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Impact of Traffic on Ambient Air Quality in Al Ain City – UAE

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United Arab Emirates University
Deanship of Graduate Studies
M. Sc. Program in Environmental Sciences

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A Thesis
Submitted to

United Arab Emirates University
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Dedication

This work is dedicated to

Dr. Jaber Eidha Al Jaberi

Executive Manager of the Environmental Operations

Environment Agency-Abu Dhabi (EAD)

Acknowledgement

All praise and thank are due to ALLAH. It is by his grace that the present work is accomplished.

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Abstract

Road traffic is considered a major source of air pollution in congested areas. The number of vehicles in Al Ain city has increased over the last seven years due to population and economic growth. The rapid growth in motor vehicles in Al Ain could contribute to an increased level of urban air pollution that may threaten human health, damage ecosystems and influence climate. No study has been conducted to assess the effects of roadway traffic on air quality in the city of Al Ain. Such study will further be useful as a baseline for future planning and development of the city. Therefore, the present study was designed to investigate the impact of traffic volume on the ambient air quality of Al Ain.

Data of several air pollutants including PM_{10}, SO_2, NO_2, CO, O_3 and HCs were collected during 2007-2009, using two fixed air monitoring stations in two areas of different traffic congestion levels; one in the downtown area and the other in a residential area in Al Ain. The levels of these pollutants were compared with Abu Dhabi Air Quality Standards. Also, the relationships among these pollutants and between pollutant level and meteorological conditions were investigated.

Data on traffic counts at the downtown area were collected from the RTTSRC at the UAE University. These traffic counts were used to predict the air pollutant emissions from traffic volume using Synchro and IVE models. The Box Model was then used to estimate ambient pollutant concentration using the estimated emissions. Predicted pollutant levels were then compared with the actual levels measured at the monitoring stations.

The results of this study indicate that the concentration levels of most of the air pollutants were below Abu Dhabi Air Quality Standard at both stations, except for PM_{10} which exceeded the Abu Dhabi Air Quality Standard many times. It was also found that there are statistically significant variations in pollutants level between the residential and the downtown area. The higher pollutants levels at the downtown area are attributed to the influence of road traffic volume and other population-related activities. Moreover, the Al Ain residential area had better air quality than Al Ain downtown area according to the air quality index. It was also found that temperature correlates well with some air pollutants.

This study showed that the traffic in the downtown of Al Ain contributes in the range of 15% to 35% of CO, with an average of 25%. The traffic also contributes in the range of 36% to 69% of NO_x, with an average of 57% and it contributes only in the range of 0.4% to 0.8% of PM_{10}, with an average of 0.5% levels. The low contribution of traffic to pollutant level (as is the case for CO and PM_{10}) indicates that other sources including commercial activities or open burning in nearby farms play a major role in determining the ambient concentration of these pollutants in the downtown of Al Ain. Finally, this study indicated the importance to develop a proactive traffic management mitigation measures for Al Ain downtown to manage traffic congestions and hence improve the air quality.

Table of Contents

List of Tables

List of Figures

List of Abbreviations

ADNOC	Abu Dhabi National Oil Company
API	Air Pollution Index
AQI	Air Quality Index
Ar	Argon
CH_4	Methane
CO	Carbon monoxide
CO_2	Carbon dioxide
EAD	Environment Agency- Abu Dhabi
FEA	Federal Environment Agency
HCM	Highway Capacity Manual
HC's	Hydrocarbons
IVE	International Vehicle Emission
NAAQS	National Ambient Air Quality Standard
NEPM	Australia Ambient Air Quality
NILU	Norwegian Institute for Air Research
NO	Nitric oxide or nitrogen monoxide
NO_2	Nitrogen dioxide
NO_x	Nitrogen oxides
O_3	Ozone
Pb	Lead
PM	Particulate matter
PM_{10}	Particulate matter with aerodynamic diameter equal or less than 10 μm
$PM_{2.5}$	Particulate matter with aerodynamic diameter equal or less than 2.5 μm
PSI	Pollutant Standard Index
RA	Roundabout
RON	Research Octane Number
RTTSRC	Roadway, Transportation and Traffic Safety Research Center
SO_x	Sulphur oxides
SPSS	Statistical Package for Social Sciences
TRB	Transportation Research Board
TS	Traffic Signal
ULG	Unleaded Gasoline
US EPA	Environment Protection Agency, US.
VOCs	Volatile organic compounds
WHO	World Health Organization

Chapter 1: Introduction

1.1 Problem definition

Road traffic is considered a major source of air pollution in congested areas. Traffic directly contributes to the emission of primary air pollutants such as carbon monoxide (CO) and nitrogen oxide (NO) and in some cases sulphur oxides (SO_x) and lead (Pb). Emissions from traffic may also result in the formation of secondary pollutants such as ozone (O_3) and nitrogen dioxide (NO_2). On the other hand, traffic may enhance the turbulence of stagnant particulates (PM_{10}) on roads, making them readily available in the breathing air. Furthermore, traffic noise is considered as one of the most important sources of noise pollution that negatively affects human health as well as the disturbance of daily activities (Pathak et al., 2007).

Several studies have been conducted to correlate air pollutants and traffic volume (Siddique, 2004; Han and Naeher, 2006; Lau et al., 2008; Xie et al., 2003; Wang et al., 2009; Oduyemi and Davidson, 1998). Since most of these studies are case-specific, common factors relating the impact of traffic on air quality include traffic volume, type of fuel used, and existing meteorological conditions. Furthermore, air quality could be indirectly influenced by the standard of living as this affects the types and year of vehicle used.

A review of previous studies in this area indicated that no study has been conducted to assess the effects of roadway traffic on air quality in the city of Al Ain. Such study will further be useful as a baseline for future planning and development of the city. With the currently available fixed air quality monitoring stations in the city, it is possible to correlate different air pollutants with the traffic volume. As such was the overall objective of this study.

1.2 Objectives

The main objective of this study was to carry out an investigation on the impacts of traffic volume on the ambient air quality in Al Ain city. The specific objectives of this study were to:

- Evaluate the concentration of several air pollutants in the down town and residential area in Al Ain city and compare these levels with air quality standards.
- Investigate possible relationships among different pollutants and between pollutant level and meteorological conditions.
- Correlate between different pollutants level and traffic volume in the down town area.
- Set recommendations for the future developments of Al Ain city.

1.3 Scope of work

The study involved analysis of air pollutant levels measured at two areas of different traffic congestion levels during the period 2007-2009. Measured pollutants included carbon monoxide (CO), nitrogen oxides (NO_x), sulfur dioxide (SO_2), particulates (PM_{10}), ozone (O_3), and hydrocarbons (HCs) such as methane (CH_4), benzene, toluene, ethyl-benzene, and xylene. In addition, meteorological conditions including air temperature, wind speed and wind direction were collected for the same period. These measurements were taken at two air monitoring fixed stations in Al Ain: one in the downtown area (referred to as Al Ain Street Station) and the other in a residential area (referred to as Al Ain School Station).

The two areas vary significantly in traffic volume. Pollutant level is measured hourly and over a period that captured possible seasonal variations in air quality. Data on traffic counts in the downtown area were obtained from the Roadway, Transportation and Traffic Safety Research Center (RTTSRC) at the UAE University. Statistical analysis was utilized to determine possible functional relationships between measured pollutants levels and traffic counts.

1.4 Approach

Assessment of air quality in Al Ain downtown relied on collection of several types of data. The methodology used in this study is outlined in Fig. 1.1 and is described below:

- Data collection of air pollutants levels from two different locations using the Environment Agency- Abu Dhabi (EAD) fixed stations in Al Ain. One station is located in the city downtown (Al Ain Street Station) and the other is located in a residential area outside the downtown (Al Ain School Station).
- Meteorological data were collected from the same stations and covered the sampling period.
- Sampled air quality parameters included CO, NO_2, SO_2, O_3, PM_{10}, and several hydrocarbons. Sample collection was taken hourly and covered periods of seasonal variations (summer and winter) during 2007-2009.
- The ambient air quality standard of EAD was utilized to compare pollutants level with the recommended standard levels. Meanwhile, air quality index (AQI) was utilized as a measure (indicator) of the overall quality of the atmosphere in the city.

- Traffic volume data were collected from the RTTSRC at the UAE University and Al Ain municipality. Traffic counts included only the peak hours.
- The Synchro model and the International Vehicle Emission (IVE) model were utilized to estimate emissions of various pollutants based on traffic count data in the downtown area. A simple box model was then used to estimate the contribution of vehicle emissions to ambient pollutant concentration. This was then allowed comparison between predicted pollutants level and the actual measurements collected in the field.

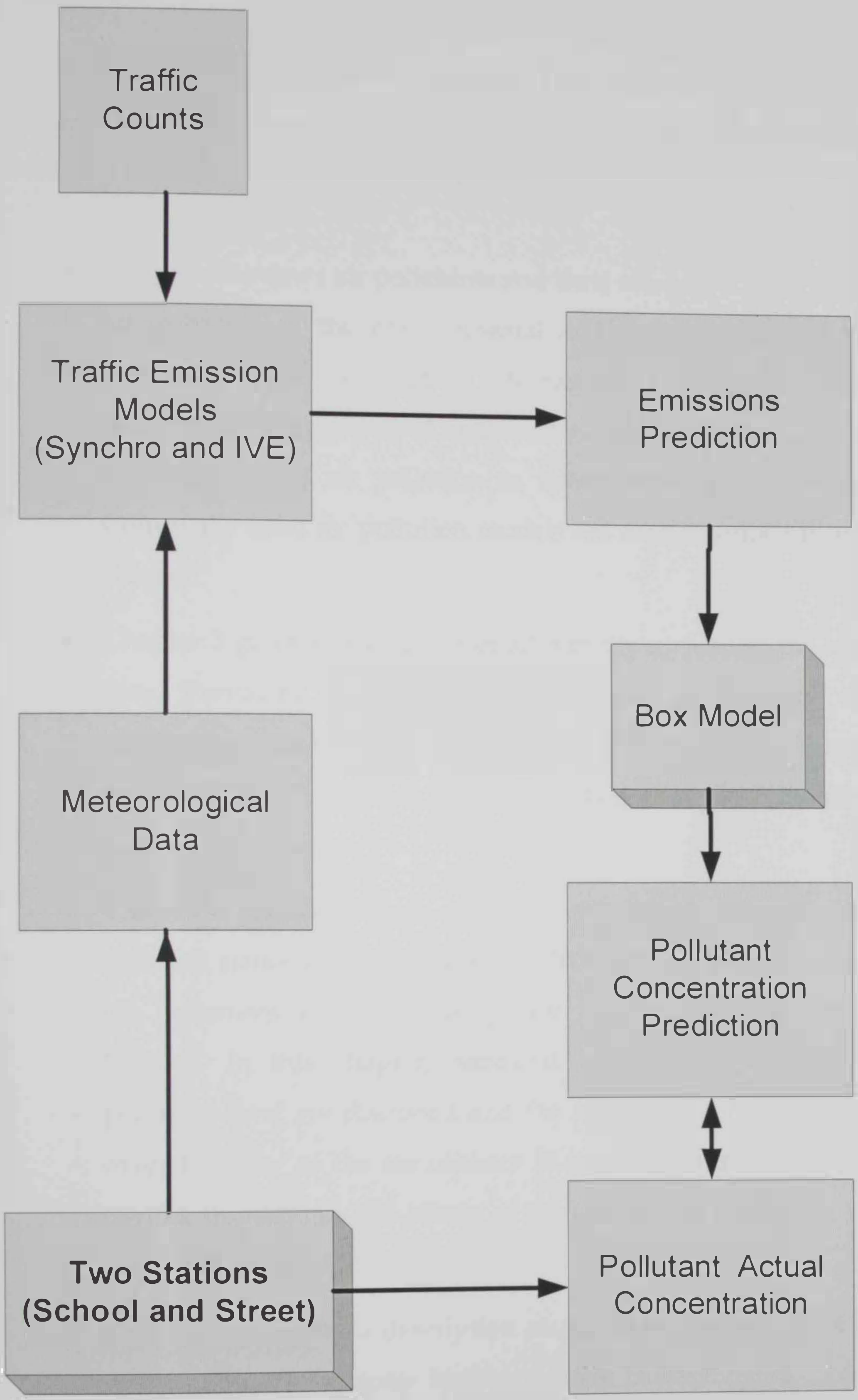

Fig. 1.1: Thesis Framework

1.5 Thesis structure

The thesis is organized into seven chapters. This chapter describes the problem definition, objectives, scope of work and the approach of this study. The remaining chapters are described as follows:

- Chapter 2 reviews air pollutants and their sources. Also, it gives an overview of the environmental and health impact of air pollutants. The applicable international and local legal frameworks are addressed and various factors influencing the concentration of air pollution in urban areas are identified. Commonly used air pollution models are also described in this chapter.
- Chapter 3 gives a description of Al Ain city as well as the land uses. Prevailing meteorological conditions in the city are highlighted in this chapter. The methodology used for pollutant and traffic data collection is also described along with the data analysis procedure.
- Chapter 4 assesses the air quality data collected from the two different stations in Al Ain during 2007-2009. Also, it compares the pollutants level with air quality standards of Abu Dhabi Emirate. In this chapter, temporal and spatial changes in pollutant level are discussed and the AQI is used to assess the overall quality of the atmosphere in the city during the study period. In addition, the effects of meteorological conditions on air pollutants level are presented.
- Chapter 5 provides a description of the street configuration in Al Ain city. The chapter highlights fleet characteristics in the city, type of fuel used, and other parameters that are significant for estimating vehicle emissions. Vehicle growth rate in Al Ain

is correlated in this chapter to number of registered vehicles in the city and quantity of fuel consumption. Actual and simulated traffic data in the city are presented in this chapter.

- In Chapter 6, the traffic pattern is identified and assessment of noise level measured at the two locations is addressed. Also, the correlation between different air pollutants level and traffic volume in the downtown area of Al Ain is investigated.
- Chapter 7 summaries the thesis and outlines the findings and sets recommendations for future developments of Al Ain city.

Chapter 2: Literature Review

2.1 Air pollutants and their sources

Air is a mixture of different gases that represents the atmosphere. The clean, dry air at ground level contains about 78% nitrogen (N_2), 21% oxygen (O_2), 1% argon (Ar), and 0.03% carbon dioxide (CO_2). Also, other trace gases are present in the air but they are considered as inert gases (Peavy et al., 1985). The concentration by volume of each gas in a clean air is given in Table 2.1. On the other hand, air is considered as the most susceptible component of the environment subject to pollution. According to Peavy et al. (1985), "air pollution can be defined as the presence in the outdoor atmosphere of one or more air contaminants such as dust, fumes, gas, mist, odor, smoke, or vapor in sufficient quantities, of such characteristics, and of such duration as to threaten to be injurious to human, plant, or animal life or to property, or which reasonably interferes with the comfortable enjoyment of life or property." Based on this definition and on Table 2.1, it is obvious that any change in the concentration of the air composition in the way that could affect the environment is considered as air pollution.

Table 2.1: Concentration of atmospheric gases in clean, dry air at ground level (Peavy et al., 1985).

Gas	Concentration, ppm by volume	Concentration, % by volume
Nitrogen (NO_2)	280,000	78.09
Oxygen (O_2)	209,500	20.95
Argon (Ar)	9,300	0.93
Carbon dixide (CO_2)	320	0.032
Neon (Ne)	18	0.0018
Helium (He)	5.2	0.00052
Methane (CH_4)	1.5	0.00015
Krypton (Kr)	1.0	0.0001
Hydrogen (H_2)	0.5	0.00005
Dinitrogen oxide (N_2O)	0.2	0.00002
Carbon monoxide (CO)	0.1	0.00001
Zenon (Xe)	0.08	0.000008
Ozone (O_3)	0.02	0.000002
Ammonia (NH_3)	0.006	0.0000006
Nitrogen dioxide (NO_2)	0.001	0.0000001
Nitric oxide (NO)	0.0006	0.00000006
Sulfur dioxide (SO_2)	0.0002	0.00000002
Hydrogen sulfide (H_2S)	0.0002	0.00000002

Air quality is an important environmental issue. It is defined as the status of the atmosphere with respect to the presence of potential pollutants. On the other hand, air quality criteria are based on a set of long term goals for the protection of human health and the environment. It is generally evaluated in terms of whether concentrations of air pollutants are higher or lower than ambient air quality standards. According to the U.S. Environmental Protection Agency (US EPA, 2010), there are six "criteria pollutants" used as indicators of air quality. These pollutants are: particulate matter smaller than 10 µm (PM_{10}), which may be liquid or solid, carbon monoxide (CO), nitrogen dioxide (NO_2), sulphur dioxide (SO_2), lead (Pb) and ozone (O_3). High concentrations of these air pollutants can have a variety of adverse health effects on people as well as impact on the natural environment.

Air pollution comes from various sources such as transportation, industry, and other sources of combustion, as well as natural sources. Transportation is considered a major source of air pollution in urbanized areas. Air pollutants, on the other hand, may be classified into either primary or secondary pollutants. Primary air pollutants are those that are emitted directly into the atmosphere including sulfur dioxide (SO_2), nitrogen monoxide (NO), carbon monoxide (CO), and volatile organic compounds (VOCs). Based on the geographical scale, primary air pollutants can be categorized into point, line or area sources. Secondary air pollutants are those formed from chemical reactions of primary pollutants within the atmosphere and include ozone (O_3) and oxides of nitrogen (NO_2 and N_2O) (WHO, 2005). In this study, the focus will be on vehicles emissions and therefore, a line source will be applicable for investigating the impact of vehicles emissions on ambient air quality.

Several air pollutants are associated with vehicles including CO and HCs that result from incomplete combustion of fuels. SO_2 is also emitted from vehicles using high sulphur fuels and lead is emitted as a result of using leaded fuel.

Also vehicles emit VOCs either directly from volatilization of a liquid fuel (such as benzene) from the fuel tank or due to incomplete combustion from vehicle engine. However, ozone could be formed as a by-product of the chemical reactions involving nitrogen oxides, VOCs and sunlight (Peavy et al., 1985).

At the city scale, the pollutant of greatest concern is CO. However, concentrations of this pollutant are typically related to traffic volume and congestion along streets and at intersections. In fact, areas of vehicle congestion that have the potential to create "pockets" of NO_x are called "hot spots" which are considered as key indicators for transportation planners.

2.2 Environmental and health impact of air pollutants

There are a number of substances present in the air which are commonly classified as air pollutants. These mainly include six pollutants: carbon monoxide (CO), nitrogen oxides (NO_x), sulphur dioxide (SO_2), particulate matter (PM_{10}), lead (Pb) and ozone (O_3). Depending on the levels and exposure duration of these pollutants, they can cause negative impacts on human health and may as well have an impact on the surrounding environment.

The effects of the major air pollutants are reviewed below:

Carbon monoxide (CO) is characterized as a colorless and odorless gas which is formed by incomplete combustion of fossil fuels (Han and Naeher, 2006). It is highly toxic to humans and animals in higher quantities as it can lead to significant toxicity of the central nervous system and heart, and even death (Wikipedia, 2010). According to NEPC (1998), this gas enters the bloodstream through the lungs and reduces oxygen delivery to the body's organs and tissues. On the other hand, the health threat of this toxic gas in the ambient air is most serious for those who suffer from cardiovascular disease such as angina pectoris. Other negative impacts associated with exposure to high CO levels include visual defect, reduced work capacity, poor learning ability, and difficulty in performing complex tasks.

Nitrogen dioxide (NO_2) is characterized as a brown gas, highly reactive gas that is formed in the ambient air through the oxidation of nitric oxide (NO). The main sources of man-made NO_x emissions are high-temperature combustion processes such as those that occur in automobiles and power plants. This gas is toxic to various humans as well as animals. The toxicity of this gas relates to its ability to form nitric acid with water in the eye, lung, mucus membrane and skin. It also causes respiratory problems such as damage of the lung tissues. However, they play a major role in the formation of ozone, acid rain, water quality deterioration, global warming, and visibility impairment (Siddique, 2006; Ministry for the environment, New Zealand, 2004).

Ozone (O_3) is considered as a secondary pollutant which is formed in the atmosphere by the reaction of VOCs and NO_x in the presence of sunlight, which is most abundant in the summer. Exposure to ozone is linked to a number of health effects, including significant decrease in lung function, inflammation, and increased respiratory symptoms such as cough and pain when taking a deep breath. Other than health problems, ozone also affects vegetation and ecosystems, leading to reductions in agricultural crop and commercial forest yields (WHO, 2005).

Sulphur dioxide (SO_2) is formed when fuel containing sulphur is burned at vehicle engines. It can cause similar effects of other pollutants on humans and environment such as cardiovascular disease, respiratory illness and lung disease as well as reduced visibility and contribution to acid rain, which is associated with the acidification of soils, lakes, and streams and accelerated corrosion of buildings (Agarwal, 2005).

Particulate Matter (PM_{10}): could be a mixture of solid particles and liquid droplets found in the air. It can be emitted directly or formed in the atmosphere. Primary particles, such as dust from roads or carbon (soot) from wood combustion, are emitted directly into the atmosphere. Secondary particles are produced in the atmosphere from primary gaseous emissions such as sulphates and nitrates which are formed from SO_2 and NO_x emissions, respectively (Nriagu, 1992). At high concentration, suspended particulate matter causes health hazards to humans, mainly those susceptible to respiratory illness. Particles are small enough to pass into the lungs and cause several health problems. Several studies have been conducted to investigate the health effects of PM, following evidence of short term and long term associations between levels of PM and mortality and morbidity (Pope et al., 1999). In addition to health problems, PM is the main cause of reduced visibility in many parts of the world. It also can impact vegetation and ecosystems and can cause damage to paints and building materials.

Fine Particulate Matter ($PM_{2.5}$): $PM_{2.5}$ is now regulated as one of the criteria pollutants. It is considered as an important indicator of risk to health from particulate pollution, and might be a better indicator than PM_{10} for suspended particles in many areas. It is mainly formed by chemical reaction between gases such as nitrogen oxides, sulfur dioxide, ammonia and volatile organic compounds, but combustion processes may also generate primary particles in this size of particulate matter. Its effects are larger than PM_{10} due to its smaller size which could infiltrate deep in the lung tissues. Many scientific studies indicated that the $PM_{2.5}$ has strong association with various respiratory and cardiac effects (Goldberg et al., 2001; Janssen et al., 2002; Magari et al., 2002).

2.3 International and local legal framework

Ambient air quality standards are defined as maximum allowable levels of air pollutants that should not be exceeded during a given time in a defined area (Lund, 1971). These standards are developed to protect the public health and the environment from negative impacts of air pollutants. In fact, all those standards are intended to avoid short term effects and will provide sufficient control to avoid the longer term effects of these pollutants.

There are many international air quality standards and guidelines dealing with air quality and noise. The most famous international standards are: the US EPA Ambient Air Quality Standards (NAAQS), WHO Guideline values and Australia Ambient air quality (NEPM). These standards are shown in Appendix A.

The primary aim of these guidelines and standards is to provide a basis for protecting public health from adverse impacts of air pollution. These guidelines may be used in planning sectors and different kinds of management decisions at community or regional level. On the other hand, ambient air quality standards can either be expressed as absolute limits which should not be exceeded, or as percentiles, which allow for occasional exceedences over defined time frames. For comparison, the popular international air quality standards are grouped into one table as shown in Table 2.2. Some of the standard values were converted from ppm to $\mu g/m^3$ for ease of comparison. From Table 2.2, it can be seen that the limit values of different international standards vary due to different approach adopted for balancing health risks, technological feasibility, economic considerations, local environment circumstances and other political and social factors.

Table 2.2: Comparison of international air quality standards (US EPA, 2010; WHO, 2000; WHO, 2005; NEPC, 2010; EC, 2008)

Pollutant	Averaging period	EU	US/EPA	NEPM, Australia	WHO Guidelines
Carbon monoxide (CO)	8-hour	10 mg/m³	10 mg/m³ 1 per year*	11 mg/m³ 1 per year	10 mg/m³
	1-hour	-	40 mg/m³ 1 per year	-	30 mg/m³
Sulphur dioxide (SO_2)	Annual mean	-	85 µg/m³	56 µg/m³	-
	24-hour	125 µg/m³ 3 per year	395 µg/m³ 1 per year	226 µg/m³ 1 per year	20 µg/m³
	1-hour	350 µg/m³ 24 per year	-	564 µg/m³ 1 per year	-
Particulate matter (PM_{10})	Annual mean	40 µg/m³	-	-	20 µg/m³
	24-hour	50 µg/m³ 35 per year	150 µg/m³ 1 per year	50 µg/m³ 5 per year	50 µg/m³
Ozone (O_3)	8-hour mean	120 µg/m³ 25 days averaged over 3 years	160 µg/m³	160 µg/m³ (4-hours), 1 per year	100 µg/m³
	1-hour	-	254 µg/m³	211 µg/m³	-
Nitrogen dioxide (NO_2)	Annual mean	40 µg/m³	100 µg/m³	61 µg/m³	40 µg/m³
	1-hour	200 µg/m³ 18 per year	203 µg/m³	243 µg/m³ 1 per year	200 µg/m³
Lead (Pb)	Annual mean	0.5 µg/m³	0.15 µg/m³ (Quarterly Average)	0.5 µg/m³	0.5-1 µg/m³

* Number of exceedances allowable per year.

For international cars emissions standards, previous researches have shown lower in permissible limits of pollutants emitted from the vehicle exhaust in many regulations. For example, the NO_x European limit has been decreased from 7.0 g/kW.hr of Euro2 in year 1996 to 2.0 g/kW.hr of Euro5 in 2008 as shown in Table 2.3.

Table 2.3: European diesel-engine emission standards in g/kW. h (Ibrahim and Bari, 2008).

Year	Standard	CO	HCs*	NOx	PM
1996	Euro2	4.0	1.1	7	0.15
2000	Euro3	2.1	0.66	5	0.1
2005	Euro4	1.5	0.46	3.5	0.02
2008	Euro5	1.5	0.46	2	0.02

*HC= Hydrocarbons

In the local framework, environmental issues in the UAE are regulated through the Federal Law No. (24) of 1999 for the protection and development of the environment and its executive regulations. In addition, each emirate issues its own regulations which implement the various federal requirements. In Abu-Dhabi, the Environment Agency -Abu Dhabi (EAD) has established a number of air quality standards including air emission standards and noise standards. These standards were revised in 2007 and cover emissions from stationary sources, incinerators, ambient air quality and noise. The standards related to ambient air quality and noises are listed in Tables 2.4 and 2.5, respectively.

On the other hand, vehicles emission standards are applicable only to direct emissions from the vehicle exhaust. Once emitted, air pollutants will disperse and may interact with the surroundings. The level of these pollutants in the atmosphere becomes subject to comparison with the ambient air quality standard. RTTSRC (2009) studied vehicles emission standards in the UAE. They noticed that the standard limits vary from one emirate to another. In Abu Dhabi, cars emission standards allows up to 4.5% CO and 1200 ppm hydrocarbons, while in Dubai, Sharjah and Ajman the limits are 4.5% for CO and 800ppm for hydrocarbons. However, there are no vehicle emission standard limits for NOx or PM as in Europe or US.

Table 2.4: UAE Ambient Air Quality Standards (FEA, 2006).

Substance	Symbol	Maximum allowable limit ($\mu g/m^3$)	Average time
Sulphur dioxide	SO_2	350 150 60	1 hr 24 hr 1 yr
Carbon monoxide	CO	30 000 10 000	1 hr 8 hr
Nitrogen dioxide	NO_2	400 150	1 hr 24 hr
Ozone	O_3	200 120	1 hr 8 hr
Total suspended particles	TSP	230 90	24 hr 1 yr
Particulate matter (with 10 microns or less in diameter)	PM_{10}	150	24 hr
Lead	Pb	1	1 yr

Table 2.5: UAE noise allowable limits in different areas, Executive Regulation (FEA, 2006).

Area	Allowable limits for noise level (dB)*	
	Day (7 a.m. - 8 p.m.)	Night (8 p.m. - 7 a.m.)
Residential Areas with Light Traffic	40 - 50	30 - 40
Residential Areas in the Downtown	45 - 55	35 - 45
Residential Areas which include some workshops and commercial business or residential areas near the highways	50 - 60	40 - 50
Commercial Areas and Downtown	55 - 65	45 - 55
Industrial Areas (Heavy Industry)	60 - 70	50 - 60

2.4 Previous studies of air quality in the UAE

Several studies on the assessment of air quality of particular regions in the Abu Dhabi emirate have been carried out. These studies are summarized below.

In 1994, Al-Wasity investigated the level of atmospheric contaminants in Abu Dhabi using a mobile air pollution monitoring station. She found that the average ambient concentration of PM_{10} in Al Ain is below the threshold limit value according to the US NAAQS. The author concluded that the sources of particulate pollution in Al Ain are mostly natural ones with minor contribution of man-made sources, particularly automobile traffic emissions and agricultural activities. Furthermore, other air pollutants were found to be below the limits set by the US NAAQS.

In 1996, Darbool investigated the SO_2 emissions around the industrial oil refinery in both onshore and offshore areas of Abu Dhabi Emirate. He also studied CO emission from motor vehicle exhaust and the health risk exposure in Al Ain city. He found that the monthly average SO_2 concentration level was below the guidelines given by the WHO of 125 $\mu g/m^3$. He also found that the level of CO frequently exceeded the NAAQS limits. The study revealed that factors such as type and size of car, type or size of cylinder, type of fuel, and maintaining service of the car, have the greatest influence on the emitted amount and concentration of CO.

Al-Aidrous (2002) carried out an investigation on the levels of air pollutants in Abu Dhabi, and the associated effects on human health. The main finding of her study was that CO and SO_2 were below the NAAQS standard limits and the proposed standard for Abu Dhabi Emirate. Also, she found that the industrial area at Mussafah was more polluted than the Al Sallam Street commercial area and Al Bateen residential area. Furthermore, she found that there was a strong association between increasing ozone levels and patients admitted for respiratory diseases and increasing SO_2 levels with admitted patients for non-respiratory diseases.

El Haty (2007) studied the assessment of air quality in Al Ain city using passive sampling technique and the health effects of air pollutants. He concluded that the high number of respiratory system patients in Al Ain compared to other cities in the UAE cannot be mainly attributed to the monitored air pollutants. He stated that other factors such as windblown sand as a source of particulates, some types of pollens, viral and bacterial infections and common cold harm the respiratory system.

2.5 Effects of road traffic on air quality

Transportation provides people access to goods, services and activities. Despite the positive impact of transportation on growth, transportation is recognized as a major and growing source of air pollution worldwide. According to the United Nations (UN) estimation, over 600 million people in urban areas worldwide were exposed to dangerous levels of traffic generated air pollutants (Cacciola et al., 2002). Currently, the air pollution and its public health impacts are drawing attention from the environmental agencies, environmental health research community, industries, as well as the public. The morbidity and mortality from respiratory and cardiovascular diseases are closely related to the quality of the air (both indoors and outdoors). The main harmful pollutants emitted from the combustion of petrol or diesel fuels from vehicles are CO, NO_x, PM_{10}, VOCs and Pb. However, the chemical reactions among those pollutants produce secondary pollutants such as O_3, NO_2 and secondary PM (Han and Naeher, 2006).

2.5.1 Relevant studies conducted abroad and locally

Several studies have been carried out to investigate the effects of road traffic emissions on urban air quality. Oduemi and Davidson (1998) investigated the effects of road traffic emissions on urban air quality in Dundee city centre, UK. The results of the investigation of long-term measurement of NO_2 and traffic flow at four main sites indicate that the annual mean NO_2 levels at all the study sites are below the current EC and WHO long-term air quality standards for NO_2 concentration in the ambient air. These results are attributed to the traffic restrictions in protecting the air quality of the city. Another study was done by Sharma et al. (2010) to investigate the impact of vehicular traffic emissions. The results of their study indicate that urban areas of Hyderabad are under considerable influence of emissions from trucks operating on diesel fuel. Borrego et al. (2000) carried out an investigation on the traffic emissions impact on the Lisbon (capital of Portugal) region air quality. The authors found that there is significant impact of traffic emissions on the air quality of the urban area of Lisbon. In 2008, Lau et al. (2008) investigated the effects of roadside vehicle emissions to general air quality in Hong Kong. They found that within the urban center of Hong Kong, variations in concentrations of different gaseous pollutants are heavily influenced by variations in local traffic volume.

In the UAE, Darbool (1996) investigated CO emissions from motor vehicles exhaust and the health risk exposure in Al Ain city. He found that the level of CO frequently exceeded the NAAQS limits. The study also revealed that factors such as age and size of car, number of cylinders, type of fuel used, maintenance service of the car, have the greatest influence on the amount and concentration of CO.

2.5.2 Factors affecting emissions from vehicle

There are many factors that influence vehicle emissions in an urban area. Several studies have found that characteristics of traffic (Hallmark et al.,2000; Rakha et al., 2000; Coelho et al., 2003), vehicles (Chang and Yeh, 2006; Beydoun and Guldmann, 2006; Kim, 2007 and Wang et al., 2008; Darbool, 1996), street configurations (Rosqvist, 2007; Mandavilli et al., 2008; Varhelyi, 2002) and ambient conditions (Wenzel et al., 2000; Joumard and Serie, 1999; Swri, 2003) affect the vehicular exhaust emissions. These factors are summarized below (Pandian et al., 2009):

- **Traffic characteristics:** include the traffic flow rate, fleet speed, queue length and mean-delay, driving mode (such as acceleration and deceleration speed), vehicular composition and traffic density.
- **Road characteristics:** include type of road, type of intersection, speed hump.
- **Vehicle characteristics:** include type, size, age of a vehicle, and condition of its engine, type and condition of emission control equipment, engine characteristics, vehicle maintenance, and weight.

2.5.3 Determination of emitted air pollutants from vehicles

There are two different approaches for determination of emitted air pollutants from vehicles. The first approach is the actual measurements of vehicles emissions. It includes three different types of emissions tests; idle, dynamometer and remote sensing. These tests measure emissions under different conditions: the idle when stationary, the dynamometer on a rolling road with a set cycle and remote sensing when on-road. Remote sensing measures vehicle emissions on road as they pass the monitor using IR and UV lights at particular wavelengths which is associated with path-averaged concentrations of gases (Bishop et al., 1989). Tunnel testing is another technique for monitoring emissions from motor vehicles. In a tunnel test, air is sampled at the exit of the tunnel and the flow of both air and vehicles through the tunnel is measured (Pierson et al., 1996).

Vehicle emission modeling is the second approach of determining vehicle emissions. This approach depends on the emission factors to estimate vehicle emissions. Several vehicle emission models were developed to estimate vehicle emissions. The most commonly used emissions models are; MOBILE6, MOVES2010, IVE, and Synchro models. These models are described below.

2.5.3.1 MOBILE6 Emission Model

The MOBILE6 model was developed by the U.S. EPA to estimate motor vehicles emission rates. It estimates several types of air pollutants such as HCs, CO, NO_x, exhaust PM, SO_2, hazardous air pollutants (HAPs) and CO_2. This model is algorithm-based and incorporates many factors which influence emission rate. These factors mainly focus on vehicle performance, fuel quality, and travel pattern (EBA, 2003).

2.5.3.2 MOVES2010 Emission Model

MOVES (Motor Vehicle Emissions Simulator) is another emission model developed by the USEPA to estimate air pollution emissions from mobile sources. This model can be used to estimate exhaust and evaporative emissions as well as brake and tire wear emissions from all types of on-road vehicles. Compared to Mobile6, MOVES includes new emissions test data and accounts for changes in vehicle technology and regulations as well as improved understanding of in-use emission levels and the factors that influence them. Also, it is much more flexible for input and output options than MOBILE6 (EPA, 2010).

2.5.3.3 International Vehicle Emissions (IVE) model

The International Vehicle Emissions (IVE) model is one of the common international models used to estimate pollutants emissions from motor vehicles in developing countries. It was developed by the International Sustainable Systems Research Center and the University of California at Riverside and funded by the US EPA. This model is designed to have the flexibility needed by developing countries in their efforts to address mobile source air emissions. The advantage of this model is that it takes into account the different technologies and conditions that exist in most developing countries and vehicle driving patterns which may affect the tailpipe emissions of vehicles (Hui et al., 2007).

2.5.3.4 The Synchro Traffic model

The Synchro traffic model is commonly used in road traffic research and transportation planning sector. It is a traffic software program used for modeling, optimizing and visualizing traffic networks to analyze capacity and timing optimization as well as simulate a wide variety of traffic network of signalized and unsignalized intersections operations (Trafficware, 2007). It also performs micro simulation and animation of vehicular traffic. It is a combination of a statistical model of intersection operations and a simulation model of vehicles movement. By using this software, the movement of individual vehicles is modeled and tracked through the roads network, keeping track of variables associated with those vehicles (Traffic Group, 2010). Furthermore, this model can be used to estimate the vehicles pollutant emissions, fuel consumption as well as vehicle kilometer traveled (TKV).

2.5.4 Traffic emissions and air quality

A wide range of air pollutants are emitted from vehicles engines. These emissions arise from fuel combustion as well as evaporative processes from vehicles. Once released into the atmosphere, these emissions are dispersed and transported and, at the same time, transformed by various physical and chemical processes that determine their final environmental fate (Atkinson, 1988). According to Zielinska (2005), the time periods of these atmospheric transformations and physical loss processes vary widely; air pollutants lifetimes range from ≈ 1 min for some highly reactive organic compounds to months for much less reactive components of direct emissions. Therefore, the reactive compounds are removed from the atmosphere relatively quickly, while more stable pollutants can be transported over larger distances.

Physical removal of emissions may occur by either dispersion or deposition processes. Dispersion (including vertical and horizontal) of emitted pollutants is mainly caused by wind flow. However, deposition (dry or wet) processes, including precipitation, scavenging, and sedimentation, cause downward movement of pollutants in the atmosphere, which eventually remove the pollutants to the ground surface (Samson, 1988).

Chemical transformations of air pollutants may take place in the atmosphere, sometimes leading to the production of more toxic products. The chemical reactions in the atmosphere may occur between the air pollutants and reactive gaseous species such as hydroxyl (OH) radicals, NO_3 radicals, NO_2 and ozone. These reactions contribute to formation of secondary air pollutants such as NO_2 and ozone (Atkinson, 1988).

On the other hand, there are many factors that could influence air pollutants concentration in an urban area. According to Siddique (2006), the dispersion process is the most significant factor influencing air pollutants concentration. The dispersion process, however, is a function of meteorological conditions, street geometry, receptor location, traffic volume, and emission factor. Other factors that may influence the concentration of air pollution are age and size of vehicles, cold and hot start of vehicles, fuel type, and fuel-burning efficiency.

Several air pollution models were developed to investigate the concentration and dispersion of air pollutants over a wide spatial area. These models have been widely used in government departments, agencies, and local authorities for assessing ambient air quality and making decisions related to traffic management and urban planning (Vardoulakis et al., 2003). These models are described as mathematical descriptions of pollutant transport, dispersion, and related processes in the atmosphere. Also, models estimate air pollutant concentrations at receptor locations, which are therefore, used to analyze the impacts of air pollutants on air quality (NDEQ, 2000).

Air dispersion models are widely used for assessing air quality of the roadside by providing predictions of present and future air pollution levels as well as temporal and spatial variations (Sharma and Khare, 2001). Vardoulakis et al. (2003) reviewed and categorized several air pollution dispersion models (from simple box models to complex fluid dynamics models) according to their physical or mathematical principles and their level of complexity. These authors' review showed that considerable differences exist between these models due to the limitations in terms of mathematical treatment of dispersion dynamics and treatment of the aerosol processes.

However, the literature shows that the most commonly used air pollutants dispersion models are STREET, OSPM, and CALINE4. A brief description of these models is provided below.

2.5.4.1 STREET Model

The STREET model is described as an empirical model which estimates a series of hourly concentration at various receptor locations within a street canyon (Vardoulakis et al., 2003). This model was developed by Johnson et al (1973) and it is function of emission rate, distance between the source and receptor, canyon geometry and wind speed, along with some empirical constants. However, this model does not take into accounts the angle of wind to the street axis.

2.5.4.2 OSPM model

The Operational Street Pollution Model (OSPM) was developed by the National Environmental Research Institute, Department of Atmospheric Environment, in Denmark (Berkowicz, 2000). This model is similar to the STREET model, but more comprehensive. It uses a Gaussian plume equation to derive the direct contribution from the source and a box model to estimate the effect of turbulence on the concentrations (Vignati et al., 1999). The main significant improvement of the OSPM over the STREET model is that it takes into consideration the angle of the wind direction to the street axis (Siddique, 2006).

2.5.4.3 The CALINE4 model

CALINE4 is the last in a series of line source air pollution dispersion model developed by the California Board of Transportation. It is the most validated and widely used in scientific and engineering applications for assessing the impact of vehicle traffic on roadside air quality (Benson, 1989). This model uses the Gaussian plume theory to simulate the dispersion of pollutants emitted from a line source of the roadway. The region directly above the road is called the mixing zone, which is considered as a zone of uniform emission and turbulence (Vardoulakis et al., 2003).

The model requires several input parameters including meteorological (e.g. wind speed, wind direction, mixing height, stability class, temperature, background concentrations), source strength (e.g. vehicle emission data) and geometrical (e.g. roadway height, receptor locations and heights, number of links, surface roughness, mixing zone width). On the other hand, this model works by treating each road as a line source and from the input data; it computes pollutant concentration for each location (receptor) located within 500 meters of the roadway and the contributions from various links are then summed for each receptor (Benson, 1989).

2.5.4.4 The BOX model

The box model is another method used to estimate the pollutants concentrations based on the conservation of mass. The air mass of the site is treated as a well-mixed air box, with the box dimensioned by the length, width and height of the surrounding built up area. This box is oriented in order that wind speed is normal to one side of the box. The height of the box is determined by atmospheric conditions, which is considered to be just the mixing height. The assumptions made in this model are; no pollution is lost from the box along the sides parallel to the wind or from the top. Also it is assumed that the pollutants are rapidly and completely mixed in the box, creating a uniform average concentration. Finally, the pollutants will be treated as if they are conservative (i.e. no reactions, decay, or fall out of the air stream) (Masters, 1997).

Chapter 3: Methodology

3.1 Site description

The UAE is located along the south-eastern of the Arabian Peninsula between 22.5° and 26° N and between 51° and 56.25° E. It is bounded by Qatar from the west and north-west, Saudi Arabia from the west and south and Oman from the north, east and south-east. It occupies a total area of about 83,600 square kilometers and has a coastline of approximately 700 kilometers along the Arabian Gulf and 100 kilometers nearby the Gulf of Oman as shown in Fig. 3.1. There are offshore islands, coral reefs and salt marshes along the Arabian Gulf, whilst the inland region are characterized by stretch of gravel plain and arid desert with some oasis (such as Liwa) as well as some mountains in the north and east of the UAE (UaeInteract, 2001; 2002).

The UAE has been established on the 2nd of December 1971, and is a federation of seven emirates including Abu Dhabi, Dubai, Sharjah, Ajman, Umm Al-Qaiwain, Ras Al-Khaimah and Fujairah. According to the Ministry of Economy, the population of the UAE is estimated to be approximately 4.5 million in 2007. However, the population is expected to increase by 6.12% to reach 4.76 million at the end of 2008 and by another 6.31% to 5.06 million at the end of 2009 (Paula, 2009).

Fig. 3.1: Map of the UAE (UAE Travel Guide 2006).

Abu Dhabi is the largest in size of the seven emirates with an area of 67,340 km^2, representing 86.7% of the total area of the UAE. It has a coastline of about 400 km along the Arabian Gulf. It is considered as the most populated emirate (1.493 million at the end of 2007), with the lowest population density in the UAE. However, Abu Dhabi Emirate is divided administratively into three main regions:

1. Abu Dhabi city, which is also the capital of the Emirate of Abu Dhabi,
2. The Eastern Region, including Al Ain city
3. The Western Region, including Bida Zayed city (UaeInteract, 2002; Paula, 2009).

Al Ain city is considered as the second biggest city in the Emirate of Abu Dhabi, after the capital itself. It is known as the garden city due to its extensive green and landscape areas. It is rich in agricultural lands with many forts and archaeological sites.

Al Ain is located approximately 160 km east of the Abu Dhabi capital, adjacent to the border with Sultanate of Oman and 130 km southeast of Dubai (Fig. 3.1). It is linked to Abu Dhabi City and Dubai by fast modern three-lane dual highway, and it generally takes about one and a half hour to either city. It is also served by an International Airport, which was commissioned in 1994 (ADAC, 2007).

The population of Al Ain has grown from a few thousand in pre-oil boom days to around 422,340 in 2005 according to 2005 Abu Dhabi census (DED, 2005). As in different places in the UAE, the expatriate residents make up a majority of the population. Al Ain is an attractive tourist destination for thousands of foreign tourists, and many thousands more from other Gulf countries and UAE cities. It is also an important academic city that supports thousands of university and higher colleges of technology students (UPC, 2008).

The geomorphology of Al Ain area includes three main features; mountains, gravel plains, sand dunes, interdune areas, and inland sabkhas. According to Shankland Cox (1986), Al Ain region is underlain mainly by tertiary limestone and marl with recent deposits of quartz sand, gravel outwash and sabkhas. The extreme eastern part of Al Ain city, adjacent to the Oman Mountains is characterized by low-angle alluvial fans and gravel plains. The region lies on the eastern part of a topographic and structural depression between the Arabian Shield and the Oman mountains.

On the other hand, the topography of Al Ain region is generally flat but rises in elevation from North-east to South West as shown in Fig. 3.2. The main mountains in Al Ain are Jabal Hafit, Jabal Moundassah, Jabal Malaqet, Jabal Al-Oha and Jabal Rawdah. However, Jabal Hafit is considered the most prominent features of the Al Ain area, and lies to the southeast, rising to 1,160m above the sea level. The rocks forming Jabal Hafit are composed of limestone, marles and dolomite limestone (Hunting Geology and Geophysics, 1979; Abou El-Enin, 1993).

Rapid development including economic, social, and industrial has been taken place in Al Ain over the past 30 years. For instance, a new industrial city was established in the west of Al Ain. In addition, many development projects were constructed such as hotels, malls, and new urban settlements. These developments could have had an impact on ambient air quality of the Al Ain city as well as the traffic volume. Consequently, the Abu Dhabi government paid attention to air quality in the emirate by establishing a new air quality monitoring network to monitor and assess ambient air quality in the emirate including Al Ain.

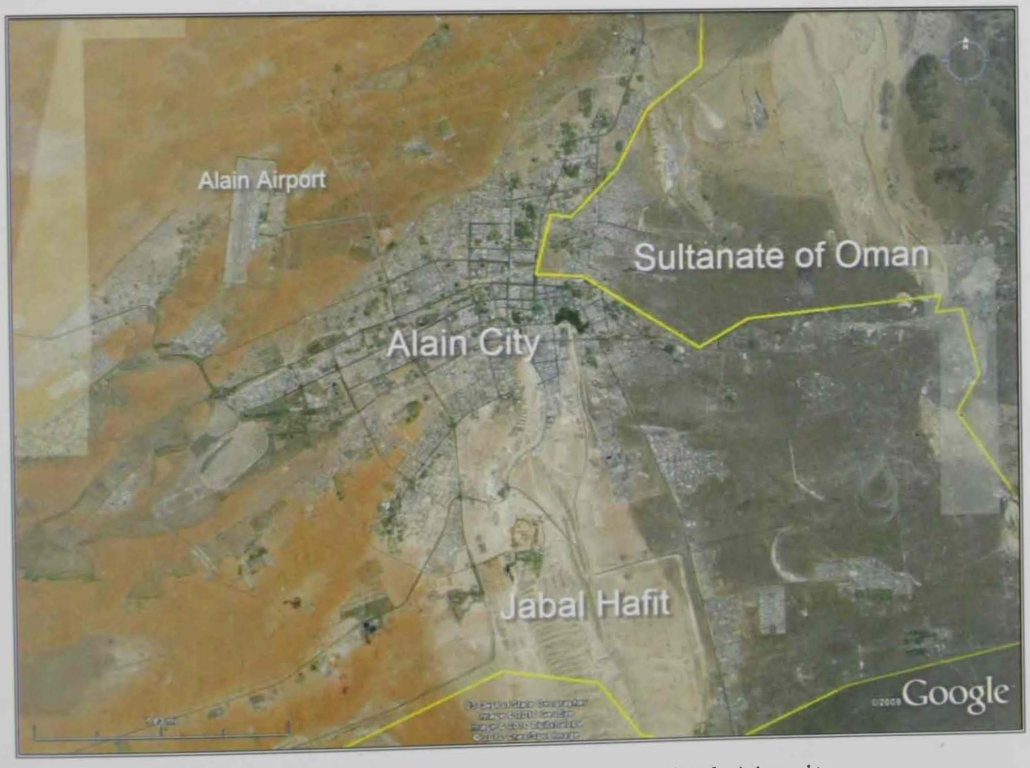

Fig. 3.2: Geographical location of Al Ain city.

3.2 Activities in Al Ain

The downtown of Al Ain is considered as one of the most important districts in the city. It is highly populated and constitutes a center of the commercial activity in the city. The study area (represented by a red rectangle in Fig. 3.3) covers an area of approximately one kilometer square. The study area is bounded by Ali Bin Abi Taleb Street in the North, Abu Baker Al Siddiq Street in the East, Zayed bin Sultan street in the South and Al Ain Street in the West.

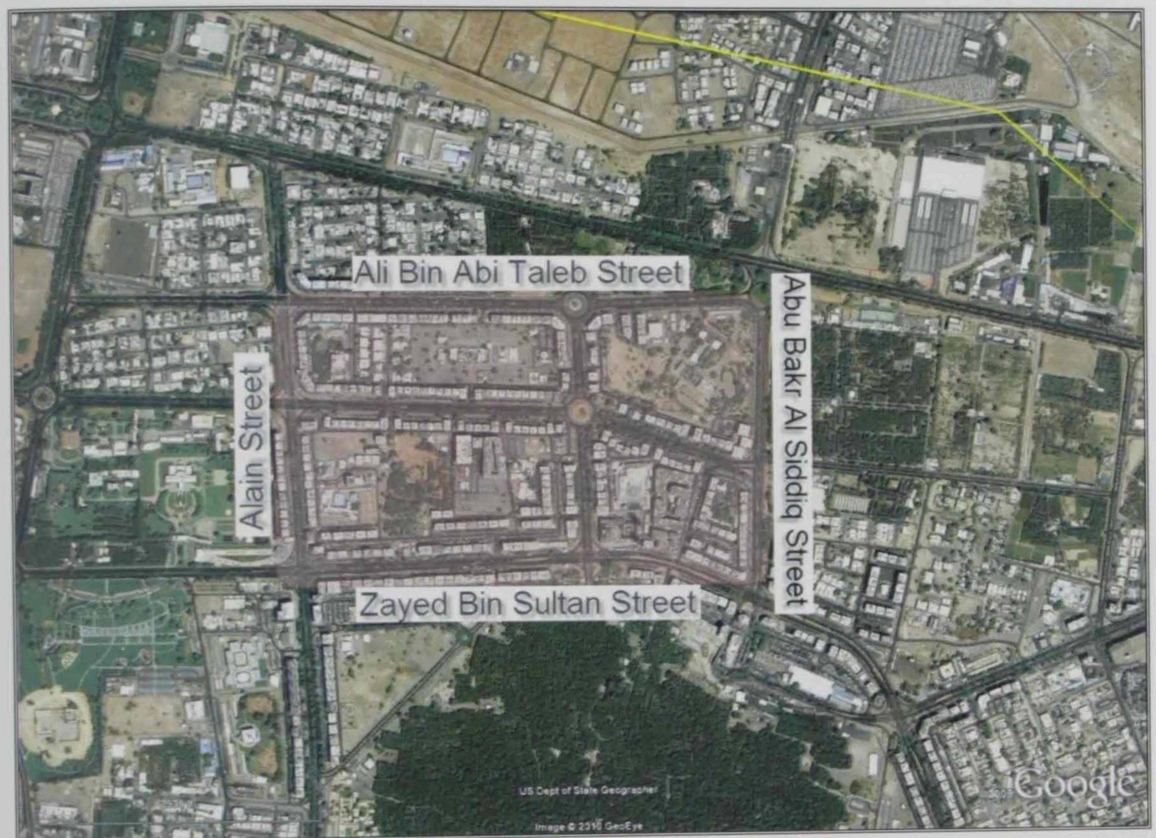

Fig. 3.3: The study area in Al Ain downtown

It should be noted that the downtown is composed of three to four-floor buildings, each joined to its neighbor, while at the same time the main streets are quite wide with dual three lanes. The height of the buildings on both sides of the streets averages about 15 meters. The characterizations of the downtown area are mainly mixed uses of commercial retail, commercial services and residential components. This character of the city downtown attracts large volume of traffic and hence increases the impact of traffic on ambient air quality. For this reason, EAD has set up a roadside air quality monitoring fixed station "referred to here as Al Ain Street Station", which is located adjacent to the Al Nafoorah Roundabout junction of Khalifa Street with Salahuddeen Al Ayyubi Street from the north-east, approximately 15 m from the nearest traffic lane.

As noted in Fig. 3.4, the industrial area in Al Ain is far away (approximately 3.5 kilometers) from the city downtown. In addition, Al Ain oasis serves as a shelterbelt from air pollutants coming from the industrial area. Therefore, the impact of industrial activities is expected to be negligible. On the other hand, the downtown does not contain industrial activities that could affect air quality. Thus, the air quality in the downtown is probably affected mainly by traffic in addition to some existing commercial activities.

Fig. 3.4: The study area and its surroundings

3.3 Meteorological conditions

The UAE is located in the arid tropical zone, extending across Asia and North Africa with high temperatures and low rainfall that is strongly influenced by the Arabian Gulf and the Indian Ocean. There are obvious variations in climate between the coastal regions, the deserts of the interior and mountainous areas. In the winter, from November to March, the daytime temperature averages 26 °C, while the nighttime temperature is slightly cooler, averaging 15 °C. In the summer, however, from June to September, the temperature is in the mid-40s, but it can be higher inland.

The prevailing winds vary between south or south-east, to west or north to north-west. Wind direction is influenced by the monsoons and also depends upon the season and location. The local north westerly winds called Al Shamal frequently build up during the winter, bringing cooler windy conditions. The humidity in coastal areas of the UAE averages between 50% and 60%, but could reach over 90% in summer, while in the inland it is far less humid. The rainfall is sparse and intermittent and in most years it rains during the winter months, usually in February or March (Uaelnteract, 2001; Paula, 2009).

Abu Dhabi Emirate is characterized by desert climate, with an average annual rainfall of 100 mm in 2008. The maximum temperature during summer, from May to October, is between 39 and 46 °C, while in winter it averages 16.8°C. The relative humidity is very high in summer, especially at the coastal areas, while it is low in the internal parts of the desert (SCAD, 2008). The meteorological conditions of Abu Dhabi Emirate during the period of 2003-2008 are shown in Fig. 3.5-3.7.

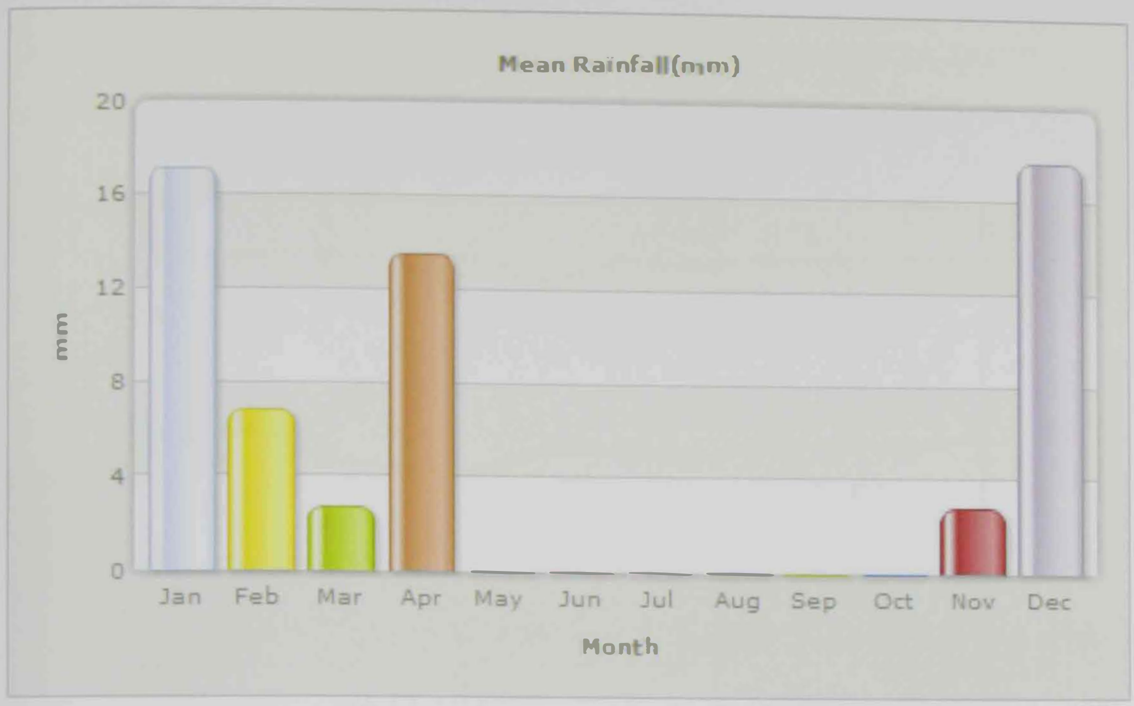

Fig. 3.5: Mean rainfall of Abu Dhabi Emirate during the period of 2003-2008 (NCMS.AE, 2008)

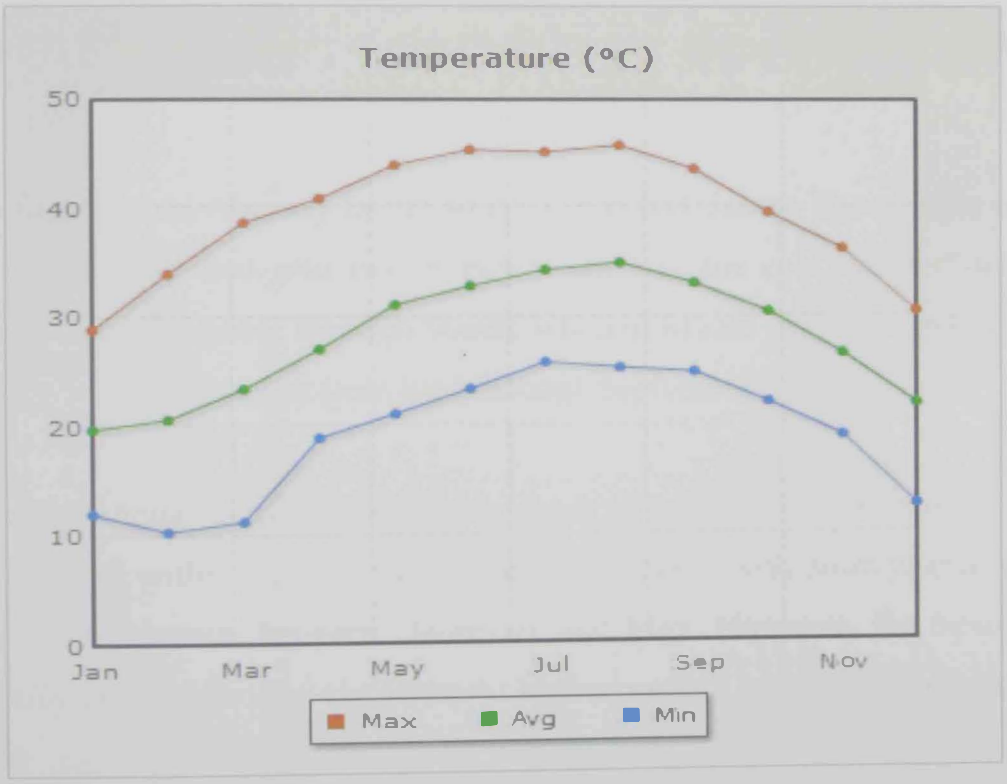

Fig. 3.6: Temperature of Abu Dhabi Emirate during the period of 2003-2008 (NCMS.AE, 2008)

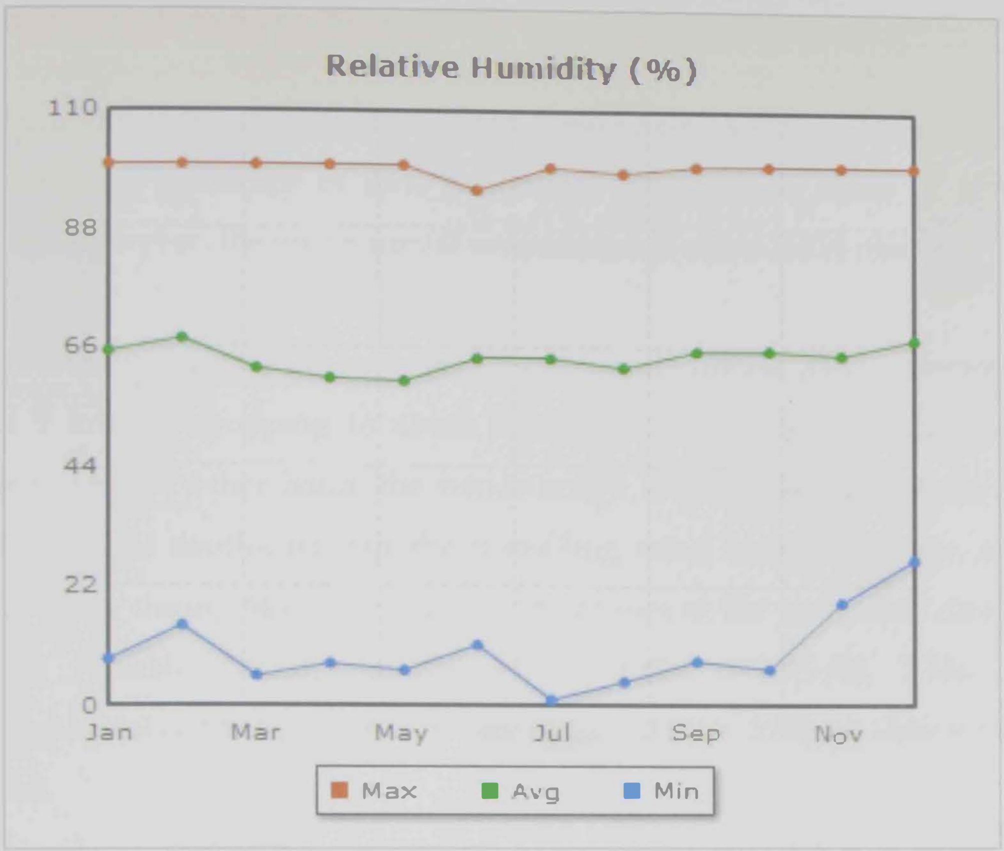

Fig. 3.7: Relative humidity of Abu Dhabi Emirate during the period of 2003-2008 (NCMS.AE, 2008)

The climate of Al Ain may be classified as hot arid desert. The seasons in Al Ain can be classified into two principal seasons: the cool "winter" season extends from December through March, when most rain falls and the long hot and dry "summer" season from June through September.

The mean annual rainfall of Al Ain is about 100 mm. However, most of this rain may fall within a few days but the total varies greatly from year to year. Most rainfall occurs between December and May. However, the mountain and hilly regions receive significantly higher rainfall compared to the plain areas.

Temperatures vary and can increase from 6°C in December and January to a peak of 50°C in June, July and August. However, monthly temperatures remain constant from year to year.

The humidity is significantly less in the period from April to October, with a mean relative humidity of 32% compared with a peak mean of 63% in January. However, the mean annual evaporation is about 3,634 mm.

The greatest wind speed is between February and August, and is consistently about 9 km/hr, dropping to about 7 km/hr on average from October to January. On the other hand, the winds arrive usually from the north-west, south-east and south-east, but the prevailing wind comes from the north-west, mainly during May and June. At other times of the year, wind direction can be variable (Shankland Cox et al., 1986; NCMS.AE, 2008). The meteorological conditions of Al Ain city during 2007 to 2008 are shown in Fig. 3.8-3.10.

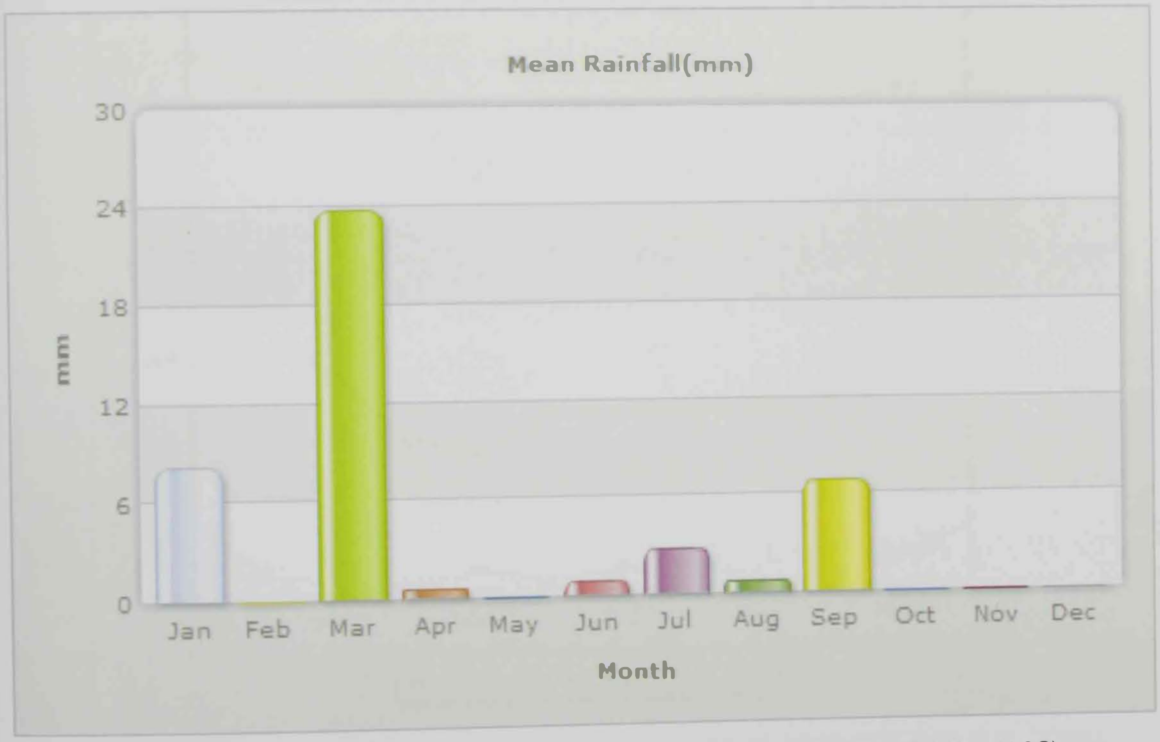

Fig. 3.8: Mean rainfall of Al Ain during 2007-2008 (NCMS.AE, 2008)

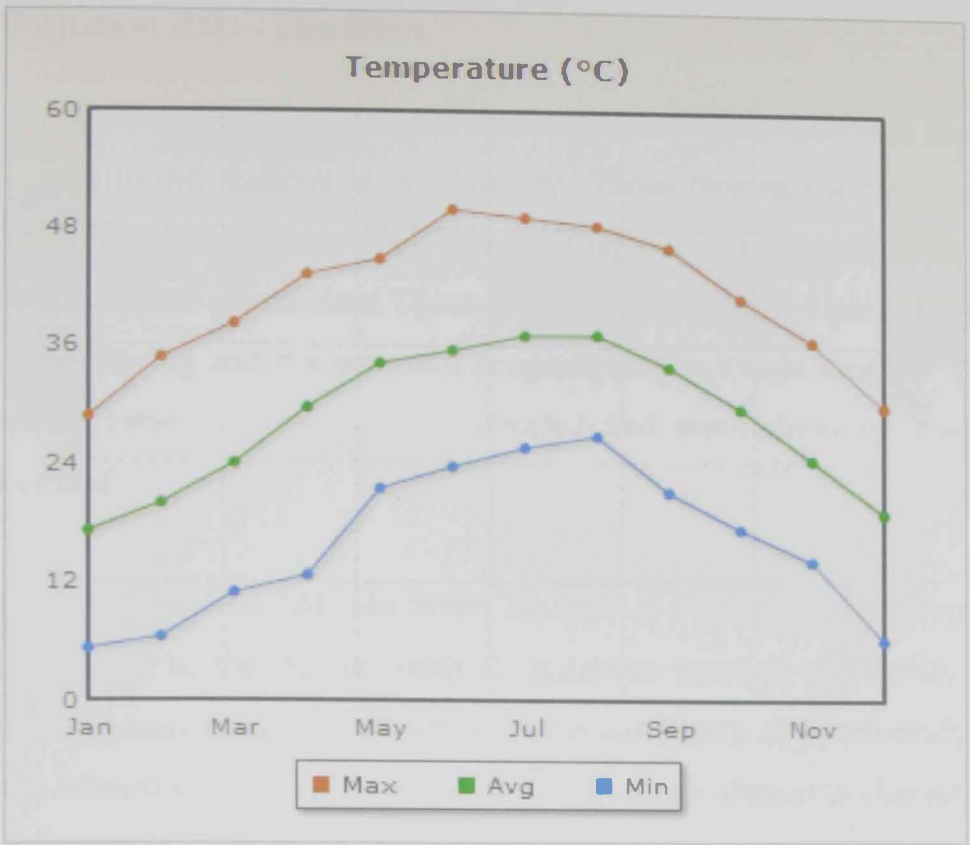

Fig. 3.9: Temperature of Al Ain during 2007-2008 (NCMS.AE, 2008)

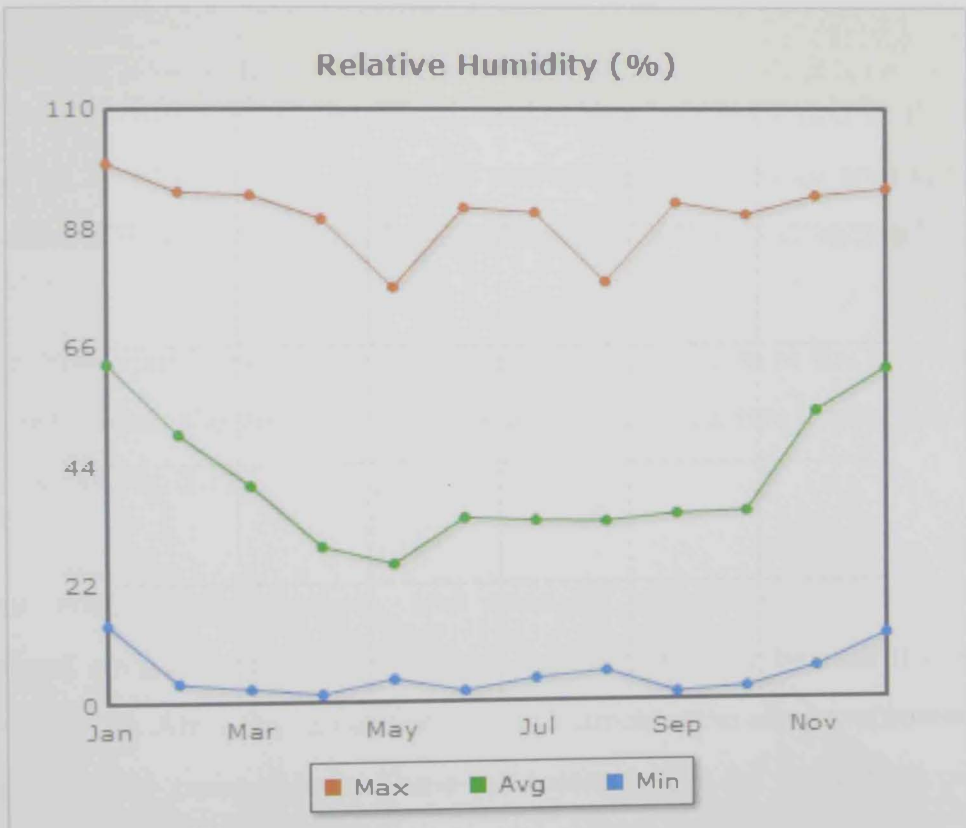

Fig. 3.10: Relative humidity of Al Ain during 2007-2008 (NCMS.AE, 2008)

3.4 Pollutant data collection

Hourly pollutant concentration data were collected from EAD two fixed air quality monitoring stations in Al Ain city. These two monitoring stations were constructed in 2007 and they continuously monitor air pollutants, noise and meteorological parameters. These stations are considered part of EAD air quality monitoring and management program in Abu Dhabi Emirate. The air monitoring network is operated, calibrated and maintained by NILU on behalf of EAD.

The first station called "Al Ain Street Station" is located in the downtown center, adjacent to the Al Nafoorah Roundabout junction of Khalifa Street with Salahuddeen Al Ayyubi Street from the north-east, approximately 15 m from the nearest traffic lane. The site of Al Ain Street station is characterized as a flat with no major buildings and very few obstacles. This station represents a highly populated area with heavy traffic.

The second station called "Al Ain School Station". It is located at the Sultan Bin Zayed Basic Education School. It represents a residential area with very low traffic. This station is considered to be a city background station.

On the other hand, the monitoring height is about 4.0 m at the two stations, which represents the ground level. The locations of the two stations in Al Ain are shown in Fig. 3.11.

Several routine maintenance and manual calibrations activities were performed on a monthly basis on each analyzer for the two air monitoring stations in Al Ain. The analyzers show current operating parameters for several internal components. These parameters give an indication of what maintenance needs to be performed. All operating parameters are recorded before and after the calibration. This will help in identifying any changes in the operating parameters of the analyzer, and to have a reference for the next calibration. Moreover, tracking of these parameters provides security in the event of damage.

The instrument calibrations are preformed to test air quality monitor responses to different input concentrations using certified cylinder gas mixtures according to the National Institute of Traceable Standards (NIST). This calibration is done for several analyzers including those of SO_2, NO, CO and non-methane hydrocarbons (NMHC). The calibration of H_2S is done using certified permeation tubes, while the calibration of ozone is done using a built-in UV lamp within the analyzer to generate known concentrations by mixing the lamp output of ozone with zero air. The calibration of PM_{10} is done by using the specific pre-weighted filter in addition to the leak checks, flow rate checks, temperature and pressure verifications (Whitford, 2008).

Fig. 3.11: Air quality monitoring stations in Al Ain

The time frame of the collected pollutant concentration data is from April, 2007 to April, 2009. The hourly average meteorological parameters such as air temperature, wind speed and direction were also obtained from the two fixed stations for the same period. However, the noise measurements data collected from the two stations are only available for 2009. These data are also on an hourly basis. Note that humidity data are not available at the stations.

The coordinates of the two stations are as follows:

- Al Ain Street Station: N 24° 13'33.12", E 55°45'56.98"
- Al Ain School Station: N 24° 13'08.62", E 55°44'05.53"

On the other hand, not all stations measure every pollutant. Both stations monitor particulate matter (PM_{10}), sulphur dioxide (SO_2), nitrogen oxides (NOx), methane (CH_4), and one of them monitor more pollutants such as carbon monoxide (CO) and ozone (O_3). Table 3.4 summaries the monitored pollutants at Al Ain stations.

Table 3.1: Emissions monitored at the fixed air quality stations in Al Ain

Parameter	Al Ain Street Station	Al Ain School Station
Particular mater (PM_{10})	√	√
Sulphur dioxide (SO_2)	√	√
Nitrogen Oxide (NO)	√	√
Nitrogen oxides (NO_x)	√	√
Methane (CH_4)	√	√
Carbon monoxide (CO)	√	-
Hydrogen sulfide (H_2S)	-	√
Ozone (O_3)	-	√
Benzene	√	-
Toluene	√	-
ethylbenzene	√	-
m,p-xylene	√	-
o-xylene	√	-
Noise	√	√
Wind speed	√	√
Wind direction	√	√
Temperature at 10 m	√	√
Temperature at 2 m	√	√
Temperature - Indoor	√	√

3.5 Traffic data collection

Traffic counts data were collected from Al Ain Municipality in cooperation with the Roadway, Transportation, and Traffic Safety Research Center (RTTSRC) at the UAE University. Hourly traffic data (i.e. vehicle flow per hour) were measured at various locations in the downtown of Al Ain city for several days in 2007 and 2009. Since various locations were measured at the same time period, two different traffic counts methods were used; manual counts and automatic traffic counts. Counting periods were chosen as four hours in the morning (from 7am to 11 am), and four hours in the evening (from 5pm to 9pm). Note that traffic counts were not performed during special community events, holidays, rain or any such event that would change typical traffic conditions and patterns.

The traffic counts cover an area of about 1,300m×700m and it combines the counts of seven roundabout junctions and two T-signal junctions around Al Ain Street air quality monitoring station at Khalifa Street. The frame study area for traffic counts is shown in Fig. 3.12.

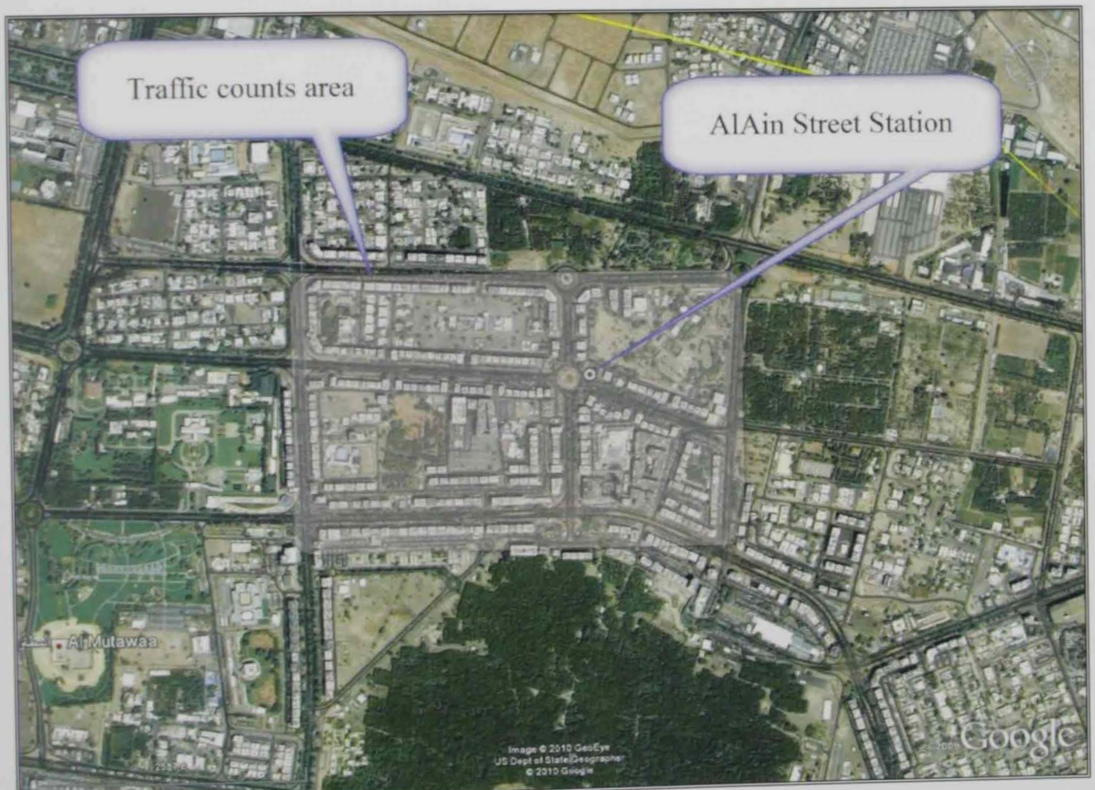

Fig. 3.12: Traffic counts area

3.6 Data analysis

3.6.1 Air Quality Standards

As mentioned in Chapter 2, ambient air quality standards are maximum allowable levels of air pollutants that should not be exceeded during a given time in a defined area (Lund, 1971). These standards were developed to protect the public health and the environment from negative impacts of air pollutants. Indeed, they are intended to avoid short term effects and provide sufficient control to avoid longer term effects of these pollutants. In this study, air pollutants levels collected at the fixed stations in Al Ain, during 2007-2009, were compared with Abu Dhabi ambient air quality standard.

3.6.2 Air Quality Index (AQI)

The air quality index (AQI) developed by the US EPA was used in this study to characterize the quality of air in Al Ain. This index is used as an indicator of the quality of ambient atmosphere with regards to health impacts. Further details on the use of the AQI will be presented in Chapter 4.

3.6.3 Identification of spatial pollutant pattern

Air pollutant data collected from the two fixed stations are utilized to investigate pollutant spatial distribution. Since the two locations are characterized by different traffic volumes, comparison among the two stations will qualitatively indicate the effect of variations in traffic density.

3.6.4 Identification of temporal pollutant pattern

Air pollutant data collected at each station during 2007 to 2009 will be utilized to investigate variation of pollution level over time. This will also capture possible daily, weekly and seasonal variations. Multiple time series plots were used to describe temporal changes in pollutants level.

3.6.5 Statistical Analysis

The statistical software package SPSS (Statistical Package for Social Sciences) was used for performing all statistical analysis to summarize, analyze and conduct statistical interpretation of the air pollutants data. This is utilized to investigate possible relationship among pollutants and between pollutants and meteorological conditions. Such step is necessary before any attempt to correlate pollutant level to traffic volume.

The statistical analysis methods that were used are as follows:

- **Descriptive statistics** was used to quantitatively summarize the air pollutants and traffic counts data sets.
- **Box-plots** were used to compare the distributions of the pollutants levels in the two stations in order to investigate the spatial changes in pollutants level.
- **Histogram-plot** was used to show the "normal" distribution for each pollutant in the two locations.
- **Independent t- test** was used to investigate the significance of difference between two categorical variables.
- **Mann-Whintney-Wilcoxon test** will be used instead of the independent t-test, if the assumptions underlying t-test are violated.
- **Kolmogrov- Smirnov** was used to test the normality of the distribution
- **Pearson's correlation coefficient** was used to measure the relationship between the two variables.

3.6.6 The Synchro Traffic Model

In this study, the Synchro model (version 6.0) was used to calculate the vehicle kilometer traveled (VTK), car pollutant emissions, and fuel consumption. A snapshot of this software is shown in Fig. 3.13. Input to the software requires data related to mapping, links, geometry, lanes, and traffic volume. On the other hand, this software can predict the total emissions of some pollutants (CO, NO_x, and VOCs), which leads us to use another model to predict the rest air pollutants. Further details on the use of this model will be presented in Chapter 6.

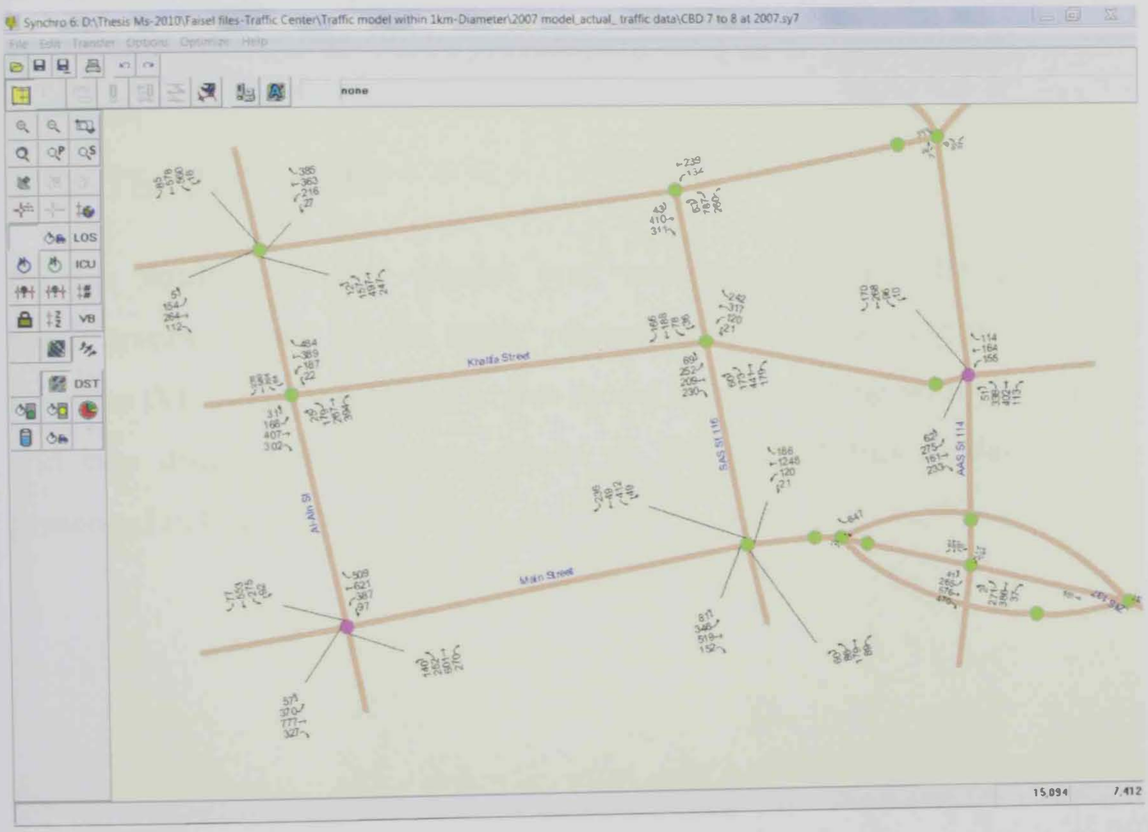

Fig. 3.13: A snapshot of the Synchro software version 6.0

3.6.7 The International Vehicle Emissions (IVE) Model

The international vehicle emissions (IVE) model (version 2.0.1) was used in this study to estimate the vehicle fleets emissions at the downtown of Al Ain (adjacent to the Street Station). This model is available on the public domain and can be downloaded from the International Sustainable Systems Research Center (ISSRC) website. The IVE model was selected because it is the most appropriate model for developing countries and it has been applied in several countries worldwide (e.g. Turkey, China, Brazil, Mexico, USA, Peru, Kenya, India, Chile, and Kazakhstan). However, other existing models might be more accurate, but they tend to be more focused on their respective regions and hence may not be applicable to the conditions of the UAE. Further details on the use of this model will be presented in Chapter 6.

3.6.8 The BOX model

In this study, the Box Model was used to calculate the pollutants concentrations based on the traffic related emissions. The output emissions from the IVE model were used in this model as inputs along with wind speed and box dimensions. Further details on the use of this model will be presented in Chapter 6.

Chapter 4: Ambient Air Quality in Al Ain

4.1 Air quality data

The present investigation included measurements of the five criteria pollutants; particulate matter (PM_{10}), sulphur dioxide, nitrogen dioxide, carbon monoxide and ozone, as well as VOCs measurements which include benzene, toluene, methane, ethylbenzene, xylene and m-and p-xylene. Data were collected during the period of April 2007 to December 2009 at the two stations; Al Ain Street, representing a downtown area, and Al Ain School, representing a residential area. In addition, several descriptive statistics were used to summarize and analyze the air pollutants data.

A. Particulate matter (PM_{10})

Table 4.1 shows the descriptive statistical analysis of PM_{10} concentration measured at the two stations during 2007-2009. On the average, the concentration of PM_{10} detected at Al Ain Street is higher than that at the School Station, with a mean of 157 μg/m^3, a minimum of 1.12 μg/m^3 and a maximum of 1725 μg/m^3. In terms of temporal variations, Al Ain School had shown the same values of mean in 2007 and 2008. However, the mean value increased by 7.7% in 2009. On the other hand, the mean value of Al Ain Street increased by 2.3% from 2007 to 2008 and decreased by 3.6% in 2009.

Figure 4.1 shows the distribution of PM_{10} at the two stations during the period of 2007-2009. The PM_{10} values are positively skewed from normal distribution with a value of 3.4. The skewness was also evident from the difference between the mean of 131.7 and median of 89.8. However, the PM_{10} values have a relatively leptokurtic distribution (that is, too tall or more peaked) with positive kurtosis of 15.1. On the other hand, the overall mean, median, minimum and maximum of the PM_{10} concentrations during the period of 2007-2009 are 131.7, 89.8, 1.12 and 1725; respectively.

B. Sulphur dioxide (SO_2)

Table 4.2 shows the descriptive statistical analysis of SO_2 concentration at the two stations during 2007-2009. On the average, SO_2 concentration in the downtown (Al Ain Street) is higher than that in the residential area (School Station), with a mean of 8.5 ppb, a minimum of 0.01 ppb, a maximum of 77.5 ppb and a median of 4.4 ppb. In terms of temporal variations, the concentration measured at Al Ain School had a mean of 1.5, 1.37 and 1.65 ppb during 2007-2009, respectively. On the other hand, the mean values at Al Ain Street have increased by 46% from 2007 to 2008 and 15.8% from 2008 to 2009.

Figure 4.2 shows the distribution of SO_2 at the two stations during the period of 2007-2009. It was found that SO_2 values are positively skewed from normal distribution with a value of 3.9. The skewness was also evident from the difference between the mean of 5.0 and the median of 2.0. However, the SO_2 concentration measurements have a relatively leptokurtic distribution with positive kurtosis of 19.5. On the other hand, the overall mean, median, minimum and maximum of the SO_2 concentrations during the period of 2007-2009 are 5.0, 2.0, 0.01 and 77.5, respectively.

C. Nitrogen dioxide (NO_2)

Table 4.3 shows the descriptive statistical analysis of NO_2 concentration at the two stations during 2007-2009. As before, the average concentration detected in the downtown is higher than that detected in the residential area for the same durations. For the downtown (Al Ain Street Station) the concentration during 2007-2009 averaged 16.6ppb, with a minimum of 0.01ppb, a maximum of 124ppb and a median of 16ppb. The mean values of NO_2 detected at Al Ain School have increased by 3.7% from 2007 to 2008 and then decreased by 33.6% from 2008 to 2009. In contrast, the mean values of Al Ain Street showed opposite behavior from Al Ain School, where it decreased by 52% from 2007 to 2008 and then increased by 60% from 2008 to 2009.

Figure 4.3 shows the distribution of NO_2 at the two stations during the period of 2007-2009. The NO_2 values are characterized by an approximately normal distribution with a skewness value of 0.8. The skewness was also evident from the similarity between the mean of 15.4ppb and the median (14.7ppb). However, the NO_2 values have a relatively mesokurtic (that is, normally high) distribution with positive kurtosis of 0.71. On the other hand, the overall mean, median, minimum and maximum of the NO_2 concentrations during the period of 2007-2009 are 13.6, 11.9, 0.02 and 60.6, respectively.

D. Carbon monoxide (CO)

Table 4.4 shows the descriptive statistical analysis of CO concentration measured at Al Ain Street Station in the downtown during 2007-2009. It was found that the mean values of CO have increased slightly by 2.0% from 2007 to 2008 and then decreased by 27.6% from 2008 to 2009.

Figure 4.4 shows the distribution of CO in ppm for Al Ain Street Station during the period of 2007-2009. It was found that the distribution of CO concentration measurements is approximately normal distribution with skewness value of 4.5. The skewness was also evident from the similarity between the mean of 1.63 and median of 1.56. However, the CO concentration measurements have a relatively leptokurtic distribution with positive kurtosis of 107. On the other hand, the overall mean, median, minimum and maximum of the CO concentrations during the period of 2007-2009 are 1.63, 1.56, 0.01 and 27.2, respectively.

E. Ozone (O_3)

Table 4.5 shows the descriptive statistical analysis of O_3 concentration at Al Ain School Station, during 2007-2009. It was found that the mean values of O_3 have decreased by 9% from 2007 to 2008 and then decreased by an additional 9% from 2008 to 2009.

Figure 4.5 shows the distribution of O_3 at Al Ain School Station during the period of 2007-2009. It was found that the distribution of O_3 values is approximately closer to normal distribution with a skewness value of 0.85. However, the O_3 measurements have a relatively platykurtic distribution (i.e. flat distribution) with a negative kurtosis of -0.128. On the other hand, the overall mean, median, minimum and maximum of O_3 concentrations during the period of 2007-2009 are 16.78, 13.47, 0.12 and 71.5, respectively.

F. Hydrocarbons (HCs)

Tables 4.6-4.11 show the descriptive statistical analysis of hydrocarbons (HCs) concentration at Al Ain Street Station in the downtown during 2007-2009. The mean values of benzene, toluene, and methane have increased by 37.8%, 35% and 6%, respectively from 2007 to 2008. In contrast, the levels of ethylbenzene, xylene and m- and p-xylene have decreased by 53%, 15% and 57%, respectively for the same period. The mean values of benzene, toluene, m- and p-xylene have increased by 5.3%, 1.3% and 27%, respectively from 2008 to 2009 and the level of ethylbenzene and methane have decreased by 0.8% and 51.9%, respectively for the same period, whereas xylene level remained almost the same during 2008 and 2009.

Figures 4.6-4.11 show the distribution of HCs at Al Ain Street Station during the period of 2007-2009. The HCs values are positively skewed from normal distribution with a value of 3.6, 3.3, 4.4, 6.1 and 5.2 for benzene, toluene, ethylbenzene, xylene and m- and p-xylene, respectively. However, the distribution of methane concentration measurements is approximately normal distributed with a skewness value of 0.51. On the other hand, HCs measurements have a relatively leptokurtic distribution with positive kurtosis of 28, 20, 27, 107 and 46 for benzene, toluene, ethylbenzene, xylene and m- and p-xylene, respectively, whereas the methane concentration measurements have a relatively platykurtic distribution (i.e. flat distribution) with a negative kurtosis of -0.840.

Table 4.1: Descriptive statistical analysis of PM_{10} ($\mu g/m^3$) at the two stations during 2007-2009

Parameter	2007			2008			2009		
	School	Street	Overall	School	Street	Overall	School	Street	Overall
Mean	98.5	158	130	98.7	165.3	133	115.3	147	131.6
5% Trimmed Mean	92.4	132	111	78.4	134.6	106	96	124.8	110.7
Median	82.1	114.7	99.5	47.3	105.5	79.4	74.7	106	89.7
Std. Dev.	64.5	159	127	132.3	190.4	168	129	152	142.2
Minimum	2.68	1.28	1.28	10.10	1.12	1.12	2.61	3.6	2.61
Maximum	511	1031	1031	1026	1032	1032	1026	1725	1725
Skewness	1.86	3.42	4.1	3.2	2.8	3.1	3.2	3.56	3.4
Kurtosis	5.8	13.2	21.3	13.8	8.4	11.0	13.2	18.8	17.5

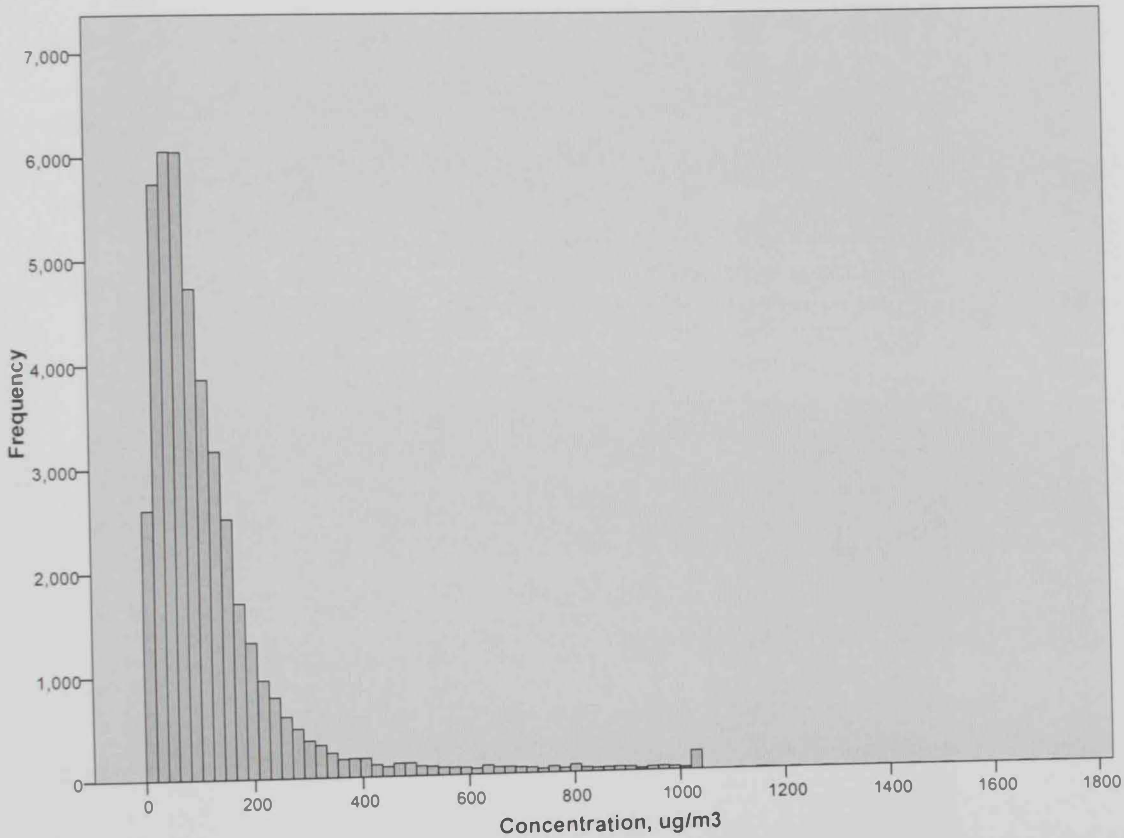

Fig. 4.1: Distribution of PM_{10} at the two stations during 2007-2009

Table 4.2: Descriptive statistical analysis of SO_2 (ppb) at the two stations during 2007-2009

Parameter	2007			2008			2009		
	School	Street	Overall	School	Street	Overall	School	Street	Overall
Mean	1.5	3.3	2.3	1.37	9.0	5.16	1.65	12.38	7.9
5% Trimmed Mean	1.3	2.9	2.0	1.17	8.3	4.36	1.5	10.3	5.6
Median	1.03	2.6	1.94	1.0	8.3	2.22	1.16	4.2	2.25
Std. Dev.	1.6	2.3	2.15	1.5	6.8	6.25	1.5	16.7	13.9
Minimum	0.01	0.46	0.01	0.01	0.01	0.01	0.01	0.02	0.01
Maximum	31.86	38.16	38.16	46.4	46.8	46.8	29.7	77.56	77.56
Skewness	4.2	4.3	3.8	7.8	1.3	1.9	4.4	1.7	2.6
Kurtosis	37.6	33.1	29.5	142	1.7	4.13	53	2.4	6.5

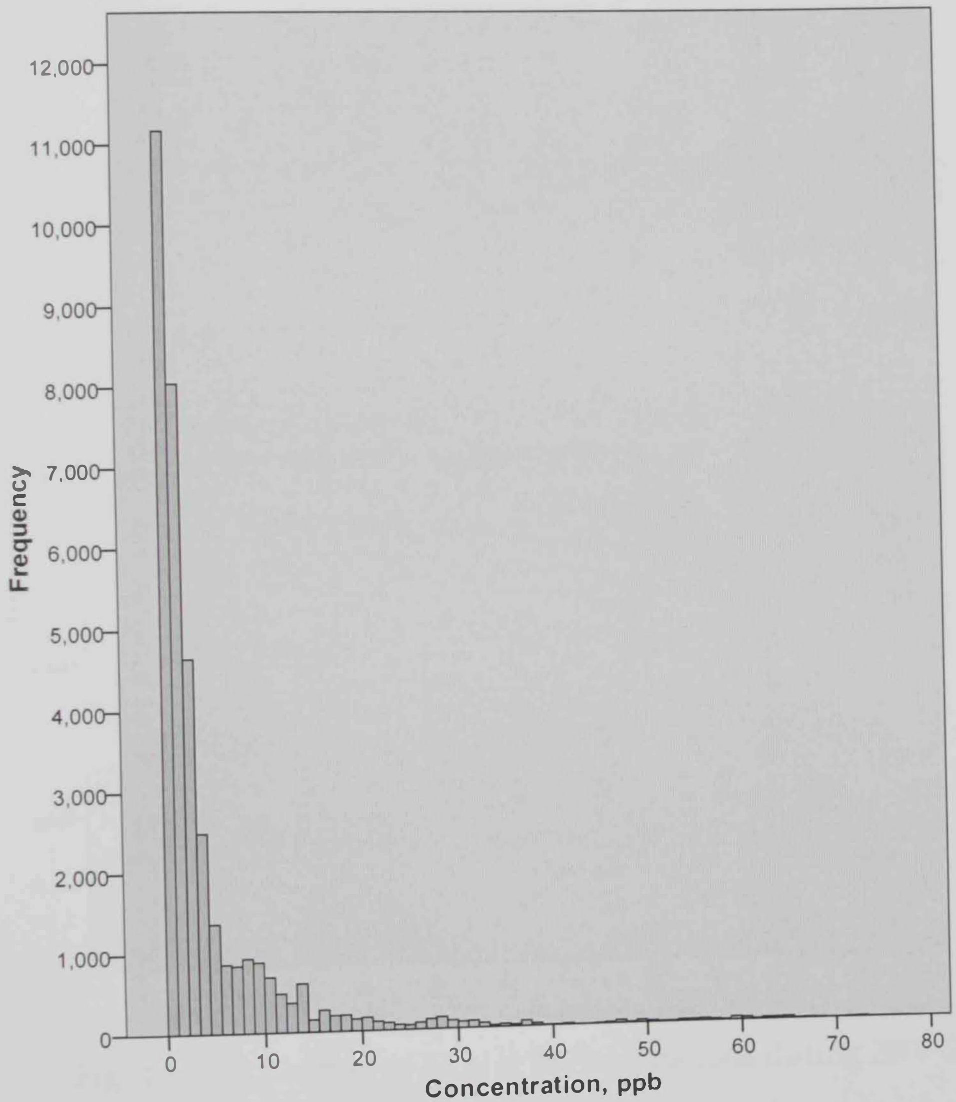

Fig. 4.2: Distribution of SO_2 at the two stations during 2007-2009

Table 4.3: Descriptive statistical analysis of NO_2 (ppb) at the two stations during 2007-2009

Parameter	2007			2008			2009		
	School	Street	Overall	School	Street	Overall	School	Street	Overall
Mean	11.15	18.8	15.0	15.7	5.9	11.3	7.8	23.6	23.5
5% Trimmed Mean	10.6	18.6	14.7	15.1	5.0	10.4	7.5	23.1	23
Median	9.3	18.3	14.4	13.9	1.24	9.4	7.6	22.2	22.1
Std. Dev.	8.1	8.3	9.0	10.5	8.2	10.6	5.0	12	12
Minimum	0.02	0.30	0.02	0.04	0.01	0.01	0.07	0.85	0.07
Maximum	47.78	53.06	53.1	60.60	56.35	60.60	21.68	124.20	124
Skewness	0.816	0.419	0.474	0.902	1.65	1.04	0.469	0.713	0.706
Kurtosis	0.123	0.153	-0.191	0.423	2.6	0.699	-0.202	0.981	0.95

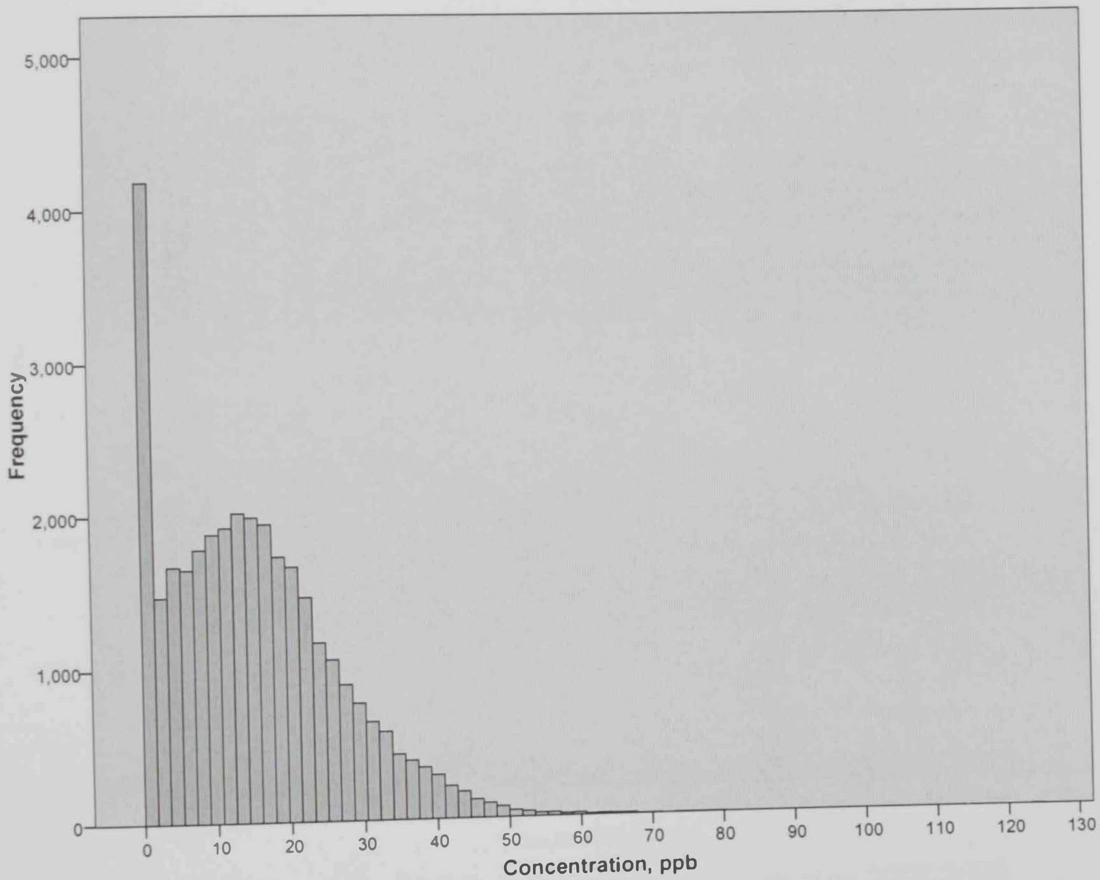

Fig. 4.3: Distribution of NO_2 at the two stations during 2007-2009

Table 4.4: Descriptive statistical analysis of CO (ppm) at the two stations during 2007-2009

Parameter	2007			2008			2009		
	School	Street	Overall	School	Street	Overall	School	Street	Overall
Mean	-	1.73	1.73	-	1.8	1.8	-	1.02	1.02
5% Trimmed Mean	-	1.72	1.72	-	1.73	1.73	-	1.02	1.02
Median	-	1.69	1.69	-	1.68	1.68	-	1.02	1.02
Std. Dev.	-	0.68	0.68	-	0.72	0.72	-	0.21	0.21
Minimum	-	0.01	0.01	-	0.59	0.59	-	0.17	0.17
Maximum	-	5.72	5.72	-	27.22	27.22	-	2.41	2.41
Skewness	-	0.35	0.35	-	7.95	7.95	-	0.89	0.89
Kurtosis	-	0.86	0.86	-	195	195	-	4.8	4.8

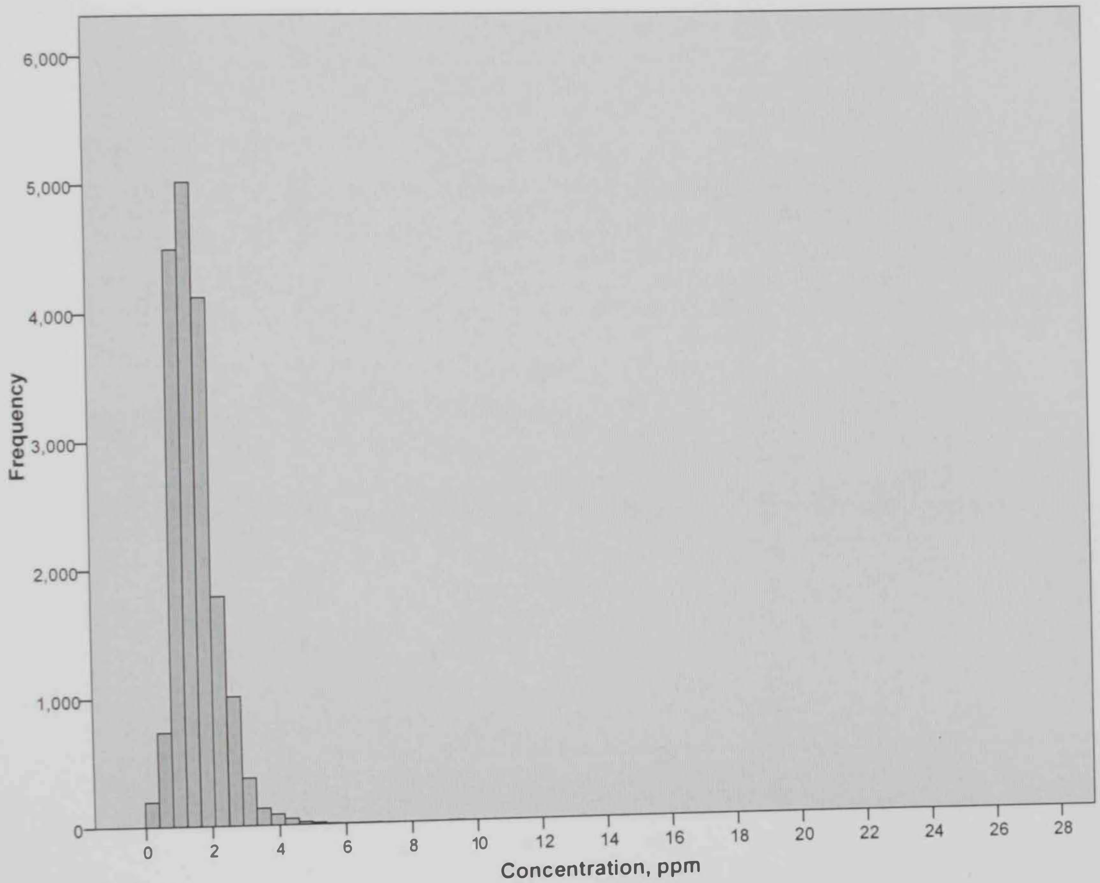

Fig. 4.4: Distribution of CO at the two stations during 2007-2009

Table 4.5: Descriptive statistical analysis of O_3 (ppb) at the two stations during 2007-2009

Parameter	2007			2008			2009		
	School	Street	Overall	School	Street	Overall	School	Street	Overall
Mean	20.2	-	20.2	16.8	-	16.8	14	-	14
5% Trimmed Mean	19.3	-	19.3	15.9	-	15.9	13.1	-	13.1
Median	17.14	-	17.14	12.8	-	12.8	12.2	-	12.2
Std. Dev.	15.97	-	15.97	14.6	-	14.6	11.22	-	11.22
Minimum	0.16	-	0.16	0.19	-	0.19	0.12	-	0.12
Maximum	69.51	-	69.51	69.92	-	69.92	71.54	-	71.54
Skewness	0.593	-	0.593	0.753	-	0.753	1.012	-	1.012
Kurtosis	-0.71	-	-0.71	-0.57	-	-0.57	1.01	-	1.01

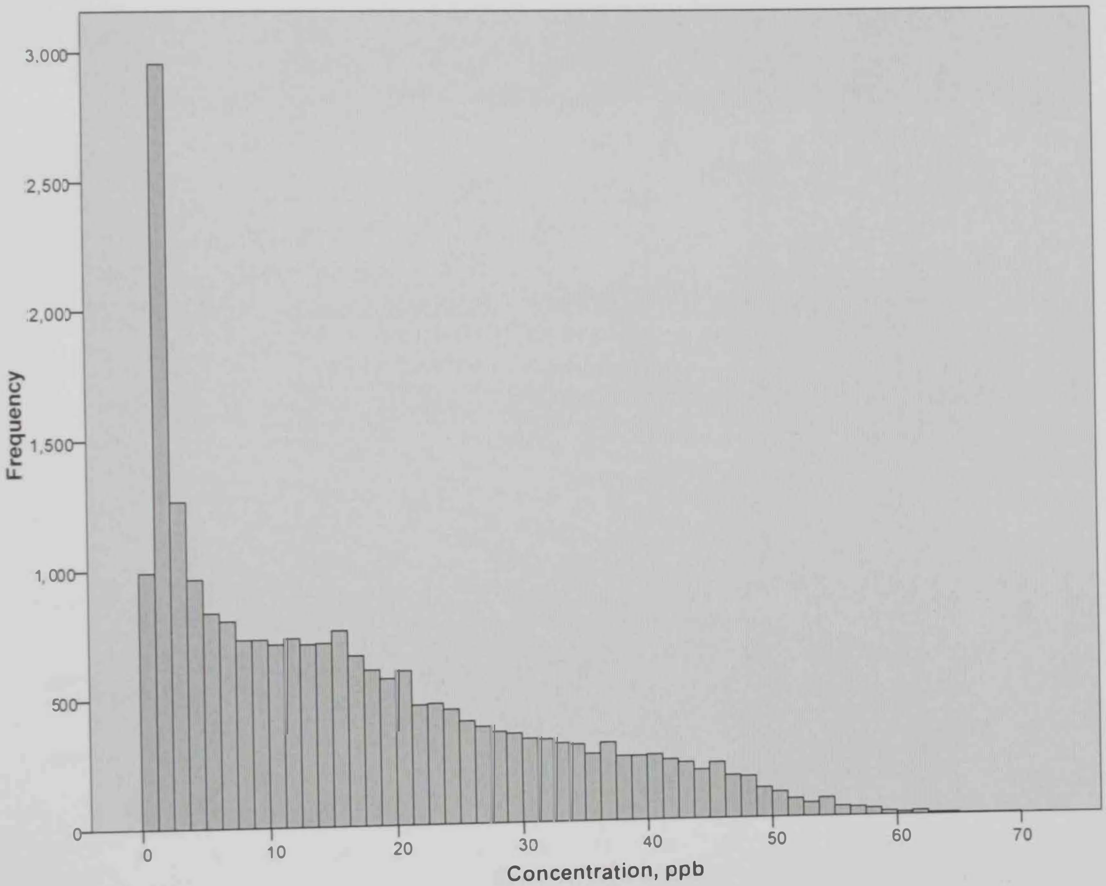

Fig. 4.5: Distribution of O_3 at the two stations during 2007-2009

Table 4.6: Descriptive statistical analysis of benzene (μg/m³) at the two stations during 2007-2009

Parameter	2007			2008			2009		
	School	Street	Overall	School	Street	Overall	School	Street	Overall
Mean	-	3.42	3.42	-	7.58	7.58	-	8.44	8.44
5% Trimmed Mean	-	2.97	2.97	-	6.78	6.78	-	7.42	7.42
Median	-	2.33	2.33	-	5.8	5.8	-	6.14	6.14
Std. Dev.	-	3.64	3.64	-	7.16	7.16	-	8.19	8.19
Minimum	-	0.02	0.02	-	0.07	0.07	-	0.01	0.01
Maximum	-	40.22	40.22	-	110.3	110.3	-	138.4	138.4
Skewness	-	3.137	3.137	-	3.126	3.126	-	3.842	3.842
Kurtosis	-	17.44	17.44	-	21.18	21.18	-	30.19	30.19

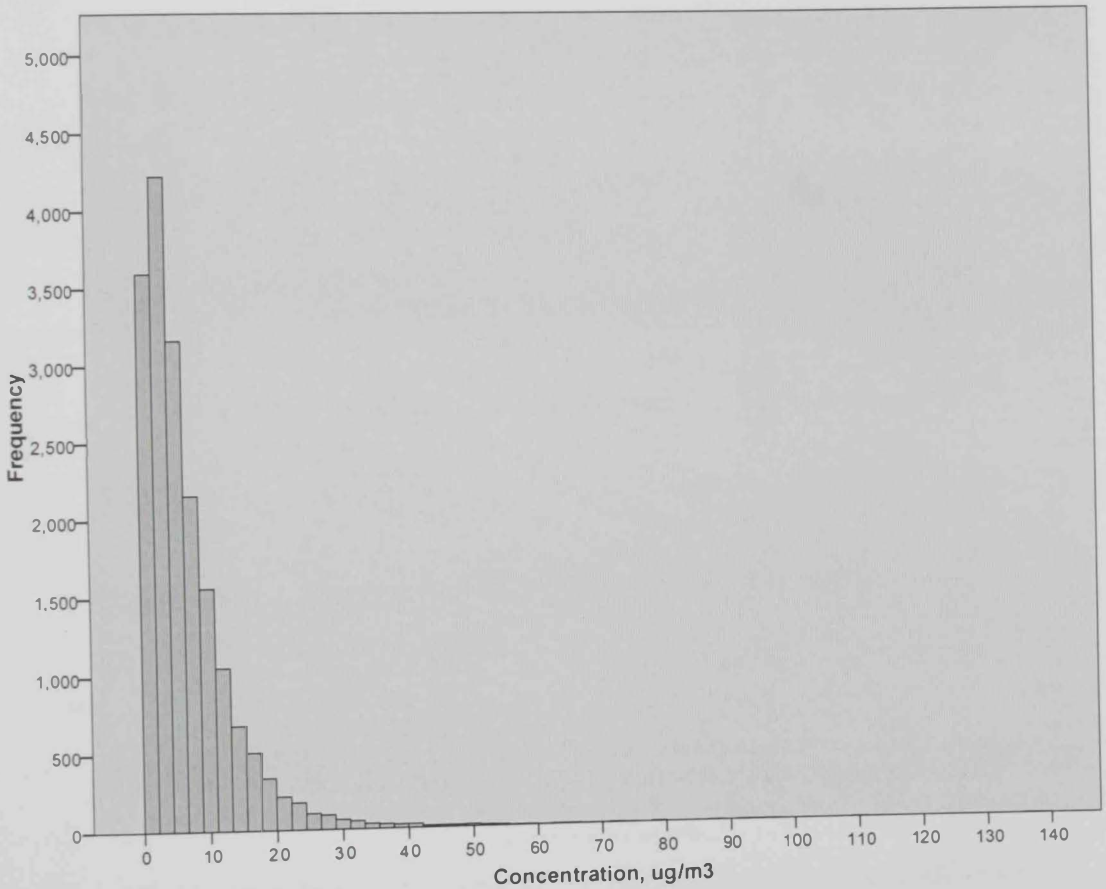

Fig. 4.6: Distribution of benzene at the two stations during 2007-2009

Table 4.7: Descriptive statistical analysis of toluene (μg/m³) at the two stations during 2007-2009

Parameter	2007			2008			2009		
	School	Street	Overall	School	Street	Overall	School	Street	Overall
Mean	-	8.84	8.84	-	18.3	18.3	-	18.8	18.8
5% Trimmed Mean	-	7.95	7.95	-	16.5	16.5	-	16.6	16.6
Median	-	6.7	6.7	-	14.7	14.7	-	14.05	14.05
Std. Dev.	-	7.8	7.8	-	16.6	16.6	-	17.4	17.4
Minimum	-	0.01	0.01	-	0.51	0.51	-	0.3	0.3
Maximum	-	76.4	76.4	-	264	264	-	177	177
Skewness	-	2.63	2.63	-	3.3	3.3	-	3.1	3.1
Kurtosis	-	11.1	11.1	-	23.4	23.4	-	14.9	14.9

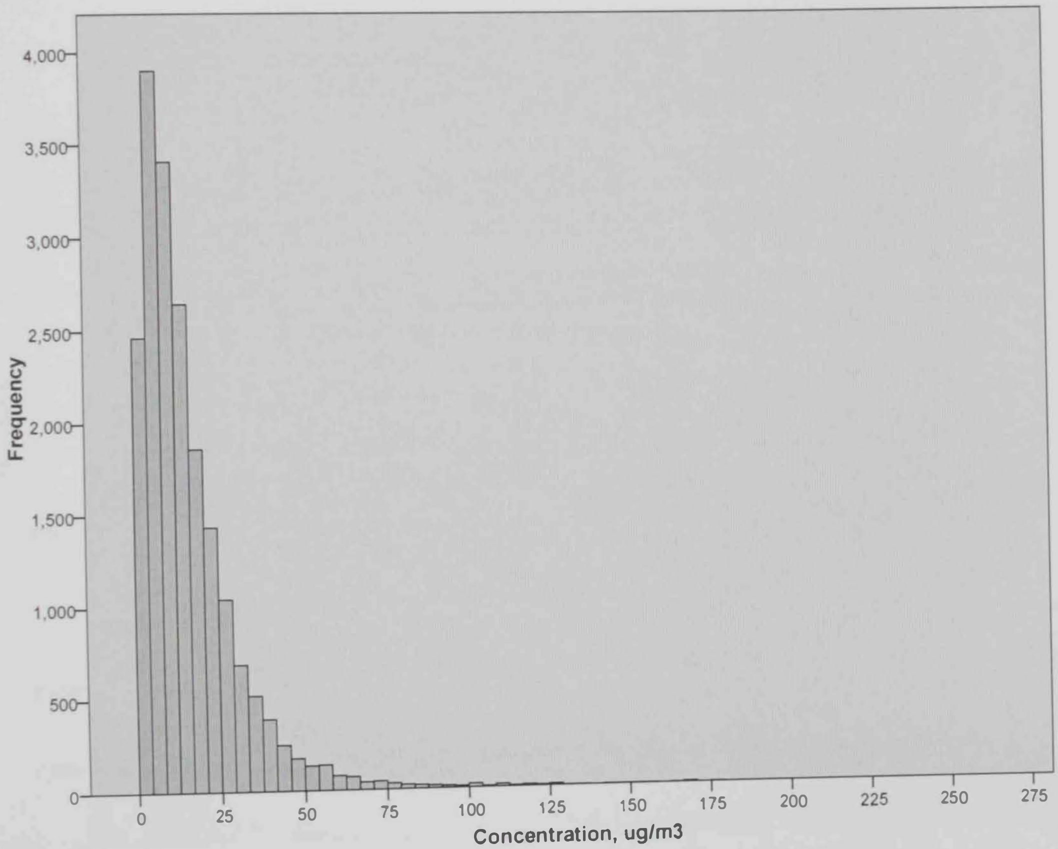

Fig. 4.7: Distribution of toluene at the two stations during 2007-2009

Table 4.8: Descriptive statistical analysis of ethylbenzene (μg/m³) at the two stations during 2007-2009

Parameter	2007			2008			2009		
	School	Street	Overall	School	Street	Overall	School	Street	Overall
Mean	-	23.48	23.48	-	7.3	7.3	-	7.18	7.18
5% Trimmed Mean	-	19.36	19.36	-	4.6	4.6	-	5.75	5.75
Median	-	11.9	11.9	-	3.0	3.0	-	4.8	4.8
Std. Dev.	-	31.3	31.3	-	16.12	16.12	-	10.16	10.16
Minimum	-	0.03	0.03	-	0.01	0.01	-	0.01	0.01
Maximum	-	246.2	246.2	-	294.5	294.5	-	172.7	172.7
Skewness	-	2.272	2.272	-	7.152	7.152	-	6.792	6.792
Kurtosis	-	7.23	7.23	-	74.31	74.31	-	70.92	70.92

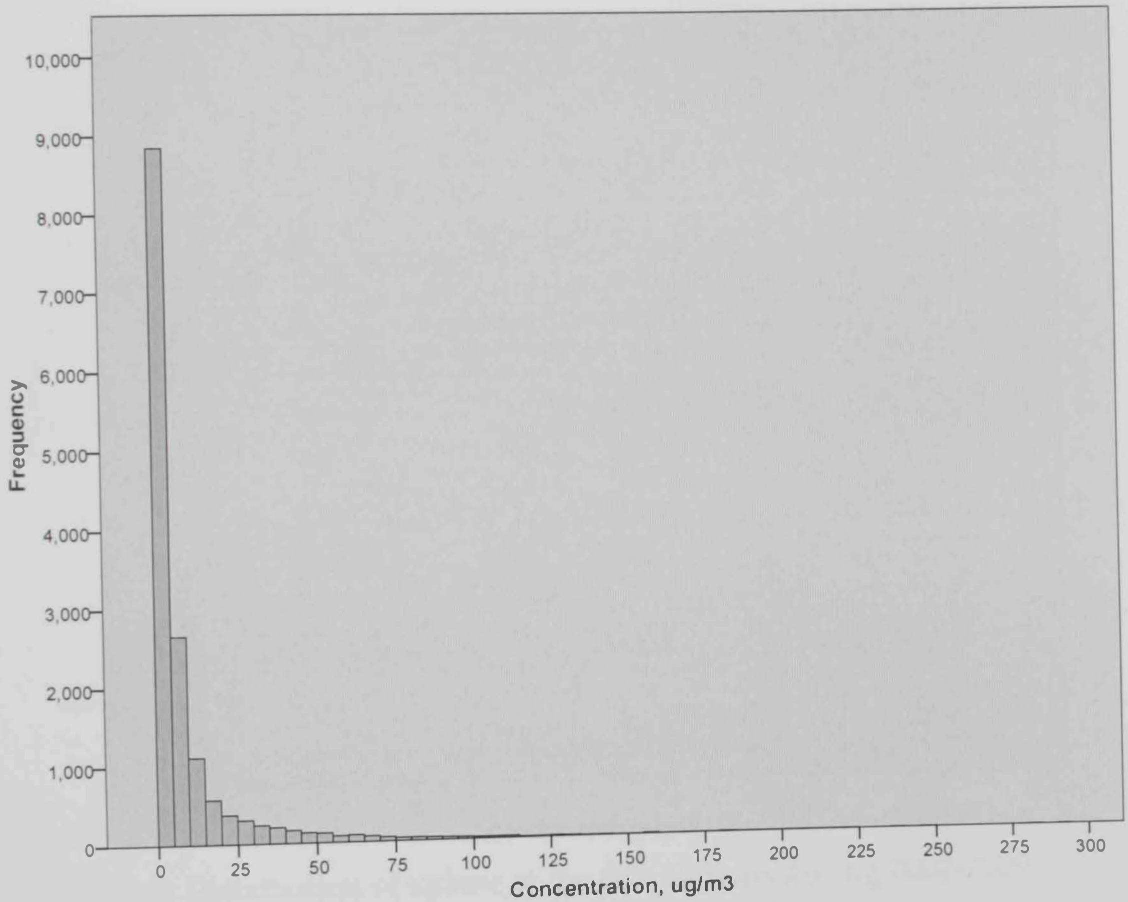

Fig. 4.8: Distribution of ethylbenzene at the two stations during 2007-2009

Table 4.9: Descriptive statistical analysis of xylene (µg/m³) at the two stations during 2007-2009

Parameter	2007			2008			2009		
	School	Street	Overall	School	Street	Overall	School	Street	Overall
Mean	-	5.46	5.46	-	4.01	4.01	-	4.01	4.01
5% Trimmed Mean	-	4.6	4.6	-	3.47	3.47	-	3.43	3.43
Median	-	3.74	3.74	-	2.88	2.88	-	2.8	2.8
Std. Dev.	-	6.22	6.22	-	4.23	4.23	-	4.93	4.93
Minimum	-	0.01	0.01	-	0.01	0.01	-	0.01	0.01
Maximum	-	93.58	93.58	-	65.05	65.05	-	170.5	170.5
Skewness	-	3.6	3.6	-	3.995	3.995	-	10.02	10.02
Kurtosis	-	23.6	23.6	-	29.6	29.6	-	24.9	24.9

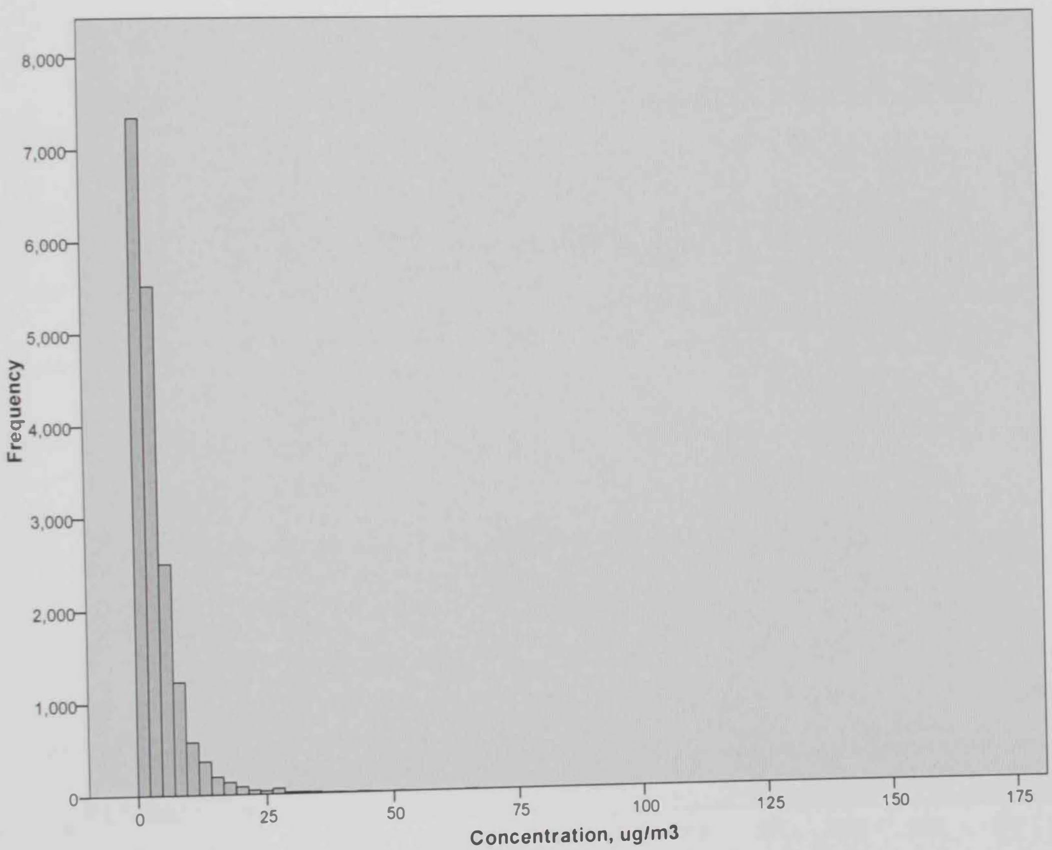

Fig. 4.9: Distribution of xylene at the two stations during 2007-2009

Table 4.10: Descriptive statistical analysis of mp-xylene (µg/m³) at the two stations during 2007-2009

Parameter	2007			2008			2009		
	School	Street	Overall	School	Street	Overall	School	Street	Overall
Mean	-	17.3	17.3	-	4.76	4.76	-	8.43	8.43
5% Trimmed Mean	-	14.4	14.4	-	4.27	4.27	-	7.57	7.57
Median	-	9.0	9.0	-	3.71	3.71	-	6.37	6.37
Std. Dev.	-	21.29	21.29	-	4.13	4.13	-	7.16	7.16
Minimum	-	0.03	0.03	-	0.40	0.40	-	0.11	0.11
Maximum	-	275	275	-	60	60	-	123	123
Skewness	-	2.8	2.8	-	3.422	3.422	-	2.97	2.97
Kurtosis	-	13.3	13.3	-	22.7	22.7	-	18.3	18.3

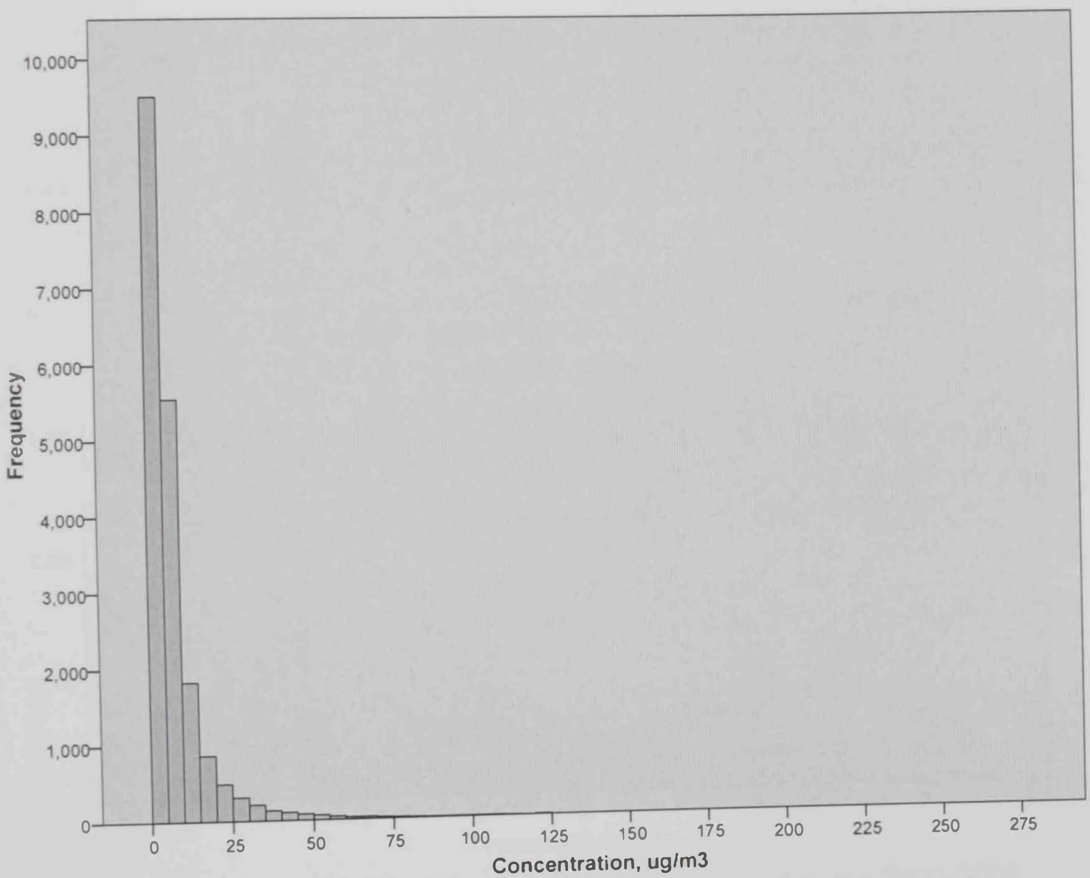

Fig. 4.10: Distribution of mp-xylene at the two stations during 2007-2009

Table 4.11: Descriptive statistical analysis of CH_4 (ppm) at the two stations during 2007-2009

Parameter	2007			2008			2009		
	School	Street	Overall	School	Street	Overall	School	Street	Overall
Mean	1.2	2.8	2.1	1.53	3.14	2.3	-	1.02	1.02
5% Trimmed Mean	1.1	2.8	2.0	1.49	3.1	2.2	-	1.02	1.02
Median	1.27	2.9	1.8	1.4	3.0	2.3	-	1.02	1.02
Std. Dev.	0.37	0.85	1.06	0.37	0.58	0.94	-	0.21	0.21
Minimum	0.01	0.01	0.01	0.67	0.97	0.67	-	0.17	0.17
Maximum	4.57	5.2	5.20	4.13	7.7	7.7	-	2.41	2.41
Skewness	0.97	-0.27	0.483	1.83	0.604	0.405	-	0.89	0.89
Kurtosis	3.5	-0.08	-0.91	2.11	1.16	-0.88	-	4.84	4.84

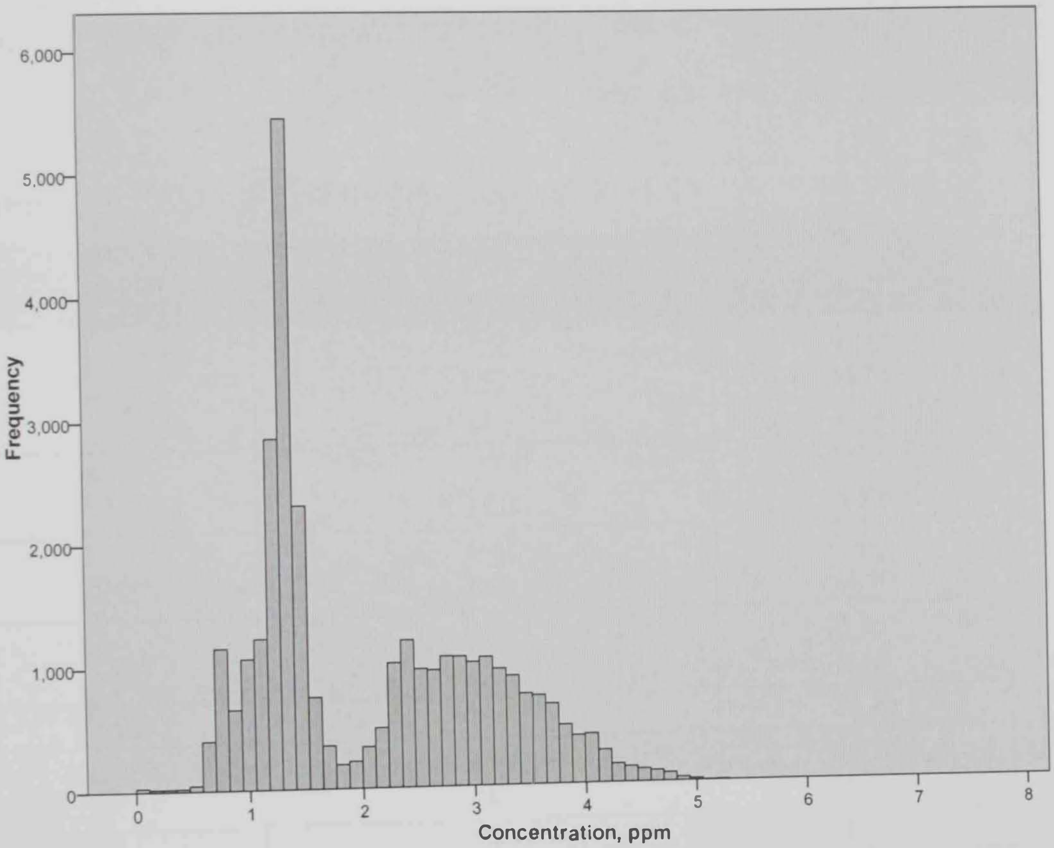

Fig. 4.11: Distribution of CH_4 at the two stations during 2007-2009

4.2 Comparison of pollutants level with air quality standards

The air quality standards are the concentrations of air pollutants that are considered to be acceptable with regards to protection of human health and the environment. EAD has developed new air quality standards for the six criteria pollutants; CO, NO_2, O_3, SO_2, PM_{10} and Pb. These standard limits along with that of total suspended particles (TSP) are shown in Table 4.12. Note that no ambient standard limits are available for methane or other VOCs.

In this study, the levels of the air pollutants measured at the two fixed stations in Al Ain, during the period of 2007- 2009 were compared with EAD Ambient Air Quality Standard.

Table 4.12: EAD Air Quality Standard, (EAD, n.d.)

Parameter	Maximum allowable limits (µg/m³)	Average time
SO_2	350 150 60	1 hr 24 hr 1 yr
CO	30,000 10,000	1 hr 8 hr
NO_2	400 150	1 hr 24 hr
O_3	200 120	1 hr 8 hr
PM_{10}	150	24 hr
TSP	230 90	24 hr 1 yr
Pb	1	1 yr

Although EAD has two air quality monitoring stations in Al Ain, but the two stations do not record all pollutants. The Al Ain Street monitoring station in the downtown monitors PM_{10}, SO_2, NO, NO_x, CO and some of the HCs, while the station at Al Ain School monitors PM_{10}, SO_2, NO, NO_x, O_3 and some of the HCs.

Figures 4.12-4.14 show the 1-hr, 24-hr and 1-yr SO_2 concentration level, respectively in Al Ain city for the period from April 2007 to August 2009. The concentration levels of SO_2 for the three exposure periods were below the EAD standard at both stations. Additionally, most of the 1-hr SO_2 levels are below 50 $\mu g/m^3$ while the average daily concentration levels in most of the cases are below 20 $\mu g/m^3$.

Particulate matter has become a major air pollution problem in Al Ain, resulting from natural causes such as windblown dust as well as movement of vehicles, industries and construction activities. The ambient PM_{10} concentration in Al Ain during the study period at the two stations exceeded the 24-hr average EAD air quality standard of 150 $\mu g/m^3$ as shown in Fig.4.15. The total number of exceedances was recorded as 472 times at both stations, which represent 99.5% of the total number of exceedances for all pollutants. However, most of the 24-hr PM_{10} levels were below 200 $\mu g/m^3$. It was also observed that the PM_{10} peak occurred in May of each year. This is due to the wind speed which tends to be higher during this month. The strong wind speed can carry sand from Iran and Saudi Arabia to the eastern region of UAE and causes an increase in PM_{10} level in the atmosphere.

Carbon monoxide (CO) was only measured at Al Ain Street Station in the downtown area of Al Ain. It was noticed that the CO 1-hr average EAD air quality standard of 30mg/m^3 was exceeded once in 6/12/2008, as shown in Fig. 4.16. This is possibly not an actual reading of the ambient concentration but a reading of a calibration standard. The 8-hr CO levels were below the EAD air quality standard limits (Fig. 4.17). Additionally, most of the 1-hr CO levels are below 5 mg/m^3 while the average 8-hr concentration levels in most of the cases are below 4 mg/m^3.

For nitrogen dioxide (NO_2), there are two primary standards in EAD air quality standard limits. One is a 1-hr average of 400 µg/m^3 and another is a 24-hr average of 150ug/m^3. Figures 4.18-4.19 show that the NO_2 levels were below the EAD air quality standard limits for both the 1-hr and the 24-hr standards at the two stations. However, most of the 1-hr NO_2 levels are below 100 ug/m^3 while the average daily concentration levels in most of the cases are below 60 ug/m^3.

Finally, ozone (O_3) was recorded only at Al Ain School station (residential area). The EAD air quality standard sets 200µg/m^3 for a 1-hr average and 120µg/m^3 for an 8-hr average as the standard limits for O_3. Figure 4.20 shows that O_3 levels were below the 1-hr standard limit, while the 8-hr average standard limit was exceeded once in 8/5/2007 as shown in Fig. 4.21. Furthermore, both the 1-hr and 8-hr O_3 levels are below 100 µg/m^3 in most of the cases.

Table 4.13 summarizes the numbers of exceedances of the standard limits of each pollutant through the study period study at the two stations. Noticeably, PM_{10} is the pollutant of concern in the ambient air with higher exceedances in the downtown area as compared to the residential area.

Table 4.13: Total number of exceedances of each pollutant during 2007-2009

Pollutant	Average period	2007		2008		2009	
		Al Ain Street Station	Al Ain School Station	Al Ain Street Station	Al Ain School Station	Al Ain Street Station	Al Ain School Station
SO_2	1 hr	0	0	0	0	0	0
	24 hr	0	0	0	0	0	0
	1 yr	0	0	0	0	0	0
CO	1 hr	0	N/A	1	N/A	0	N/A
	8 hr	0	N/A	0	N/A	0	N/A
NO_2	1 hr	0	0	0	0	0	0
	24 hr	0	0	0	0	0	0
O_3	1 hr	N/A	0	N/A	0	N/A	0
	8 hr	N/A	1	N/A	0	N/A	0
PM_{10}	24 hr	93	39	114	67	95	64

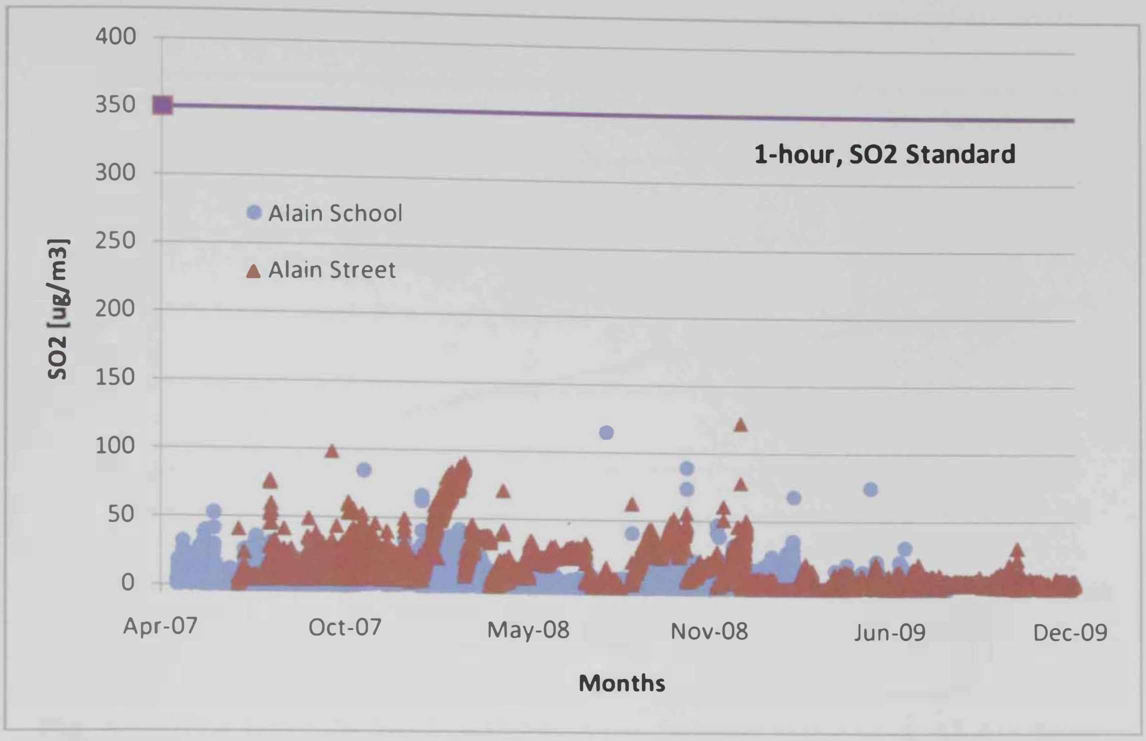

Fig. 4.12: The 1-hr SO_2 level in the two monitoring stations in Al Ain from April 2007 to August 2009

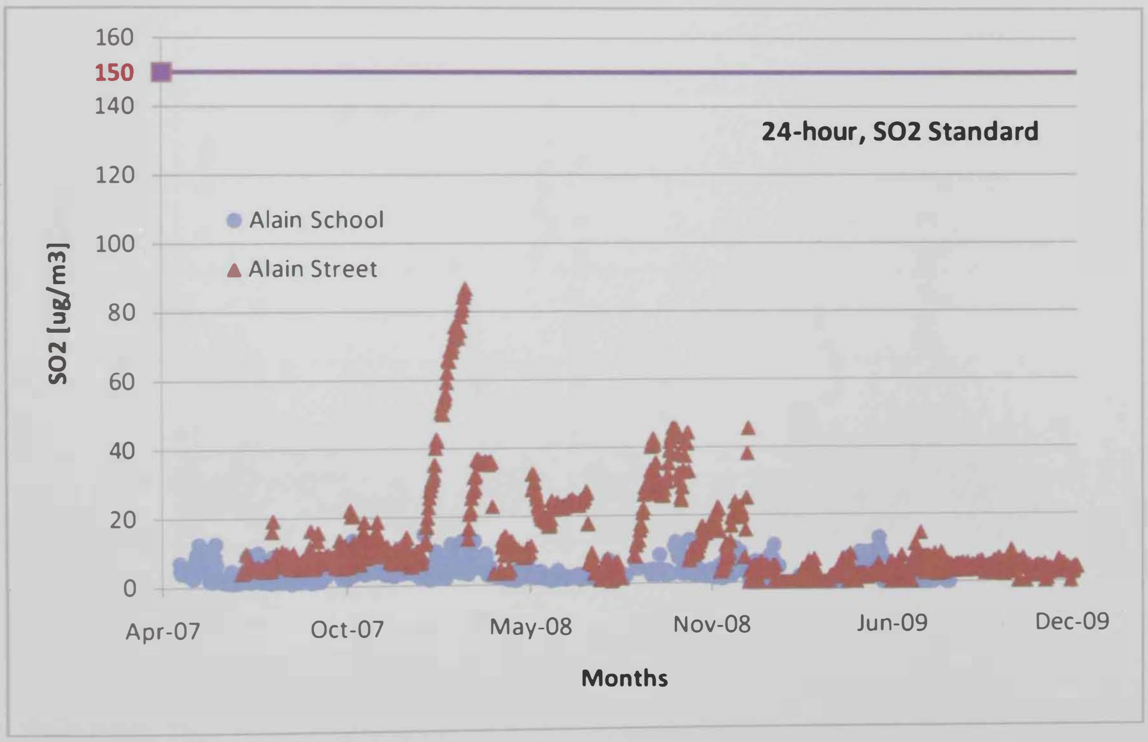

Fig. 4.13: The 24-hr SO_2 level in the two monitoring stations in Al Ain from April 2007 to August 2009

Fig. 4.14: The 1-yr SO_2 level in the two monitoring stations in Al Ain from April 2007 to August 2009

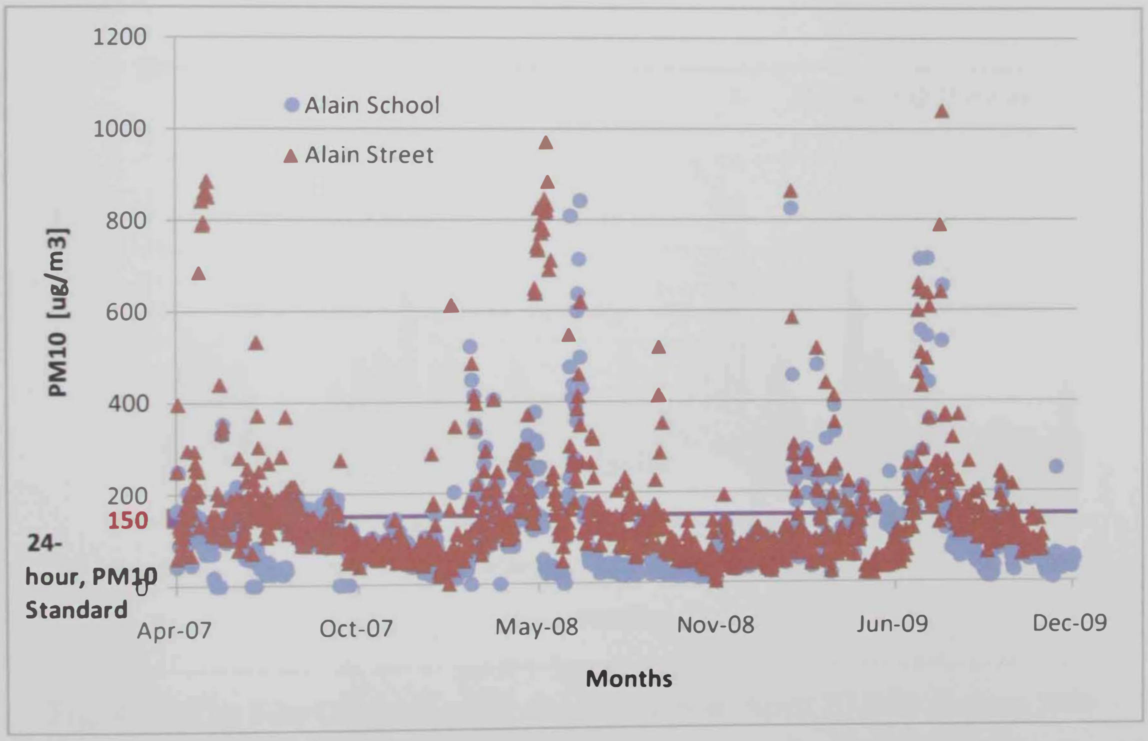

Fig. 4.15: The 24-hr PM_{10} level in the two monitoring stations in Al Ain from April 2007 to August 2009

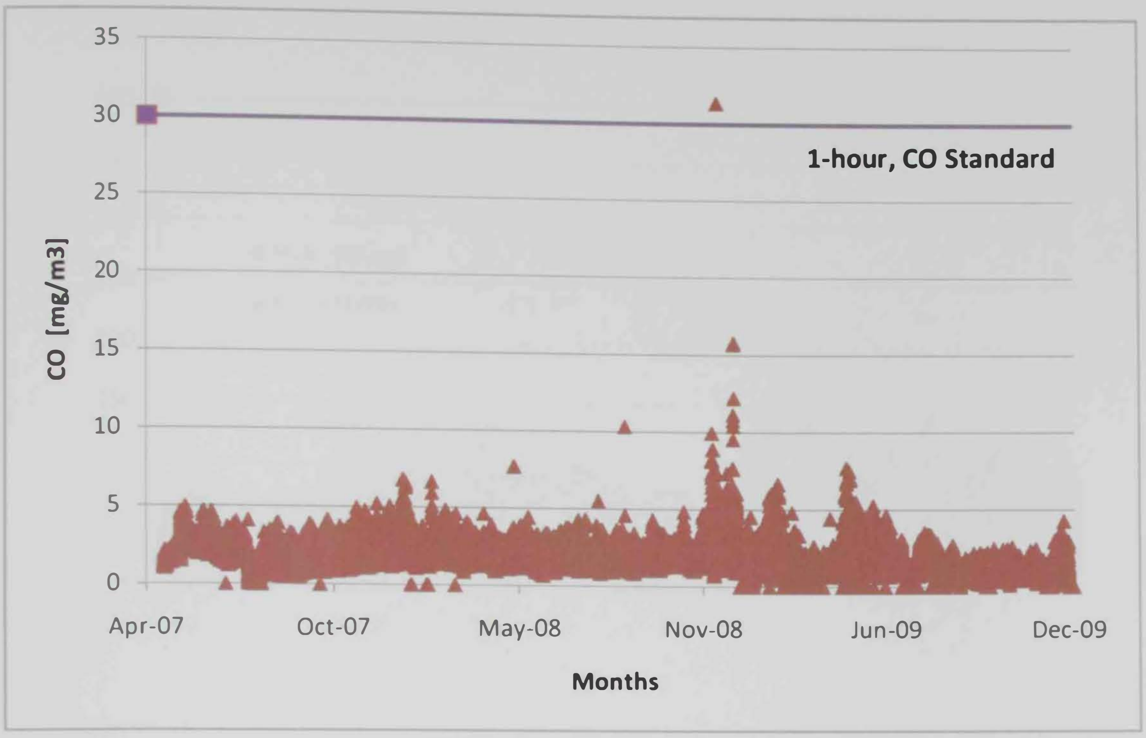

Fig. 4.16: The 1-hr CO level at Al Ain Street from April 2007 to August 2009

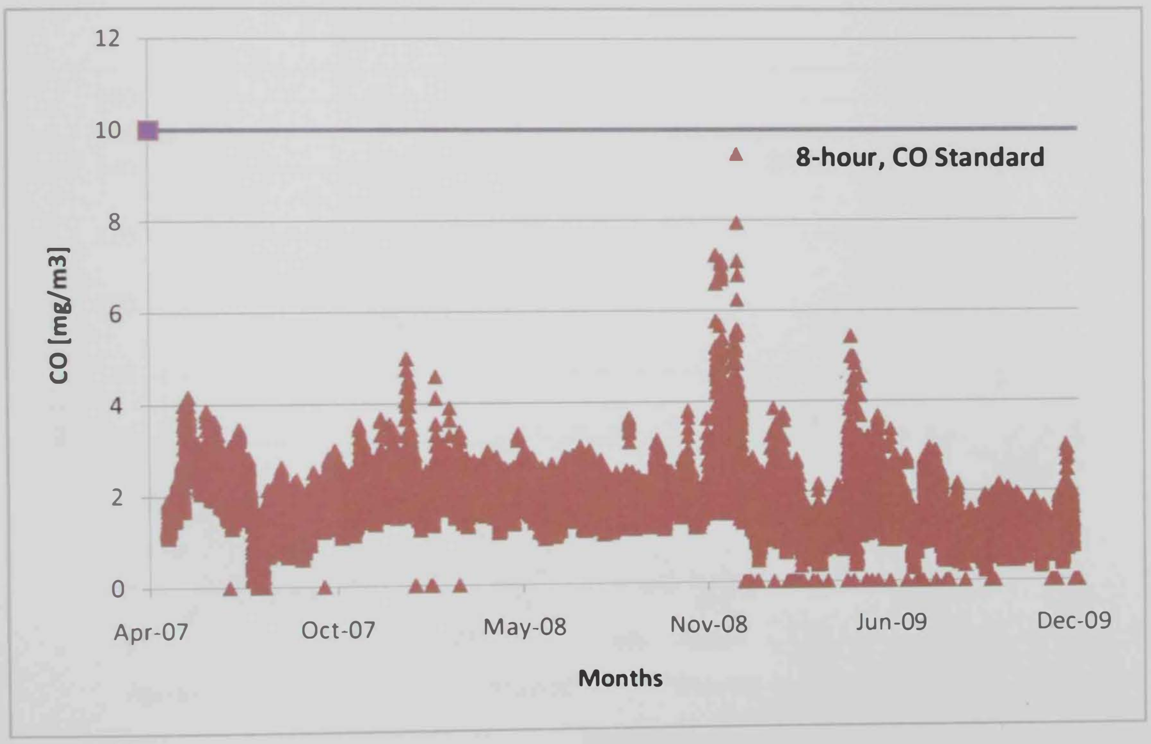

Fig. 4.17: The 8-hr CO level at Al Ain Street from April 2007 to August 2009

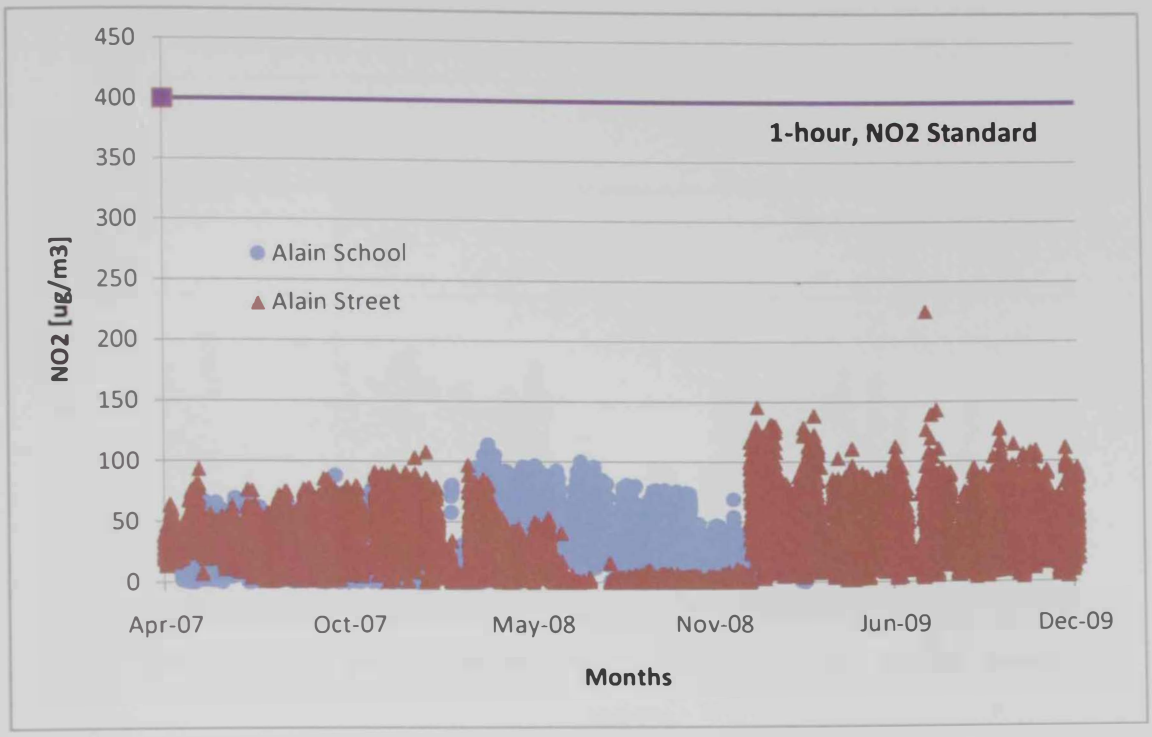

Fig. 4.18: The 1-hr NO_2 level in the two monitoring stations in Al Ain from April 2007 to August 2009

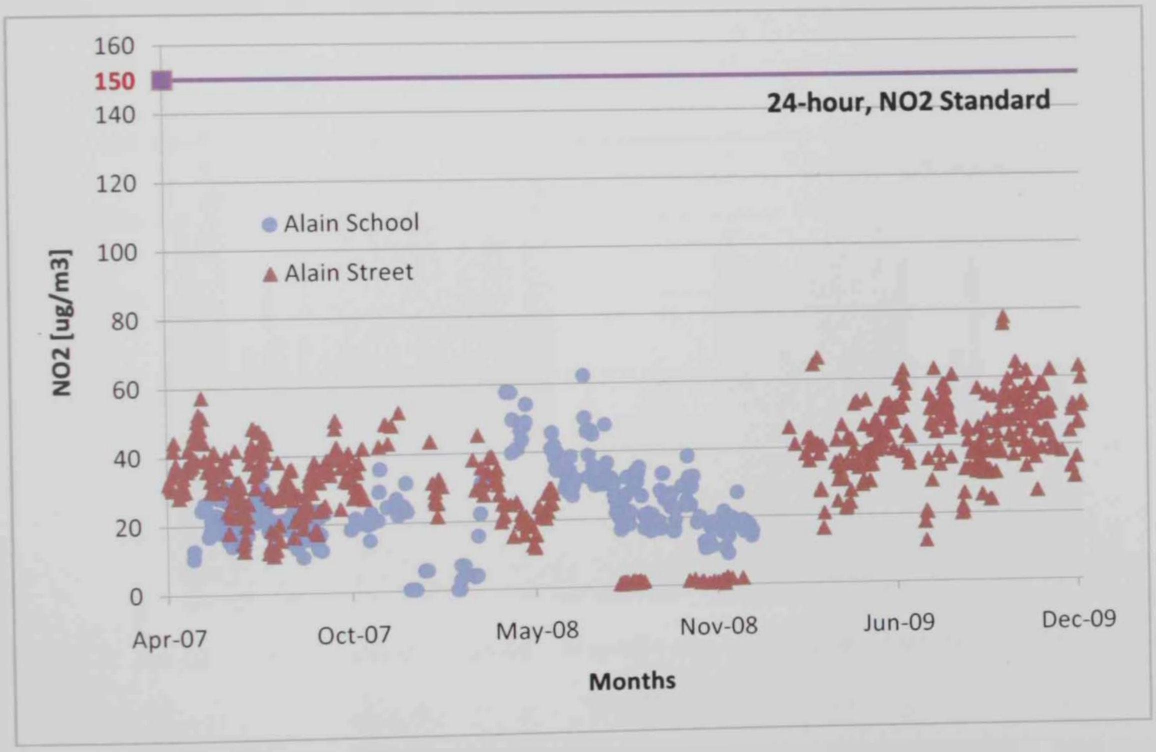

Fig. 4.19: The 24-hr NO_2 level in the two monitoring stations in Al Ain from April 2007 to August 2009

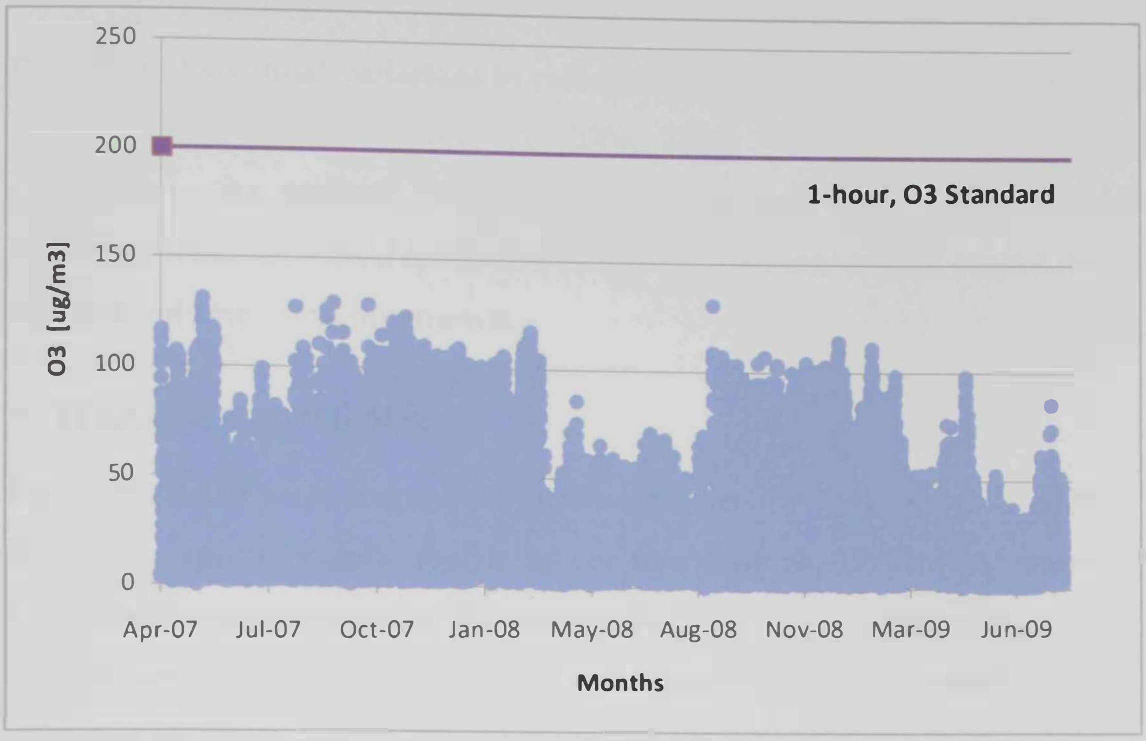

Fig. 4.20: The 1-hr O_3 level at Al Ain School from April 2007 to August 2009

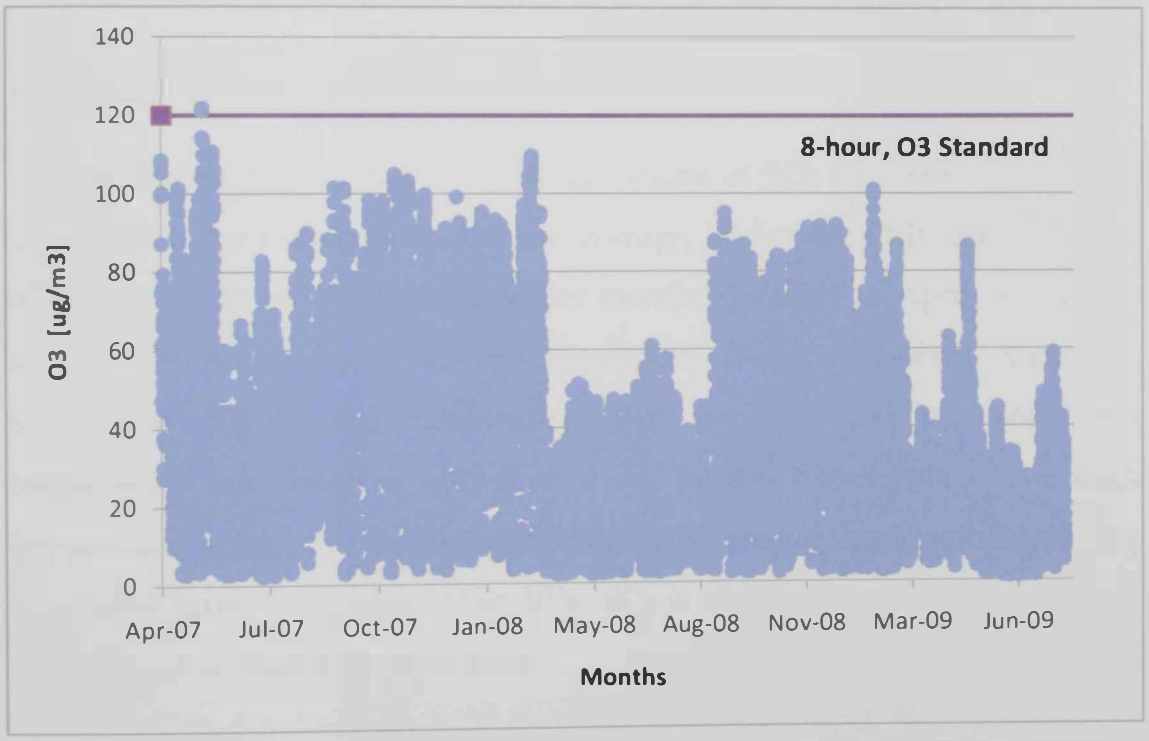

Fig. 4.21: The 8-hr O_3 level at Al Ain School from April 2007 to August 2009

4.3 Temporal changes in pollutant level

The effect of seasonal variations in pollutants concentration was investigated at the downtown site during 2007-2009. These seasonal variations were attributed to the different meteorological conditions such as temperature, humidity, wind direction/speed and sunshine intensity, as well as variations in traffic volume at the downtown.

A. Particulate matter (PM_{10})

Figures 4.22-4.23 show that the seasonal variations of PM_{10} levels during 2007-2009 were approximately similar at the two stations. The lowest seasonal PM_{10} levels were recorded in the winter season during the period November to February due to probably low wind speed and high humidity which enhances aggregation of small particles, which in turn helps in particulates deposition. However, the high PM_{10} levels were noticed during the summer months from May to August due to the higher wind speed that occurred between February and August as well as drier weather conditions.

B. Sulphur dioxide (SO_2)

Figures 4.24-4.25 show the seasonal variations of SO_2 concentration during 2007-2009 at the two stations. On the average, higher monthly concentration of SO_2 was detected during the winter months (January to April) and lower levels were noticed during the summer months (May-September). According to Wilson (1970), the relationship between SO_2 concentration with temperature and relative humidity is an inverse relationship. The high temperature accelerates the oxidation rates of SO_2 to sulphuric acid. However, at relative humidity greater than 30%, SO_2 is oxidized to SO_3, which reacts with vapour to form sulphuric acid.

C. Carbon monoxide (CO)

Figure 4.26 shows the seasonal variations of CO levels during 2007-2009 at Al Ain Street Station in the downtown. There was a marked increase in CO levels in the winter months (December and January) due probably to the inversion conditions as well as the cold start of vehicle engines. However, the lowest CO level was noticed in July and August due to reduction of traffic and other human activities as a result of summer vacations. On the other hand, the CO level approximately had a similar variation in the rest of the year. Another point of interest is that there is generally a slight drop in the CO level from 2008 to 2009. This is probably due to the construction activities at Khalifa Street roundabout in 2009, as the two streets were combined into one street and hence the traffic flow was decreased.

D. Nitrogen dioxide (NO_2)

Figures 4.27-4.28 show the seasonal variation of NO_2 concentration during 2007-2009 at the two stations. During summer months, NO_2 levels were higher compared with winter months, which mean that NO_2 levels depend on the variation in temperature and humidity. The higher intensity of sunshine in the summer period accelerates the oxidation of NO to NO_2, then NO_2 reacts with humidity (above 30% level) to form nitric acid (Wilson, 1970). However, humidity in winter can be more but the intensity of sunshine is very low which leads to an increase in the level of NO_2 in the atmosphere.

E. Ozone (O_3)

The seasonal variation of ozone is shown in Fig. 4.29. Lower levels of ozone were detected in the summer months compared with winter months. Despite the intensity of sunshine in summer, the low levels of VOCs and NO_x lead to a decrease in the level of ozone due to low traffic volume in the summer period.

F. Hydrocarbons (HCs)

Figures 4.30-4.35 show the seasonal variations of HCs concentrations during 2007-2009 at Al Ain downtown. The HCs (including benzene, ethylbenzene, mp-xylene, o-xylene, toluene, and methane) show similar seasonal trend, with higher concentrations in winter and lower ones in summer. This behavior was mainly caused by the variations of traffic volume during winter and summer periods. HCs also can be removed by particulate matter through dry and wet deposition as well as chemical removal by OH radicals during the summer period. According to Wathne (1983), HCs removal is faster in summer than winter as more sunlight and higher temperatures produce higher chemical removal reaction rate.

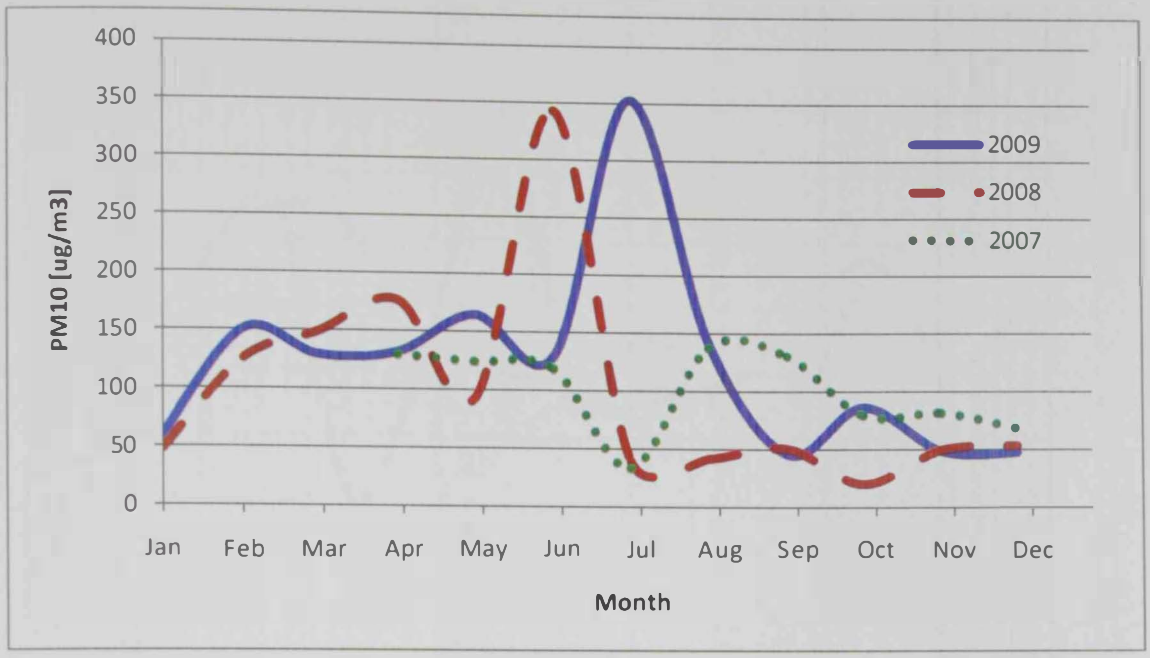

Fig. 4.22: Monthly average PM_{10} at Al Ain School during 2007-2009

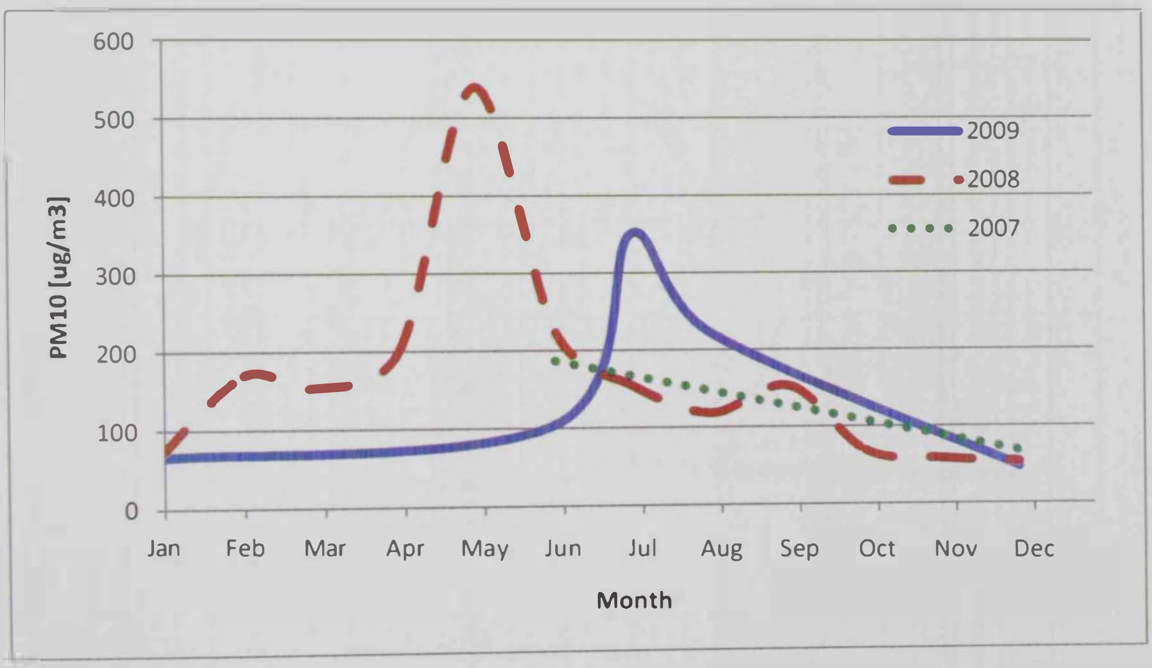

Fig. 4.23: Monthly average PM_{10} concentration at Al Ain Street during 2007-2009

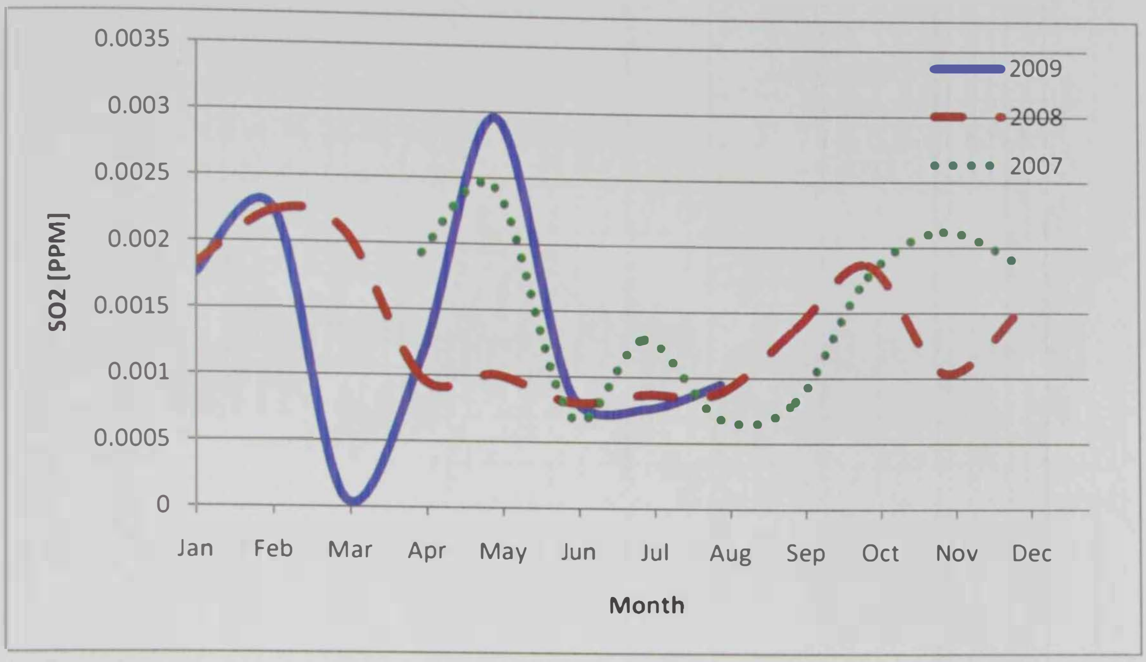

Fig. 4.24: Monthly average SO_2 concentration at Al Ain School during 2007-2009

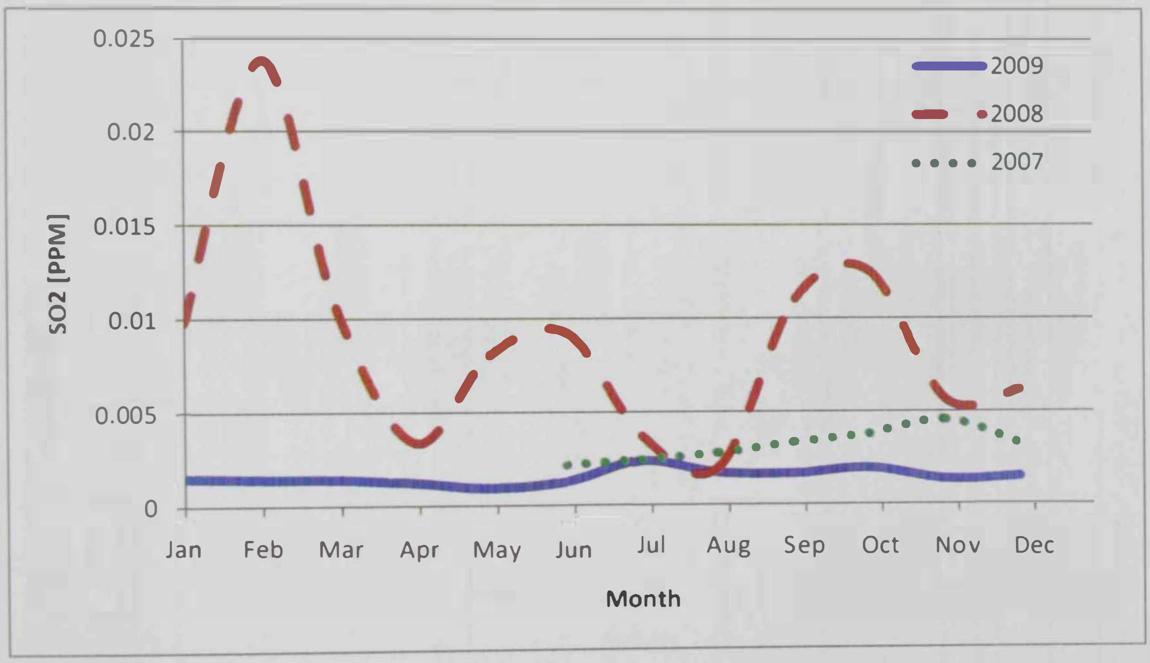

Fig. 4.25: Monthly average SO_2 concentration at Al Ain Street during 2007-2009

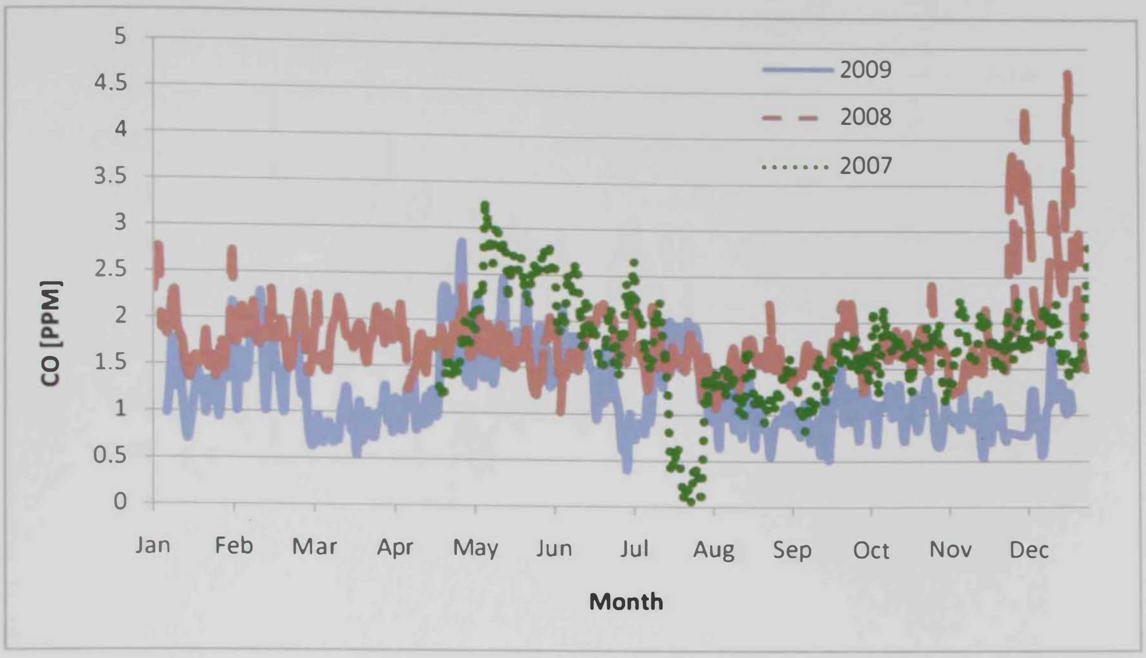

Fig. 4.26: Daily average CO concentration at Al Ain Street during 2007-2009

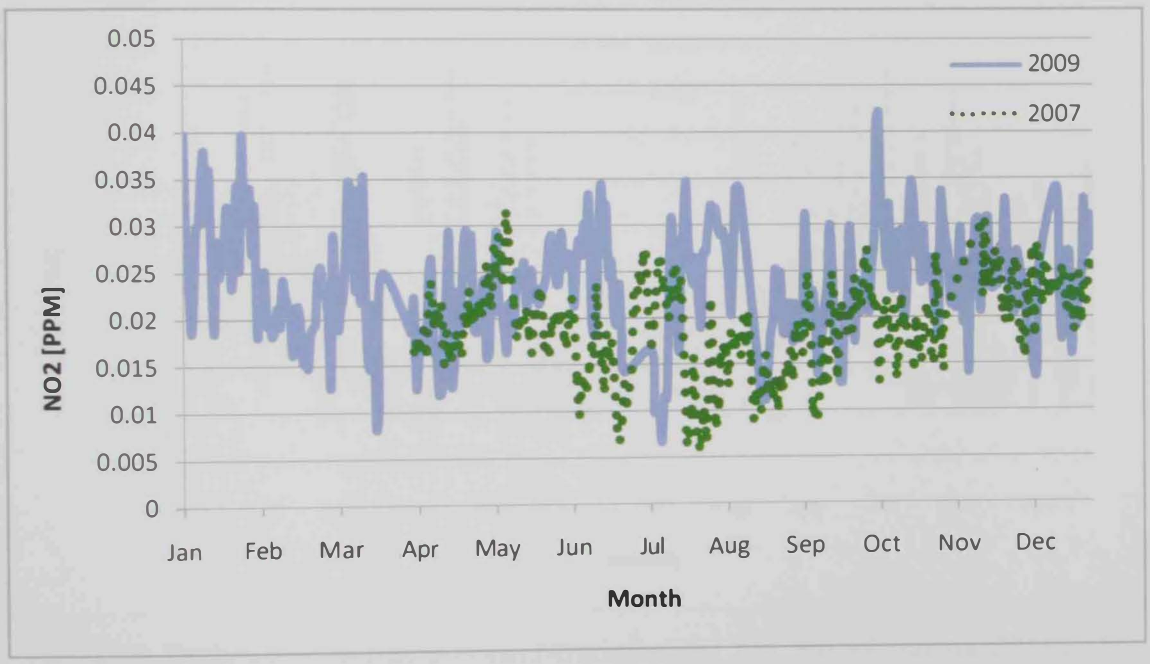

Fig. 4.27: Daily average NO_2 concentration at Al Ain Street during 2007-2009

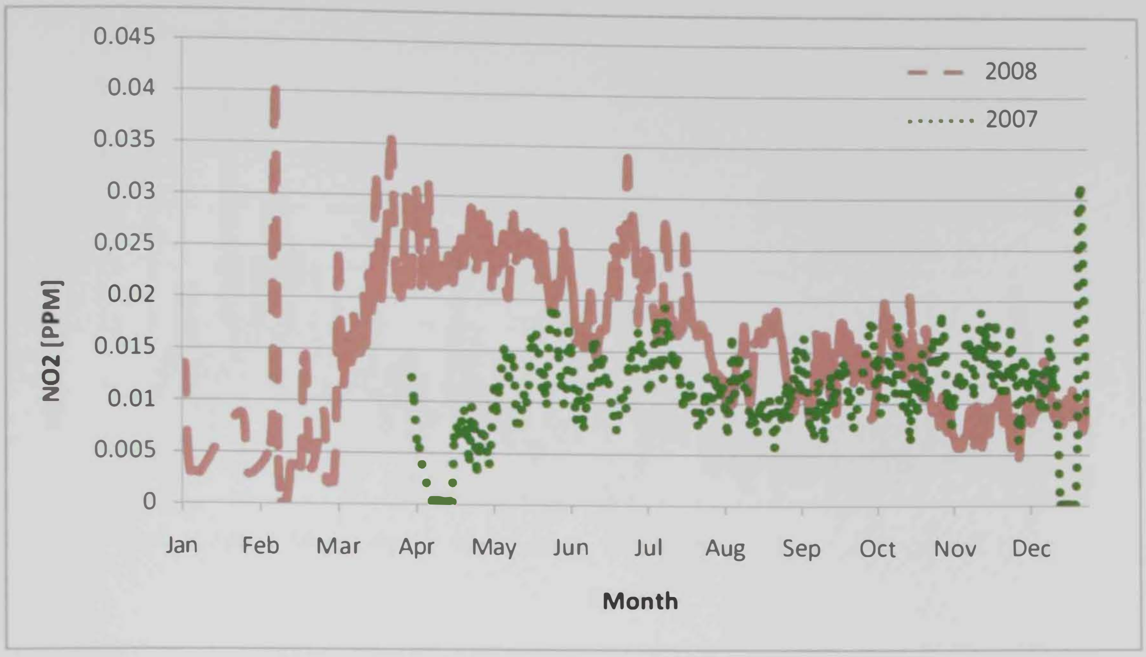

Fig. 4.28: Daily average NO_2 concentration at Al Ain School during 2007-2009

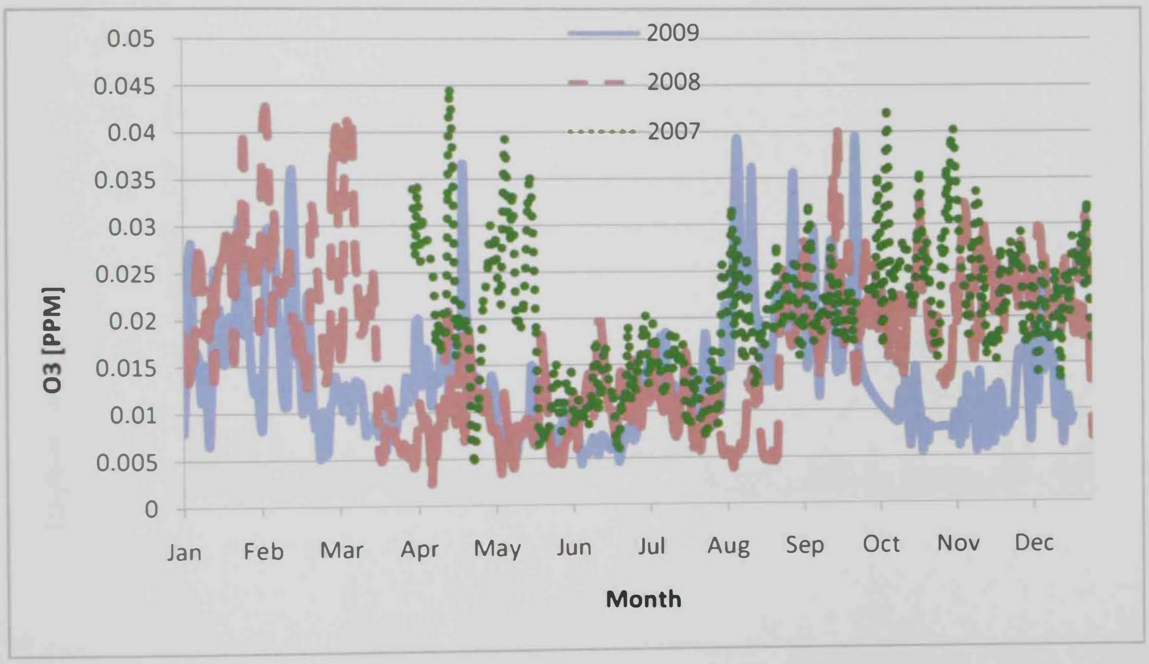

Fig. 4.29: Daily average ozone concentration at Al Ain School during 2007-2009

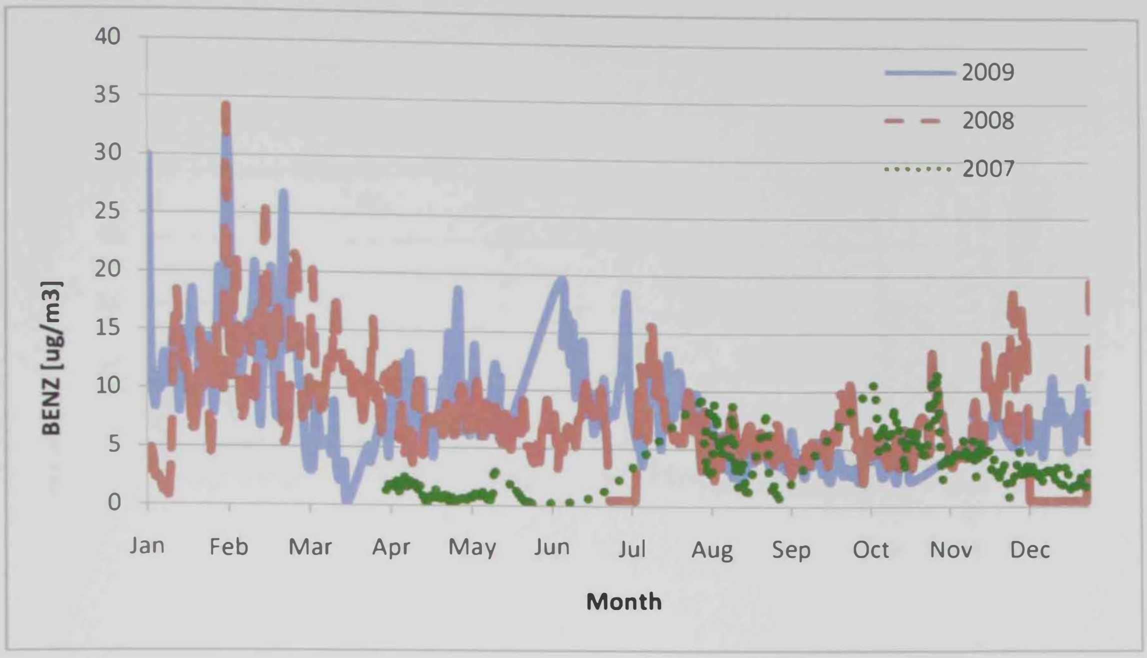

Fig. 4.30: Daily average benzene concentration at Al Ain Street during 2007-2009

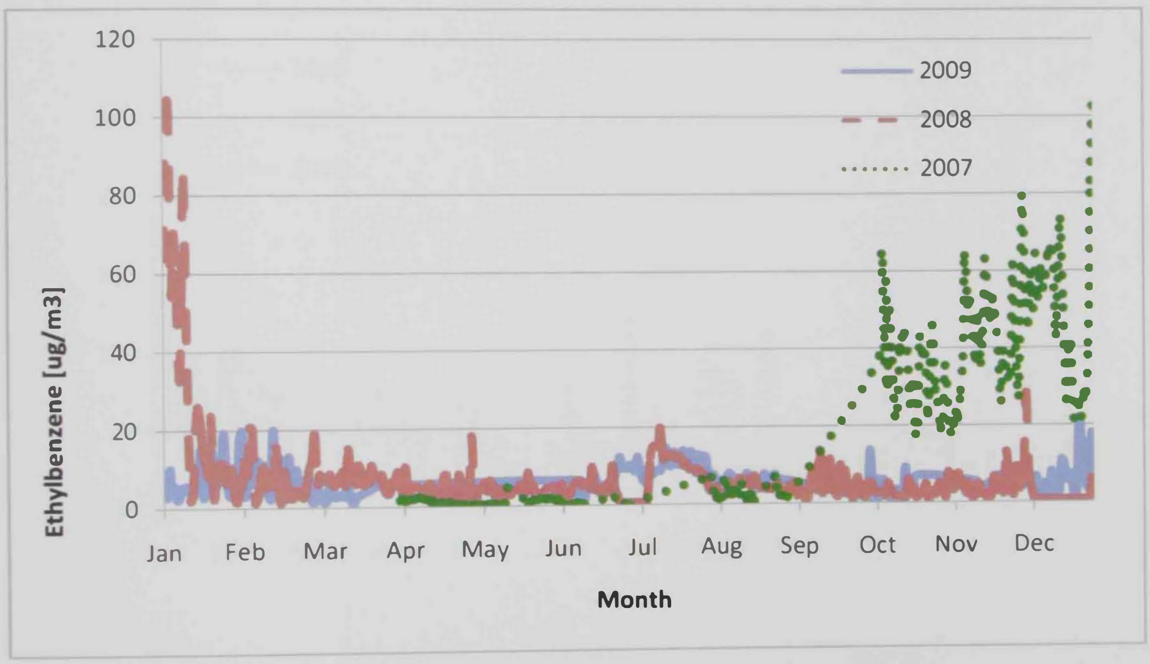

Fig. 4.31: Daily average ethylbenzene concentration at Al Ain Street during 2007-2009

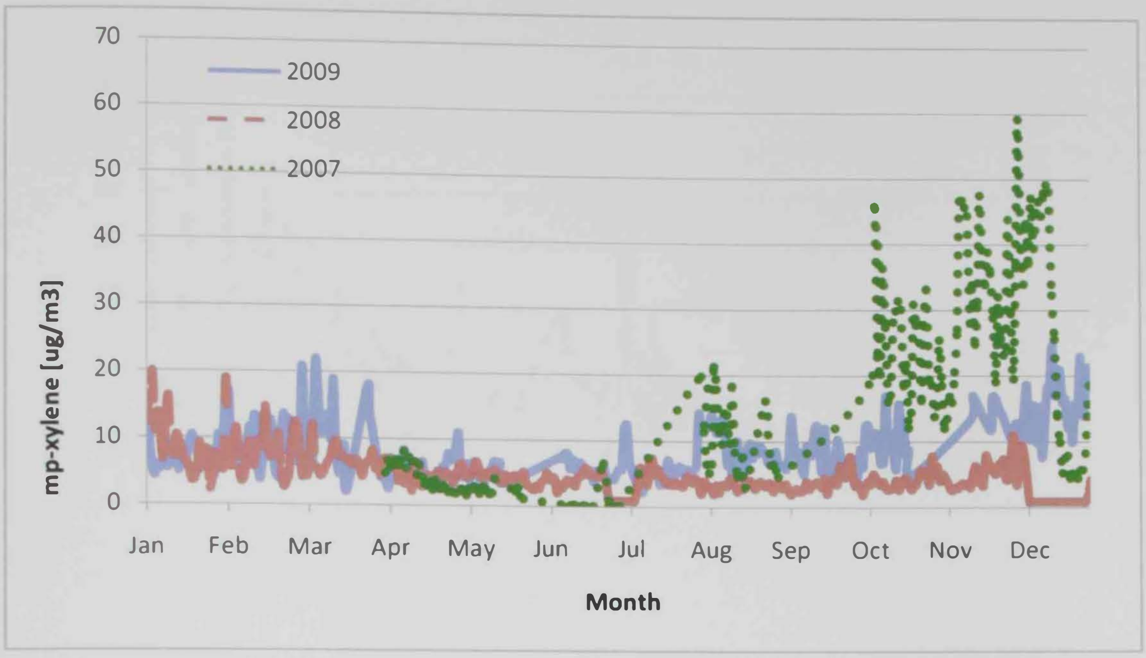

Fig. 4.32: Daily average mp-xylene concentration at Al Ain Street during 2007-2009

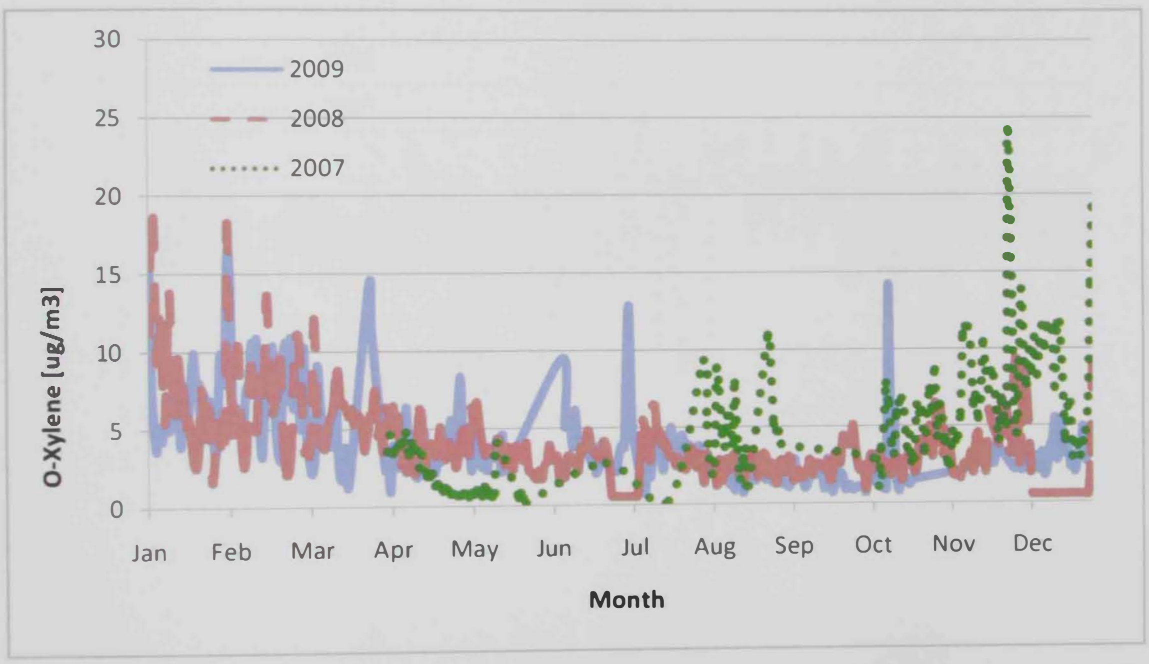

Fig. 4.33: Daily average o-xylene concentration at Al Ain Street during 2007-2009

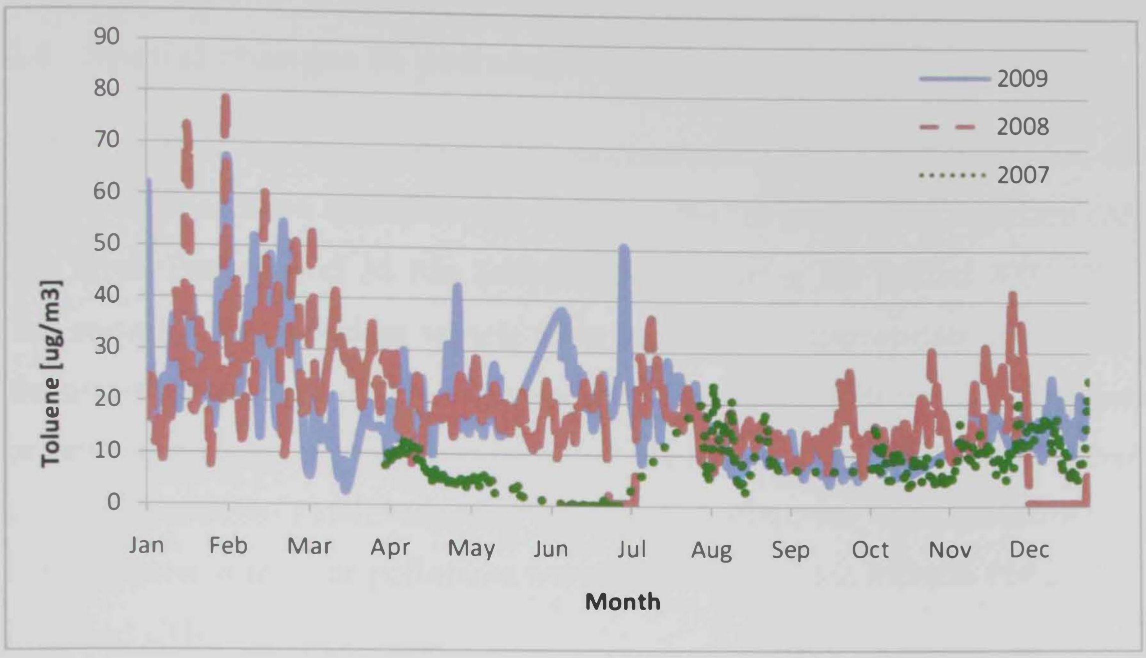

Fig. 4.34: Daily average toluene concentration at Al Ain Street during 2007-2009

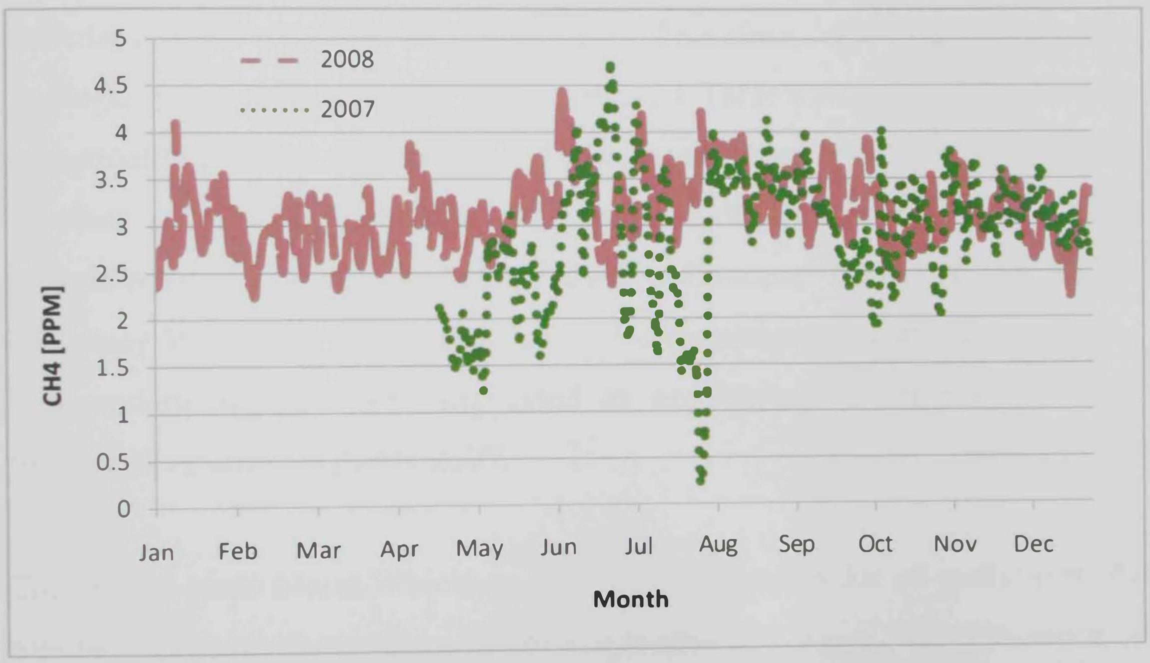

Fig. 4.35: Daily average methane concentration at Al Ain Street during 2007-2009

4.4 Spatial changes in pollutants level

In this section, the variations in the concentrations of air pollutants due to spatial changes were examined for the two different monitoring locations (Al Ain Street Station and Al Ain School Station) during the period 2007-2009. The statistical independent sample t-test technique is appropriate to analyze the mean comparison of two independent locations for determining whether or not the pollutants concentration levels are significantly different between the two locations. However, since not all the pollutants were measured at both stations, only four pollutants were examined, which include PM_{10}, SO_2, NO_2 and CH_4.

The assumptions underlying the independent sample t-test are the normal distribution and equal variance on the dependent variable, which is the pollutant concentration in this case. Therefore, the normality and homogeneity of variance need to be examined. Table 4.14 shows that the tests of normality and test of homogeneity of variance failed for all pollutants since p-values of all pollutants are less than 0.05. Therefore, the independent sample t-test is not appropriate for these pollutants. However, the Mann-Whintney-Wilcoxon test procedure (Nonparametric test) in the two independent samples was suggested as an alternative for the t-test for independent samples (SPSS, 2005).

Tables 4.15 gives Mann-Whintney-Wilcoxon test results for all pollutants. As can be seen from these tables, there is a statistically significant difference in pollutants levels between Al Ain School Station at the residential area and Al Ain Street Station at the downtown area (the significance p-values < 0.05).

Figures 4.36-4.39 show the box plot comparison for the four pollutants levels at the two stations during 2007-2009. It was found that Al Ain Street has a higher pollutant levels than Al Ain School Station. The higher pollutants levels at Al Ain Street Station are attributed to the influence of road traffic volume and populations intensity compared to Al Ain School Station area.

Table 4.14: Tests of normality, homogeneity for all pollutants

Pollutant	Station	Test of Normality (Kolmogorov-Smimov)		Test of homogeneity of variance (Levene)	
		Statistic	p-value	Statistic	p-value
PM_{10}	Al Ain School	0.201	0.000	667	0.000
	Al Ain Street	0.217	0.000		
SO_2	Al Ain School	0.180	0.000	9730	0.000
	Al Ain Street	0.214	0.000		
NO_2	Al Ain School	0.078	0.000	834	0.000
	Al Ain Street	0.091	0.000		
CH_4	Al Ain School	0.248	0.000	32051	0.000
	Al Ain Street	0.093	0.000		

Table 4.15: Mann-Whitney test for all pollutants

Pollutant	Mann-Whitney test	
	Statistic	p-value
PM_{10}	-55.116	0.000
SO_2	-120.398	0.000
NO_2	-18.102	0.000
CH_4	-97.728	0.000

Table 4.16: Descriptive statistics of PM_{10} levels at the two stations during 2007-2009

Descriptives

PM10, ug/m3

	N	Mean	Std. Deviation	Std. Error	Minimum	Maximum
Alain School	21097	104.3299	116.59748	.80275	2.61	1026.64
Alain Street	22894	157.0975	169.59721	1.12088	1.12	1725.88
Total	43991	131.7914	148.94087	.71012	1.12	1725.88

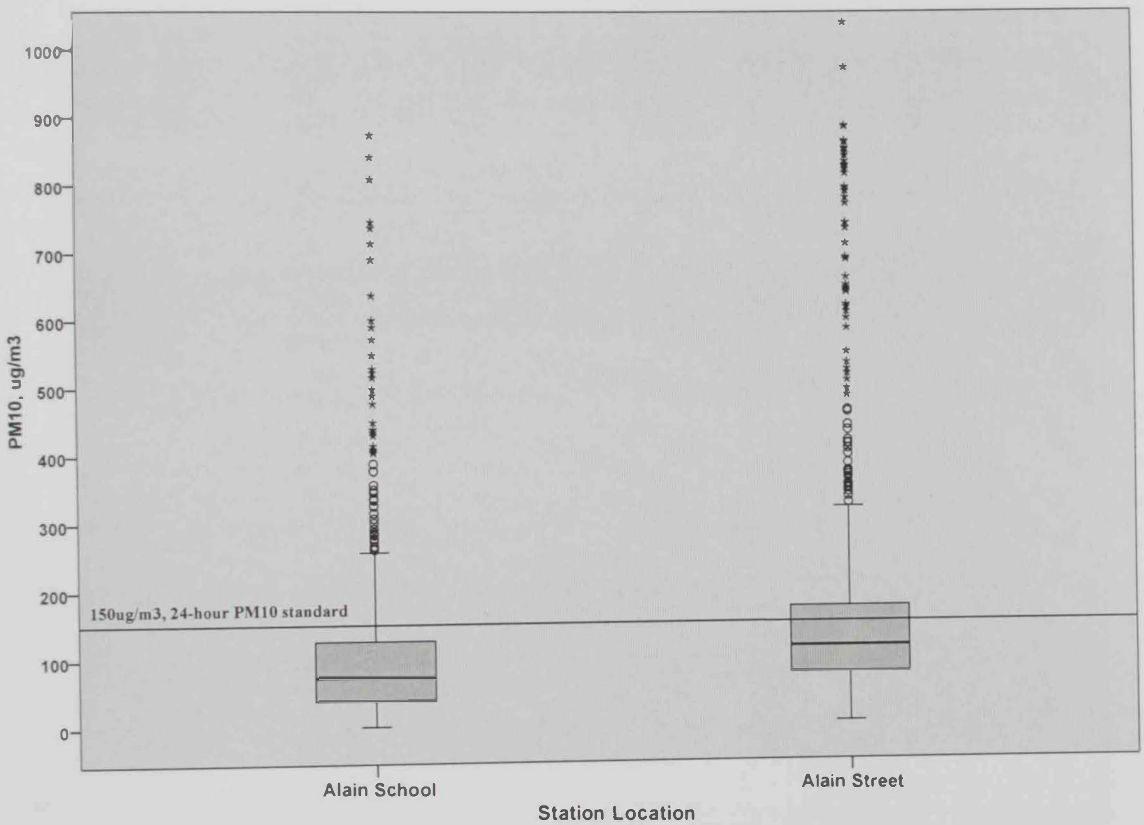

Fig. 4.36: Box plot comparison for 24-hr PM_{10} levels at the two stations during 2007-2009

Table 4.17: Descriptive statistics of SO_2 levels at the two stations during 2007-2009

Descriptives

SO2, ppb

	N	Mean	Std. Deviation	Std. Error	Minimum	Maximum
Alain School	17921	1.4712	1.57654	.01178	.01	46.40
Alain Street	18219	8.5861	10.81646	.08014	.01	77.56
Total	36140	5.0580	8.53617	.04490	.01	77.56

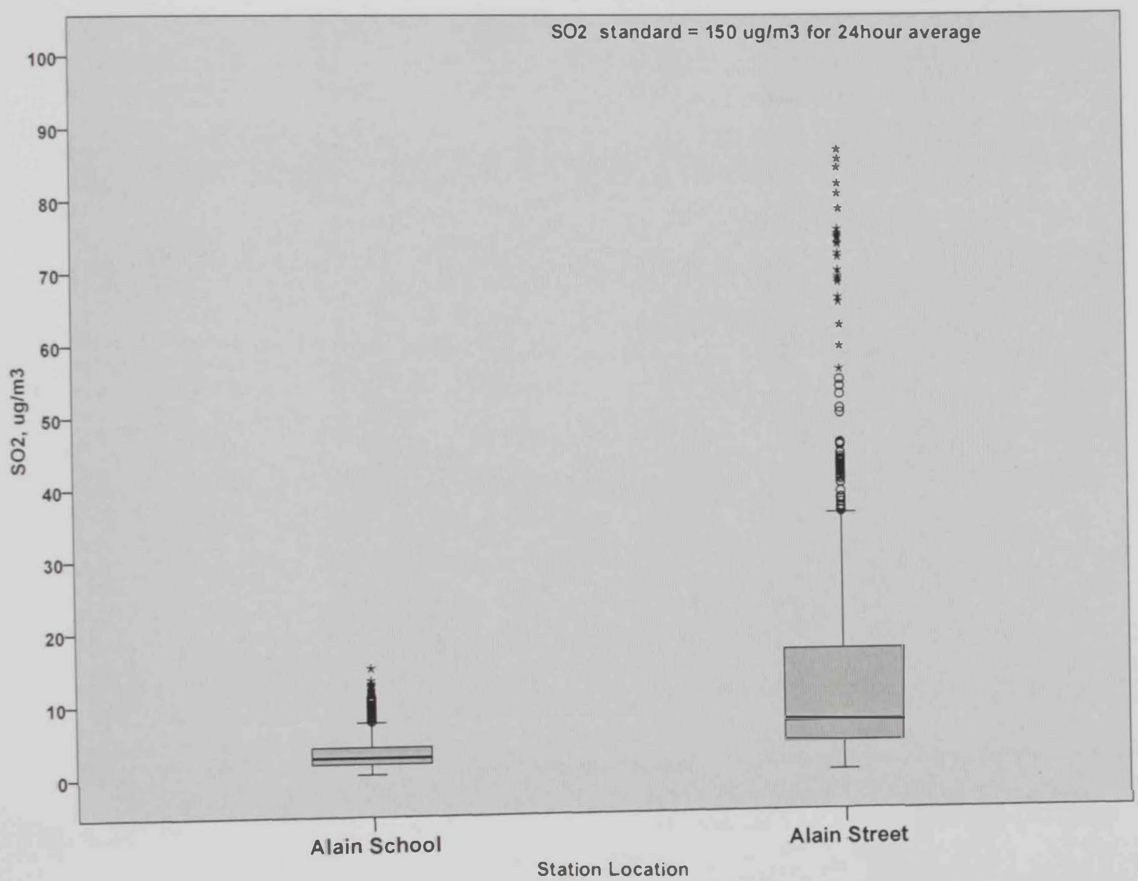

Fig. 4.37: Box plot comparison for 24-hr SO_2 levels at the two stations during 2007-2009

Table 4.18: Descriptive statistics of NO_2 levels at the two stations during 2007-2009

Descriptives

NO2, ug/m3

	N	Mean	Std. Deviation	Std. Error	Minimum	Maximum
Alain School	12943	25.7790	18.11026	.15919	.08	114.33
Alain Street	19489	30.7869	23.01517	.16486	.02	224.80
Total	32432	28.7883	21.33538	.11847	.02	224.80

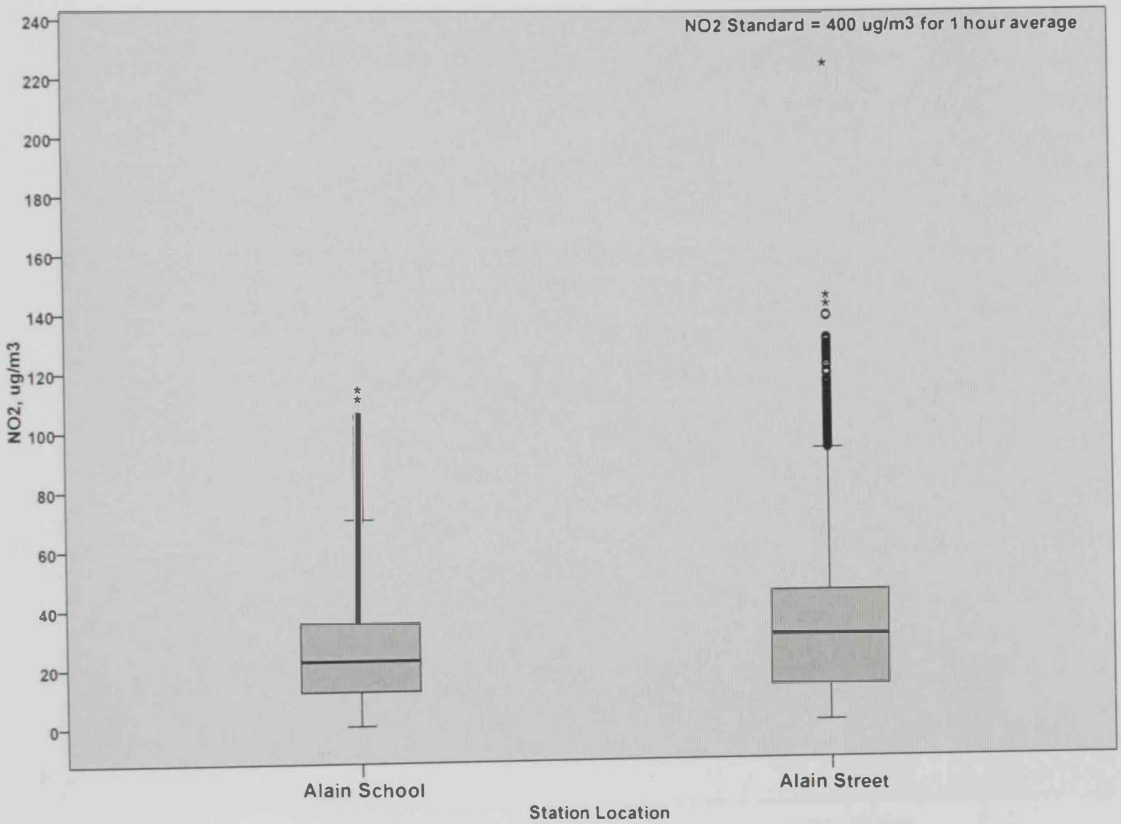

Fig. 4.38: Box plot comparison for 1-hr NO_2 levels at the two stations during 2007-2009

Table 4.19: Descriptive statistics of CH_4 levels at the two stations during 2007-2009

Descriptives

CH4, ppm

	N	Mean	Std. Deviation	Std. Error	Minimum	Maximum
Alain School	13931	1.4136	.40385	.00342	.01	4.57
Alain Street	18122	2.6643	1.01325	.00753	.01	7.70
Total	32053	2.1207	1.01769	.00568	.01	7.70

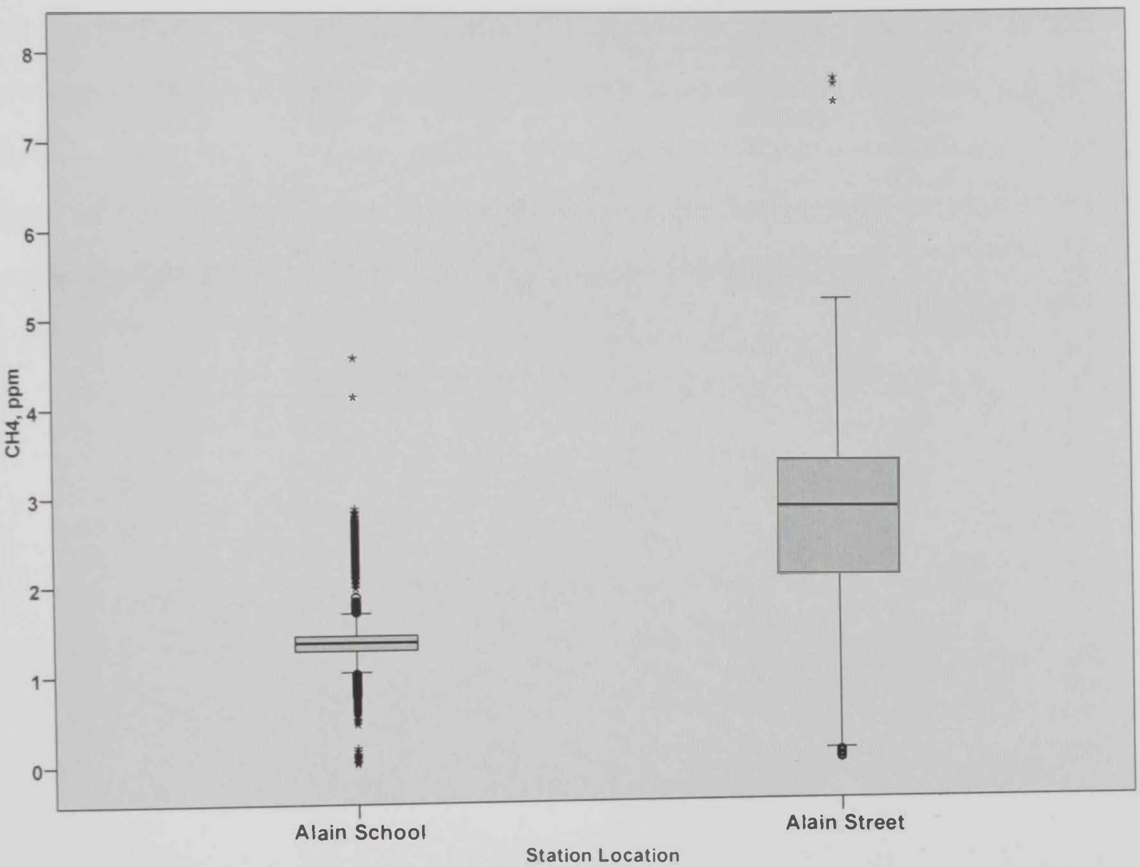

Fig. 4.39: Box plot comparison for 24-hr CH_4 levels at the two stations during 2007-2009

4.5 Air quality index

The air quality index (AQI) is a very useful parameter, developed by the US EPA to characterize the quality of the air at a given location. It is also known as the air pollution index (API) or pollutant standard index (PSI). The AQI integrates air quality data for the five criteria pollutants (CO, O_3, PM_{10}, SO_2 and NO_2) into a single number that represents the worst daily air quality in an urban area. That means if the concentration of any one of the five criteria pollutants rises to the level of its air quality standard at any location, the air quality in that area is considered "unhealthy" for that particular day, even though the concentrations of the other four criteria pollutants may be below their corresponding standard limits. On the other hand, lead (Pb) is not included in the AQI since it does not have a short term limits in the US NAAQS. Descriptive terms ranging from good to hazardous are given to ranges of the AQI values as shown in Table 4.20. As the AQI increases, the adverse human health effects are also increased (Masters, 1997).

Table 4.20: AQI values, descriptors, and associated health effects (EPA, 2009).

AQI Levels of Health Concern	Numerical Value	Meaning
Good	0 to 50	Air quality is considered satisfactory, and air pollution poses little or no risk
Moderate	51 to 100	Air quality is acceptable; however, for some pollutants there may be a moderate health concern for a very small number of people who are unusually sensitive to air pollution.
Unhealthy for Sensitive Groups	101 to 150	Members of sensitive groups may experience health effects. The general public is not likely to be affected.
Unhealthy	151 to 200	Everyone may begin to experience health effects; members of sensitive groups may experience more serious health effects.
Very Unhealthy	201 to 300	Health alert: everyone may experience more serious health effects
Hazardous	301 to 500	Health warnings of emergency conditions. The entire population is more likely to be affected.

According to Masters (1997), there are some limitations of the use of the AQI. The AQI does not take into consideration the damage air pollution that may cause to animals, vegetation and materials as it is only based on human health. It also does not take into account the possibility of interaction effects between the pollutants. For instance, the combination of SO_2 and particulates is considered to be much more damaging to health than the sum of the individual effects. Furthermore, Peavy et al. (1985) mentioned that the AQI of a given area can be affected by data inaccuracies due to mis-calibration as well as other variables such as topography, tall buildings, and micrometeorology.

In the Abu Dhabi Emirate, the EAD calculates the AQI according to the US EPA AQI standard. The AQI of a day can be calculated based on air quality standard breakpoints which are shown in Table 4.21. This table shows the AQI numbers corresponding to various pollutant concentrations. Linear interpolation between breakpoints may be used to compute the AQI "sub index" for each pollutant. Note that the highest AQI sub-index decides the overall air quality level on that day.

In this study, the air pollutants concentrations from the two fixed stations in Al Ain were used to compute the AQI. The AQI for every hour for each pollutant at the two stations was calculated daily based on AQI breakpoints (Table 4.21). On the other hand, the air pollutants data collected from the two fixed stations had inconsistency in their format. Some of these pollutants are expressed in $\mu g/m^3$ whereas others are in ppm or ppb. Therefore, the values were converted to the appropriate unit so that the pollutant sub-index can be determined. The conversion factors were 1 ppm = 0.001 ppb; 1 ppm of CO=0.87 mg/m^3; 1 ppb of SO_2 = 0.38 $\mu g/m^3$; 1 ppb of NO_2 = 0.53 $\mu g/m^3$; and 1 ppb of O_3= 0.51 $\mu g/m^3$.

Table 4.21: Breakpoints for the AQI (US EPA, 2009)

O_3 (ppm) 8-hr	O_3 (ppm) [1-hr]	PM10 (μg/m³) [24-hr]	$PM_{2.5}$ (μg/m³) [24-hr]	CO (ppm) [8-hr]	SO_2 (ppm) [24-hr]	NO_2 (ppm) [1-hr]	AQI	AQI category
0.000 - 0.059	-	0 - 54	0.0 - 15.4	0.0 - 4.4	0.000 - 0.034	(2)	0 - 50	Good
0.060 - 0.075	-	55 - 154	15.5 -40.4	4.5 - 9.4	0.035 - 0.144	(2)	51 - 100	Moderate
0.076 - 0.095	0.125 - 0.164	155 - 254	40.5 - 65.4	9.5 - 12.4	0.145 -0.224	(2)	101 - 150	Unhealthy for Sensitive Groups
0.096 - 0.115	0.165 - 0.204	255 - 354	65.5 - 150.4	12.5 - 15.4	0.225 - 0.304	(2)	151 - 200	Unhealthy
0.116 - 0.374 (0.155 - 0.404)[4]	0.205 - 0.404	355 - 424	150.5 - 250.4	15.5 - 30.4	0.305 - 0.604	0.65 - 1.24	201 - 300	Very unhealthy
(3)	0.405 - 0.504	425 - 504	250.5 - 350.4	30.5 - 40.4	0.605 - 0.804	1.25 - 1.64	301 - 400	Hazardous
(3)	0.505 - 0.604	505 - 604	350.5 - 500.4	40.5 - 50.4	0.805 - 1.004	1.65 - 2.04	401 - 500	Hazardous

1 Areas are required to report the AQI based on 8-hr ozone values. However, there are areas where an AQI based on 1-hr ozone values would be more protective. In these cases the index for both the 8-hr and the 1-hr ozone values may be calculated and the maximum AQI reported.

2 NO2 has no short-term NAAQS and can generate an AQI only above a value of 200.

3 8-hr O3 values do not define higher AQI values (≥ 301). AQI values of 301 or higher are calculated with 1-hr O3 concentrations.

4 The numbers in parentheses are associated 1-hr values to be used in this overlapping category only.

Tables 4.22-4.27 show the summary of AQI values including the average, minimum and maximum values for the years 2007-2009 in Al Ain. The results show that air quality varies from "good" in winter months (November to February) to "unhealthy" in pre-summer months (March to May). Conversely, the air quality improves ("good" to "moderate") during the transition from summer to winter periods (Fig. 4.40-4.45). The PM_{10}, however, was identified as the dominant pollutant in the index value more than 98% of the time at most locations.

At Al Ain Residential area (Al Ain School Station)

The air quality was considered "good" 18%, 56% and 27% of the time, "moderate" 68%, 26% and 51% of the time, "Unhealthy for sensitive groups" 13%, 9% and 14% of the time and "unhealthy" 1%, 3% and 3% of the time, during 2007-2009, respectively. However, the air quality was considered as "very unhealthy" 0%, 2% and 1% of the time, and "hazardous" 0%, 3% and 4% of the time, during 2007-2009, respectively. Also, the annual average AQI values were 72, 70 and 89 showing that the air quality was "moderate" most of the time during 2007-2009, respectively. All the AQI values exceeded the 50 value (good level) due to PM10 level. However, the AQI values of SO_2, NO_2 and O_3 were very small compared to AQI values of PM_{10} at Al Ain School Station as a result of low traffic volume and little commercial activities nearby.

At Al Ain Downtown area (Al Ain Street Station)

The air quality was considered "good" 5%, 17% and 14% of the time, "moderate" 64%, 54% and 55% of the time, " unhealthy for sensitive groups" 21%, 14% and 18% of the time, "unhealthy" 5%, 6% and 5% of the time, during 2007-2009, respectively. However, the air quality was considered as "very unhealthy" 1%, 2% and 2% of the time, and "hazardous" 4%, 7% and 5% of the time, during 2007-2009, respectively. Also, the annual average AQI value was 116, 112 and 100 showing that the air quality was "moderate" most of the time, during 2007-2009, respectively. On the other hand, all the AQI values exceeded the 50 value (good level) due to PM_{10} level.

In general, the assessment of air quality during 2007-2009 at the two stations in Al Ain indicates that 52% of the calculated average AQI values are categorized as ''moderate'' and 24% as ''good", 15% " unhealthy for sensitive groups", 4% "unhealthy", 1% "very unhealthy" and 4% "hazardous". However, the Al Ain residential area had better air quality than Al Ain downtown area, since most of the 82% of AQI values at Al Ain School Station were concentrated between good to moderate levels, and 18% of AQI values distributed within unhealthy to hazardous levels, while at Al Ain Street Station, 70% of the AQI values were between good and moderate, and 30% of the AQI values distributed within unhealthy to hazardous levels. On the other hand, it was noticed that air was much more polluted in pre-summer and summer months than in other seasons. Also, the critical pollutant affecting the AQI was PM_{10} at the two locations in Al Ain.

Table 4.22: Number of days of each AQI category based on data from Al Ain School Station in 2007

Month	0-50 Good	51-100 Moderate	101-150 Unhealthy for Sensitive Groups	151-200 Unhealthy	201-300 Very Unhealthy	>300 Hazardous	AQI Range	AQI Average
January	-	-	-	-	-	-	-	-
February	-	-	-	-	-	-	-	-
March	-	-	-	-	-	-	-	-
April	2	18	6	1	-	-	38-165	89
May	2	18	3	2	-	-	6-200	85
June	1	19	7	-	-	-	48-132	76
July	29	2	-	-	-	-	21-51	31
August	-	21	10	-	-	-	55-121	92
September	-	19	7	-	-	-	64-123	89
October	1	27	-	-	-	-	40-82	63
November	2	28	-	-	-	-	44-95	64
December	9	22	-	-	-	-	23-81	56
Σ	46	174	33	3	-	-	6-200	72
%	18%	68%	13%	1%	0%	0%		

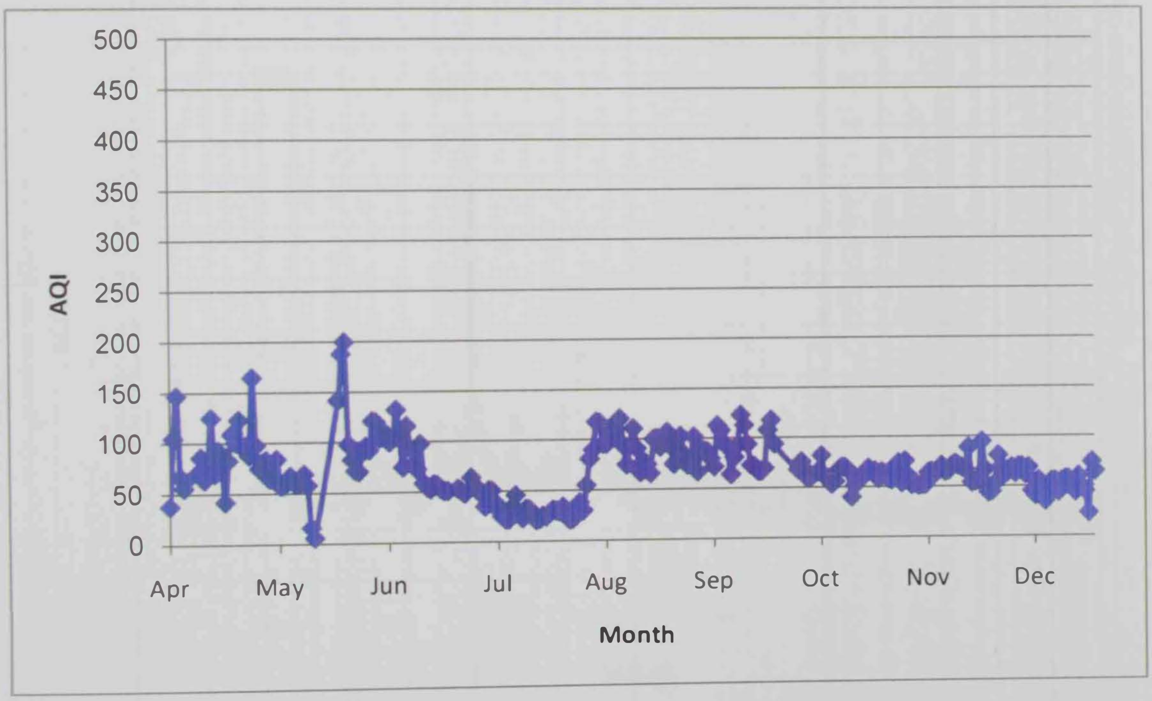

Fig. 4.40: AQI based on Al Ain School Station data in 2007

Table 4.23: Number of days of each AQI category based on data from Al Ain Street Station in 2007

Month	0-50 Good	51-100 Moderate	101-150 Unhealthy for Sensitive Groups	151-200 Unhealthy	201-300 Very Unhealthy	>300 Hazardous	Range	Average
January	-	-	-	-	-	-	-	-
February	-	-	-	-	-	-	-	-
March	-	-	-	-	-	-	-	-
April	-	11	11	4	1	3	56-500	154
May	-	16	4	3	-	8	68-500	202
June	-	11	14	3	1	1	58-428	122
July	-	11	17	2	1	-	76-221	113
August	-	23	8	-	-	-	66-132	92
September	-	25	4	1	-	-	65-160	86
October	2	29	-	-	-	-	35-85	65
November	4	26	-	-	-	-	44-93	61
December	7	23	-	-	-	-	36-80	57
Σ	13	175	58	13	3	12	44-500	116
%	5%	64%	21%	5%	1%	4%		

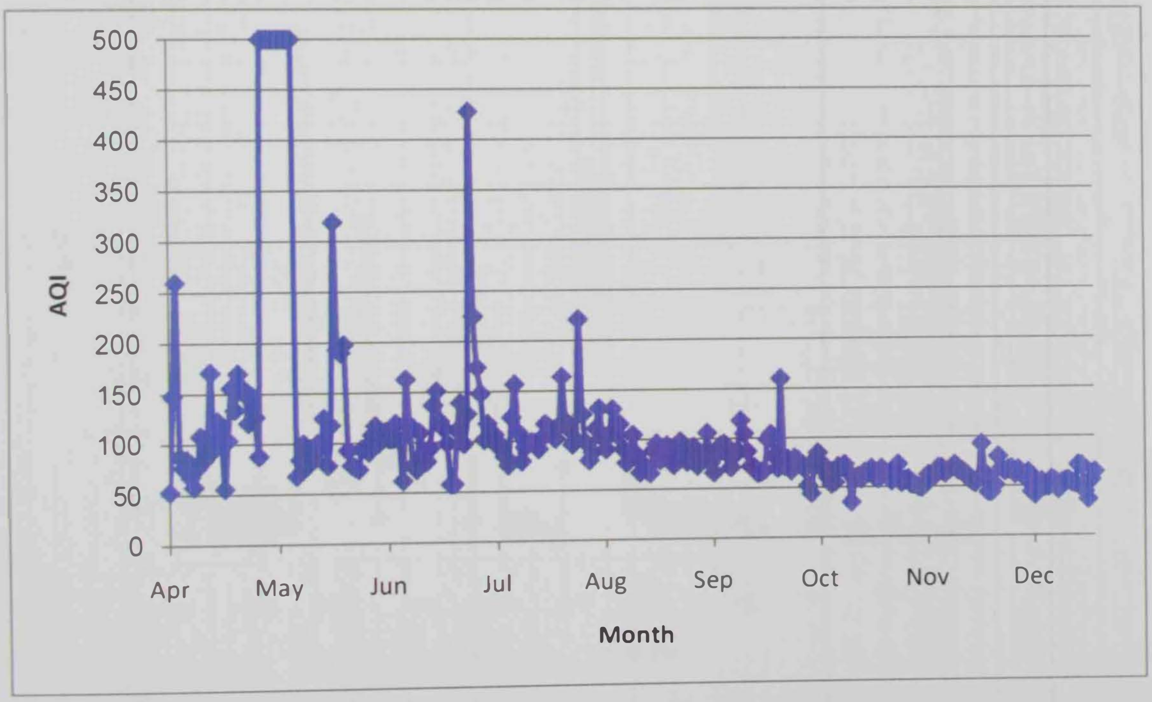

Fig. 4.41: AQI based on data from Al Ain Street Station in 2007

Table 4.24: Number of days of each AQI category based on data from Al Ain School Station in 2008

Month	0-50 Good	51-100 Moderate	101-150 Unhealthy for Sensitive Groups	151-200 Unhealthy	201-300 Very Unhealthy	>300 Hazardous	Range	Average
January	22	9	-	-	-	-	13-99	40
February	13	7	3	2	1	2	11-417	95
March	1	20	6	2	1	-	34-271	96
April	1	11	14	4	-	-	29-186	110
May	22	2	3	3	1	-	13-231	66
June	2	5	7	1	3	10	14-500	225
July	27	4	-	-	-	-	19-61	37
August	25	6	-	-	-	-	14-87	33
September	23	7	1	-	-	-	15-101	40
October	31	-	-	-	-	-	9 – 37	18
November	19	11	-	-	-	-	9 – 88	33
December	19	12	-	-	-	-	26-76	46
Σ	**205**	**94**	**34**	**12**	**6**	**12**	9-500	70
%	56%	26%	9%	3%	2%	3%		

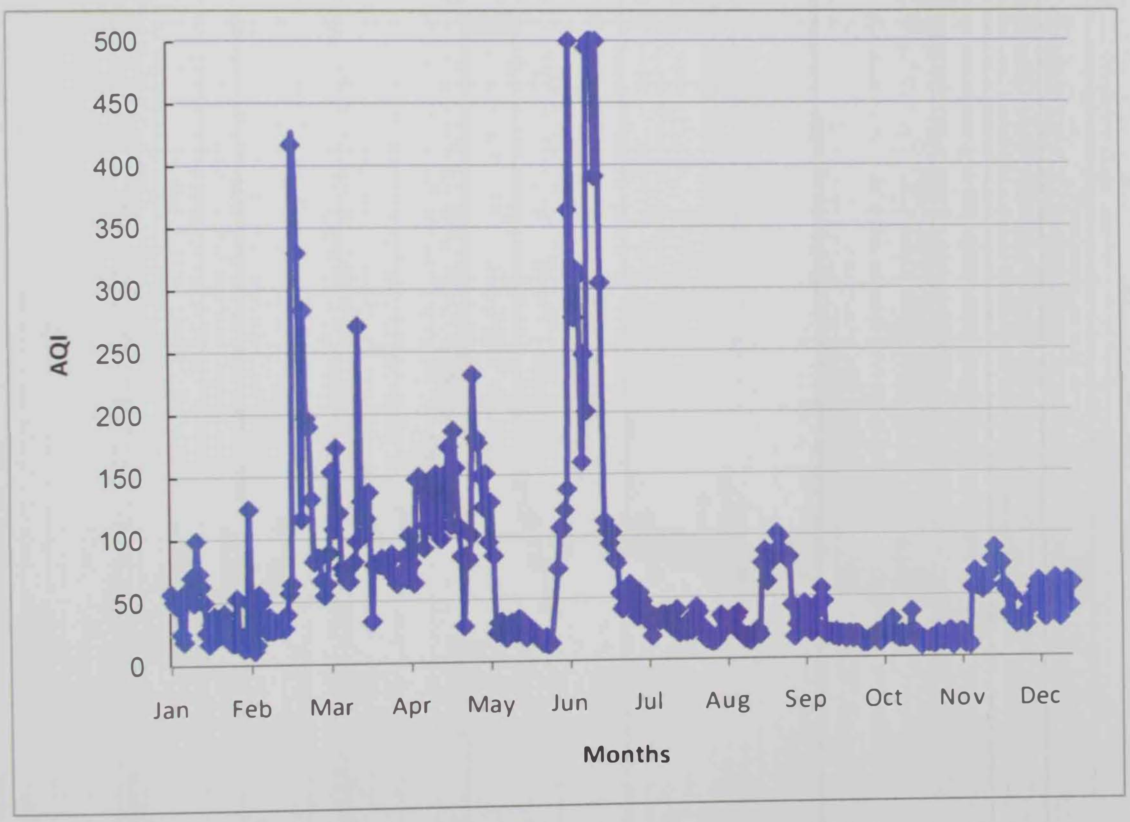

Fig. 4.42: AQI based on data from Al Ain School Station in 2008

Table 4.25: Number of days of each AQI category based on data from Al Ain Street Station in 2008

Month	0-50	51-100	101-150	151-200	201-300	>300	Range	Average
	Good	Moderate	Unhealthy for Sensitive Groups	Unhealthy	Very Unhealthy	Hazardous		
January	11	16	2	1	-	-	17-166	58
February	4	16	4	2	2	2	45-500	121
March	-	21	8	1	1	-	55-273	101
April	-	9	12	8	1	-	74-223	124
May	1	6	5	-	-	19	44-500	345
June	-	14	5	6	2	3	63-500	151
July	-	21	7	3	-	-	65-186	100
August	-	25	6		-	-	51-139	82
September	-	24	2	2	1	1	54-419	106
October	7	24	-	-	-	-	42-90	57
November	22	7	1	-	-	-	17-119	48
December	16	15	-	-	-	-	27-82	50
Σ	61	198	52	23	7	25	17-500	112
%	17%	54%	14%	6%	2%	7%		

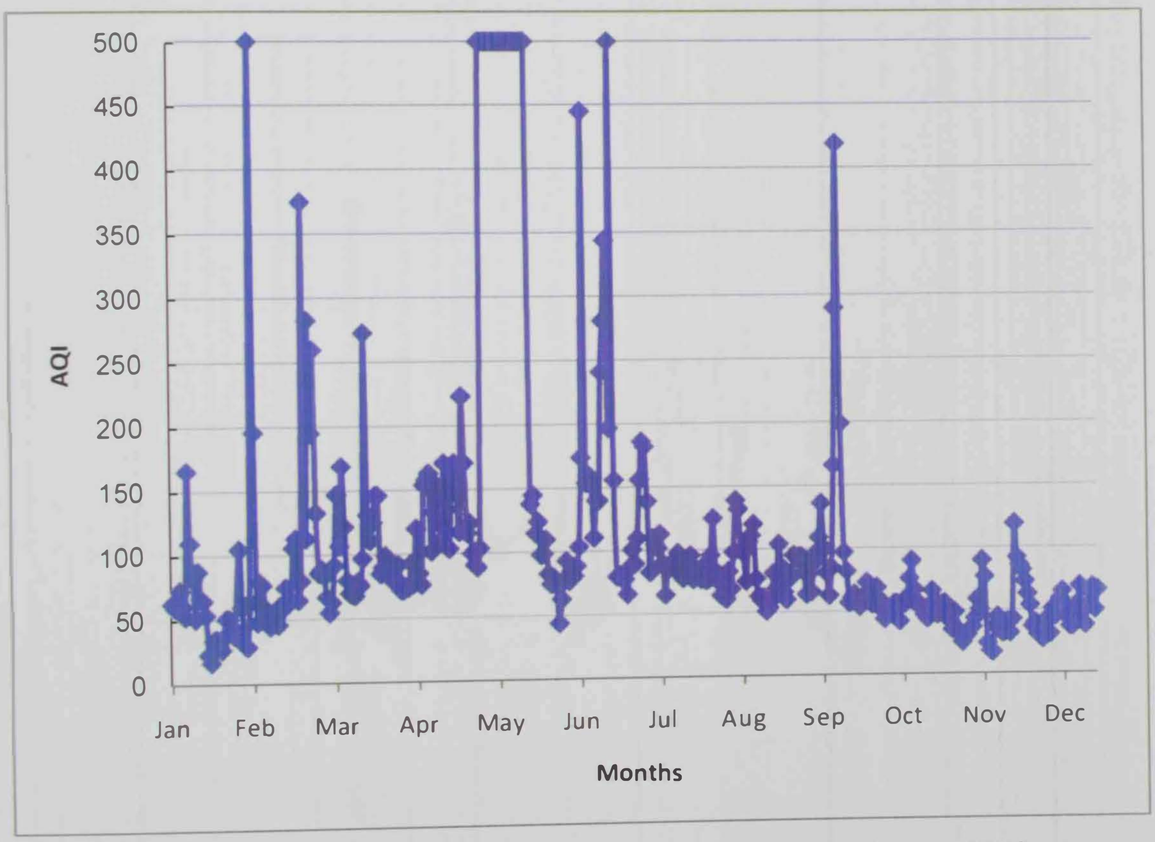

Fig. 4.43: AQI based on data from Al Ain Street Station in 2008

Table 4.26: Number of days of each AQI category based on data from Al Ain School Station in 2009

Month	0-50 Good	51-100 Moderate	101-150 Unhealthy for Sensitive Groups	151-200 Unhealthy	201-300 Very Unhealthy	>300 Hazardous	Range	Average
January	14	17	-	-	-	-	21-78	50
February	2	19	3	2	-	2	39-500	104
March	8	12	9	1	-	1	19-370	90
April	-	21	4	1	1	-	52-251	90
May	-	12	7	-	-	-	86-133	107
June	3	13	7	2	-	-	31-165	89
July	-	-	9	2	2	7	105-500	246
August	-	22	4	1	-	2	51-500	105
September	19	11	-	-	-	-	9--82	40
October	4	22	2	-	-	-	22-123	64
November	15	9	-	-	-	-	17-86	42
December	22	3	1	-	-	-	7-148	40
Σ	87	161	46	9	3	12	7-500	89
%	27%	51%	14%	3%	1%	4%		

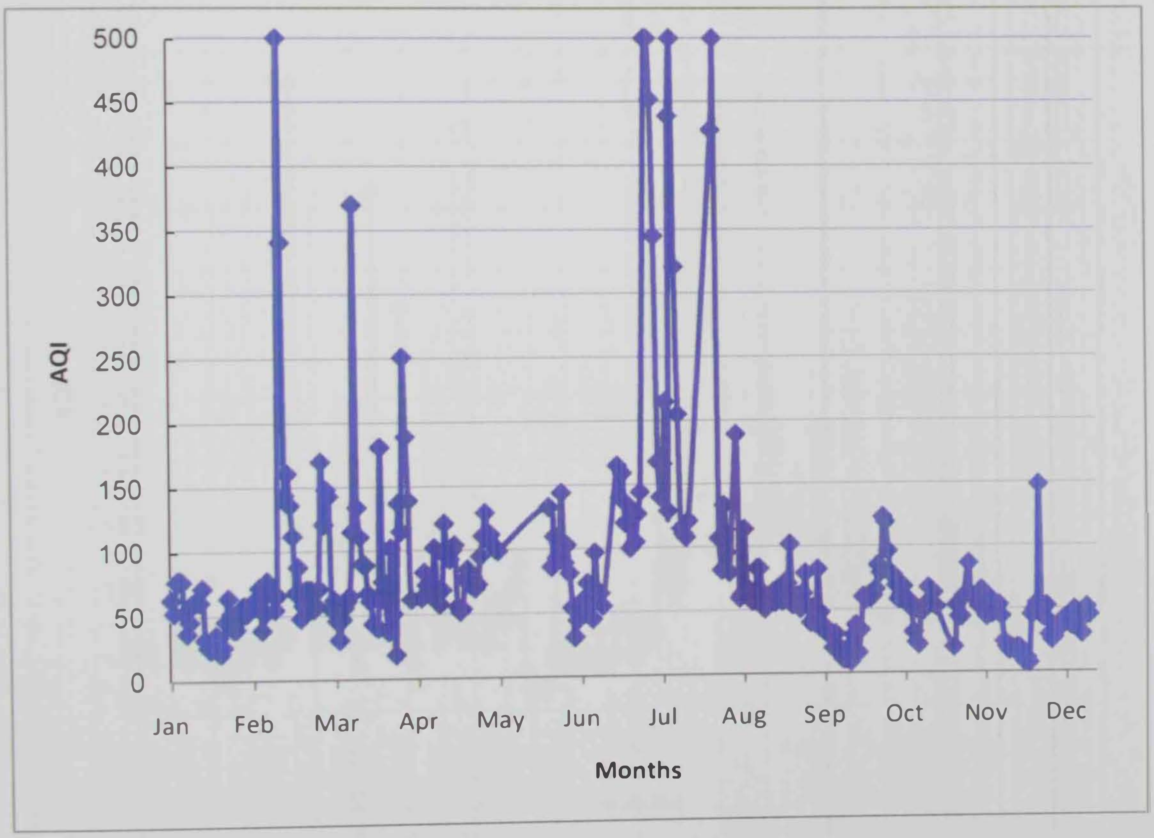

Fig. 4.44: AQI based on data from Al Ain School Station in 2009

Table 4.27: Number of days of each AQI category based on data from Al Ain Street Station in 2009

Month	0-50 Good	51-100 Moderate	101-150 Unhealthy for Sensitive Groups	151-200 Unhealthy	201-300 Very Unhealthy	>300 Hazardous	Range	Average
January	12	19	-	-	-	-	22-84	54
February	1	20	2	3	-	2	42-500	118
March	6	14	7	2	-	2	21-412	101
April	-	21	6	2	1	-	53-281	91
May	22	4	5	-	-	-	17-128	47
June	0	0	0	1	-	-	36-153	73
July	-	3	13	4	1	10	88-500	231
August	-	13	10	3	3	2	77-500	147
September	-	23	4	1	-	-	52-151	85
October	-	24	7	-	-	-	53-144	89
November	-	23	-	-	-	-	57-97	68
December	-	-	-	-	-	-	-	-
Σ	**41**	**164**	**54**	**16**	5	**16**	17-500	100
%	**14%**	**55%**	**18%**	5%	2%	5%		

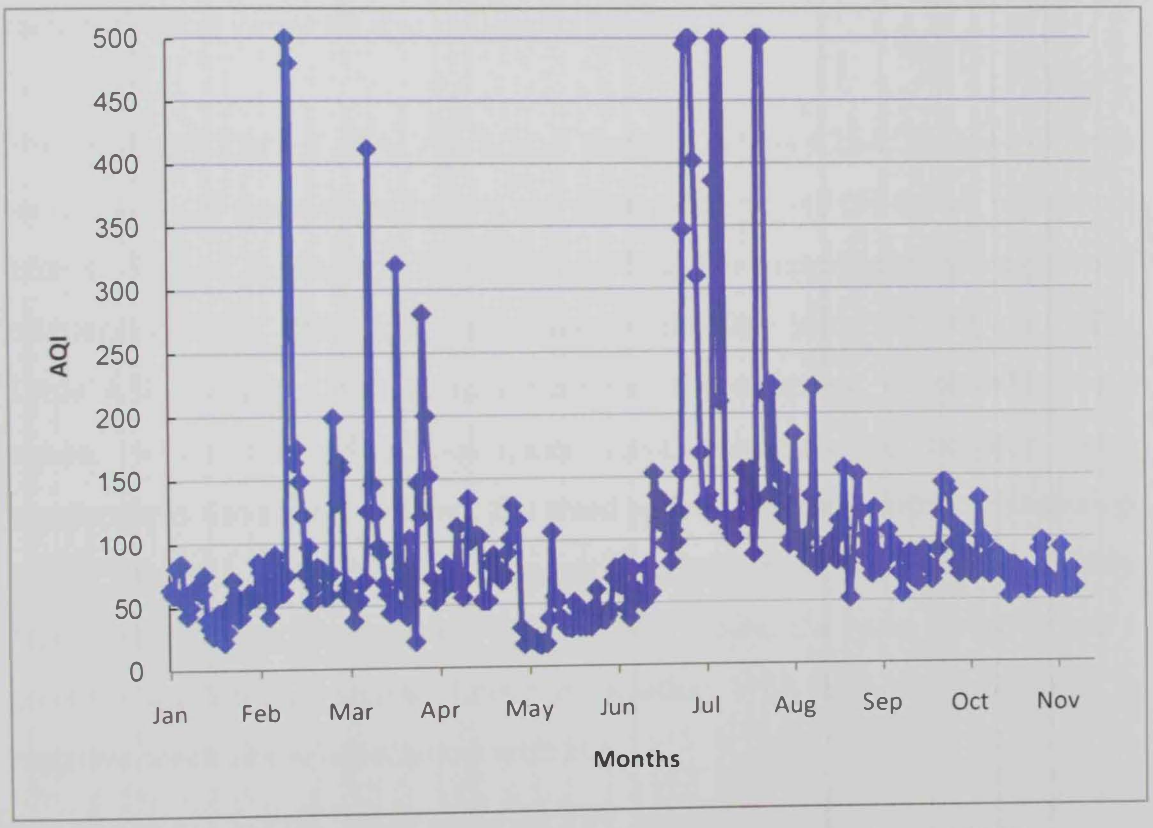

Fig. 4.45: AQI based on data from Al Ain Street Station in 2009

4.6 Effects of meteorological conditions on pollutant level

Although motor vehicles are possibly a major cause of air quality deterioration, meteorological conditions (temperature, wind speed and direction) influence the concentration level of emitted pollutants by dilution, conversion, or spread into an originally unaffected zone. In this section, the effects of air temperature, wind speed and wind direction on pollution level in Al Ain were investigated. A bivariate correlation analysis was used to measure the association or relationship between the meteorological variables and pollutants level. The results of this analysis were summarized in Tables 4.28-4.42 for the two stations during 2007-2009. Note that the Pearson's coefficient (r) was used and it varies between -1 and +1, where a +1 represents a positive perfect degree of association, and a -1 represents a negative perfect degree of association between the two variables. Moreover, the p-value indicates the statistical significance of the correlations between the meteorological variables and pollutants levels.

For the data collected at Al Ain School Station, Tables 4.28-4.32 show that the meteorological parameters have a significant effect ($p<0.05$) for all pollutants except NO_2 and for the wind direction on CH_4. The temperature has a positive relationship with PM_{10} and a negative relationship with SO_2, O_3 and CH_4. Table 4.30 indicates that temperature has the strongest relationship with ozone, while the other pollutants have moderate relationship with temperature. On the other hand, the wind speed shows a positive relationship with PM_{10}, O_3 and CH_4 and a negative relationship with SO_2. All these relationship are moderate linear association. Finally, the wind direction has a positive moderately strong linear association with PM_{10} and O_3 and a negative weak linear association with SO_2.

For the data collected at Al Ain Street Station, Tables 4.33-4.42 show that the meteorological parameters have a significant effect ($p<0.05$) for all pollutants except the wind speed on CH_4 and ethylbenzene. Temperature has a positive relationship only with PM_{10} and a negative relationship with other pollutants. Table 4.34 indicates that the temperature has a negative strongest relationship with SO_2. However, the temperature shows moderate strong linear association with PM_{10}, NO_2, benzene, toluene, ethylbenzene, mp-xylene and o-xylene and a weak linear association with CO and CH_4. On the other hand, the wind speed shows a positive relationship only with PM_{10} and a negative relationship with other pollutants. All these relationships are moderate strong linear association except for CO and NO_2 which have weak linear associations with wind speed. Finally the wind direction has a positive relationship with all pollutant except with SO_2 which shows a negative relationship. However, all these relationships are weak except for PM_{10} which has a moderate strong linear association with wind direction.

Table 4.28: Effect of meteorology on PM_{10} level at Al Ain School during 2007-2009

Year	Temperature		Wind Speed		Wind Direction	
	Pearson Correlation (R)	p-value	Pearson Correlation (R)	p-value	Pearson Correlation (R)	p-value
2007	0.272**	0.000	0.187**	0.003	-0.169**	0.007
2008	0.021	0.688	0.062	0.243	0.237**	0.000
2009	0.315**	0.000	0.190**	0.001	0.284**	0.000

Table 4.29: Effect of meteorology on SO_2 level at Al Ain School during 2007-2009

Year	Temperature		Wind Speed		Wind Direction	
	Pearson Correlation (R)	p-value	Pearson Correlation (R)	p-value	Pearson Correlation (R)	p-value
2007	-0.336**	0.000	-0.199**	0.002	-0.088	0.167
2008	-0.383**	0.000	0.325**	0.000	-0.201**	0.000
2009	0.083	0.278	-0.237**	0.000	-0.127*	0.024

Table 4.30: Effect of meteorology on O_3 level at Al Ain School during 2007-2009

Year	Temperature		Wind Speed		Wind Direction	
	Pearson Correlation (R)	p-value	Pearson Correlation (R)	p-value	Pearson Correlation (R)	p-value
2007	-0.359**	0.000	-0.200**	0.001	0.126*	0.040
2008	-0.633**	0.000	0.392**	0.000	0.212**	0.000
2009	-0.626**	0.000	0.121*	0.027	0.351**	0.000

Table 4.31: Effect of meteorology on NO_2 level at Al Ain School during 2007-2009

Year	Temperature		Wind Speed		Wind Direction	
	Pearson Correlation (R)	p-value	Pearson Correlation (R)	p-value	Pearson Correlation (R)	p-value
2007	0.007	0.908	0.003	0.958	0.068	0.269
2008	0.491**	0.000	-0.258**	0.000	0.023	0.678
2009	-	-	-	-	-	-

Table 4.32: Effect of meteorology on CH_4 level at Al Ain School during 2007-2009

Year	Temperature		Wind Speed		Wind Direction	
	Pearson Correlation (R)	p-value	Pearson Correlation (R)	p-value	Pearson Correlation (R)	p-value
2007	0.160**	0.014	0.139**	0.033	0.119	0.069
2008	-0.640**	0.000	0.730**	0.000	-0.046	0.387
2009	-	-	-	-	-	-

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

Table 4.33: Effect of meteorology on PM_{10} level at Al Ain Street during 2007-2009

Year	Temperature		Wind Speed		Wind Direction	
	Pearson Correlation (R)	p-value	Pearson Correlation (R)	p-value	Pearson Correlation (R)	p-value
2007	0.299**	0.000	0.464**	0.000	0.158**	0.009
2008	0.254**	0.000	0.375**	0.000	0.317**	0.000
2009	0.196**	0.000	0.180**	0.001	0.138*	0.013

Table 4.34: Effect of meteorology on SO_2 level at Al Ain Street during 2007-2009

Year	Temperature		Wind Speed		Wind Direction	
	Pearson Correlation (R)	p-value	Pearson Correlation (R)	p-value	Pearson Correlation (R)	p-value
2007	-0.269**	0.000	-0.354**	0.000	-0.194**	0.007
2008	-0.344**	0.000	0.000	0.995	0.064	0.227
2009	-0.636**	0.000	-0.398**	0.000	-0.152*	0.022

Table 4.35: Effect of meteorology on CO level at Al Ain Street during 2007-2009

Year	Temperature		Wind Speed		Wind Direction	
	Pearson Correlation (R)	p-value	Pearson Correlation (R)	p-value	Pearson Correlation (R)	p-value
2007	-0.141*	0.024	-0.134*	0.032	0.187**	0.003
2008	-0.356**	0.000	-0.106*	0.043	0.081	0.121
2009	0.174**	0.001	0.025	0.648	0.168**	0.002

Table 4.36: Effect of meteorology on NO_2 level at Al Ain Street during 2007-2009

Year	Temperature		Wind Speed		Wind Direction	
	Pearson Correlation (R)	p-value	Pearson Correlation (R)	p-value	Pearson Correlation (R)	p-value
2007	-0.428**	0.000	-0.071	0.255	0.141*	0.022
2008	-0.248**	0.000	0.143*	0.012	0.164**	0.004
2009	-0.136*	0.014	-0.315**	0.000	-0.016	0.772

Table 4.37: Effect of meteorology on CH_4 level at Al Ain Street during 2007-2009

Year	Temperature		Wind Speed		Wind Direction	
	Pearson Correlation (R)	p-value	Pearson Correlation (R)	p-value	Pearson Correlation (R)	p-value
2007	-0.100	0.111	-0.276**	0.000	0.201**	0.001
2008	0.369**	0.000	0.083	0.116	0.174**	0.001
2009	-0.300**	0.000	-0.079**	0.351	-0.260*	0.002

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

Table 4.38: Effect of meteorology on benzene level at Al Ain Street during 2007-2009

Year	Temperature		Wind Speed		Wind Direction	
	Pearson Correlation (R)	p-value	Pearson Correlation (R)	p-value	Pearson Correlation (R)	p-value
2007	-0.042	0.595	-0.482**	0.000	-0.277**	0.000
2008	-0.219**	0.000	-0.023	0.664	0.169**	0.001
2009	-0.298**	0.000	-0.195**	0.001	0.128*	0.029

Table 4.39: Effect of meteorology on toluene level at Al Ain Street during 2007-2009

Year	Temperature		Wind Speed		Wind Direction	
	Pearson Correlation (R)	p-value	Pearson Correlation (R)	p-value	Pearson Correlation (R)	p-value
2007	-0.407**	0.000	-0.418**	0.000	-0.009	0.907
2008	-0.209**	0.000	-0.006	0.903	0.182**	0.000
2009	-0.260**	0.000	-0.217**	0.000	0.121*	0.038

Table 4.40: Effect of meteorology on ethylbenzene level at Al Ain Street during 2007-2009

Year	Temperature		Wind Speed		Wind Direction	
	Pearson Correlation (R)	p-value	Pearson Correlation (R)	p-value	Pearson Correlation (R)	p-value
2007	-0.774**	0.000	-0.779**	0.000	-0.114	0.129
2008	-0.239**	0.000	-0.041	0.435	0.181**	0.001
2009	0.026	0.710	0.009	0.896	0.258**	0.000

Table 4.41: Effect of meteorology on mp-xylene level at Al Ain Street during 2007-2009

Year	Temperature		Wind Speed		Wind Direction	
	Pearson Correlation (R)	p-value	Pearson Correlation (R)	p-value	Pearson Correlation (R)	p-value
2007	-0.541**	0.000	-0.684**	0.000	-0.046	0.557
2008	-0.336**	0.000	-0.043	0.409	0.234**	0.000
2009	-0.297**	0.000	-0.273**	0.000	0.082	0.161

Table 4.42: Effect of meteorology on o-xylene level at Al Ain Street during 2007-2009

Year	Temperature		Wind Speed		Wind Direction	
	Pearson Correlation (R)	p-value	Pearson Correlation (R)	p-value	Pearson Correlation (R)	p-value
2007	-0.520**	0.000	-0.572**	0.000	0.131	0.100
2008	-0.359**	0.000	-0.053	0.314	0.215**	0.000
2009	-0.409**	0.000	-0.215**	0.000	0.116*	0.047

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

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

Chapter 5: Vehicle Characteristics and Fuel Consumption

5.1 Street configuration

Street configuration is one of the most important elements in urban area, where population and traffic density are relatively high. Resident's exposure to air pollution is expected to significantly increase when the buildings are packed and streets are narrow (Green and Etheridge, 2001). However, street configuration influences the concentration and dispersion of air pollutants especially in a street canyon. The total pollution concentration can be estimated by the summation of street contribution and background contribution. Street contribution includes the direct plume from traffic and recirculation air between the upwind building (leeward side) and downwind side (windward) (Berkowicz, 2000). In addition, the road distance between two major intersections can influence the pollution dispersion.

The wind flow regimes influence the concentration and dispersion of pollution in an urban street canyon. Oke (1988) classified the wind flow regimes into isolated roughness, wake interface, and skimming flow as shown in Fig. 5.1.

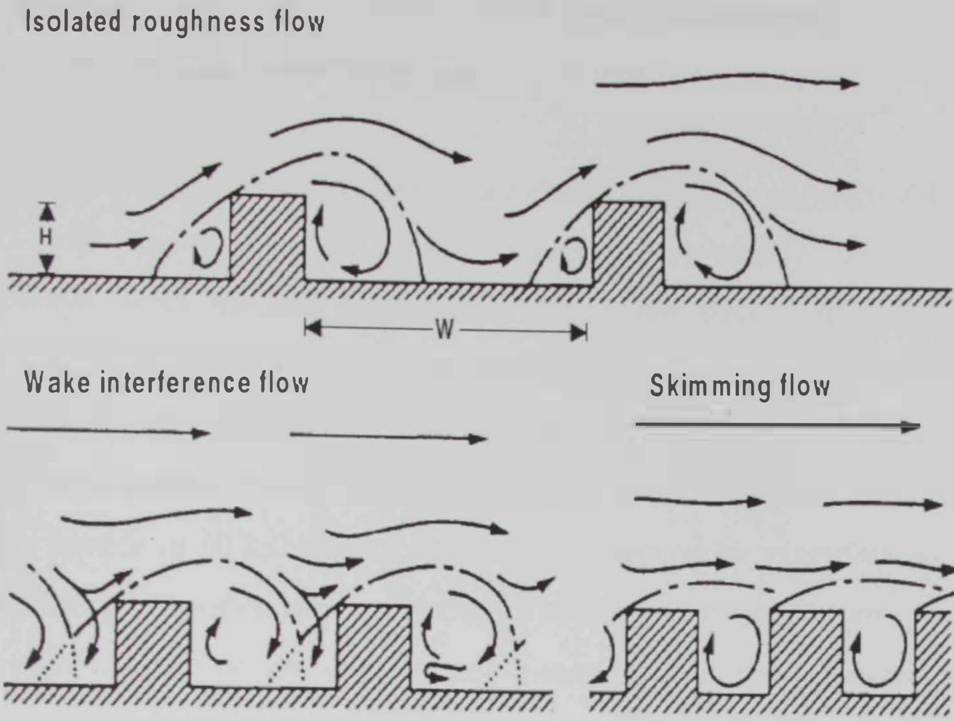

Fig. 5.1: Wind flow regimes associated with air flow over building and aspect ratio (Oke, 1988)

For a wide canyon, where the height of building over the width between the buildings and the buildings opposite to street is less than 0.3, the buildings are well separated and act essentially as isolated roughness elements. In this case, the air flows a significant distance downward from the first building before facing the next one. In the wake interface regime, the buildings are more closely spaced ($H/W \approx 0.5$) and the air flow has inadequate distance to readapt the flow before facing the next obstacle. On the other hand, the air flow skims over the buildings in the regular canyon street geometry ($H/W \approx 1$) producing skimming flow (Oke, 1988).

In Al Ain city, the wide canyon street geometry is approximate to the relative dimensions of Khalifa Street, where Al Ain Street Station is located. Since the maximum height of the buildings is approximately 20m and the width between buildings across the street is about 70m, so the ratio of the height over width is approximately less than 0.3. Therefore, the isolated roughness flow is applicable to Khalifa Street. However, most of the streets in Al Ain city are nearly flat with the exception of Jabel Hafit area.

In Al Ain downtown area, the streets are characterized as modern grid-type system, with mostly major arterial streets of typically dual 3-lanes carriageways, with median landscaping along the streets and additional landscaped features at junction roundabouts. The width of each lane is approximately 3.7m and that of the separator (median) is 5m. Most of the medians are unpaved and utilized to grow palm trees. The roads are designed for traffic speeds of 60 kilometers per hour and served by excessive amounts of car parking. However, most of the city's arterial intersections are operated by roundabouts and others with signals intersection, but these roundabouts are currently upgraded to signalized intersections and the overpass (bridge) is being removed (RTTSRC, 2007).

On the other hand, the buildings in Al Ain downtown area follow a horizontal pattern in expansion. They are characterized generally by three to four story buildings, each joined to its neighbor with commercial frontage on two sides. The average height of the buildings on both sides of the streets is about 15 meters.

The study area of Al Ain downtown, which covers a rectangular area of approximately one kilometer square, is illustrated in Fig. 5.2. It is bounded by Ali Bin Abi Taleb Street in the North, Abu Baker Al Siddiq Street in the East, Zayed bin Sultan Street in the South and Al Ain Street in the West. There are six roundabouts, one traffic signal intersection and two T- junctions in the downtown study area as shown in Fig. 5.2. Note that many of the roundabouts in the downtown have been replaced recently by traffic signals and such changes on air quality have not been considered in this study.


Fig. 5.2: The study area in Al Ain downtown

5.2 Traffic data

The traffic count data (i.e. vehicle flow per hr) are important for this study as they are required to estimate the emission rates produced at the intersections. Peak hourly traffic count data were collected using automatic counters as well as manual counts at the intersections in the downtown of Al Ain as shown in Fig. 5.3. These data were collected for a period of five days in December, 2006, seven days in April, 2009 and four days in August, 2008. All the intersections (roundabouts and T-junctions) were covered in 2006, while only three intersections (two roundabouts and one T-junction) at Khalifa Street were covered in 2009 and two intersections were covered in 2008. The study combines the traffic counts of nine intersections (seven roundabouts and two T-junctions) close to Al Ain Street air quality monitoring station and uses the data on an hourly basis.

Fig. 5.3: The study area with the main downtown intersections

Statistical analysis was used to summarize and analyze the traffic data. Descriptive statistics, one-way ANOVA model and parallel box-plot were used to quantify the differences and compare the mean values and the distribution of the traffic data at each intersection in the study area.

Table 5.1 summarizes the descriptive statistics of traffic volume for each intersection in Al Ain downtown in December, 2006. The average traffic volume for all intersections in the study area was approximately 3803 vehicles per hour. It can be seen that the (T-signal-108) intersection has the largest mean value of 5566, while the (RA-B121) intersection has the lowest mean value of 1720. Also, the maximum traffic volume was 6243 vehicles in the T-signal-108 and the minimum traffic volume was 1325 vehicles in RA-B121 intersection. The Skewness and Kurtosis values indicate that the traffic volumes for almost all intersections are close to normal distribution with a little positive and negative skewed distribution.

On the other hand, Fig. 5.4 shows the box-plot comparison for the traffic volumes at each intersection in Al Ain downtown. It was found that (T-Signal-111 junction) has more traffic volume than the other intersections.

As in the independent t-test, ANOVA assumes that the data are normally distributed and homogeneity of variances. Tables 5.2 shows that some of the intersections traffic data are normally distributed (p-value>0.05) and others are not. However, Table 5.3 shows that the Levene statistic rejects the null hypothesis that the group variances are equal. Therefore, we may choose to transform the data or perform a nonparametric test that does not require these assumptions. The nonparametric test called "Kruskal-Wallis test" is the best alternative when the assumptions of ANOVA test are invalid or suspected. Table 5.4 shows the results of Kruskal-Wallis test. The results indicate that there is a statistically significant difference among the traffic intersections groups.

Table 5.1: Descriptive statistics of the traffic data at specific intersections in December, 2006

Statistic Analysis	RA-120	RA-105	RA-B121	RA-107	RA-106	T-SIG-111	T-SIG-108	RA-109	RA-110
Mean	3841	2696	1720	4709	3975	2943	5566	5272	3509
5% Trimmed Mean	3838	2700	1719	4715	4015	2948	5563	5302	3513
Median	3790	2752	1642	4715	4232	3013	5507	5429	3532
Std. Dev.	175	322	278	441	612	229	424	730	149
Minimum	3640	2247	1325	4021	2781	2571	4946	3833	3217
Maximum	4110	3076	2124	5285	4452	3218	6243	6170	3734
Skewness	0.587	-0.2	0.2	-0.23	-1.4	-0.97	0.3	-1.1	-0.79
Kurtosis	-1.157	-1.6	-1.3	-0.97	0.9	-0.25	-0.35	-1.3	1.97

RA: Roundabout
T-SIG: Traffic Signal

Table 5.2: Tests of normality for traffic volume at each intersection in December, 2006

Tests of Normality

		Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Intersection	Statistic	df	Sig.	Statistic	df	Sig.
Traffic counts	RA-120	.211	8	.200*	.914	8	.381
	RA-105	.166	8	.200*	.914	8	.384
	RA-B121	.176	8	.200*	.944	8	.654
	RA-107	.152	8	.200*	.960	8	.808
	RA-106	.252	8	.142	.800	8	.028
	T-Sig-111	.318	8	.017	.841	8	.077
	T-Sig-108	.169	8	.200*	.972	8	.913
	RA-109	.190	8	.200*	.933	8	.545
	RA-110	.238	8	.200*	.928	8	.496

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

Table 5.3: Test of homogeneity of variance for traffic volume at each intersection in December, 2006

Test of Homogeneity of Variance

		Levene Statistic	df1	df2	Sig.
Traffic counts	Based on Mean	3.165	8	63	.004
	Based on Median	1.883	8	63	.078
	Based on Median and with adjusted df	1.883	8	27.825	.103
	Based on trimmed mean	2.900	8	63	.008

Table 5.4: Kruskal Wallis Test for traffic volume at each intersection in December, 2006

Test Statistics[a,b]

	Traffic counts
Chi-Square	64.286
df	8
Asymp. Sig.	.000

a. Kruskal Wallis Test

b. Grouping Variable: Intersection

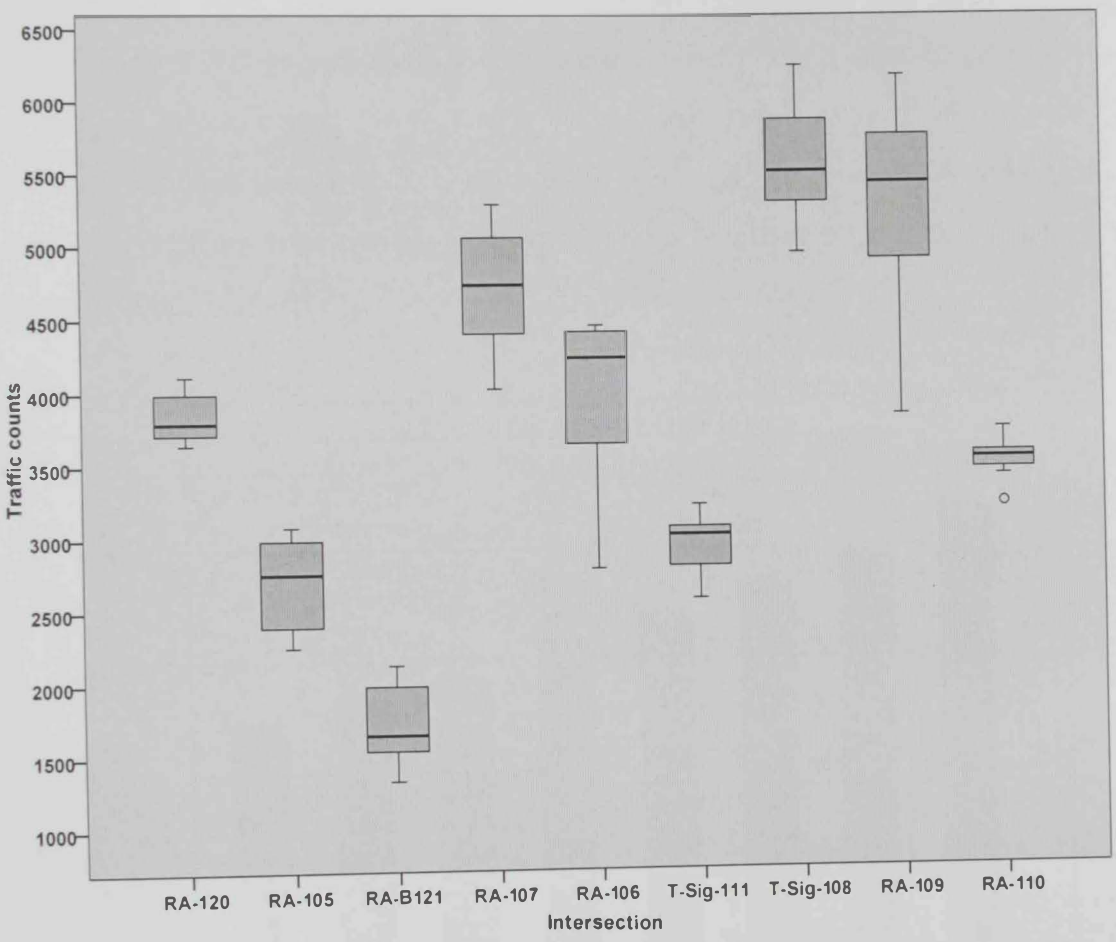

Fig. 5.4: Box-plot of traffic data for each intersection in Al Ain downtown in December, 2006

5.3 Vehicle growth

Air pollution from motor vehicles has become an issue, because of the steady increase both in the number of vehicles in use and the distance travelled by each vehicle each year. As a result, the use of vehicles currently produces more air pollutants, such as CO, HCs, SO_2 and NO_x, than any other human activity. In the UK, road transport produces 90% of CO, 51% of NO_x, 33% of HCs and 46% of black smoke (Colls, 1997).

In this study, data of registered vehicles in Al Ain during 2002-2009 were collected from Abu Dhabi Statistics Center to investigate the growth in vehicles. Figure 5.5 shows that Al Ain vehicles have been growing rapidly over the last seven years. There was a particularly rapid growth in the total registered vehicles between 2008 and 2009, with 4.4% increase. Overall, the increase in vehicles was steady with an average of almost 3.1% increase per year since 2002.

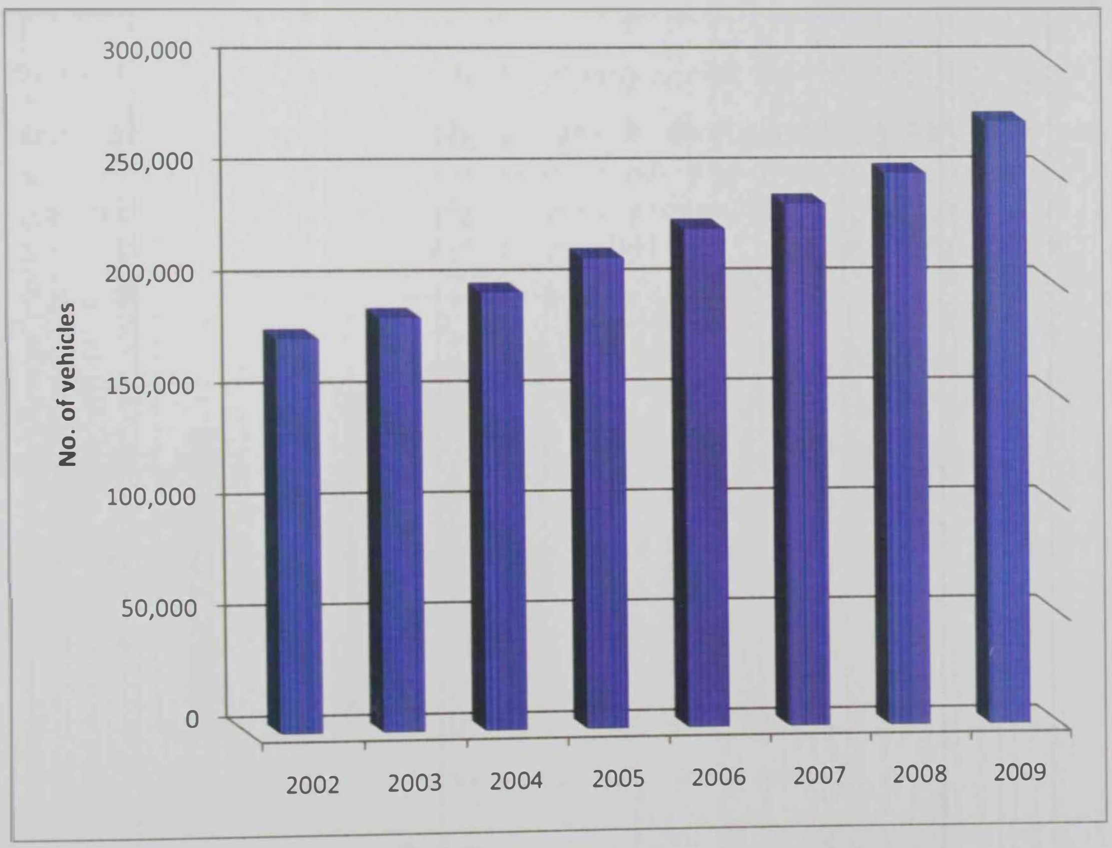

Fig. 5.5: Vehicle growth in Al Ain during 2002-2009

5.4 Vehicle type

The vehicle fleet in Al Ain city is divided into seven categories, namely; motorcycle, private car, taxi, van, pick-up, bus, truck. However, Abu Dhabi Police Department classifies the vehicle fleet according to licenses as motorcycle, light and heavy vehicles, light and heavy buses, light and heavy mechanical vehicles. In term of engine size, the vehicle fleet is classified into four or less, six, eight, twelve or more cylinders. On the other hand, cars, small pick-ups and taxis constitute most of the flow in the downtown area of Al Ain, while heavy trucks are not allowed to pass into the downtown area unless there is a construction activity. Heavy trucks emit a lot of particulates in addition to poisonous gases such as NOx, CO, SO_2 and HCs.

In this study, data of registered vehicles by fleet and engine size in Al Ain during 2004-2009 were collected from Abu Dhabi Statistics Center in order to investigate the growth of vehicles by cars fleet in the city. Figure 5.6 shows the growth of on-road vehicles by fleet categories in Al Ain. The growth of private passenger cars is particularly remarkable. However, Table 5.5 shows the total registered vehicles in terms of engine size during 2008-2009. It can be seen that vehicles with four cylinders are the most prevailing ones in Al Ain.

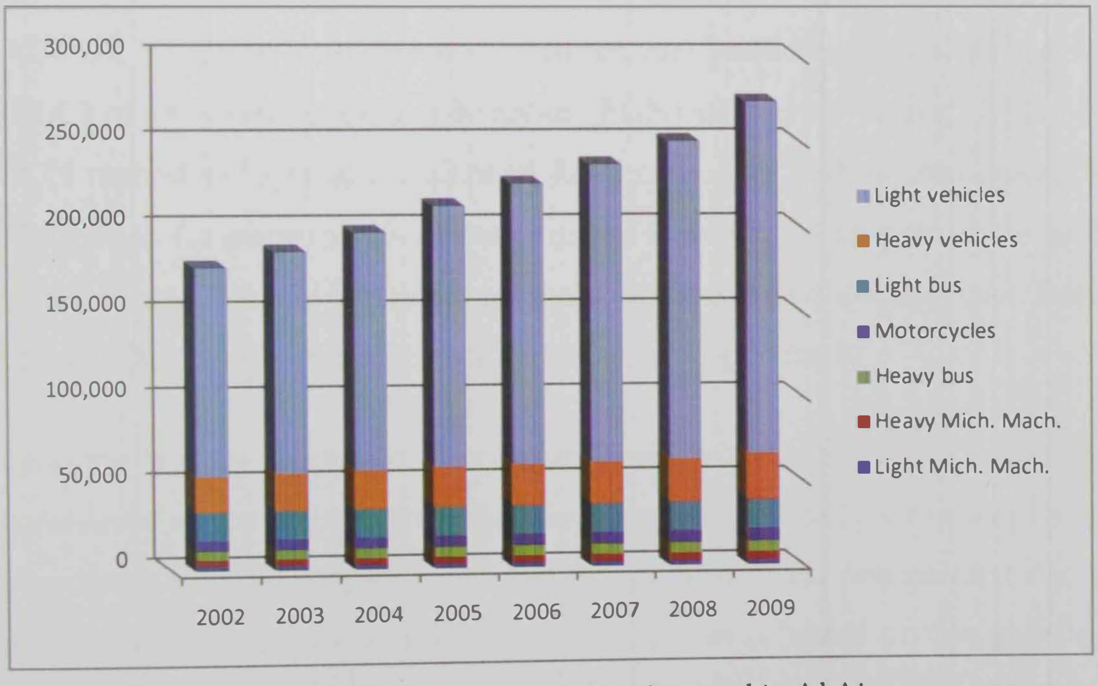

Fig. 5.6: Motor vehicles fleet licensed in Al Ain

Table 5.5: Total motor vehicles classified by engine size in Al Ain

Engine Size	2008	2009
4 cylinders	70,029	81,212
6 cylinders	55,452	62,934
8 cylinders	24,669	31,961
12 cylinders	360	436
Total	**150,510**	**176,543**

5.5 Fuel consumption

Rapid growth of petroleum consumption in Al Ain can be linked to the growth of on-road transportation vehicles, since all vehicles are fueled almost entirely by gasoline and diesel. In order to investigate the growth of fuel consumption, data were collected from Al Ain ADNOC Distribution Company concerning fuels consumed at all gas stations in the city during 2007-2009. It was estimated that the amount of fuel consumption in Al Ain has increased by 15% from 2007 to 2008 and 13% increase in 2009 relative to 2007. However, the reduction in fuel consumption in year 2009 (i.e. 2% decrease relative to 2008) is probably due to the economic global crisis.

ADNOC produces four types of vehicles fuel including unleaded gasoline (ULG) of 98 Research Octane Number (RON) named as "Super", ULG of 95 RON named as "Special", ULG of 91 RON named as "E-Plus" and diesel fuel. The Super Gasoline of 98-octane number is available only in some petrol stations in Al Ain and it is not commonly used because of its high cost. Details of ADNOC fuel specifications are provided in Appendix-B.

Gasoline is a by-product of petroleum, contains carbon and hydrogen. It is considered as the main fuel for the spark ignition internal combustion engine. The octane number of gasoline is essential parameter for determining the fuel quality. The difference in fuel names and prices is based on the gasoline's octane number. The octane number of any fuel is defined as the percentage, by volume, of iso-octane to heptanes in fuel mixture. It is also a measure of a fuel resistance to detonation (engine knocking) during combustion engines. Gasoline may have a higher or lower octane rating, depending on how its anti-knock performance compares to the performance of pure hydrocarbon octane (Cenk et al., 2005; Wikipedia, 2010). On the other hand, many people think that the higher-octane rating makes better engine performance. However, Cenk et al. (2005) stated that using octane ratings higher than the requirement of an engine not only decreases engine performance but also increases exhaust emissions.

Diesel is another vehicle fuel produced by ADNOC Company. It comes from the residue of the crude oil after the more volatile fuels, such as gasoline and kerosene, are removed during the petroleum refining process (IPAS, 2003). Diesel fuel is mainly used by trucks, buses and heavy equipments. This fuel, however, is likely to cause harmful effects to human health and the environment due to harmful emissions of toxic gases such as sulphur dioxide. Because of that, ADNOC Company is planning to produce in 2012 a new Ultra Low Sulfur Diesel (ULSD) that has sulphur content of 10ppm, named as "Green Diesel". This fuel will be used by vehicles and industry in Abu Dhabi Emirate (ADNOC, 2007).

In Al Ain, as in other areas in the Abu Dhabi Emirate, a large majority of the automobiles use gasoline and a relatively small fraction uses diesel. Table 5.6 shows that gasoline fuel represents 78% of the vehicles fuel consumption compared to 22% consumption of diesel fuel during 2007-2009. Moreover, the ULG-95 represents 50% of all vehicles fuel consumption in Al Ain.

Table 5.6: Comparison between gasoline and diesel fuels consumption during 2007-2009 in Al Ain

Year	Gasoline (gal.)		Diesel (gal.)
	ULG-95	ULG-91	
2007	67,222,841	51,043,276	24,064,114
2008	88,799,006	49,111,462	56,512,815
2009	106,439,926	43,545,946	37,245,544
Total	262,461,773	143,700,684	117,822,473
Percentage (%)	50.1%	27.4%	22.5%

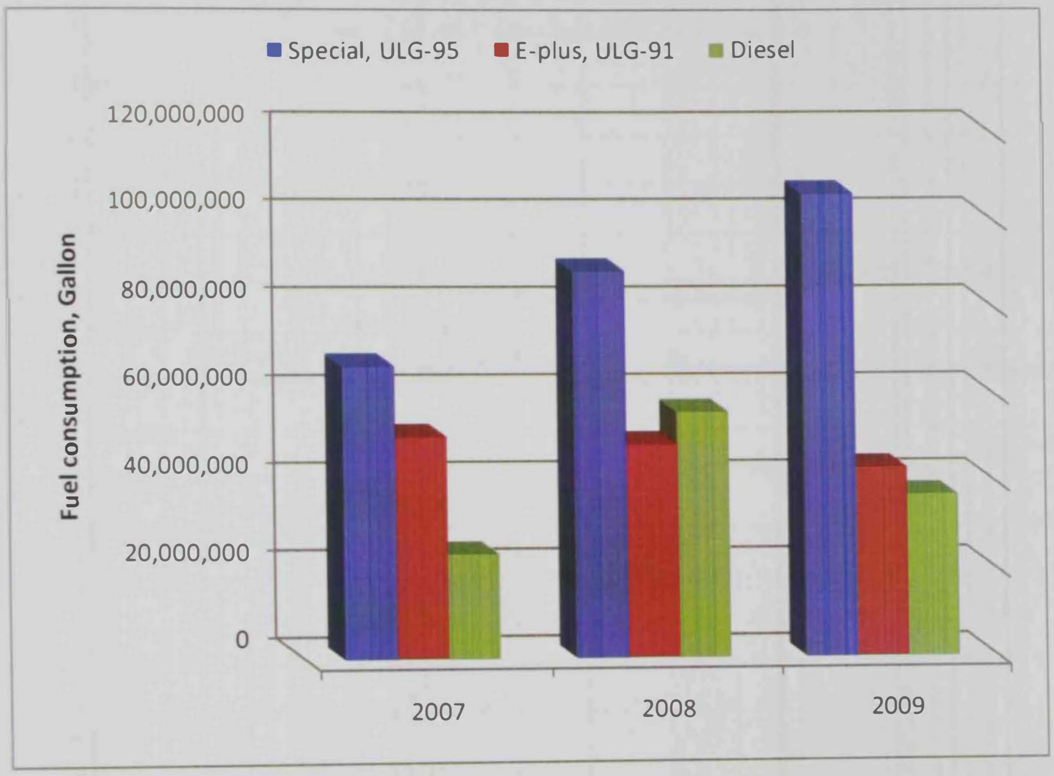

Fig. 5.7: Fuel consumption by type in Al Ain during 2007-2009

Figures 5.8-5.10 show the temporal trend of fuel consumption of gasoline and diesel in Al Ain during 2007-2009. Consumption of the ULG-95 has rapidly increased by 14% from 2007 to 2008 and then increased by 9% in 2009, while the ULG-91 shows almost the same variations during 2007-2009, with 2% reduction from 2007 to 2008 and then 6% reduction in 2009. However, diesel fuel consumption has increased by 40% from 2007 to 2008. This occurred despite the increase in global diesel prices. An explanation for this is that the diesel fuel was raised in the northern emirates in that year, but it remained stable in the Abu Dhabi Emirate. This attracted some companies and factories in the northern emirates to buy diesel from the Abu Dhabi Emirate which resulted in an increase in diesel consumption in emirate. After that, diesel fuel consumption has decreased by 21% in 2009 due to the global economic crisis. In summary, it can be seen that ULG-95 is the most fuel used in Al Ain compared to ULG-91 and diesel. The increase of gasoline fuel consumption is attributed to increase of vehicles volume in Al Ain city during 2007-2009.

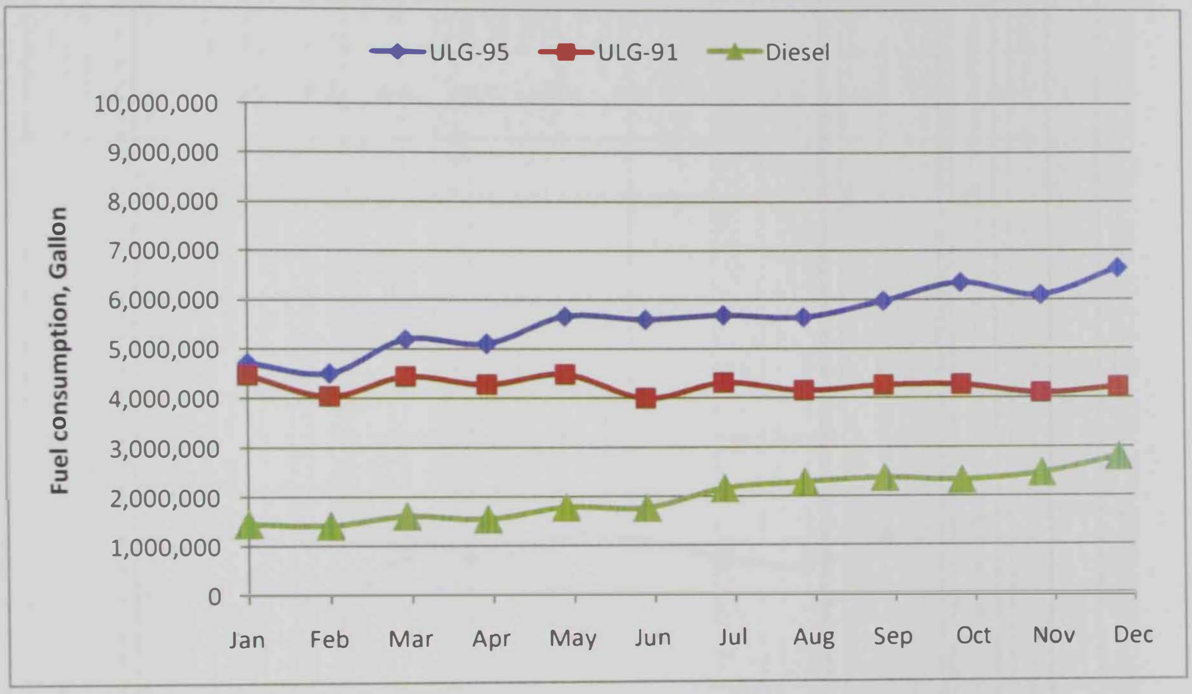

Fig. 5.8: Gasoline and diesel consumption in Al Ain in 2007

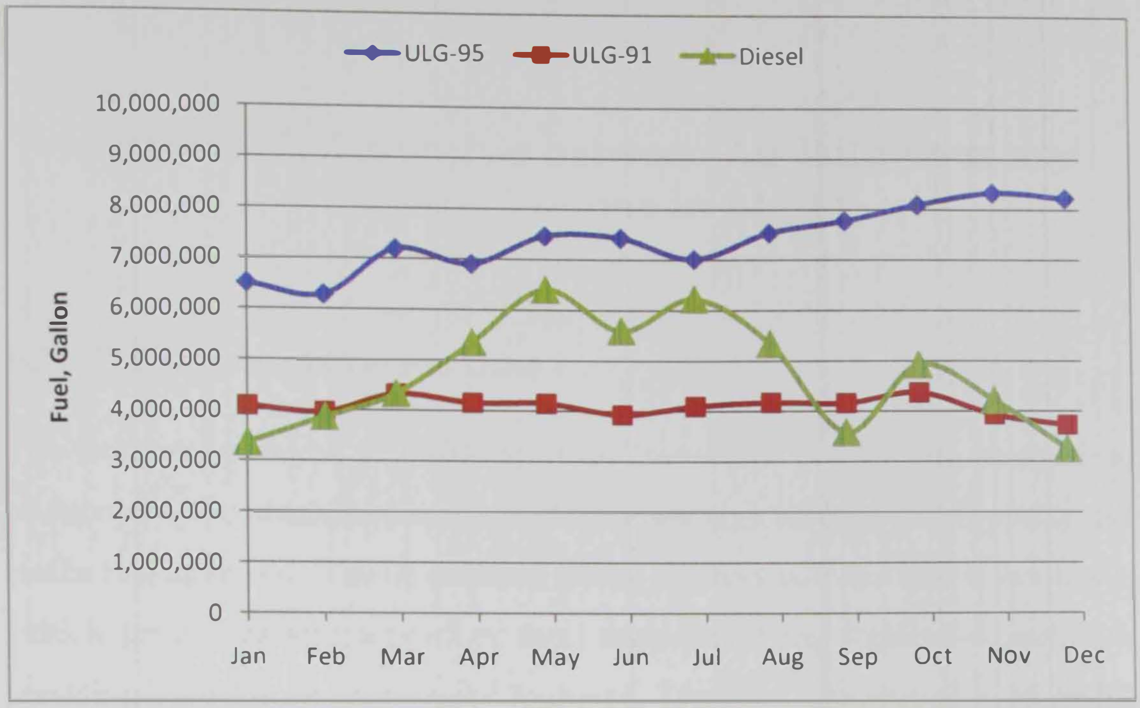

Fig. 5.9: Gasoline and diesel consumption in Al Ain in 2008

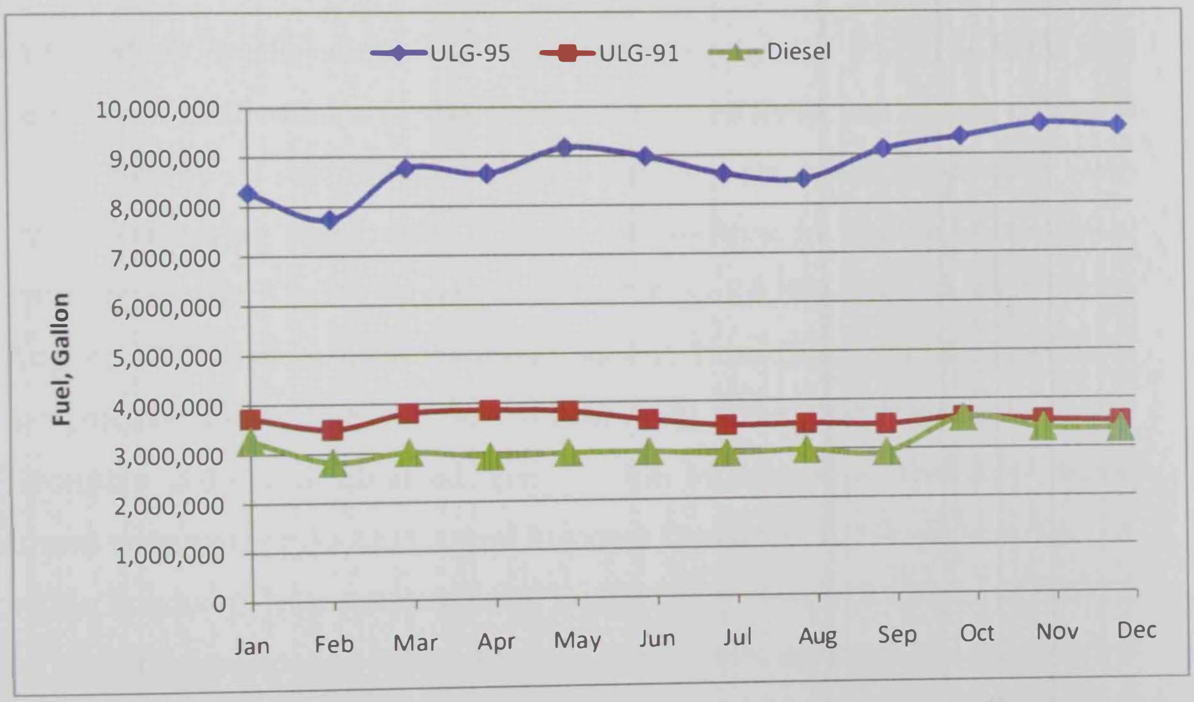

Fig. 5.10: Gasoline and diesel consumption in Al Ain in 2009

Chapter 6: Relationship between Air Pollutants and Traffic Volume in Al Ain

6.1 Traffic counts versus time

The temporal patterns of traffic are very important in planning in order to understand the characteristics of traffic series and further develop effective traffic management. Traffic patterns can be defined as those characteristics of vehicle groups passing a point or short segment during a specified period or traveling over longer sections of highway. Typically, investigation of traffic patterns significantly reduces congestions (Varaiya, 2005). Additionally, traffic time series data are measured in different time scales for different purposes such as planning of infrastructure facilities (Lan et al., 2007).

In this study, traffic counts were undertaken in the downtown area (Al Ain Street). The residential area was excluded from analysis due to lack of traffic counts nearby Al Ain School Station. Traffic counts in the downtown were conducted during April, 2009 at three intersections in Khalifa Street. Also, traffic counts at Khalifa Street (from RA106 to RA107) were carried out in August, 2008 to investigate the traffic pattern. In addition, traffic counts data at 9 intersections within and on the boundary of the downtown area during December 2006 were obtained from Al Ain Municipality. The latter traffic counts were part of Al-Ain Central Business District (CBD) Project carried out by the Roadway Transportation and Traffic Safety Research Center (RTTSRC) for Al Ain Municipality. However, the traffic counts are available only for one day for each intersection, in December 2006 and five days for Roundabout number 106 (close to Al Ain Street station), in April 2009 and they cover only the peak hours. Traffic data at Khalifa Street intersections were predicted for 2008 based on the traffic counts of 2006 and assuming an annual increase in traffic volume of 4%. This percentage was estimated based on previous traffic studies conducted for Al Ain (Al Ain CBD project; Al Ain School Zone; and Traffic Impact Study for Nadood Jeham), (RTTSRC, 2006; 2007).

Figure 6.1 shows the total hourly traffic at Khalifa Street (from RA106 to RA107) in each direction for some of the weekdays (Wednesday and Thursday) and weekend (Friday and Saturday) in August 2008. The figure shows two main peaks. The first peak occurred at 9:00, reaching maximum traffic counts at 12:00, followed by a major decrease until 16:00 in the afternoon, then quickly increased until 19:00 and the second peak value occurred at 21:00. After that, traffic counts decreased sharply until it reached a minimum value for the whole day at 5:00. The figure also shows that there are some variations in traffic volume between the weekdays and weekends. This appears obviously on Friday, where most of the government offices and private sectors are off. Statistical analysis using Kruskal Wallis Test showed that there is statistically a difference between traffic counts during the weekdays and weekends with a p-vale less than 0.05. Note that the traffic counts in this figure are much less than those in figure 6.2. This is because the vehicles turning left, through and right are not considered here.

Figure 6.2 shows the average traffic volume at three intersections at Khalifa Street during 2007-2009. Despite the increase in the predicted average traffic volume in 2008, the actual average traffic volume of 2009 has decreased. This is probably due to construction activities related to intersections at Khalifa Street during 2009, where the street was narrowed into a one lane in both directions.

Figure 6.3 shows how traffic flow varies over the day at various intersections in the downtown area during December, 2006. It can be seen that all intersections have almost the same traffic pattern, with two peak hours; 10-11am and 8-9pm. However, the T-Signal-108 intersection has the highest traffic volume compared to other intersections.

Figure 6.4 shows the hourly traffic volume at Khalifa Street RA-106 intersection during five days in April, 2009. The traffic volume has almost the same pattern as that in 2007. The highest traffic volume has been recorded on Sunday. However, there is a slight difference in the traffic volume throughout the weekdays (Sunday-Thursday).

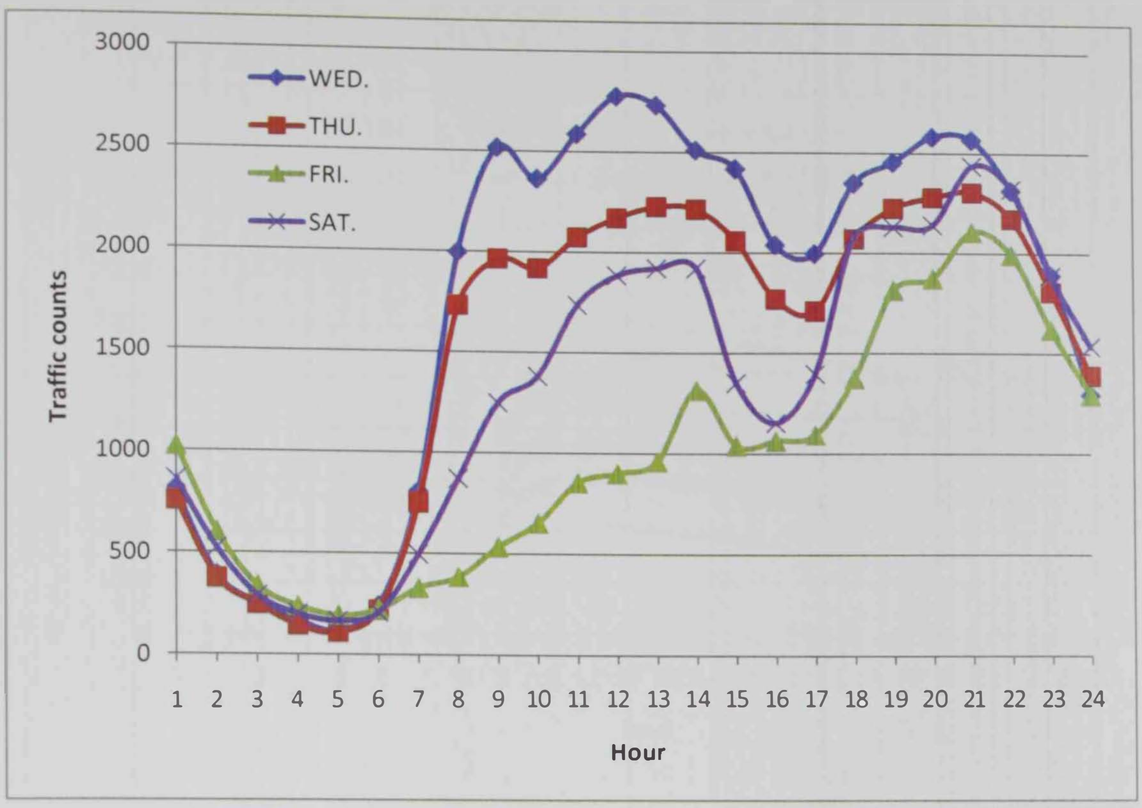

Fig. 6.1: Total hourly traffic at Khalifa Street (from RA106 to RA107) for weekdays and weekends in August, 2008

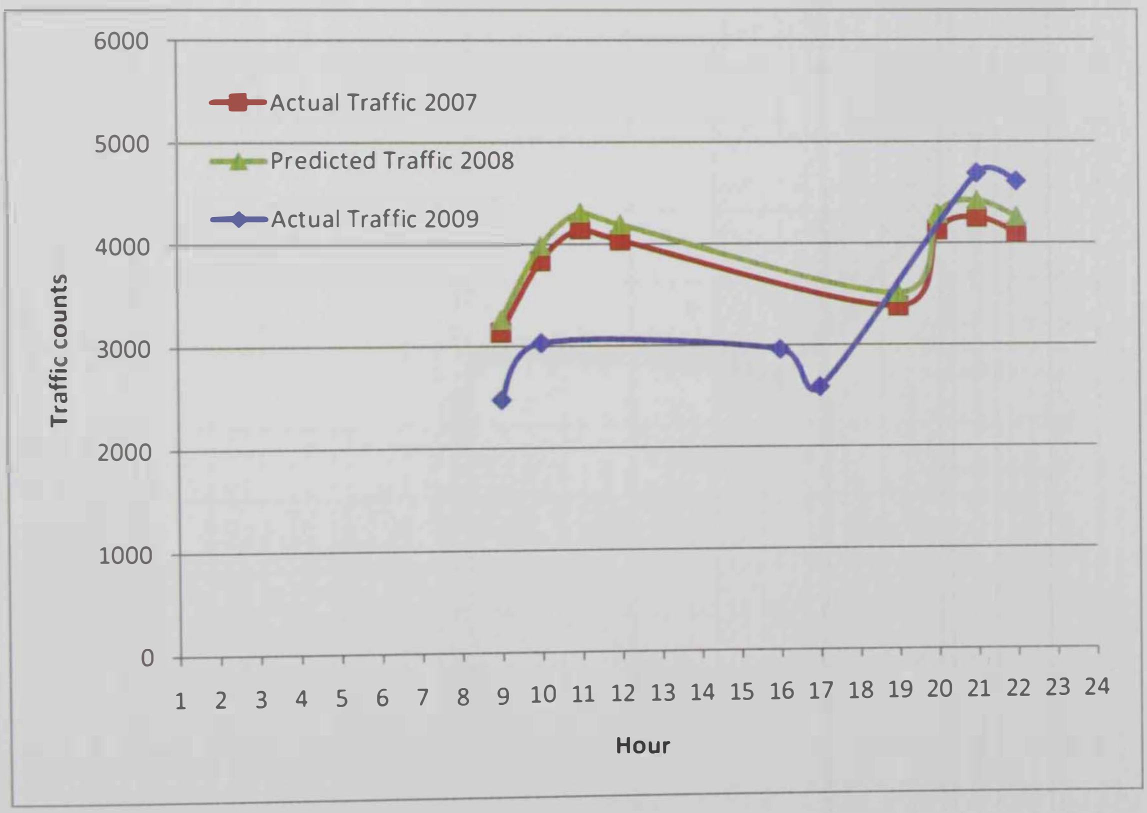

Fig. 6.2: Hourly traffic volume at Khalifa Street during 2007-2009

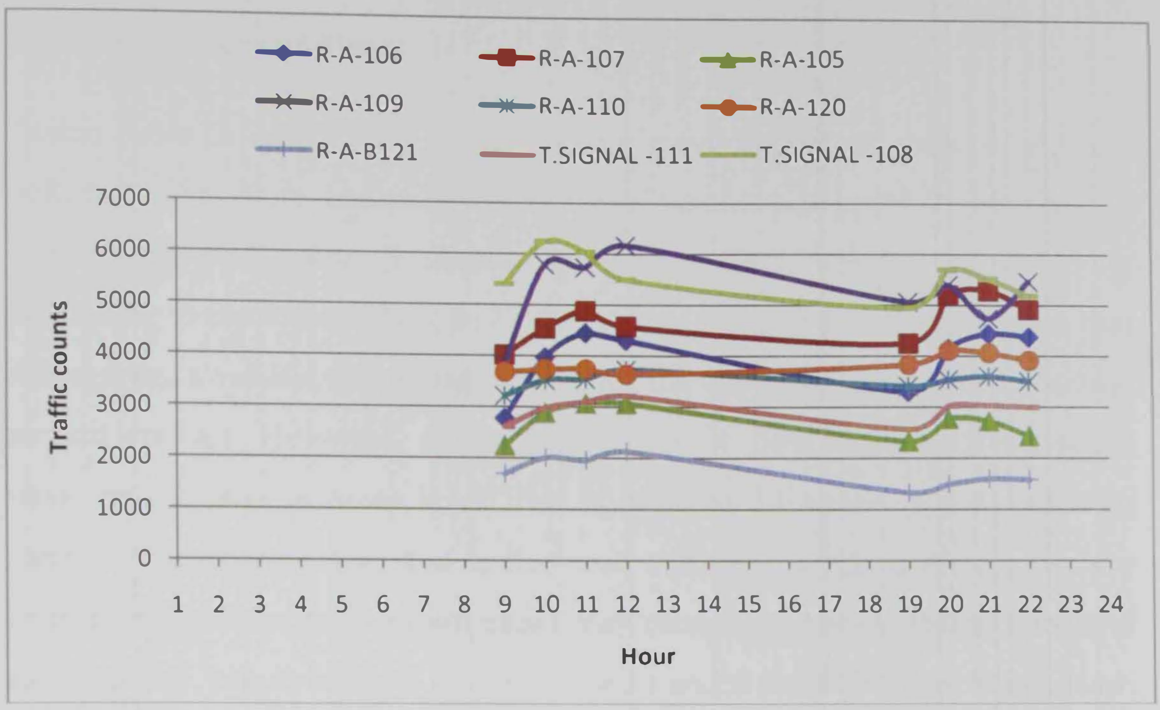

Fig. 6.3: Hourly traffic volume at different intersections in the downtown area during December, 2006

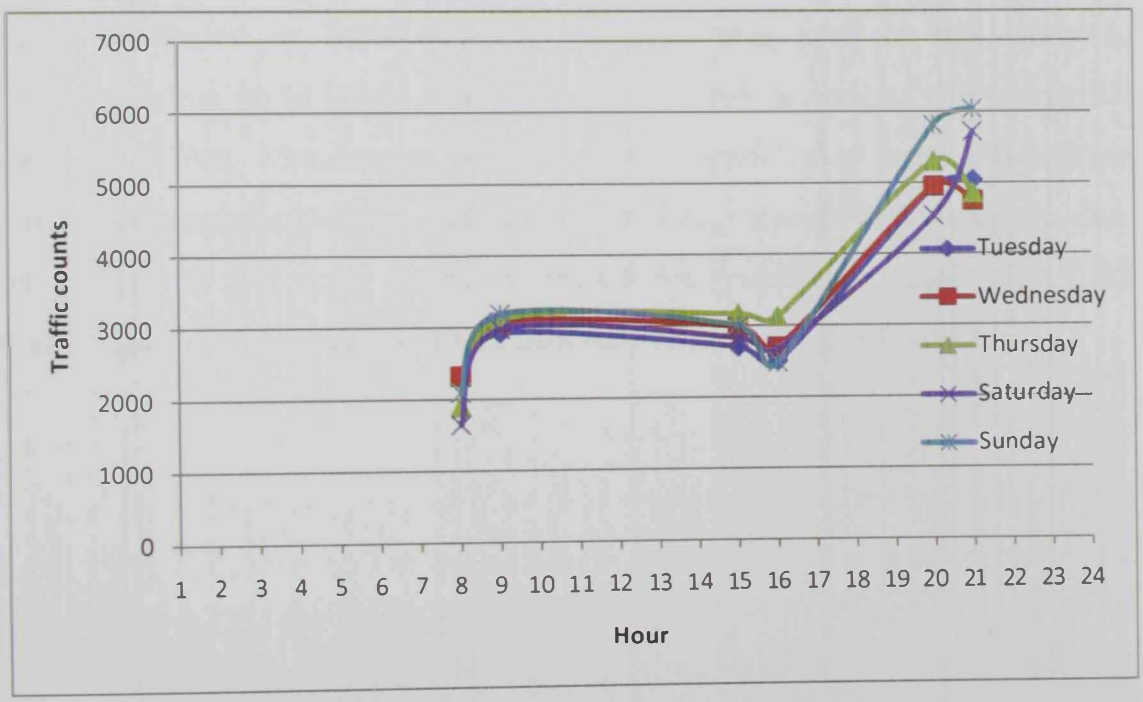

Fig. 6.4: Hourly traffic volume at Khalifa Street (RA-106) during five days in April, 2009

6.2 Noise versus time

Traffic noise is considered as one of the most important sources of noise pollution. The daily equivalent noise levels can reach up to 75-80 dBA on densely traveled roads (Williams and Creae, 1995; Yoshida et al., 1997). According to Stoilova and Stoilov (1998), there are many sources of noise that comes from a vehicle, including the engine, the transmission and the tire-road surface contact. However, an increase in traffic flow does not necessarily mean an increase in noise level. This is because the speed is reduced with congestion causing noise due to tire-road surface contact to reduce. Noise from moving vehicles in urban areas may cause annoyance, deterioration of sleep quality, interference to communication and stress-related ischemic heart disease (Morrell et al., 1997; Stoilova and Stoilov, 1998).

In the UAE, Law No. 12 of 2006, concerning the protection of air from pollution, has set standards for the ambient noise levels specific to different areas as shown in Table 6.1. This standard was used in this study to investigate the noise levels in the downtown area as well as the residential area of Al Ain. Monitoring locations at the School and Street Station are classified as residential area and downtown area, respectively. Therefore, they are subject to the noise limits prescribed for "residential areas with light traffic" and "commercial areas and downtown" as defined in Table 6.1.

Table 6.1: Allowable limits of noise level in different areas (FEA, 2006)

Area	Allowable limits for noise level (dBA)*	
	Day (7 a.m. - 8 p.m.)	Night (8 p.m. - 7 a.m.)
Residential areas with light traffic	40 - 50	30 - 40
Residential areas in the downtown	45 - 55	35 - 45
Residential areas which include some workshops and commercial business or residential areas near the highways	50 - 60	40 - 50
Commercial areas and downtown	55 - 65	45 - 55
Industrial areas (heavy industry)	60 - 70	50 - 60

*dBA means decibels adjusted. dBA is used for determining the sound exposure to humans.

In this study, hourly equivalent noise measurements were collected from Al-Ain downtown area (Al Ain Street Station) and the residential area (Al Ain School Station) during 2007-2009. Table 6.2 shows the descriptive statistics of noise measurements at the two stations during 2007-2009. It can be seen that the noise level at the downtown was much higher than the noise level at the residential area. The average noise level at the downtown was 63.5 dBA, while in the residential area the average noise level was 49.7 dBA. The variations in noise levels between the two locations are probably due to variations in traffic volumes as well as variations in other population-related activities.

The noise levels ranged between 50.7 and 74.7dBA in the downtown area, whereas the noise level in the residential area ranges between 43.7 and 67.4 dBA. On the other hand, the noise measurements at the two stations approximately exhibit a normal distribution. This is clear from the skewness and kurtosis values of the two locations. Figure 6.5 shows that there are differences in the noise distributions between the two locations.

Figure 6.6 shows the daily average noise levels at the residential area (Al Ain School Station) during 2007-2009. The noise level fluctuated around 50dBA during the months of 2007, 2008 and 2009. Also, the hourly average noise level has the same fluctuation around 50dBA for a 24-hour period during 2007, 2008 and 2009 as shown in Fig. 6.7. According to the noise standard limits for "residential areas with light traffic", these values are considered as the upper noise limit permitted in the daytime and exceed the upper noise limit for the nighttime. The high level of noise in Al Ain School Station is attributed to the movement of wind, since the traffic volume in this area is very low.

Figure 6.8 shows the daily average noise levels at the downtown area (Al Ain Street Station) during 2007-2009. It was found that the monthly average noise level fluctuated around 61dBA during 2008 and 2009, and fluctuated around 67dBA during 2007. Also, the hourly average of the noise level has the same fluctuation (i.e., around 61dBA during 2008 and 2009, and 67dBA during 2007) as shown in Fig. 6.9. The noise level in 2007 was higher than that in 2008 and 2009. It seems that there is an error in noise reading in 2007 as it remained almost around 67 dBA, which is very high level of noise. Also, it can be seen that the noise levels decreased at late night to reach an average of 55 dBA, whereas at day-time the noise level increased to reach 65 dBA in 2008 and 2009. This behavior is probably due to variation in traffic volume between daytime and nighttime. On the other hand, the daytime noise levels at the downtown were in compliance with the noise standard limits with an average of 63 dBA. The night time noise levels, however exceeded the 55 dBA noise standard for "commercial areas and downtown".

Table 6.2: Descriptive statistics of noise at the two monitoring stations in Al Ain

Statistic Analysis	Al Ain School				Al Ain Street			
	2007	2008	2009	Overall	2007	2008	2009	Overall
Mean	49.6	49.8	49.5	49.7	67.4	62.2	61.8	63.5
5% Trimmed Mean	49.6	49.7	49.5	49.7	67.4	62.3	62	63.6
Median	49.5	49.7	49.4	49.6	67.6	62.7	61.6	63.7
Std. Dev.	1.6	1.7	2.3	1.9	1.5	2.7	3.0	3.5
Minimum	45.6	45.1	43.7	43.7	62.5	50.7	52	50.7
Maximum	58.6	58.1	67.4	67.4	74.7	70.7	73.5	74.7
Skewness	0.65	0.55	0.53	0.52	-0.33	-0.75	-0.4	-0.36
Kurtosis	0.75	0.46	2.0	1.8	1.48	1.42	-0.45	-0.13

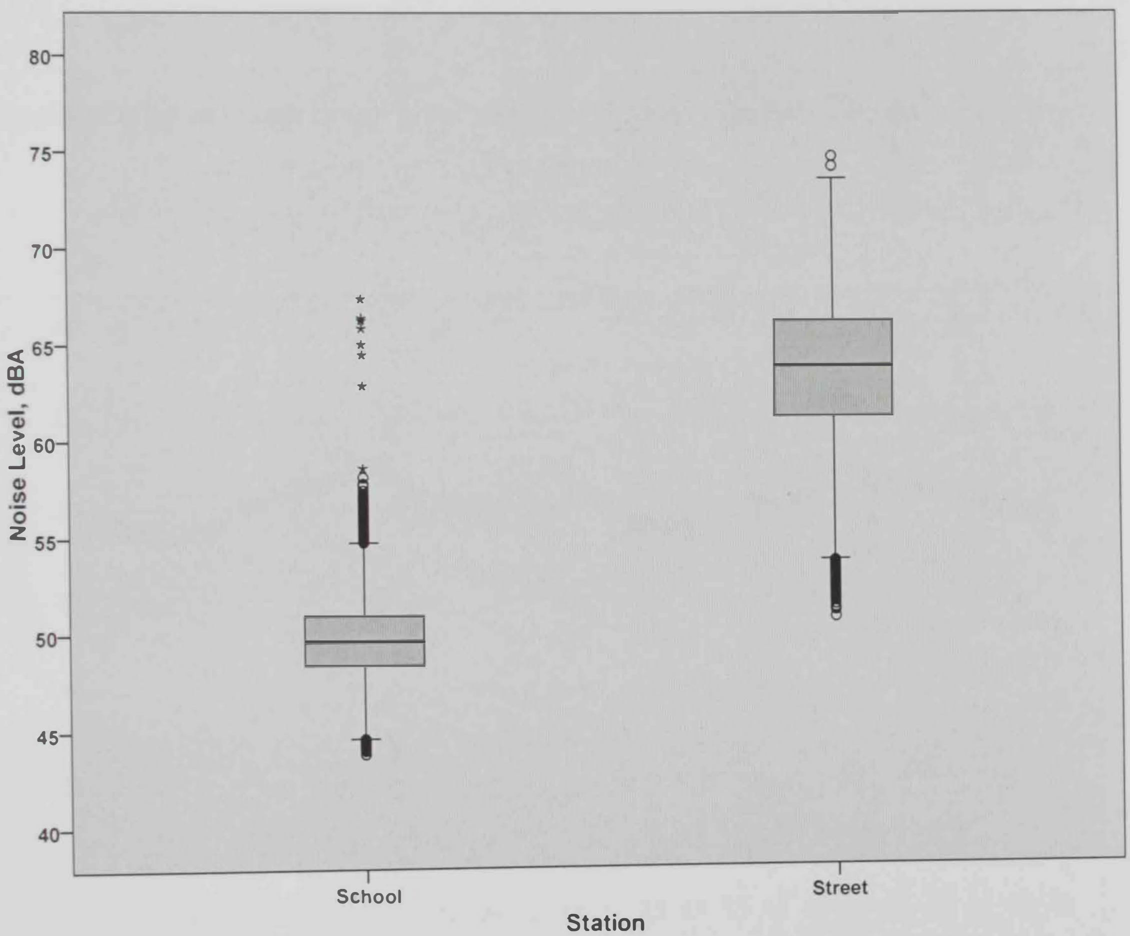

Fig. 6.5: Noise level at the two stations in Al Ain during 2007-2009

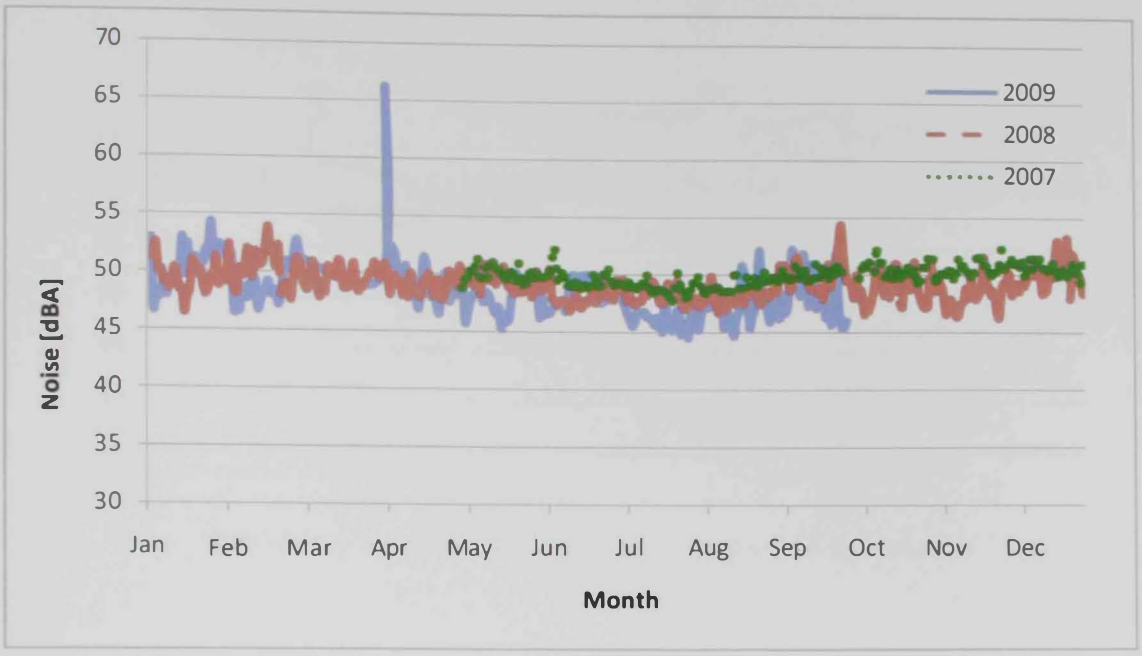

Fig. 6.6: Daily average noise level measured at Al Ain School Station during 2007-2009

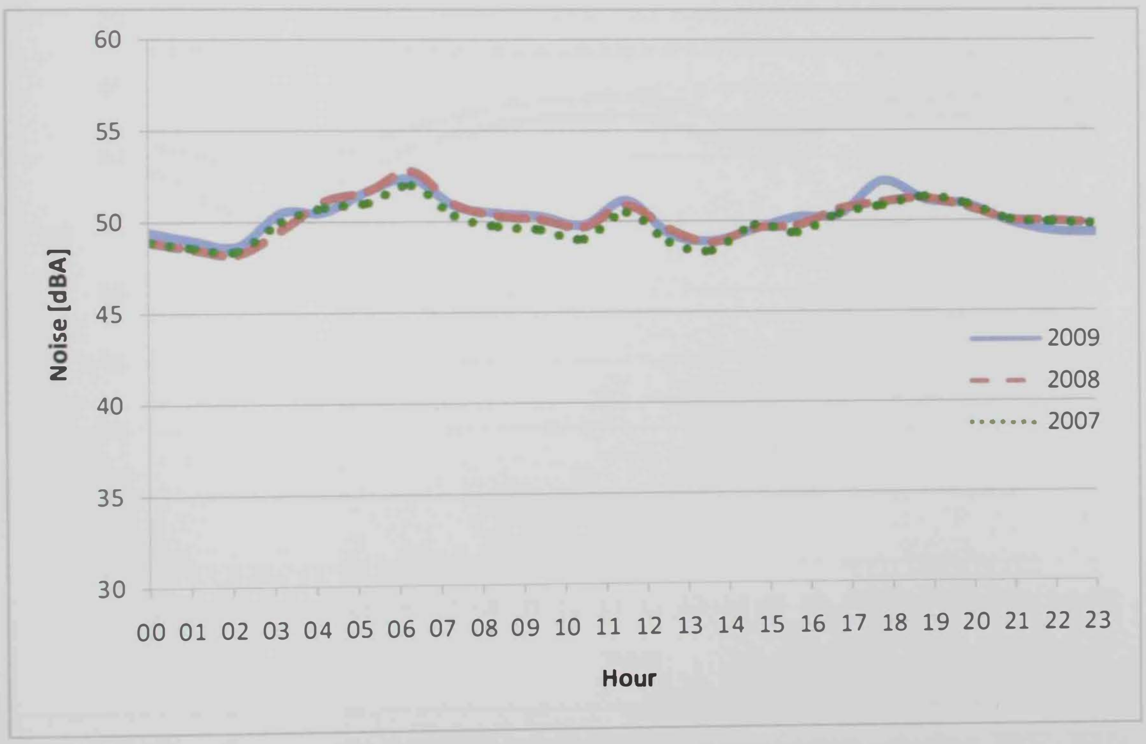

Fig. 6.7: Hourly average noise level at Al Ain School Station during 2007-2009

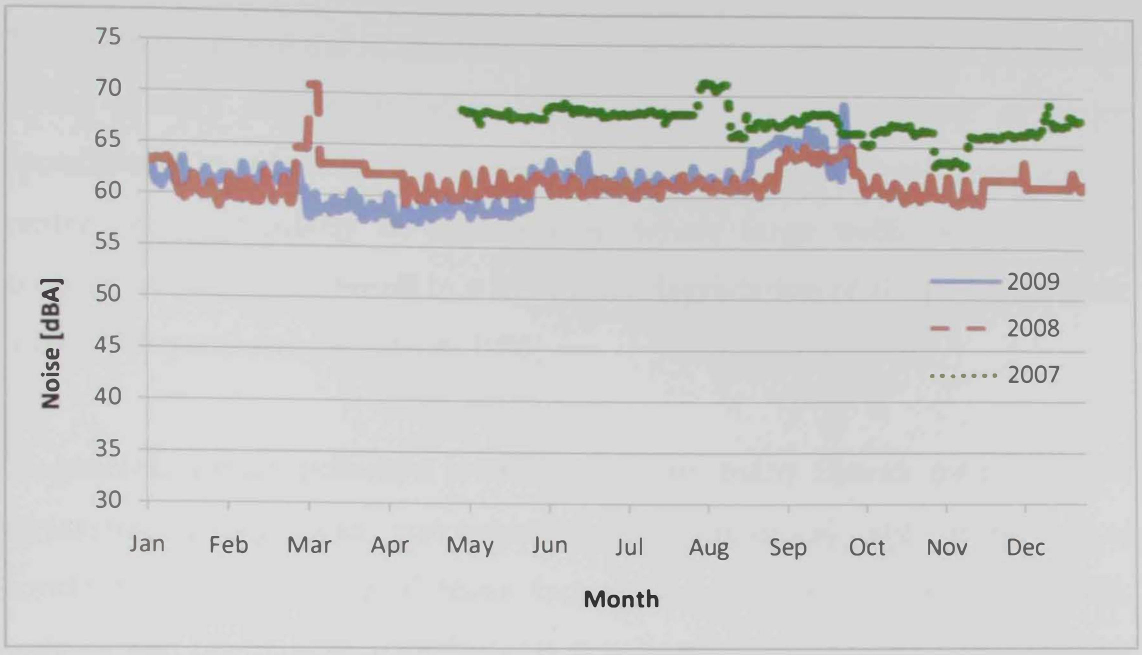

Fig. 6.8: Daily average noise level at Al Ain Street Station during 2007-2009

Fig. 6.9: Hourly average noise level at Al Ain Street Station during 2007-2009

6.3 Pollutants versus traffic count

The investigation of the relationship between traffic volume and air pollutants levels is very important, since road vehicles are considered as major contributors to urban air pollution. This relationship is most severe in city centre and particularly at intersections, where large traffic volumes and congestion commonly result in a significant degradation of air quality in these areas (Oduyemi and Davidson, 1998).

In general, the air pollutant levels depend on many factors mainly; traffic emissions, background concentration, meteorological and geographical conditions, etc. Because of these factors, the relationship between traffic volume and the level of air pollutants is very complex and strongly nonlinear (Elsplin, 1994).

In this section, the relationship between the actual traffic volume and corresponding air pollutants levels was investigated using time series analysis. Since the actual traffic data are only available for five days in April, 2009, the whole analyses will be based only on these days. Hourly averages were calculated for each pollutant at the corresponding traffic hours during this week. Also, the traffic volumes for the five days were averaged, since the traffic patterns are almost similar for the five days. In addition, the Roundabout No. 106 at Khalifa Street will be the focus of these analyses, as it is the closest to Al Ain Street Station. Pollutant levels were examined two weeks before and after the week during which the actual traffic data were collected to make sure that they have the same patterns.

Carbon Monoxide (CO):

Figure 6.10 shows the hourly average traffic volume and carbon monoxide concentrations level at Al Ain Street Station during the 7-12 April, 2009. It was noticed that the CO level starts accumulating during the day, beginning from 5-6 am, reaching the first peak value at 7:00am. This is probably due to the cold start of vehicle engines. Then, the CO level remained almost steady until 12:00 Noon. Afterward, it decreased to a low value at 15:00, when almost all the markets close and traffic volume is very low. It then starts accumulating as markets start opening, until it reached a second peak value at 19:00. After that, it decreased sharply till 21:00 and then increased significantly to a late night-time peak at 23:00 and decreased slowly until it reached the minimum of the whole day at 5:00.

Figure 6.10 also shows that there is a lag between CO level and traffic volume. This indicates that the CO level was not only attributed to emissions from vehicles but there were other sources of CO including downtown restaurants, which emit CO from burning coal during cooking. To confirm this, the CO level was plotted versus traffic volume during the first week of Ramadan (25 to 30 August, 2009). Fig. 6.11 shows that the CO level was higher in the afternoon, reaching the maximum value at 16:00, and also late night at 2:00am, though the traffic flow was the lowest at these times. This may indicate that other activities including restaurants close to the monitoring station at Khalifa Street contribute to a high level of CO concentration.

Nitrogen dioxide (NO_2):

Figure 6.12 shows the hourly average traffic volume and NO_2 level at Al Ain Street Station during 7- 12 April, 2009. The NO_2 concentration exhibits almost a similar daily average pattern as CO, with three-peak values. The first peak appears at 6:30, and then remained almost unchanged until 14:00; afterward it decreased to a low value at 15:00, and then quickly increased until it reached the second peak value at 18:00. After that, it decreased till 20:30 and then increased to a late night-time peak at 23:00. Following that it decreased slowly till it reached its minimum value at 4:00.

There was also a lag between NO_2 level and traffic volume as shown in Fig. 6.12. It seems that the NO_2 is not only attributed to traffic but there were other sources emitting NO_2 such as restaurants. Again, to confirm this, the NO_2 level was plotted versus traffic volume during the first week of Ramadan (from 25-30 August, 2009). Fig. 6.13 shows that the NO_2 level was higher at late night, reaching the maximum value at 24:00, and also in the afternoon at 12:00, though the traffic flow was the lowest at these times. This may indicate that other activities like restaurants close to the monitoring station at Khalifa street contribute to a high level of NO_2 concentration.

It should be noted that the analysis presented previously on the correlation between air pollutants demonstrated a strong positive relationship between NO_2 and CO levels. The statistical analysis using Pearson correlation coefficient showed that the NO_2 and CO were highly correlated ($r = 0.74$) with a significant p-value at the 0.01 level.

Sulphur dioxide (SO_2):

Figure 6.14 shows the hourly average traffic volume and SO_2 levels at Al Ain Street Station during 7- 12 April, 2009. The SO_2 variation pattern is different from those of CO and NO_2. It began to increase at 7:00 in the morning, reaching a maximum value at 13:00, and then slowly decreased with little fluctuations until it reaches a minimum value at 2:00. It seems that the SO_2 doesn't change much with traffic, which implies that the influence of traffic is minimal. Therefore, the relationship between SO_2 level and traffic volume is weak, probably due to the low sulphur in the used unleaded gasoline. Only vehicles, which use diesel as a fuel such as heavy and light buses and pickups, could contribute to the emissions of SO_2. Note that the sulphur content in diesel fuel in Abu Dhabi Emirate is now 500 ppm. Another significant source of SO_2 at Khalifa Street could be burning coal at restaurants that may be intensive during lunch and evening meal time.

Particulate matter (PM_{10}):

Figure 6.15 shows the hourly average of traffic volume and PM_{10} levels at Al Ain Street Station during 7-12 April, 2009. From 7:00, PM_{10} began to increase and reached the first peak at 11:00 followed with a gradual decrease until 17:00, then remained steady for two hours before it increased sharply at 19:00 and reached its maximum peak value at 24:00. After that, it slowly decreased during late night until it reached its low value at 6:00. From this pattern, it can be noted that there is a lag (shift to the right) in the increase of PM_{10} compared to the increase in traffic volume. This shift could be due to a lag between the time particulates are agitated and released from the street surface and the time of detection at the monitoring station. That is obvious at 7:00 and 19:00, when the traffic flow starts to increase, PM_{10} starts to accumulate in the atmosphere, then it remains in the air for a while, followed by gradual decrease at late times due to a low traffic volume and then it is agitated again by traffic to start accumulating in the atmosphere. This is an indication that traffic has an influence on the PM_{10} concentration in the ambient air, although not all PM_{10} could have resulted from car emissions.

Hydrocarbons (HCs):

Figure 6.16 shows the hourly average traffic volume and BTX level at Al Ain Street Station during 7-12, 2009. The BTX levels start accumulating during the day, beginning from 5-6 am, reaching the first peak value at 7:00am. This is probably due to cold start of vehicle engines. Then, the BTX level remained almost steady until 14:00. Afterward, they decreased to a low value in the afternoon at 16:00 and then sharply increased until they reached a second peak value at 20:00. BTX then slowly decreased during the late times until they reached the lowest value at 5:00. All BTX exhibited the same pattern of concentration variation during the day, although the levels of each individual compound differ from the others.

The BTX concentrations found at Al Ain Street Station are generally related to the automobile exhaust emissions in Al Ain downtown area, consistent with the findings of others (Truc and Oanh, 2007; Kerbachi et al., 2006; Lee et al., 2002; Grosjean et al., 1998; Zielinska et al., 1996). Figure 6.17 shows the BTX levels in Al Ain downtown during the first week of Ramadan (25-30 August, 2009). It was obvious that the BTX levels in Ramadan were lower, by about 50%, compared with their levels in other days (Fig. 4.16). This is probably due to traffic volume reduction during Ramadan.

It can be noted that toluene concentrations were higher than other BTX pollutants (Fig. 6.16 and 6.17), followed by benzene, then m- and p-xylene and xylene. Benzene accounts for an average of 18% of the total BTX while toluene contribution is 40% and all the xylene compounds account for approximately 42%. It is interesting to notice that ethylbenzene (E) was not detected at the monitoring station during this week. This is probably due to inability or calibration of sensor during that week. The BTX profiles show similarity in compounds concentrations variation at Al Ain Street Station. Such profile is similar to that of road traffic variation, suggesting that these compounds originate from the same source (i.e. traffic vehicles).

Toluene to benzene ratio (T/B) is frequently reported by researches in investigating hydrocarbons sources. Lee et al. (2002) mentioned that the Hong Kong and other Asian cities have relatively large (T/B) ratio (i.e. T/B ≈ 5-10). Gee and Sollars (1998) recommended that there are large additional sources of toluene in these cities or that there are major differences in the fuels or vehicles used. In Al Ain downtown, the (T/B) ratio is about 2.5 during 2007-2009. This ratio is similar to that reported by Brocco et al. (1997) for vehicle emission in the urban area of Rome. In addition, Wang et al. (2002)

mentioned that previous studies representing motor vehicle emissions found B/E ratios typically < 5 and T/E ratios < 6. In Al Ain downtown, the ratios of B/E and T/E are 1.2 and 2.6, respectively during 2007-2009. These results confirm the significant contribution of traffic-related emission to BTX pollution in Al Ain downtown area.

As shown in Table 6.3, benzene, toluene, m- and p-xylene and xylene correlations were evaluated using Pearson correlation coefficient. It can be seen that there is a strong positive correlations between the BTX ($p<0.01$), with Pearson correlation coefficient (r) ranged from 0.85 to 0.975 at a significant level of 0.01. The strong correlations among the aromatic hydrocarbons in Al Ain downtown indicate that they came mainly from a single source, most possibly traffic-related emissions. However, other non-traffic sources of BTX such as cooking at restaurants using kerosene may have contributed to the levels of these compounds.

In summary, it can be concluded that the BTX pattern and correlation analysis indicate that their level in the ambient air in Al Ain downtown is mainly influenced by road traffic.

Table 6.3: Summary of BTX correlations

Correlations

		Benzene	Toluene	Xylene	mpXylene
Benzene	Pearson Correlation	1	.963**	.918**	.850**
	Sig. (2-tailed)		.000	.000	.000
	N	24	24	24	24
Toluene	Pearson Correlation	.963**	1	.975**	.949**
	Sig. (2-tailed)	.000		.000	.000
	N	24	24	24	24
Xylene	Pearson Correlation	.918**	.975**	1	.969**
	Sig. (2-tailed)	.000	.000		.000
	N	24	24	24	24
mpXylene	Pearson Correlation	.850**	.949**	.969**	1
	Sig. (2-tailed)	.000	.000	.000	
	N	24	24	24	24

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

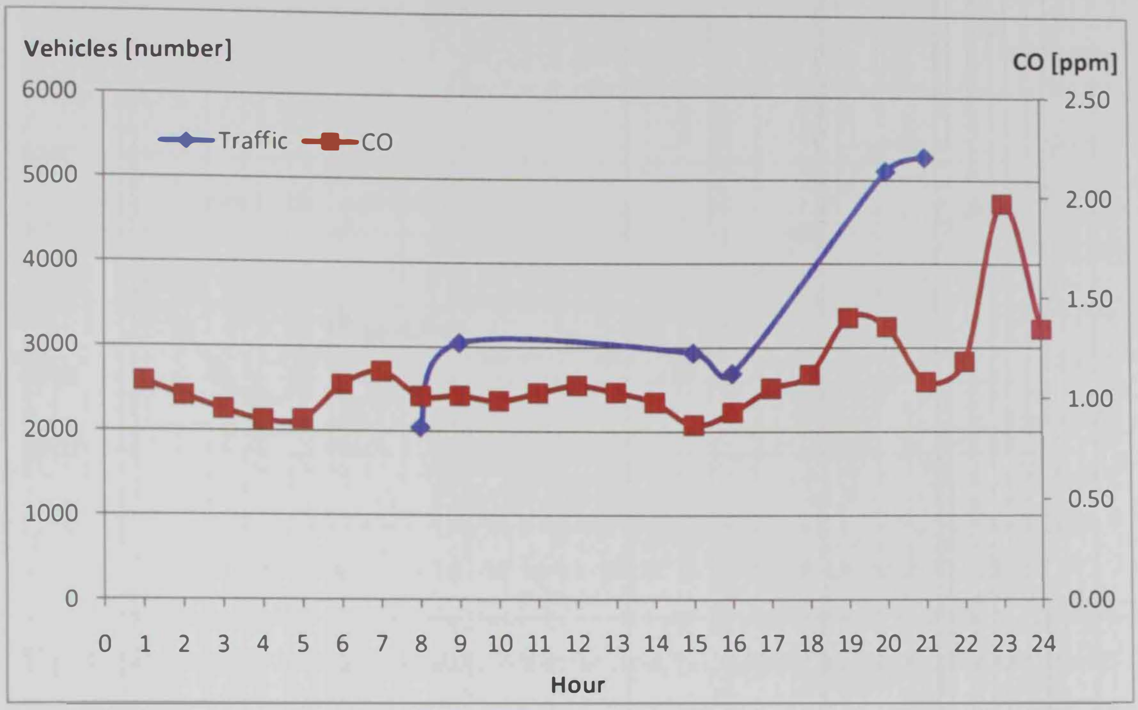

Fig. 6.10: Hourly average traffic volume and CO level in Al Ain downtown during 7-12 April, 2009

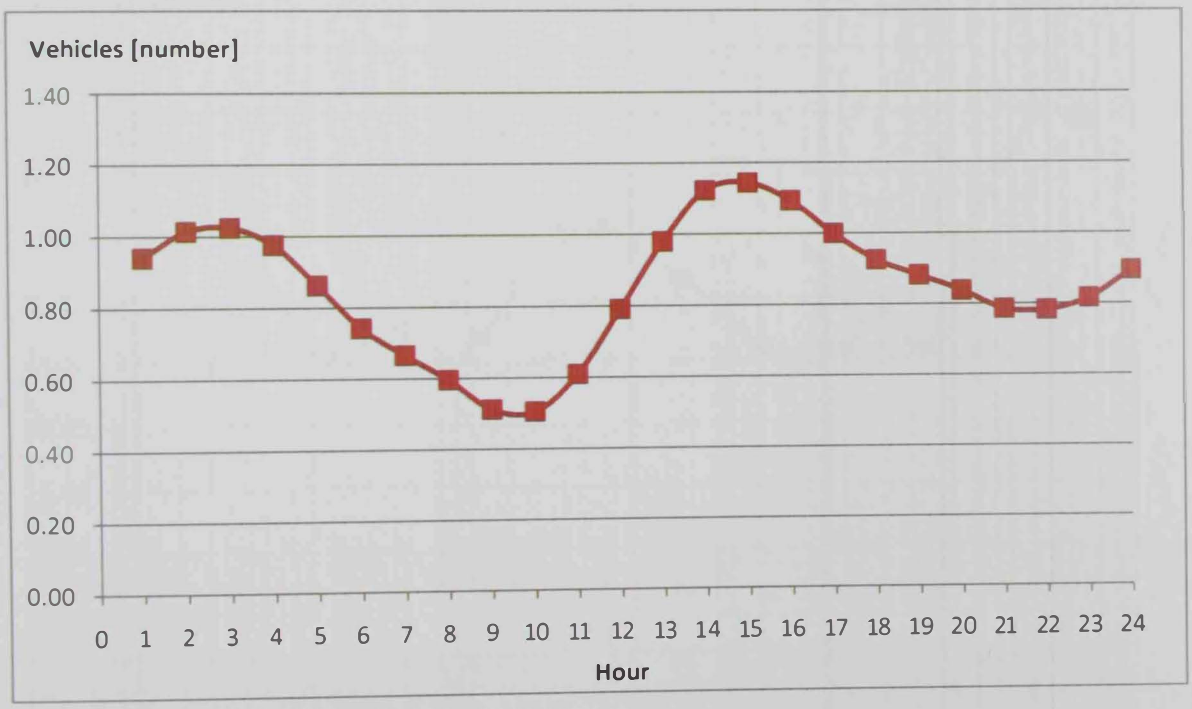

Fig. 6.11: Hourly average traffic volume and CO level in Al Ain downtown during the first week of Ramadan, 25-30 August, 2009

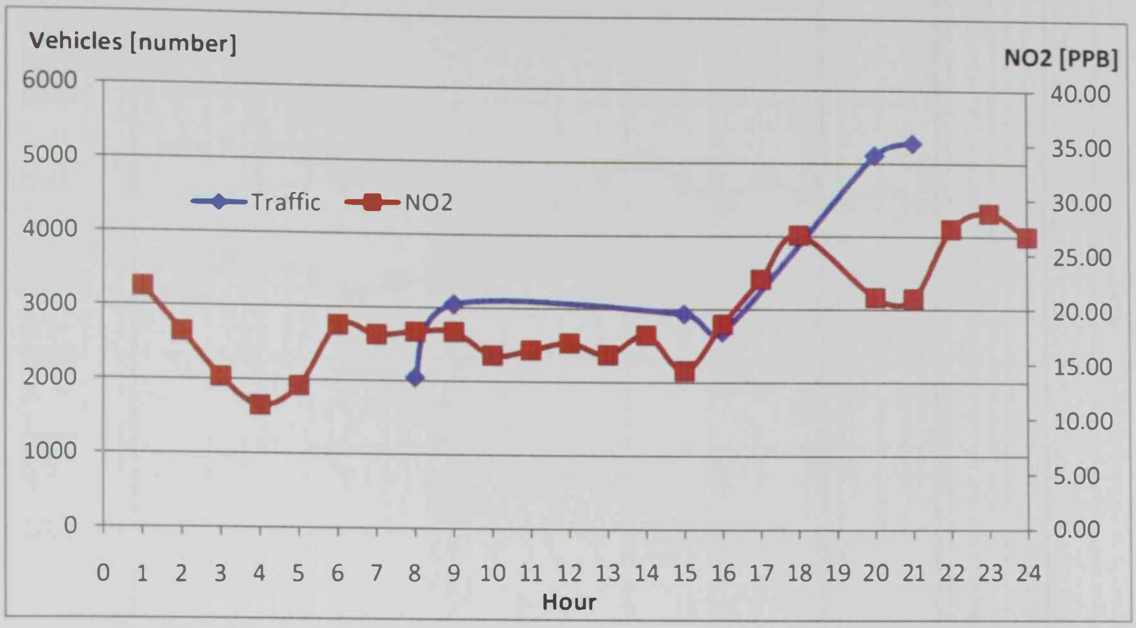

Fig. 6.12: Hourly average traffic volume and NO_2 level in Al Ain downtown during 7-12 April, 2009

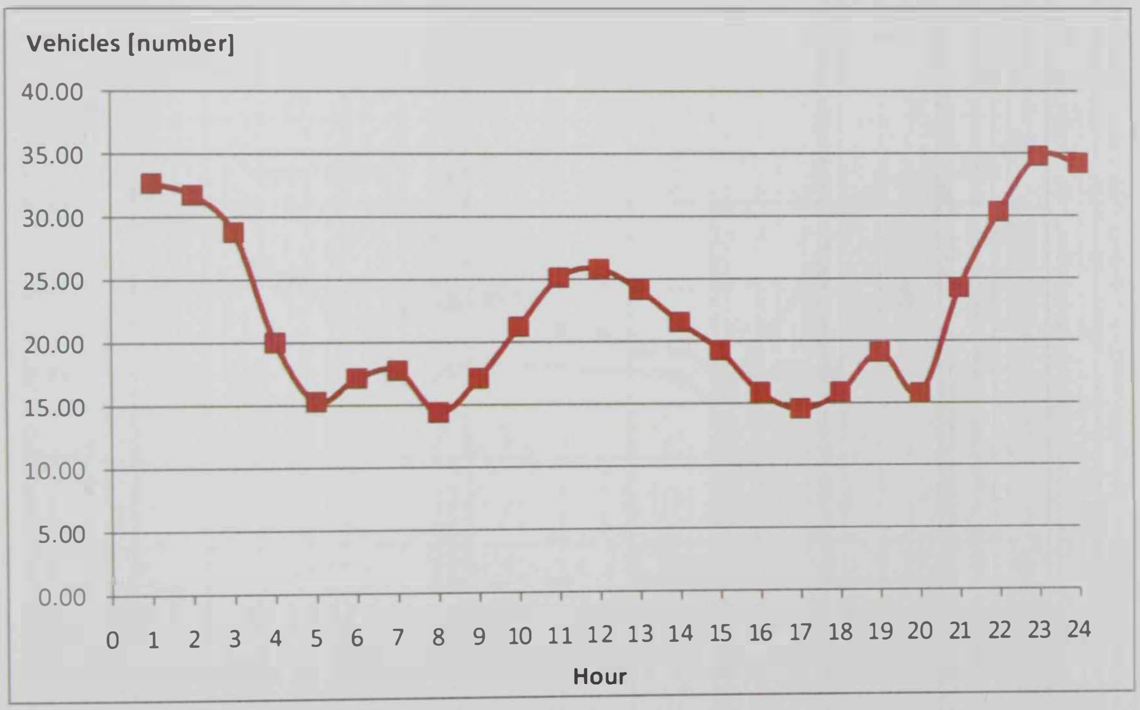

Fig. 6.13: Hourly average traffic volume and NO_2 level in Al Ain downtown during the first week of Ramadan, 25-30 August, 2009

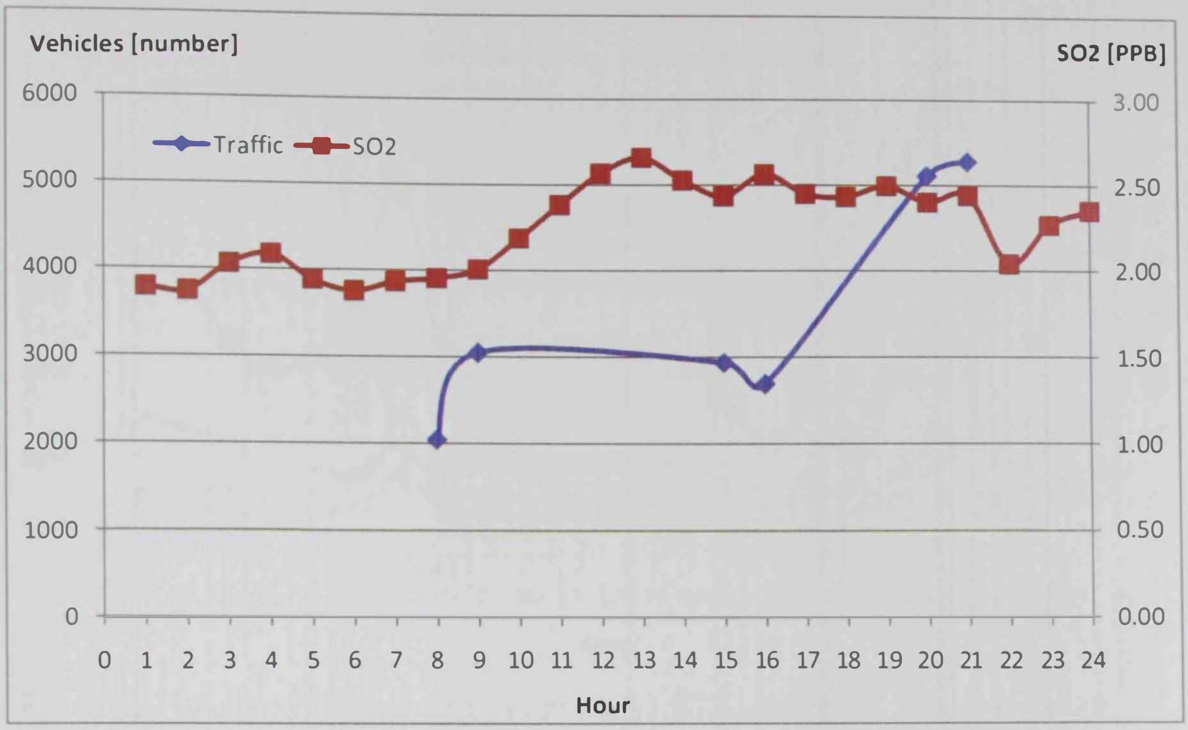

Fig. 6.14: Hourly average traffic volume and SO_2 level in Al Ain downtown during 7-12 April, 2009

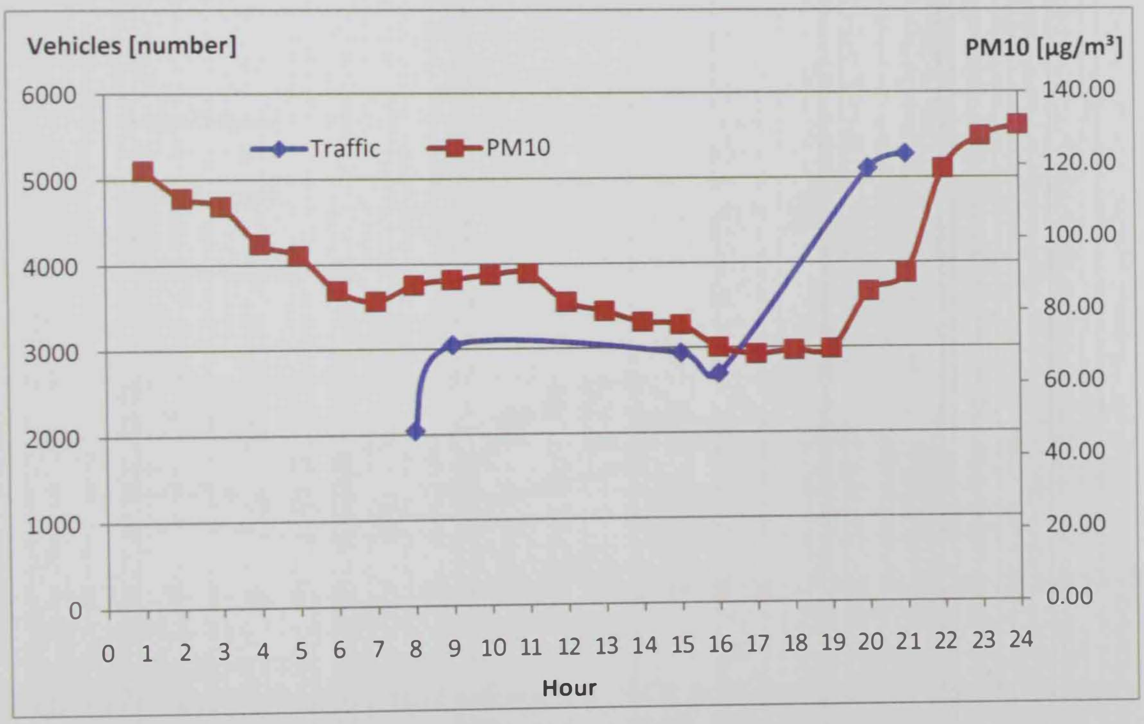

Fig. 6.15: Hourly average traffic volume and PM_{10} level in Al Ain downtown during 7-12 April, 2009

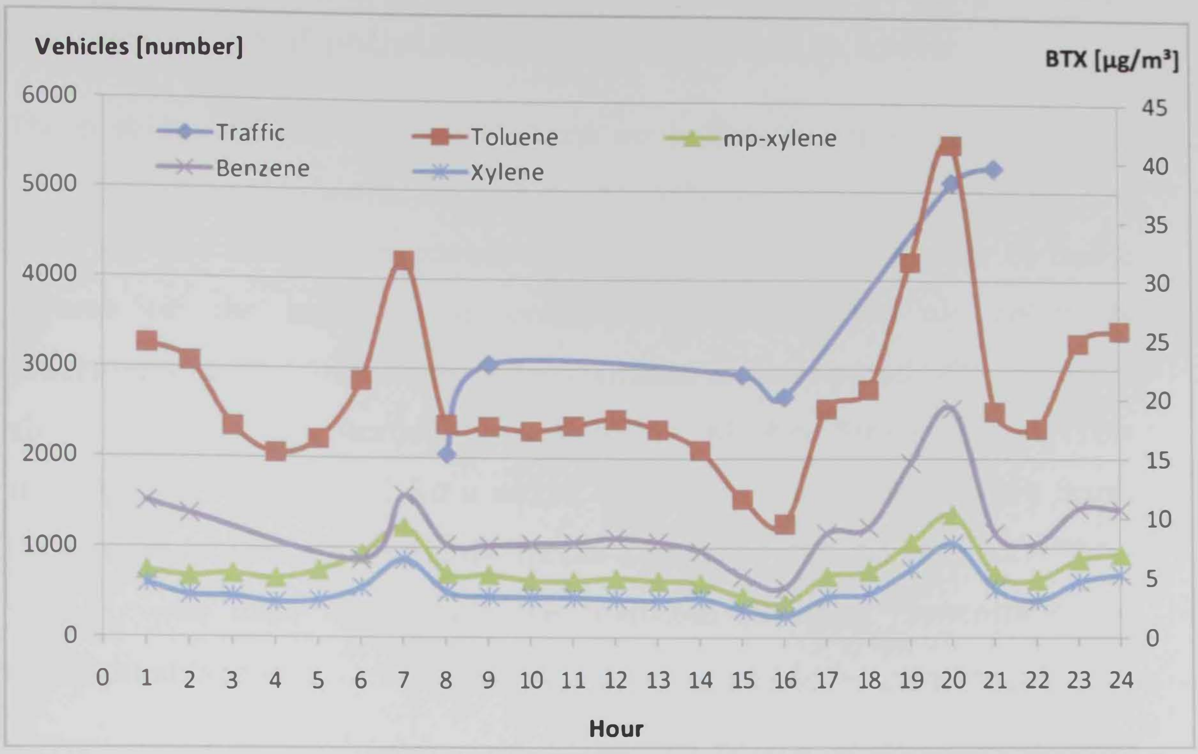

Fig. 6.16: Hourly average traffic volume and BTX level in Al Ain downtown during 7-12 April, 2009

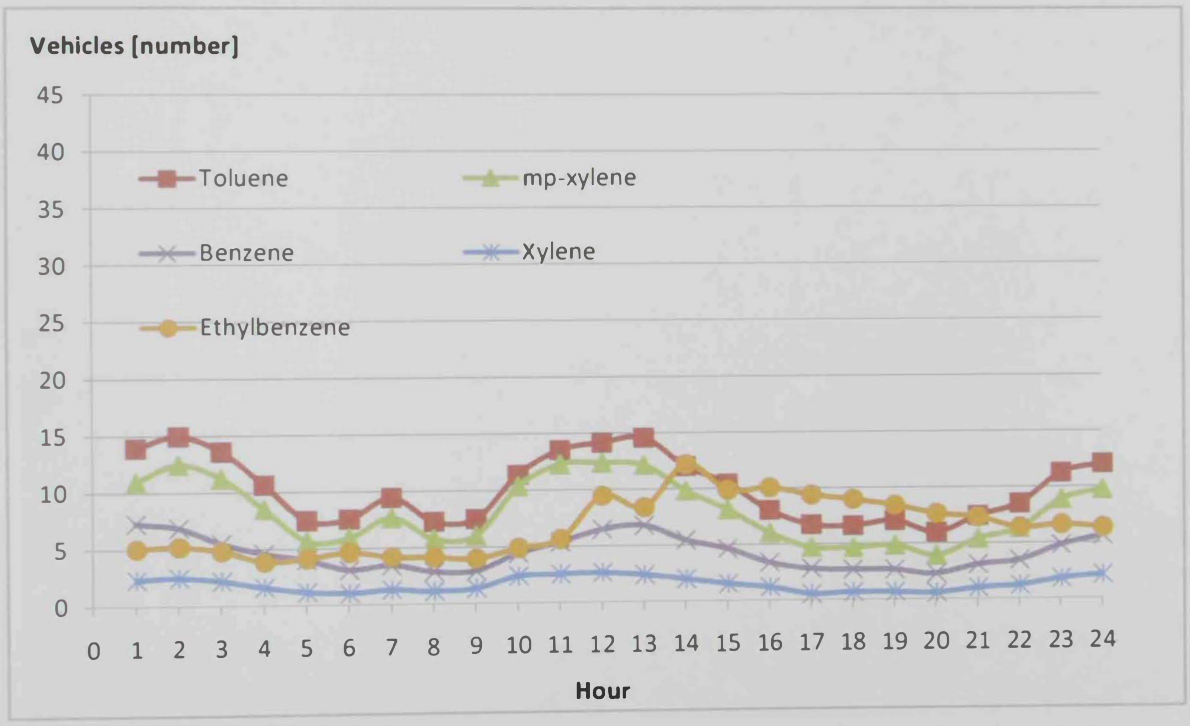

Fig. 6.17: Hourly average traffic volume and BTX level in Al Ain downtown during the first week of Ramadan, 25-30 August, 2009

6.4 Prediction of pollutant concentration due to traffic

The previous section revealed that the air pollutants measured at Al Ain Street Station in the downtown area are not only related to traffic volume, but there are also some other contributors. To examine the influence of traffic volume on the level of air pollutants, the predicted air pollutants concentrations from traffic flow were evaluated and compared with the actual air pollutants concentrations measured at Al Ain Street Station. This investigation was applied for a model domain of 1 km^2 with Al Ain Street Station nearly centered within the model domain as shown in Fig. 6.19. Three models were used to estimate the predicted pollutant concentration as highlighted below.

Fig. 6.18: The model domain used to determine pollutant concentration from vehicle traffic in the downtown area

a) The Synchro model:

The Synchro software model was used in this study to estimate the traveled distance as well as the traffic emissions based on the loaded traffic at the intersections and street links. Figures 6.19 and 6.20 show snapshots of the study area and the traffic signal intersection between Al Ain Street and Zayed bin Sultan Street in the Synchro software. The main inputs of the Synchro model are:

- **Road Network Geometry**: including the road network links and nodes, number of lanes (3), lane width (3.7m), average operating speed (60km/hr), travel directions, presence of medians, and intersections geometry.
- **Traffic Volumes**: including the hourly traffic volume of four directions (i.e. Right, Through, Left, U-turn)
- **Traffic control system**: whether it is a pre-timed or actuated signal system. For roundabouts, the approaches are assigned a "yield" control.

SimTraffic is a simulator that randomly generates the traffic streams on the road network that is analytically modeled in Synchro. Therefore, to find out the effectiveness of the traffic analytical output obtained from Synchro, multiple runs of the SimTraffic is usually conducted. For each run, SimTraffic generates random number of traffic arrivals that gives a different result for the vehicle emissions and traffic performances. The first several runs are also called "warming up period" where the simulated network usually tries to gain a stable scenario. Therefore, 5 runs of the SimTraffic simulator is adopted in this study (Table 6.4), as it was also observed that after at least 5 runs, the average results almost coincide with 10 runs or more.

Table 6.4: Output of the Synchro model for one hour (7-8 am) in 2007

Total Network Performance by Run						
Run number	1	2	3	4	5	Average
Total delay (hr)	44	51.2	44	38.6	39.9	43.5
Delay / vehicle (s)	92.2	103.8	89.6	81.5	85.5	90.9
Total stops	3472	3889	3890	3279	3456	3594
Travel distant (km)	2213.9	2197.8	2323.2	2220.1	2176.6	2226.3
Travel time (hr)	87.7	94.8	89.8	82.5	82.8	87.5
Average speed (km/hr)	27	24	27	28	28	27
Fuel used (l)	635	610.3	651.6	605.7	621.1	624.8
Fuel efficiency (km/l)	3.5	3.6	3.6	3.7	3.5	3.6
HC emissions (g)	492	492	530	490	496	500
CO emissions (g)	24321	23902	26521	24418	24824	24797
NOx emissions (g)	1640	1612	1769	1652	1663	1667
Vehicles entered	1811	1929	1891	1795	1781	1834
Vehicles exited	1626	1620	1642	1611	1581	1615
Hourly exit rate	9756	9720	9852	9666	9486	9690
Denied entry before	7	12	11	7	25	11
Denied entry after	63	62	15	23	34	38

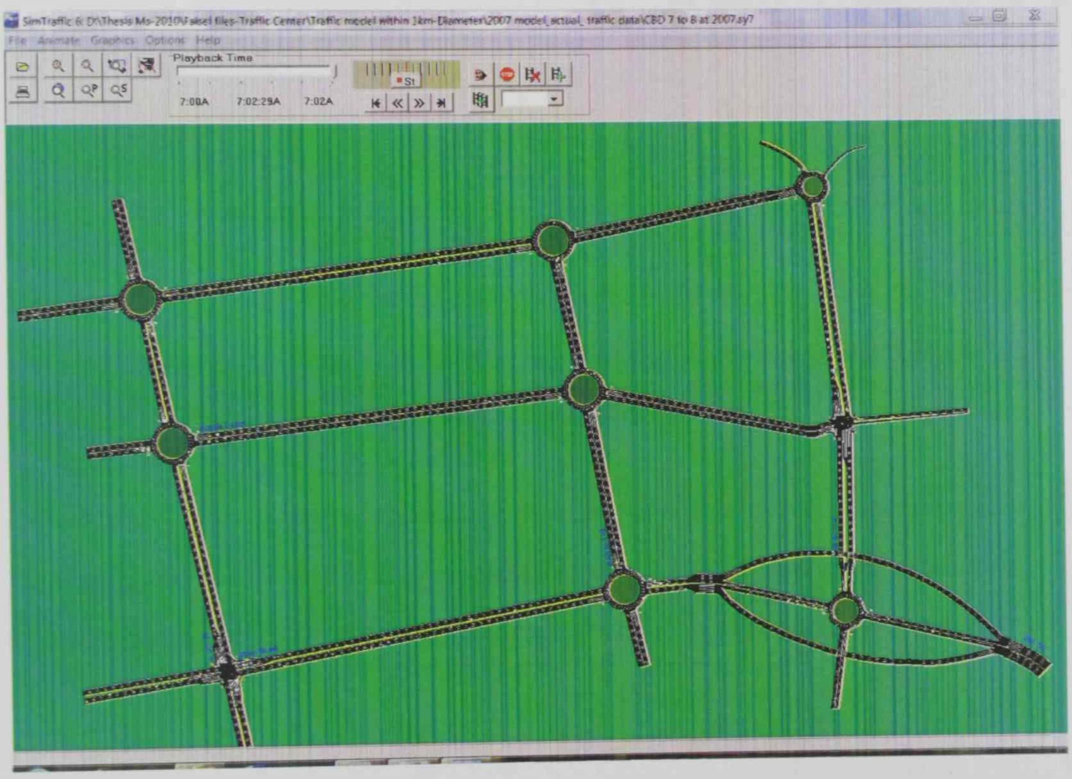

Fig. 6.19: A snapshot of the study area in the Synchro software

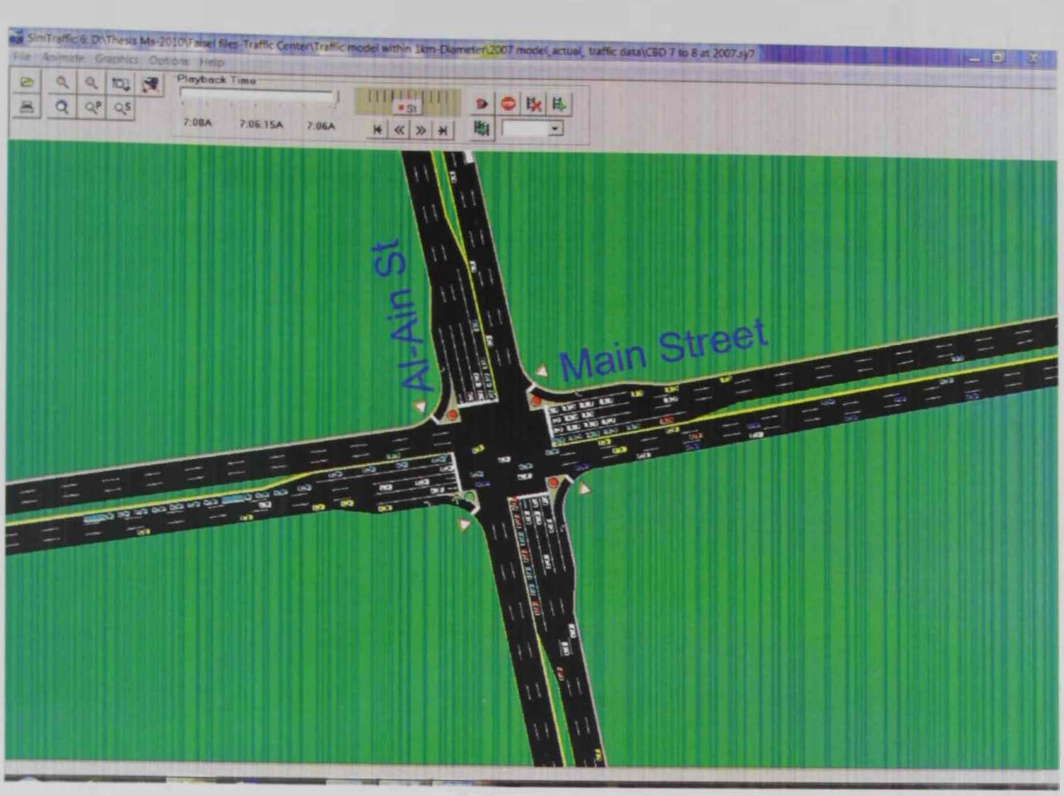

Fig. 6.20: A snapshot of the traffic signal intersection between Al Ain Street and Zayed bin Sultan Street.

b) The IVE model:

The International Vehicle Emissions (IVE) model was used in this study to calculate traffic related emissions in Al Ain downtown. The IVE model is a java-based software model as shown in Fig. 6.21. The IVE model depends on a number of input variables as summarized below:

- **Fleet composition**: including various vehicle types such as passenger vehicles, buses, trucks, motorcycles; technology distribution (i.e. emission and engine control technology) and other parameters like model year, odometer reading, air conditioning use, inspection and maintenance methods and fuel quality.

- **Environmental variables**: including altitude, ambient temperature, humidity and road gradient.
- **Vehicle activity**: including driving patterns (i.e. average speed and acceleration profile), distance travelled and start patterns (i.e. number of engine startups including the hot and cold starts and the soak pattern (i.e. how long the vehicle has soaked before starting).

The fleet composition was obtained from the records of the Statistics Center - Abu Dhabi of all registered road vehicles in Al Ain city. The environmental variables were obtained from the EAD monitoring stations in Al Ain. The Synchro model was used to estimate the traveled distance of the study region and the driving pattern of Los Angeles data were taken as an approximate representation of the driving patterns in Al Ain.

On the other hand, because the Synchro model estimates only emissions of some pollutants, the IVE model was used to predict a whole range of emissions of pollutants (i.e., CO, HC, NO_x, toxics and global warming pollutants) for a complete assessment of ambient air quality. Table 6.5 shows the total hourly vehicle emissions (g) estimated by the IVE model for the 1-km^2 model domain in 2007. It can be seen that the emission output values from the IVE are much higher (sometimes more than an order of magnitude) than those estimated using the Synchro model for the hour 7-8am. Estimates of the IVE model should be more reliable as the model accounts for more variables such as vehicle fleet, fuel and driving characteristics.

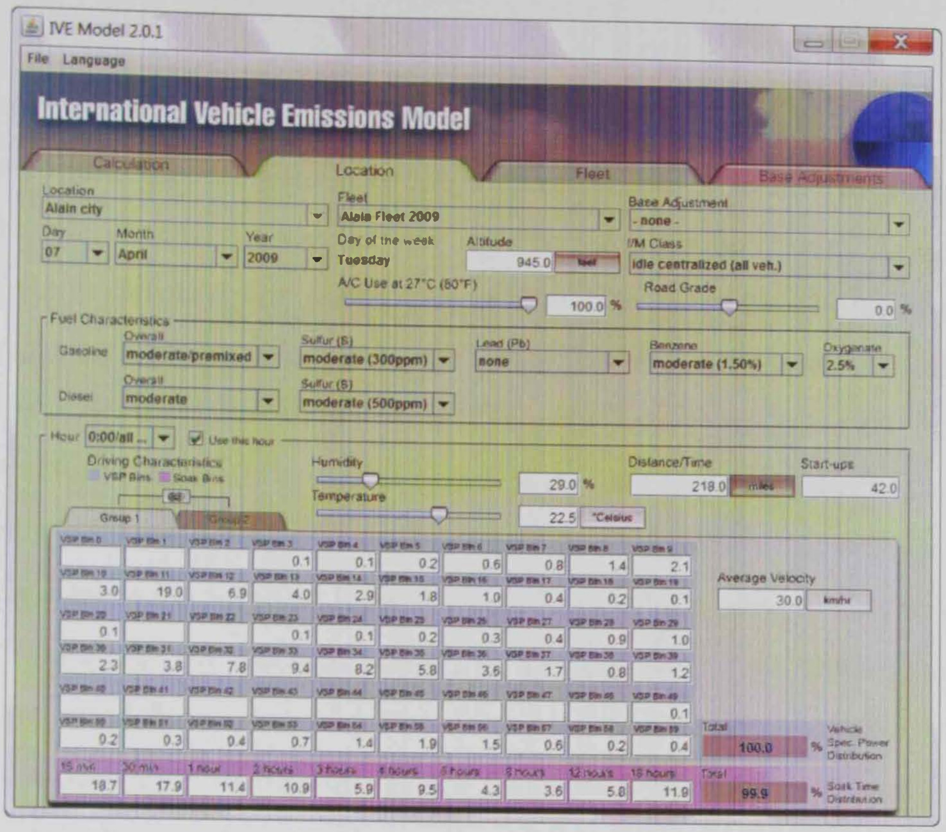

Fig. 6.21: A snapshot of the IVE software

Table 6.5: Total hourly vehicle emissions (g) estimated by the IVE model for the 1-km² model domain in 2007

Time	CO	VOC	VOC (evap.)	NOx	SO_2	PM_{10}	Benzene
7.00 - 8.00 am	92,963	1,891	621	13,098	143	389	82
8.00 - 9.00 am	140,712	2,398	908	17,027	180	481	105
9.00 - 10.00 am	160,282	2,663	985	19,124	203	537	116
10.00 - 11.00 am	185,573	2,734	1149	19,706	202	533	121
5.00 - 6.00 pm	172,233	2,535	1063	18,169	186	493	112
6.00 - 7.00 pm	187,847	2,783	1176	20,058	205	542	123
7.00 - 8.00 pm	150,870	2,539	951	18,134	192	511	111
8.00 - 9.00 pm	149,180	2,517	946	18,081	191	507	110

c) The Box Model:

The simple box model was used in this study to estimate the pollutants concentrations based on the concept of conservation of mass. The air mass of the site was treated as well-mixed in a rectangular box, with dimensions: length (L), width (W) and height (H) as shown in Fig. 6.23. The height of the box was taken as the mixing depth. Also, the emissions per unit area are given by (q_s). Pollutants were assumed to be uniformly mixed in the box with concentration (C), while on the upwind of the box the concentration was C_{in}. An assumption is made that no pollution was lost from the box along the sides parallel to the wind or from the top. The pollutants were also treated as conservative (i.e. no reaction, decay, or fall out of the air stream) and the incoming wind blows into the box were assumed to be clean and thus the initial concentration in the box is zero (Masters, 1997). The concentration (C) found by the box model could be expressed as:

$$C(t) = \frac{q_s L}{uH} \left(1 - e^{\frac{-u(t)}{L}} \right)$$

where, C is the pollutant concentration in the box (mg/m³), which equals to the concentration leaving the box for a well-mixed system, q_s is the emission rate per unit area (mg/m². sec), H is the mixing height, L is the length of the box, W is the width of the box, u is the average wind speed against one edge of the box (m/s), and t is the time duration (sec).

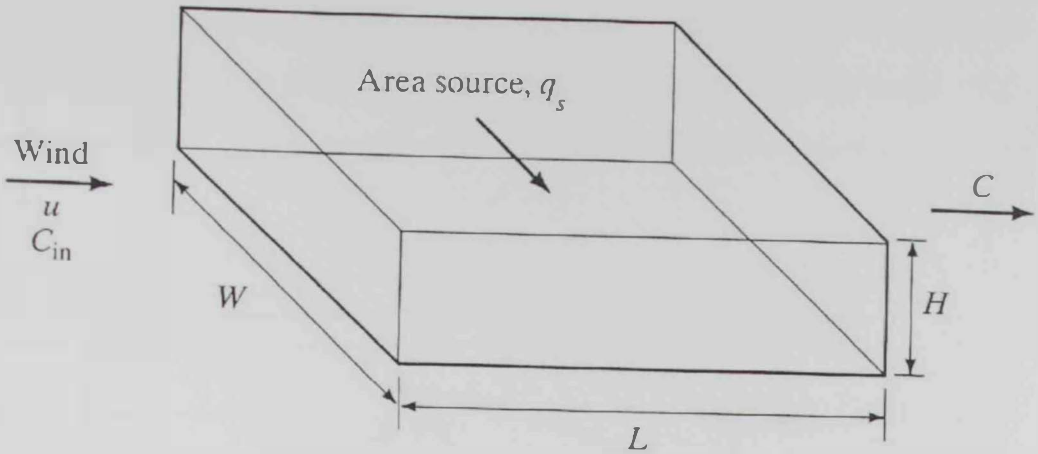

Fig. 6.22: A simple rectangular box model for the air mass over a study region (Masters, 1997)

The emissions results from the IVE model were used in the Box model and the average wind speed was obtained from Al Ain Street Station. For the mixing height, Lena and Desiato (1998) suggested to adopt a minimum mixing height of 50 m in order to avoid too small mixing heights in very low wind or calm situations. However, the mixing height is a function of several parameters such as meteorology, surface turbulent fluxes and physiographic characteristics (Baklanov et al., 2006). Due to the lack of temperature profile data for Al Ain city, it is not possible to get an estimate of the average mixing height value. Therefore, it is decided to calculate a representative average mixing height for the period during which traffic data were collected using the BTX data, assuming the only source of BTX is traffic. The predicted BTX concentration for different mixing height values were calculated starting from a mixing height value of 50m as the minimum value. Based on the sum of squares residuals, the best fit mixing height value for BTX was found to be 70m. This mixing height was then used to predict CO, NOx and PM_{10} levels due to traffic emissions. Predicted levels of these pollutants were then compared with those measured at the station.

Figure 6.23 shows the predicted and measured values for BTX based on the best fit mixing height value. Note that the estimated VOC from the IVE model was treated as the sum of the BTX compounds, since these are the major VOC components emitted from traffic while other VOCs are assumed to be negligible.

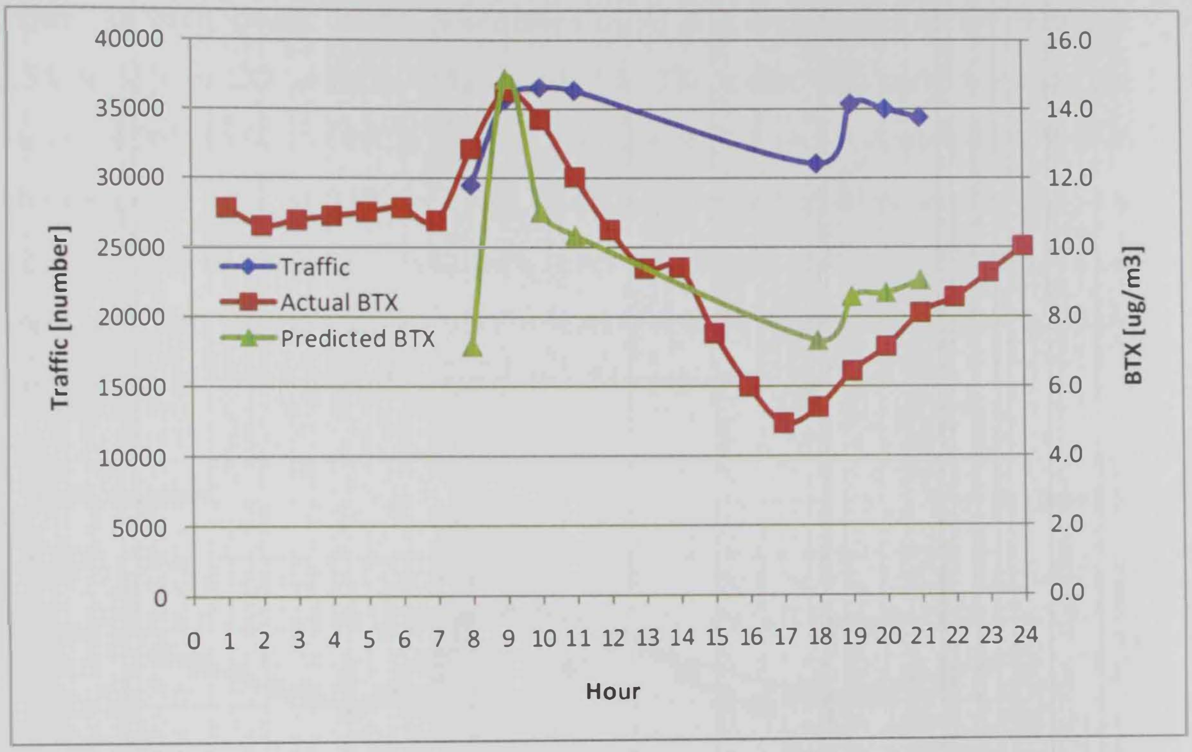

Fig. 6.23: Predicted and actual BTX concentration in April, 2007

Figures 6.24-6.26 show a comparison of predicted and actual measured pollutants concentrations by hour during April, 2007. It should be noted that the actual traffic counts were conducted at the beginning of January, 2007, whereas the actual pollutants monitoring station was commissioned in April, 2007. Comparison between predicted and actual pollutant concentration was based on the assumption that the traffic volume in January, 2007 was the same as that in April, 2007. The SO_2 was not measured during this period and hence it was not included in this analysis.

The results indicated that the actual concentrations for CO, NOx and PM_{10} were larger than the predicted ones. Larger actual concentration than predicted for CO, NOx and PM_{10} could be attributed to presence of other sources beside traffic that contribute to their levels in the atmosphere or due to model inaccuracy. The contribution of traffic to pollutant level was calculated based on the ratio of predicted to actual pollutant level for each hour. As such, traffic in the downtown of Al Ain contributes to the range of 15% to 35% of CO, with an average of 25%. The traffic also contributes to the range of 36% to 69% of NO_x, with an average of 57% and it contributes only to the range of 0.4% to 0.8% of PM_{10}, with an average of 0.5% levels. The low contribution of traffic to pollutant level (as is the case for CO and PM_{10}) indicates that other sources play a major role in determining the ambient concentration of these pollutants in the downtown of Al Ain.

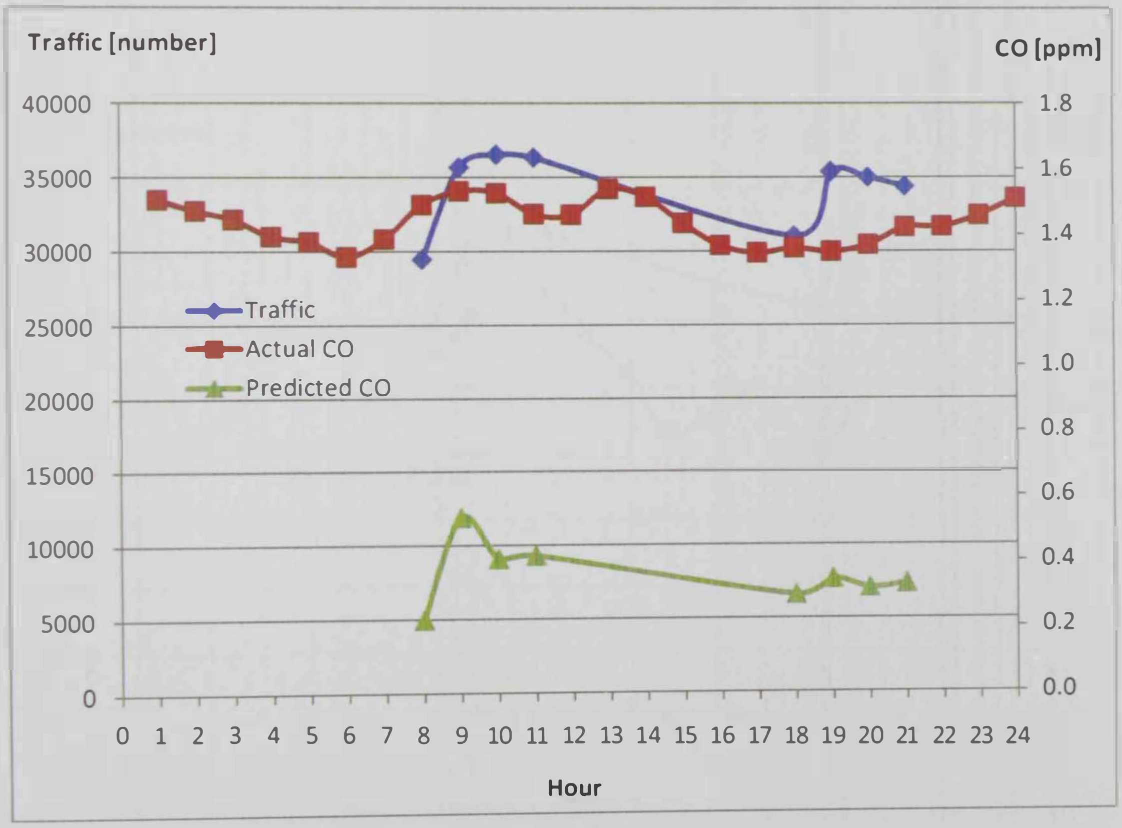

Fig. 6.24: Predicted and actual CO concentration in April, 2007

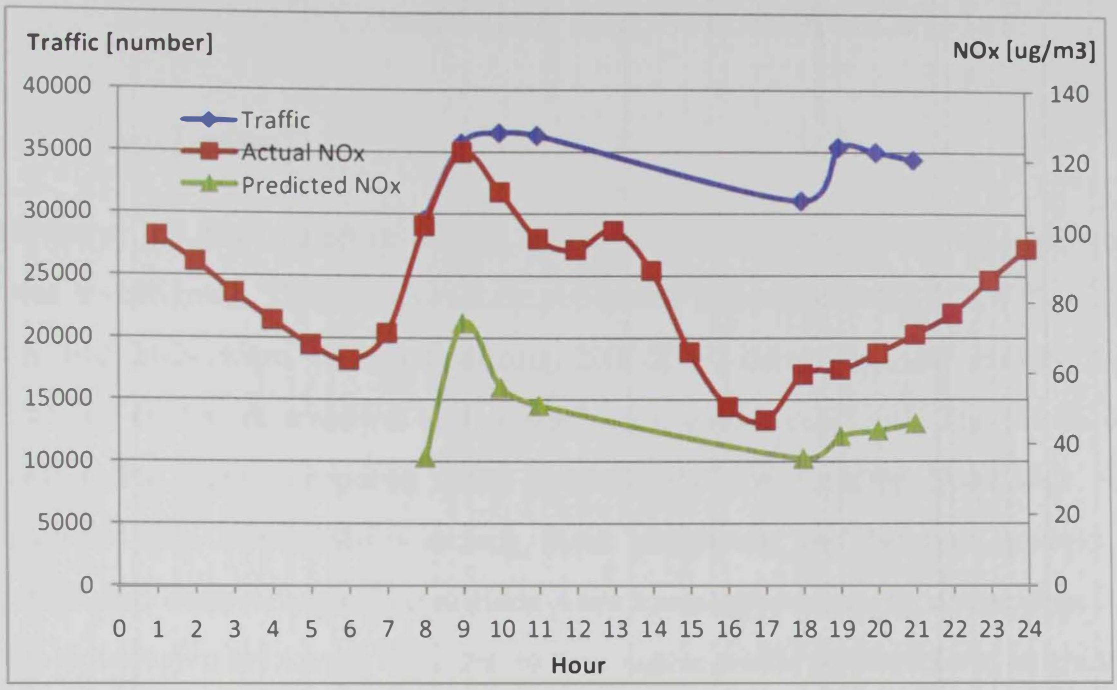

Fig. 6.25: Predicted and actual NO_x concentration in April, 2007

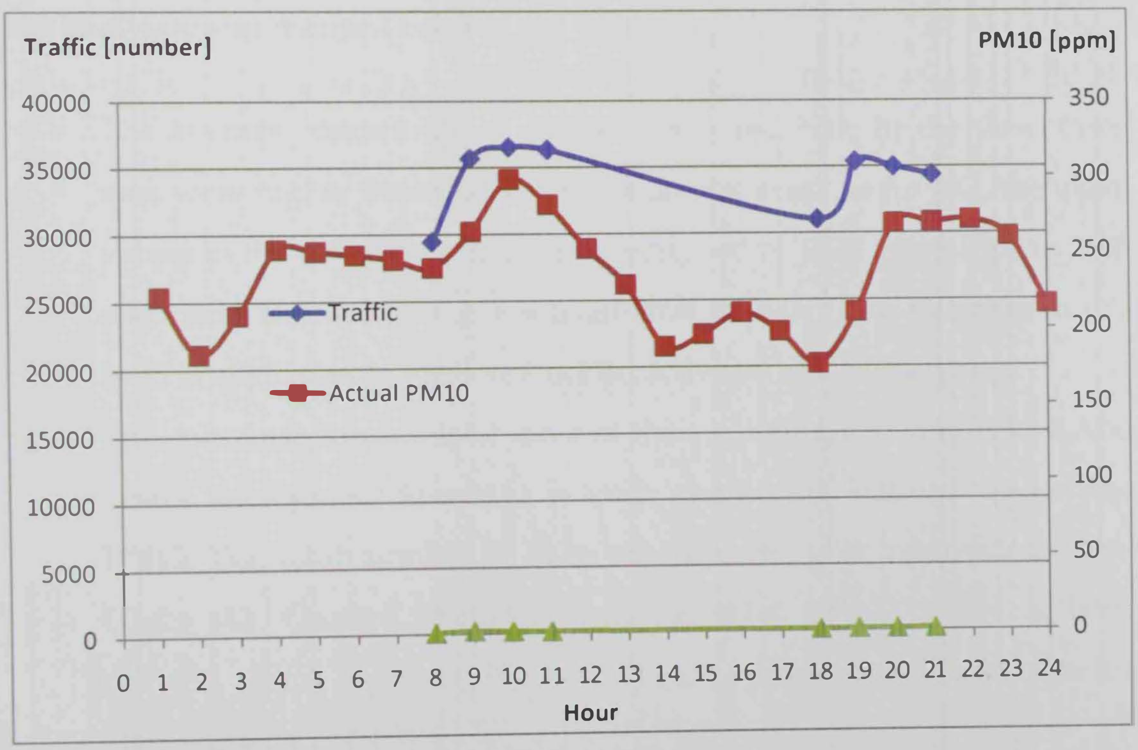

Fig. 6.26: Predicted and actual PM_{10} concentration in April, 2007

Chapter 7: Conclusion and Recommendations

7.1 Conclusion

In this study, the impact of vehicle traffic on ambient air quality in Al Ain city was investigated. Data of several air pollutants including PM_{10}, SO_2, NO_2, CO, O_3 and HCs were collected during 2007-2009, using two air monitoring stations in the downtown and a residential area in Al Ain. The levels of pollutants were compared with Abu Dhabi Air Quality Standards. In addition, the relationships among these pollutants and between pollutant levels and meteorological conditions were investigated. Traffic count data for the downtown area were collected to investigate traffic pattern. Data on traffic counts were used to predict the concentration of air pollutants emitted from traffic. Predicted pollutants levels were compared with the actual levels measured at the monitoring station in the downtown. The major findings of this study are summarized below:

- The average concentrations of PM_{10}, SO_2 and NO_2 in the downtown area were higher than that in the residential area. As for CO, the mean values in the downtown area have increased by 2.0% from 2007 to 2008 and then decreased by 27.6% from 2008 to 2009. This decrease in CO level is attributed to the construction activities at Khalifa Street.
- The concentration levels of most of the air pollutants were below Abu Dhabi Air Quality Standard at both monitoring stations, except the PM10. The total number of PM_{10} exceedances, with reference to Abu Dhabi Air Quality Standard, was recorded as 472 times at both stations, which represent 99.5% of the total number of exceedances for all pollutants.

- Higher monthly concentrations of pollutants were detected during the winter months (January to April) and lower levels were noticed during the summer months (May-September). This is attributed to removal reactions of pollutants, inversion conditions and less traffic volume in the summer. However, PM_{10} showed an opposite pattern than other pollutants, with lowest concentration level in the winter season and highest during the summer period.
- Data analysis showed that there is a statistically significant difference in pollutants levels at Al Ain School Station (residential area) and Al Ain Street Station (downtown area), with higher pollutant levels at the latter. The higher pollutants levels at Al Ain Street Station are attributed to higher vehicle traffic volume and other population-related activities..
- Assessment of air quality during 2007-2009, based on the pollutant levels at the two stations in Al Ain, indicates that 52% of the calculated average AQI values are categorized as "moderate". The remains are categorized as follows: 24% "good", 15% "unhealthy for sensitive groups", 4% "unhealthy", 1% "very unhealthy" and 4% "hazardous". The Al Ain residential area had better air quality than Al Ain downtown area. It was further noticed that air was more polluted in pre-summer and summer months than in winter. Also, the critical pollutant affecting the AQI at the two monitoring locations in Al Ain was PM_{10}.
- There is a relatively strong inverse relationship between temperature and the level of ozone or SO_2. However, the other pollutants have moderate relationship with temperature. Also, wind speed and wind direction have moderate relationship with the level of all pollutants.
- The increase in vehicles in Al Ain city was steady with an average of almost 3.1% per year over the last seven years. However, the growth of private passenger cars is particularly remarkable and vehicles with four cylinders are the most prevailing ones in Al Ain.

- Gasoline fuel represents 78% of the vehicles fuel consumption compared to 22% consumption of diesel fuel during 2007-2009. Moreover, the ULG-95 represents 50% of all vehicles fuel consumption in Al Ain. Vehicles fuel consumption has increased by 13% during 2007-2009. This increase is attributed to an increase in the number of vehicles in Al Ain during 2007-2009.
- The traffic volume at Khalifa Street has the same behavior for the whole week, normally high at peak hours in the morning at 9:00-12:00 and evening at 20:00-21:00, and low at around noon and late night off-peak hours. On the other hand, there is some variation in traffic volume between weekdays and weekends. This is more obvious on Friday when most of the offices (government and private) are closed.
- Despite the increase in the predicted average traffic volume in 2008, the actual average traffic volume in 2009 has decreased. This is probably due to construction activities related to intersections at Khalifa Street during 2009, where the street was narrowed into a one-lane road in both directions.
- The noise level at the downtown area was much higher than the noise level at the residential area. The average noise level at the downtown area was 63.5 dBA, while at the residential area the average noise level was 49.7 dBA. The variation in noise levels between the two locations is probably due to variations in traffic volumes as well as variations in other population-related activities.
- The noise levels in the residential area are considered as the upper limit permitted by the Abu Dhabi Noise Standard for "residential areas with light traffic" during daytime and exceeded the upper noise limit during nighttime. However, the daytime noise levels at the downtown area were in compliance with the Abu Dhabi Noise Standard for "commercial areas and downtown" with an average of 63 dBA. The night time noise levels however exceeded the upper noise limit of the standard during night time.

- The CO and NO_2 concentrations exhibit almost a similar daily average pattern, with three-peak values at 6:30, 18:00 and 23:00. Also, there was a strong positive relationship between the NO2 and CO, with Pearson correlation coefficient (r = 0.74). On the other hand, there was a lag between CO and NO2 level and traffic volume. This indicates that there are other non-traffic sources of these pollutants such as commercial activities (like restaurants).
- The relationship between SO2 level and traffic volume is weak. This is probably due to the low sulphur in the used unleaded gasoline.
- Traffic has an influence on the PM10 concentration in the ambient air, although not all PM10 could have resulted from car emissions.
- The BTX profiles show similarity in variation patterns among these compounds as detected at Al Ain Street Station. Such a profile is similar to that of road traffic variation, suggesting that these compounds originate from the same source (i.e. traffic vehicles)
- There are strong positive correlations between the BTX compounds, with Pearson correlation coefficient (r) ranging from 0.85 to 0.97 at a significant level of 0.01. The strong mutual correlations among the BTX compounds suggest that they came mainly from a single source, most possibly traffic-related emission. However, other non-traffic sources of BTX such as cooking operations at the restaurants using kerosene may contribute to the levels of these compounds in the ambient air.
- The actual concentrations for CO, NOx and PM_{10} were larger than the predicted ones. Larger actual concentration than predicted for CO, NOx and PM_{10} could be attributed to the presence of other sources beside traffic that contribute to their levels in the atmosphere.

- The traffic in the downtown area of Al Ain contributes in the range of 15% to 35% of CO, with an average of 25%. The traffic also contributes in the range of 36% to 69% of NO_x, with an average of 57% and it contributes only in the range of 0.4% to 0.8% of PM_{10}, with an average of 0.5% levels. The low contribution of traffic to pollutant level (as is the case for CO and PM_{10}) indicates that other sources play a major role in determining the ambient concentration of these pollutants in the downtown of Al Ain.

7.2 Recommendations

Recommendations on Traffic management:

- Further study is necessary for a comprehensive investigation of the impact of traffic on ambient air quality in the downtown of Al Ain, especially after the recent modifications of changing the roundabouts to traffic signals and removing the bridge from the city centre. Such a study will be useful to assess the influence of the new modification on the local air quality.
- It is recommended to develop proactive traffic management mitigation measures for Al Ain downtown area to manage traffic congestion and hence improve the air quality.
- Installing traffic acount station in the downtown area for continuous monitoring of the traffic flow. This will help in the management of traffic congestion and hence reduce traffic related emissions. It will also help researchers focusing on traffic management and assessing air quality in the city.
- Construct a shaded walking pathway system in the downtown area of Al Ain and encourage people to walk instead of using vehicles. Also, encourage people to use public transportation instead of private cars. These will help in reducing traffic congestion and hence decrease the emissions from vehicles.
- Reduction of air pollutant emission from road traffic seems to be necessary which can be achieved through better vehicle control and maintenance and by mandating the use of catalytic converters in all vehicles, and the use of cleaner fuels such as natural gas and Liquefied Propane Gas (LPG).

- Emissions inventory of mobile sources in Al Ain should be undertaken, with future consideration given to expansion of Al Ain town and the potential decrease in the air quality as a possible consequence of traffic increase.
- As BTEX compounds are major pollutants from vehicle exhaust, there is a necessity to develop strict automobile emission standards in Abu Dhabi Emirate for such toxic compounds. Also, it is recommended to include the NO_x and PM_{10} within ADNOC regular inspection of the exhaust vehicles tests for the renewal of the vehicle license.

Recommendations on Air quality management:

- It is recommended to install continuous monitoring device at the current two stations for monitoring $PM_{2.5}$, since this pollutant is currently regulated as one of the criteria pollutants and its effect is larger than PM_{10} due to its smaller size which could infiltrate deep in the lung tissues. Therefore, it is considered as an important indicator of risk to health from particulate pollution, and might be a better indicator than PM_{10} for suspended particles.
- Further studies on the assessment of noise level in Al Ain are required, since most of the current noise measurements exceeded the noise standards limits of Abu Dhabi Emirate.
- The international WHO standard for $PM_{2.5}$ should be included within the air quality standards of Abu Dhabi Emirate.
- Expanding the present air quality monitoring network for better air pollution measurements which will help develop better control and allow epidemiological studies to assess the impact of air pollution on the population in the Abu Dhabi Emirate.

- EAD has established the Abu Dhabi Air Quality Website to provide essential information related to the field of air quality including the online Air Quality Index color-coded system to help those who suffer from respiratory problems. But this service is only available on the internet webpage and not all the people have access to internet, especially the elderly and illiterates. Therefore, it is recommended to include the AQI information within the weather forecasts news on the TV, radio and newspapers in order to be available to all.

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Appendices

Appendix A

International Ambient Air Quality Standards

US EPA Ambient Air Quality Standards (NAAQS)

The US EPA has set National Ambient Air Quality Standards for six major pollutants, which are called "criteria" pollutants. Units of measure for the standards are parts per million (ppm) by volume, milligrams per cubic meter of air (mg/m3), and micrograms per cubic meter of air (μg/m³).

Table A-1: US EPA Ambient Air Quality Standards (NAAQS)

	Primary Standards		Secondary Standards	
Pollutant	Level	Averaging Time	Level	Averaging Time
Carbon Monoxide	9 ppm (10 mg/m³)	8-hour (1)	None	
	35 ppm (40 mg/m³)	1-hour (1)		
Lead	0.15 μg/m³ (2)	Rolling 3-Month Average	Same as Primar	
	1.5 μg/m³	Quarterly Average	Same as Primary	
Nitrogen Dioxide	0.053 ppm (100 μg/m³)	Annual (Arithmetic Mean)	Same as Primar	
	0.100 ppm	1-hour (3)	0.053 ppm (100 μg/m³)	Annual (Arithmetic Mean)
Particulate Matter (PM10)	150 μg/m³	24-hour (4)	Same as Primary	
Particulate Matter (PM2.5)	15.0 μg/m³	Annual (5) (Arithmetic Mean)	Same as Primar	
	35 μg/m³	24-hour (6)	Same as Primar	
Ozone	0.075 ppm (2008 std)	8-hour (7)	Same as Primar	
	0.08 ppm (1997 std)	8-hour (8)	Same as Primar	
	0.12 ppm	1-hour (9)	Same as Primar	
Sulfur Dioxide	0.03 ppm	Annual (Arithmetic Mean)	0.5 ppm (1300 μg/m³)	3-hour (1)
	0.14 ppm	24-hour (1)		

Source: (US Environmental Protection Agency.2010)

(1) Not to be exceeded more than once per year.
(2) Final rule signed October 15, 2008.
(3) To attain this standard, the 3-year average of the 98th percentile of the daily maximum 1-hour average at each monitor within an area must not exceed 0.100 ppm (effective January 22, 2010).
(4) Not to be exceeded more than once per year on average over 3 years.
(5) To attain this standard, the 3-year average of the weighted annual mean PM2.5 concentrations from single or multiple community-oriented monitors must not exceed 15.0 μg/m3.
(6) To attain this standard, the 3-year average of the 98th percentile of 24-hour concentrations at each population-oriented monitor within an area must not exceed 35 μg/m3 (effective December 17, 2006).
(7) To attain this standard, the 3-year average of the fourth-highest daily maximum 8-hour average ozone concentrations measured at each monitor within an area over each year must not exceed 0.075 ppm. (effective May 27, 2008)
(8) (a) To attain this standard, the 3-year average of the fourth-highest daily maximum 8-hour average ozone concentrations measured at each monitor within an area over each year must not exceed 0.08 ppm.
(b) The 1997 standard—and the implementation rules for that standard—will remain in place for implementation purposes as EPA undertakes rulemaking to address the transition from the 1997 ozone standard to the 2008 ozone standard.
(c) EPA is in the process of reconsidering these standards (set in March 2008).
(9) (a) EPA revoked the 1-hour ozone standard in all areas, although some areas have continuing obligations under that standard ("anti-backsliding").
(b) The standard is attained when the expected number of days per calendar year with maximum hourly average concentrations above 0.12 ppm is < 1.

Table A-2: World Health Organization (WHO) Ambient Air Quality Guidelines

Compound	Guideline Value	Averaging Time
Ozone (O3)	100 μg/m^3	8 hours mean
Nitrogen dioxide (NO2)	40 μg/m^3 200 μg/m^3	Annual mean 1 hour mean
Sulfur dioxide (SO2)	20 μg/m^3 500 μg/m^3	24 hours mean 10 minute mean
Particulate matter (PM10)	20 μg/m^3	annual mean
	50 μg/m^3	24 hours mean
Carbon monoxide (CO)	100 mg/ m^3 (90 ppm)[a] 60 mg/ m^3 (50ppm) 30 mg/ m^3 (25 ppm) 10 mg/ m^3 (10 ppm)	15 min 30 min 1 hour 8 hours
Lead b (Pb)	0.5 to 1.0 μg/m^3	Annual

Source: (WHO.2000 & 2005)

a) The guideline is to prevent carboxyhemoglobin levels in the blood from exceeding 2.5%, the values above are mathematical estimates of some of the CO concentrations and averaging times at which this goal should be achieved.

b) The guideline for lead was established by WHO in 1987.

Table A-3: National Environmental Protection Measures (NEPM), Australia Ambient Air Quality Standard

Pollutant	Averaging period	Maximum concentration	Goal within 10 years maximum allowable exceedences
Carbon monoxide	8 hours	9.0 ppm	1 day a year
Nitrogen dioxide	1 hour 1 year	0.12 ppm 0.03 ppm	1 day a year none
Photochemical oxidants (as ozone)	1 hour 4 hours	0.10 ppm 0.08 ppm	1 day a year 1 day a year
Sulfur dioxide	1 hour 1 day 1 year	0.20 ppm 0.08 ppm 0.02 ppm	1 day a year 1 day a year none
Lead	1 year	0.50 μg/m3	none
Particles as PM_{10}	1 day	50 μg/m3	5 days a year

Source: (NEPC 2010)

Table A-4: Air Quality Standards for European Union

Pollutant	Concentration	Averaging period	Permitted exceedences each year
Fine articles (PM2.5)	25 μg/m3	1 year	n/a
Sulphur dioxide (SO2)	350 μg/m3	1 hour	24
	125 μg/m3	24 hours	3
Nitrogen dioxide (NO2)	200 μg/m3	1 hour	18
	40 μg/m3	1 year	n/a
PM10	50 μg/m3	24 hours	35
	40 μg/m3	1 year	n/a
Lead (Pb)	0.5 μg/m3	1 year	n/a
Carbon monoxide (CO)	10 mg/m3	Maximum daily 8 hour mean	n/a
Benzene	5 μg/m3	1 year	n/a
Ozone	120 μg/m3	Maximum daily 8 hour mean	25 days averaged over 3 years
Arsenic (As)	6 ng/m3	1 year	n/a
Cadmium (Cd)	5 ng/m3	1 year	n/a
Nickel (Ni)	20 ng/m3	1 year	n/a
Polycyclic Aromatic Hydrocarbons	1 ng/m3 (expressed as concentration of Benzo(a)pyrene)	1 year	n/a

Source: (EC 2008)

Appendix B

ADNOC Fuel Specifications

Table B-1: Unleaded Gasoline 95 (3400), ADNOC

Property	Unit	Limit	Test Method
Appearance		Clear & Bright Liquid	Visual
Colour		Green	Visual
Corrosion, Copper Strip (3 Hrs. at 50 °C)		Max 1	ASTM D 130
Density at 15 °C	kg/l	Min 0.710 Max 0.790	ASTM D 1298 or D 4052
Distillation			ASTM D 86
10% vol recovered at	°C	Max 65	
50% vol recovered at 50% vol recovered at	°C °C	Min 77 Max 115	
90% vol recovered at	°C	Max 180	
End point	°C	Max 215	
Residue	vol%	Max 2.0	
Doctor Test		Negative	ASTM D 4952 or IP 30
Gum, Existent	mg/100 ml	Max 4	ASTM D 381
Induction Period	minutes	Min 480	ASTM D 525
Lead Content	gmPb/lit	Max 0.013	ASTM D 3237 or D 5059 or IP 224
Octane Number, Research		Min 95.0	ASTM D 2699
Octane Number, Motor		Min 85.0	ASTM D 2700
Reid Vapour Pressure at 37.8°C	kg/cm^2	Min 0.45	ASTM D 323 or D 5191
Summer (Mar to Oct)	kg/cm^2	Max 0.60	
Winter (Nov to Feb)	kg/cm^2	Max 0.70	
Sulphur, Total	ppm/wt	Max 500	UOP 357 or ASTM D 1266 or ASTM D 5453 or D 4045
Allowed Oxygenate/MTBE (If added)	%vol	Max 15.0	ASTM D 4815
T V/L 20 (Summer)	°C	Report	ASTM D 4814
Aromatics	%vol	Max 50.0	ASTM D 1319/4420/5580
Benzene	%vol	Max 3.0	ASTM D 3606/4420/5580
Olefins	%vol	Max 10.0	ASTM D 1319
Odour		Marketable	Oil factory

Table B-2: Unleaded Gasoline 91 (3291), ADNOC

Property	Unit	Limit	Test Method
Appearance		Clear Bright Liquid	
Colour		Red	Visual
Corrosion, Copper Strip (3 Hrs. at 50 °C)		Max 1	ASTM D 130
Density at 15°C	kg/l	Min 0.71 - 0.77	ASTM D 1298 or D 4052
Distillation			ASTM D 86
10% vol recovered at	°C	Max 65	
50% vol recovered at	°C	Min 77 - 115	
90% vol recovered at	°C	Max 180	
End point	°C	Max 205	
Residue	vol%	Max 2.0	
T V/L 20	°C	Report	
Doctor Test		Negative	ASTM D 4952 or IP 30
Gum, Existent	mg/100ml	Max 4	ASTM D 381
Induction Period	minutes	Min 480	ASTM D 525
Lead Content	gmPb/lit	Max 0.005	ASTM D 3237 or 3341 or D 5059 or IP 352 or IP 228
Octane Number, Research		Min 91.0	ASTM D 2699
Anti Knock Index*		Min 87.0	Calculated
Reid Vapour Pressure at 37.8°C	kg/cm^2	Min 0.45	ASTM D 323
Summer (Mar to Oct)	kg/cm^2	Max 0.60	
Winter (Nov to Feb)	kg/cm^2	Max 0.70	
Sulphur, Total	ppm/wt	Max 100	ASTM D 1266 or UOP 357 or ASTM D 3120 or IP 336
Aromatics	%vol	Max 50.0	ASTM D 1319/4420/5580
Benzene	%vol	Max 3.0	ASTM D 1319/4420/5580
Olefins	%vol	Max 10.0	ASTM D 1319
MTBE	%vol	Max 10.0	ASTM D 4815
Odour		Marketable	Oil factory

*Anti Knock Index (AKI) is average of Research Octane Number (RON) & Motor Octane Number (MON)

Issued August 2006

Table B-3: Gas Oil 500ppm S (3400), ADNOC

Property	Unit	Limit		Test Method
		Min	Max	
Acid Number,	Total Strong	mg KOH/g	0.1 Nil	ASTM D 974
Appearance			Clear	Visual
Ash	mass %		0.01	ASTM D 482
Particulate Contaminants	mg/l		20.0	ASTM D 6217
Carbon Residue, (10% MCRT)	mass %		0.2	ASTM D 4530
Cetane Index		52		ASTM D 4737
Cetane Number		55		ASTM D 613
Cloud Point	°C		Report	ASTM D 2500 or D 5773
CFPP	o C		Report	ASTM D 6371 / IP 309
Colour, ASTM			2.0	ASTM D 1500
Copper Corrosion(3 hrs, 50 °C)			1	ASTM D 130
Density at 15 °C	kg/l	0.820	0.845	ASTM D 1298 or D 4052
Distillation	90% Recovery at	°C	357	ASTM D 86
Filter Plugging Tendency			1.4	ASTM D 2068 or IP 387
Flash Point	PMCC	°C	66	ASTM D 93
Pour Point (1)	°C		0	ASTM D 5949
Total Aromatics	mass %	10		ASTM D 5186 or IP 391
Poly Aromatics Hydrocarbons	mass %		11	ASTM D 5186 or IP 391
Lubricity (HFRR) (2)	microns		460	ASTM D 6079 or IP 450
Oxidation Stability	g/m 3		25	ASTM D 2274
Unhydrotreated Cracked Material	vol %		nil	By Declaration
Water Content	% mass		0.02	ASTM E 203
Sulphur , Total	mg/kg		500	ASTM D 2622 or D 4294
Viscosity at 40 °C	mm 2 /s	2.0	4.5	ASTM D 445
Note: (1) Use of flow improver allowed (2) Use of Lubricity additive allowed				

أشارت نتائج هذه الدراسة إلى أن مستويات تراكيز معظم الملوثات الهوائية في المحطتين كانت ضمن الحدود المسموح بها لمعايير جودة الهواء بإمارة أبوظبي، باستثناء الحبيبات الصلبة (PM_{10}) والتي تجاوزت معايير جودة الهواء المتبعة في امارة أبوظبي بمرات عديدة. كذلك لوحظ وجود اختلافات في مستويات تلك الملوثات بين المنطقة السكنية ومنطقة وسط المدينة. حيث ان تركيز الملوثات الهوائية في منطقة وسط المدينة اعلى من نظيراتها في المنطقة السكنية. وتعزى المستويات العالية للملوثات الهوائية في منطقة وسط المدينة إلى تأثير الحركة المرورية والأنشطة المختلفة للسكان القانطين بها. من ناحية أخرى، فقد تبين أن المنطقة السكنية تتميز بنوعية هواء أفضل من منطقة وسط المدينة وذلك وفق مؤشر نوعية الهواء (AQI). وقد وجد أيضا أن هنالك علاقة ما بين درجة حرارة الجو وبعض الملوثات الهوائية.

وقد توصلت هذه الدراسة إلى أن حجم الحركة المرورية في منطقة وسط مدينة العين تساهم بنسبة تتراوح ما بين 15% الى 35% من أول أكسيد الكربون، وبمتوسط قدره 25%. وتساهم أيضا بنسبة تتراوح ما بين 36% الى 69% من أكاسيد النيتروجين، وبمتوسط قدره 57%. وتساهم بنسبة ضئيلة تتراوح ما بين 0.4% إلى 0.8% من الحبيبات الصلبة (PM_{10})، وبمتوسط قدره 0.5%، في الهواء الجوي. المساهمة المنخفضة لحركة المرور على مستوى الملوثات الهوائية (كما هو الحال بالنسبة لأول أكسيد الكربون والجزيئات الصلبة)، يشير إلى أن هنالك مصادر أخرى تلعب دورا رئيسيا في تحديد تركيز هذه الملوثات في الهواء الجوي لمنطقة وسط مدينة العين. وأخيرا، فقد أشارت هذه الدراسة على أهمية تطوير استراتيجيات فعالة لإدارة حركة المرور في منطقة وسط مدينة العين، وما يترتب على ذلك من تحسين لجودة الهواء.

ملخص الرسالة

تعتبر الحركة المرورية من أهم المصادر الرئيسية لتلوث الهواء في المناطق المزدحمة. وقد ازدادت أعداد المركبات في مدينة العين خلال السبع سنوات الأخيرة، وذلك نتيجة للنمو السكاني والإقتصادي في المدينة. ويمكن للنمو السريع في أعداد المركبات بالعين أن يساهم في زيادة مستوى تلوث الهواء المحيط مما قد يؤثر على صحة الإنسان، والنظم الإيكولوجية، بالإضافة إلى إمكانية تأثير ذلك على المناخ.

لم يتم إجراء أية دراسة لتقييم الآثار الناجمة عن حركة المرور على نوعية الهواء المحيط بمدينة العين، مثل هذه الدراسة سوف تكون مفيدة كأساس للتخطيط والتطوير المستقبلي للمدينة. وبناءا على ذلك، فإن الدراسة الحالية قد أعدت للبحث في تأثير حركة المركبات على نوعية الهواء المحيط في المدينة.

وقد تم جمع بيانات الملوثات الهوائية والتي تشمل الحبيبات الصلبة أصغر من 10 مايكرون (PM_{10})، ثاني أكسيد الكبريت (SO_2)، ثاني أكسيد النيتروجين (NO_2)، أول أكسيد الكربون (CO)، الأوزون الأرضي (O_3) والعناصر الهيدروكربونية (HCs) خلال الفترة 2007-2009، وذلك باستخدام إثنتين من محطات الرصد الجوي الثابتة في منطقتين ذات مستوى حركة مروري مختلف: الأولى في منطقة وسط المدينة والأخرى في منطقة سكنية بالعين. وقد تم مقارنة مستويات هذه الملوثات الهوائية مع معايير جودة الهواء لإمارة أبوظبي. بالإضافة إلى بحث العلاقات ما بين تلك الملوثات مع بعضها، وبينها وبين الظروف الجوية.

أما بالنسبة لبيانات الحركة المرورية، فقد تم جمعها من خلال مركز بحوث الطرق والمواصلات وسلامة المرور التابع لجامعة الإمارات العربية المتحدة. وقد استخدمت تلك البيانات في التنبؤ بالملوثات الهوائية التي تنبعث من الحركة المرورية، حيث تم ذلك باستخدام نماذج (IVE) و(Synchro) لحساب انبعاثات الملوثات الهوائية من المركبات ، بالإضافة إلى استخدام نموذج (Box model) لحساب تركيز تلك الملوثات في الهواء الجوي بعد انبعاثها. بعد ذلك تم مقارنة مستويات تلك الملوثات المتنبأ بها بمستويات الملوثات الهوائية التي تم رصدها بواسطة محطات الرصد الجوي.

جامعة الإمارات العربية المتحدة
عمادة الدراسات العليا
برنامج ماجستير علوم البيئة

تأثير حركة المرور على نوعية الهواء المحيط في مدينة العين- الإمارات العربية المتحدة

رسالة مقدمة من الطالب
صالح محمد علي السقاف بني هاشم
بكالوريوسهندسة كيميائية

رسالة مقدمة إلى
جامعة الإمارات العربية المتحدة
إستكمالا لمتطلبات الحصول على درجة الماجستير في علوم البيئة

تحت إشراف

المشرف الرئيسي **الدكتور/ منجد مرقة** قسم الهندسة المدنية والبيئية كلية الهندسة جامعة الإمارات العربية المتحدة	المشرف المساعد **الدكتور/ ياسر حواس** قسم الهندسة المدنية والبيئية كلية الهندسة جامعة الإمارات العربية المتحدة