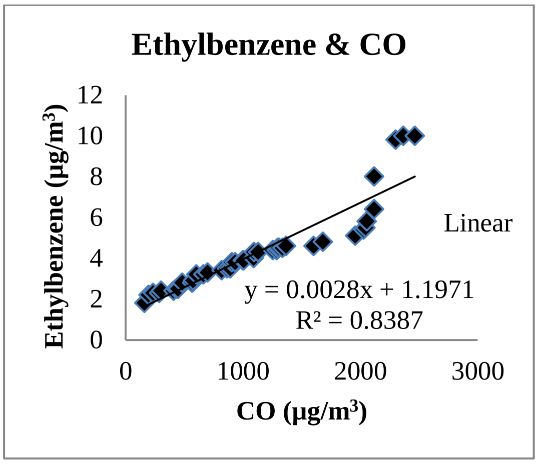

Toluene & NOx
Toluene (µg/m³)
100
80
60
40
20
0
0
100
200
300
400
NOx (µg/m³)
Linear
y = 0.2252x + 17.668
R² = 0.9553

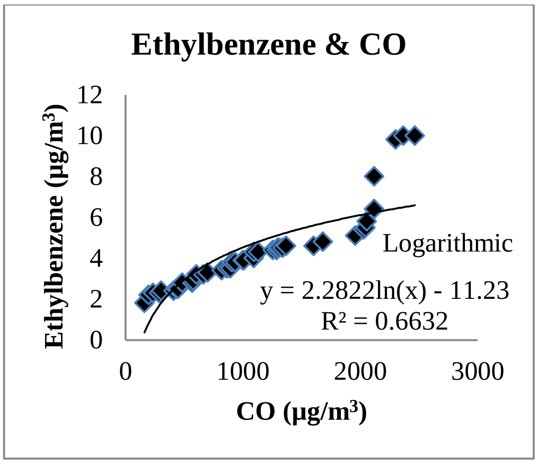

Toluene & NOx
Toluene (µg/m³)
100
80
60
40
20
0
0
100
200
300
400
NOx (µg/m³)
Logarithmic
y = 22.451ln(x) - 56.03
R² = 0.8094

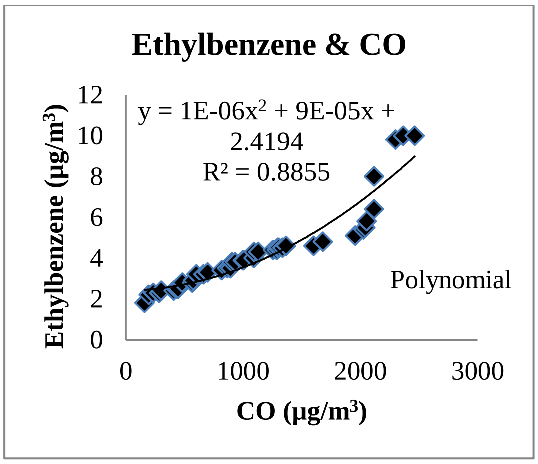

Toluene & NOx
Toluene (µg/m³)
120
100
80
60
40
20
0
0
100
200
300
400
NOx (µg/m³)
y = 6E-05x² + 0.2039x + 18.757
R² = 0.9559
Polynomial

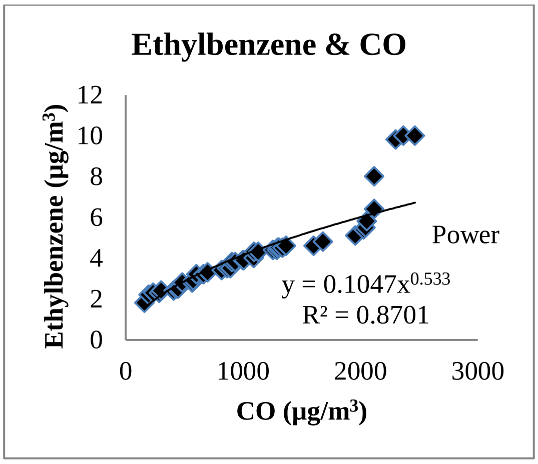

Toluene & NOx
Toluene (µg/m³)
100
80
60
40
20
0
0
100
200
300
400
NOx (µg/m³)
Power
y = 4.234x^0.5041
R² = 0.943

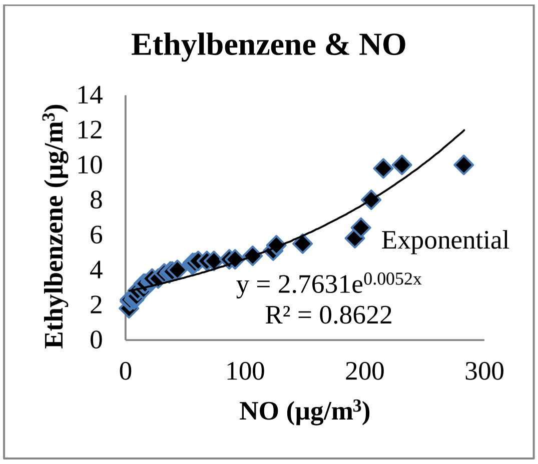

Ethylbenzene & CO
Ethylbenzene (µg/m³)
12
10
8
6
4
2
0
0
1000
2000
3000
CO (µg/m³)
Exponential
y = 2.0204e^0.0006x
R² = 0.932

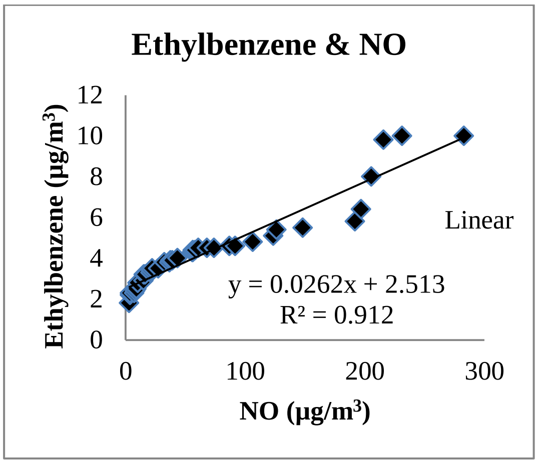

Ethylbenzene & CO
Ethylbenzene (µg/m³)
12
10
8
6
4
2
0
0
1000
2000
3000
CO (µg/m³)
Linear
y = 0.0028x + 1.1971
R² = 0.8387

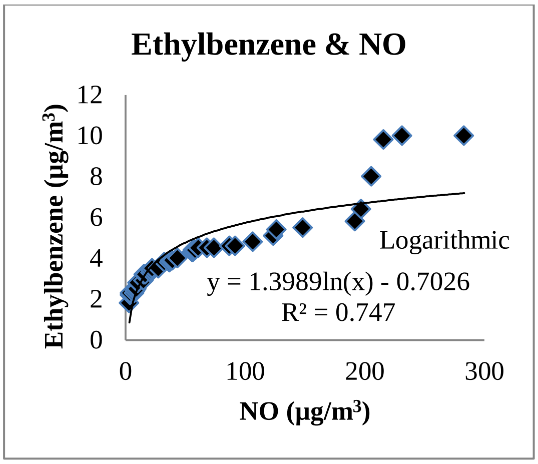

Ethylbenzene & CO
Ethylbenzene (µg/m³)
12
10
8
6
4
2
0
0
1000
2000
3000
CO (µg/m³)
Logarithmic
y = 2.2822ln(x) - 11.23
R² = 0.6632

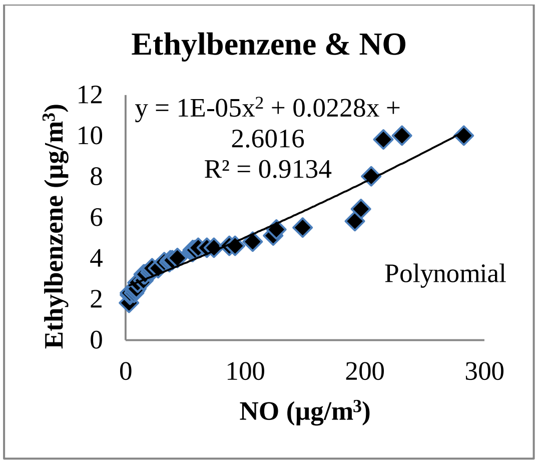

Ethylbenzene & CO
Ethylbenzene (µg/m³)
12
10
8
6
4
2
0
0
1000
2000
3000
CO (µg/m³)
y = 1E-06x² + 9E-05x + 2.4194
R² = 0.8855
Polynomial

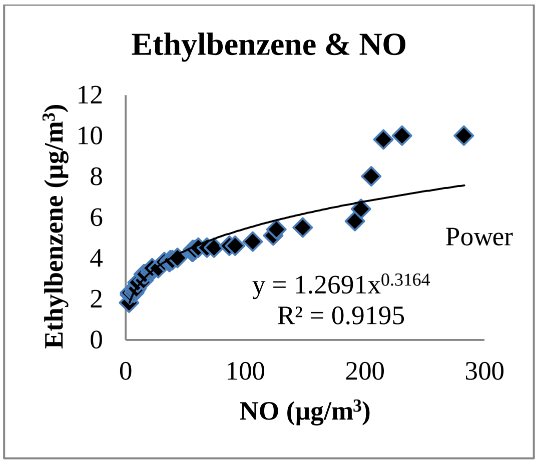

Ethylbenzene & CO
Ethylbenzene (µg/m³)
12
10
8
6
4
2
0
0
1000
2000
3000
CO (µg/m³)
Power
y = 0.1047x^0.533
R² = 0.8701

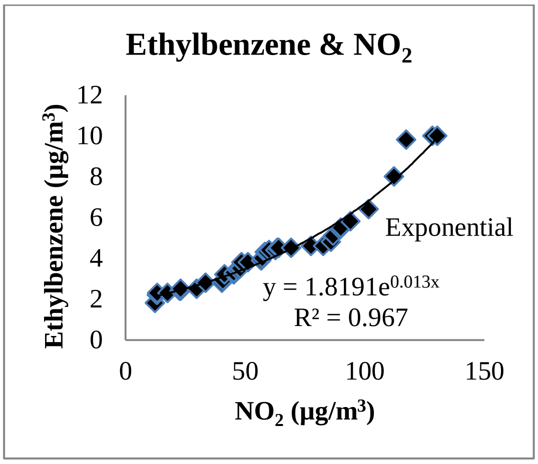

Ethylbenzene & NO
Ethylbenzene (µg/m^3)
14
12
10
8
6
4
2
0
0
100
200
300
NO (µg/m^3)
Exponential
y = 2.7631e$^{0.0052x}$
R² = 0.8622

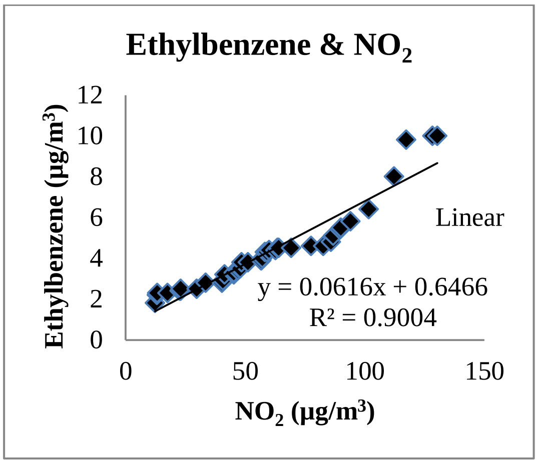

Ethylbenzene & NO
Ethylbenzene (µg/m^3)
12
10
8
6
4
2
0
0
100
200
300
NO (µg/m^3)
Linear
y = 0.0262x + 2.513
R² = 0.912

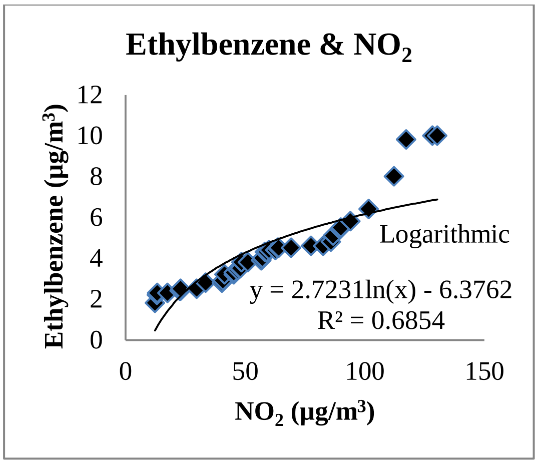

Ethylbenzene & NO
Ethylbenzene (µg/m^3)
12
10
8
6
4
2
0
0
100
200
300
NO (µg/m^3)
Logarithmic
y = 1.3989ln(x) - 0.7026
R² = 0.747

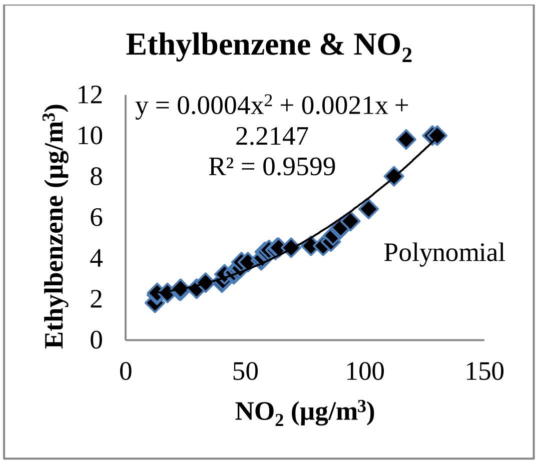

Ethylbenzene & NO
Ethylbenzene (µg/m^3)
12
10
8
6
4
2
0
0
100
200
300
NO (µg/m^3)
y = 1E-05x² + 0.0228x + 2.6016
R² = 0.9134
Polynomial

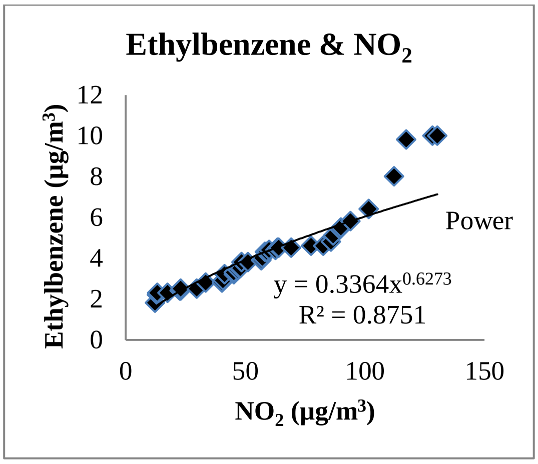

Ethylbenzene & NO
Ethylbenzene (µg/m^3)
12
10
8
6
4
2
0
0
100
200
300
NO (µg/m^3)
Power
y = 1.2691x$^{0.3164}$
R² = 0.9195

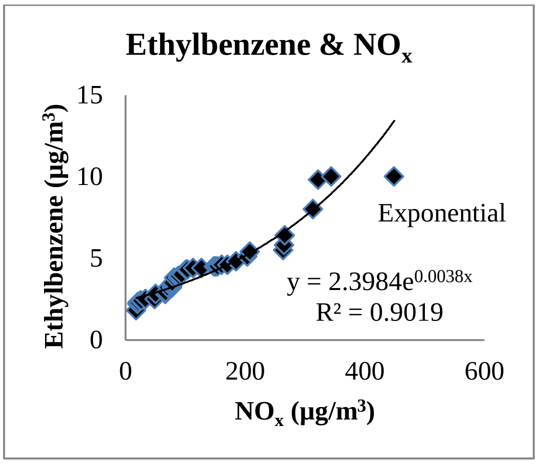

Ethylbenzene & NO$_2$
Ethylbenzene (µg/m^3)
NO$_2$ (µg/m^3)
0
2
4
6
8
10
12
0
50
100
150
Exponential
y = 1.8191e$^{0.013x}$
R² = 0.967

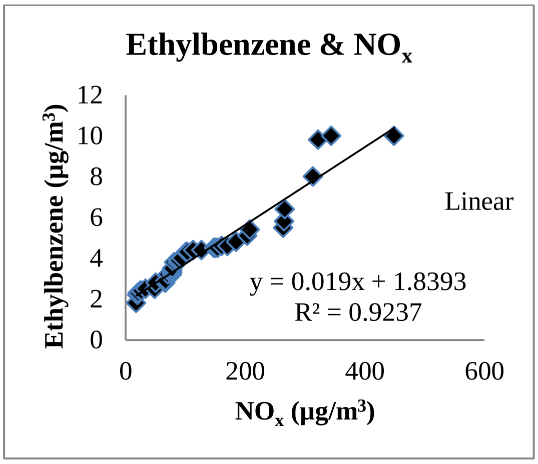

Ethylbenzene & NO$_2$
Ethylbenzene (µg/m^3)
NO$_2$ (µg/m^3)
0
2
4
6
8
10
12
0
50
100
150
Linear
y = 0.0616x + 0.6466
R² = 0.9004

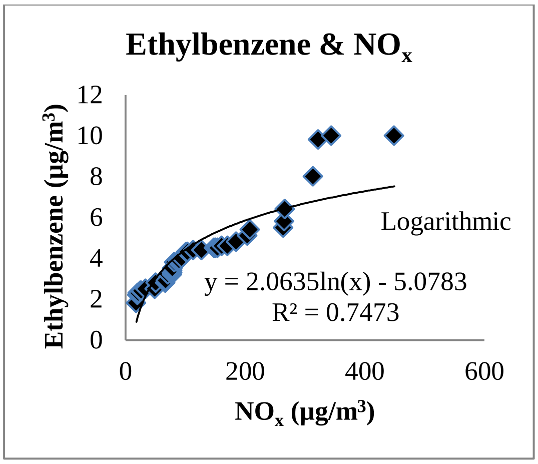

Ethylbenzene & NO$_2$
Ethylbenzene (µg/m^3)
NO$_2$ (µg/m^3)
0
2
4
6
8
10
12
0
50
100
150
Logarithmic
y = 2.7231ln(x) - 6.3762
R² = 0.6854

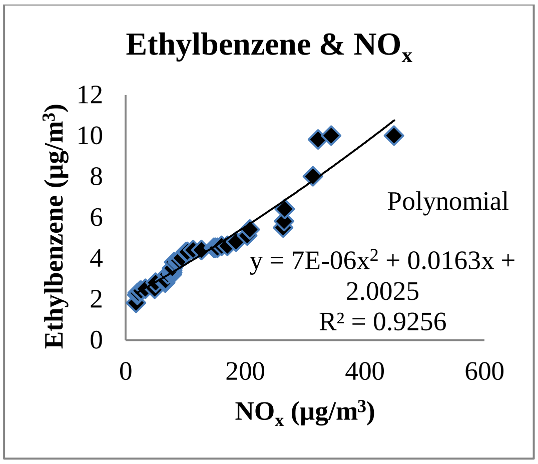

Ethylbenzene & NO$_2$
Ethylbenzene (µg/m^3)
NO$_2$ (µg/m^3)
0
2
4
6
8
10
12
0
50
100
150
y = 0.0004x² + 0.0021x + 2.2147
R² = 0.9599
Polynomial

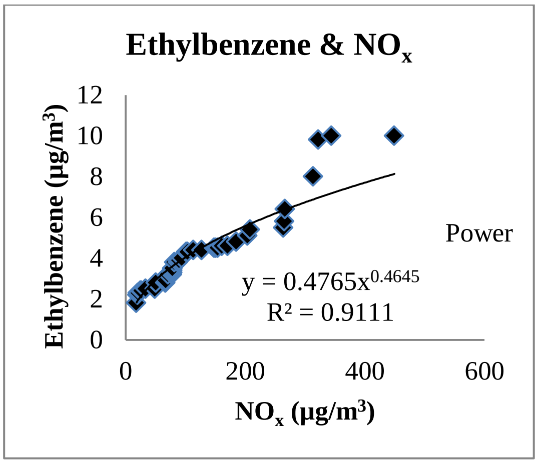

Ethylbenzene & NO$_2$
Ethylbenzene (µg/m^3)
NO$_2$ (µg/m^3)
0
2
4
6
8
10
12
0
50
100
150
Power
y = 0.3364x$^{0.6273}$
R² = 0.8751

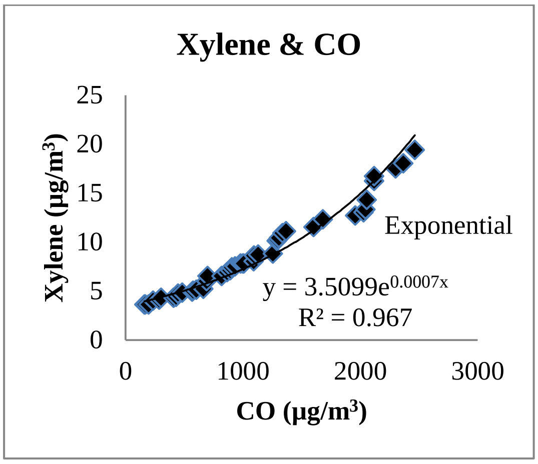

Ethylbenzene & NOx
Ethylbenzene (µg/m3)
15
10
5
0
0
200
400
600
NOx (µg/m3)
Exponential
y = 2.3984e0.0038x
R² = 0.9019

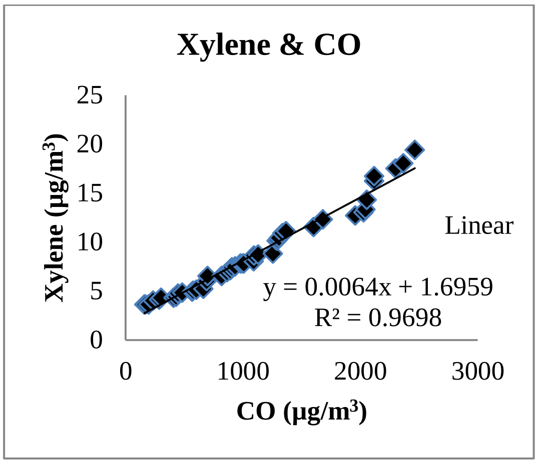

Ethylbenzene & NOx
Ethylbenzene (µg/m3)
12
10
8
6
4
2
0
0
200
400
600
NOx (µg/m3)
Linear
y = 0.019x + 1.8393
R² = 0.9237

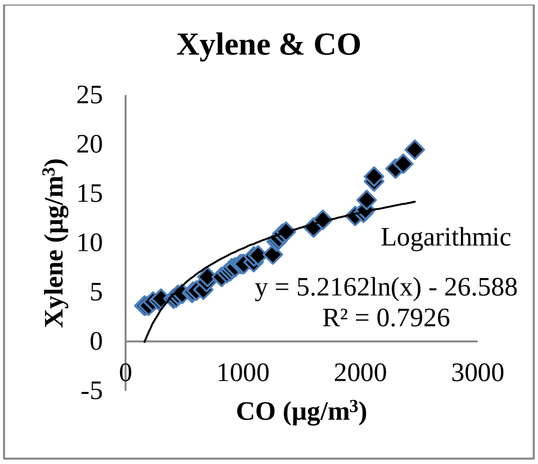

Ethylbenzene & NOx
Ethylbenzene (µg/m3)
12
10
8
6
4
2
0
0
200
400
600
NOx (µg/m3)
Logarithmic
y = 2.0635ln(x) - 5.0783
R² = 0.7473

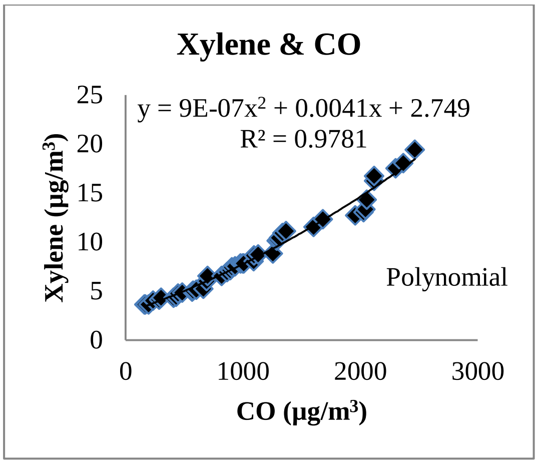

Ethylbenzene & NOx
Ethylbenzene (µg/m3)
12
10
8
6
4
2
0
0
200
400
600
NOx (µg/m3)
Polynomial
y = 7E-06x2 + 0.0163x + 2.0025
R² = 0.9256

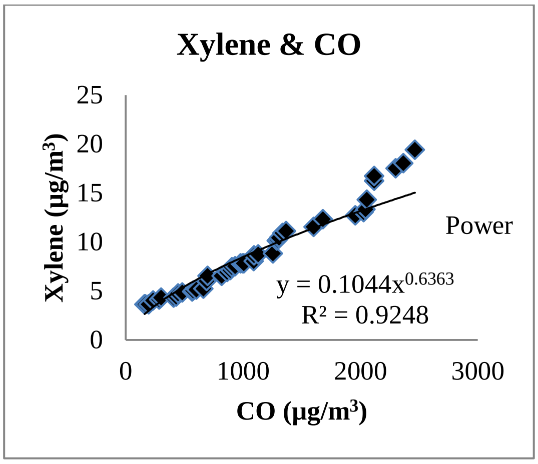

Ethylbenzene & NOx
Ethylbenzene (µg/m3)
12
10
8
6
4
2
0
0
200
400
600
NOx (µg/m3)
Power
y = 0.4765x0.4645
R² = 0.9111

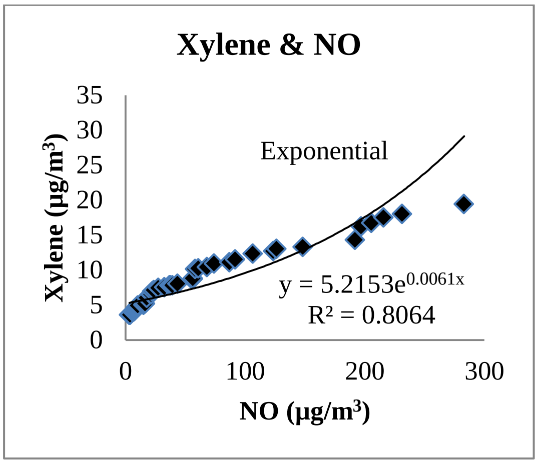

Xylene & CO
Xylene (µg/m³)
25
20
15
10
5
0
0
1000
2000
3000
CO (µg/m³)
Exponential
y = 3.5099e^0.0007x
R² = 0.967

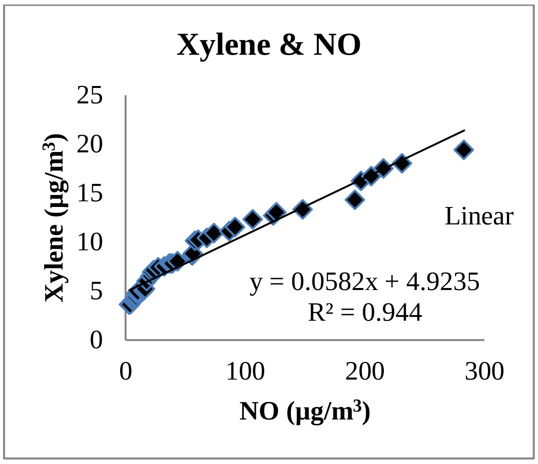

Xylene & CO
Xylene (µg/m³)
25
20
15
10
5
0
0
1000
2000
3000
CO (µg/m³)
Linear
y = 0.0064x + 1.6959
R² = 0.9698

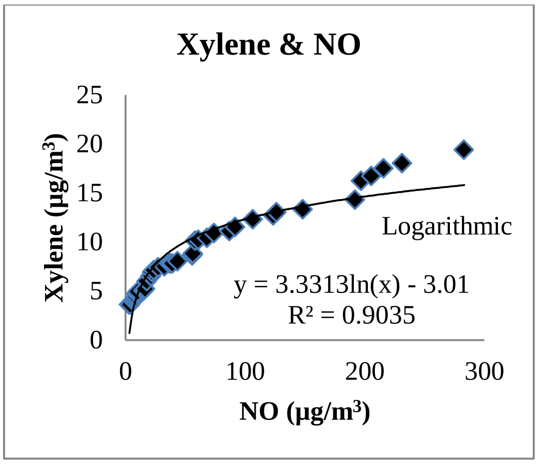

Xylene & CO
Xylene (µg/m³)
25
20
15
10
5
0
-5
0
1000
2000
3000
CO (µg/m³)
Logarithmic
y = 5.2162ln(x) - 26.588
R² = 0.7926

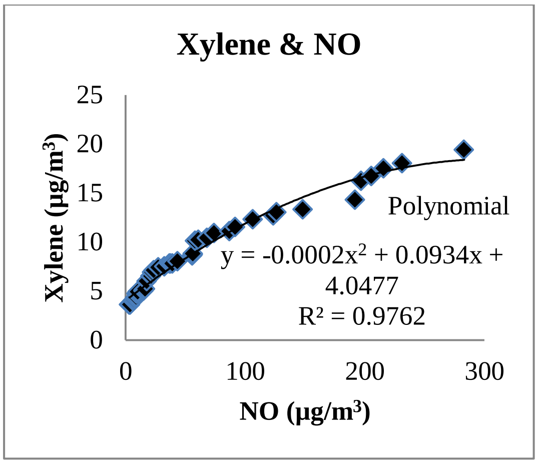

Xylene & CO
Xylene (µg/m³)
25
20
15
10
5
0
y = 9E-07x² + 0.0041x + 2.749
R² = 0.9781
Polynomial
0
1000
2000
3000
CO (µg/m³)

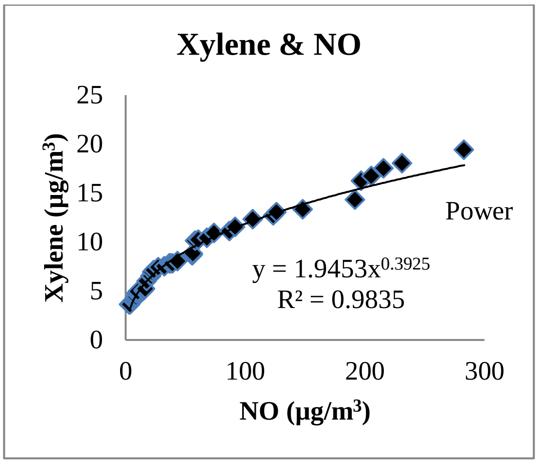

Xylene & CO
Xylene (µg/m³)
25
20
15
10
5
0
0
1000
2000
3000
CO (µg/m³)
Power
y = 0.1044x^0.6363
R² = 0.9248

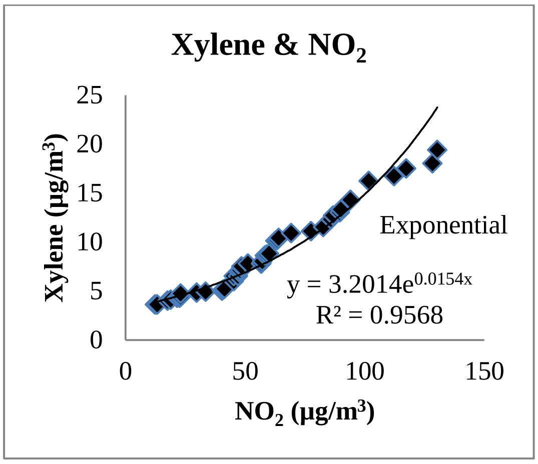

Xylene & NO
Exponential
y = 5.2153e^0.0061x
R² = 0.8064
Xylene (µg/m³)
35
30
25
20
15
10
5
0
0
100
200
300
NO (µg/m³)

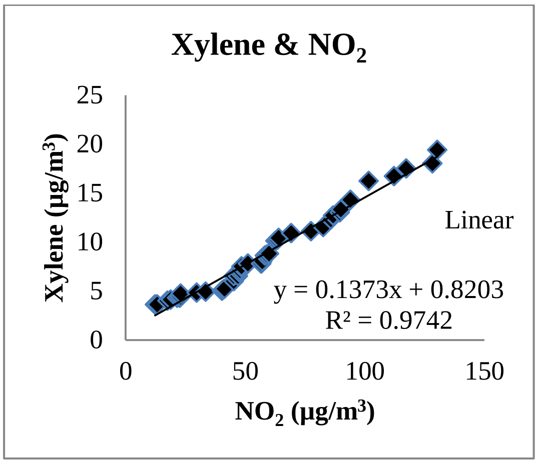

Xylene & NO
Linear
y = 0.0582x + 4.9235
R² = 0.944
Xylene (µg/m³)
25
20
15
10
5
0
0
100
200
300
NO (µg/m³)

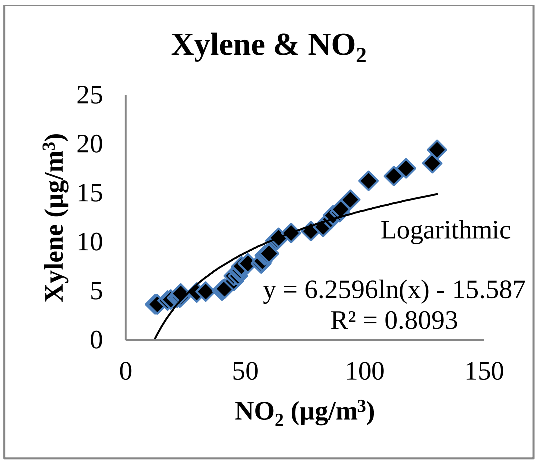

Xylene & NO
Logarithmic
y = 3.3313ln(x) - 3.01
R² = 0.9035
Xylene (µg/m³)
25
20
15
10
5
0
0
100
200
300
NO (µg/m³)

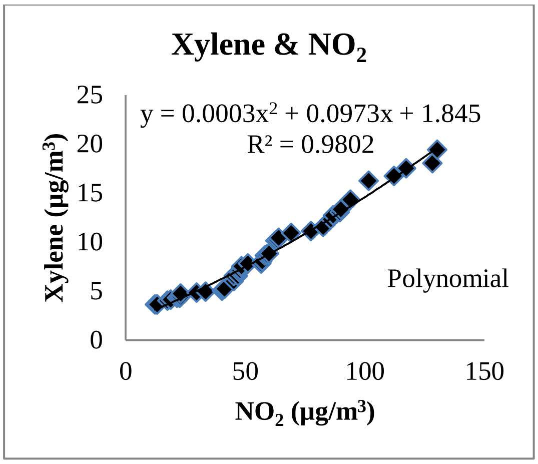

Xylene & NO
Polynomial
y = -0.0002x² + 0.0934x + 4.0477
R² = 0.9762
Xylene (µg/m³)
25
20
15
10
5
0
0
100
200
300
NO (µg/m³)

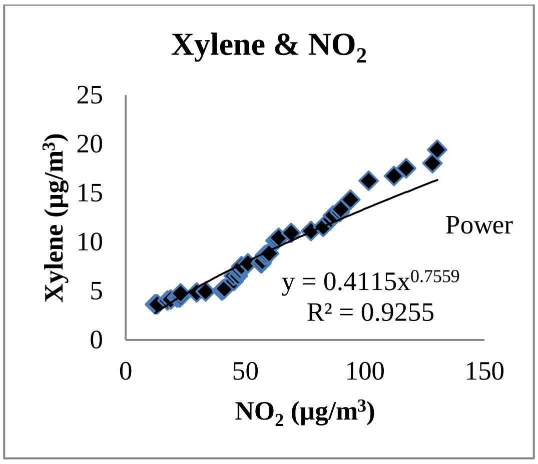

Xylene & NO
Power
y = 1.9453x^0.3925
R² = 0.9835
Xylene (µg/m³)
25
20
15
10
5
0
0
100
200
300
NO (µg/m³)

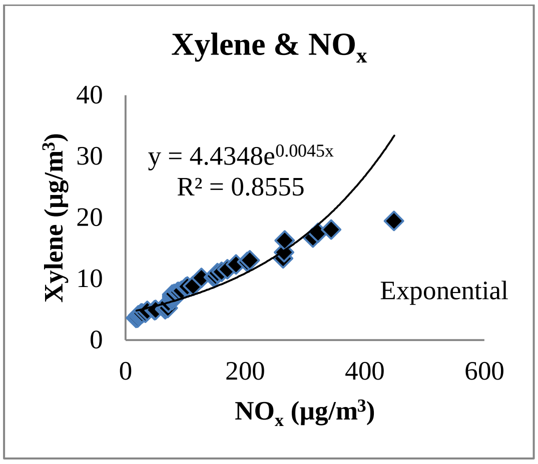

Xylene & NO2
Xylene (µg/m3)
25
20
15
10
5
0
0
50
100
150
NO2 (µg/m3)
Exponential
y = 3.2014e0.0154x
R² = 0.9568

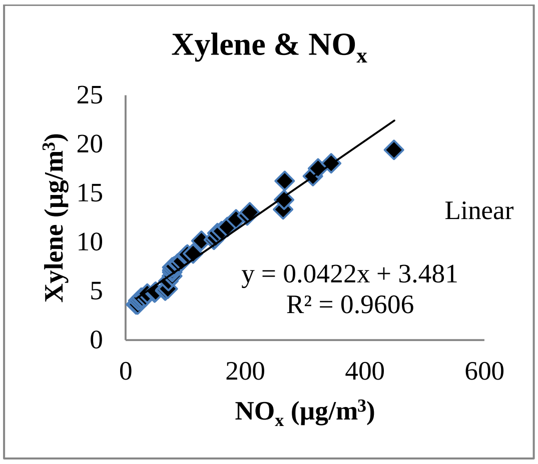

Xylene & NO2
Xylene (µg/m3)
25
20
15
10
5
0
0
50
100
150
NO2 (µg/m3)
Linear
y = 0.1373x + 0.8203
R² = 0.9742

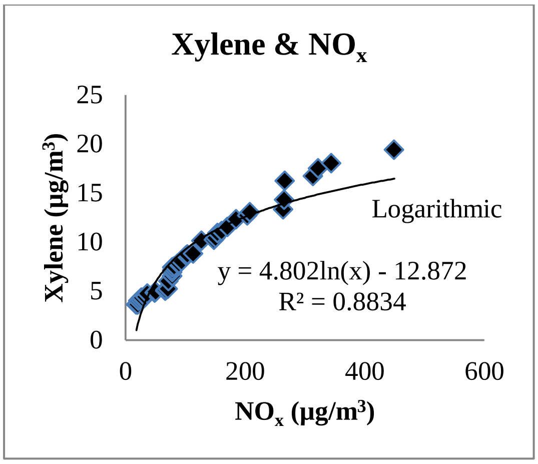

Xylene & NO2
Xylene (µg/m3)
25
20
15
10
5
0
0
50
100
150
NO2 (µg/m3)
Logarithmic
y = 6.2596ln(x) - 15.587
R² = 0.8093

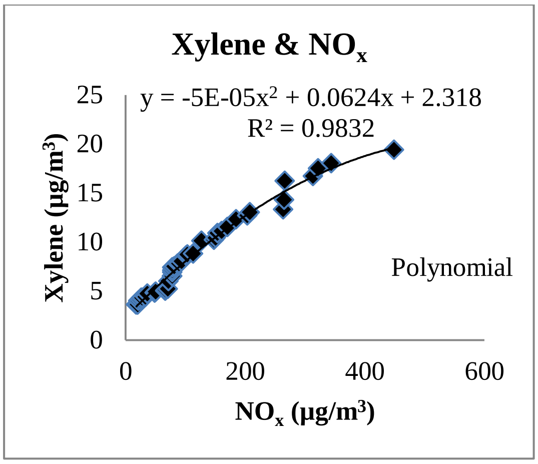

Xylene & NO2
Xylene (µg/m3)
25
20
15
10
5
0
0
50
100
150
NO2 (µg/m3)
y = 0.0003x² + 0.0973x + 1.845
R² = 0.9802
Polynomial

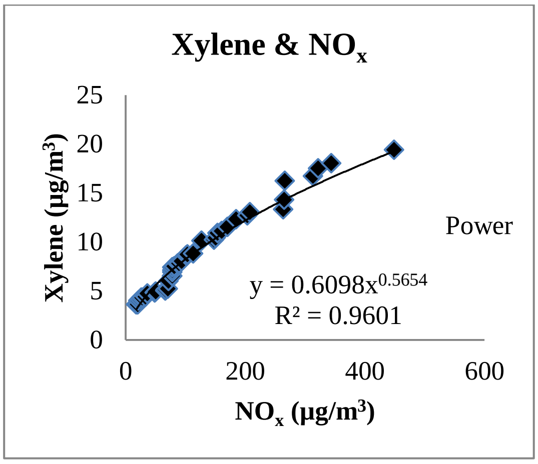

Xylene & NO2
Xylene (µg/m3)
25
20
15
10
5
0
0
50
100
150
NO2 (µg/m3)
Power
y = 0.4115x0.7559
R² = 0.9255


Xylene & NO_x
$y = 4.4348e^{0.0045x}$
$R^2 = 0.8555$
Exponential
40
30
20
10
0
0
200
400
600
Xylene (μg/m³)
NO_x (μg/m³)


Xylene & NO_x
Linear
$y = 0.0422x + 3.481$
$R^2 = 0.9606$
25
20
15
10
5
0
0
200
400
600
Xylene (μg/m³)
NO_x (μg/m³)

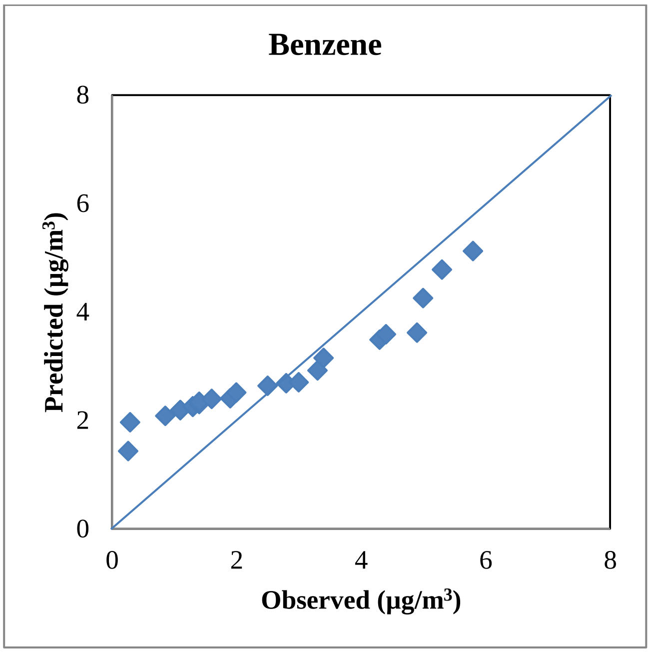

Xylene & NO_x
Logarithmic
$y = 4.802\ln(x) - 12.872$
$R^2 = 0.8834$
25
20
15
10
5
0
0
200
400
600
Xylene (μg/m³)
NO_x (μg/m³)

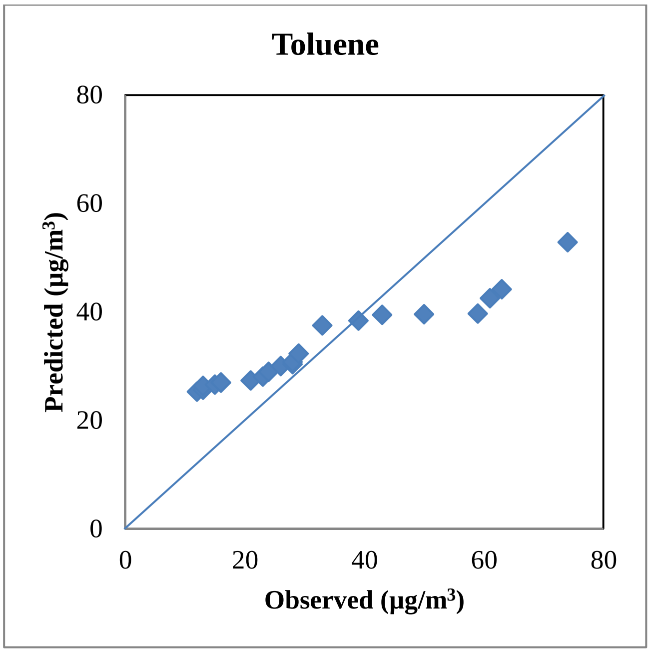

Xylene & NO_x
$y = -5E-05x^2 + 0.0624x + 2.318$
$R^2 = 0.9832$
Polynomial
25
20
15
10
5
0
0
200
400
600
Xylene (μg/m³)
NO_x (μg/m³)

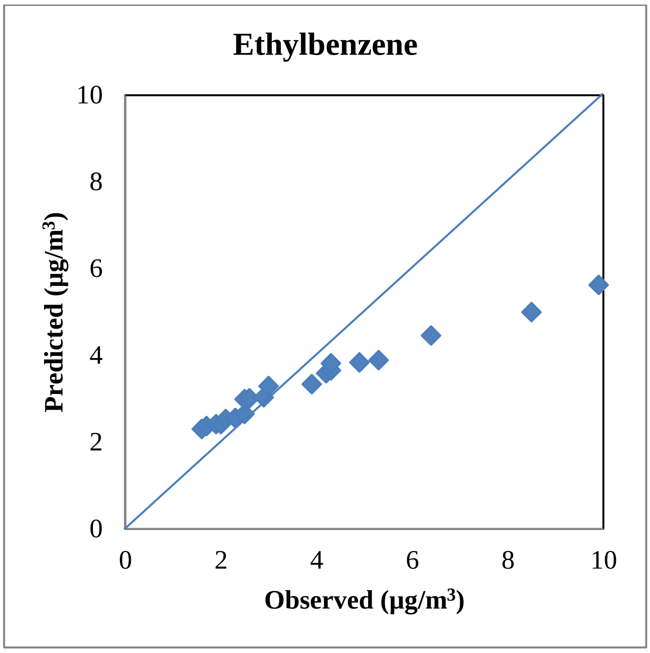

Xylene & NO_x
Power
$y = 0.6098x^{0.5654}$
$R^2 = 0.9601$
25
20
15
10
5
0
0
200
400
600
Xylene (μg/m³)
NO_x (μg/m³)

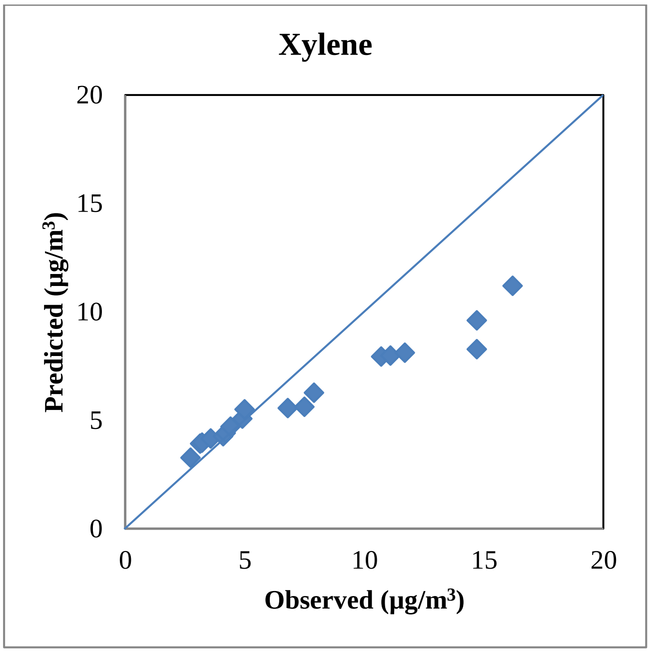
APPENDIX C

A Q-Q PLOT FOR MODEL VALIDATION OF DATA FROM THE YEAR 2014






Ethylbenzene
Predicted (µg/m³)
Observed (µg/m³)
0
2
4
6
8
10
0
2
4
6
8
10


Xylene
Predicted (µg/m³)
Observed (µg/m³)
0
5
10
15
20
0
5
10
15
20

APPENDIX D

PUBLICATION

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Impact of fuel switching to the level of air toxic and its potential health impact in Bangkok, THAILAND

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Keywords: Air toxic, Benzene, 1, 3-butadiene, Health impact

Abstract

The annual arithmetic mean concentrations of benzene and 1, 3-butadiene were gradually decreasing tendency from the year 2008 – 2011 at every monitoring stations in Bangkok. Dramatically decreasing of these air toxics, measured in the road curbside areas were found in the year 2012 when the Thai's government implemented the improvement of fuel quality from Euro 2 to Euro 4 standards. Calculated cancer risk of benzene and 1, 3-butadiene dramatically decreased at every monitoring stations. The results indicated that the population was estimated to receive an excess lifetime cancer risk greater than 1 x 10^{-5}, which is proposed as the permissible maximum value for individual excess lifetime cancer risk by the Japan Environmental Agency (JEA). However, cancer risk from air toxic was found significantly decreased in the year 2012. These finding elucidated the effectiveness of changing of fuel quality to the reduction of airborne air toxic concentration in Bangkok environment.

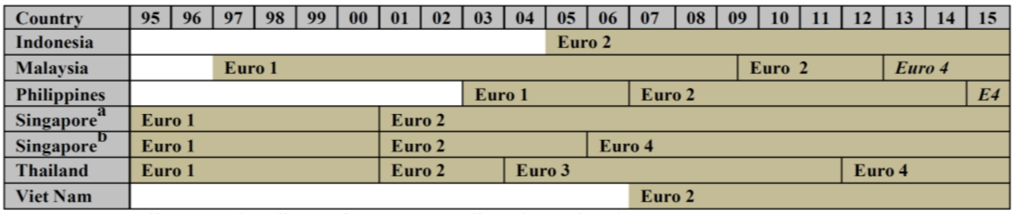
Introduction

Air pollution is contamination of the outdoor or indoor environment by any physical, biological or chemical agent that modifies the natural characteristics of the atmosphere. Air pollution can cause long-term and short-term health effects. Volatile Organic Compounds (VOCs) are a major group of pollutants which significantly affect the chemistry of atmosphere and human health. They play an important role in the stratospheric ozone depletion, formation of highly toxic secondary pollutants, and enhance the global greenhouse effect [1]. Their toxic and carcinogenic human health effects are also well recognized [2], [3], [4]. VOCs can be emitted from combustion processes utilizing fossil fuels, petroleum storage and distribution, solvent usage and other industrial processes. In urban atmospheres, high concentrations of VOCs mainly originate from motor vehicle exhausts and their levels increase with increasing traffic densities. In such cases, ambient VOC concentrations are affected by the fuels used, type and age of vehicles, flow rate and speeds of traffic as well as environmental conditions in the city [5], [6].

Table 1 shows the current and planned vehicle emissions standards for new LDVs in selected ASEAN countries [7]. The Thai government has been attempting in respond to the environmental problems, in which several effective pollution control measures were initiated. The measures aim not only at exhaust gas emission controls but also at the improvement of fuel and vehicle specifications. The measure directed toward reducing vehicle emissions is fuel reformation.

Euro 4 standard vehicles derived from the standards set by European Union countries. The order of the applicable standard sort since the sequence 1, 2, and 3. Euro 4 standard can be used for any standard of cars and fuel standards. Thailand has announced the date for enforcing Euro 4 standards on January 1, 2012. Therefore, the standard Euro 4 vehicle has set its optimal fuel to the engine as shown in Table 2 [8].

Table 1 Emission standards for New Light-Duty Vehicles (LDV)



Country	95	96	97	98	99	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15
Indonesia											Euro 2										
Malaysia			Euro 1												Euro 2				*Euro 4*		
Philippines									Euro 1				Euro 2								*E4*
Singapore[a]	Euro 1						Euro 2														
Singapore[b]	Euro 1						Euro 2					Euro 4									
Thailand	Euro 1						Euro 2			Euro 3								Euro 4			
Viet Nam													Euro 2								

Notes: Italics – under discussion; a – gasoline; b – Diesel

Table 2 Euro 4 fuel quality standards

Gasoline or Gasohol	Diesel
Octane is not less than 85 percent	Cetane number of at least 50 units
Sulfur content not exceeding 50 parts per million	Sulfur content not exceeding 50 parts per million.
Benzene amount not to exceed 1 percent by volume.	Polycyclic aromatic hydrocarbons (PAHs) concentration does not exceed 11 percent by weight
Concentration of olefins less than 18 percent by volume	
Lead content not exceed 0.005 g / liter	

Methodology

1. Data collection

The air monitoring data used in this study were from January 2008 to December 2012. VOCs were monitored at four monitoring stations in Bangkok metropolitan area namely Din Dang, Chok Chai 4, Bansomdaj and Chula Hospital respectively. The monitoring sites are operated by Pollution Control Department (PCD). VOCs samples were collected by 6 liter evacuated canisters (0.05 mmHg) and were analyzed using Gas Chromatography/Mass Spectrophotometer (GC/MS). Analyze method was based on US.EPA. TO15. When the canisters were opened to the atmosphere, the VOCs sample was introduced into the canisters by the differential pressure between atmospheric pressure and vacuum pressure inside each canister. With a flow control, the sub-atmospheric sampling system maintained a constant flow rate from full vacuum to within about 7kPa (1.0 psi) or less below ambient pressure. Canister flow rate was controlled by flow controller and was adjusted to 3.3 ml/min for 24-hr sampling. After collecting the ambient VOCs, the sample canister was pressurized by humidified nitrogen about 20 psia in order to prevent the contamination entering the sample canister. Samples were transferred to the thermal desorption unit, working as a pre-concentrator prior to being sent to GC/MS [9].

2. Data Analysis

Daily average (24 hours average) of Benzene and 1, 3-butadiene data were used in this study. Zero value was used to replace non-available data. As for the cases that data values were less than mark (<), half of those values were used in the analysis.

3. Health risk assessment

The health risk assessment of benzene and 1, 3-butadiene due to inhalation was evaluated in this study. The Integrated Risk Information System (IRIS) is an Environmental Protection Agency (US EPA) database of human health effects that may result from exposure to various substances found in the environment suggested a unit risk of $2.9\mathrm{x}10^{-5}$ $(\mu g/m^3)^{-1}$ of benzene concentration and $3\mathrm{x}10^{-5}$ $(\mu g/m^3)^{-1}$ of 1, 3-butadiene concentration. Cancer risk of people living in Bangkok calculated based on US EPA guidance for inhalation risk assessment is as shown in Eq. 1 [10].

$$\text{Risk} = \text{IUR} \times \text{EC} \qquad (1)$$

Where: IUR = inhalation unit risk $(\mu g/m^3)^{-1}$
EC = exposure concentration $(\mu g/m^3)$

Results and Discussions

The box plot of benzene and 1, 3-butadiene concentrations were examined from January 2008 to December 2012 as shown in Fig. 1 and Fig. 2. The horizontal solid line in the box indicated the median. The point lying outside the range defined by the whiskers were plotted as outlier dot and the star denoted the extreme event of the distribution of the year [11]. As for benzene, it was found that there were decreasing tendency of annual arithmetic mean concentrations from the year 2008 – 2011were within 6.99 – 5.28 μg/m^3, 4.91 – 3.88 μg/m^3, 3.68 – 2.80 μg/m^3 and 6.20 – 4.45 μg/m^3, for the year 2012 were 5.04 μg/m^3, 3.26 μg/m^3, 1.56 μg/m^3 and 3.94 μg/m^3 at every monitoring stations in Bangkok. The trend was downward until the year 2010, whereby each of the stations begins to transition to an upward trend at the year 2011 after that in the year 2012 the trend was dramatically decreased.

As for 1, 3-butadienee, it was found that there were decreasing tendency of annual arithmetic mean concentrations from the year 2008 – 2011 were within 0.97 – 0.006 μg/m^3, 0.48 – 0.006 μg/m^3, 0.31 – 0.03 μg/m^3 and 0.82 – 0.07 μg/m^3, for the year 2012 were 0.013 μg/m^3, 0.011 μg/m^3, 0.011 μg/m^3 and 0.013 μg/m^3, respectively according to enforcing of Euro 4 standards on January 1, 2012.

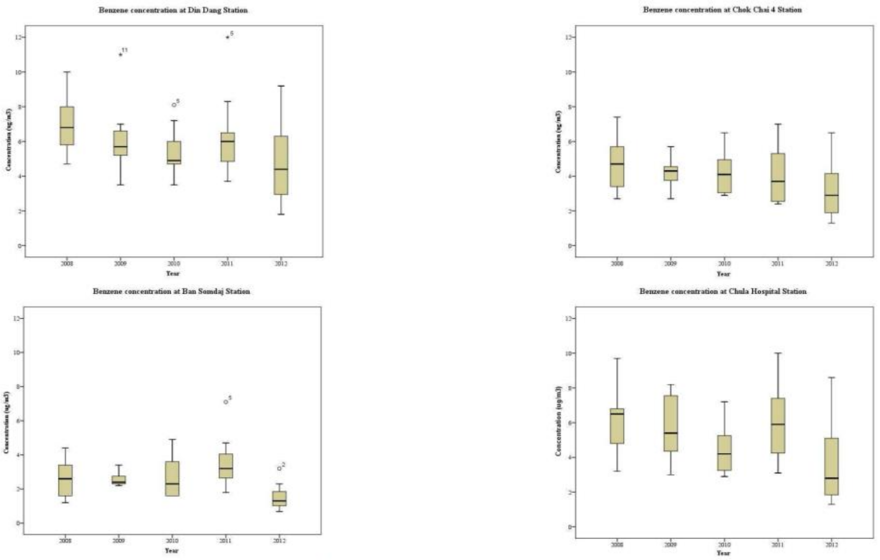
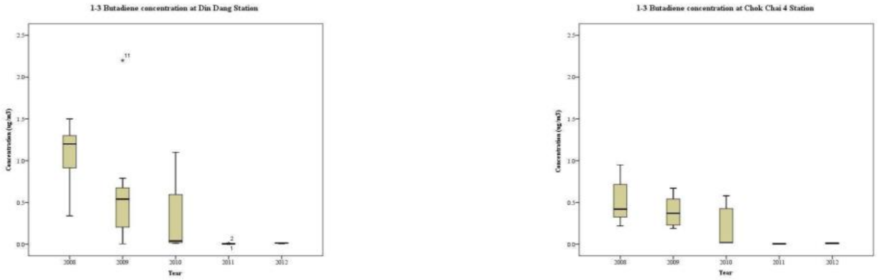


Figure 1 Box plot of benzene concentration



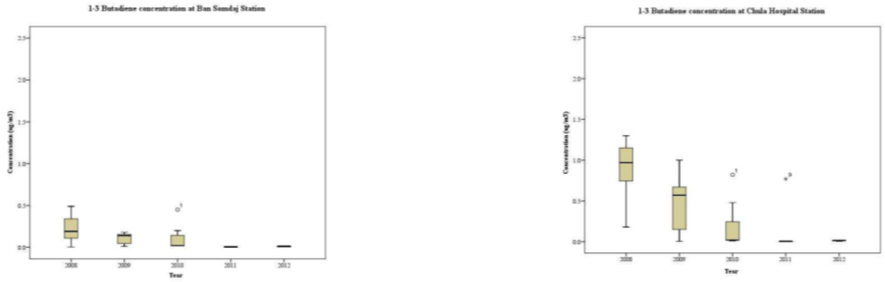


Figure 2 Box plot of 1, 3-butadiene concentration

Calculated cancer risk of benzene and 1, 3-butadiene dramatically decreased at every monitoring stations in Bangkok as shown in Fig. 3 and Fig. 4. Cancer risk of benzene at Din Dang were within $2.03x10^{-4}$ – $1.46x10^{-4}$, these values at Chok Chai 4, Ban Somdej and Chula hospital were $1.41x10^{-4}$ – $9.40x10^{-5}$, $1.06x10^{-4}$ – $4.50x10^{-5}$ and $1.77x10^{-4}$ – $1.14x10^{-4}$, respectively. The excess lifetime cancer risk of the population was calculated as the product of the benzene level and the unit risk for benzene. The results indicated that the population was estimated to receive an excess lifetime cancer risk greater than $1x10^{-5}$, which is proposed as the permissible maximum value for individual excess lifetime cancer risk by the Japan Environmental Agency (JEA) [12].

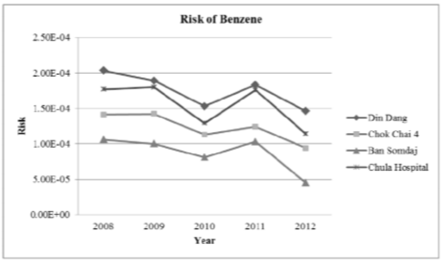


Figure 3 Risk of benzene

As for 1, 3-butadiene, cancer risk at Din Dang were within $2.91x10^{-5}$ – $3.90x10^{-7}$, at Chok Chai 4 were $1.44x10^{-5}$ – $3.30x10^{-7}$, at Ban Somdaj were $9.30x10^{-6}$ – $3.90x10^{-7}$ and at Chula hospital were $2.50x10^{-5}$ – $3.90x10^{-7}$, respectively. The results indicated that the population was estimated to receive an excess lifetime cancer risk greater than $1x10^{-5}$ except at Ban Som Daj station, which is proposed as the permissible maximum value by Japan Ministry of the Environment [13]. However, the cancer risks in the year 2012 were found significantly decreased which indicated a success of utilization of better fuel quality to the reduction of air toxic concentration in Bangkok.

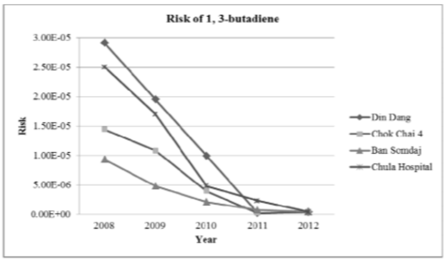


Figure 4 Risk of 1, 3-butadiene

Conclusion

This paper was presented the trend and cancer risk of benzene and 1, 3-butadiene from the year 2008 – 2012 in Bangkok, Thailand. Cancer risk of benzene was within $9.40 \times 10^{-5} – 2.03 \times 10^{-4}$ and 1, 3-butadiene was $3.90 \times 10^{-7} – 2.91 \times 10^{-5}$. The results have shown dramatically decreased at every monitoring station especially in between the year 2011 to 2012 because Thailand enforcing Euro 4 standards on January 1, 2012.

Acknowledgement

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References

[1] B. J. Finlayson-Pitts and J. N. Pitts Jr., Chemistry of the Upper and Lower Atmosphere: Theory, experiments and applications, first ed., Academic, San Diego, 2000.

[2] J. Dewulf and H. V. Langenhove, Anthropogenic volatile organic compounds in ambient air and natural waters: A review on recent developments of analytical methodology, performance and interpretation of field measurements, J. Chromatography A, 843 (1999) 163-177.

[3] H. Guo, S. C. Lee, P. K. K. Louie and K. F. Ho, Characterization of hydrocarbons, halocarbons and carbonyls in the atmosphere of Hong Kong, J. Chemosphere, 57 (2004) 1363-1372.

[4] A. Srivastava, A. E. Joseph, S. Patil, A. More, R. C. Dixit and M. Prakash, Air toxics in ambient air of Delhi, J. Atmospheric Environment, 39 (2005) 59-71.

[5] P. D. Kalabokas, J. Hatzianestis, J. G. Bartzis and P. Papagiannakopoulos, Atmospheric concentrations of saturated and aromatic hydrocarbons around a Greek oil refinery, J. Atmospheric Environment, 35 (2001) 2545-2555.

[6] T. Elbir, B. Cetin, E. Cetin, A. Bayram and M. Odabasi, Characterization of volatile organic compounds (VOCs) and their sources in the air of Izmir, Turkey, J. Environ Monit Assess, 133 (2007) 149-160.

[7] Information on http://www.globalfueleconomy.org/Documents/Publications/wp1_asean_fuel_economy.pdf

[8] Information on http://aqnis.pcd.go.th/node/4588

[9] S. Thepanondh, J. Varoonphan, P. Sarutichart and T. Makkasap, Airborne volatile organic compounds and their potential health impact on the vicinity of petrochemical industrial complex, J. Water Air Soil Pollut, 214 (2011) 83-92.

[10] Information on http://www.epa.gov/oswer/riskassessment/ragse/

[11] B. A. Begum, S. K. Biswas, and P. K. Hopke, Assessment of trends and present ambient concentrations of $PM_{2.2}$ and PM_{10} in Dhaka, Bangladesh, J. Air Qual Atmos Health, 1 (2008) 125-133.

[12] H. Kajihara, S. Ishizuka, A. Fushimi, A. Masuda and J. Nakanishi, Population risk assessment of ambient benzene and evaluation of benzene regulation in gasoline in Japan, J. Environ Engg and Policy, 2 (2000) 1-9.

[13] H. Higashino, K. Mita, H. Yoshikado, M. Iwata and J. Nakanishi, Exposure and risk

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