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MEASUREMENT AND MODELING OF NO_2 TRAFFIC-RELATED AIR POLLUTION IN DOHA, QATAR

A Thesis in

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By

Noora Abdulla Al-Naimi

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COMMITTEE PAGE

The thesis of Noora Abdulla Al-Naimi was reviewed and approved by the following:

We, the committee members listed below accept and approve the Thesis of the student named above. To the best of this committee's knowledge, the Thesis conforms the requirements of Qatar University, and we endorse this Thesis for examination.

Name Ipek Goktepe

Signature [signature] Date 26-5-2013

Name Mohammad Al-Ghouti

Signature [signature] Date 26/5/2013

Name P. BALAKRISHNAN

Signature P. Balakrishnan Date 26/5/2013

Name [illegible] Kabsing

Signature [signature] Date 25 May 2013

ABSTRACT

Six major intersections along C-ring road of Qatar were investigated for NO_2 emission. NO_2 is considered to be a marker of vehicular pollution thus in this study, its relationship was established with traffic volume in each intersection during December 2012 and March-April 2013. Significant differences were established between the NO_2 concentration in each intersection. Higher concentrations were observed in areas with high traffic volume. The magnitude of the dispersion of the NO_2 emission was further evaluated by monitoring two proximity points within 250m on each side of the main intersection. It was observed that there were no significant differences between the NO_2 concentrations measured in the main intersection and the two proximity points. It was evident that the vehicular traffic continuously flow within the area. The effects of the dispersion of the automobile emissions on the other hand was investigated by considering neighboring points which were situated away from the main intersection. Significantly lower concentrations were recorded in the areas away from direct impact of the emissions from automobile exhaust. It was evident in the study that traffic related emissions significantly influenced the NO_2 concentrations. However, meteorological conditions were also found to influence the level in addition to the topographical structure within the area. The CALINE 4 model employed during the study estimated the influence of the measured NO_2 concentration on the predicted NO_2 value by only 31.12 %. The low percentage may have accounted for the uncertainties brought about the vehicle emission factor, non-availability of temporal dynamics during the time of sampling.

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INTRODUCTION

Transportation plays a significant role in the lives of individuals and communities. However, it has both productive effects on human development and detrimental effects on public health (Al-Koas, 2010). Motor vehicles are an essential source of urban air pollution and are increasingly important contributors of anthropogenic carbon dioxide and other greenhouse gases (HEI,2010). Traffic-related air pollution is a complex mixture that includes particles and gaseous pollutants such as carbon monoxide, nitrogen oxides and ozone. Road traffic is related to undesirable health effects caused by air pollution, noise and accidents (Al-Koas, 2010). Over recent years, traffic-related air pollution and its health effects have received considerable attention. Emission inventories consistently identify motor vehicles as a predominant source of anthropogenic pollution (Henderson and Brauer,2005). Many studies and scientific evidences have associated exposure to traffic related pollutants with a wide range of negative health effects including increased mortality, cardiovascular and respiratory diseases, and cancer. According to the World Health Organization (WHO), around 2,4 million people die each year of causes directly attributable to air pollution, with most of these deaths occurring in developing countries (Haluzan, 2011).

Traffic-related emissions affect ambient air quality on a wide range of spatial scales, from local roadsides and urban scales to broadly regional background scales (HEI,2010). A number of epidemiologic studies have reported associations between residential proximity to busy roads and a variety of adverse respiratory health outcomes in children, including respiratory symptoms, asthma exacerbations, and decrements in lung function. In some reports, truck traffic has been more strongly associated with these adverse outcomes than total vehicular traffic (Kim et al, 2004).

As awareness of the potential health effects of air pollution from traffic has grown, many countries have computed several studies to estimate and understand the status of the air quality in order to improve it. New monitoring technologies have been introduced to help in evaluating the degree of exhaust gases that contribute in air pollution. The development of Geographic Information Systems (GIS) and air dispersion modeling techniques have assessed in understanding the trends of pollutants spread and the correlation of exposure to these pollutants with human health.

Recently, the State of Qatar has developed dramatically in terms of economics, building, population and knowledge. As a result of the exponential growth of population, the demand of automobiles increased as well. So far, there are no studies conducted in Qatar to evaluate the traffic-related air pollution. This study is carried out to monitor the levels of nitrogen dioxide (NO_2) as a marker of pollution related to traffic. The study has been conducted in one of the busiest areas in Doha which is characterized by the variety of land use features and high density of traffic. The aim of this study is to build a baseline for traffic related pollution in Qatar by monitoring and modeling NO_2 emissions. The main objectives of this study are:

1. Monitoring and measuring NO_2 concentrations along the road passing through the study area.
2. Estimating NO_2 levels across the study location using air dispersion model taking into consideration meteorological data such as temperature and wind speed.
3. Integrating the model output into GIS to help in understanding the process of NO_2 diffusion.
4. Interpolating the collected results to predict the effects of many factors such traffic, relative humidity, temperature and wind on the levels of NO_2 emissions.

LITERATURE REVIEW

Air pollution is a major problem that has been recognized throughout the world for hundreds of years. It dates back to the 18^{th} century when the industrial revolution began. It is a serious global problem causing negative impacts on human health and the environment. Air pollution includes all contaminants commonly found in the Earth's atmosphere, some of which can synergistically react with each other resulting in changes in their natural chemistry. These contaminants can be either in the form of gases or particles and usually it is a complex mixture of both. Such contaminants are derived from numerous natural and anthropogenic sources. Although a number of natural activities such as volcanoes and wildfires release different pollutants in the atmosphere, anthropogenic activities are the major source of environmental air pollution (Kampa & Castanas, 2008).

History of Air Pollution

Throughout the years, the world has witnessed numerous disasters due to natural or man-made causes. Those disasters are remembered by their severe impacts they leave behind, including victims and alteration in life and natural processes. Air pollution has often been the cause of many accidents that affected people and environment as well. Winters often provide favorable atmospheric conditions for the pollution episodes to occur. The combined impact of widespread emissions, cold weather, persistent fog, stagnant winds, and low air inversions lead to sharp increase in the harmful effects of pollution including deaths and illnesses of the respiratory system (Phalen & Phalen, 2012). There are three notable episodes in the first half of the twentieth century that were well documented and were known as "the great air pollution disasters". These episodes made world-wide headlines and still widely referred to by air pollution researchers and regulators (Phalen & Phalen, 2012). The first of the three historic air pollution episodes occurred in eastern Belgium in Meuse River Valley which was heavily industrialized with a variety of air pollutant sources. Approximately 6,000 residents in the valley became ill with respiratory diseases and around sixty had died. Many deaths of cattle due to air pollution were also reported (Nemery et al., 2001).

The second notable incident took place in 1948 at a river valley that included the communities of Donora and nearby Webster in southwestern Pennsylvania, USA. The area was occupied by a large steel mill, a sulfuric acid plant, and a large zinc production plant. Twenty people died, and most of them had pre-existing cardiac or respiratory system diseases (Jun, 2009). The most severe air pollution disaster in modern history occurred in London in 1952 taking the lives of more than 4,000 people. The causes of death included pneumonia, bronchitis, and heart disease (Jun, 2009). During that period, there was a heavy, motionless layer of smoky, dusty fumes from the region's million or more coal stoves and local factories settled in the London basin (Davis et al., 2002).

Recently, in January 2013, air pollution has hit record levels in China (New York Times, 2013).Pollution levels were 30 times higher than levels deemed safe by the World Health Organization (WHO) (Kaiman, 2013) Air pollution was at dangerous levels which forced airlines to cancel flights because of poor visibility and pressured the city government to close roads and warn residents to stay indoors (Wong, 2013) According to the Guardian News and Media, The US embassy reported a level of Particulate Matter PM2.5, one of the worst pollutants, at 526 $\mu g/m^3$, or "beyond index", and more than 20 times higher than the WHO safety levels over a 24-hour period (Wong, 2013).

Air Quality Standards

The occurrence of these air pollution disasters helped in recognizing how air pollution can have serious adverse health impacts on communities. In the immediate period following the 1952 episode in London, the British Clean Air Act of 1956 was issued to regulate smoke (Phalen & Phalen, 2012). The first U.S. Clean Air Act of 1963 called for cooperation of state and federal agencies in their enforcement efforts to control air pollution in the US (Phalen & Phalen, 2012). Shortly afterward, the U.S. Air Quality Act of 1967 and the extended British Clean Air Act of 1968 more firmly set the stage for stern enforceable emission standards (Phalen & Phalen, 2012). In the United States, a milestone event was the creation of the U.S. Environmental Protection Agency (U.S. EPA) in 1970 (Phalen & Phalen, 2012). The U.S. EPA is responsible for setting ambient air standards to protect the general public. These standards are called the "National Ambient Air Quality Standards (NAAQS)" (Phalen & Phalen, 2012). The NAASQ, which are intended to be revised every five years, includes standards for six common criteria pollutants. The U.S. EPA has identified six criteria pollutants that can injure health, harm the environment, and cause property damage. These pollutants are ozone (O_3), particulate matter (PM), carbon monoxide (CO), nitrogen oxides (NOx), sulfur dioxide (SO_2), and lead (Pb). In the State of Qatar, the Ministry of Environment (MoE) sets standards and air quality criteria for a number of environmental pollutants based mainly on those of the US EPA and taking into consideration the WHO standards (Almarri, 2003). Table 1 lists NAAQS, WHO and the Qatari ambient air quality standards, used for evaluating the air quality. The State of Qatar has given particular consideration to the air quality through dedicated regulations and implementation of norms and standards and through dissemination of knowledge and awareness among the society at large. By publishing the executive regulations of law number 30 of 2002 related to the environmental protection in Qatar, the norms and standards related to gas emissions to the atmosphere became legally binding (UN Department of Economic and Social Affairs, 2012). These standards and norms define the air quality and the maximum authorized values of pollutant gases that shall not be released from any source in the country (UN Department of Economic and Social Affairs, 2012). The new environmental protection law in Qatar holds an entire chapter on "the air environment" based mostly on the U.S. Clean Air Act (1970) and the U.K. Clean Air Act (1956). The law stipulates that any industrial project must be built at a site suitable for its activities to ensure it does not exceed the allowed limits of air pollutants, and to guarantee that pollution resulting from all the industrial projects on the same site remains within the permissible limits (Qatar Environment Protection Law No. 30, 2002). The law also bans burning liquid and solid wastes except in the designated areas away from residential, industrial, and agriculture areas and water courses (Qatar Environment Protection Law No. 30, 2002).

Table 1 NAAQS, WHO and the Qatari ambient air quality standards (EPA, 2012; WHO, 2012; MoE, 2005)

Pollutant		NAAQA		WHO		Qatari Standards	
		Averaging Period	Level	Averaging Period	Level	Averaging Period	Level
Carbon monoxide		8-hour	9 ppm	8-hour	10 mg/m^3	8-hour	10 mg/m^3
		1-hour	35 ppm	1-hour	30 mg/m^3	1-hour	40 mg/m^3
Nitrogen dioxide		1-hour	100 ppb	1-hour	200 µg/m^3	1-hour	400 µg/m^3
		Annual	53 ppb	Annual	40 µg/m^3	Annual	100 µg/m^3
Ozone		8-hour	0.075 ppm	8-hour	100 µg/m^3	8-hour	120 µg/m^3
						1-hour	235 µg/m^3
Particulate matter	$PM_{2.5}$	Annual	12-15 µg/m^3	Annual	10 µg/m^3	-	-
		24-hour	35 µg/m^3	24-hour	25 µg/m^3	-	-
	PM_{10}	24-hour	150 µg/m^3	Annual	20 µg/m^3	Annual	50 µg/m^3
				24-hour	50 µg/m^3	24-hour	150 µg/m^3
Sulfur Dioxide		1-hour	75 ppb	24-hour	20 µg/m^3	Annual	80 µg/m^3
		3-hour	0.5 ppm	10-minutes	500 µg/m^3	24-hour	365 µg/m^3
Lead		3 months' average	0.15 µg/m^3	Annual	0.5 µg/m^3	3 months' Average	1.5 µg/m^3

Effects of Air Pollution on Human Health

Throughout history, air pollution has been a problem causing diverse effects on human health, the environment, and economy. Due to the dramatic air pollution episodes, a global recognition of the harmful effects that air pollution can have on the health had arisen. The period after the London's Smog incident, witnessed a substantially increase in the number of toxicological and epidemiological studies focusing on the industrial air pollution as encountered by the public (Stanek et al., 2011). According to Takizawa (2011), there is increasing evidence, which supports a relationship between air pollutants and general respiratory symptoms and/or pulmonary function. The respiratory tract is the portal of entry of air pollutants, and thus the lung is the first affected organ. The range of respiratory diseases due to air pollution exposure is wide (Pereza et al., 2010). In his research, Takizawa (2011) demonstrated that exposure to ozone at concentrations found in the ambient air is associated with a reduction in lung function and induction of respiratory symptoms including cough and shortness of breath. Recent epidemiologic, human, and animal model studies have shown that diesel exhaust particulates (DEPs) from traffic, major source of air pollution, increased airway inflammation and can exacerbate and initiate asthma and allergy (Kim & Hong, 2012). Epidemiological studies also exhibited that exposure to ambient PM is associated with significantly higher risks of lung cancer mortality (Block et al., 2012) in the United States, specifically in the District of Columbia and Puerto Rico (Pope et al., 2002). In 2007, a study conducted in the United Arab Emirates (UAE) estimated that the total number of premature deaths in the UAE caused by exposure to anthropogenic PM is approximately 545 (around 7 %

of the total deaths occurring in the UAE in 2007) while around 62 deaths were due to ground-level O_3 exposure (about 1 % of total deaths in 2007) (Li et al., 2010).

Even though much of the early research focused on respiratory diseases, more recent epidemiologic studies have shown that air pollution substantially contributes to the onset and aggravation of cardiovascular diseases and that these effects occur at relatively low levels of exposure (Massimo & Mannucci, 2011). Accumulating evidence indicates that the health effects of air pollution extend past the respiratory tract, resulting in cardiovascular damage and consequent elevation of morbidity and mortality (Block et al., 2012). Numerous studies in humans have demonstrated deleterious effects on various measures of cardiovascular health including systemic inflammation, blood, heart rate variability, vascular function, altered cardiac structure and function and atherosclerosis due to exposure to major air pollutants (Block et al., 2012). In his research, Brook (2008) stated that exposure to air pollution and automobile traffic had been shown to trigger myocardial ischemia and infarctions within hours following exposure and that the risks of strokes and hospitalizations for ischemic events increase. The National Morbidity, Mortality and Air Pollution Study, which involved 50 million people in the 20 largest cities in the United States, found that total mortality rates were independently associated with particle concentrations and that, on the day before death, each 20 $\mu g/m^3$ rise in PM_{10} was associated with a 0.6% increase for cardiopulmonary mortality (Franchini and Mannucci, 2011). In Europe, a stronger association between adverse health outcomes and air pollution was shown by the Air Pollution and Health European Approach study. For 43 million people living in 29 European cities, the estimated daily increase in cardiovascular mortality was 1.5% for each 20 $\mu g/m^3$ rise in PM_{10} (Franchini and Mannucci, 2011). The Meta-analysis of Italian Studies on the short-term effects of air pollution, which collected data from 9 million people from 15 Italian cities through the period 1996-2002, had shown an increased daily rate of cardiorespiratory mortality associated with increased levels of several air pollutants (NO_2, CO, SO_2, and PM_{10}) (Franchini and Mannucci, 2011).

While the majority of prior studies have focused on the effects of air pollution in cardiovascular and pulmonary diseases, evidence now points to a potential role for air pollution in Central Nervous System (CNS) diseases as well (Block et al., 2012). More recent epidemiological and animal toxicology studies have raised concerns about the potential impact of air pollution on CNS outcomes including chronic brain inflammation, microglia activation, and white matter abnormalities leading to increased risk for autism spectrum disorders; lower IQ in children, neurodegenerative diseases as Alzheimer's disease (Block et al., 2012). Studies have shown that exposure to traffic-related air pollution, as NO_2, $PM_{2.5}$, and PM_{10} during pregnancy and during the first year of life was associated with autism (Volk et al., 2013). Among the studies that were conducted to examined associations between autism and air pollution exposures during the prenatal period is one which concluded that children born to mothers living within 309 m of a freeway during pregnancy were more likely to be diagnosed with autism than children whose mothers lived > 1,419 m from a freeway (Volk et al., 2013; Volk et al., 2010). Human studies have revealed that individuals living in highly polluted cities show Alzheimer's disease (AD)-like and Parkinson's disease (PD)-like pathology, when compared to individuals living in cities with less pollution

(Levesque et al., 2013). Lead is strongly implicated in neuronal damage and CNS disease. The clinical manifestation of lead neurotoxicity includes impaired intellectual function and attention, encephalopathy, and convulsions (Block et al., 2012).

Effects of Air Pollution on the Environment

Besides causing adverse health effects, air pollution can also negatively impact the environment around us including living and non-living things. Acid rain is mainly caused by nitric and sulfuric acids which are formed primarily by nitrogen oxides (NOx) and sulfur oxides (SOx) released into the atmosphere. There are two ways of precipitation of acid rain, either wet deposition in the form of rain, snow, or fog; or dry deposition as particulates (US EPA,2013). Acid rain destroys plants, crops, man-made sculptures, and buildings. The acidity of water bodies and soil is increased by acid rain resulting in many living organisms' death. Another effect of air pollution on water bodies is the increased concentration of nutrients as nitrogen in the water. For example, NOx emissions from transportation and power plants contribute to the increased amount of nitrogen entering aquatic ecosystems. As the concentration of nitrogen gets higher in a water body, it stimulates the growth of algae, which in turn can cause loss of plant and animal diversity (Massachusetts Department of Environmental Protection, 2012). This phenomenon is known as eutrophication. Other environmental effect of air pollution includes urban smog and reduced visibility, which are associated with ozone-forming NOxand volatile organic compound emissions (VOCs). NOx and ground level ozone both cause necrosis to plants which reduces the photosynthesis process and as a result plants die. Figure 1 shows the procedure for the release of NOx and SOx into the atmosphere and the formation of acid rain.

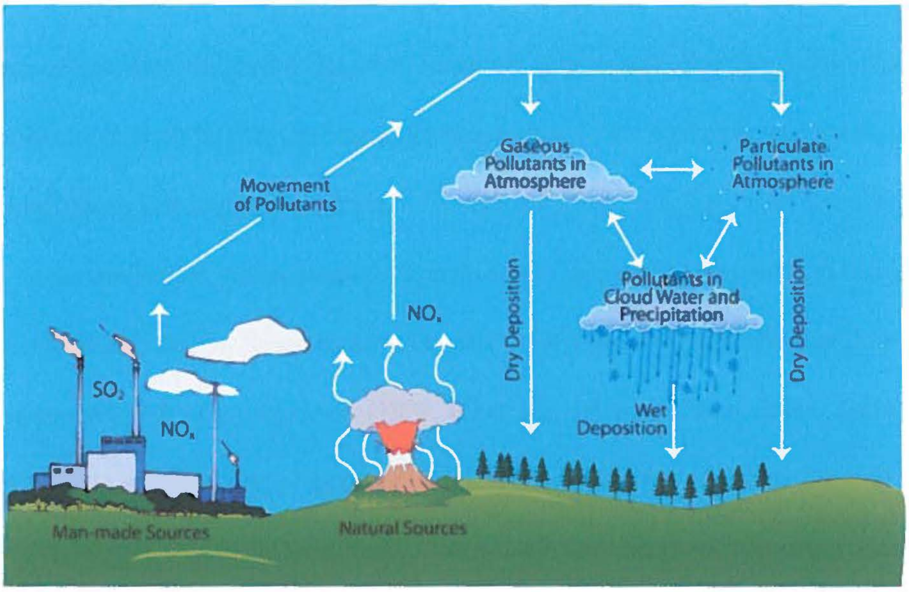

Figure 1 Acid rain formation (Source: http://rainacids.blogspot.com)

Economic Impacts of Air Pollution

The effects of air pollution on human health and the environment also have economic impacts. According to the Healthy People 2000 report, each year in the United States the health costs of human exposure to air pollutants range from $40 to $50 billion. The Environmental Defense Fund (EDF) states that acid rain causes $6 billion a year in damage to crops, forests, lakes, and buildings (Cleaner & Greener, 2011).

Traffic related Air Pollution

Transportation is a vital part of modern life and plays a fundamental role in the lives of individuals and development of societies (Krzyzanowski et al.,2005). However, it has a negative impact on the human health in several ways, most important being the vehicular emissions and accidents (Al-Koas, 2010). One of the leading concerns is the adverse effect on health due to air pollution emitted by motor vehicles. In recent decades, research consistently indicated that outdoor air pollution harms health, and the evidence points to air pollution that stems from transport as an important contributor.

Air pollution, particularly in urban areas, has strong impacts on our daily lives (Narashid, 2010). Since motor vehicles contribute a significant portion of the emissions of CO, Hydrocarbons (HC), (Ox) and PMs in urban areas, emissions from vehicle engines are considered to be a major source of urban air pollution (Jin and Fu, 2005). These pollutants, along with secondary by-products, such as ozone and secondary aerosols (e.g., nitrates and inorganic and organic acids), can cause adverse effects on health and the environment (HEI, 2010). The United Nations (UN) estimated that over 600 million people in urban areas were exposed to dangerous levels of traffic-generated air pollutants worldwide (Han and Naeher, 2006). It has also been estimated that urban air pollution is responsible for about 800,000 annual deaths around the world (Dionisio et al., 2010). Numerous epidemiological studies have associated exposure to ambient air pollutants with a range of adverse respiratory and cardiovascular health effects in different populations around the globe (Laumbach and Kipen ,2010).

Children are particularly vulnerable to airborne pollution due to their undeveloped respiratory and immune systems and the fact that they generally inhale more air per pound of body weight than adults, which would increase their exposure to air pollutants (Gasana et al.,2012; Kim&Hong 2012). Children are often very active outdoors and breath through their mouth especially when they exercise. The mouth-breathing process bypasses the natural filtering of air pollutants by the nose and allows large volumes of polluted air to affect the more sensitive areas of children's lungs which are still developing. Therefore, they can be subject to oxidant-induced injury to the lungs, which can lead to permanent lung changes (Gasana et al.,2012). Kim and Hong (2012) demonstrated that air pollutants have various adverse effects on early life, and some of the most important harmful impacts of these pollutants are perinatal disorders, infant mortality, respiratory disorders, allergy, increases in oxidative stress, and endothelial dysfunction. They also mentioned that those effects of air pollution in early life may be related to many chronic diseases later in life (Kim&Hong 2012). Many epidemiologic studies have shown that exposure to air pollution from road traffic is associated with respiratory health in children, including upper and lower respiratory symptoms (Mustapha et al., 2011). According to *Gasana et al.*(2012), traffic-related air pollutants were suggested to promote airway sensitization by modulating the allergenicity of airborne allergens. Airway mucosal damages and impairments of the mucociliary clearance functioning induced by pollutants may facilitate the penetration of inhaled allergens leading to a vicious cycle which can lead to wheeze and asthma (Gasana et al.,2012). In their research, Bener et al. (2007) found some evidence which relates exposure to outdoor air pollutants to the increased risk of childhood asthma, eczema, and allergic rhinitis in school children in Qatar. In another study, the same research team also found an association between increased air pollutant levels and the higher hospital admission due to respiratory and cardiovascular diseases. The results also showed that the critical air pollutants in the urban areas of Qatar were CO and NO_2 (Bener A et al. 2009).

Nitrogen dioxide (NO_2), one of the main traffic-related air pollutants and precursors forming photochemical smog (together with VOCs) and ground-level ozone, is currently under intensive investigations (Han and Naeher, 2006). It belongs to a family of highly reactive gases called NOx. These gases form when fuel is burned at high temperatures, and come principally from motor vehicle exhaust (EPA, 2012). The gas is reddish brown and highly reactive in ambient air. It undergoes a complex chain of chemical and photochemical reactions with nitric oxide (NO), O_3, and other gases. Usually the NO_2 in the atmosphere comes from two sources, either directly from emission sources (primary pollutant) or from chemical reactions in the atmosphere (secondary pollutant) (Han and Naeher, 2006). In urban areas, NO_2 is predominantly produced by vehicle emissions and; thus, its concentration at any given location depends on the local traffic density (Lee & Shaddick, 2010). Both O_3 and NO_2 are oxidant pollutants which are known to increase augment allergic sensitization, asthma and wheeze, and exposure to them may prime eosinophils to subsequent activation by inhaled allergens in atopic patients (Gasana et al.,2012). Studies on rodent models of asthma showed that nitrogen dioxide can boost the degree of allergic airway inflammation and prolong allergen-induced airway hyper-responsiveness as found in rodent models (Gasana et al.,2012). High concentrations or continued exposure to low levels of NO_2 have been associated with the development and exacerbation of respiratory and cardiovascular diseases (Wang J. et al., 2011). A study by Hussain et al. (2004) on murine model showed that short-term exposure to nitrogen dioxide may cause epithelial damage, reduced mucin expression, and increased respiratory smooth muscle tone. It was found that the reduction of mucin production may happen due to long term exposure to NO_2. Environmental exposure to nitrogen dioxide may promote allergen sensitization, resulting in allergic airway disease in response to otherwise innocuous inhaled antigens even when the inhalation of antigen occurs as much as several days following exposure (Gasana et al.,2012). Using nitrogen dioxide as a marker for vehicle exhaust, it was found that it may not only worsen asthma symptoms but may also induce the disease (Gasana et al.,2012).

Air Quality Monitoring and Modeling

Urban air pollution is a key factor to be considered when it comes to decision making. Both monitoring and modeling of air pollution are important in providing information about the status of air. Air pollution monitoring is needed to control air pollution in urban areas and is significant to know the baseline status of many parameters such as CO, CO_2, NO_2, SO_2 and PM (Jha et al., 2011). Air quality modeling (AQM) has the ability to assess the current and future air quality and plays an essential role in formulating air pollution control and management strategies by providing information about the status of air quality and efficient plans to enhance the quality of air in a specific region (Sharma , 2003).

Urban Air Quality Assessment

Many approaches have been developed to help in assessing the impact of urban air pollution on public health. These approaches include the use of interpolation methods [e.g. Kriging, Inverse Distance Weighing (IDW)], conventional dispersion models (e.g. AERMOD, CALINE, OSPM), and land-use regression (LUR) models (Hoek et al., 2008). Another approach is the use of remote sensing as it has been widely used for environmental applications. Recent advances in tropospheric remote sensing have opened the way for measuring, monitoring, and understanding processes involved in air pollution (Edwards, 2006). Satellite remote sensing method has many advantages of monitoring air quality at micro-scale level as the satellite observations can provide a complete survey of the city; show the major sources of pollution and the distribution pattern (Narashid, 2010).

Passive diffusion tubes have been widely used in many countries such as the UK , the US and the UAE to measure gaseous pollutants as NO_2. This method of monitoring is simple, cheap and easy to use, and is a very useful tool for measuring spatial and temporal variations (Cape, 2005). During 2007, AEA Energy & Environment has undertaken a year-long monitoring study in Jersey, UK using diffusion tube. The tubes were used to monitor NO_2 at 24 different locations on the island some of the locations were roadside site at the Central Market. The results of the diffusion tube survey indicated that all monitoring sites in Jersey meet the UK Air Quality Strategy Objective of 40µg m-3 for the annual mean NO_2 concentration. (Alison Loader & Brian Stacey, 2008). In Al-Ain city at the UAE, passive samplers were used for NO_2 monitoring for over a year. This study had showed that passive samplers were not only precise but also of low cost, low technical demand, and expediency in monitoring different locations (Salem, 2009).

AQMs are computerized representations of the atmospheric processes responsible for air pollution. Air pollution modeling is a numerical tool used to describe the causal relationship between emissions, meteorology, atmospheric concentrations, deposition, and other factors (Daly and Zannetti, 2007). Using mathematical and numerical techniques, AQMs simulate the physical and chemical processes that affect air pollutants as they disperse and react in the atmosphere. (EPA, 2013). Due to their capability to assess the relative importance of the relevant processes, air pollution models play an important role in research and science. Air pollution models are the only method that quantifies the deterministic relationship between emissions and concentrations/depositions, including the consequences of past and future scenarios and the determination of the effectiveness of abatement strategies (Daly and Zannetti, 2007). AQMs are important tools for air quality management and control; therefore, they are widely used by regulatory agencies (EPA,2013). Moreover, AQMs can also be used to predict future pollutant concentrations from multiple sources after the implementation of a new regulatory program, in order to estimate the effectiveness of the program in reducing harmful exposures to humans and the environment (EPA, 2013). Air quality models can be classified depending on the source of pollutants which they model as point, area or line. Line source models are used to simulate the dispersion of traffic pollutants near highways or roads where vehicles continuously emit pollutants (Sharma, 2003).

CALINE4 is a line source air quality model developed by the California Board of Transportation (Kenty et al., 2007). CALINE4 is an example of Gaussian model, the most commonly used program for modeling air pollution, which describes the transport of a pollutant from a source to a receptor (Wallace & Kanaroglou, 2008). It is capable of predicting concentrations of pollutants within 500 m of a roadway given the required meteorological (e.g. wind speed, wind direction, mixing height, stability class, temperature, background concentrations), source strength (e.g. vehicles per hour, vehicle emission factor) and geometrical (e.g. roadway height, receptor locations and heights, number of links, surface roughness, mixing zone width) input parameters (Kenty et al., 2007). In addition to its application to roadways, special options allow the model to be applied to intersections, street canyons and parking lots (Kenty et al., 2007). Kenty et al. (2007) had applied the CALINE4 dispersion model to roadside measurements of NO and NO_2 near the Gandy Bridge in Tampa, Florida. Based on their study results, the model described the measured concentrations of conserved NO_x quite well. CALINE4 has been validated for estimating PM_{10} and NO_2 concentrations in Cracow, UNESCO World Heritage Site in Poland, over the period of 2001-2005 (Méline et al., 2011). The CALINE4 model was integrated with GIS and applied to predict the concentration of vehicular pollutants especially CO on the road between Delhi and Agra in India as well (Sharma, 2003).

Air Quality in the Middle East and Arab Region

Global scale atmospheric modeling research has shown that the Middle East is a significant source for photochemical air pollution and dust storm activity (Adelman *et al.,* 2009). Vehicular emission is also a significant source of air pollution in the Arab Region. Nighty per cent of total emissions of CO in Arab countries are due to vehicular transportation. The Arab world's motor vehicles emit 1.1 million tons/year of NOx (40% of total-60% originates from the energy and industry sectors) (United Nations Environment Programme and League of Arab States, UNEP and League of Arab States, 2012). A combination of NOx and SOx contributes to a large extent (about one-third) to acid deposition on soil, vegetation and water, thus causing damage to crops, forest, fish, etc. Most importantly, NOx are a cause of the photochemical smog often observed in large cities, particularly during the summer (UNEP and League of Arab States, 2012). Despite a unique combination of large anthropogenic emission sources, related to rapidly growing urban populations and concentrated industrial sites, and topography that is conducive to frequent dust emissions events, there have been relatively few regional-scale modeling studies (Figure 2) to assess air pollution exposure in the Middle East (Adelman *et al.*, 2009).

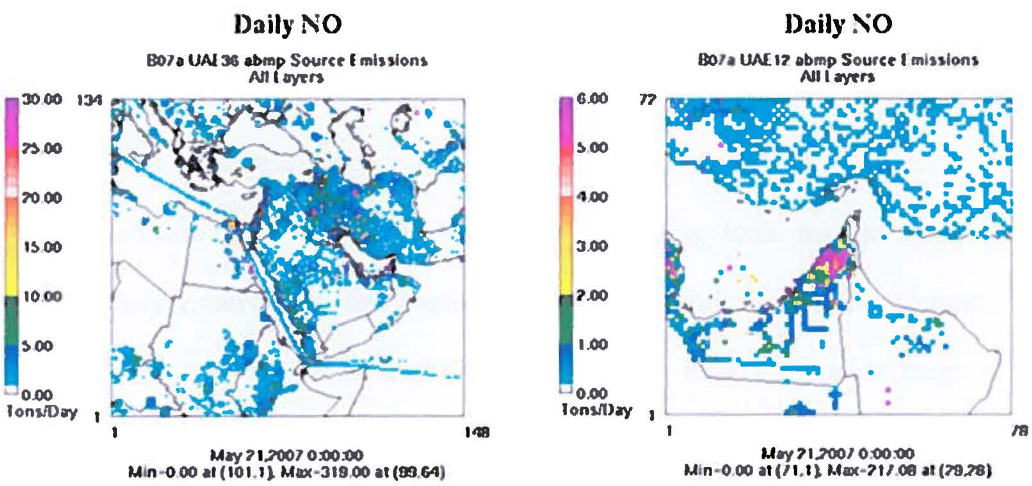

Figure 2 Daily tile plots of NO emission for two days in May 2007 on the 36-km (left) and 12-km (right) MEEMP modeling grids in the UAE. (Source: Adelman et al., 2009)

Application of GIS in Air Pollution

The recent development of spatial data management in the frame of Geographic Information Systems (GISs) has created the new era of environmental modeling (Matejicek, 2005). GIS is a computer-based tool for mapping and analyzing geographic phenomenon that exists and events that occur on Earth (Sharma, 2003). GIS integrates hardware, software, and data for capturing, managing, analyzing, and displaying all forms of geographically referenced information. GIS consists of the following major components: hardware, software, data, and people.

- *Hardware:* Consists of devices and computational machines on which the GIS software runs. The computer is usually paired with peripheral equipment such as input and output devices. Input devices such as scanners or digitizers can be used to provide input data to the GIS where they convert a "paper" image into a digital form for further processing. Plotters and printers are examples of universally used output devices for GIS (Al-Koas, 2010).
- *Software:* provides functions and programming tools needed to store, analyze and display geographic and attributable information. A commonly used GIS software is ESRI's ArcGIS which includes a wide range of features required for spatial creation, editing, analysis, model development, and visualization.
- *Data:* is the most important component of GIS. Geographic data and related tabular data can be collected in-house (primary) or bought from a commercial data provider (secondary). Most GISs integrate the spatial data

with other data sources and Database Management System (DBMS) which are used by most organizations to maintain and manage their non-spatial data to create and maintain a database to help organize and manage data.

- *People:* refers to GIS users, ranging from technical specialists who design and maintain the system to those who use it to help them to do their everyday work. GIS is useless without the people who design, program, and maintain it, supply it with data, and interpret its results.

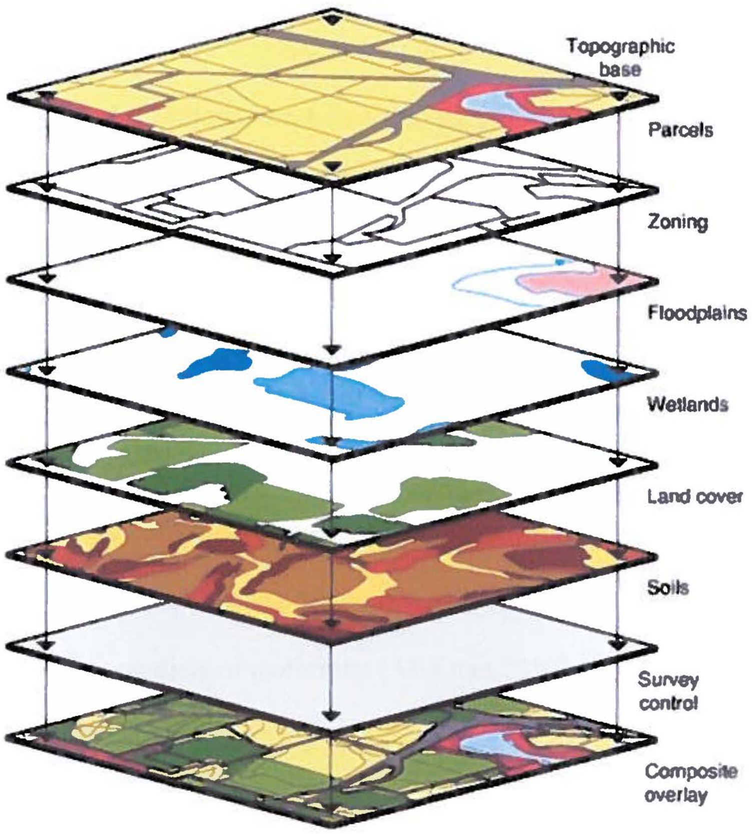

Figure 3 A typical GIS data model (Source: http://www.amalgamatellc.com/our-services/data-assessment.html)

The application of GIS technology is very powerful in supporting highly critical decision in reducing the effects of air pollution on public health. It is a way that can help reducing decision making time; for example, with traffic related human health problems. The time to make regulatory decision can be reduced by conducting a spatial analysis for the evolution of a suitable methodology and modeling (Al-Koas, 2010). GIS is increasingly being used in analyzing, understanding, modeling, and management of the natural environment to estimate and monitor pollutants in the air, soil or water (Environmental Systems Research Institute, ESRI, 2012; Narashid and Wan Mohd., 2010). Recently, several efforts have been made in the USA, Europe and some Asian countries such as India; for mapping traffic related pollution and determining pollution patterns in urban areas using GIS. The application of GIS in transportation related air quality modeling and management was started in early nineties. The demand for the visualization of spatial data has increased to identify areas with great potential threats. GIS helps in meeting this increasing demand and its functions go beyond what maps or databases alone can do. Geographic information systems are fundamentally capable of answering descriptive questions of What? Where? When? How big or how much? GIS can reveal patterns that would otherwise escape attention of its users as engineers, scientists or governors (Al-Koas,2010).

Local Status of Air Pollution

In the last decade, the State of Qatar has been going through many changes and developments in economic, urban, and construction fields. In December 2002, Qatar's population was 616,718, while according to the latest figures released by the Qatar Statistic Authority (QSA), the population reached 1.84 million at the end of September 2012 (QSA, 2012). This figure is expected to increase to reach three million by 2026 (Ministry of Municipality and Urban Planning, 2012). This increment in the population was coupled with an increment in the transportation. Brigadier Mohamed A al-Malki, a senior expert in Qatar's traffic sector, mentioned that in the last decade, the number of vehicles in Qatar grew more than 130 %. (GULF TIMES,2012). According to the latest statistics revealed by the Traffic Department of the Ministry of Interior, the number of new vehicles registered in 2012 reached 88,146 which indicates an increase compared to previous year, 2011 (Traffic Department) Figure 4 represents a graph of the growth in registered cars in Qatar during the past three years.

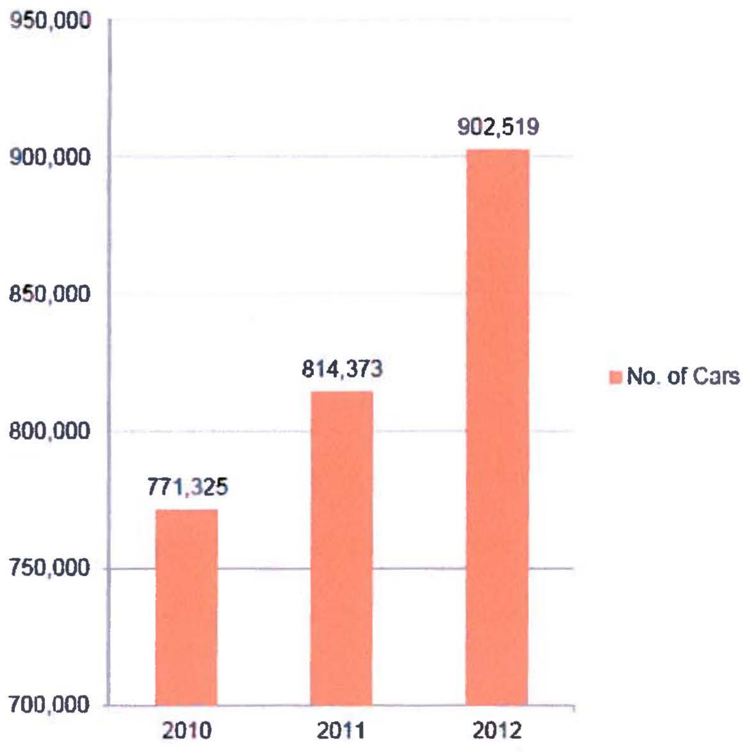

Figure 4. Total Number of registered cars in Qatar (2010-2012)

This rapid growth in both population and cars resulted in many environmental changes in the country. The needs to manage environment and balance between economic growth, social development, and environmental protection lead to the development of Qatar's National Vision 2030. The vision emphasizes on sustaining the environment for the future generations by balancing between developmental needs and the protection of its natural environment, whether land, sea or air (Qatar National Vision 2030, QNV2030, 2012). Air quality study field in Qatar is attracting much needed attention by researchers. A substantial body of epidemiological evidence now exists that establishes a link between exposure to air pollution and increased mortality (especially premature death) and morbidity due to a wide range of adverse cardiovascular and respiratory problems (Lira *et al.,* 2012). The statistics obtained from the Department of Epidemiology and Medical Statistics at Hamad Medical Cooperation (HMC) shows that the number of visitors complaining from respiratory diseases in 2010 were about 11,198 patients and 40% of them where children. While in 2011, the numbers increased by 6.3% and reached 11,955 patients among whom 43% of were also children. In both years, 28% of those patients were admitted to the hospital for further treatment and assistant. The recorded percentage of deaths among the admitted patients was 2%. Table 2 shows the recorded statistics on respiratory diseases in 2010 and 2011 in the State of Qatar (Department of Epidemiology and Medical Statistics at Hamad Medical Cooperation (HMC)) .

Table 2 Health statistics on respiratory diseases in Qatar among 2010 and 2011

	Total Visitors (Pulmonary diseases)	% of patients needed further treatment & assistant	No. of Deaths among further treated patients	No. of Deaths Due to respiratory diseases
2010	11,198 (40% children)	28%	2%	1%
2011	11,955 (43% children)	28%	2%	1%

The State of Qatar is one of the most rapidly growing nations in the world . It is a peninsula that extends northward covering an area of 11,437 Km^2 and lies halfway along the West Coast of the Arabian Gulf, east of the Arabian Peninsula. Qatar is substantially a flat land, except for some hills and sand heaps that reach up to 40 meters above sea level in some areas. The weather in Qatar is of the typical arid desert type with a hot, humid summer and a relatively warm winter. Doha is the capital of Qatar and holds most of its population. As the country expands industrially, its environmental problems also grow relatively. Since the number of cars has tripled in Qatar in the last 10 years, the related environmental concerns have not been looked at.

At the moment, there is no published literature available on the levels of air pollutants, specifically NO_2, due to traffic in Doha-Qatar. Additionally, there has not been any study conducted on air quality modeling in Qatar. As a result, this study was carried out to (1) monitor the levels of traffic related air pollutants (NO_2) in Doha in a seasonal trend, (2) identify sampling locations that reflect variability in land use and heavy traffic, (3) integrate emissions within a framework of GIS through the use of air dispersion modeling techniques.

METHODOLOGY

Study Area

The C-Ring area in Doha was selected for this study based on many criteria that have been taken into consideration as the land use and traffic density. The selected area has different forms of land use where there are commercial buildings, health centers, schools, residential buildings, and a park. The major source of pollution in the selected area is due to the considerably high traffic density

The study area was divided into six main sampling locations representing main traffic intersections. Each main sample location had four sampling sites located on the corners of each intersection and two more sampling sites on both right and left sides of the intersection. The total length of the road passing through the area is approximately 6.7 kilometers starting from the White Palace Intersection near Hamad Medical City and ending at Najma Intersection. Figure 5 represents a schematic map of the C-Ring area along with the main intersections and sampling locations.

Figure 5 Location map of the study area showing the C-Ring road and sampling locations

NO_2 Measurement and Analysis

Passive diffusion tubes from Gradko International were used for trapping nitrogen dioxide (NO_2) from air. Since their introduction in the late 1970s for measuring personal exposure to NO_2, passive diffusion tubes have been used as an inexpensive method for sampling NO_2 concentrations in air over periods from a few days to a few weeks (Cape, 2005). The main advantages of the diffusion tubes are the lack of requirement for electrical power, the lack of need for maintenance, the low cost of the materials, the simplicity of the analytical procedure, and the provision of an absolute air concentration that (in principle) does not require calibration (Cape, 2005). The tubes provide long-term monitoring options with detection limits in the low parts per billion to parts per million range (Gradko Inter. Ltd., 2012). The results acquired from the diffusion tubes are not as accurate or precise as might be obtained from real-time instruments. However, the results from these tubes can still be of considerable value under circumstances where instrument cost, size and electrical power are concerns such as in our study (Nash and Leith, 2010). These tubes consist of a small acrylic tube, approximately 71 mm length x 11 mm internal diameter, fitted with gray and white thermoplastic rubber caps. The gray cap holds stainless steel mesh discs, coated with an absorbent which is 20% Triethanolamine (TEA) / De-ionized Water (Figure 6) (Gradko Inter. Ltd., 2012). During sampling, one end is open where the white cap is removed and the other end is closed. The closed end contains the absorbent. Diffusion tube samplers operate on the principle of molecular diffusion (Bush et al., 2000). During molecular diffusion, gas molecules move from a region of high concentration (open end of the tube) to an area of low concentration (absorbent end of the tube).

Figure 6 Passive diffusion tube

The measurement and monitoring was carried out in two different periods of the year depending on the weather conditions which in turn reflects two seasons, winter and summer. The exposure periods were intended to help in understanding the effect of environmental factors such as temperature, humidity and wind velocity on NO_2 emissions. Table 3 summarizes the different periods of sampling.

Table 3 NO_2 Monitoring Schedule

Exposure Period	Start Date	End Date
Period 1	05 December 2012	20 December 2012
Period 2	23 March 2013	08 April 2013

The diffusion tubes were received from the supplier (Gradko Int.) in two batches depending on the monitoring schedule. Once received from the supplier, the tubes were stored in an airtight bag in a refrigerator at 10°C and have been used within 3 weeks of the preparation date displayed on the label. The tubes were mounted on light or traffic poles as available about 2 meters high from the street and exposed at selected sites to the atmosphere for the study period (Figures 7, 8). Each sampling site location had a unique identifying code to keep track of the tubes mounted. Three tubes were fixed at each location to increase the accuracy of the NO_2measurements. A data collection sheet was prepared to record the location, date, and time of each tube that have been exposed to air during each monitoring period. On the day of collection, the exposure period was calculated for each tube and recorded on the exposure sheet. The diffusion tubes were labeled with a barcode and unique identification number, sealed in air tight bags and shipped along with the exposure sheet to Gradko International analytical laboratories for quantitative analysis (Figures 9, 10). Gradko is based in the United Kingdom and are UKAS accredited that work to ISO: 17025.

Figure 10 Diffusion tubes mounted on a traffic pole in one of the study area sampling locations

Figure 7 Fixing tubes on select location

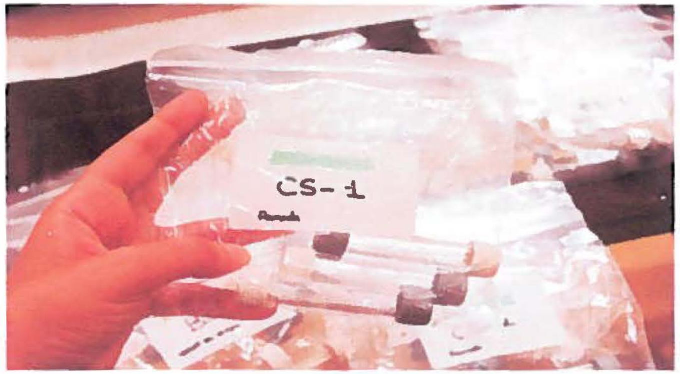

Figure 9 Collected tubes after each monitoring period

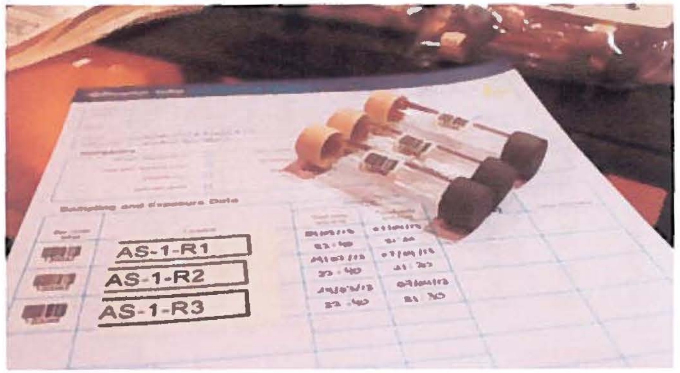

Figure 8 Labeling and filling NO_2 monitoring sheet record

Quantitative Analysis

The analysis was carried out at Gradko International analytical laboratories in the UK. Nitrogen dioxide was absorbed as nitrite by triethanolamine. The first stage of analysis involved extracting the absorbed nitrite from the TEA-coated grids into a solution, so that it is available to react with the reagents. This was done by adding 3.0 mL of deionized water to the tube and agitating it using a vortex mixer for at least 15 seconds. The tubes were left to stand for about ten minutes and then transferred to an autosampler where the color reagent solution (2% suphanilamide, 5% orthophosphoric acid, 14% ethylene diamine dihydrochloride) was automatically dispensed through different loops in the automatic analyzer (Targa et al., 2008). Nitrite reacts with the added reagent to form a reddish purple azo dye, which is measured spectrophotometrically at 540 nm using a UV/visible spectrophotometer (Figure 11).

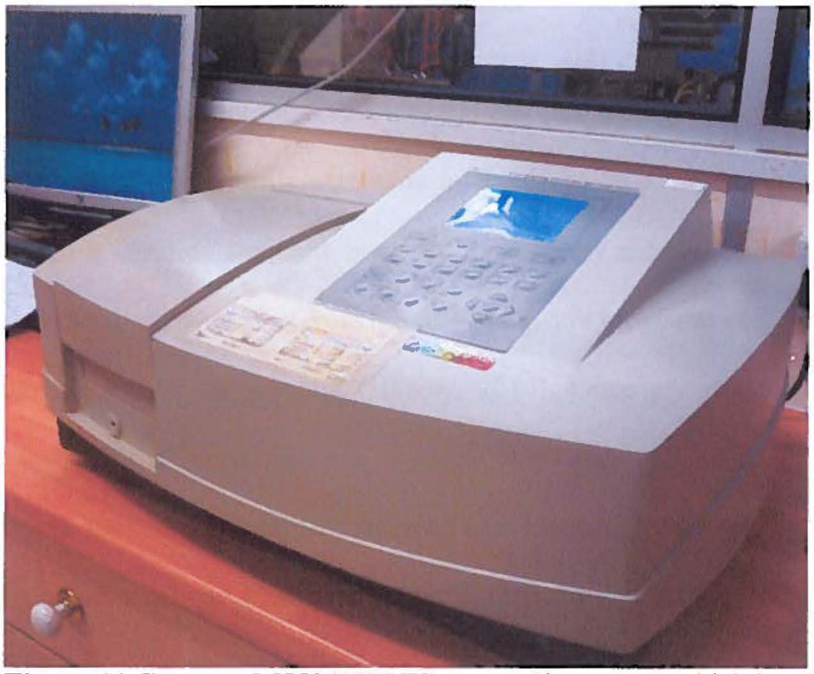

Figure 11 Camspec M550 UV-VIS spectrophotometer which is used in Gradko for the analysis of NO2

The mass 'm_t' of nitrite in each tube was calculated as:

$$m_t(\mu g) = C_s(\mu g/mL) \times V\ (mL)$$

where:

- Cs = Concentration of nitrite in the relevant standard solution – as prepared

- V = Total volume of standard solution added, i.e. 0.05 mL (50 μ L)

The concentration, C_t, of nitrite in each tube was calculated as:

$$C_t(\mu g/mL) = \frac{m_t(\mu g)}{V_x(mL)}$$

m_t = The total mass of nitrite in the tube

V_x = The total extraction volume

The overall uncertainty of the method have been reported by the lab as 7.8% +/-

Quality Control

Reference to Gradko International, the system was calibrated prior to each analytical sampling using nitrite standards in the range of 1 to 2 ppm on tube made up from a certified standard stock solution. Every month a full range of nitrite standard solutions ranging from 0.5 to 4 ppm were measured and compared to the instrument calibration graph (Hickey, 2010). Once per month, a stock solution containing a known amount of nitrite from Atomic Energy Authority AEA Technology Environment was received by Gradko International analytical laboratories and measured. The results were used as part of the UK NO_2 Survey QA/QC Scheme. This stock solution was then used by Gradko to check the UV spectrophotometer calibration graph. Quality control standards spiked onto clean tubes were analyzed before, during and after each analysis. Blank tube values were monitored from each batch of tubes prepared. The accuracy of Gradko laboratory measurements were monitored by participation in an external Laboratory Measurement Proficiency Scheme, the 'Workplace Analysis Scheme for Proficiency' (WASP), implemented by the Health and Safety Laboratory in the UK. The analysis was carried out in accordance with Gradko International Ltd. Internal Laboratory Quality Control Procedure GLM7 and within their U.K.A.S. Accreditation Schedule.

Air dispersion model CALINE4

CALINE4 Description

CALINE4 (CALifornia LINE Source Dispersion Model, version 4) is an air dispersion model developed by the California Department of Transportation (Caltrans), which is devoted to the modeling of road traffic air pollution (Méline et al., 2011). CALINE4 is the latest version of the CALINE series of pollutant dispersion models and one of the most validated models available for assessing the impact of vehicle traffic on roadside air quality (Vardoulakis, 2002). This model is considered as an international reference, which has been used and applied in many research studies (Méline et al., 2011) and has been widely used in the scientific and engineering applications mainly concerning highway development and management (Vardoulakis, 2002). It is based on the Gaussian diffusion equation and employs a mixing zone concept to characterize pollutant dispersion over the roadway (Lakes Environmental, 2013). In addition to predicting CO concentrations, CALINE4 has an advanced method for calculating

NO_2 concentrations using the Discrete Parcel Method, which assumes that emissions and ambient reactive species are fully mixed in the roadway mixing zone initially, and that the dispersion of this initial mix is characterized as a scattering of discrete parcels, with reactions proceeding as isolated processes within each parcel (Wang et al., 2011; Coe et al. 1998). The model has the ability to predict air quality reliably up to 500 m from the roadway and the special options for modeling air quality near street canyons, intersections, and parking facilities which is a great advantage of the model (Majumdar et al., 2009). The US EPA lists CALINE4 as the preferred/recommended roadway model and the UK Department of the Environment, Transport and the Regions lists it as an advanced model (Ministry for the Environment in New Zealand, 2013). CALINE4 (CALROADS View) model is user-friendly, can operate with WINDOWS operating system and easily integrates with GIS; because of these features, it was chosen to be used in this study (Méline et al., 2011).

Input requirement for CALINE4

CALINE4 air dispersion model requires the following data as input:

- *Traffic Parameters*: Road traffic volume (i.e. number of vehicles per hour) passing by the study area is required as an input for the CALINE4 model. Traffic data was collected from both the Public Works Authority (ASHGHAL) and the Traffic Department at the Ministry of Interior. The time period of the study was classified into three main rush hours and a low traffic hour depending on the highest traffic density. For each intersection, the hourly traffic volume passing through that specific intersection was calculated in units of vehicles per hour. Table 9 – Appendix- shows the total number of vehicles passed through the main intersections of the study area during the different rush hours in the study period.

- *Emission Factor Parameters*: An emission factor based on fleet composition weighted by vehicle type, vehicle age and operating mode of a vehicle is called a composite emission factor. The composite emission factor expressed in grams/distance traveled is the quantity of pollutants emitted per unit distance and is dependent on a combination of calibrated parameters (Méline et al., 2011). According to CALINE4 Guide, the emission factors should be modeled using the CT-EMFAC computer model. The EMFAC model issued by the California Air Resources Board is used for this process in California (California Dept. of Transport,2013). Due to the lack of Emissions Inventory as well as factors specifically designed for Qatar, we used the EMFAC emissions database. Emission factors were obtained from the database for the different vehicles' types and different speeds ranging between 60 km/hr to 120 km/hr which is the maximum allowable speed in Qatar. The composite emission factor was calculated according to the formula ∑(Average emission factor for vehicle class × percentage of vehicle in this class) which have been used in a study by *Burden et. al.*(1997). Table4 lists the composite emission factors used to estimate NO_2.

Table 4 Composite Emission Factors of Vehicles used for NO2 estimation

	NO_x Emission Factor (g/mi-vehicle)	
	December 2012	**March - April 2013**
Morning Rush Hour	0.7113	0.635
Afternoon Rush Hour	0.7113	0.635
Evening Rush Hour	0.516	0.449
Low Traffic Hour	3.831	3.563

- *Meteorological Parameters*: Because of their importance in the spatial dispersion of air pollutants, meteorological conditions are an essential component used in CALINE4 modeling. The use of several meteorological parameters is required to establish local meteorological conditions capable of influencing the estimation of the concentrations of NO_2 pollutant as well as its distributions (Méline et al., 2011). The hourly meteorological data (i.e. ambient temperature, relative humidity, and wind speed and direction) were obtained from the Climatology Department at the Civil Aviation Authority for the nearest weather station to the study area. The averages of the meteorological parameters were calculated. Table 10 - Appendix- shows the average meteorological data (ambient temperature, relative humidity and wind speed) recorded during December 2012 and March-April 2013.

- *Background Concentrations*: CALINE4 requires the background concentrations of NO, NO_2 and O_3 in order to allow the model to calculate the effect of photochemical reactions between nitrogen pollutants for O_3, NO and NO_2. The values of background concentrations for NO and O_3 have been determined by calculating the average concentrations of each pollutant over the period of the study. The concentrations of NO and O_3 were provided by the MoE. Due to the sensitivity of the data and the agreement with the MoE, these values are not reported in this text. NO_2 background concentrations have been calculated as the average of the measurements of the diffusion tubes. In order to estimate the importance of photochemical reactions between NO_2, NO and O_3, CALINE4 requires the photolysis rate constant. The default value given in the CALINE4 model is equal to 0.004 s^{-1} is selected in this study as it had been used in the study done by Méline et al., 2011.

Statistical Analysis

Several statistical analyses were employed on the data obtained in this study. They are tools to help understand the results of an analysis, possibly predict the outcome based on this understanding and quantify the confidence of the inferences established. The statistical tools used in this study are Analysis of Variance (ANOVA), Linear Regression and a post hoc to further delineate the differences being established.

Analysis of variance (ANOVA) is a collection of statistical models used to analyze the differences between group means and their associated treatment. It provides a statistical test of whether or not the means of several groups are all equal. A test result, calculated from the null hypothesis and the sample, is called statistically significant if it is deemed unlikely to have occurred by chance, assuming the truth of the null hypothesis (Gelman, 2005). A statistically significant result is when a probability (p-value) is less than a threshold, significance level; therefore it justifies the rejection of the null hypothesis. From the p-value we would conclude that the null hypothesis that there is no difference between treatments means should be rejected at the 5% significance level since p-value is less than 0.05 (Gelman, 2005). ANOVA depends on the assumptions: 1) that the observations are independent, 2) that the residuals (deviations from group means) have a normal distribution, 3) the variation is the same in each group. These last two assumptions should always be examined by studying the "residuals", i.e. deviations from group means (Kirk, 1995).

ANOVA is an *omnibus* test statistic and cannot tell you which specific groups were significantly different from each other, only that at least two groups were. To determine which specific groups differed from each other, you need to use a *post-hoc* test. In this study, Tukey's Honestly Significant Difference was utilized. Tukey's test compares the means of every treatment to the means of every other treatment; that is, it applies simultaneously to the set of all pairwise comparisons and identifies any difference between two means that is greater than the expected standard error (Jaccard, *et. al.*, 1984). Tukey's test is based on a formula very similar to that of the t-test. In fact, Tukey's test is essentially a t-test, except that it corrects for experiment-wise error rate. It corrects for type I error when there are multiple comparisons being made (Jaccard, *et. al.*, 1984). Another *post hoc* test employed for this study is the Dunnett's t test. Dunnett's test is performed by computing a Student's t-statistic for each experimental, or treatment, group where the statistic compares the treatment group to a single control group. In particular, the t-statistics are all derived from the same estimate of the error variance which is obtained by pooling the sums of squares for error across all (treatment and control) groups (Ramsey, 1993).

Linear regression is carried out to estimate the relationship between a dependent variable, *Y*, and a single explanatory variable, *x*, given a set of data that includes observations for both of these variables for a particular population. Given the value of the explanatory variable, x, simple linear regression analysis is able to predict the value of the dependent variable *y*. Least squares criterion is to estimate the equation generated for the analysis, the sum of squares of the differences between the actual and predicted values for each observation in the sample is minimized (Walter, 1985). In terms of a hypothesis test, for the case of a simple linear regression the null hypothesis, H0 is that the coefficient relating the explanatory (x) variable to the dependent (y) variable is 0. In other words that there is no relationship between the explanatory variable and the dependent variable. The alternative hypothesis H1 is that the coefficient relating the x variable to the y variable is not equal to zero. In other words there is some kind of relationship between x and y (Wichura, 2006).

RESULTS AND DISCUSSIONS

Concentrations of nitrogen dioxide (NO_2) were studied along C-ring road. The area is heavily populated with vehicular transportation of any kind passing through each intersection along the whole stretch of the road (Figure 5). Nitrogen dioxide is considered to be a marker of vehicular pollution, in fact it is listed by the U.S. EPA as one of the six criteria pollutants of which 33% is accounted for on-road vehicular emissions (U.S. EPA 2008a). In the study of Danish and Madany (1992), they conducted a monitoring of NO_2 along the north-eastern part of Bahrain to south-east of Muharaq island where concentrations decreased from 76 $\mu g\ m^{-3}$ to 13 $\mu g\ m^{-3}$ in relation to the decrease of traffic volume and density along these areas while in the study of Chow and Chan (2003), the NO_2 level spiked from 349 – 478 ppb during non-rush hours to 366 – 538 ppb during rush hours.

In this study, concentrations of NO_2 were recorded from six main intersection points and its relationship to vehicular density was established. To further evaluate the distribution of the NO_2 emission within the areas studied, two proximity points within 250m on each side of the main intersection were included and to compare the dispersion of the pollutant, and the effect of the vehicular traffic, neighboring points away from the highway were also considered. Figures 12-17 show the aerial view of the intersections with its two proximity and neighboring points. The study was conducted for two periods during December 2012 and March-April 2013. The relationship and magnitude of the dispersion of the pollutant between each station was evaluated using the Analysis of Variance (ANOVA) and further delineated using a post hoc Tukey's Honestly Significant Difference (Tukey's HSD) test. Seasonal variation were also examined basing on some meteorological conditions such as ambient temperature, relative humidity, and wind direction prevalent at the time of sampling to check their effects on NO_2 concentrations. During the December 2012 sampling, the average ambient temperature and relative humidity was 21.61°C and 66.75% while during March-April 2013 was 25.67°C and 43.43%, respectively. Table 10 and Figures 38 and 39 in the Appendix show the average and hourly variation of ambient temperature and relative humidity recorded throughout the sampling period. The prevailing wind during December 2012 was from the northwest (NW) direction with an average speed of 6.6 mph while for March-April 2013 was from north-northwest (NNW) and east-southeast direction with an average speed of 7.16 mph (Figures 18 and 19). In addition, a control standard was also utilized to establish a relationship between the dispersion of the pollutant within the vicinity of the C-ring road in comparison to a location away from this road with less traffic volume and with a presence of vegetation. This control was installed in the Environmental Studies Center, QU (South, Madinat Khalifa) compound where there is a number of vegetation, presence of high infrastructure and away from any busy streets.

The relationship between the vehicular density and the degree of NO_2 emission is assessed using the CALINE4 dispersion model. CALINE4 (CALifornia LINE Source Dispersion Model, version 4) is an air dispersion model devoted to the modeling of road traffic air pollution. This model was used to study the influence of traffic volume within the C-ring road and validated using Multiple Linear Regression.

Figure 12. Intersection nearby Hamad Hospital (A) with 2 – 250m proximity points (RM and LM) and neighboring points away from the main road (RN and LM). Google Earth,2012

Figure 13. Intersection nearby Qatari Bin Al-Fujaah (B) with 2 – 250m proximity points (RM and LM) and neighboring points away from the main road (RN and LM). Google Earth,2012

Figure 14. Intersection nearby Ramada Hotel (C) with 2 – 250m proximity points (RM and LM) and neighboring points away from the main road (RN and LM). Google Earth,2012

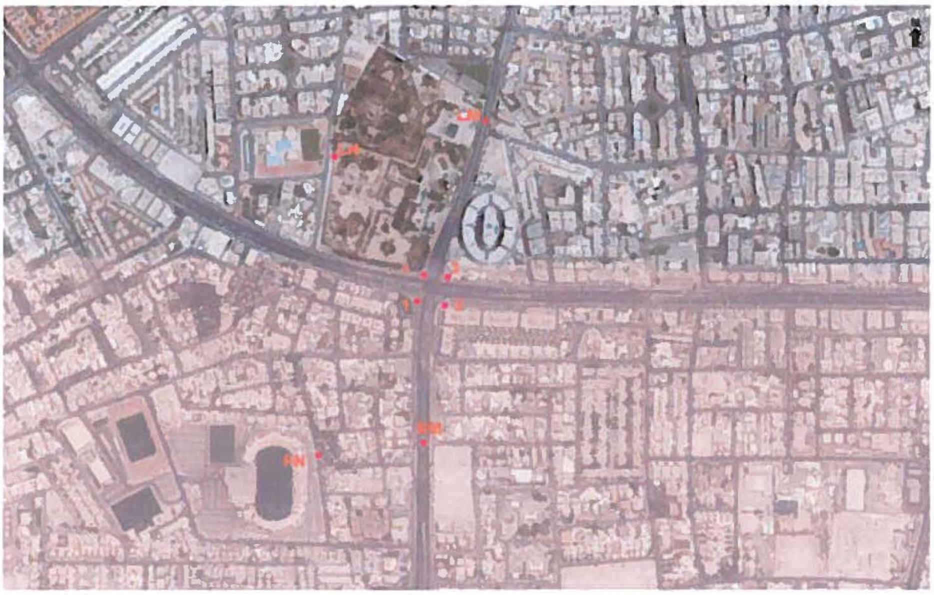

Figure 15. Intersection in Al-Muntazah Signal (D) with 2 – 250m proximity points (RM and LM) and neighboring points away from the main road (RN and LM). Google Earth,2012

Figure 16. Intersection nearby Toyota Tower (E) with 2 – 250m proximity points (RM and LM) and neighboring points away from the main road (RN and LM). Google Earth, 2012

Figure 17. Intersection nearby Gulf Cinema (G). (proximity and neighboring points were disregarded due to inaccessibility of the area) Google Earth, 2012

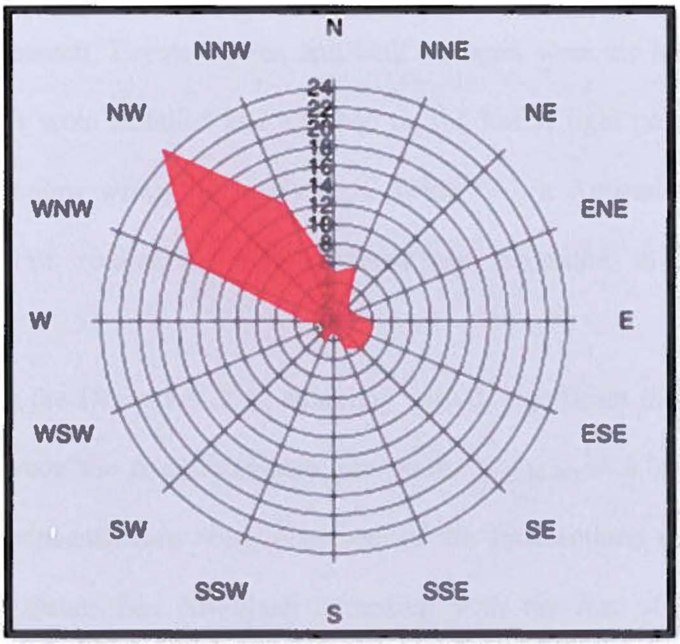

Figure 18 Wind direction distribution in December 2012 in (%) percentage

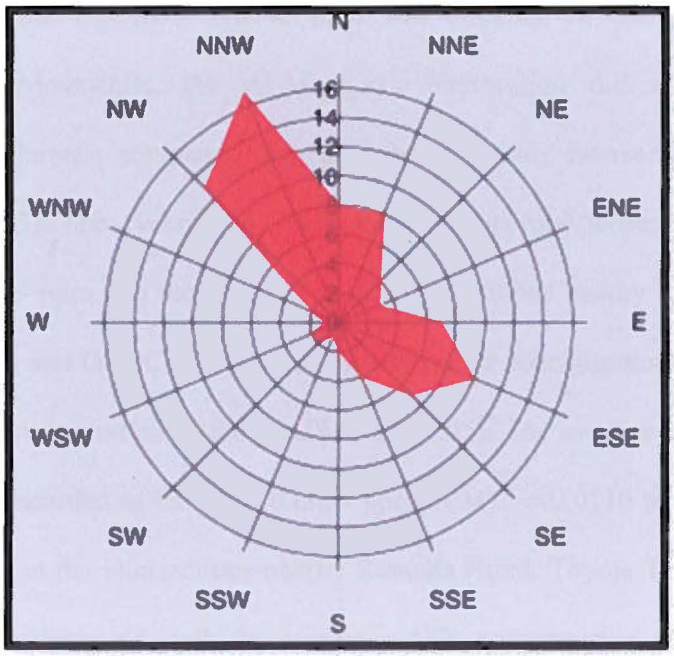

Figure 19. Wind direction distribution in March 2013 in (%) percentage

NO_2 Concentration At The Main Intersection Points

The intersections nearby Hamad Hospital, Qatari Bin Al-Fujaah, Ramada Hotel, Al-Muntazah, Toyota Tower, and Gulf Cinemas were the locations where diffusion tubes were installed and attached on the traffic light poles to measure NO_2 concentrations within the study area. Table 8 – in Appendix – show the consolidation of results for NO_2 concentration recorded in the different intersections.

During the December 2012 sampling period, significant differences were observed between the 6 main intersection points ($F_{(5,30.39)} = 8.096$; $p < 0.05$). Lower NO_2 concentrations were observed in the intersections nearby Hamad Hospital and Qatari Bin Al-Fujaah compared with the rest of the sampling intersections (Tukey's HSD, $p < 0.05$). The average concentration of 0.0385 ± 0.0050 ppm and 0.0386 ± 0.0040 ppm was obtained in both intersections, respectively. Meanwhile, the Al-Muntazah intersection did not show any significant difference compared with the other sampling intersections (Tukey's HSD, $p > 0.05$). The average NO_2 concentration recorded within this area was 0.0438 ± 0.009 ppm. On the other hand, the intersections nearby Ramada Hotel, Toyota Tower, and Gulf Cinema had relatively higher concentrations among the 6 intersection points studied (Tukey's HSD, $p < 0.05$). The average concentrations of NO_2 were recorded as 0.0478 ± 0.0057 ppm, 0.0477 ± 0.0110 ppm and 0.0483 ± 0.0058 ppm in the intersections nearby Ramada Hotel, Toyota Tower and Gulf Cinema, respectively. Overall, the minimum NO_2 concentration of 0.0301 ppm was determined at the intersection nearby Hamad Hospital while the maximum concentration of 0.0652 ppm was recorded nearby Toyota Tower. The total average NO_2 concentration obtained along the entire C-ring road during this period was 0.0440 ± 0.0080 ppm (Figure 20).

Similarly, significant differences were observed between the 6 main intersection points during the March-April 2013 sampling period ($F_{(5,66)} = 27.758$; $p < 0.05$). Lower NO_2 concentration was observed in the intersection nearby Hamad Hospital with an average concentration of 0.0415 ± 0.0065 ppm while the intersection nearby Toyota tower had the highest average concentration of 0.0697 ± 0.0045 ppm (Tukey's HSD, $p < 0.05$). The intersections nearby Qatari Bin Al-Fujaah (0.0543 ± 0.0067 ppm) and Al-Muntazah signal (0.0564 ± 0.0077 ppm) were monitored to have average NO_2 concentration which did not vary significantly between each other and between the intersection nearby Ramada Hotel (0.0525 ± 0.0028 ppm) and Gulf Cinema (0.0600 ± 0.0070 ppm) (Tukey's HSD, $p > 0.05$). However, from the data obtained, the average level obtained in the intersection nearby Ramada Hotel varies significantly at the Gulf Cinema (Tukey's HSD, $p < 0.05$) intersection. Overall, the average NO_2 concentration of 0.0557 ± 0.0103 ppm was determined around the C-ring road during this period and ranged from 0.0275 ppm (Hamad Hospital intersection) to 0.0747 ppm (Toyota tower intersection) (Figure 20).

Based on the two sampling periods, traffic volume ($F_{(1,142)} = 21.188$; $p < 0.05$) and seasonal variation ($F_{(1,142)} = 58.281$; $p < 0.05$) significantly affect the concentrations of NO_2 in the study location. High concentrations of NO_2 were observed in the intersection nearby Toyota tower which also registered highest for the number of cars passing by in this area during the two periods. The airport is also located within the vicinity which aircraft emissions could have influenced the level of the pollutant. On the other hand, although the intersection nearby Hamad Hospital did not have the least number of passing cars but it recorded the lowest NO_2 concentration. The prevailing wind at the time of sampling (NW for December 2012 and NNW and ESE for March-April 2013) and the open layout of the area could have dispersed the pollutant. The relative humidity had also significantly affected the NO_2 concentrations as December 2012 recorded the highest vehicular population yet it had the lowest pollutant concentration compared with March-April 2013. The moisture in the atmosphere may have oxidized the NO_2 to HNO_3 thereby decreasing the pollutant level. Figure20 and Table 5 show the graphical representation and the descriptive statistics depicting the NO_2 concentration recorded in different intersections along C-ring road.

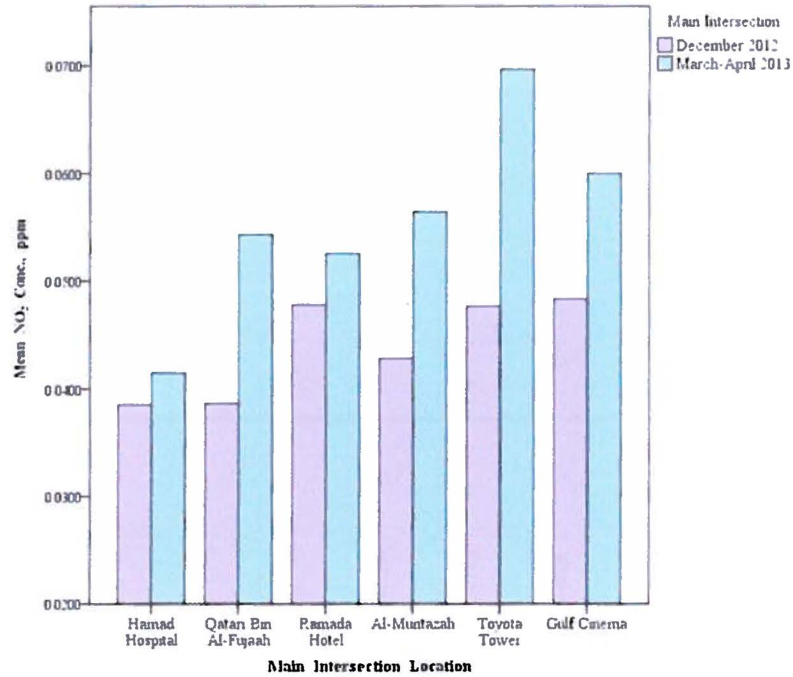

Figure 20 Average NO_2 concentrations recorded in different intersections along C ring road during Dec. 2012 and March – April 2013

Table 5 NO_2 concentrations (in ppm) recorded in different intersections along C ring road during Dec. 2012 and March – April 2013.

Intersection	December 2012				March - April 2013			
	Mean	± SD	Min	Max	Mean	± SD	Min	Max
Hamad Hospital	.0385	.0050	.0301	.0465	.0415	.0065	.0275	.0472
Qatari Bin Al-Fujaah	.0387	.0040	.0326	.0460	.0543	.0067	.0413	.0673
Ramada Hotel	.0478	.0057	.0409	.0541	.0525	.0028	.0481	.0577
Al-Muntazah	.0428	.0085	.0322	.0610	.0564	.0077	.0454	.0702
Toyota Tower	.0477	.0110	.0320	.0652	.0697	.0045	.0623	.0747
Gulf Cinema	.0483	.0058	.0414	.0614	.0600	.0070	.0499	.0746
Total of All Intersections	.0440	.0080	.0301	.0652	.0557	.0103	.0275	.0747

NO_2 Concentration At The 250m Proximity Points

Within the main intersection along the C-ring road, several proximity points were considered to evaluate further the dispersion of the NO_2 emission. These points lie within 250 m perimeter from left and right with reference to the main crossing. These proximity points were monitored for NO_2 concentration during December 2012 and March-April 2013 and it was found that significant differences were observed between the measured NO_2 within proximity points and sampling locations ($F_{(3,30)} = 18.043$; $p < 0.05$). It was evident from both sampling periods in both perimeters (left and right) that the intersection nearby Qatari Bin Al-Fujaah had the lowest average NO_2 concentrations. The measured concentrations within this area ranged from 0.0284 ppm to 0.0509 ppm. The low level may be indicated by the least number of vehicles passing by in this area which may be due to the narrow street which the motorist may have avoided.. The highest average concentration for both sampling periods, on the other hand, was observed for the right proximity points in the intersection nearby Ramada Hotel which ranged from 0.0433 ppm to 0.0698 ppm while for the left proximity points was in Al-Muntazah intersection which ranged from 0.0437 ppm to 0.0707 ppm (Tukey's HSD, $p < 0.05$). The increased pollutant level in the right proximity of the intersection nearby Ramada Hotel may have been brought about by the prevailing wind transporting the emissions from the cars passing by the adjacent D-ring road. D-ring road is also one of the major busy streets in Qatar and the vehicular population within this area may have contributed to the level. On the other hand, the presence of commercial building and high rise residential apartments in addition to the busy streets within Al-Muntazah area may have concentrated the pollutant level with the area.

Based on the two sampling periods, seasonal variation significantly affect the concentrations of NO_2 within the proximity points along C-ring road ($F_{(1,142)} = 27.906$; $p < 0.05$). The right proximity points for March-April 2013 sampling had the highest pollutant concentrations. This may be accounted for the emissions transported from the vehicles passing by the adjacent D-ring road since these points are almost halfway to this road. The high ambient temperature during this season may also have influenced the photochemical reactions that produce secondary pollutants such as ozone that might react with NO producing NO_2 (Chameides, et. al., 1992). Furthermore, NO_2 concentrations from the 250m right and 250m left proximity points did not differ significantly compared with the NO_2 concentration recorded for main intersection except the concentration obtained from the left proximity measured during December 2012, which it was found to significantly differ with the result measure in the main intersection during the March-April 2013 sampling ($F_{(1,8)} = 9.800$; $p < 0.05$). This proved that the dispersion of the pollutant within the study area is homogeneous besides the fact that these proximity points lie along the C-ring road where the vehicles are passing through from one end to the other. Figure 21 and Tables 6,7 show the graph and the descriptive statistics of the NO_2 concentrations recorded in 250 m right and left perimeter with reference to the main intersection along C-ring road.

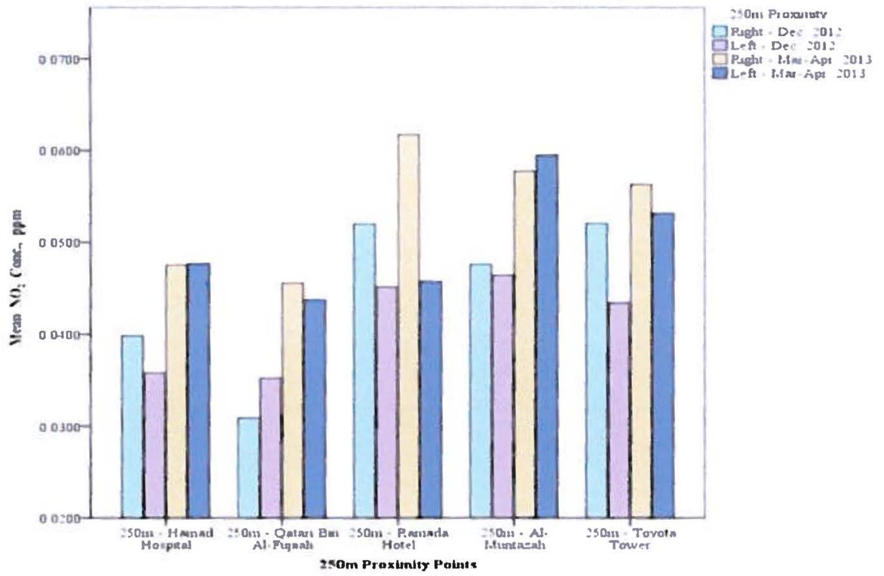

Figure 21 Average NO2 concentrations recorded within 250 meters with reference to the different intersections along C ring road during Dec. 2012 and March – April 2013

Table 6. NO_2 concentrations recorded within 250-meter perimeters (right) with reference to the different intersections along C ring road during Dec. 2012 and March – April 2013.

December 2012						March - April 2013				
250m Proximity Points		Mean	± SD	Min	Max	250m Proximity Points	Mean	± SD	Min	Max
Hamad Hospital	Right (ppm)	.0398	.0087	0.0327	0.0495	Right (ppm)	.0475	.0013	0.0464	0.0489
Qatari Bin Al-Fujaah		.0309	.0025	0.0284	0.0334		.0456	.0046	0.0424	0.0509
Ramada Hotel		.0520	.0076	0.0433	0.0569		.0617	.0075	0.0550	0.0698
Al-Muntazah		.0476	.0029	0.0452	0.0508		.0577	.0007	0.0569	0.0583
Toyota Tower		.0521	.0043	0.0481	0.0566		.0563	.0037	0.0522	0.0592
Total		.0445	.0097	0.0284	0.0569		.0538	.0074	0.0424	0.0698

Table 7. NO_2 concentrations recorded within 250-meter perimeters (left) with reference to the different intersections along C ring road during Dec. 2012 and March – April 2013.

December 2012						March - April 2013				
250m Proximity Points		Mean	± SD	Min	Max	250m Proximity Points	Mean	± SD	Min	Max
Hamad Hospital	Left (ppm)	.0358	.0040	0.0328	0.0403	Left (ppm)	.0477	.0008	0.0468	0.0482
Qatari Bin Al-Fujaah		.0352	.0009	0.0342	0.0360		.0437	.0020	0.0419	0.0458
Ramada Hotel		.0451	.0024	0.0435	0.0479		.0457	.0056	0.0396	0.0507
Al-Muntazah		.0464	.0026	0.0437	0.0488		.0595	.0099	0.0518	0.0707
Toyota Tower		.0434	.0012	0.0426	0.0448		.0532	.0072	0.0456	0.0600
Total		.0412	.0053	0.0328	0.0488		.0500	.0079	0.0396	0.0707

Comparison of NO_2 Concentration at Locations Away from the Main Intersection

Several locations away from the main intersection were considered to investigate the magnitude of the diffusion of the NO_2 emission. Unlike the proximity points where it is located along the main highway, these locations are situated outside the busy streets. These are the neighboring points away from the traffic populated highway (Figures 12-17). Significantly, lower concentration was observed for the neighboring points as compared to the concentration observed for the main intersection and the proximity points ($F_{(1,144)} = 31.921$; $p < 0.05$). However, it did not significantly differ with the concentration obtained for the control standard (Dunnett t, $p > 0.05$) The total average concentration of the neighboring points at the right side with reference to the main intersection was 0.03277 ± 0.0030 ppm for December 2012 sampling while 0.0334 ± 0.0060 ppm for March-April 2013 sampling. On the other hand, the total average concentration of the neighboring points at the left side with reference to the main intersection was 0.0298 ± 0.0020 ppm for December 2012 sampling while 0.0331 ± 0.0070 ppm for March-April 2013 sampling. The difference in the results may be accounted for the distance and direct impact of emissions from vehicles in the main intersection and proximity points along the C-ring road as compared with the concentrations observed in the neighboring points away from the main highway. (Figure 22). Furthermore, the concentration of the control standard significantly differs from that of the concentration observed within the main intersection and the 250m perimeter points which is evident from the difference in the volume of vehicular traffic (Dunnett t, $p < 0.05$). However, fluctuating relationship was established with the concentrations obtained from the neighboring points. The concentration of the control standard did not differ significantly to all of the Left neighboring points during the December 2012 monitoring (Dunnett t, $p > 0.05$) period which contradicts the observations gathered from the March-April 2013 monitoring Period (Dunnett t, $p < 0.05$). In another condition, the concentration of the control standard showed significant difference with all of the Right neighboring points for March-April 2013 sampling (Dunnett t, $p < 0.05$) but not for December 2012 monitoring (Dunnett t, $p > 0.05$). This proves that there are a lot of factors that affect the level of pollutant within an area. These factors may be accounted for the topography within the study area and the meteorological variation at the time of sampling. In fact based on the meteorological data observed, the relative humidity for December 2012 is 21.17% higher than the March-April 2013. Many variables need to be considered to predict the magnitude of the emission and diffusion of the pollutant when conducting a monitoring study. Rosenlund *et. al.* (2007) estimated a model to predict the concentration of NO_2 and compared the results with an emission model using information on the types of vehicles circulating, traffic counts and driving patterns. They also utilized information on the characteristics of the area such as geographic locations within the circular traffic zones (i.e. main ring road, green strip, inner ring road, and traffic-limited zone), distance from busy streets, distance from parks, distance from sea, size of the census block, population density and altitude. These characteristics are contributory factors to the level of pollution. In the study of Ross *et al.* (2006), it was found that road length around 40 meters, traffic volumes distance to the coast had a noticeable effect on the concentration of NO_2.

Moreover, Gilbert *et al.* (2005) revealed in their study in Montreal that in the first application of distance to highway, traffic counts on the nearest highway, length of highway, major roads within 100 meters, length of minor roads within 500 meters, open land use within 100 meters, and dwelling density within two kilometers significantly contribute to the concentration of NO_2.

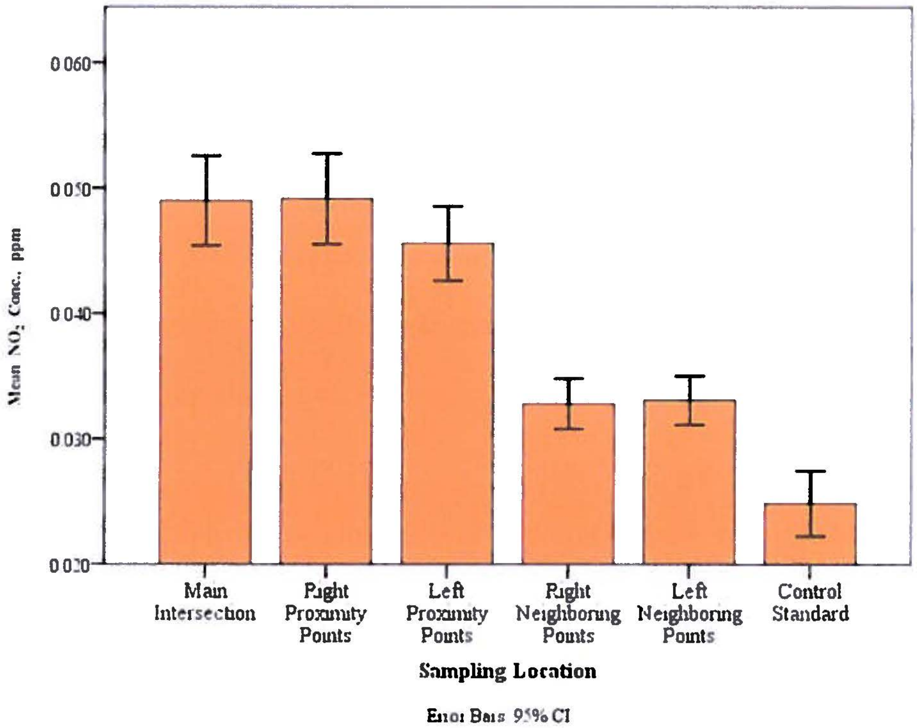

Figure 22 Comparison of Average NO2 concentrations from different locations

Modeling Using CALINE4 Dispersion Model

The output data from CALINE4 model have been integrated and analyzed in ArcGIS. The integration of estimated NO_2 concentrations included several phases where the spatial variation of pollutant level contour was generated within the intersections along C-ring road. The degree of the emission of pollutant varied disproportionately throughout the study area during the two sampling periods.

As previously stated, vehicular traffic and seasonal variation had a significant impact on the varied concentrations obtained during the study. During the December 2012 sampling period, lower concentrations of NO_2 were obtained although higher traffic volume was recorded during this period (Figures 20,23). Based on the regression analysis, vehicular density did not significantly influence the pollutant concentration (R^2 = 0.031; $F_{(1,70)}$=2.269, p >0.05) as during this season, high relative humidity and scattered precipitation was experienced at the time of sampling. On the other hand, March-April 2013 had higher NO_2 concentrations and based on the linear regression analysis, traffic volume was found to significantly influenced the level of NO_2 pollutant within the area (R^2 = 0.134; $F_{(1,70)}$=10.836, p <0.05). Lower number of cars were recorded during this season however, the emissions from the vehicles may have mostly contributed to the level and the fact that during this season, the average temperature increased by 4°C with mostly higher concentrations on mid-day from 8:00A.M. to 1:00P.M. (Figures 20,23)

According to McGregor (1996), the level of pollution within an area varies from one place to another due to different land uses, transportation characteristics and human activities. Meteorological factors such as temperature, relative humidity, wind direction and wind speed may influence the pollutant level. During the study period, high relative humidity was observed during December 2012 which may have oxidized NO_2 to HNO_3 in the presence of moisture (OH radical); thereby, decreasing the measured concentrations during this sampling period. Based on the study of Allen et Al., (1989), the prime influence on the concentrations of nitric acid is ambient temperature, relative humidity, and ammonia concentrations. In addition, the low ambient temperature observed during this period has also prevented the photochemical reactions that produce secondary pollutant such as ozone that will react with NO to produce NO_2 (Figures 38,39—Appendix).

Meanwhile, the high concentrations of NO_2 during March-April 2013 may be attributed to the high temperature and less relative humidity during this sampling period in addition to the volume of the traffic which, based on the statistical analysis, significantly influenced the measured levels (Figures 38,39 – Appendix and Figure 23). The wind direction has also played an important role in the diffusion and dispersion of the emission of the pollutants during this study. The CALINE4 model (Figures 24and 25) showed the dispersion of predicted NO_2 concentrations within 500 meter. The dominant wind during the December 2012 sampling period was from northwest (NW), with an average wind speed of 6.6 mph. The distribution of the measured concentrations of NO_2 was the highest on the opposite of this direction which is evident on the data obtained from 250m right perimeter. Although the average concentration did not vary significantly between the left and right proximity points during March-April 2013, the NO_2 concentration is compounded within the intersection as there was an opposite wind direction prevailing during this season. The wind was blowing from North-Northwest (NNW) and East-Southeast (ESE) directions with an average speed of 7.16 mph. There was no significant difference between the left and right proximity points during this period.

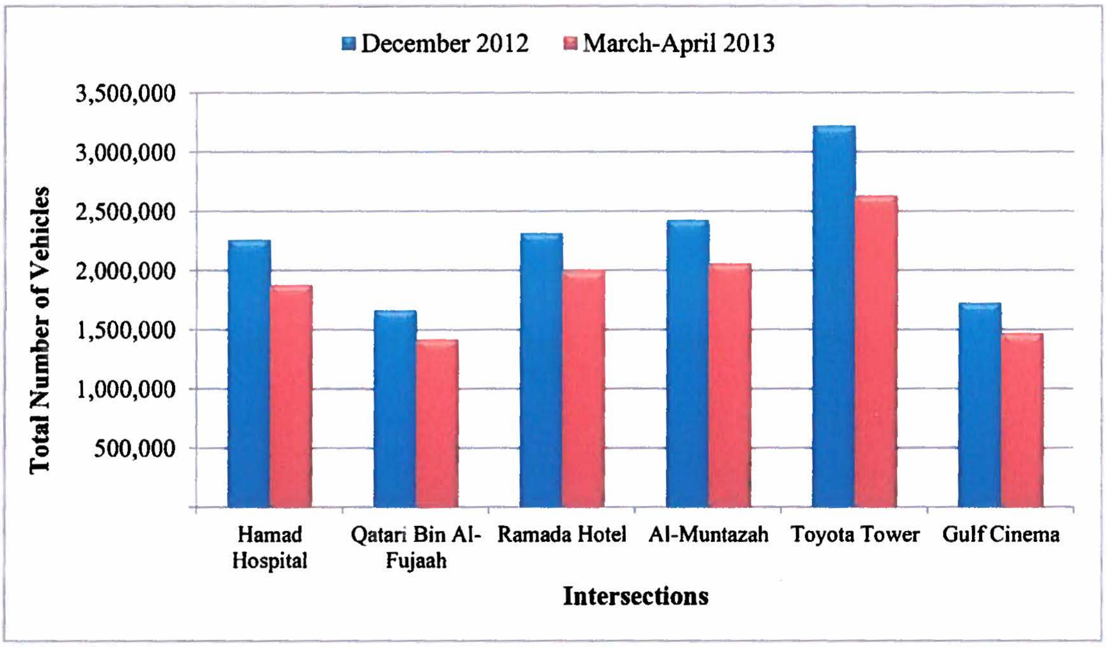

Figure 23. Record of the total number of vehicles during December 2012 and March-April 2013.

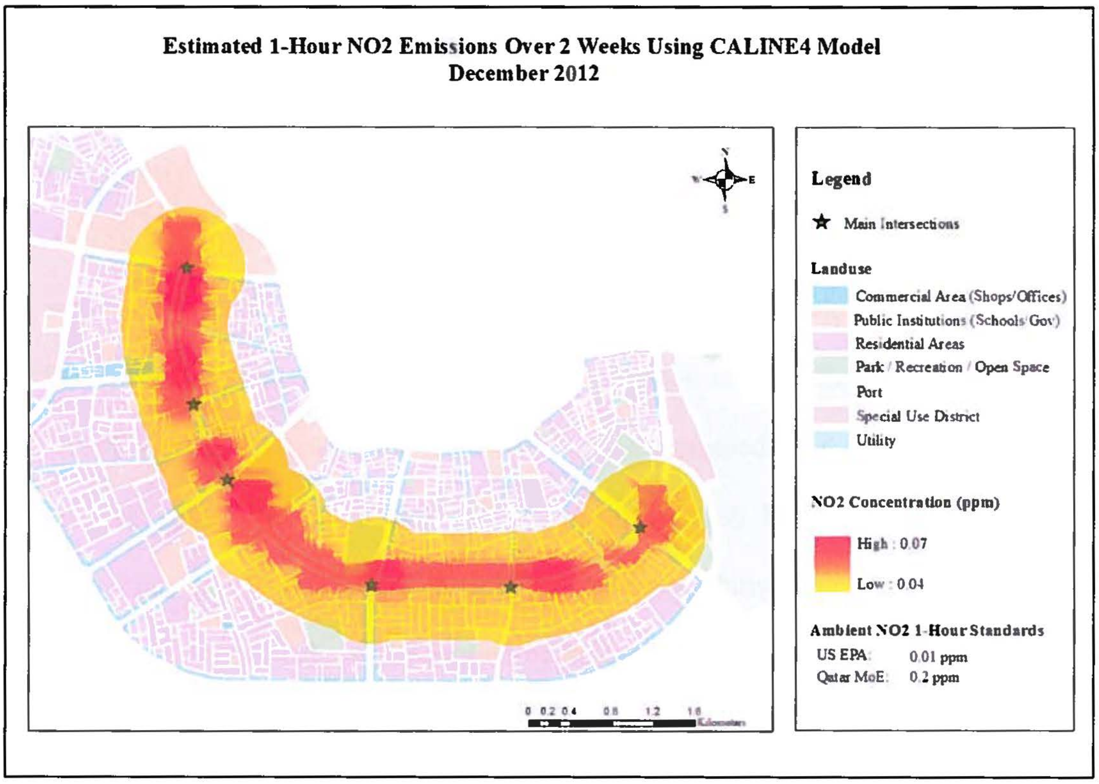

Figure 24 CALINE4 Dispersion Model for December 2012

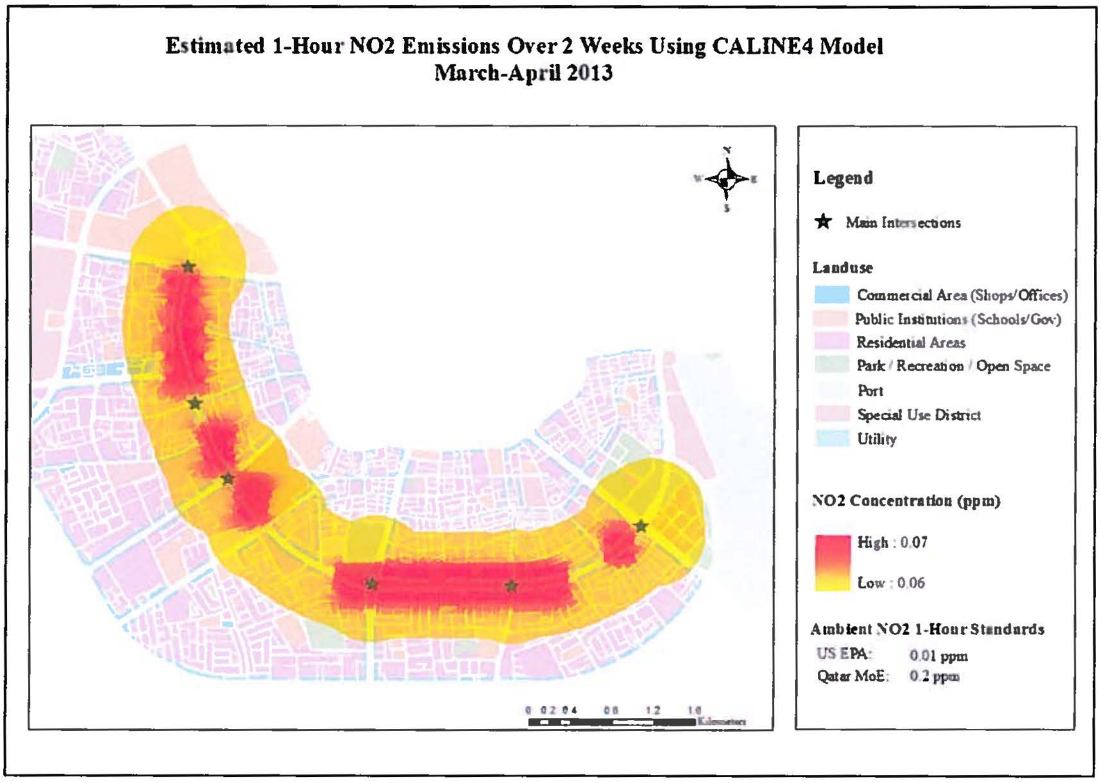

Figure 25 CALINE4 Dispersion Model for March-April 2013.

Predicted NO_2 Concentrations during Rush Hours

In December 2012, the high concentrations of NO_2 on the main intersections are also clearly noticed during morning, afternoon, and evening rush hours (Figures 26-28). The hourly maximum value during morning rush hour is up to 0.08 ppm while it is up to 0.09 ppm during afternoon and evening rush hours. The reason behind this increment in the maximum concentration value is that the number of vehicles passing through the intersections has increased in the afternoon and evening rush hours compared with the morning rush hour. In addition, the availability of UV radiation from sunlight and high relative humidity during this season allows photochemical reaction of moisture liberating free radical (OH or OOH) during the morning hours. With an increased vehicular traffic during afternoon and evening hours, these free radicals catalyzed degradation of organic carbon pollutants from road traffic exhaust and in the presence of oxygen and will convert NO_x to NO_2 thereby increasing the NO_2 concentrations which is evident in the results obtained (Atkinson, 1998; Jenkin and Clemitshaw, 2000) (Figure 29).

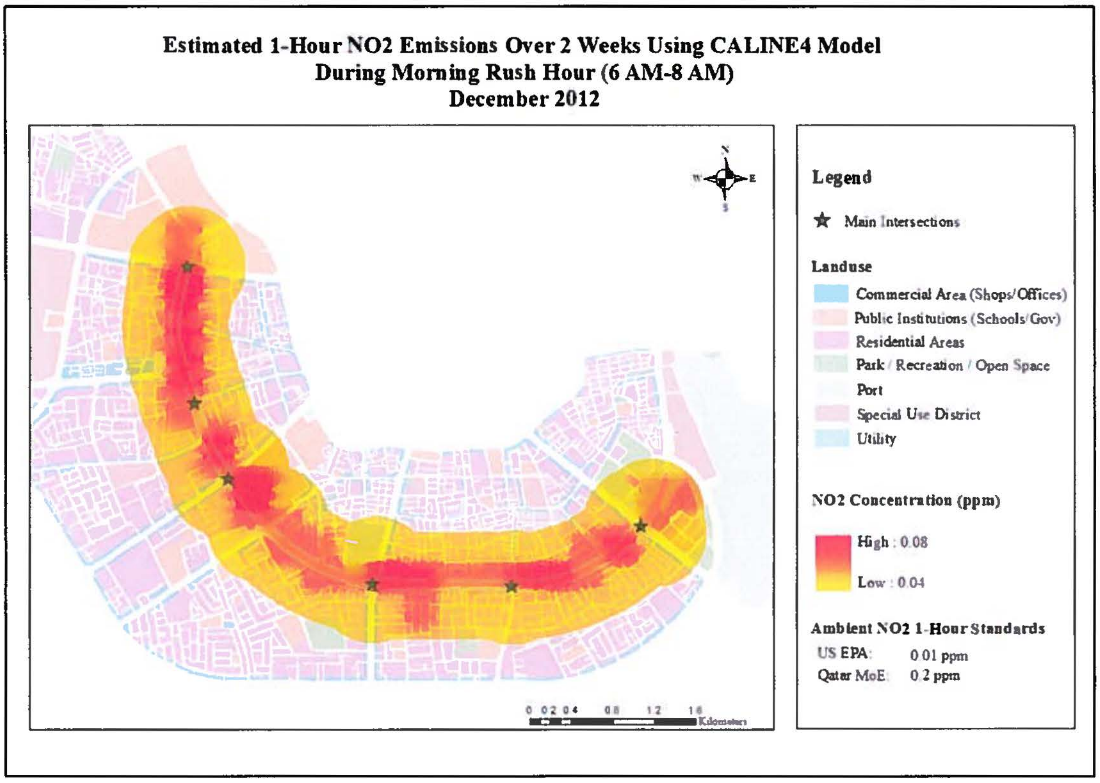

Figure 26. CALINE4 Dispersion Model During Morning Rush Hour, December 2012

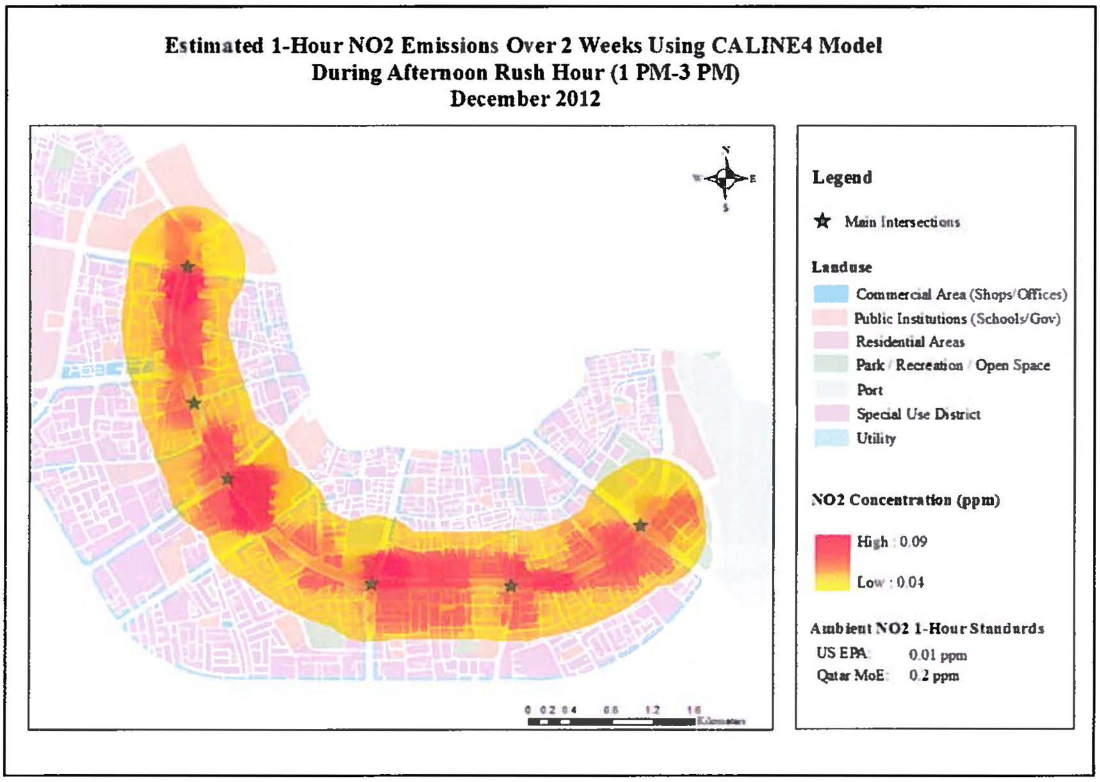

Figure 27 CALINE4 Dispersion Model During Afternoon Rush Hour, December 2012

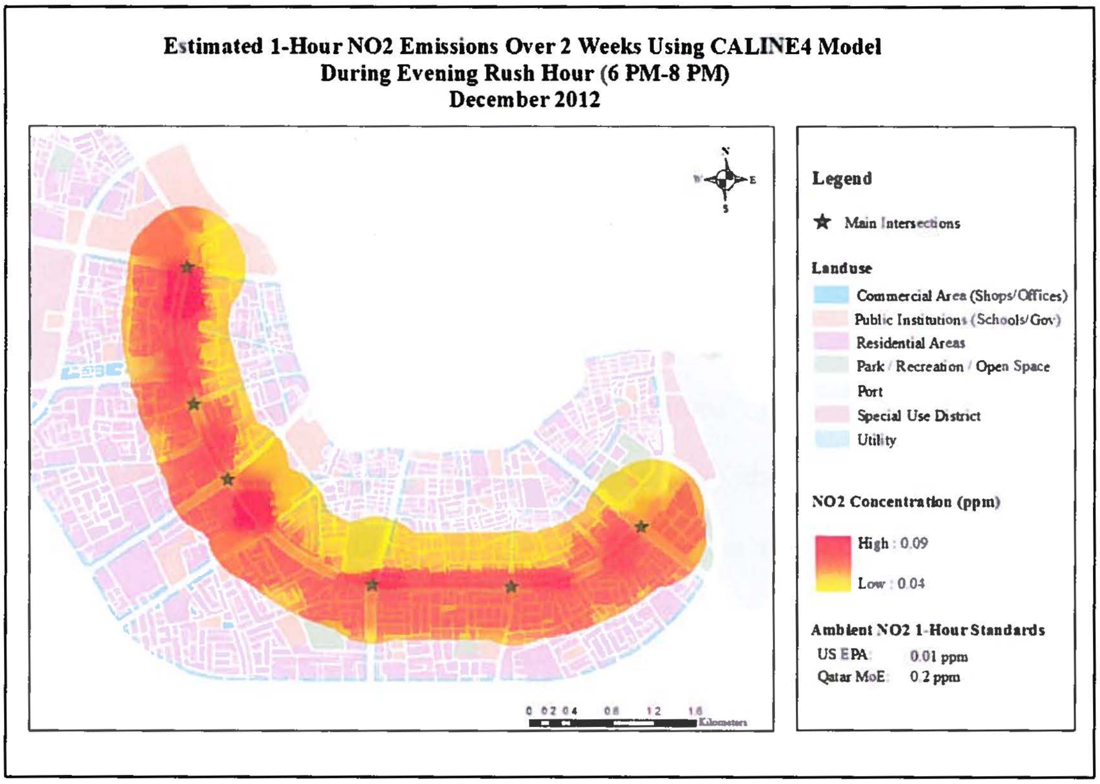

Figure 28. CALINE4 Dispersion Model During Evening Rush Hour, December 2012

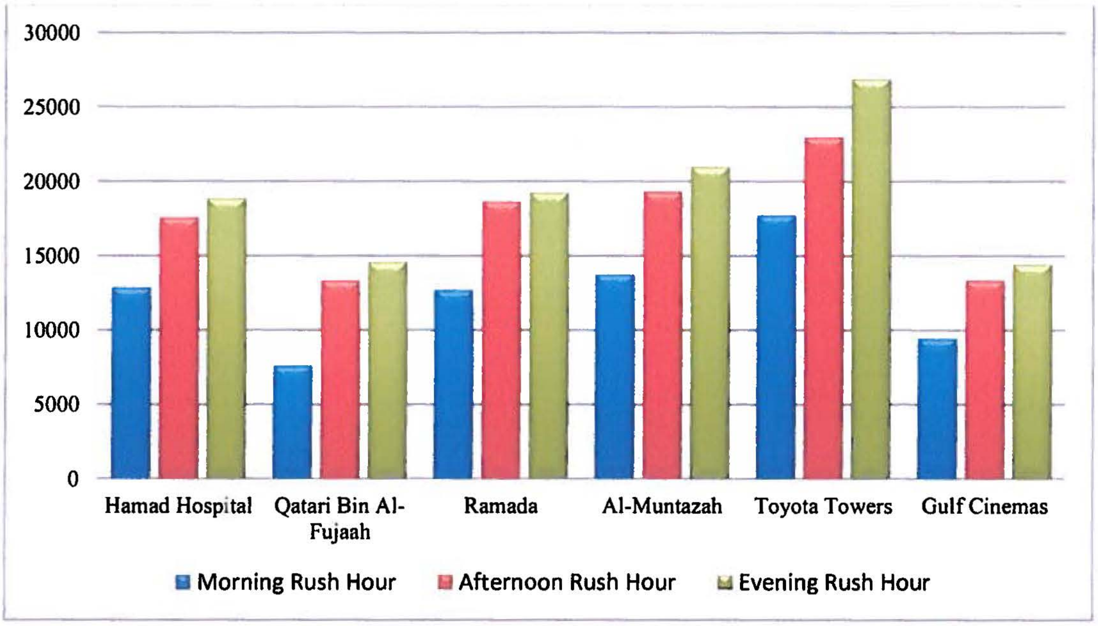

Figure 29. Hourly Traffic Volume Per Intersection Recorded in the Morning, Afternoon, and Evening Rush Hours During December 2012

During low traffic density hours, the high NO_2 concentration continues to appear at intersections (Figure 30). Although traffic density is less, the emission factor is higher than the other periods because at 4 AM, the majority of traffic is of heavy duty trucks and buses. Most heavy duty trucks and buses in Qatar are fueled with diesel due to its cheaper prize. However, its low price comes with a high pollution emission especially NO_2 pollutant. Available studies on combustion-related vehicular emissions indicate that the proportion of NO_x emitted in the form of NO_2 is greater on diesel gasoline although the NO_2 input also depends on vehicle type and on driving conditions, its direct emission also varies from one location to another, or from one time to another, as a result of varying vehicle fleet composition and driving speeds (Heywood, 1988 and PORG, 1997).. In December 2012, the prevailing wind from NW helps in the dispersion of the NO_2 to the SE of each location. During that period, some NNE wind has been recorded which affected the dispersion of the NO_2 to the SW direction of each sampling location.

Estimated 1-Hour NO2 Emissions Over 2 Weeks Using CALINE4 Model
During Low Traffic Hour (4 AM)
December 2012

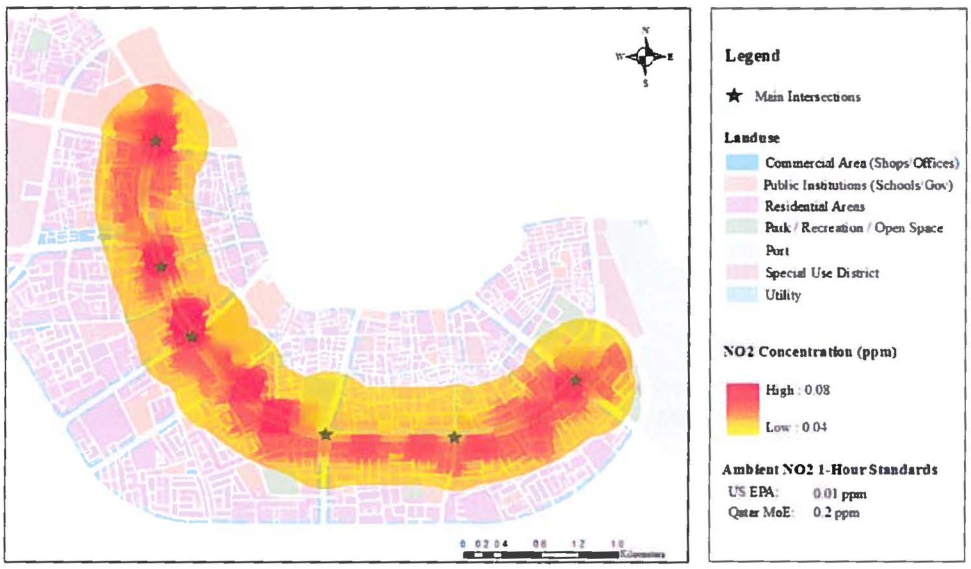

Figure 30. CALINE4 Dispersion Model During Low Traffic Hour, December 2012

In March-April 2013, the dominant wind direction or wind flow is from NNW and ESE directions. This wind blowing in opposite directions has limited the dispersion of NO2 to about 200 meters on the sides of the road (Figures 31-33). The lowest estimated value of NO_2 concentration was reported to be 0.06 ppm during all three rush hours. The emissions of NO_2 on the link road between the intersections near Al-Muntazah and the Gulf Cinemas (denoted D and G respectively on Figure 31 and 32) were accumulated due to the effect of rising building (3 – 5 levels) along the road side.

Estimated 1-Hour NO2 Emissions Over 2 Weeks Using CALINE4 Model
During Morning Rush Hour (6 AM-8 AM)
March-April 2013

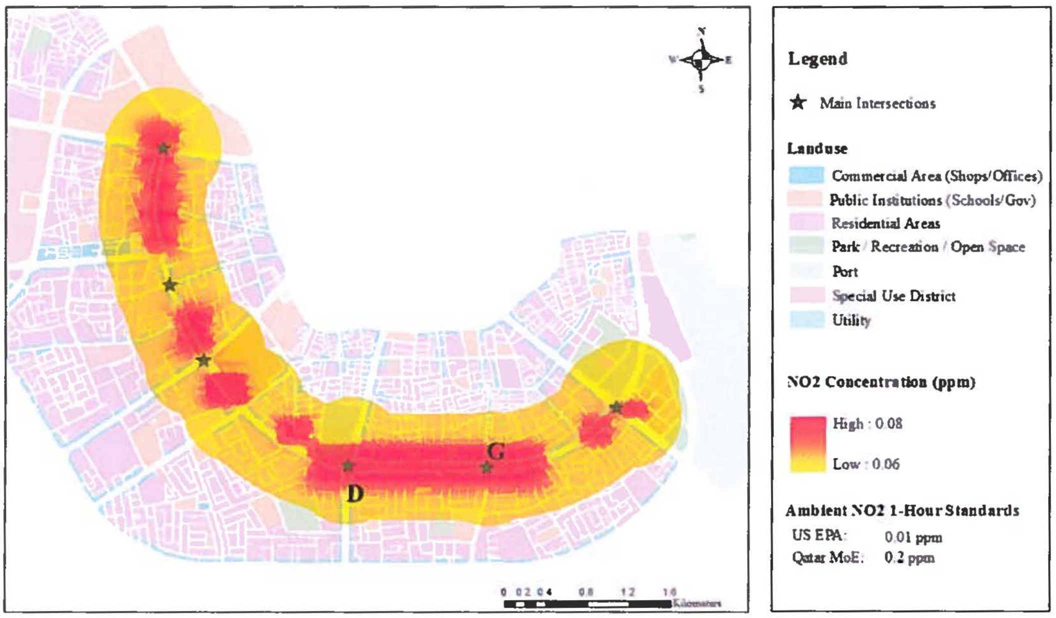

Figure 31 CALINE4 Dispersion Model During Morning Rush Hour, March-April 2013

Estimated 1-Hour NO2 Emissions Over 2 Weeks Using CALINE4 Model
During Afternoon Rush Hour (1 PM-3 PM)
March-April 2013

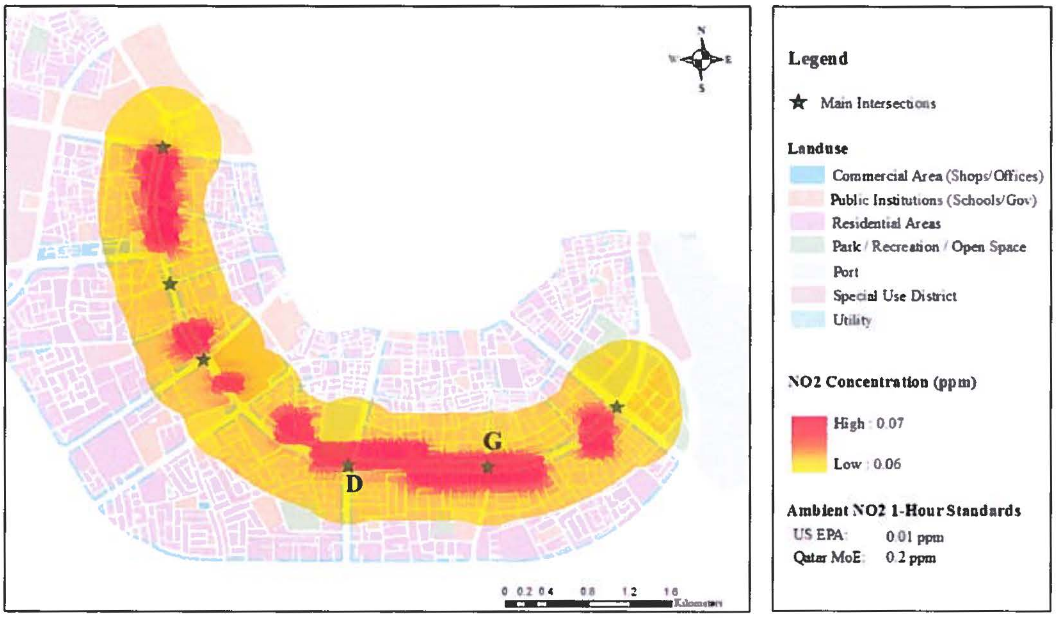

Figure 32. CALINE4 Dispersion Model During Afternoon Rush Hour, March-April 2013

Estimated 1-Hour NO2 Emissions Over 2 Weeks Using CALINE4 Model
During Evening Rush Hour (6 PM-8 PM)
March-April 2013

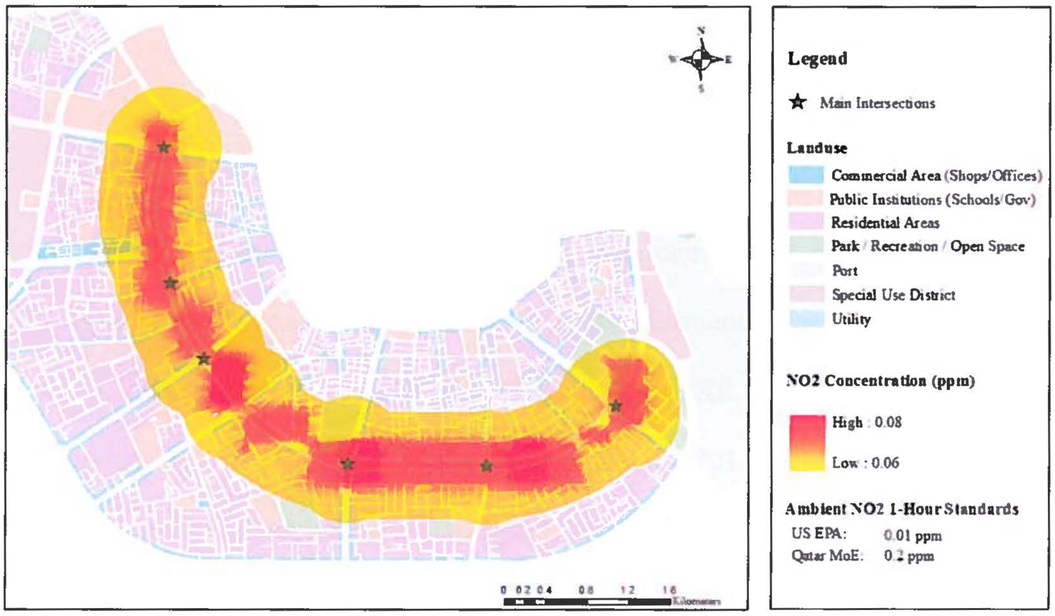

Figure 33. CALINE4 Dispersion Model During Evening Rush Hour, March-April 2013

During the low traffic hour, the maximum estimated NO_2 concentration is 0.09 ppm which is induced by the emission factor during that time period as the number of heavy duty traffic and buses increases compared with the other time periods (Figure 34).

Estimated 1-Hour NO2 Emissions Over 2 Weeks Using CALINE4 Model
During Low Traffic Hour (4 AM)
March-April 2013

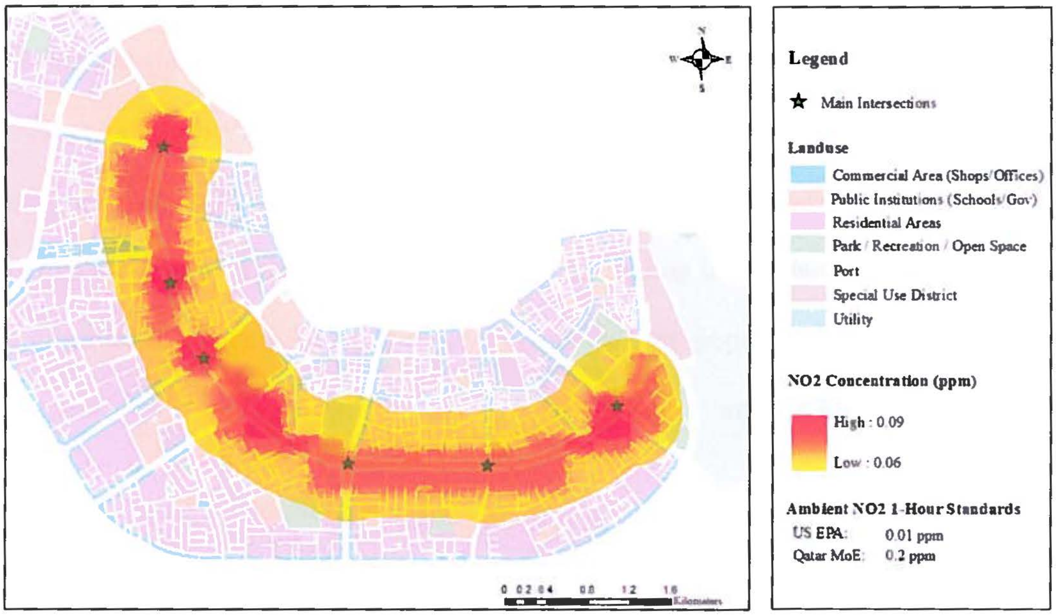

Figure 34. CALINE4 Dispersion Model During Low Traffic Hour, March-April 2013

Most of the area along the C-Ring road which is affected by the NO_2 is either occupied by residential buildings or some commercial and dining places. This indicates that people living or visiting these surrounded areas are exposed to some levels of traffic generated NO_2 emissions. All estimated 1-hour NO_2 emissions during December 2012 and March-April 2013 were considered high and above the 1-hour standard (0.01 ppm) set by the US EPA. When compared to the Qatari standard adopted by the MoE (0.2 ppm), the estimated values are considered safe and below the standard limit.

The population density (per square kilometer) for the zones near by the C-Ring road was calculated and obtained from the latest 2010 census layer linked to ArcGIS. In this study, the focus was on the vulnerable population groups such as children of different age groups as they are sensitive to air pollutants. Figures 35 and 36show the density of children population of age groups 0-4 years and 5-9 years, respectively, living nearby the zones studied in this project. The high density of children is displayed on the map by the dark orange shade. Most of the children are living on the north direction of the sampling locations. These values are expected to increase during the last years as the total population of Qatar has increased between 2010 and 2012.

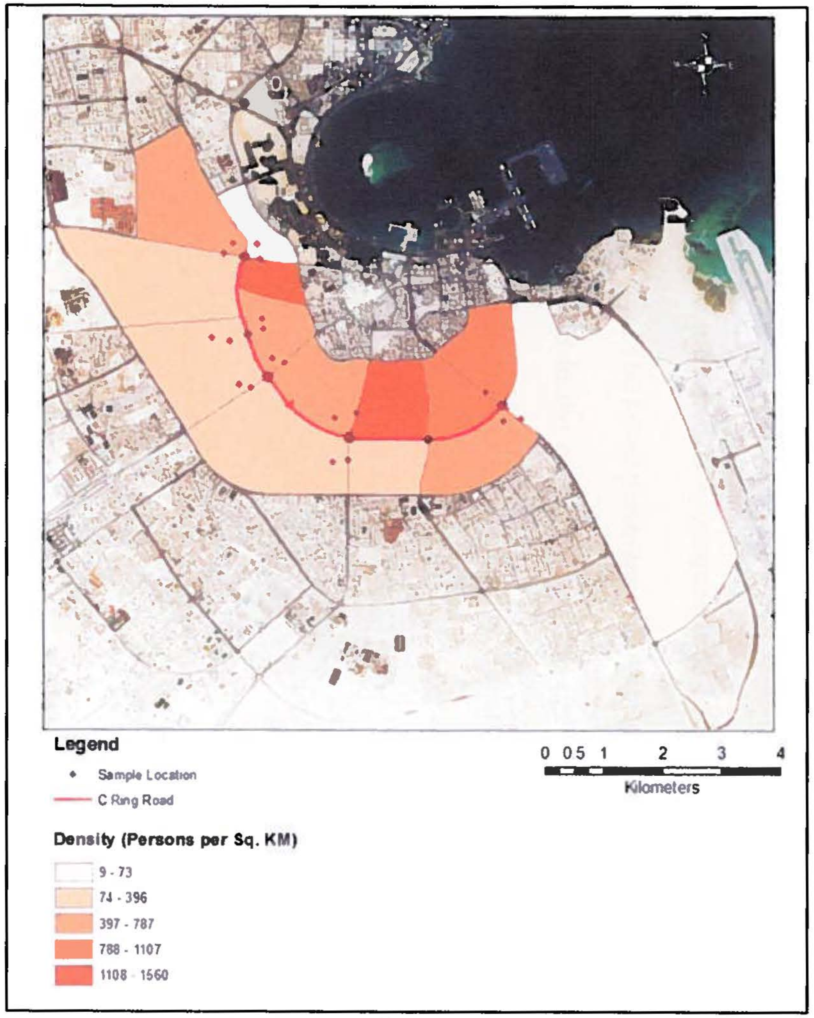

Figure 36. Population Density of Age Group 0-4 years (2010)

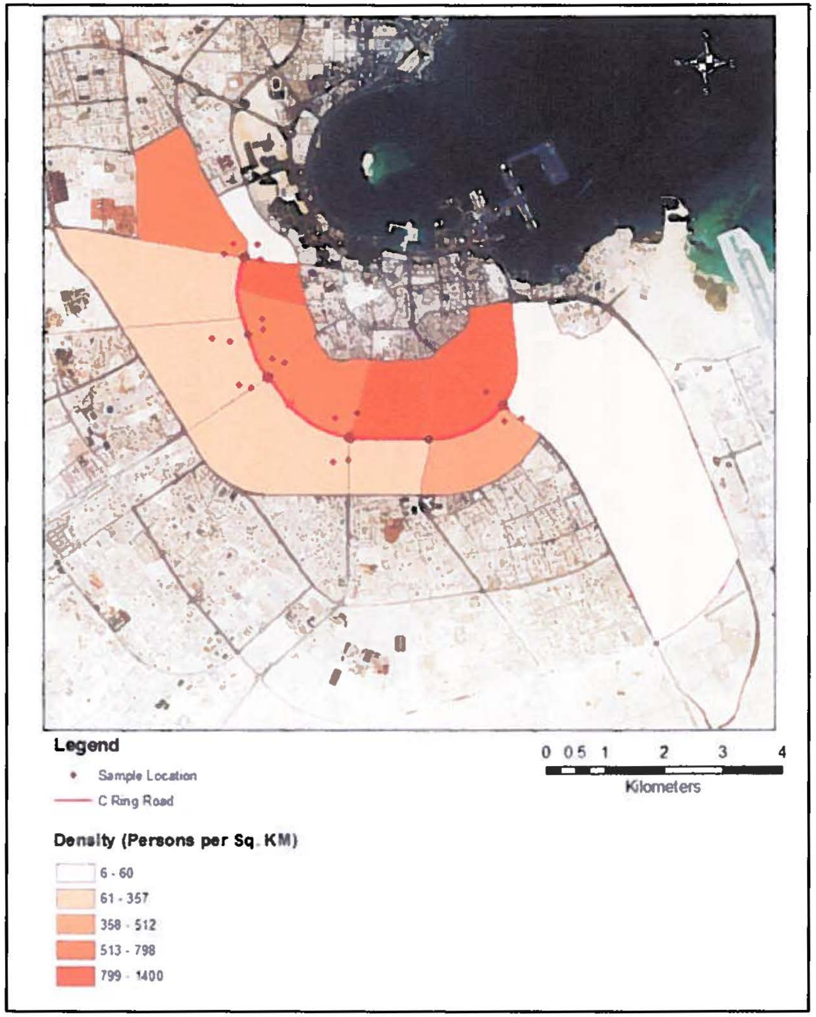

Figure 35. Population Density of Age Group 5-9 years (2010)

Validation Of CALINE4 Dispersion Model

Generally, the validation of using an air dispersion model such as CALINE4 in the assessment of traffic related air pollution involves the comparison between the estimated (predicted) and measured concentrations at the same spatio-temporal scales (Méline et al., 2011). An attempt to validate the results obtained in this study was made. In order to validate the CALINE4 model for NO_2 in the study area, the CALINE4 predicted hourly average NO_2 concentrations at each monitoring location were plotted against the measured average of NO_2 concentrations determined by diffusion tubes. Scatter graphs of measured levels versus predicted levels for the entire duration of the study have been drawn and the linear best-fits have been plotted with their respective equations. Figure 37 shows the validation graphs of for this study period. The linear regression analysis was used to evaluate the dependence of the predicted value with the measure NO_2 concentrations. Based on the graph, the estimated prediction that the measured NO_2 concentration had influenced on the predicted value is by 31.12 %. The lower percentage may be accounted for the uncertainties of the variables used in the model such as the emission factor for the different types of vehicles and others as listed on the next section.

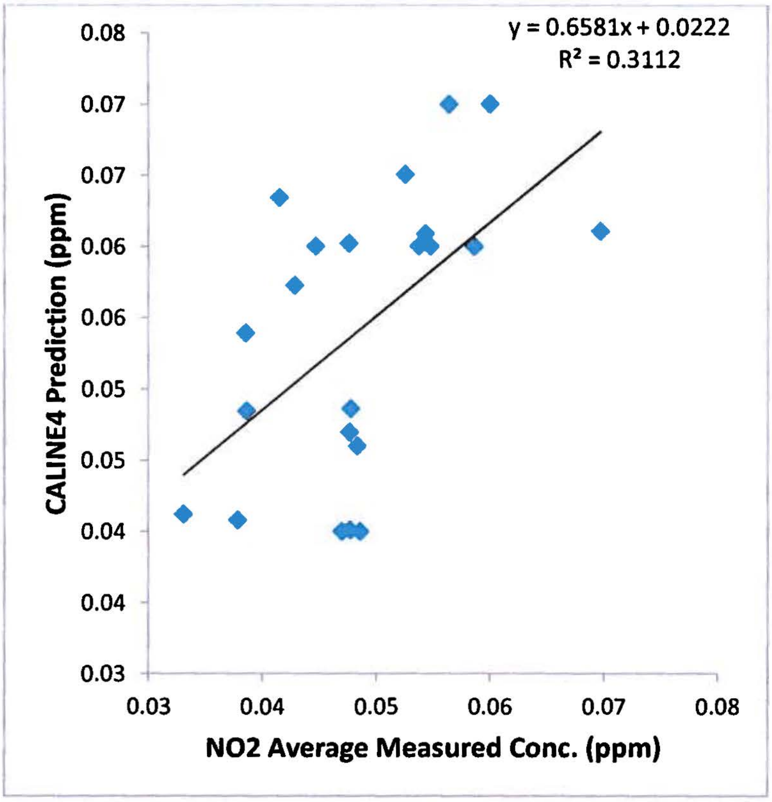

Figure 37 NO_2 CALINE4 Validation

Uncertainty of NO2 Measurements

Many factors affect the uncertainty of the prediction in any model. In India, one of the greatest inaccuracies in vehicular pollution modeling occurs due to the considerations of improper emission factors used for different categories of vehicles (Sharma, 2003). This also is considered as a major source of inaccuracy in the applied CALINE4 model in this study as there is no emission factors determined for different categories of in-use vehicles in Qatar. Another source is the uncertainty of the measured NO_2 concentrations in the laboratory as reported in the methodology chapter of this thesis. Sharma (2003) also reported that the non-availability of onsite meteorological data is another source of the inaccuracy of air dispersion models. The meteorological inputs during this study were averaged as per the duration of the sampling period. It was reported in several studies (Henderson et al., 2007; Wheeler et al., 2008; Ross et al., 2007) that the averaged meteorological data over an extended period basically obscure the temporal dynamics of the model being investigated. It is; therefore, beneficial to have a field-monitored pollution measurement data that provides instantaneous measurement of pollution at a given point in time in a given location. With this scheme, it provides a unique dataset to test the hypotheses with respect to temporarily varying variables such as wind speed, wind direction, temperature, relative humidity, and other meteorological data which will lessen the uncertainties. In addition, an annual monitoring scheme would also eliminate the uncertainties brought about by the seasonal variation and would increase the reproducibility of the results.

Geographical conditions may also be a contributory factor on the uncertainty of the measurement as each location has different topography in terms of building structures which can influence the wind distribution and dispersion of pollutants.

CONCLUSION AND RECOMMENDATIONS

In the State of Qatar, recent statistics show a continued increase in the motor-vehicle fleet commensurate with population growth and economic improvements. This trend together with the rapid expansion of urban areas and the increased dependence on automobiles has resulted in pollution increase near traffic sources, indicating that the risk of exposure to vehicles' emissions is higher and that these emissions must be considered in terms of their spatial and temporal occurrence.

Nitrogen dioxide is considered to be a marker of vehicular pollution. In the present study, the concentrations of NO_2 significantly differ from each sampling stations in each period. The study area is situated along the 6 intersections of C-ring road and was monitored during December 2012 and March-April 2013. Lower concentrations of NO_2 were obtained along this road during December 2012 sampling period as compared with March-April 2013. Although the traffic volume was recorded high during this period but based on the regression analysis, vehicular density did not significantly influence the pollutant concentration. The seasonal variation may have contributed to this observation as high relative humidity and scattered precipitation was experienced at the time of sampling.

March-April 2013 higher on the other hand, had NO_2 concentrations and based on the linear regression analysis, traffic volume was found to significantly influence the level of NO_2 pollutant within the area. Lower number of cars was recorded during this season. However, the emissions from the vehicles may have mostly contributed to the level and the fact that during this season, the average temperature increased by

4°C with mostly higher concentrations on mid-day from 8:00A.M. to 1:00P.M allowing for photochemical reactions producing secondary pollutants such as ozone which reacts with NO to produce NO_2. Wind direction and the topography of the area, and distance to traffic intersection were known as contributory factors to the pollutant level.

A dispersion model was employed in this study to calculate for the predictive NO_2 emission given variable conditions. The CALINE4 dispersion model was known to reliably predict air quality up to 500 m from the roadway. Based on the linear analysis, the estimated prediction that the measured NO_2 concentration had influenced on the predicted value is by 31.12 %. The lower percentage may be accounted for the uncertainties of the variables used in the model such as the emission factor for the different types of vehicles and the averaged value used in the meteorological conditions. Scientists and authorities are encouraged to build up an emission inventory based of the profile and status of vehicle fleets here in Qatar in order to reduce the uncertainty coupled with the emission factor as a vital input in the dispersion model.

Allowing an annual monitoring scheme for the air quality measurement would eliminate the uncertainties brought about by the seasonal variation and would increase the reproducibility of the results. In this way, there will be a replicate of results for the different season. It would also be beneficial to the country and for formulating rules and regulations if the number of study locations will be increased to represent the pollutant emission within Qatar. The non-availability of onsite hourly meteorological data is another source of the inaccuracy of air dispersion monitoring. The meteorological inputs during this study were averaged as per the duration of the sampling period and it has been found that the averaged meteorological data over an extended period basically obscure the temporal dynamics during the time of the study. It is; therefore, beneficial to have a field-monitored pollution measurement data that provides instantaneous measurement of pollution at a given point in time in a given location which will provide data to test for the influence of the meteorological inputs such as wind speed, wind direction, temperature, and relative humidity, to pollutant emission.

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APPENDIX

Table 8 NO_2 Measured Concentrations at Sampling Locations During December 2012 and March-April 2013

Location			December-2012		March - April 2013	
Near by	ID	Coordinates	ppm (Measured)	ppm (Predicted*)	ppm (Measured)	ppm (Predicted*)
Hamad Hospital	AS-1	25°17'27.08"N, 51°30'24.55"E	0.033	0.053	0.037	0.062
	AS-2	25°17'25.70"N, 51°30'23.72"E	0.038	0.056	0.047	0.065
	AS-3	25°17'25.35"N, 51°30'25.51"E	0.044	0.055	0.046	0.064
	AS-4	25°17'26.92"N, 51°30'26.28"E	0.040	0.051	0.036	0.062
	AS-RM	25°17'28.24"N, 51°30'12.59"E	0.040	0.041	0.048	0.060
	AS-RN	25°17'33.96"N, 51°30'18.43"E	0.026	0.047	0.034	0.060
	AS-LM	25°17'24.77"N, 51°30'34.50"E	0.036	0.041	0.048	0.060
	AS-LN	25°17'33.32"N, 51°30'32.69"E	0.031	0.042	0.036	0.060
Qatari Bin Al-Fujaah	BS-1	25°16'43.90"N, 51°30'26.55"E	0.039	0.049	0.060	0.061
	BS-2	25°16'43.22"N, 51°30'26.65"E	0.039	0.048	0.050	0.061
	BS-3	25°16'43.60"N, 51°30'27.73"E	0.040	0.048	0.055	0.061
	BS-4	25°16'44.29"N, 51°30'27.56"E	0.037	0.049	0.052	0.061
	BS-RM	25°16'40.23"N, 51°30'16.16"E	0.031	0.042	0.046	0.060
	BS-RN	25°16'41.42"N, 51°30'5.62"E	0.025	0.040	0.034	0.060
	BS-LM	25°16'46.59"N, 51°30'36.42"E	0.035	0.040	0.044	0.060
	BS-LN	25°16'52.38"N, 51°30'35.77"E	0.030	0.040	0.041	0.060

Location			December-2012		March - April 2013	
Near by	ID	Coordinates	ppm (Measured)	ppm (Predicted*)	ppm (Measured)	ppm (Predicted*)
Ramada	CS-1	25°16'20.57"N, 51°30'37.60"E	0.053	0.050	0.053	0.065
	CS-2	25°16'19.06"N, 51°30'39.04"E	0.053	0.048	0.055	0.064
	CS-3	25°16'20.38"N, 51°30'40.73"E	0.044	0.048	0.051	0.065
	CS-4	25°16'21.83"N, 51°30'39.13"E	0.041	0.049	0.052	0.066
	CS-RM	25°16'14.47"N, 51°30'29.26"E	0.052	0.040	0.062	0.060
	CS-RN	25°16'16.17"N, 51°30'21.85"E	0.033	0.040	0.042	0.060
	CS-LM	25°16'28.26"N, 51°30'49.03"E	0.045	0.040	0.046	0.060
	CS-LN	25°16'30.26"N, 51°30'42.07"E	0.031	0.044	0.030	0.062
Al-Muntazah	DS-1	25°15'45.95"N, 51°31'26.72"E	0.044	0.050	0.062	0.070
	DS-2	25°15'45.75"N, 51°31'29.23"E	0.053	0.053	0.062	0.070
	DS-3	25°15'47.91"N, 51°31'29.46"E	0.040	0.067	0.050	0.070
	DS-4	25°15'48.11"N, 51°31'27.34"E	0.034	0.058	0.051	0.070
	DS-RM	25°15'34.35"N, 51°31'27.31"E	0.048	0.040	0.058	0.060
	DS-RN	25°15'33.51"N, 51°31'18.01"E	0.027	0.040	0.034	0.060
	DS-LM	25°16'0.72"N, 51°31'33.06"E	0.046	0.040	0.060	0.060
	DS-LN	25°15'57.69"N, 51°31'19.46"E	0.030	0.041	0.036	0.060

Location			December-2012		March - April 2013	
Near by	ID	Coordinates	ppm (Measured)	ppm (Predicted*)	ppm (Measured)	ppm (Predicted*)
Toyota Tower	ES-1	25°16'3.81"N, 51°33'0.85"E	0.063	0.047	0.070	0.061
	ES-2	25°16'5.17"N, 51°33'2.01"E	0.043	0.048	0.070	0.061
	ES-3	25°16'6.06"N, 51°33'0.57"E	0.042	0.047	0.070	0.061
	ES-4	25°16'4.78"N, 51°32'59.43"E	0.043	0.045	0.069	0.062
	ES-RM	25°15'56.98"N, 51°33'12.08"E	0.052	0.040	0.056	0.060
	ES-RN	25°15'55.88"N, 51°33'2.13"E	0.033	0.041	0.039	0.060
	ES-LM	25°16'12.20"N, 51°32'50.98"E	0.043	0.040	0.053	0.060
Gulf Cinemas	GS-1	25°15'45.33"N, 51°32'15.50"E	0.053	0.044	0.062	0.070
	GS-2	25°15'45.37"N, 51°32'16.75"E	0.051	0.044	0.055	0.070
	GS-3	25°15'46.71"N, 51°32'16.61"E	0.045	0.048	0.068	0.070
	GS-4	25°15'46.75"N, 51°32'15.36"E	0.044	0.048	0.055	0.070

* Values predicted using CALINE4 air dispersion model.

Table 9 Total Traffic Recorded at Study Locations During December 2012 and March-April 2013

Location	December 2012					March - April 2013				
	Whole Period of Study	Morning Rush Hour	Afternoon Rush Hour	Evening Rush Hour	Low Traffic Hour	Whole Period of Study	Morning Rush Hour	Afternoon Rush Hour	Evening Rush Hour	Low Traffic Hour
Hamad Hospital	2,258,796	277,456	352,488	365,666	21,215	1,877,928	254,426	292,214	297,913	21,633
Qatari Bin Al-Fujaah	1,661,902	163,961	262,411	279,052	12,492	1,418,587	162,906	227,973	234,255	9,219
Ramada	2,310,694	271,022	365,853	367,963	19,423	1,992,481	260,461	315,757	316,199	15,592
Al-Muntazah	2,423,453	291,398	380,679	401,749	20,489	2,057,419	261,667	326,105	348,104	16,477
Toyota Tower	3,219,298	366,088	456,689	513,257	71,887	2,630,541	312,944	379,949	422,256	53,460
Gulf Cinemas	1,721,328	198,580	263,819	277,886	22,120	1,468,082	182,195	230,919	242,599	17,345

Table 10 Average Meteorological Data (Ambient Temperature, Relative Humidity and Wind Speed) Recorded During December 2012 and March-April 2013

December 2012					March - April 2013				
Whole Period of Study	Morning Rush Hour	Afternoon Rush Hour	Evening Rush Hour	Low Traffic Hour	Whole Period of Study	Morning Rush Hour	Afternoon Rush Hour	Evening Rush Hour	Low Traffic Hour
Ambient Temperature (°C)					Ambient Temperature (°C)				
21.61	23.60	22.29	20.61	19.59	25.97	29.06	27.21	24.48	24.44
Relative Humidity (%)					Relative Humidity (%)				
66.75	56.00	65.20	73.90	74.25	43.43	31.57	37.77	48.46	49.44
Wind Speed (mph)					Wind Speed (mph)				
6.60	7.29	8.42	5.23	4.78	7.16	9.55	10.62	6.04	1.15

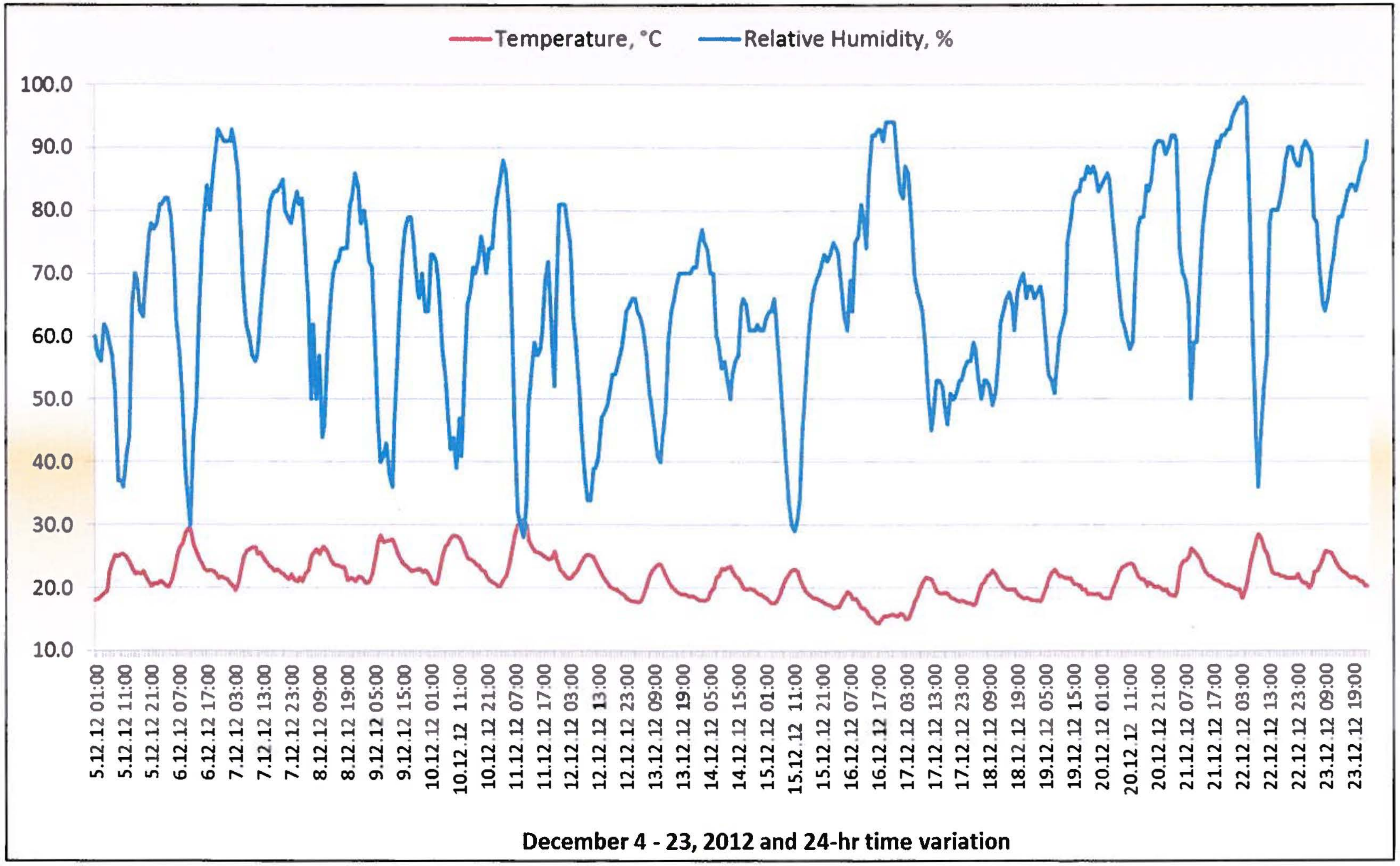

Figure 38 Hourly Variation of Ambient Temperature and Relative Humidity, December 2012

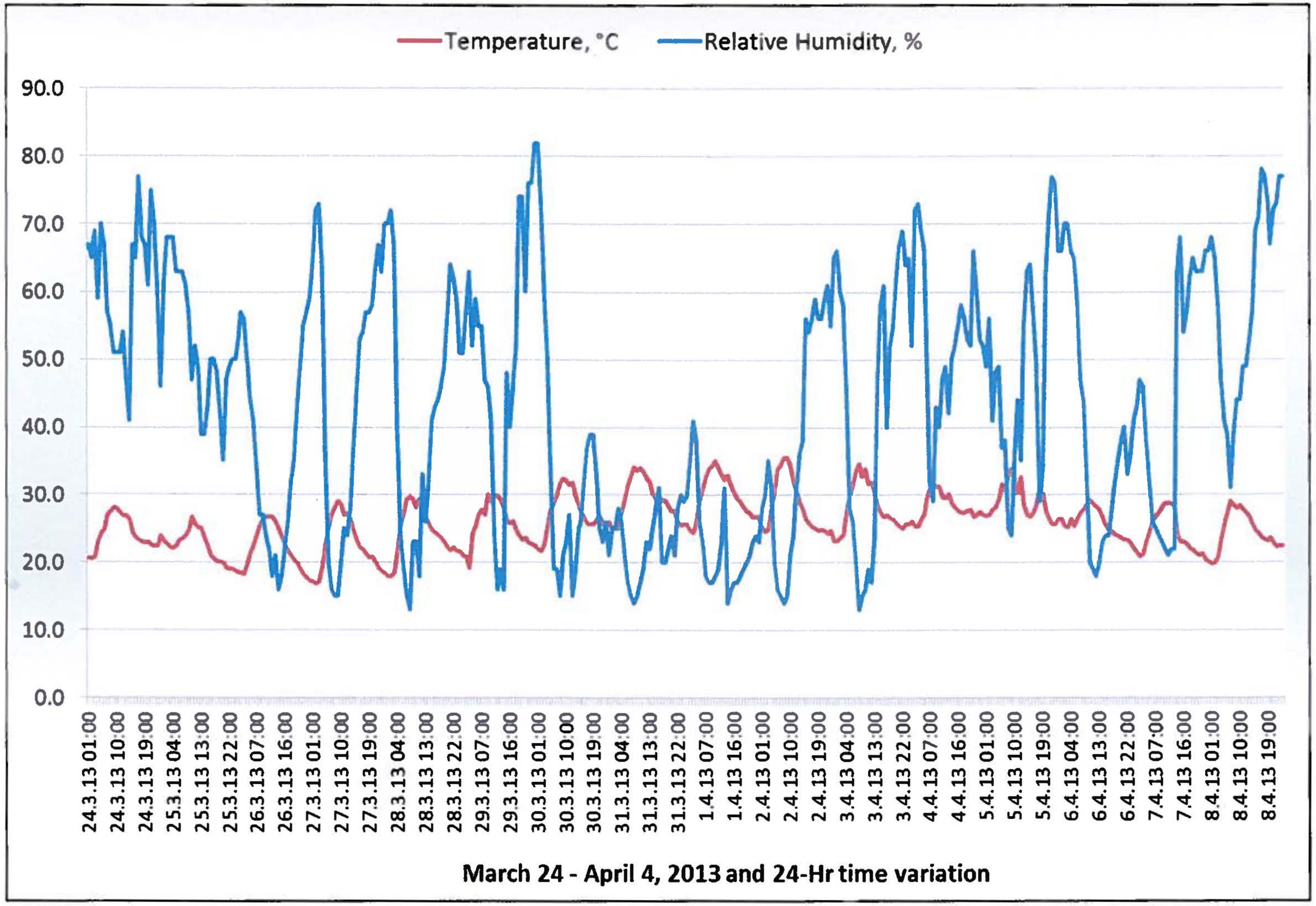

Figure 39 Hourly Variation of Ambient Temperature and Relative Humidity, March-April 2013