The Influence of the Meteorological Conditions on Air Pollution Levels in Emirate of Dubai, United Arab Emirates

By

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Abstract

The subject of pollution has been of great interest recently, especially in understanding the chemical behaviour and the concentration of gases in the atmosphere. This thesis contains an initial study of pollution patterns in the United Arab Emirates in the Emirate of Dubai. The thesis investigates the influence of meteorological conditions e.g. wind direction, wind speed, temperature, relative humidity and vapour pressure on concentrations of NO_2 and O_3. Dubai City has developed rapidly in last the 20 years and is part of the rapid development of cities and industrial areas in the Arabian Gulf. It is necessary at this time to identify the air quality in the region.

In order to provide information on the spatial distribution of NO_2 concentrations in the ambient air at eleven sites in and around Dubai City, the passive sample diffusion tubes were used to measure two-week average NO_2 concentrations, during a two year period from January 1996 to December 1997.

In addition to the diffusion tube survey, data for NO, NO_2 and O_3 from Dubai Municipality's air quality monitoring network were analysed.

The main aim in the first part of this study was to evaluate both the use of diffusion tubes in a hot country, and to establish a database of measurements for NO_2 concentrations for Dubai. The main aim in the second part is to test the influence of the sea breeze circulation on concentrations of O_3 and NO_2 using data from the air quality monitoring network during the two years 1996 and 1997.

The results indicate that the overall NO_2 concentrations throughout the Emirate of Dubai are low. The results reveal that the NO_2 concentration shows little monthly variation. However, the concentration of NO_2 during winter is high when compared with summer. The results show that the concentrations of NO_2 at a suburban area with low traffic density were in the range between 6 and 21ppb. In an urban area with high traffic density, the values was ranged between 36 and 76ppb.

The second part of this study was based on testing the hypothesis that the air masses rich in photochemical pollutants can be transported offshore and then back onshore as a result of land breeze and sea breeze circulation. The analysis was based on the hourly average of O_3, NO_2 and NO concentrations from four stations at Dubai Municipality, Mushrif park, Al Safa park and Jebel Ali village during days of different types of wind pattern.

Different meteorological parameters such as wind direction, wind speed, temperature and vapour pressure were analysed. This was used to determine the influence of weather conditions on pollution levels during the four different observed patterns of daily wind variations.

The results show that there are diurnal variations of O_3, for all day types of wind pattern in the coastal zone. The highest O_3 concentration (40-45ppb) were recorded during days of no sea breeze with northwesterly wind. High value (29-33ppb) were also found during days of summer sea breeze. The Al Safa station recorded consistently low O_3 concentrations (9-11ppb), while Jebel Ali village station has consistently high O_3 concentrations (43-45ppb). Hourly average daytime O_3 concentrations were always greater than the nighttime average.

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Chapter One

Introduction and Objectives

1.1 Geographical background

The United Arab Emirates form one of the Arabian Gulf States. It is located at the southwestern part of the Arabian Gulf, bounded in the northwest by Qatar and Saudi Arabia. The northeastern boundary beyond the sea is Iran, and in the south is the Sultanate of Oman. The gross area of UAE is about 77,700 km^2. The Emirate of Dubai, the focus of this study extends about 3,986 km^2 and has been selected because it represents the biggest commercial centre and one of the cities with the highest population in the Arabian Gulf region. It is also bounded to the west by the commercial free zone and Jebel Ali is the largest man-made port in the world.

During the last three decades, due to the oil industry, there have been dramatic economic, social, industrial and environmental developments is the western part of the Arabian Gulf, which includes UAE, eastern Saudi Arabia, Qatar and Bahrain. For instance, many national industrial estates were established, e.g. Jebel Ali free-zone in the Emirate of Dubai and the industrial areas in Saudi Arabia. Due to this population growth the vehicle density has risen, and recent statistics in the Emirate of Dubai stated that vehicles increased from 206,070 during 1996 to 235,703 during 1997. Furthermore, there is seasonal tourism and it is estimated that around one million tourists have been attracted to the Emirate of Dubai for about four months a year since 1996, most of them driving in cars from the other Gulf countries.

This type of development has had a great impact on air pollution in particular and the environment in general, such as elevated nitrogen dioxide and ozone levels. At the same time, the correlation between the meteorological conditions and increased air pollution has been of great interest. Researchers such as Guicherit and Van Dop (1977) were interested in the photochemistry of ozone and its relation to meteorology in Western Europe. Lalas *et al.,* (1983) investigated the diurnal variation and studied the re-circulation of pollution by sea breeze cells in Athens, while in the hot countries Madany *et al.,* (1993) carried out an investigation into the level of nitrogen dioxide in different locations in the State of Bahrain.

During the middle of the eighties, the Government of the Emirate of Dubai paid attention to industrial issues, and this alerted the government to the possibility that there might be a pollution problem. In 1991 the government of Dubai passed a local order, and within the local law there is serious consideration about controlling the air pollution in Dubai City.

The Dubai Municipality Office of the Environment already existed but, although they routinely collected data about air quality parameters such as O_3, NO_2, NO, NO_x, CO, SO_2 and dust, these data were not very detailed and did not reveal much about pollution levels. In 1993, however, the Department started to pay more attention to pollution, which might become a problem in the future.

An annual report is produced by the Dubai Municipality about the air quality within the Emirate of Dubai and how it is affected by different gases. The conclusions in these reports do not give an accurate picture. For example, it is stated that the weather in Dubai is (Good), but these do reveal that the level of pollution is only just within the accepted the air quality standards of the World Health Organization.
It is therefore important that accurate research should be conducted in order to give a true picture of the pollution levels in Dubai taking into account the relationship between the weather conditions and impact of different meteorological parameters.
The author hopes that this study will give a scientific basis to decisions on control of pollution and the influence of weather conditions in arid lands.

Literature surveys show that there is a gap of research studies for the evaluation or assessment of the degree of influence of weather conditions such as sea breeze circulation, on air pollution in the Emirate of Dubai. Frequently scientific researchers can build on what previous researchers have found in other comparable or related studies. In the case of this study, however, there has been no previous research for the author to access, with the exception of weather data from Dubai airport and data from pollutant gas network monitoring.

1.2 Research objectives

The objectives of this research are drawn from the issues raised in this introduction and they include:

1. To establish a database of measurements for nitrogen dioxide concentrations in an arid urban environment, the Emirate of Dubai, throughout a two years period.
2. To evaluate the feasibility of using diffusion tubes in a hot country.
3. To investigate the impact of sea breeze patterns on the variation of NO_2 and O_3 concentrations for two-week periods over the same two-year period.
4. To examine the relationship of meteorological conditions and air pollution.

The first survey was a measure of NO_2 concentration by using diffusion tubes, which were exposed for 14-day periods. Preliminary field and laboratory work was carried out to ascertain the levels of NO_2 at different locations throughout Dubai City. Monitoring sites were chosen to include an urban area with high traffic density, suburban areas with low traffic density, and commercial and industrial areas. To ensure that the sites chosen were representative over all of the area, spatial comparisons were made between the sites. The results show that the concentrations of nitrogen dioxide at Dubai city were in the range of 6-21 ppb in the suburban area with low traffic density, while in an urban area with high traffic density the values ranged between 36-76 ppb.

The second survey was an investigation of the influence of meteorological parameters on the pollution levels in The Emirate of Dubai particularly the different patterns of wind direction. Classification of different sea breeze types was based on the diurnal variation of wind direction and wind speed in the Emirate of Dubai.

The variability of the flow characteristics during the years 1996 and 1997 was classified into four wind direction pattern categories and two-day types of sea breeze

1. Days of summer sea breeze
2. Days of winter sea breeze
3. Days of no sea breeze with predominantly southeasterly wind blowing from the land
4. Days of no sea breeze with predominantly northwesterly wind blowing from the sea.

1.3 Introduction to the data used

A- Two years of fieldwork were undertaken in Dubai City during 1996 and 1997, which entailed the measuring of the nitrogen dioxide levels by using the diffusion tubes technique. Samples site were chosen to include an urban area with high traffic density, suburban areas with low traffic density, and commercial and industrial areas, to ensure that the sites chosen were representative of the area.

The sites were selected to ensure a good spatial distribution of sites throughout Dubai City and its surroundings. These sites include

1- An open green area distant from the city centre.

2- The edge of the city centre, next to the main transport routes to and from it.

3- Inner city centre.

4- Industrial areas.

B- The data for secondary pollutants O_3 and NO_2 and primary pollutant NO for year 1996 and 1997 used in this project were obtained from the Dubai Municipality

Environmental Office. Five different stations throughout Dubai City were set up by the Environmental Office as a network of monitoring sites:

1. Dubai Municipality
2. Jebel Ali Port
3. Jebel Ali Village
4. Mushrif Park
5. Al Safa Park

C- Meteorological data were also used from Dubai International Airport such as the hourly averages of wind direction, wind speed, temperature, humidity and vapour pressure. These were used to examine the synoptic weather during selected days of sea breeze. Because of the meteorological characteristics of arid and coastal areas, such factors as high temperatures, high levels of solar radiation and wind direction may have the largest effects on pollutant distribution.

1.4 Thesis organisation

This section provides an overview of the organisation of this thesis.

Chapter 2 Introduces sea breeze circulation, as the meteorologists and atmospheric scientists have studied mesoscale sea breeze circulation for many years. These studies show that during the summer air rich in photochemical pollutants can be transported offshore and then back inshore as a result of the land and the sea breeze circulations system. The first section then considers the characteristics of air pollution in coastal areas, and discusses these concepts in detail with other related work.

Chapter 3 is an introduction to both the United Arab Emirates and the Emirate of Dubai. The details of seasonal variation of weather conditions during winter months and summer months are provided. Then follows a section discussing the area under investigation. Next the details of meteorological parameters and days of sea breeze in Dubai are illustrated; a) days of summer sea breeze; b) days of winter sea breeze; c) days of no sea breeze with northwesterly winds and d) days of no sea breeze with southeasterly winds. This section shows the influence of wind direction and wind speed on the four categories of day types. Finally, for each measure site, the concentrations of nitrogen dioxide in Dubai City in particular in the coastal zone are presented.

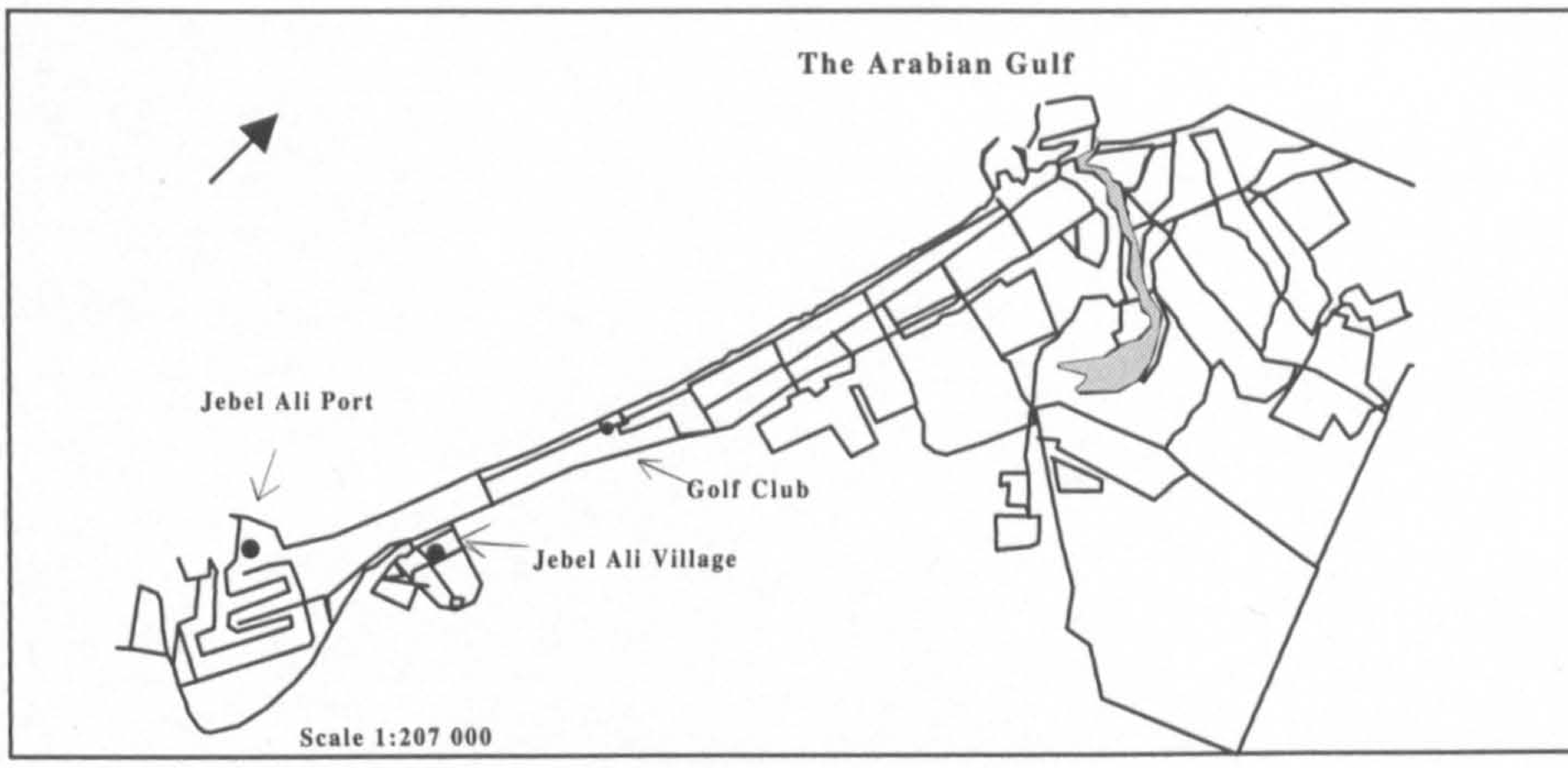
Chapter 4 provides a survey of the earlier studies measuring nitrogen dioxide, and the general chemistry of the primary pollutants and secondary pollutant of O_3 and NO_2. It starts by discussing the validity of using diffusion tubes in both urban and rural areas. The details of formation, sinks, seasonal and spatial variation of NO_2 are given. Then the detail of the secondary ozone pollutants is reviewed.

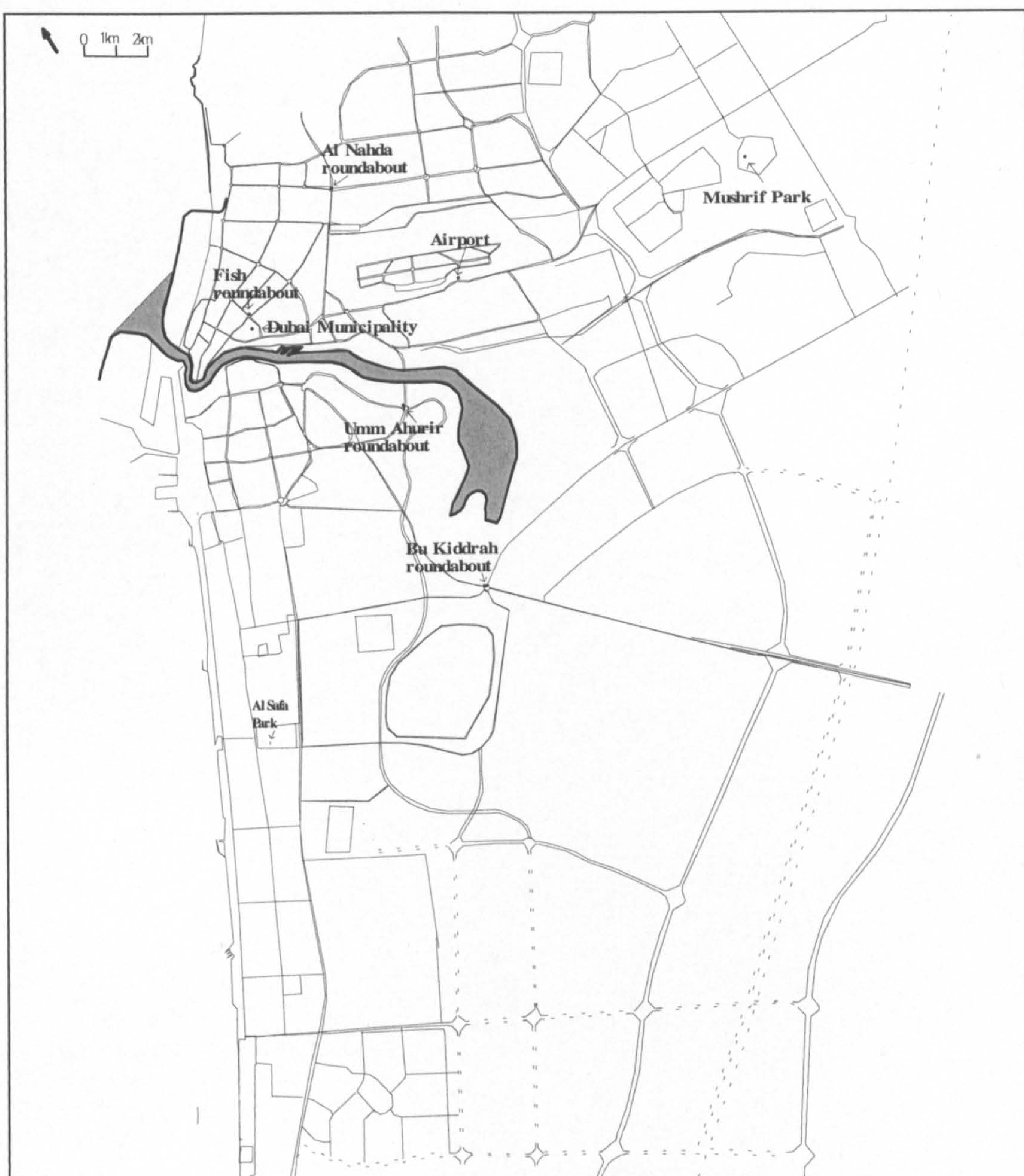
Chapter 5 introduces both the diffusion tube theory and the methodology. It reviews the principles of diffusion tubes, advantages and disadvantages of using diffusion tubes, different contamination and definitions of different blanks.

Chapter 6 illustrates the results of measuring NO_2 concentration by using diffusion tubes during 1996 and 1997, while the results for O_3 are illustrated in Chapter 7.

In chapter 8 the results of the diffusion tube survey is discussed in terms of seasonal variation and local site variation. At the same time the factors which influence the distribution of O_3 during daytime and nighttime will be discussed. Finally, the conclusions from the study are outlined, and recommendations for further work are discussed.

Fig 1.1 Maps (A and B) of the location of sample sites throughout Emirate of dubai





Chapter Two

Atmospheric Pollution near Coastal Areas

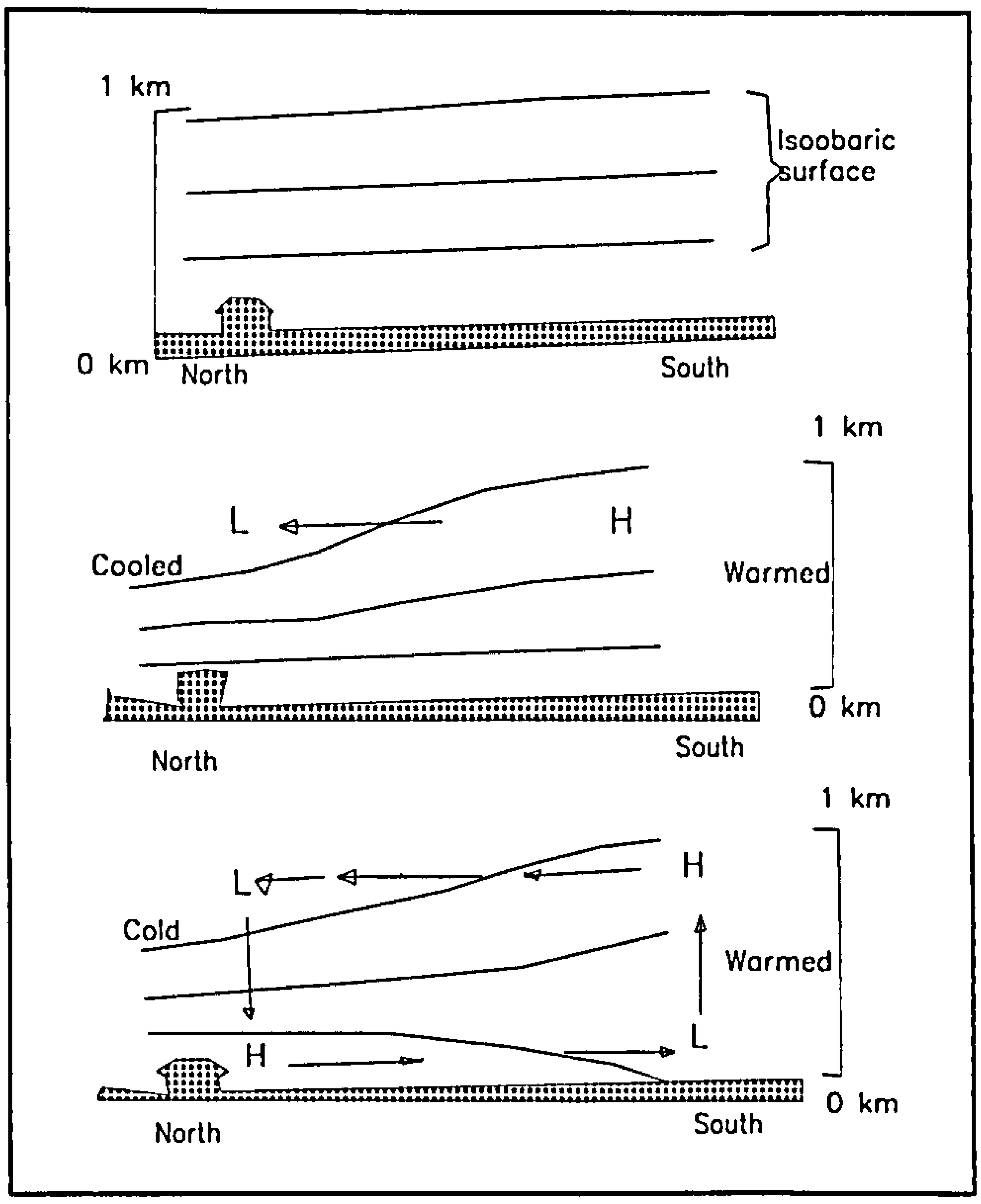
2.1 Introduction

This chapter is an introduction to sea breeze circulation and its impact on air pollutant concentrations. The difference of air temperature between land and sea is the main reason for this coastal phenomenon. During the summer air masses rich in photochemical pollutants can be transported offshore and then back onshore as a result of the land and the sea breeze circulations system. The first section considers the characteristics of air pollution in coastal areas. The second section discusses the effects of meteorological conditions on the diurnal distribution of NO_2 and O_3.

Sea breeze patterns occur at specific geographic locations (Melas *et al.,* 1998). Pioneers such as Haurwitz (1947), Schmidt (1947) and Neumann (1977) illustrated the broad outline of the sea breeze mechanism.

Meteorologists and atmospheric scientists have studied mesoscale sea breeze circulation for many years. It is important in the study of air quality in many coastal areas, including Athens (Fortezza and Strocchi, 1993; Lalas *et al.,* 1983; Batchvarova and Gryning 1998); Jerusalem, Israel (Steinberger and Ganor, 1980); in southeast England (Bower *et al.*, 1989; Gay, 1991) and Monterey Bay of California (Banta, 1995; Atkins and Wakimoto 1997). Due to variations in temperature between the moist air above the sea and dryer air above the land, a variety of sea/land breeze circulations have been observed. At the same time, the weakening of the synoptic winds allows the development of local circulation systems (Melas *et al.,* 1995).
A thermal wave is produced by the variation of temperature in the lower layers of the atmosphere. The thermal waves are produced due to the difference in the diurnal variation of temperature between land and sea, leading to the diurnal circulation of the sea and land breeze (Simpson, 1994; Lohar *et al.,* 1994). Ahrens (1991) described this movement of air as a thermal circulation, an atmospheric condition where the air surrounding any area either cools or warms, a column of warm air will expand while a column of colder air will contract. In other words the thickness of a column of heated air will increase. The horizontal difference in pressure from land to sea results in a pressure gradient force (See Fig 2.1 below).

Fig 2.1 The thermal circulation produced by the heating and cooling of the atmospheric near the ground surface (after Ahrens 1991).

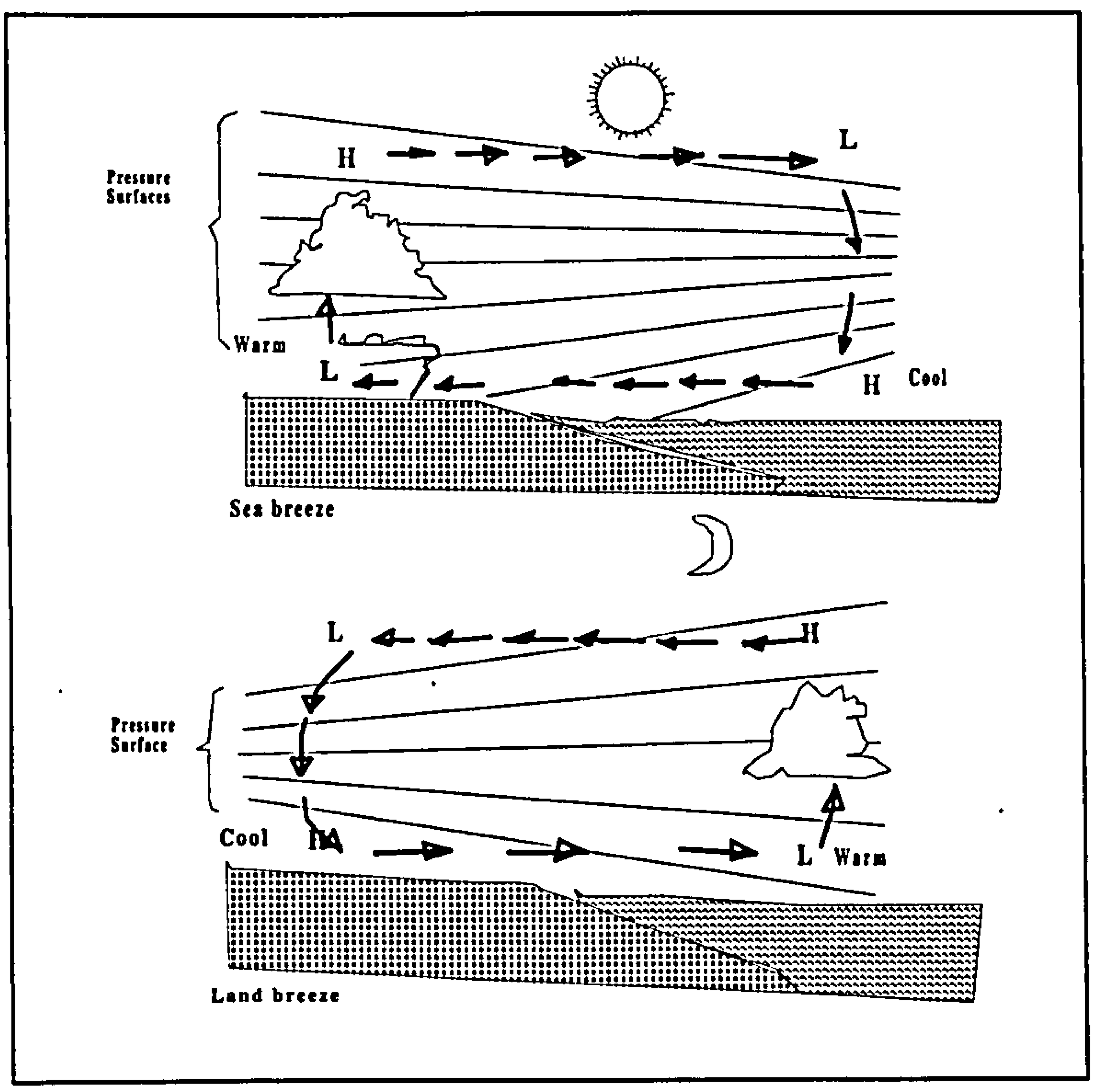


2.2 Definition of sea/land breeze

The prime cause of sea breeze circulation is the difference in temperature between the moist air over the sea and the dry air over the land (Zhong and Takle, 1992). The development of the sea breeze during the day occurs when the geostrophic winds are either weak or absent, such a situation could be critical for air pollution (Ozoe *et al.*, 1983: Klemm *et al.*, 1998)

As solar radiation increases during the daytime, the land surface heats more quickly than the sea surface. This means that the column of air over land will expand, because it being heated from the ground below. This causes the distance between constant pressure surfaces to increase. However, over the sea the distance between pressure surfaces remains about the same, because the air is not being heated. The pressure surfaces over the land will be higher than over the sea and spread further apart which causes the formation of high pressure (H) over land, and low pressure (L) above the sea. The overall effect of this pressure distribution is called the ***sea breeze*** and the ***land breeze*** (Petterssen, 1969). According to Ozoe *et al.* (1983), the land and sea breeze are spiral or helical in shape, but in general on the sea side there is a descending flow and on the inland side there is a rising flow. Orciari *et al.* (1998) in their investigation of the coastal area of Northern Italy (Ravenna) confirmed this idea.

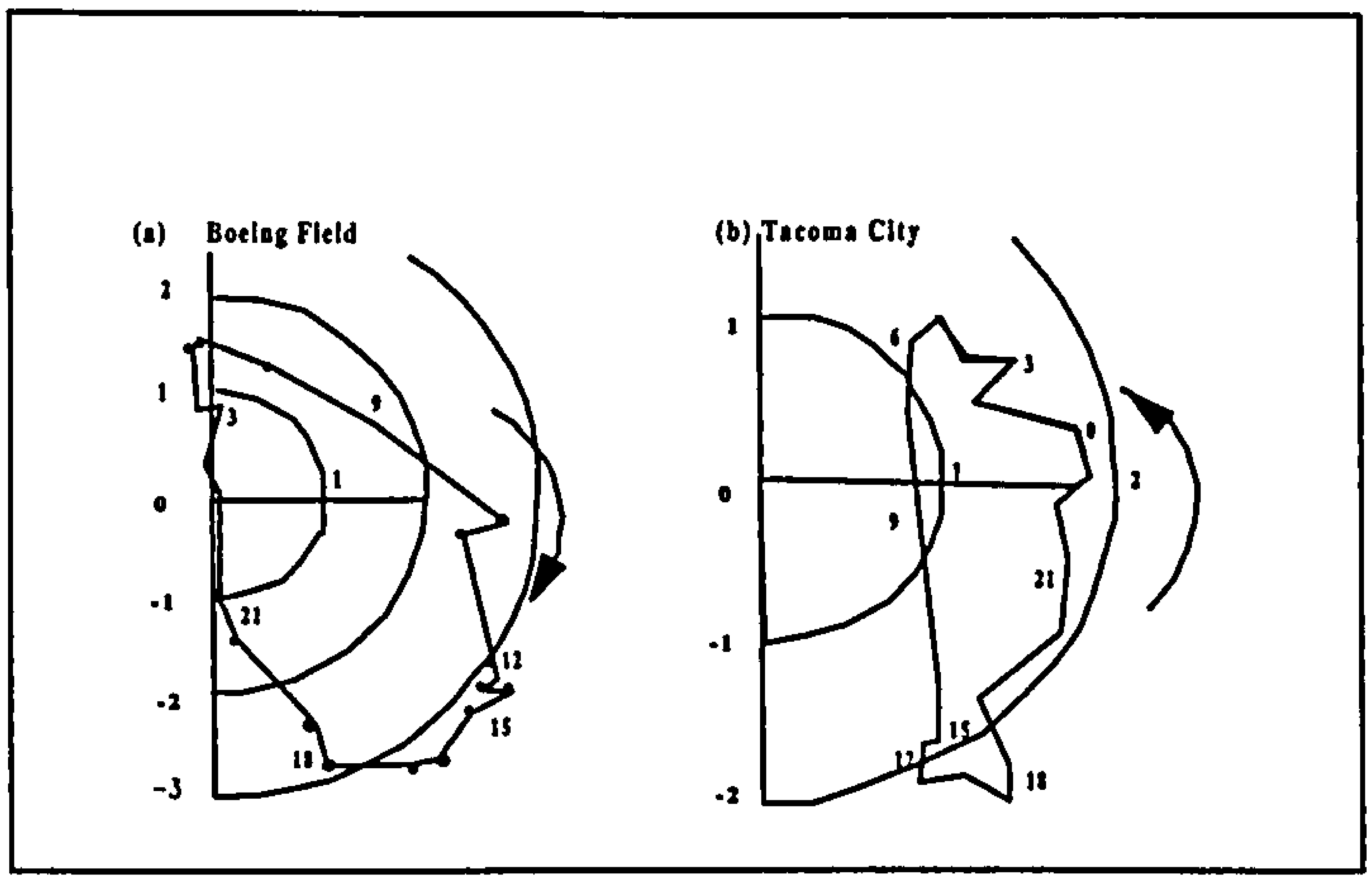
Fig 2.2 Development the sea breeze and land breeze (after Ahrens 1991).



2.2.1 Hodograph: strength and direction of sea breeze

The best way of presenting measurements of sea breeze is to use a wind hodograph (e.g. Fig 2.3) traced by the end point of the wind direction as its value changes with time. At any given locality the hodograph shows a complete 360° turn during the day, especially with weakness of synoptic gradient winds (Simpson 1994; 1996). Figure 2.3 below shows a hodograph at Boeing Field and Tacoma City, Washington, the vertical scale refers to wind speed, while the numbers within the graph refers to time in hours. Although both cities are close, show anti-clockwise and clockwise rotation. This is probably due to their different positions relative to the mountain mass in the south. Such conditions of sea breeze circulations occur in many tropical regions. Haurwitz (1947), a pioneer researcher who clarified a linear model considering friction and Coriolis forces, found that the sea breeze hodograph in the Northern Hemisphere, created from internal forces, should always be elliptical with a clockwise rotation. At the same time, the sea breeze circulation near to the coastline generally veers before sunset (Simpson, 1996). However, many studies have shown that the turning of the sea breeze circulation can be anticlockwise (Neumann, 1977). Helmis *et al.* (1995) studied the Saronic Gulf during the summer of 1992, and emphasised the above idea. They found that the hodograph shows anticlockwise rotation when the background flow possesses a westerly component, while the clockwise rotation was created by an easterly background component. It became known that the reason for anticyclonic rotation is complex topography. Thus mountains can affect the sea breeze near the shoreline. Banta (1995), working on the California coast, found that the direction of rotation was influenced by the establishment of mesoscale pressure gradients, which has been confirmed by studies in Athens (Helmis *et al.*, 1995).

Fig 2.3 Sea-breeze hodographs for August in the Northwest of the state of Washington, USA (a) clockwise rotation at Boeing Field, (b) anti-clockwise rotation at Tacoma City. (In Simpson 1994, after Staley, 1957).



2.3 The characteristics of air pollution in coastal area

According to (Mantis *et al.*, 1992; Simmonds and Derwent, 1991) the meteorological factors such as wind and turbulence play an important role in determining pollution concentration caused by a given rate of pollutant emission. In coastal areas where cities are located close to a gulf or bay, it has generally been thought that air blowing from the sea is pollution free. But this is no longer considered likely, due to the serious air contamination. Therefore, many studies have attempted to describe the complex interactions between atmospheric pollution and sea breeze circulation. Recently models have been developed using the wind speed, wind direction and atmospheric turbulence to identify the interference between the meteorological variables, for example in Athens (Batchvarova and Gryning, 1998).

An investigation in Athens (Varvayanni *et al.*, 1998) and a model made by Koo and Reible (1995) suggest that the local climate is determined by mesoscale wind systems especially with weakening of synoptic pressure. However, the most important effect on the climatology and air quality conditions in the coastal area is likely to be the land/sea breeze circulation (Nester, 1995). The circulation of the sea breeze recycles pollutants as a result of interactions between the surface flow and the return flow aloft (Suppan *et al.,* 1998; Eleftheriadis *et al.,* 1998). These interactions might result in increases in pollution concentrations in coastal areas. Bornsteint and Thompson (1981) found in their investigation over New York City (NYC) that a sea breeze frontal passage resulted in decreasing pollutant concentrations in the upwind portions of the city and increasing concentrations in the downwind portions of the city. Because the clean air which as it travels over the city, becomes polluted and arrives in downwind areas with relatively high concentrations. One important point must be taken into consideration when describing air pollution patterns in coastal areas, the wind-monitoring network studies have been confined to the situation over the land, thus information regarding coastal sea breeze is limited. Due to restricted knowledge of the wind field over one half of the domain of interest, the theory is often only speculative.

2.4 The influence of meteorological conditions

In general, it could be said that during the morning and evening the atmospheric boundary layer acts as a pollution receiver (Orciari *et al.,* 1998). The depth and rate of the growth of the daytime boundary layer have a major impact on air quality in urban areas. The structure of the boundary layer in the vicinity of a shoreline may on occasions be very complex, primarily due to land/sea temperature and land roughness (Melas *et al.,* 1995). Zhang and Roo (1998) suggests that the vertical mixing process may be the main source of increased O_3 concentrations at ground level during the early morning, especially when the solar radiation and temperature may not be significant. This mixing is well correlated with the land/sea breeze circulation system (Orciari *et al.*, 1998).

In addition Melas *et al.* (1998) who carried out an investigation at Athens, found that convection of the boundary layer increases during the daytime due to increases in heat, which leads to expansion of warm air over the land surface. The effects of the heating continue until the afternoon, which may influence the development of the sea breeze circulation.

The development of the turbulence and thermal conditions occurs mainly during daytime when the mixing layer can extend up to 500m or higher above the ground surface. As a result of these thermal conditions any pollution will be dispersed within the whole boundary layer, thus diluting the concentrations (Gay, 1991).

The mixing layer affects the transport of any pollutant over long and short distances in the atmosphere (Smith and Hunt, 1978; Grisogono and Keislar, 1992). The shallower the layer, the stronger the conversion of any pollutant in the atmosphere. However, when the layer is deeper the wind direction and heat play a very important role in the diffusion of the pollutant.

Helmis *et al.* (1995), in their investigation of the Saronic Gulf in Athens during summer months, found that the variation in midday temperature and humidity during the experimental days was caused by the solar radiation level (clear sky). Olszyna *et al.* (1997) confirmed the results of Helmis *et al.* (1995), and found that the formation process of ozone requires high air temperatures higher than approximately 32°C near to the ground surface. Thus, midday with a cloudless sky leads to the highest concentrations. These conditions are also associated with well-developed sea/land breeze circulation. Kalabokas and Bartzis (1998) found that meteorological conditions such as high solar radiation levels favour for the production of ozone due to photochemical reactions because of the availability of O_3 precursors and NO_x

Fortezza and Strocchi, (1993) carried out a study in Ravenna on the northwest Adriatic coast. They found that the primary and secondary pollution varies during the day due to the variations of the meteorological and climatic conditions. They found that the photochemical reactions and the pollution transport by the sea breeze are responsible for high ozone concentrations, between sunrise and late evening along the coast.

Melas *et al.* (1995) pointed out that the low average wind speed over Athens of 2-3 ms^{-1} (4-6 knots) is related to the high roughness of the city. Lalas *et al.* (1983) and Kambezidis *et al.* (1998) found that the stability of weather conditions caused lower wind speeds during the early morning and during night hours. Another likely explanation for the low wind speeds is that, during early morning and evening, the boundary layer is very shallow above the land surface due to reduced heat and the influx of cold air from the sea (Melas *et al.*, 1995; Fortezza and Strocchi, 1993). In addition, a significant change in wind direction was associated with fully developed sea breeze circulation in Athens by Suppan *et al.* (1998).

Koo and Reible (1995) found that at midday during the sea breeze it is often difficult to detect the position of the front, which separates sea and land air. This is due to unstable atmospheric conditions caused by heat flows at ground level (Smith and Hunt, 1978). While during the afternoon the sea breeze front rapidly penetrates inland, during late afternoon it is easy to detect the sea breeze front when the temperature and wind velocity of the day are decreased (Koo and Reible, 1995).

2.5 Diurnal pollution distribution during the presence of the sea/land breeze circulation

The effects of daytime meteorological conditions on pollution distribution were illustrated by Kelly *et al.* (1984). They divided the daytime into two periods. In the first time period T_1 (0600-1000) vertical mixing accounted for half of the O_3 concentration. From the morning the levels of O_3 rise, followed by dissipation of the surface based nocturnal inversion, especially with high levels of O_3. The second time period, T_2 (1000-1400) is when the concentration of O_3 increases due to the local photochemistry. They assumed that ~6 ppb of O_3 was formed per ppb of NO_x.

According to Kleinman *et al.* (1994) it is well known that O_3 concentrations vary during the day, due to the variations in levels of NO_x and hydrocarbons, in addition to the effects of meteorological and climatic conditions.

During the early hours of the morning, before the full development of the sea breeze circulation the concentrations of NO and NO_2 found to be high. This can be attributed to high traffic density (Ganor *et al.,* 1978; Kambezidis *et al.,* 1998). From sunrise to early afternoon strong convection occurs. During this time the concentration of ozone close to the ground level is lower than the background level of 30 ppb (Nester, 1995).

During midday and the early afternoon, when the wind speed is increasing with the sea breeze, the lowest NO concentrations are recorded. This is associated with the strongest transformation of NO $\rightarrow$ NO_2. In the evening, with reducing wind speed the highest concentration of NO and NO_2 is recorded, especially with the presence of the land breeze (Nester, 1995; Kambezidis *et al.,* 1998).

Kelly *et al.* (1984) carried out an investigation about sinks of O_3 in different rural areas located near to Vermillion Bay in the U.S.A and found that O_3 generation during the daytime is complicated due to the diurnal variation. This is mainly because no study regarding vertical mixing has been accomplished.

During the evening, in the absence of sunlight, the O_3 concentrations are close to zero, due to reduced photochemical reactions. Furthermore, while the sea breeze changes to land breeze, higher concentrations of NO and NO_2 are recorded. Physick and Scott (1976) carried out an investigation in South Australia at St Vincent Gulf, and found that especially during the warm months the land breeze at night plays a very important role as it trapped pollution and transported it out over the Gulf, only to return it back over the city on the next sea breeze.

Chemical destruction occurs during nighttime due to the stable atmospheric conditions, which result from light wind speed and calm weather. In a study in Athens Kalabokas *et al.* (1998), found that the increased emission of NO and HCs from car traffic destroys ozone concentration during the night. Moreover Kelly *et al.* (1984) in their investigation in southern U.S.A, found that the dry deposition had more influence in O_3 reduction than a period of well-developed turbulent mixing. In contrast, some studies found high ozone values during nighttime. According to

(Ganor *et al.*, 1978; Steinberger and Ganor, 1980) the O_3 concentrations during nighttime were related to the local conditions trapping photochemical O_3 under the inversion layer. Lalas *et al.* (1983) suggested a similar reason in their investigation in Athens. In addition, the presence of HCs and NO, largely emitted from car traffic, act as sinks for O_3 (Gusten and Heinrich, 1988).

Chapter Three

The Meteorological Condition of the United Arab Emirates and the Area under Investigation in the Emirate of Dubai

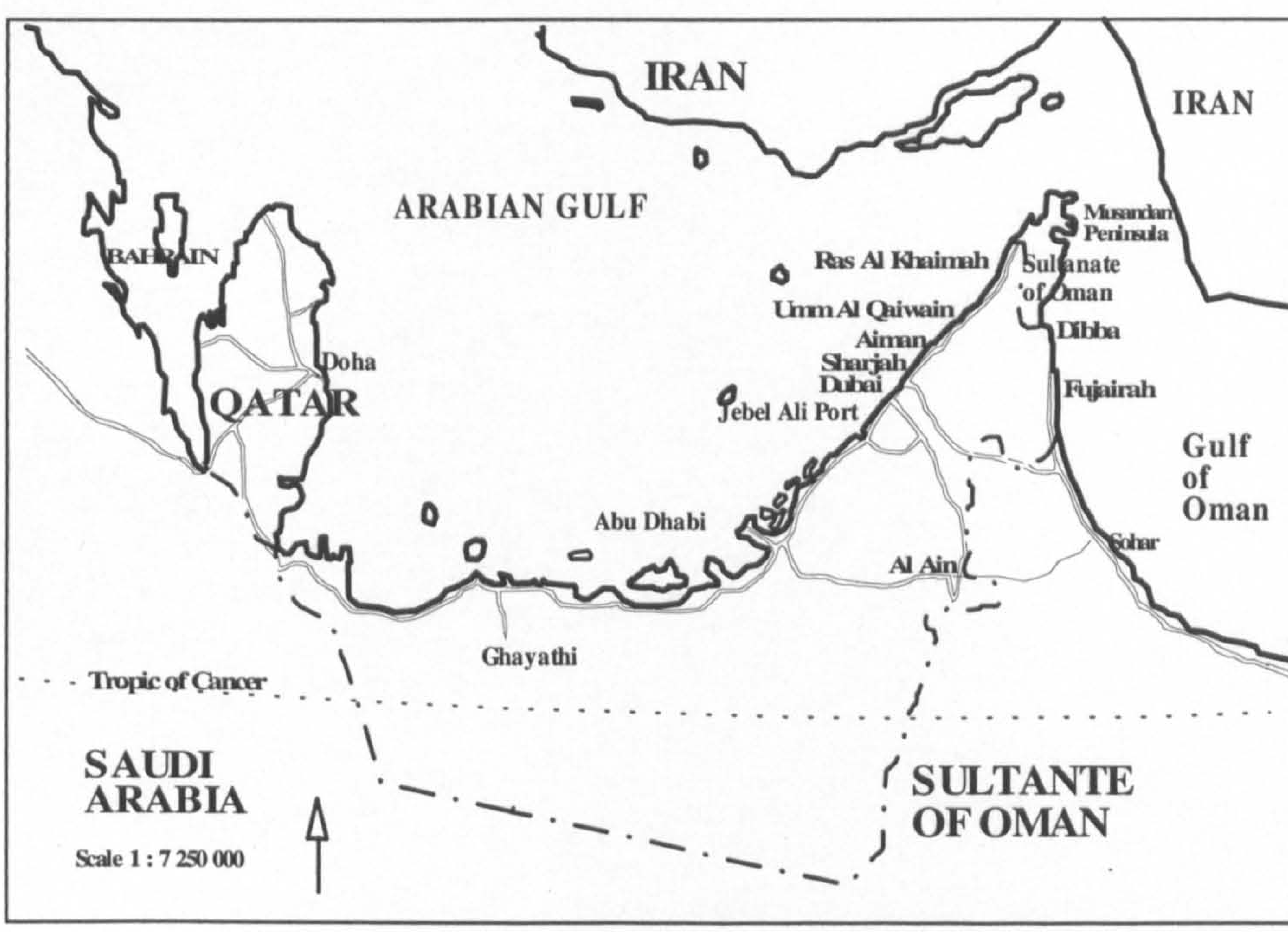
3.1 Introduction

In chapter 3 the geographical location of the United Arab Emirates (UAE) and Emirate of Dubai are given. The effects of the different factors of climatic conditions are described e.g. location, land and water distribution, topography and air masses. The contexts of seasonal variation of weather conditions during winter months and summer months are provided, and the details and location of each of the NO_2 measuring sites in Dubai City.

3.2 The United Arab Emirates climatology characteristics

In the eastern part of the Arabian Peninsula, which is one of the well-known arid lands located on the west side of Asia, the United Arab Emirates is located. The Arabian Peninsula is one of the largest areas of desert within the subtropical belt. The southern part of the Arabian Peninsula consists of large sand desert of Al Rub' al Khali (Empty Quarter), while the Great Nafud desert lies in the northern part. 90% of the interior area of the UAE represents the southeast part of Al Rub' al Khali desert.

Fig 3.1 Map showing the location of United Arab Emirates (National Atlas of UAE, 1993).



United Arab Emirates (UAE) is one of the six countries of the Arabian Gulf located south-east between Qatar peninsula to the west and Musandam peninsula to the east. The UAE is a federation of seven Emirates as follows; Abu Dhabi the capital, Dubai, Sharjah, Ras Al Khaimah, Fujairah, Ajman, and Umm Al Quwain. Fujairah is, situated on the coast of the Gulf of Oman.

The Arabian Gulf lies in the low latitudes where semi dry climate prevails surrounded by lands with a markedly continental climate. This region of the Arabian Gulf has the characteristics of extreme temperature and the very high humidity. The region can be subdivided into two by climatic variation.

1. The northern region, which experiences a short cold winter and a long hot, humid summer and scarce rainfall during November to May (Kholieb, 1990).
2. The southern regions experience mild, warm winters and long hot summers with rare annual rainfall, especially over the western area (Grove 1977; Kholieb 1990).

3.2.1 Factors affecting the climate of UAE

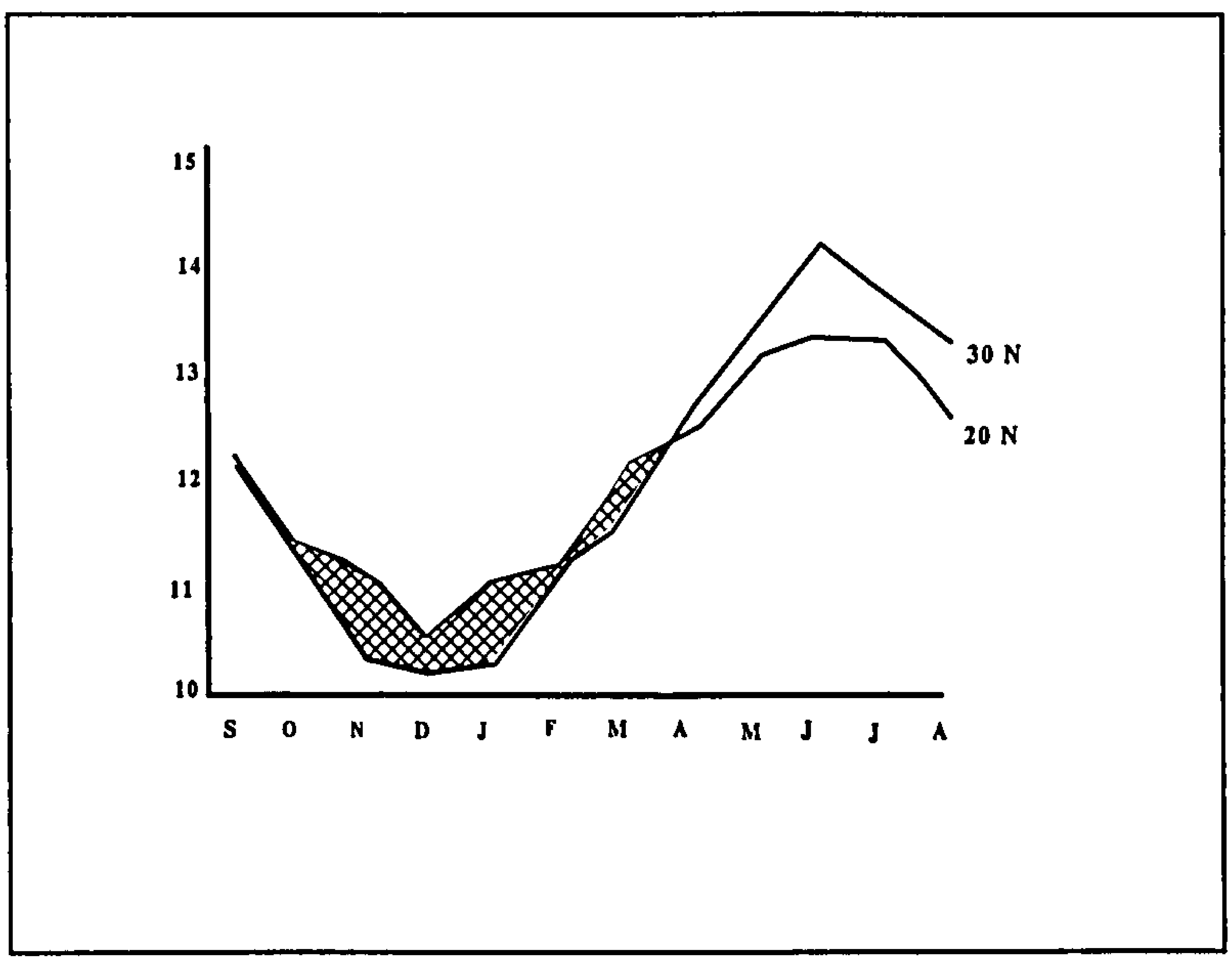
Tropical deserts (hot deserts) are characterised by high temperature and low rainfalls. Climatic conditions over most of the UAE are typically arid with two distinct seasons (UAE climate, 1996), a dry prolonged summer period, of very high temperatures between April and November and a winter period of mild to warm temperature between December and March. The minimum temperature is relatively high during winter, because it is affected by the warm masses of sea winds, which are permanently above the Arabian Gulf.

July is the hottest month of the year, with air temperatures up to 50°C. But usually during the summer period the maximum air temperature ranges between 41°C and 45°C. The annual mean temperature is more or less uniform throughout the country, with slight local variations, most noticeably in the mountains to the east, where higher altitudes result in mean temperatures of 25°C (National Atlas of UAE, 1993). There is also a tendency for temperatures to vary seasonally between the coastal zone and the interior area, with the latter being slightly cooler in winter and warmer in summer.

1. Location

The United Arab Emirates has 3 clear land elevation zones, the desert zone, the mountain zone and the coast zone. The UAE is situated between the parallels of latitude 22° and 27° north, and across the Tropic of Cancer, therefore during the month of June receives maximum solar insolation, which contributs to a hot and dry climate.

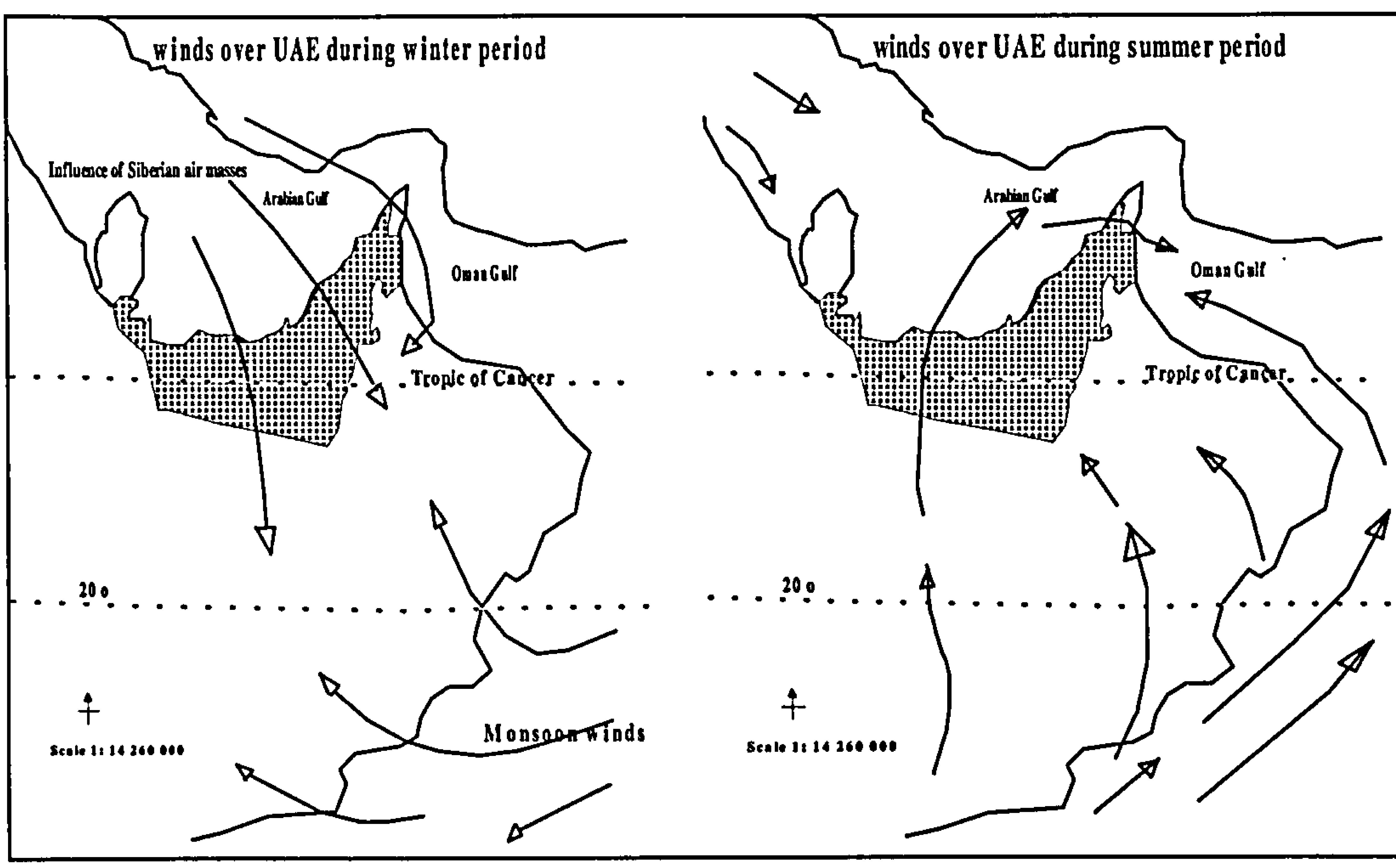
Fig 3.2 Daylight hours for Latitudes 20-30 N° (National Atlas of UAE, 1993).



2. Land and water distribution

The UAE is located close to the small sea areas of the Arabian Gulf on the north, and the Gulf of Oman on the northeast. This leads to the minimization of its effect on the temperature and average rainfall, but plays a greater role in increasing the humidity. Al Rub' al Khali desert occupies and stretches from the south, up towards the eastern part of the country, towards the mountains. This results in the effect of hot, dry continental conditions during the summer and the spring seasons (Abu-Aleinein, 1996).

Fig 3.3 Map showing different trajectory of wind direction during different months (National Atlas of UAE, 1993).



3. Topography

The UAE has characteristic wide flat plains, which do not exceed 300 metres above sea level (National Atlas of UAE, 1993). In the interior part of the country the land is covered with sand dunes, which cover ¾ of the whole country. These sand dunes contribute to local sandstorms from the inner parts in the northern and southeastern sectors of the country i.e. Al Kuss winds and Shamal wind sandstorms (UAE climate, 1996). There are no latitudinal contour extensions to obstruct the effect of the climatic conditions, except in the eastern part of the country, where there are high mountain ranges from 600 m to 2000 m above sea level (Ganiam, 1981). They extend from north to Ras Al Khaima to the southern parts of Al Ain town in the south.

4. Air mass

The weather condition of UAE is influenced by different air masses, continental or maritime. The influences of these air masses vary depending upon seasonal winds and pressure distributions, either within the global pressure gradient or by regional and local pressures.

In general, during the summer period, subtropical high pressure disappears (Issa *et al.,* 1996). Then the maritime air mass from the Indian Ocean effects the area, which influences the monthly average humidity. In summer the continental air mass from the African Sahara increases the air temperature, resulting in droughts (Abu-Aleinein, 1996).

During winter, the Siberian high pressure affects the northern part of the Arabian Gulf in contrast to southern part, the north is markedly dry, cold and has low air temperatures (Bazuhair and Al-Gohani, 1997; Issa *et al.,* 1996). However, from the west, the Westerly winds blow from the Mediterranean Sea toward UAE, increasing the annual average rainfall. These affect the weather conditions, which produces local winds and decrease the monthly air temperature. For more details see the section below.

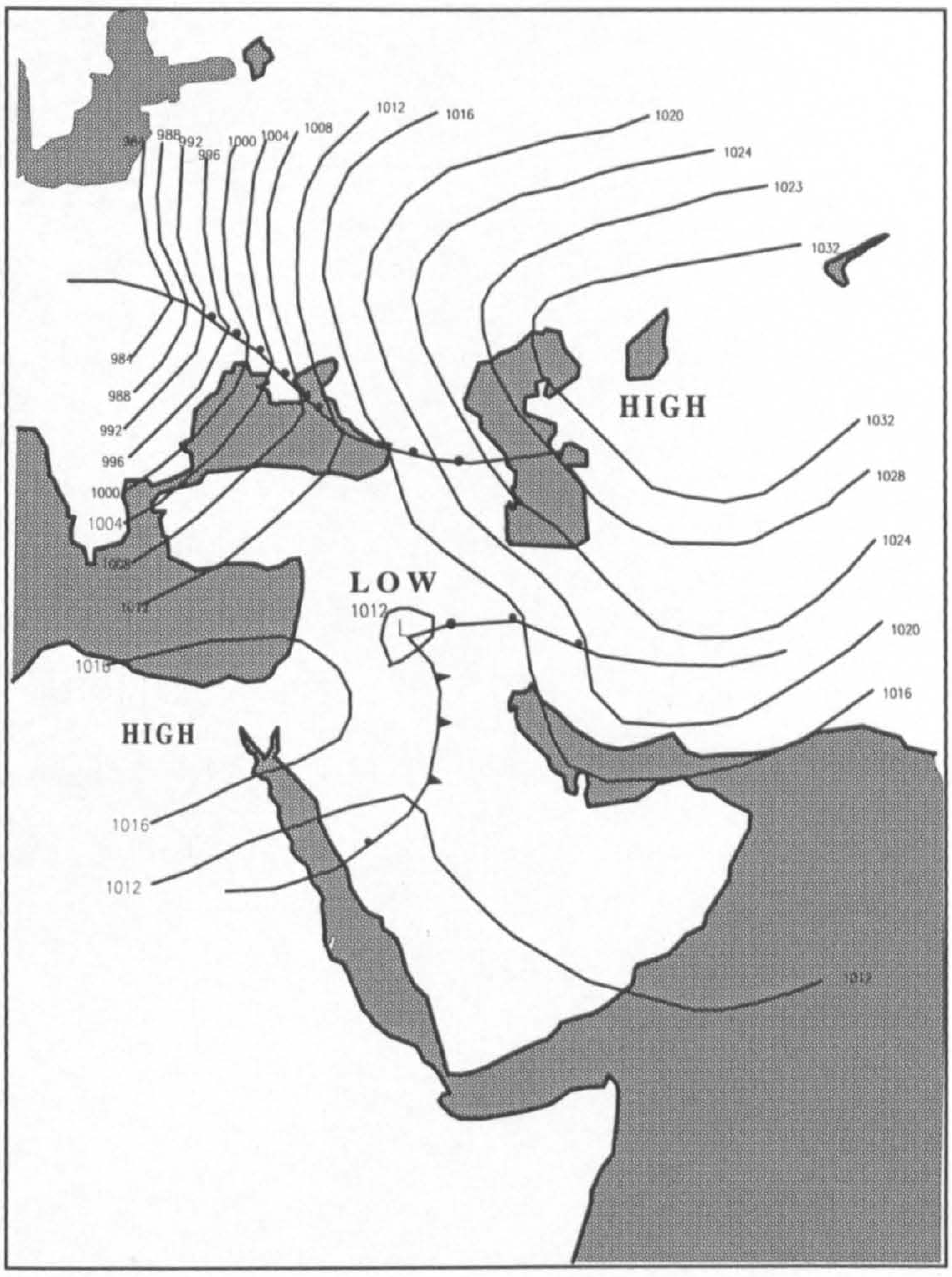
3.3 Seasonal variation

3.3.1 Weather condition during summer months

By the beginning of the summer period, in early July, the Subtropical high pressure disappears from southeast Asia, due to intensification of monsoon low pressure, which is centered over Northeast Indian, and extends towards the Arabian Peninsula (UAE climate 1996; Issa *et al.,* 1996; Al Baloushi 1998). The northeast wind, which is markedly stronger during the afternoon, and decreases during nighttime is known as Shamal winds (Ali, 1992).

These a low-pressure of 1000-1008 mb centered over the Indian Ocean, that is relatively high compared to the low pressure over the Arabian peninsula 994-1000 mb (Al Baloushi, 1998). These low pressures affect the winds causing movement from the Indian Ocean toward the Arabian Peninsula, which causes an increase in the average monthly humidity.

Fig 3.4 Map showing a northward moving tropical maritime air mass. At 15:00 local time December 2nd 1976 (Kholieb 1990).



In general during the summer period the northwesterly wind affects the western and southern parts of the Arabian Gulf with the exception of the area close to Musandam Peninsula.

Al Baloushi (1998) shows that there are two important phenomena, which are common during the summer period;

1. Diurnal circulation of sea/land breeze;

A- Land breeze from southeasterly to south occurs during nighttime with maximum wind speed of 2-4 ms^{-1}.

B- Sea breeze from northwesterly to west occurs during daytime particularly in the afternoon with maximum wind speed of 4-7 ms^{-1}.

2. Thunderstorms, particularly during the afternoon, cause two different weather conditions;

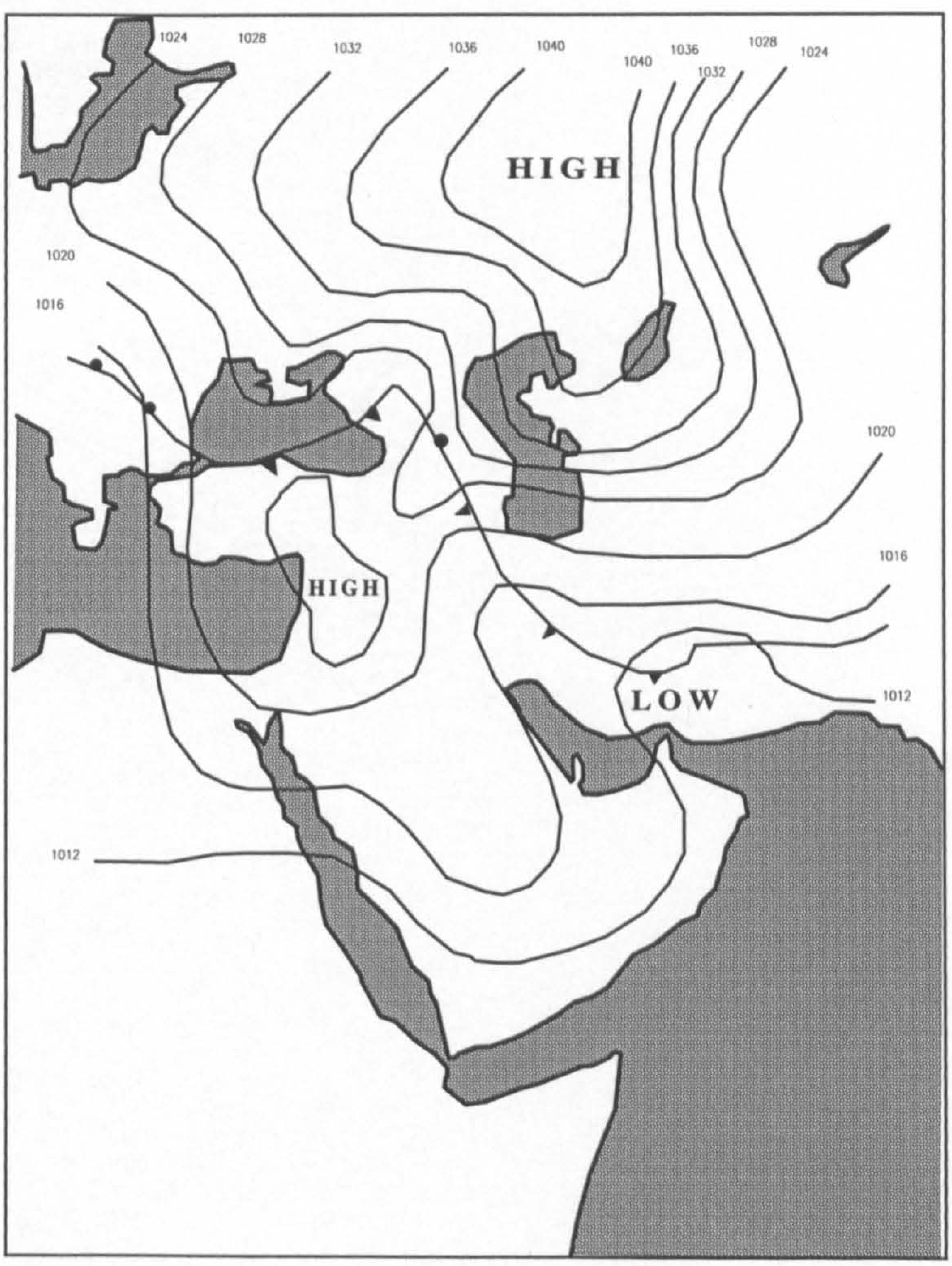
A- Heavy rains which affect Al Ain town the southeast of UAE, during July and August, due to the influence of topographic rain.

B- Sandstorms, which effects the visibility and increases the dust during summer days

3.3.2 Weather condition during winter months

During the winter period there is a low-pressure centred over the Arabian Gulf, due to the air over the sea being warmer than the air over the land (Kholieb 1990; Al Baloushi 1998; Bazuhair and Al-Gohani, 1997; Issa *et al.,* 1996). Therefore, the Arabian Peninsula is effected by two high-pressure. The Siberian high pressure intensifies over Pakistan and Iran, and heads toward the Arabian Peninsula. From the eastern Mediterranean area, the northwest winds break up and follow southeast, toward the Arabian Gulf.

Fig 3.5 Map showing continental polar cP, covers the Arabian Peninsula, at 15:00 local time February 15-1976 (Kholieb 1990)



Location of the UAE is close to the vast southwest Asia region, with its complex topographical features, this has a strong influence on the weather condition of the country (Al Baloushi 1998; Abu-Aleinein, 1996). Regions of large mountains; Zagros, Taurus and high land of Anatolia; act as a barrier to winds coming from the north, preventing the cold air reaching the Arabian Peninsula. Although the mountain regions located in the north of the Arabian Peninsula might suggest the blocking of the northern winds, they actually contribute towards weather conditions, by the anticlockwise movement of air around the mountain region. This causes fluctuations in the wind circulation during the winter period causing many local winds (Al Baloushi, 1998). These include:

1. Southeasterly winds, which are markedly hot and dry, known as the Al Kaus (UAE climate, 1996). This wind is associated with thunderstorms and sandstorms.
2. When high pressure occurs over eastern Europe, cold strong air blows over Saudi Arabia with a downstream trough over Iran, this cold air known as Al Shamal (Ali, 1996). A Shamal wind occurs 1-3 days per month, with maximum wind speed of 10 ms^{-1}.
3. Intensification of Siberian high pressure over Pakistan and Iran causes a north east wind to blow. This strong, cold and dry wind is known as Elnashi, and decreases the air temperature (Al Baloushi, 1998; Al Bayan Press, 1996).

3.4 The location of the Emirate of Dubai

The Emirate of Dubai emerged as a commercial centre at the beginning of the 19^{th} century. Dubai City is divided into two parts by Khor Dubai (Creek). Deira on the north side of the creek, while to the south is Bur Dubai. Dubai Creek crosses the city of Dubai and extends inland for a distance of 14 kilometres. Dubai Emirate covers an area of 3,986 km^2 (1,500 square miles). It is the second largest City of the seven emirate states of UAE, (Dubai past and present, 1997). It occupies 5% of the total area of the UAE. Dubai extends along the coast of the Arabian Gulf for 72 km (45 miles) and extends inland for a distance of 70 km (40 miles). The dimensions of Dubai City area are eight kilometres from north to south, and seven kilometres from east to west. The Arabian Gulf borders the west, the Emirate of Sharjah north and east, the Emirate of Abu Dhabi south. It occupies a long coastal belt that extends from the mountains in Oman to the Arabian Gulf.

3.4.1 Location of measurement sites in the Dubai city

The sites for measuring NO_2 levels in Dubai were selected to ensure a good spatial distribution throughout Dubai City and its surroundings (for more details see Fig 1.1 map A and B) . These sites include

- An open green area distant from the city centre.
- The edge of the city centre, next to the main transport routes to and from it.
- Inner city centre.
- Industrial areas.

3.4.2 An open green area distant from the city centre.

3.4.2.1 Mushrif National Park

Mushrif Park is located in Deira, to the southeast of the city centre, and it is closer to the desert which is outside the city than to the city centre. It is approximately 15 km away from the city centre. Most of Mushrif Park is covered with grass, and has thousands of trees. The whole area is 40 m above sea level. The site was chosen to be near the green area to avoid the extremes of temperature. The Park is hardly used by the public during the weekday, because of its distance from the city center. However, during the weekend (Thursday and Friday) it attracts many visitors, thus there are some local sources of NO_2.

Initially the chosen site was near palm trees and set in sandy land but was relocated due to the damage made by park visitors, and it is now relocated in more secure area.

3.4.2.2 Al Safa Park

Al Safa Park, which is a recreational park with marged lawns, extends $1^1/_2$ km away from the coastal line. This site is located in the Bur Dubai area, south of the city centre, and is surrounded by residential buildings on three sides, the north, the west and the south. However, to the east of Al Safa Park is the highway(Sheikh Zayed road). Beyond this is open land which stretches up to approximately 6 km, after which there is an industrial area (cement factory, heavy industrial area and electric transformer station).

The initial site was located inside the bird reserve, on grassland. However due to the damage from the visitors this has been relocated near to a residential area, outside one of the houses. The new site is 0.5 km away from the first location, and it is outside the Al Safa Park.

3.4.3 The edge of the city centre, next to the main transport routes

3.4.3.1 Bu Kidrah roundabout

This roundabout, in the south west of the city, can be found at the intersection of the Oud Metha road to the north, Al Ain road to the south, road 309 to the north west and Ras Al Khor road east. It links the Dubai Emirate with Al Ain City. This roundabout was chosen because it is particularly busy at the beginning of the weekday between 06:00 and 09:00 a.m. local time, with heavy lorries and cars as well as at the start of the weekend when employees return to their own emirates.

3.4.3.2 Al Nahda roundabout

This roundabout is situated in the northern part of Dubai Emirate. It links Dubai Emirate with Sharjah Emirate and is the intersection of the Al Wuheida road west, Al Qusais road east, and Al Ittihad road north and south. There is a tunnel which runs under the roundabout and links the Emirate of Dubai to the Emirate of Sharjah. Buildings of different heights surround the area. The highest building is Al Mullah plaza, which is approximately 20 metres high and is located east of the roundabout. The site is located on the green area surrounding the roundabout itself.

3.4.3.3 The Golf Club

The site is located close on 250 km a long the Sheikh Zayed Road which lies to the south of the city centre and links Dubai Emirate to Abu Dhabi Emirate via the coast zone. The road separates two types of area: residential areas to the west (Al Wasal, Jumera, Al Satwa and Umm Suqeim) and industrial areas to the east (Za beel and Al Quaz). There is a petrol station which just 6 m away from the site.

3.4.4 Inner City Area

3.4.4.1 Umm Ahureir roundabout

This roundabout, to the west of the city centre in the Bur Dubai area, was selected according to the Road Department of the Dubai municipality in (1995) because it has the lowest average traffic density of all the busy roads in Dubai (69,873 cars per week). The roundabout is surrounded by the following: an undeveloped area to the east, opposite the Dubai Creek bank, embassy complexes situated to the north west and school complexes to the west.

The roundabout is the intersection of the Al Seef road to the northwest, Tareq Iban Zeyad road to the east, Khalid Iban Al Waleed road to the west, and Za beel road to the south. The diameter of the roundabout is 8.8 metres. The site is located in the central reservation of the Za beel road. It was chosen to represent the crowded roads in Bur Dubai.

3.4.4.2 The Fish roundabout

This roundabout is situated in Deira, east of the city centre. The area is busy with traffic, particularly during rush hours. The roundabout is surrounded by different buildings: the Al Maktum Hospital, the Sea Rock Hotel and Royal Crystal Hotel to the west, Claridge Hotel (roughly 6 - 7 storeys high) to the east.

It is at the intersection with the Umer Iban Khattab road, which extends from the northwest to the south east, the Al Maktoum road west and Salah Al Din road to the east. This roundabout has the highest average traffic density of all roads in Dubai (84,574 cars per week) as recorded by the Road Department of Dubai municipality in 1995. The site is located in the centre of the roundabout, near a tree.

3.4.4.3 Dubai Municipality (Environment department office)

This area is in the east of Deira. The site is located on an open area near the municipality building. The location has two sampling sites one north facing the other south facing. The latter site was chosen to ascertain if the temperature difference of the tubes caused any variation. In addition, the sampling site is close to the Dubai municipality gas monitoring equipment for comparison.

3.4.4.4 Dubai International Airport

This is located four kilometres to the east of Dubai city centre. The initial site of the sample was located between the landing and takeoff area. However, due to rebuilding works, the site of the sample was relocated on the airport periphery, near to the Dubai royal family's private gate.

3.4.5 Industrial areas

3.4.5.1 Dubai Municipality (at Jebel Ali free zone)

The Dubai Municipality building is near the Jebel Ali free zone. It is a small building with a yard, about eight metres long. The site is located in the back yard of Dubai municipality building. The area to the north of Dubai municipality contains many chemical factories and companies, e.g. Dubai Natural Gas Liquefaction (DUGAS), and Dubai Aluminum Co Ltd (DUBAL), as well as the power station which supplies the whole Dubai Emirate with electricity using natural gas. The area is near to the coastline, about 0.75 kilometres away.

3.4.5.2 Jebel Ali village

The Jebel Ali village stands on a small hill, seven metres above the sea level, beyond the Arabian Gulf. To the north of the Jebel Ali village there is the power station and DUBAL. The Jebel Ali industrial area is located two km away from the village. The site is located near the main gate of Jebel Ali village on sandy land. This location was chosen to ascertain if there is any high pollution levels which might be influenced by the industrial area.

3.5 Meteorological data from Dubai International Airport

Hourly averages of various meteorological parameters e.g. wind direction wind speed, temperature and relative humidity were obtained from the Meteorological Office of Dubai International Airport (Annual report of Climatological information from, 1995 to 1997). Wind direction and wind speed were used to present sea breeze circulation patterns, based on seasonal variation between summer and winter months for the years 1996 and 1997.

Weather charts from the Meteorological Office of Abu Dhabi were used to examine the synoptic weather during selected days of the sea breezes. The pattern of wind direction were illustrated by using two different types of charts; the first type is the hodograph, which is based on the hourly data of wind direction and the hourly data of wind speed plotted together during 24 hours, obtained from the Meteorological Office of Dubai International Airport. The second type were time series, based on two different sources of data wind direction and wind speed from Dubai Airport and Jebel Ali port, plotted together. Both Figures showed it is more reliable to use the data from Dubai International Airport.

Therefore, wind direction data, which were used in this study, were recorded from the Meteorological Office of Dubai International Airport, which is a professional station. However, the Jebel Ali port station is a small and mobile station located near the Jebel Ali free zone, which basically belongs to Dubai municipality for air quality purposes.

Finally, the local time of UAE was used, the local time being four hours ahead of GMT. However, the GMT time was used for the Meteorological Office at Dubai Airport. Within this study all the data were adjusted to local time instead of GMT.

3.6 Choosing the day types of sea breeze

The different patterns of sea breeze were classified by the diurnal variation of wind direction in the Dubai Emirates. Wind speed was also examined to show how far wind speed variations, were associated with change in wind direction.

The variability of the flow characteristics during years 1996 and 1997 was classified into four types of wind direction patterns.

A. Days of summer sea breeze

B. Days of winter sea breeze

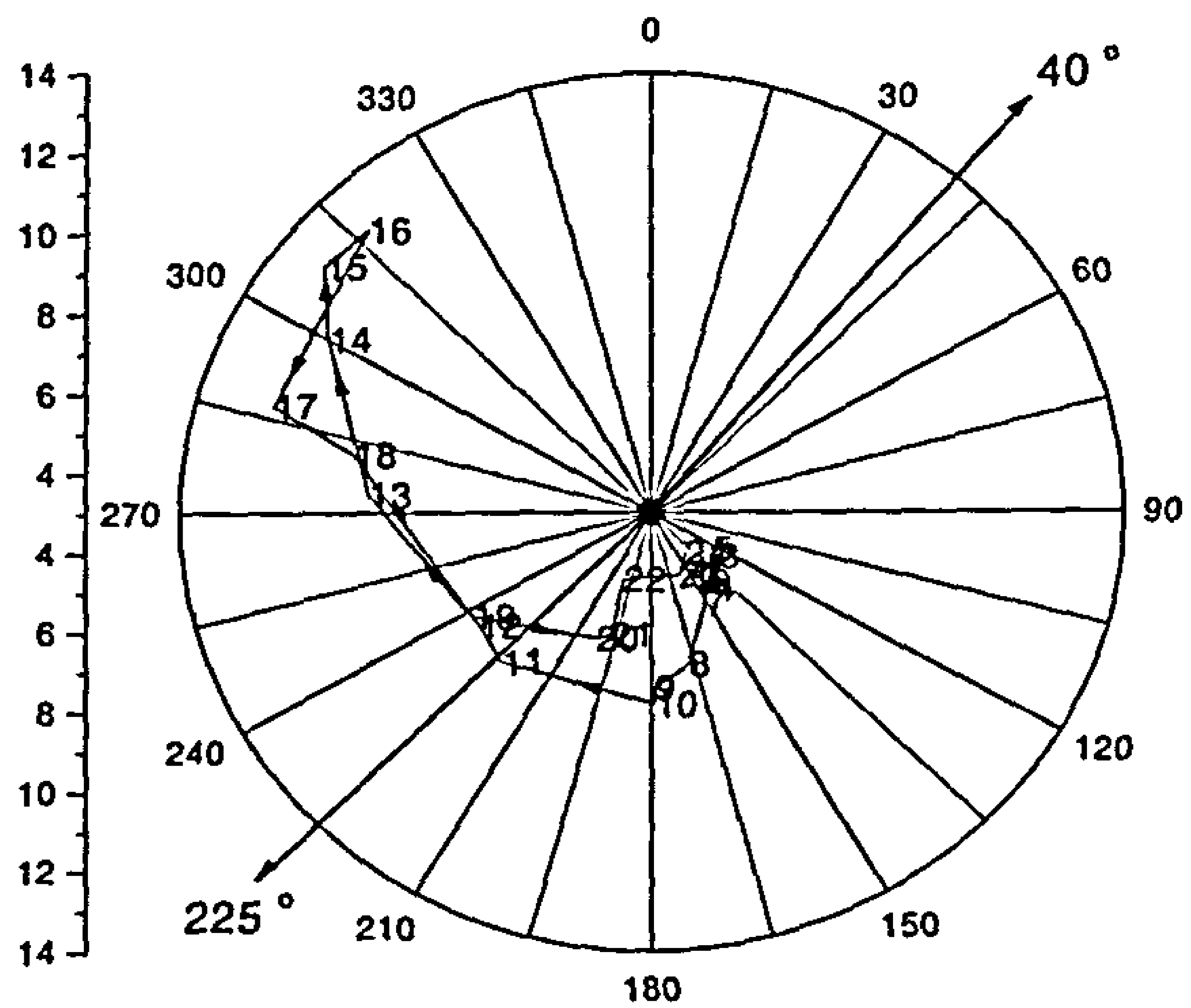
C. Days of no sea breeze with predominantly southeasterly winds over land

D. Days of no sea breeze with predominantly northwesterly winds over sea.

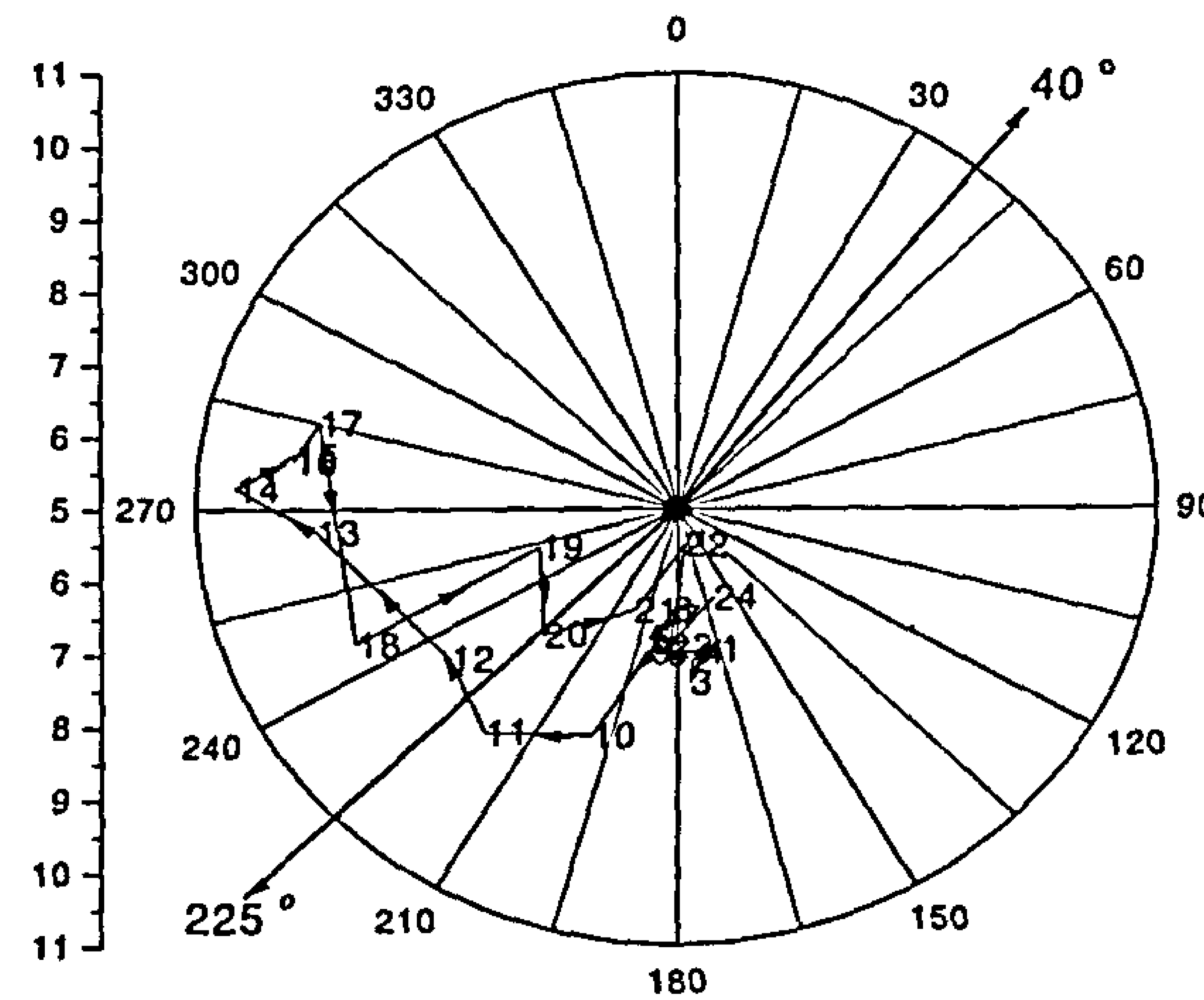
A quantification of these categories was carried out on the basis of observed wind direction at Dubai airport and Jebel Ali station.

Figure 3.1 shows the hodographs of the four different wind direction patterns. According to Simpson (1994), a useful way of presenting measurements of the sea breeze is to use a wind hodograph traced by the end point of the wind vector as its value changes with time. Hodographs show at any given locality, a complete turn of sea breeze circulation during the day, particularly when the gradient wind is weak Figure 3.1 was constructed to give a general overview of those days; more details will be given separately for each categories of wind pattern with a separate hodograph in the sections below.

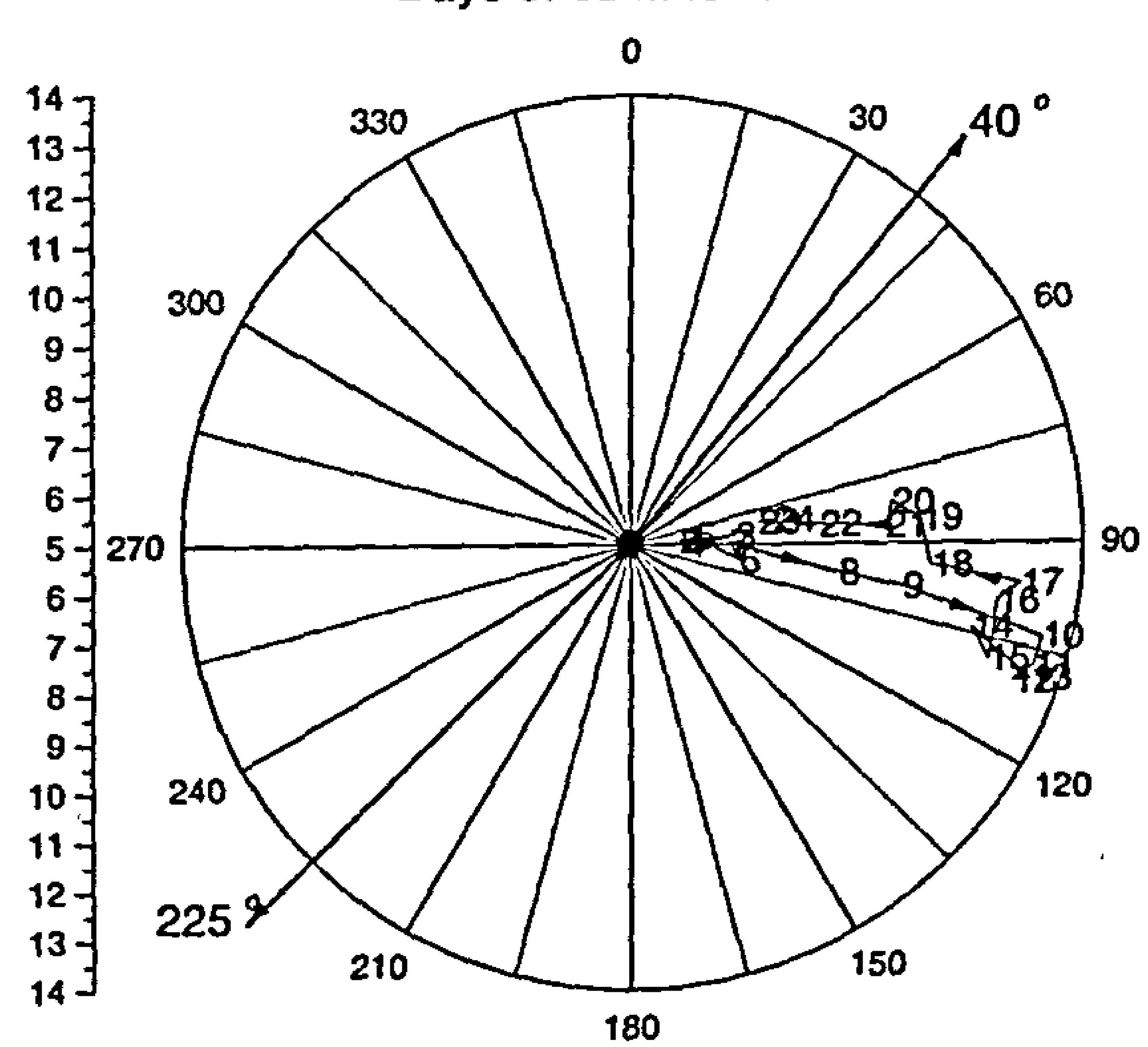
Fig 3.6 Hodogrphs of different day types of Wind pattern



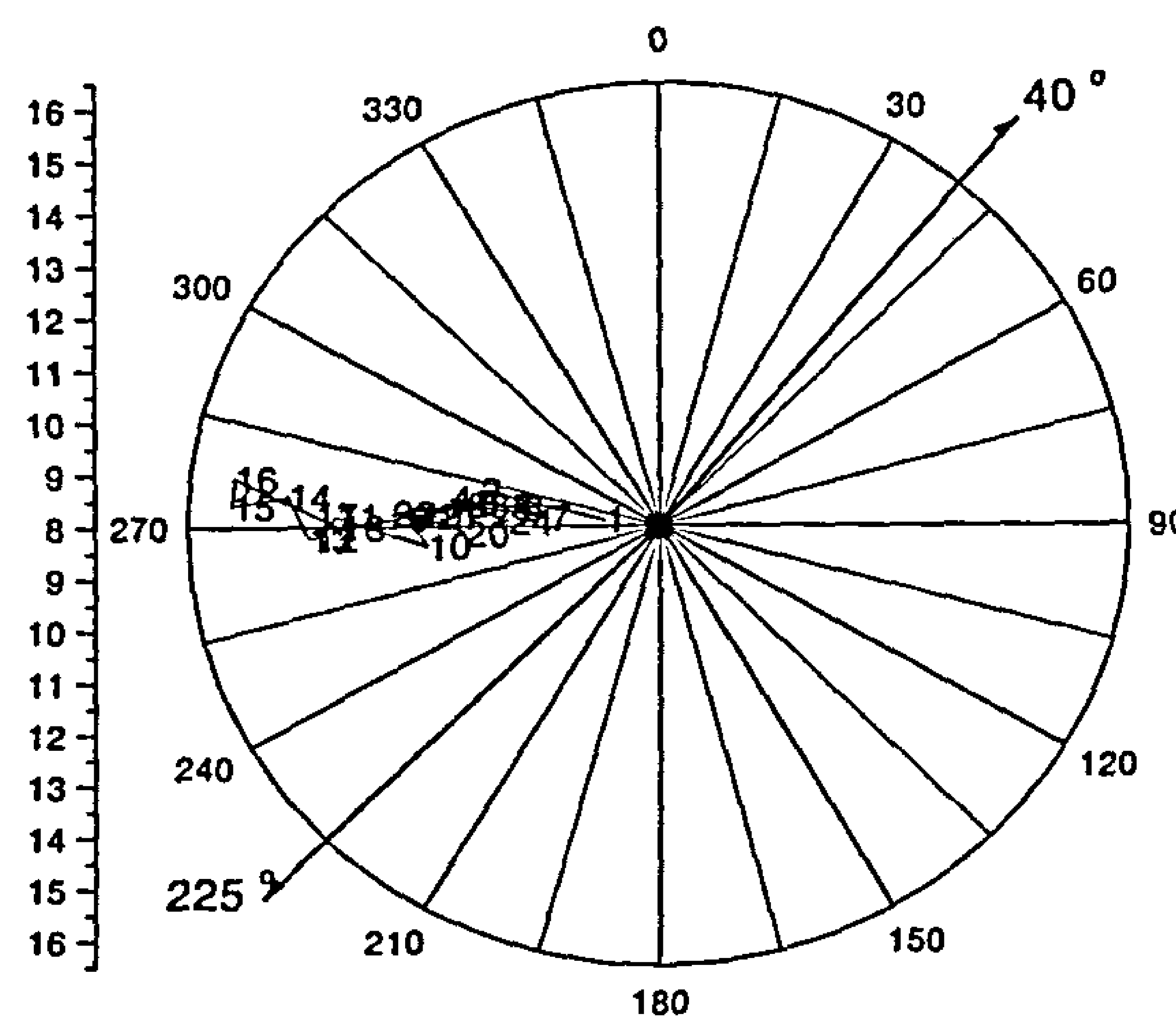
Days of summer sea breeze **a**



Days of winter sea breeze **b**



Days of no sea breeze with southeasterly winds over land **c**



Days of no sea breeze with northwesterly winds over sea **d**

3.6.1 Synoptic observation for days of summer sea breeze

The summer period of UAE extends from June to September. During this long period the diurnal circulation of the sea/land breeze occurs almost every day, due to the difference in temperature between the air over the land and the air over the Arabian Gulf.

The average air temperatures ranged from 30 to 39°C, while the average relative humidity ranged from 40 to 67 %. (For more details see Table 3.1)

Table 3.1 Hourly averages of temperatures, relative humidity, wind direction, wind speed and vapour pressure during summer sea breeze.

HOURS	TEMEPPERATURE °C	VAPOUR. P mb	RELATIVE. H %	WIND DIRECTION deg °	WIND SPEED Knots
1	31.8	29.4	63	151	5
2	31.2	28.9	64	151	5
3	30.9	28.6	64	123	5
4	30.4	28.4	66	139	6
5	30.3	28.5	66	105	5
6	30.3	28.5	67	128	5
7	31.1	28.3	65	136	5
8	32.9	27.9	58	155	6
9	34.9	27.6	52	168	7
10	36.7	26.8	46	171	8
11	38.1	24.8	40	213	8
12	38.5	25.3	40	225	7
13	38.3	28.9	44	275	10
14	37.6	28.8	47	304	12
15	37.0	30.1	49	315	13
16	36.4	31.2	52	324	14
17	35.6	30.3	53	288	13
18	35.1	31.3	57	279	10
19	34.6	30.7	57	229	8
20	34.6	29.4	54	198	6
21	34.4	29.1	55	182	6
22	33.7	29.2	56	207	5
23	33.3	29.3	58	169	4
24	32.6	29.1	60	149	4

3.6.1.1 Wind direction and wind speed during days of summer sea breeze

The summer sea breeze circulations were based on the diurnal variation of wind direction and wind speed. Subsequently, 18 days of summer sea breeze were carefully selected from the 1996 and 1997 data to represent the rapid development of summer sea breeze circulation.

Figure 3.6 Hodograph A, shows summer sea breeze circulation. As can be seen from the hodograph, in the early morning before sunrise the wind pattern over Dubai is still dominated by weak south-easterly wind between 90° and 150°, with low wind speeds ~3 knots. 2 to 2 ½ hours sunrise, as the air becomes warmer, the wind speed rapidly increases from 3 to 5 knots, approximately around 8:00 local time. Between 09:00 and 11:00 local time a clear change of wind direction appears, as the winds start to veer from southerly to westerly 180°–225° from the land to the Arabian Gulf. Wind speeds also increase rapidly during this time. The fullest development of the sea breeze was observed between 14:00 and 16:00 local time, as the wind direction veered between 300°- 330° northwesterly, which was also associated with maximum wind speed of 10-14 knots. During the late afternoon and night time the wind direction was observed to back from westerly to southeasterly 320°- 150° between 15:00 and 23:00 local time. The speeds decreased rapidly from 14 to 2 knots associated with wind direction changes from the Arabian Gulf to the land.

3.6.2 Synoptic observation for days of winter sea breeze

During the winter period which includes the three months of December, January and February, the period of day-hours was shorter by one hour than in the summer, because the sunrise and sunset occurs between 5:00 and 18:00 local time. The weather conditions are presented in Table 3.2, the average of air temperatures ranged from 16°C to 23°C, while the averages of the relative humidity ranged from 54% to 82%.

Table 3.2 Hourly averages of temperatures, relative humidity, wind direction, wind speed and vapour pressure during days of winter sea breeze

HOURS	TEMEPPERATURE °C	VAPOUR. P mb	RELATIVE. H %	WIND DIRECTION deg °	WIND SPEED Knots
1	18.1	15.1	74	165	7
2	17.8	15.3	76	175	7
3	17.2	15.1	77	176	7
4	17.1	15.1	77	171	7
5	16.7	15.1	78	184	7
6	16.4	15.1	81	191	7
7	16.5	15.1	81	179	7
8	16.4	15.3	82	183	6
9	17.7	16.3	80	190	7
10	19.7	16.4	72	199	8
11	21.2	16.7	67	218	9
12	22.3	17.1	64	234	9
13	22.8	16.1	58	266	10
14	22.8	17.1	56	273	11
15	22.9	15.1	54	279	10
16	22.8	16.1	56	278	10
17	22.2	16.1	59	285	10
18	21.6	16.1	63	245	9
19	21.1	16.1	65	253	7
20	20.2	16.2	68	224	7
21	19.8	16.1	70	201	7
22	18.7	15.6	72	170	6
23	18.3	15.1	71	183	7
24	17.8	15.1	73	160	6

3.6.2.1 Wind direction and wind speed during days of winter sea breeze

Measurements of winter sea breeze circulations were based on the diurnal variation of wind direction and wind speed during winter months. Eight days of winter sea breeze were carefully selected from the 1996 and 1997 data, to represent the rapid development of winter sea breeze circulation.

Figure 3.6 Hodograph B, shows winter sea breeze circulations. During the early morning before sunrise the wind pattern over Dubai is still dominated by southerly winds 180°, with speeds of 7 knots. Between 09:00 and 10:00 local time the wind direction starts to change, and the wind speeds increase. The southerly wind veers to southwesterly between 180° and 210°. The wind speed rapidly increases to 8 knots, as the air warms over land and sea breeze circulation starts. During the daytime, between 10:00 and 12:00 local time the winds veer from southerly to westerly 180°–225° over the Arabian Gulf. The fully developed winter sea breeze circulations are associated with westerly winds between 14:00 and 17:00 local time, and wind speeds are observed of between 10 and 11 knots. During late afternoon the winds continue to back from the Arabian Gulf to the land westerly to southeasterly 270° to 150° between 17:00 and 20:00 local time, until the following morning, when the prevailing wind direction is southerly.

3.6.3. Synoptic observation for days of no sea breeze with predominantly southeasterly winds

The day types of no sea breeze with predominantly southeasterly winds are based on the absence of diurnal variations of wind direction between the land and the sea, and a total of 14 days were selected from the 1996 and 1997 data, to represent this type. During days of no sea breeze with the predominantly southeasterly wind blowing from the land, the average of air temperature ranged from 20°C to 29°C. The relative humidity ranged from 40 % to 67%. (For more details see Table 3.3)

Table 3.3. Hourly averages of temperatures, relative humidity, wind direction, wind speed and vapour pressure during no sea breeze with predominant southeasterly winds over land

HOURS	TEMEPPERATURE °C	VAPOUR. P mb	RELATIVE. H %	WIND DIRECTION deg °	WIND SPEED Knots
1	21.1	17.4	66	85	6
2	20.5	17.1	66	86	6
3	20.5	16.6	65	85	7
4	20.4	16.5	66	90	6
5	20.3	16.8	67	82	6
6	20.3	16.6	66	98	7
7	20.3	16.5	66	89	7
8	21.6	16.3	61	98	9
9	23.6	16.2	54	99	11
10	25.4	15.6	48	103	13
11	26.5	15.3	43	107	13
12	27.7	15.1	39	110	13
13	28.4	15.1	37	109	13
14	28.7	14.7	37	104	12
15	28.7	14.7	37	108	13
16	28.2	15.3	40	99	12
17	27.6	15.6	42	96	13
18	26.2	15.6	45	94	11
19	25.1	15.6	48	85	11
20	24.1	16.9	55	81	10
21	23.2	16.8	57	86	10
22	22.4	17.1	60	84	9
23	22.1	17.2	62	80	8
24	21.6	17.2	63	80	8

3.6.3.1 Wind direction and wind speed during days of no sea breeze with predominantly southeasterly winds

Figure 3.6 Hodograph C, shows days of no sea breeze with the predominantly southeasterly wind blowing from the land.

As can be seen from Figure 3.6 hodograph C the southeasterly winds were predominant between 80° and 100° during days of no sea breeze. Wind speeds varied between daytime and nighttime. During daytime the wind speed increased to reach the maximum of 13 knots between 10:00 and 15:00 local time. While the minimum wind speed ranged between 6 and 8 knots occurred during early morning hours and evening hours.

3.6.4 Synoptic observation for days of no sea breeze with predominantly northwesterly winds

The day types of no sea breeze with the predominantly northwesterly winds from the Arabian Gulf was based on the absence of diurnal variations of wind direction between the land and the sea. Six days were selected from the 1996 and 1997 data. The average air temperatures ranged between 22°C and 24°C, while the average relative humidity ranged between 49% and 67%. (For more details see Table 3.4) There was a similarity between the weather conditions during this wind pattern and days of winter sea breeze. However, the wind speed is faster for this group.

Table 3.4. Hourly averages of temperatures, relative humidity, wind direction, wind speed and vapour pressure during days of no sea breeze with the predominantly northwesterly winds

HOURS	TEMEPPERATURE °C	VAPOUR. P mb	RELATIVE. H %	WIND DIRECTION deg °	WIND SPEED Knots
1	22.5	17.7	65	277	9
2	22.5	17.8	65	282	11
3	22.4	18.3	67	278	11
4	22.2	17.9	66	278	12
5	22.1	17.6	66	278	11
6	21.8	17.6	67	278	11
7	21.7	16.9	64	275	10
8	22.3	16.9	62	277	12
9	22.8	16.6	59	272	13
10	23.3	16.1	56	265	12
11	23.6	16.1	55	272	14
12	24.0	16.2	54	268	14
13	23.9	15.8	53	268	14
14	24.1	15.9	53	275	15
15	24.1	14.7	48	273	16
16	23.6	14.8	50	277	16
17	23.3	14.4	50	272	14
18	22.6	14.8	53	270	14
19	22.4	14.8	54	273	12
20	22.2	15.2	56	268	12
21	22.0	15.1	57	273	12
22	22.0	14.5	54	273	13
23	21.7	14.7	56	277	12
24	21.6	15.5	59	272	11

3.6.4.1 Wind direction and wind speed during days of no sea breeze with predominantly northwesterly winds

Figure 3.6 Hodograph D, shows days of no sea breeze with predominantly northwesterly wind blowing from the Arabian Gulf.

As can be seen from figure 3.6 hodograph D it can be seen the wind is constantly blowing from the north-west between 330° and 320°. at the same time, the wind speed was varying throgh the 24 hours period, with the maximum speed observed during the daytime with an average of 20 knots.

Summary;

The different meteorological parameters were used to describe sea breeze circulation patterns. Wind direction and wind speed from Dubai International Airport and Jebel Ali station were the main parameters used to select the four types of wind pattern and days of sea breezes. The hodograph is useful way to show the circulation of the sea breeze. The days of summer sea breeze and days of winter sea breeze both show a strong diurnal circulation, while the two other days of northwesterly winds and southeasterly winds showed an absence of sea breeze circulations. The days of no sea breeze with predominantly northwesterly winds showed markedly faster wind speeds during the daytime and nighttime than any other types of wind pattern categories. However, the wind speed during other categories of wind pattern was varied.

3.7 Analysis of the monitoring data

A comparison of emissions and concentrations of primary pollutants provides a method for establishing the relative importance of atmospheric processes, which modify the local concentration. Dubai municipality Office of the Environment is one of the environmental departments in UAE which specialise in air pollution. The Dubai air quality-monitoring network (AQMN) was set up during the year 1992-1993. The AQMN provides information on the air quality and has established and maintains a database for future air quality planning and control. This is an important activity given the Dubai Emirates rapid development with factories, such as motor vehicles and power generating plants, which emit pollutants into the atmosphere. The primary and secondary pollutants which are measured, such as NO_2, O_3, CO, SO_2, MHCs, NMHC, dust, PM_{10}, UV-A Radiation, UV-B Radiation and lead, were observed within the limit of air quality standard.
The annual report of the Dubai municipality Office of the Environment refers to the high levels of O_3 concentrations during the long period of summertime at Jebel Ali station, Mushrif and Deira. During winter months the levels of NO_2 concentrations were observed to be higher than during summertime.

At the same time, and according to the latest annual report of Dubai municipality Office of the Environment for year 1998, the numbers of pollution days increased from 11 days during 1997 to 20 days during 1998, in particularly for O_3 levels at Deira, Mushrif and Jebel Ali stations.

3.7.1 Overview of the Air Quality Measurement Data from AQMN

The following analysis is based upon the results obtained by the monitoring stations of the by Dubai Municipality and published in their Annual Reports (1993-1998) which cite 15 minutes, hourly and monthly averages. Annual averages have been calculated from these figures. Concentrations in the air of several pollutants are highly variable with respect to time and location. High population areas and industrial areas were selected to obtain the air quality-monitoring network AQMN.

Since 1992 the air quality program was developed to measure the most important pollutants in Dubai City, and it started with three stations measuring continuous air quality. However, not all the stations operated continuously and also not all the pollutants are monitored at every monitoring station in Dubai City.

1. Sulphur dioxide

Emission of SO_2 are emitted to the atmosphere from various sources. The concentrations of SO_2 were measured at four stations, Deira, Al Safa, Jebel Ali village and Jebel Ali Port. The standard value of 0.130 ppm is the average of one-hour. Table 3.5 showed the standard SO_2 values and concentrations from Dubai municipality.

Table 3.5 The concentrations of SO_2 at different stations

Standard of SO_2	DEIRA		AL SAFA		JEBEL ALI PORT		JEBEL ALI VILLAGE	
0.130 ppm	1996	1997	1996	1997	1996	1997	1996	1997
Average of one-hour	0.010	0.010	0.008	0.008	0.137	0.146	0.014	0.018

The annual concentration average at Deira station was 0.010 ppm during 1996 and 1997, while at Al Safa station the concentration was 0.008 ppm during 1996 and 1997. At Jebel Ali village station the concentrations ranged between 0.014 ppm during 1996 and 0.018 ppm during 1997. The annual concentration average at Jebel Ali port ranged between 0.137 ppm during 1996 and 0.146 ppm during 1997.

The monitoring sites at Deira, Al Safa and Jebel Ali village were affected by mobile sources (Annual report 1997) such as traffic. The concentration of SO_2 at Jebel Ali village is greater than Deira and al Safa stations, at the same time, this station is located only 4 km away from a gas refinery. Jebel Ali Port station is the only station where the SO_2 concentration was found to exceed the standard value, probably due to its location proximity to the gas refinery.

2. Carbon monoxide

Monitoring sites were set up during 1993 at Deira and Al Safa stations, with the standard value for the maximum of one-hour average of 20 ppm. AQMN refers to the fact that motor vehicles were the main source for CO emission. Table 3.6 showed the standard CO values and concentrations from Dubai municipality.

Table 3.6 The concentration of CO at Deira and Al Safa station.

Standard of CO	DEIRA		AL SAFA	
20 ppm	1996	1997	1996	1997
Average of one-hour	5.46	5.37	3.33	3.29

The annual average concentrations at Deira and Al Safa stations were found to be extremely low. The concentrations ranged between 5.5 ppm during 1996 and 5.4

ppm during 1997 at Deira stations, while at Al Safa stations the concentrations ranged between 3.3 ppm during 1996 and 3.3 ppm during 1997.

3. Nitrogen dioxide

The two stations at Deira and Jebel Ali Village have monitored NO_2 since 1993, with two NO_2 Standards, the maximum of one-hour average of 0.150 ppm, and the maximum of 24 hour average of 0.060 ppm. Table 3.7 showed the standard NO_2 values and concentrations from Dubai municipality.

Table 3.7 The concentration of NO_2 at Deira and Jebel Ali village

Standards of NO_2		**DEIRA**		**JEBEL ALI VILLAGE**	
0.150 ppm	**0.060 ppm**	**1996**	**1997**	**1996**	**1997**
Average of one-hour	**Average of 24 hours**	**0.017**	**0.034**	**0.037**	**0.013**

The annual average NO_2 concentration was higher at Deira station than Jebel Ali village. At Deira station the concentrations ranged between 0.017 ppm during 1996 to 0.034 ppm during 1997, while at Jebel Ali village the concentrations ranged between 0.037 ppm during 1996 to 0.013 ppm during 1997. At Al Safa station new monitoring of NO_2 concentration started during August of 1997. The average highest concentration of 0.045 ppm was observed at Al Safa station during August 1997.

4. Ozone

The concentrations of O_3 were measured at four stations, Deira, Mushrif, Al Safa, and Jebel Ali village. The source of O_3 in the Emirate of Dubai and particularly close to coastal zone could be locally emitted from cars or industrial activity, or regional, which might be transported to the Dubai area by the winds. Table 3.8 showed the standard O_3 values and concentrations from Dubai municipality.

Table 3.8 The concentrations of O_3 at the four difference stations

Standard of O_3	DEIRA		MUSHRIF		AL SAFA		JEBEL ALI VILLAGE	
0.080 ppm	1996	1997	1996	1997	1996	1997	1996	1997
Average of one-hour	0.100	0.099	0.094	0.012	0.074	0.080	0.014	0.117

The concentration of 0.080 ppm is the standard values of one-hour average of O_3 concentration in Dubai. According to (Municipality Annual report 1996 and 1997), during the summer period, when the maximum air temperature reaches 44.9°C, only did Al Safa station record 0.074 ppm during 1996, and 0.080 ppm during 1997, which are within the hourly average values of O_3. At the same time Deira, Mushrif and Jebel Ali village stations did exceed the hourly average of O_3 concentration. During 1996 the concentration of O_3 were 0.100 ppm at Deira station, 0.094 ppm at Mushrif station. At Jebel Ali port station measuring of O_3 only started in October of 1996. Nevertheless it is still higher when compared with other station measurements. During year 1997 the concentration of O_3 were 0.099 ppm at Deira station, 0.012 ppm at Mushrif station and 0.117 ppm at Jebel Ali station.

Chapter Four

General Chemistry and Measurement of Gases and Air Pollutants

4.1 Introduction

The subject of pollution in the atmosphere has aroused great interest recently, especially in understanding the chemical behaviour and the concentration of gases in the atmosphere.

This chapter reviews the general chemistry of the primary pollutant NO_2 and secondary pollutant O_3. It starts by reviewing the early studies of measurement of nitrogen dioxide. After that it discusses the validity of using diffusion tubes at both urban and rural sites. The details of nitrogen dioxide formation and sinks are discussed. Then it illustrates the seasonal and spatial variation of NO_2. Next the details of the secondary ozone pollutants are given. Chapter 4 will end by reviewing the processes O_3 the formation and destruction.

4.2 Review of NO_2 measurement

The concentrations of NO_2 and O_3 have been measured at many network sites throughout Britain, European countries, and North America. Palmes *et al.* (1976) pioneered the personal passive sampler to measure the level of nitrogen dioxide indoors. This is based on measurement of the quality of the air by using small tubes and is dependent on molecular diffusion of NO_2 in air. In the measurement of nitrogen dioxide (NO_2) many authors have used the above method. These include indoor measurement of the levels of nitrogen dioxide in homes using gas and electric cookers (Palmes *et al.*, 1976; Atkins *et al.*, 1978; Girman *et al.*, 1983) and outdoor measurements (Atkins *et al.*, 1986; Gair *et al.*, 1991; Amann, 1990).

In many of these studies, the researchers have investigated and developed diffusion tubes for indoor measurements, and estimated the performance of passive diffusion tube samplers for outdoor measurement (Atkins *et al.*, 1986; Miller, 1988; Girman *et al.*, 1983). The most important conclusions from these studies are described in the following section.

4.2.1 Validation of the diffusion tube

Apling *et al.* (1978) made an early study using diffusion tubes to compare the result of air pollution instruments in three homes. This work was carried out by the Warren Spring Laboratory (WSL). Original studies were undertaken using instrumental monitoring for carbon monoxide (CO), nitric oxide (NO) and nitrogen dioxide (NO_2). The advantage of instrumental monitoring over the diffusion tubes is the ability to detect short-term peak concentrations and immediately give the results of measurement. But, the disadvantages are it is expensive, physically bulky, and there is visual and noise intrusion.

The results showed that there was good agreement between the diffusion tubes and instrumental monitoring, and demonstrated the validity of the diffusion tube method under varied practical exposure conditions Glasius *et al.* (1999) The estimate was accurate to about 10% when used in a normal domestic environment.

Atkins *et al.* (1986) carried out initial studies to investigate outdoor NO_2 pollution by using diffusion tubes. A comparison of diffusion tube and chemiluminescent monitor NO_2 measurements for a period of one week were made. The results achieved good accuracy for the samplers in both rural sites where NO_2 concentrations rarely exceed 30 ppb and at urban sites in central London where the concentrations are higher. The precision was generally good with coefficients of variation between 5% and 8% for average NO_2 of > 5 ppb. At the same time, in the case of the lower concentrations, the precision was a predictably poor 50%. They suggested that the precision of lower concentrations could probably be improved by using longer sampling periods. Miller (1988) and Gair *et al.* (1991) have recommended the use of chromatography to increase the sensitivity of the sample analysis for tubes exposed in very low concentration areas.

Summary;

The above studies refer to successful use of diffusion tubes and estimate the performance of passive sampling for indoor and outdoor measurement. The results of the above studies also have found good agreement between passive diffusion tube and instrumental monitoring to measure NO_2 concentration.

4.3 Nitrogen dioxide measurement in urban areas

Since 1986 the researchers have examined and estimated the significance of nitrogen dioxide NO_2 as a pollutant affecting human health in urban and rural areas in both hot and cold regions. Lyons *et al.* (1990) carried out measurements in Perth, Western Australia, and found that the air pollution and urban structure are linked directly through the way that vehicles are driven. This is mainly when CO and NO_x increases in emission rate are particularly caused by changes in speed and acceleration. Bower *et al.* (1991a) pointed out that the temporal variation of NO_2 concentration in Greater London was substantially lower than NO at all times. The main source of NO is the traffic, especially during the morning rush hours. Laxen and Noordally (1987) found the same results in a canyon street in London.

Bower *et al.* (1991b) performed experiments in two types of urban areas. The first area was affected by motor vehicles, i.e. central London, Manchester and Glasgow, whilst the second area investigated was affected by industrial pollution, i.e. Billingham and Walsall. They found that the NO_2 concentrations in London are 50-60% higher than the corresponding levels for the country as a whole, which are related to the high traffic density, as the major source of NO_2. Also the concentrations of NO_2 were found to be higher in winter than summer. Finally, they pointed out that there is not a high correlation between NO_2 and SO_2. Campbell *et al.* (1994) carried out a survey throughout the UK, and found that vehicle density accounts for about half of NO_x emission. Also found that the meteorological conditions, such as strong westerly winds, appear to have contributed to overall NO_2 concentration. Williams *et al.* (1988) undertook investigations simultaneously at the Central London Laboratory in Victoria and a kerbside site on the Cromwell Road and compared the results. They pointed out that the frequency distributions of NO and NO_2 are log-normal, and that the temporal and spatial variation of NO was higher than for NO_2 concentrations. They also found that the annual average ratio for NO_2 /NO_x showed a non-linear relationship in urban and suburban areas particularly when there was a high annual average concentration of $NO_x \geq 30$ ppb.

In urban areas most of this work has been carried out in temperate climates. However, a few investigations of nitrogen dioxide concentration in urban areas have been carried out recently in hot regions, such as the state of Bahrain (Danish and Madany, 1992; Madany and Danish, 1992; Madany *et al.*, 1993; Nasralla, 1983). Danish and Madany (1992) investigated air quality indoors, using the method of diffusion tubes to measure NO_2. Madany (1992; 1993) found that traffic was the major source of high levels of nitrogen dioxide in the state of Bahrain. They also found that in hot countries the NO_2 levels do not reveal significant monthly variations. Madany (1992; 1993) pointed out that the summer/winter ratio in hot countries was different from that in European countries and North America. In Bahrain the concentrations of NO_2 were higher in summer than winter. Nasralla *et al.* (1983) investigated air pollution in Jeddah Saudi Arabia. They found that the atmosphere of Jeddah favours the accumulation of air pollution, particularly dust, carbon monoxide and photochemical oxidants. The meteorological factors such as dust storms and long periods of sunshine play an important role in determining levels of the air pollution.

4.4 Nitrogen dioxide measurement in rural areas

Monitoring of nitrogen dioxide has been carried out in rural areas as well as urban areas by a number of researchers. Ashenden and Bell (1989) and Ashenden and Edge (1993) carried out investigations in Wales. They found that the concentrations of NO_2 were higher in winter than in summer months because of greater use of fossil fuels in generating heat for both industrial and domestic process. They also pointed out that the pollution level was higher in the north-eastern and south-eastern parts of Wales, because the easterly winds brought polluted air from the industrial area of Britain and Europe to Welsh counties. The lowest level of NO_2 was found along the coastal area. Atkins and Lee (1995) carried out a national survey throughout the UK. They measured and established the concentration of NO_2 in a number of rural areas. The aim of these studies was to determine differences in background between locations, and established the minimum levels of pollution throughout the year. Indeed, the concentration of nitrogen dioxide has been studied to estimate the risk of nitrogen dioxide as a pollutant in rural areas.

Martin and Barber (1981) carried out an investigation over two years at Bottesford, a rural site in central England. The diffusion tubes samplers were located 1 km from traffic and 20 km away from an industrial area of a town. They found that during summer months there is more O_3 (1.1 times annual mean) but less SO_2, NO and NO_2 (0.9, 0.7 and 0.7). They also found that the concentrations of SO_2, NO and NO_2 at Bottesford meet the interim guidelines for population exposure limits suggested by the World Health Organisation (WHO), but the peak hourly values of O_3 particularly in summer do not being greater than 50-100ppb. Martin and Barber (1984) followed up their previous investigation, which had used Bottesford as its background site, and set up three new samplers in rural districts but near power stations. They found that the monthly and daily concentration pattern of the four gases is corresponded to those found in 1981. However, the concentrations of O_3 and NO_2 have exceeded the WHO on occasion. They point out that the main sources of pollution were derived from vehicles in distant towns, the gases then travelling in shallow inversion layers.

Summary;

Measuring the effect of NO_2 concentration in urban and rural area shows successful results use of diffusion tubes within different areas. The above studies indicate that pollution levels differ according to the climatic conditions and to the variation of the seasons. The results also depend on the period and types of fuel combustion.

4.5 The behaviour of atmospheric nitrogen dioxide

Nitrogen dioxide is a secondary pollutant, formed from the oxidation of primary emissions of NO. Nitrogen dioxide is a coloured gas that is light yellowish orange to reddish brown at relatively low and high concentrations, respectively. It is pungent and irritating. It is also relatively toxic, and because of its high oxidation rate it is extremely corrosive as well.

4.5.1 Formation of NO_2

The concentrations of NO_2 vary through the year and also from site to site. To understand the reasons for this variation, nitrogen dioxide can be produced by the direct oxidation of NO;

$$2NO + O_2 = 2NO_2 \qquad (4.1)$$

This takes place at low atmospheric NO levels shortly after combustion. It may account for less than 25% of all NO conversion.

The other reaction route is the secondary oxidation of NO to NO_2 in the ambient atmosphere. However, in polluted or even weakly polluted atmospheres such shifts in O_3 chemistry occur in the presence of peroxy radicals RO_2 Derwent and Hov, (1982). It can be called a photochemical reaction which involves:-

$$NO + O_3 = NO_2 + O_2 \qquad (4.2)$$

$$RO_2 + NO = NO_2 + RO \qquad (4.3)$$

According to Williams *et al.* (1988) and Bower *et al.* (1991a), the timescale of photochemical oxidation processes of equation (4.3) is dependent on the mix of hydrocarbons. The reaction involves OH attack on HCs to form RO_2.

$$HO_2 + NO = NO_2 + HO \qquad (4.4)$$

NO_2 can also be photo-dissociated by light of wavelength ≤ 430 nm;

$$NO_2 \rightarrow NO + O \qquad (4.5)$$

Nitrogen dioxide is also converted into nitric oxide by nighttime chemical reactions involving O_3.

$$NO_2 + O_3 \rightarrow NO_3 + O_2 \qquad (4.6)$$

$$NO_2 + NO_3 \rightarrow N_2O_5 \qquad (4.7)$$

N_2O_5 reacts with H_2O rapidly and irreversibly to reduce to HNO_3.

4.5.2 Sinks of NO_2

According to Williams *et al.* (1988) the major chemical sink for NO_2 during the day is the reaction with OH radicals to form HNO_3.

Williams *et al.* (1988) pointed out that a typical annual average concentration of OH is ~ 0.5 x 10^6 cm^{-3}, the rate of this reaction implies a half-life of NO_2 of the order of 16 *h* or a loss of ~ 5% of NO_2 over a travel distance of 20 km at a wind speed of 5 ms^{-1}. At night the reaction of NO_2 with O_3 can be important. With a temperature of 5°C and the presence of 30 ppb of O_3, the effective first order decay of NO_2 is ~ 1.56 x $10^{-5}s^{-1}$, or a half-life of ~ 12 *h*.

However, the average O_3 concentration in an urban area is likely to be < 30 ppb so that this is probably a lower limit for a half life in urban areas. The major loss mechanisms are, therefore, of little importance in determining annual average NO_2 concentration in major urban areas.

Summary;

Nitrogen dioxide is an important secondary pollutant in the ambient atmosphere, which might affect human health as a contribution to the acidification of the environment and its role in the formation of photochemical oxidants. The above paragraphs showed the difference in production of NO_2 to reaction either in the lower atmosphere by direct oxidation of NO or by photochemical reaction particularly with O_3. However, during the daytime the major chemical sink of NO_2 is reaction with OH to produce the HNO_3.

4.6 Effects of environmental conditions on NO_2 concentrations

4.6.1 The NO_2/NO_x relationship

The NO_2/NO_x relationship of average annual concentrations has been shown to be non-linear at urban and suburban sites with high NO_x (Bower *et al.,* 1991a; Bower *et al.,* 1991b; Campbell *et al.,* 1993; Williams *et al.,* 1988; Madany and Danish 1992; Madany *et al.,* 1993). This has important implications for the efficiency of control strategies for NO_x emissions, since a given reduction may not result in a proportional reduction in NO_2 concentrations. Bower *et al.* (1991b) are examined the NO_2/NO_x relationship in some detail, by comparing daily average concentration for Sundays and Mondays. The results show changes in ambient concentration, quantified by the gradient $\Delta NO_2/\Delta NO_x$, which was less than 1 for all sites whether summer or winter. Campbell *et al.* (1993) suggested that the NO_2 concentration had not increased because of the limited availability of ozone.

4.6.2 Seasonal variations for NO_2

Seasonal variation of NO_2 is influenced by many factors. Bower *et al.* (1991a) have mentioned that the changes of an emission throughout the year were also affected by the meteorological conditions, atmospheric chemistry and deposition rates and all these factors could influence seasonal variation of NO_2. However the main important factors are;

Firstly, meteorological conditions exert a strong influence on the ambient pollution concentrations. In the winter, especially in the USA and Europe, atmospheric stability is increased, which causes reduced mixing depths and consequent poorer air quality particularly in cold regions.

Secondly, emissions of NO also influence seasonal pollutant levels, which are greater during the winter months when there is an increased use of heating fuels. However, since the conversion of NO to NO_2 is related to solar intensity, higher NO_2 levels can be expected on warm, sunny days in winter.

In addition, there are seasonal effects due to variation in removal efficiency. According to Atkins and Lee (1995) seasonal variability in the chemical removal of NO_2 is complex. This is because of interactions between photochemistry, dry and wet removal processes of oxidised nitrogen, and in particular in the formation of HNO_3 in the atmosphere from the daytime reaction of NO_2 with OH radicals, which are of higher concentration in summer. However, reduced photochemical activity may be expected in winter months as the concentration of OH radicals at this time may be lower by an order of magnitude, so that possible night-time reaction of NO_2 with O_3 becomes much more important. This can lead to higher concentration of NO_2 in winter than in summer (Atkins and Lee, 1995).

Furthermore, the NO_2 winter/summer ratio shows an obvious pattern in seasonal variation of NO_2 levels in the UK and the European Community. Williams *et al.* (1988) found ratios of NO_2 ~ 0.67-1.10 in urban areas whilst Campbell *et al.* (1993) found corresponding winter/summer ratios of 1.6-2.5 over the period of a month in London sites.

On the other hand, Ashenden and Bell (1989) found that in rural areas of Wales the concentration of NO_2 was generally higher in winter months, especially January and February, and assumed that this might happen because of:-

1. Use of fossil fuels in generating heat for both industrial and domestic premises.

2. Dry weather with easterly winds that may bring polluted air into industrial parts of the UK and Europe.

Madany and Danish (1992) and Madany (1993), in their study of Bahrain, found different results of a winter ratio pattern for NO_2 concentrations than those found in previous studies in colder countries. The study shows that the NO_2 was higher in summer with values of 33 $\mu g\ m^{-3}$ compared to 23 $\mu g\ m^{-3}$ in winter months as an average annual concentration. They assumed that this was due to the increasing emission and the effects of meteorological conditions, such as temperature and sunshine. They also found that summer NO_2 concentrations exceed those in winter, which indicates that the effect of photochemical activity, which leads to increasing $NO \rightarrow NO_2$ oxidation rate during summer outweighs the effects of emission patterns.

Summary;

There is a non-proportional relationship between NO_2/NO_x concentrations for the annual and daily average. In general, there are several factors that are likely to contribute to the seasonal trends for NO_2 concentrations. These factors are the density of the traffic, and meteorological conditions such as temperature, relative humidity, wind speed wind direction and sunshine. The summer/winter NO_2 concentrations pattern in hot countries such as Bahrain, is opposite to those, which are found in European countries.

4.6.3 The spatial trends in the NO_2 concentration

The variations in NO_2 concentration depend on where the measurement is taken and the characteristics of the areas. Laxen and Noordally (1987) found the NO_2 concentration in a London street canyons was fairly uniform along the street over a distance of 50 metres, but was higher closer to and upstream of traffic lights. Madany and Danish (1992) confirmed this result and also provide a logical explanation, i.e. greater traffic density close to the traffic lights because of lower speed and the increase of motor vehicles' emissions, and greater NO_x emission from traffic as it accelerates away from the lights. Laxen and Noordally (1987) showed, in the investigations at the back of the pavement of a London street canyon that the levels of NO_2 increased between 15-30% close to the traffic area compared to 60 metres upstream.

Bower *et al.* (1991a) showed that the pollution is high throughout the year at a London site; the average annual value was 100 ppb, which is considerably higher than in industrial sites. Madany and Danish (1992) supported this finding when they found that industries in Bahrain were not a major contributor to NO_2. In addition Williams *et al.* (1988) found the concentration of NO_2 at the kerbside of Cromwell Road was higher for both annual and seasonal averages.

In rural areas, Ashenden and Bell (1989) suggested that industrial sites and population concentrations might result in high levels of NO_2 concentration in the north east and south east of Wales. In addition, Atkins and Lee (1995) showed the spatial distribution of NO_2 concentration had two points:-

1. The mean concentration of <6 ppb was found in Scotland, northern England, west Wales and the south-west of England, which was due to the predominance of low level emissions from vehicles. On the other hand, motor vehicles could

possibly be the dominant source for NO_2 pollution, which means an increasing level of ground concentrations. Lyons *et al.* (1990), Bower *et al.* (1991a), Bower *et al.* (1991b) and Campbell (1993) have confirmed these results.

2. A mean concentration of >9 ppb was found in England due to the higher level of emission from power stations.

Summary;

The concentration of NO_2 is dominated by two sources. Firstly, the low-level emission of vehicles motors, and secondly, the high level emission of power stations. The location for sampling sites was carefully selected either in urban areas or in rural areas. In general, the highest NO_2 levels were recorded in urban areas that are characterised by high traffic density.

4.7 European Air Quality

According to Hov and Larssen, (1984) much investigation has been carried out in European countries between the mid-1970s and the early 1980s. The preliminary studies were to estimate and establish the minimum level of nitrogen dioxide NO_2 concentration in the short-term. Warren Springs Laboratory and AEA Harwell carried out the studies of NO_2 concentration through the UK in 1986 by using diffusion tubes. As an initial study to assist in the selection of long-term monitoring sites, as required from the European Community Directive on air quality standards for nitrogen dioxide. Campbell *et al.* (1993) conducted the above investigation

The European Community Directive in relation to urban air quality has set a limit value for one-hour average for NO_2 of 105 ppb (200μg m^{-3}). In addition, the advisory values for the annual 50th percentile (26 ppb) and the annual 98th percentile (70.6 ppb) has also been established. The hourly average of 98th percentile concentration throughout the one year should not be exceeded for more than 2% of the time (Bower *et al.*, 1991a) Table 4.1 shows the standard NO_2 values for WHO Air Quality Guidelines (Murley, 1997).

Table 4.1 Nitrogen dioxide standard values for year 1994.

SUBSTANCE	LIMIT VALUE		AVERAGE TIME
	μg/m^{-3}	ppb	
Nitrogen dioxide	200	105	Average one hour
	40-50	25	Annual average

In addition, a maximum 1-*h* exposure of 190-320 μg m^{-3} should be consistent with the protection of public health.

4.8 The secondary pollutants ozone

4.8.1 Introduction

As a polluted air mass moves slowly across an urban area the ozone tends to be more of an environment problem, picking up emissions of NO_2 and hydrocarbons which both are important in the production of ozone a secondary pollutant. According to Ball and Bernard (1976) maximum O_3 concentrations take place typically an hour or more to form from the precursor pollutants such as NO_2 and hydrocarbons. The concentration of O_3 peaks in the afternoon when the greatest intensity of sunlight occurs, while the level of O_3 decreases at night when no new O_3 is formed. Therefore, considerable attention has been paid to reduce the elevated concentration of O_3 in urban areas during the daylight hours in the summer months, (Kirby, 1995). There is evidence of adverse health effects arising from human exposure to increasing concentrations of O_3 (Harrison, 1990). In particular during the summer with dry, sunny weather conditions in stagnant air (Feister and Balzer, 1991). Table 4.2 showed the standard ozone values for WHO Air Quality Guidelines (Murley, 1997).

Table 4.2 Ozone standard values for year 1994

SUBSTANCE	LIMIT VALUE		AVERAGE TIME
	$\mu g/m^{-3}$	ppb	
Ozone	120	60	8 hour
Population warning	360	180	1 hour
Health protection	110	55	8 hour mean

Photochemical processes and O_3 cycling are found in the planetary boundary layer. The planetary boundary layer plays an important role in the production of O_3, (Vukovich, 1994; Vukovich *et al.* 1996). However, industrialisation and human activities produce and add pollutants to the atmosphere. Hydrocarbon and NO_x emissions react in the presence of sunlight leading to the formation of a wide range of ozone secondary products, Chameides *et al.* (1992).

The production of photochemical oxidants including O_3 in the lower atmospheric is controlled by the concentration of NO_x ($NO + NO_2$), meteorological and climate conditions of given area (Kleinman *et al.*, 1994; Olszyna *et al.*, 1994).

4.8.2 Sources of ozone

It is more than four decades since hydrocarbons and nitrogen oxides were identified as the two key chemical precursors of high ozone concentrations (Chemeides *et al.*, 1992; Sillman *et al.*, 1990). Vukovich (1994) suggested that the oxidation of CO and NMHCs is probably the primary source of the troposphere O_3, since the carbon monoxide and non-methyl hydrocarbons are mainly emitted into the atmosphere due to industrial processes. According to (Hedley *et al.*, 1994; Lenner, 1987) large NO_2 concentrations lead to a net production of O_3 in the atmosphere, and NO_2 is the main significant photochemical source of O_3. Kelly *et al.* (1984) found that CO is less efficient in producing O_3. Vanlente and Thorton (1993) investigated for O_3 production in Tennessee, and found values of $CO < 150$ ppbv and $SO_2 < 0.2$ ppbv. They suggested that these two primary pollutants could not affect ozone production because the levels were extremely low.

SO_2 is another source of ozone production. SO_2 has been attributed to atmosphere pollution by traffic (Lalas *et al.*, 1993). However, Olszyna *et al.* (1997) found that the effects of mobile emission sources on SO_2 is negligible, due to the large sources of SO_2 emitted from power plants and stationary industrial sources.

4.9 Formation and destruction mechanisms of ozone in the troposphere

The total amount of ozone in the atmosphere is exceedingly small. Lin *et al.* (1988) pointed out two interesting results about the production of ozone. Firstly, there is not enough solar UV radiation in the troposphere to dissociate O_2 directly to produce ozone. Secondly, the photochemical processes involved in ozone production from the oxidation of non-methane hydrocarbons (NMHCs) are very complex.

Therefore, the reaction of secondary pollutant ozone mainly occurs near to the ground surface, because this involves primary pollutant gases, such as nitrogen oxides and hydrocarbons (Guicherit and van Dop, 1977). The hydrocarbon and NO_x emission react in the presence of sunlight which may cause large-scale pollution of O_3 concentration (Cape *et al.,* 1994).

4.9.1 Formation processes

Formation of ozone can arise in many different ways, particularly during the summer months and under certain meteorological conditions. One of the most important is the recombination of atomic and molecular oxygen, and reactions by the photolysis of NO_2. In Equation (4.9) M is an energy-absorbing species such as O_2 or N_2.

$$O + O_2 + M \rightarrow O_3 + M \qquad (4.9)$$

$$NO_2 + h\nu\ (\text{sunlight}) \rightarrow NO + O\ (^3P) \qquad (4.10)$$

$$NO + O_3 \rightarrow NO_2 + O_2 \qquad (4.11)$$

The steady-state concentration of O_3 is

$$[O_3]\ k_1/\ k_3 \cdot [NO_2]/[NO]. \qquad (4.12)$$

Where (k_1 and k_3) are the reaction rates which are constant for reaction (4.10) and (4.11). The steady-state relationship plays a dominant role in determining the ambient O_3 concentration because the NO_2/NO ratio is usually < 1 and k_3 can be regarded as constant, consequently, the solar radiation in the lower atmosphere, is the most important parameter in the O_3 production process (Guicherit and van Dop, 1977; Angle and Sandhu, 1989; Brimblecombe, 1986).

4.9.2 Destruction processes

Derwent and Hov (1979) pointed out in a computer modelling study that the depletion, of the O_3 concentration starts after sunset. For first hour after sunset there are no changes in the O_3 reactions. During the four hours before midnight there is a decreasing concentration of O_3. But at midnight the O_3 concentration decreases sharply in urban areas, especially when there are low wind speeds. The resulting ozone concentrations stay close to the background concentrations, which means that dilution of O_3 due to vertical mixing with clean air, which starts at approximately 18:00 PM, is inefficient as a sink for ozone over the urban area. However, this does not necessarily occur in every urban area.

Many studies have investigated O_3 destruction during the night period and most results showed loss by two atmospheric processes; dry depositions and reaction with NO (Kelly *et al.,* 1984; Sillman 1990). During the nighttime the O_3 destruction occurs near the surface in the presence of NO emissions particularly from mobile sources. Since there is an absence of sunlight, the NO_2 can not photolyse (Zhang *et al.*, 1994) and thereby cannot regenerate the O_3

$$NO + O_3 \rightarrow NO_2 + O_2 \qquad (4.14)$$

Also the NO and HCs which are produced locally during the evening and night because of traffic, both act as sinks for O_3 especially where a weak wind is involved, which reduces the O_3 levels to zero (Gusten and Heinrich,1988). Zhang *et al.* (1994) pointed out that net ozone production ceases when the dust level increases.

Therefore, there are a numbers of processes that can lead to the destruction of O_3 near the surface of the earth.

4.10 Ozone distribution in urban and rural areas

The transport of any pollutants over long distances in the planetary boundary layer is strongly controlled by the depth of the mixing layer. The deeper the mixing layer the lower the conversion of pollutants (Smith and Hunt, 1978). However, at urban coastal and industrial areas the transport of pollutants is markedly influenced by local air circulation, which in summertime is mainly characterised by land sea breeze circulation (Fortezza and Strocchi, 1993).

The diurnal peak of ozone concentration usually occurs around mid afternoon during summer months, while the levels of ozone decreases during night periods when no new O_3 is formed. An active photochemistry is favoured by high solar intensity, temperature and absolute humidity, which are common in summer time conditions (Kleinman *et al.*, 1994; Bower *et al.*, 1989).

Bower *et al.* (1989) who investigated Sibton and Lullington Heath, located near the coast in south east England, found that the O_3 concentration peak occurred during the afternoon when the sunlight intensity is at its greatest. This was attributed to either the photochemical generation of O_3 or influence from the continent, with peak concentrations exceeding 50ppb.

Olszyna *et al.* (1997) in their investigation in Giles County, Tennessee pointed out that there is a strong relationship between increases of O_3 and high temperature. O_3 concentrations increased at a rate of approximately 3±1 ppb per degree °C, especially when the temperature recorded is above 29°C. At the same time Simmonds and Derwent, (1991) found that the ozone and aerosol could travel over considerable distances having been formed in photochemical reacting air, polluted by human activities.

In addition, rural areas might experience the greatest frequency of raised ozone concentration compared with urban areas, since many studies have been carried out in the eastern and southern parts of the USA (Logan, 1989; Kleinman *et al.,* 1994; Trainer *et al.,* 1993; Olszyna *et al.,* 1994). This is because formation of O_3 occurs during the transport of polluted air away from urban sources (Kleinman *et al.,* 1994). The rural O_3 concentrations may then persist because the main factor of NO concentration destroying O_3 is at a minimum (Olszyna *et al.*, 1994).

Summary;

Ozone is a secondary pollutant product from photochemical reactions mainly involving oxides of nitrogen and hydrocarbons. Human activities, particularly in industrial areas produce CO, SO_2 and NMHCs, but these are likely to be the primary sources of the ozone precursor.

The transport of any pollutants is considerably influenced by local air circulation, which mainly depends on the depth of the mixing layer. An effect of this circulation is that the concentration of O_3 differs between mid afternoon, which is known as the period of peak ozone concentration, and nighttime when the concentrations decrease. Meteorological conditions such as solar radiation and high temperature might impact on the ozone concentrations. Studies reported in the literature that the O_3 concentrations in the rural areas higher than in urban areas, due to the O_3 being produced and transported away from the city.

Chapter Five

Diffusion tubes: Theory, Application, Construction and preparation procedure

5.1 Introduction

In chapter 5 the first part focuses on the early development of diffusion tube theory and on their construction. Then advantages and disadvantages of the technique are given. Before going further and discussing the possible contamination effects the influence of meteorological conditions on different tube performance is discussed. The second part of this chapter starts by reviewing the experimental process and the definition of different blanks which were used. Finally there is a discussion of the lowest exposure limit (LEL).

Many studies have been carried out to measure the most important gaseous pollutants such as sulphur dioxide (SO_2), nitrogen dioxide (NO_2), nitric oxide (NO) and ozone (O_3). Until ten years ago almost all the investigators considered NO_2 to be an urban pollutant and of little significance in rural environments. Nitrogen dioxide is a significant environmental air pollutant, which is generated by automobiles and from the combustion of fuels in industrial processes. Its adverse impact on human health and vegetation is well documented (National Academy of Sciences, 1977). However, a secondary and more common effect of the occurrence of NO_2 concentration is the formation of photochemical smog, which is a mixture of strong oxidation species formed from the interaction between NO, hydrocarbons and sunlight.

There are many methods for measuring pollutant gases, most require the deployment of bulky and expensive instruments in the field. However, over the last 25 year there has been gradual development of inexpensive passive samplers. Hargreaves, (1993), grouped the passive samplers into two broad categories;

1. The badge type; which has a large absorbent surface area and a short diffusion pathlength.
2. The tube-type; has a long diffusion pathlength and low absorbent surface area.

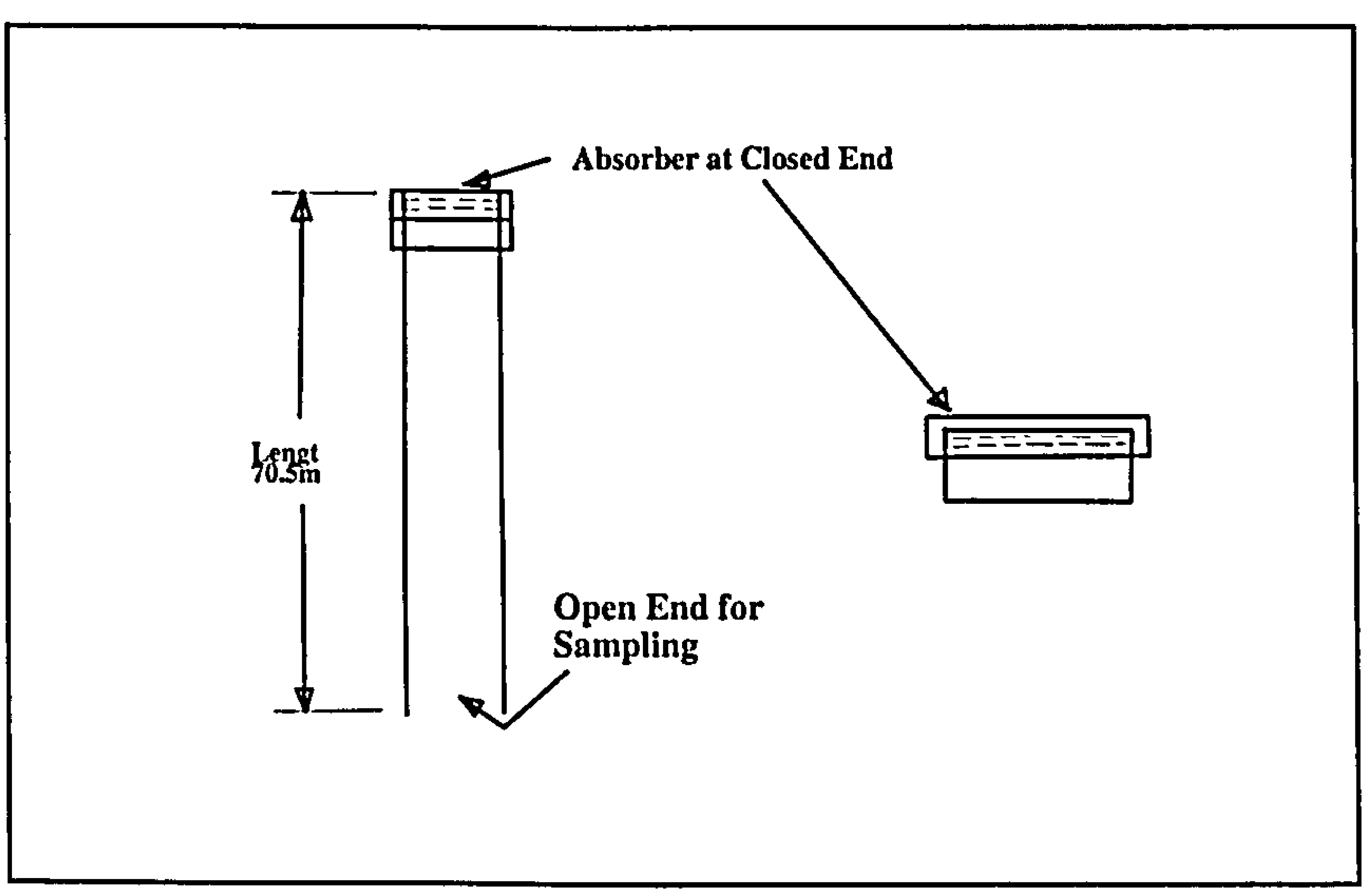
One of the oldest types of personal passive sampler is the diffusion tube, based on measurement of the quantity of the air through the tube, dependent on molecular diffusion. The theory is based on measurement of the quantity of the test gas in a given exposure when the gas is transferred through a tube to an absorbent surface by molecular diffusion. The diffusion tube was originally developed for use indoors in the field of occupational exposure (Palmes *et al.,* 1976). It has been validated by several workers for the measurement of outdoor NO_2 (Atkins *et al.*, 1986; Campbell *et al.*, 1988).

For reasons given in Chapter 4, diffusion tubes were used in this research. Preparing the diffusion tubes under controlled procedures is very important, especially because of problems that can be caused by contamination. Each diffusion tube must be cleaned and prepared following precisely the same method. Reducing contamination levels at this preliminary stage from other sources in the environment is very important in the context to this study, as it will help to assess the success of the method used in the urban environment.

5.2 Construction and preparation procedure

The diffusion tube is composed of an acrylic tube. The size is 70.5mm high x 10.9mm internal diameter.

Fig 5.1 The diffusion tube diagram



It is fitted with one blue and one white airtight polythene end-cap. The diffusion tubes must be cleaned before use. The tubes are soaked overnight in 2% solution of Decon 90 (Decon 2% = 100 ml in 5000 ml water), then thoroughly rinsed out in double distilled water, washed with double distilled water, left for 20-30 minutes to drain, then soaked overnight in a 5% solution of hydrochloric acid (5% = 250 ml in 5000 ml water). They are thoroughly rinsed in double distilled water twice, and left to dry at room temperature.

Two clean stainless steel mesh discs (12.5mm diameter) are soaked in 50% $^{v}/_{v}$ triethanolamine (TEA) and acetone solution. The acetone is allowed to evaporate by placing the discs on filter paper, thus leaving a fine coating of TEA. The discs are placed at one end of the tubes inside the blue cup, and placed in the selected position. During exposure, the discs act as collectors of NO_2. The other end of the diffusion tube is sealed with a white polythene cap to prevent contamination.

During storage and transportation the diffusion tubes with both end-caps are placed in sealed polythene bags and stored in a refrigerator at 4°C.

For each batch of tubes made, 20 tubes are taken and stored in the refrigerator. These blank tubes are used to show any background concentration of NO_2 absorbed during preparation and storage or contamination from reagents.

5.3 The principles of diffusion tubes

According to Atkins *et al.,* (1987) and Hargreaves, (1993) the equation for unidirectional isothermal diffusion of gas species 1 through a constant pressure mixture of gas 1 and 2, derived from Fick's first law, is:

$$J_1 = -D_{12}\, dc_1 / dz \qquad (5.1)$$

Where:

J_1 = molar flux of species 1 (moles /cm^2 /sec).

D_{12} = diffusion coefficient of gas 1 through gas 2 (cm^2/sec)

The diffusion coefficient for NO_2 in air is 0.154 cm^{2}sec^{-1}.

C_1 = concentration of diffusing species (moles/ cm^3)

Z = distance in direction of diffusion (cm).

If the concentration of gas is maintained at zero by a suitable absorbent in one end of the tube, and the other end is exposed to the environment to be measured, then:

$$Q_1 = J_1 (\pi r^2)\ t \text{ mol} \qquad (5.2)$$

Where:

Q_1 = quantity of gas transferred (Q_1 mol).

t = time by seconds.

πr^2 = cross-sectional area.

$$Q1 = -J_1 (c_1 - c_0)(\pi r^2)\ t/z \text{ mol.} \qquad (5.3)$$

5.4 Laboratory analysis:

The diffusion tubes used in this survey were accurately measured. A standard technique for the analysis of the tubes was followed using the method of (Winberry, 1993).

5.4.1 Reagent preparation.

- Stock solution (25 mM NO_2)

    1. 3 g of sodium nitrite ($NaNO_2$) was dried in a vacuum desiccator over night, then 1.725 g was weight and made up to 1000 ml with double distilled water. This solution was used to prepare working standards.

- Colour solution

    1. 10 g of sulphanilamide (NH_2 C_6 H_4 SO_2 NH_2) was mixed with 25 ml concentrated ortho-phosphoric acid (H_3PO_4) and made up to 1000 ml with double distilled water.
    2. 0.14g N-(1-naphthyl)-ethylenediamine dihydrochloride (NEDA) made up to 100 ml with double distilled water.

Colour reagents can be kept for several weeks in a refrigerator.

Both solutions when mixed give a purple-red azo dye, which is analysed on a spectrophotometer at 540 nm (Palmes *et al.*, 1976; Atkins *et al.*, 1986) The spectrophotometer is calibrated against standard nitrite solution, to allow the total NO_2 (as nitrite NO_2^-) collected by the tube to be determined. Nitrite ion concentration, was obtained by reference to a calibration curve derived from the analysis of standard nitrite solutions of $NaNO_2$.

5.4.2 Preparation of working standards

1. The standards used ranged from 0 to 60 nanomoles. These standards were made by pipetting 0.0ml, 1.0 ml, 2.0 ml, 3.0 ml, 4.0 ml, 5.0 ml, 6.0 ml of $NaNO_2$ into 50 ml volumetric flasks making up to 50 ml with double distilled water.
2. Six plastic test new tubes were then prepared as working standards as follows: 100 μl of the appropriate working standard and 10 ml of colour reagents was added to each tube. The tube was then left for 30 minutes to allow the colour reagents to develop.
3. The solution was then injected into the flow injection analyzer and graphs of deflection against the concentrations were obtained.

5.4.3 Analysis of the diffusion tubes

2.0 ml of the colour reagent was added directly to each sample diffusion tube, the tubes were then re-sealed, shaken, and left to stand for 30 minutes, then re-shaken. The flow injection analyzer was first zeroed using double distilled water. The solution was then injected into flow injection analyzer and using a spectrophotometer set at 540 nm, the absorbance was measured. Values of the concentration in the tubes were obtained using calibration curves. Standards were run at the start and an end of each analysis run.

5.5 The techniques used to measure NO_2

Despite the availability of several different types of equipment for measuring air quality, the diffusion tube which is used in this research, was the only NO_2 measuring equipment available for this study when the researcher began the work.

Also it is one of the cheapest and the best equipment which was found suitable for the Emirate of Dubai, for the following reasons,

1. It is inexpensive equipment and it is widely used in European countries and US, to measure the pollution concentration.
2. Easy to prepare in the laboratory
3. Convenient for transportation between the field area in the Emirate of Dubai and analysis in the laboratory at Liverpool.
4. It is easy for the person who replaces and changes the tubes in the Emirate of Dubai.

However, the advantages and disadvantages of different kinds of measuring equipment are made in the comparison below.

Woebkenberg *et al.,* (1982) compared three personal passive sampling methods in the laboratory, which include the Palmes tube, the Pro-Tex Calorimetric air monitoring system, and the Chronotox system.

1. The Palmes tube collects NO_2 on screens coated with triethanolamine, and the analysis is colorimetric. Also, it is the smallest and lightest of the samplers and it is the lowest in cost. On the other hand, it is the only system, which requires chemical preparation.
2. The Du Pont Pro-Tek badge employs a modification of Blacker's method for trapping NO_2 from the air. The system itself is expensive, but the saving in cost of reagents and reduced labour must be considered. However, the badge containing liquid which could be a disadvantage in some instances.
3. The MDA Chronotox system is an electrochemical system that detects gas molecules after they diffuse through a membrane and impinge on the measuring

electrode in the sensor cell. It is also very easy to operate. Although it saves time, because of the higher cost of reagents and labour this system is not used.

Therefore, from all the different techniques, most of which are complicated and expensive, the diffusion tube sampler has been choice because it is simple to use for a person without any laboratory experience. It is also less expensive.

5.6 The effect of meteorological conditions on the precision of the diffusion tubes

1. The diffusion tube requires that an efficient collecting medium is placed at one end of the tube while the other end is exposed to the contaminated atmosphere (Palmes *et al.*, 1976; Palmes and Tomczyk 1979).
2. The accuracy of the diffusion tube measurement depends on the efficiency of the absorber. Triethanolamine TEA is highly efficient in the absorption of NO_2 (Atkins *et al.*, 1986).
3. The diffusion tube efficiency is assumed to be 100% (Gair *et al.*, 1991).

In most of the investigations mentioned above the results show better agreement for indoor measurement than for outdoor measurement. The degree of disagreement varies with the temperature at which the measurement was taken. For more details, Girman *et al.* (1983) examined the effect of temperature upon the performance of the NO_2 passive samplers. They assumed the sampling rate is affected by the temperature, they observed that only 1.7% of the change in sampling efficiency over at temperature change from 10°C to 21°C. Two groups of diffusion tube samplers were prepared. Group A were exposed to successively increasing temperatures from 7°C to 38°C. Group B were exposed to successively decreasing temperatures from

30°C to 7°C. The results show that below 15°C the collection efficiency is fairly constant at an average of 82%. However, above 27°C it gradually rises. The average was 96%.

Triethanolamine (TEA) is hydroscopic in humid atmospheres, and the liquid range of the TEA is extended. Atkins *et al.* (1987) found that melting the TEA occurred over a wide range of temperature between 16°C to 21°C.

In addition, Gair *et al.* (1991) found the overall effect of temperature on diffusion tube calculated is a 1% increase for every 5°C increase in temperature. No effect of atmospheric pressure was found in diffusion tubes.

5.6.1 Wind effects

Atkins *et al.* (1986) found that the effects of wind speed appear to be dependent on the site location. Campbell *et al.* (1994) confirmed the results of Atkins *et al.* (1986), and they explained that the effect of winds is negligible when the tube is in a sheltered location. However, the roof site was more exposed than any other site in their survey, where the tubes were mounted on the sides of buildings. Gair and Penkett (1995) produced a similar result. Campbell *et al.* (1994) pointed out that the concentrations of NO_2 were overestimated up to 40% by using the diffusion tube measurement. Heal and Cape (1997) confirmed the results of Campbell *et al.* (1994), and they suggested it was characteristic of a shortening of effective diffusion tube path length caused by wind speed and turbulence at the face of the sample. However, according to Heal and Cape (1997) both a shortening of diffusion tube path length and chemical reaction in the tubes, lead to an over-estimate of NO_2.

5.7 Contamination of diffusion tubes

The contamination of unexposed samplers (blanks) could possibly be caused by absorption and desorption of NO_2 from and through the acrylic tubes. Two other types of contamination can appear in diffusion tube theory:-

1. Contamination of reagents.
2. Contamination of tubes.

The contamination of reagents is not a serious problem as the bottle of the triethanolamine TEA gave only a trace of nitrite when tested. Yet serious problems could come from handling the tubes during preparation and analysis (Miller, 1988). They suggested avoiding contamination during preparation and analysis by removing the mesh and fastening in Teflon liners, which are never touched by hand at any stage of analysis or preparation. Also they suggested the removal of any traces of NO_2 from air during the preparation of the tubes by using copper which is heated to 550°C and passing the nitrogen gas to the copper in a suitable atmosphere in which to dry the coated mesh. Miller (1988) found that average blank levels had risen to 150 ppb h after one month of being capped and stored. The test to study the affect of storage time in blank concentrations was done as follows: Palmes tubes were exposed to a known concentration of NO_2 inside an exposure chamber. The observed results were consistently low by 10-30%, and the actual exposures ranged from 64 to 1600 ppb h. They found from this test that the acrylic plastic tube absorbed NO_2 reversibly. That means that when exposed to ambient air for a suitable time, the concentration absorbed in the acrylic tubes comes to equilibrium with the ambient concentration. When the tube was capped, the coated screen scavenged the NO_2 from the closed air space inside the tube and NO_2 desorbed from the acrylic tube.

To examine the penetration of gas into the sealed tubes, Gair *et al.* (1991) prepared a group of tubes and stored them under water. The results show that contamination was lower by 30%. Storing under water prevents more NO_2 from being absorbed into the tube from the surrounding air. It also prevents leakage around the caps. As an alternative to water storage, Gair *et al.* (op. cit.) recommend storage in a refrigerator to limit sample contamination. In addition, storage or transportation time should be kept to a minimum.

5.8 Choosing the measurement sites

For the measurement of NO_2 concentration in ambient air in both urban and rural areas, the site location should be chosen carefully in order to avoid any local sources of NO_2 or its precursor. Bower *et al.* (1991a) established, on behalf of the UK Department of the Environment, a new national air quality-monitoring network to determine the compliance with the European Community Directive for the concentration of NO_2. The studies were restricted to sites in urban areas that were affected by pollutants from vehicular emission and industrial emission sources. In this case, it is clear that this survey covers the most important areas of high pollution in the UK. Bower *et al.* (1991b) confirmed the previous study by segregating the sites into three discrete location types;

1. Urban background sites, which were more than 50 metres away from a busy roadway.
2. Intermediate sites, which were less than 50 metres from a major road.
3. Near-road sites that may contain a few kerbside locations.

In addition, a similar division of selected sites has been made by Danish *et al.* (1992) in their studies of NO_2 in a hot climate in the state of Bahrain. All the sites were chosen to include industrial, residential, heavy and low traffic roads, airports and commercial areas.

According to Laxen and Noordally, (1987) and Bower *et al.* (1991a) sampling sites for rural areas must be located well away from obvious sources of NO_2 or its precursors such as power plants, building heating and mobile source. According to Bower *et al.* (1991a) the distance of 50 metres should be selected for urban area sites. Nevertheless, there was disagreement between the researchers about where monitoring sites should be located, at least in the UK. This controversy was about the positioning of the sample sites, e.g. kerbside, back of the pavement, on the building facade or somewhere away from the road but still in the area affected by heavy traffic. Laxen and Noordally, (1987) suggested that the difference of a few metres could make little difference to measured concentrations. There is a minimal effect on the measured concentration over a distance of 20 metres if the concentration at the area of investigation is close to the limit value for NO_2. However, this relatively small difference in distance might be crucial in determining where the standard values were exceeded or not.

5.9 The quality of diffusion tube and blank data

Throughout this section references are made to the term blank. These blanks are unexposed diffusion tubes, and act as the control in the batches of five diffusion tubes (placed on a stand) that are used in each site measurement test: of these five tubes four are exposed (see Experiment subsection for details) and one unexposed i.e. a field blank.

For the purposes of this study, there were three types of nominated blank: Liverpool laboratory blanks, Dubai laboratory blanks, and Field blanks. (See next subsection for definition).

During two years of fieldwork, a total of 35 measurements at all the sites of NO_2 were undertaken. The consistency of the results from the blank tests allowed a decision to be taken, after the 20^{th} test, to reduce the number of blanks, used as controls for each sample, from 40 blanks to 20 (again see Experiment subsection for details). The variation within the blank values was low over all time scales, therefore, for the data quality purposes, the lowest exposure limit (LEL) was calculated.

5.10 The blank definition and the experiment process

Blanks are unexposed diffusion tubes from which the protective translucent plastic cap is not removed. The tubes are protected against contamination and also used as a background for the whole data set. The blank value was used to correct elevated baseline values appearing during the preparation, transportation and analysis process. To avoid any contamination during the preparation gloves were worn at all times.

Within this study three types of blanks were used,

1. Liverpool laboratory blanks: these were prepared and stored at 4°C in a refrigerator in Liverpool.
2. Dubai laboratory blanks: these were prepared in Liverpool, sent to Dubai and stored at 4°C in a refrigerator, then return back to Liverpool.

3. The local laboratory blank refers to individual blank value taken from each eleven sites in Dubai City during the sample period measurements. One blank was put in a stand with four exposed diffusion tubes but remained capped.

While the two below are the average of the main blank tubes;

1. The Field blank refers to average values of these local blanks.
2. Global laboratory blank refers to average values taken between the Dubai and Liverpool blanks

During the sample test, in four of the five exposure tubes, the lower translucent cap was removed to allow diffusion of NO_2 to the absorbent discs to begin and the tubes pointed downwards to prevent the entry of rain and dust, whilst one (the field blank) remained capped. The number of the laboratory blanks including Liverpool blanks and Dubai blanks, were changed during experiment.

Initially the experiment started with 40 laboratory tubes per measurement cycle, which were spilt into 20 tubes as Dubai laboratory blank and 20 tubes as Liverpool laboratory blank. However, because of the similar results given by the test of 20 blanks and 40 blanks, the decision was taken to reduce the blank to 20 tubes in total to save both time and cost.

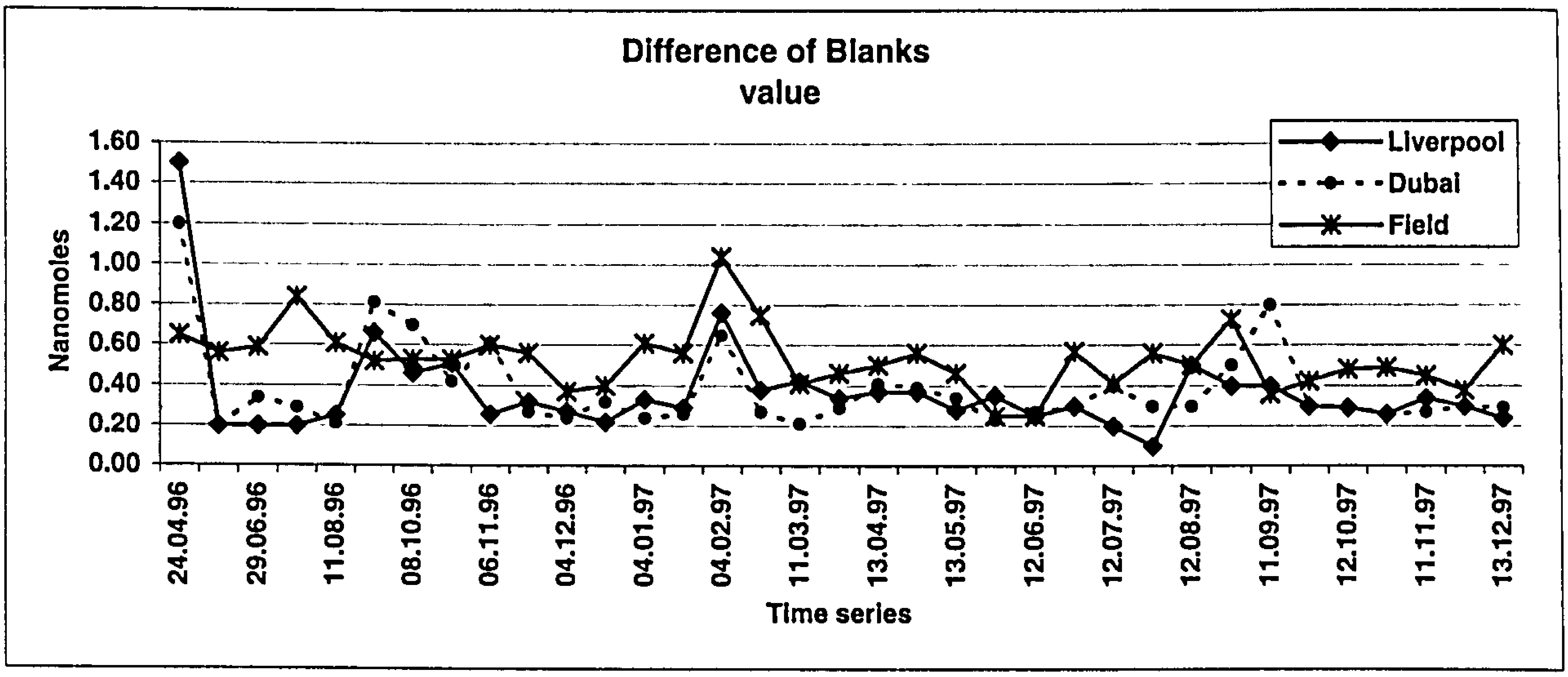
5.11 Analysis the blank tube values

A decision needs to be taken to decide which blank values should be used to subtract from the analyzed results for the four exposed tubes? To find an answer to this question the data set was statistically analyzed to show an average, the standard deviation and the coefficient of variation (COV) were calculated.

$$\mathrm{COV} = \frac{s}{\bar{x}}(100) \qquad (5.4)$$

There were similarities between Liverpool and Dubai blanks, while the highest average values were found in the field blanks.

Fig 5.2 The average of different blanks value.



As it can be seen from (Fig 5.2) that the values of the field blank were considerably higher than Dubai laboratory blank and Liverpool laboratory blank value. Although, there is a variation of values within the three different blanks, the peaks and dips appear at almost the same time.

However, it is not often possible to give a logical reason for any differences between the blanks. In general the difference in values of blanks might be due to slight contamination while prepared the tubes in Liverpool laboratory. On the other hand the blank tubes might be affected by meteorological conditions during the exposure period, e.g. the influences of high temperature and dust storm at daytime or during the transportation process. Another reason that is possible especially for field tubes which might be leaking during exposure time.

All the above reasons could provide an explanation for the variation of the values especially to the field blank.

To show the correlation between laboratory values for Liverpool blank and Dubai blank, the values were graphically plotted in (Fig 5.3) Below.

Fig 5.3 The Correlation between laboratory blanks.

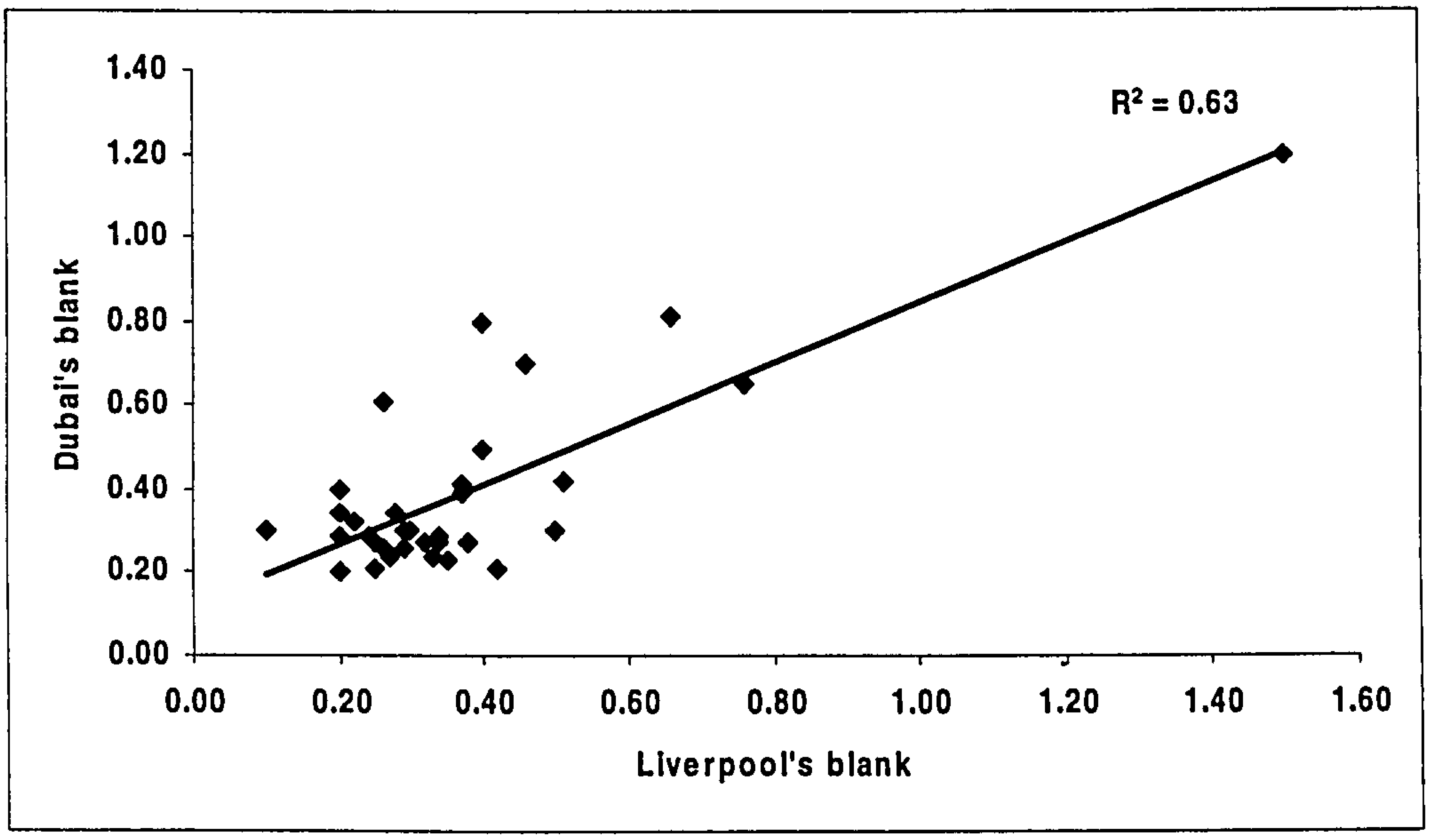


Figure 5.3 shows the correlation between two laboratory blanks (Dubai laboratory blanks and the Liverpool laboratory blanks), including high values (1.50, 1.20). As it can be seen from the (Fig 5.3) the $r^2 = 0.625$ which is indicating to a positive relationship between Dubai laboratory blank and Liverpool laboratory blanks. Clearly testing the r^2 value or scale a skewed data set is not valid. But it is equally clear that a positive relationship exist even for the lower concentration

Any uncertainty resulting from choice of blank has however, little significance, as shown below, and the blank values are too small to make a significant difference.

5.12 Lowest Exposure Limit (LEL)

It should be noted here that the mean exposed value is 40 times larger than the mean blank values. Therefore, subtraction of the blank value will not make a big difference in the final results of nitrogen dioxide (NO_2) concentrations.

To test the data quality of blank values the Lowest Exposure Limit (LEL), was determined.

The question worth asking at this stage is why a period of measurement was chosen to be of two weeks? For this study a few important points must be taken into account

1. Preparing the blank tubes needed between 3 and 4 days in the Liverpool University laboratory.
2. Transporting the tubes between Dubai and Liverpool or vice versa needs between 4 and 5 days.
3. In Dubai City the person needs a whole day to visit, remove and replace the tubes at all the eleven measurement sites, as changing all the tubes must be done at the same time. All these reasons contributed to the decision for periods of two weeks measurement rather than one week.

5.12.1 Experiment

Calculating the lowest exposed limit for the whole data set, statistical analyses were undertaken within all the values of three types of blank. The principle is that for a measurement to be made the signal must be at least 3 times greater than the standard deviation of the blank. Average of lowest value is 0.1 nanomoles, which is from a group of measurements taken from the Liverpool laboratory blanks. Standard deviation of these values is 0.04 nanomoles.

$S.D \times 3 = 0.12$ nanomoles.

$0.1 + 0.13 = 0.22$ nanomoles.

As the limiting concentration of blank values had been calculated, an examination of the effect of subtracting the blank value from the lowest NO_2 concentration was carried out. As 4 ppb was the lowest concentration from the exposed diffusion tubes of a give site and was from Mushrif Park. For the exposure time of the tubes in this study the blank is a very small proportion of the total signal.

5.13 Choice of blank

Therefore, the decision was taken to use the global blank, which is represent the average of Dubai's laboratory blank and Liverpool's laboratory blank, because the values are close to each other. On the other hand, the field blanks values seem to be higher than laboratory blanks, and that might be due to leakage while the tubes were exposed in the field, and was then probably inappropriate. Finally, the result is not sensitive to the choice of blank value, because the blanks were all so low compared with exposed sample.

5.14 NO_2 and diffusion tubes

5.14.1 Usefulness of diffusion tubes as a method

The network monitoring stations maintained by Dubai municipality at Deira and Jebel Ali Village produced nearly the same results as the diffusion tubes. There is particularly strong agreement in the results from the Deira station and some disagreement in the results from Jebel Ali Village (see Fig 5.4 and Fig 5.5).

Fig 5.4 Monthly average NO_2 at Deira station by using diffusion tubes and monitoring network during 1996-1997.

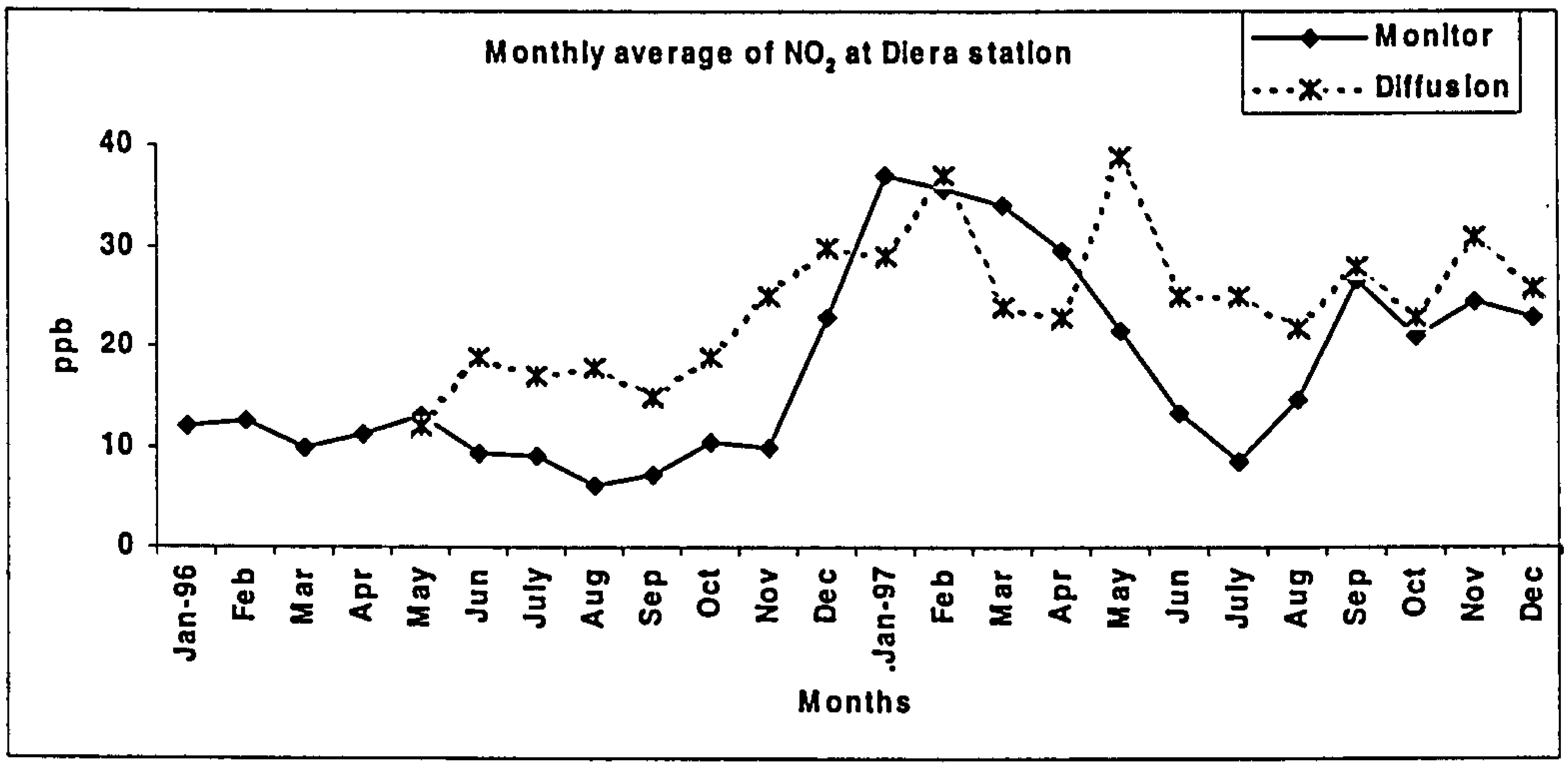


Fig 5.5 Monthly average NO_2 at Jebel Ali Village station by using diffusion tubes and monitoring network during 1996-1997.

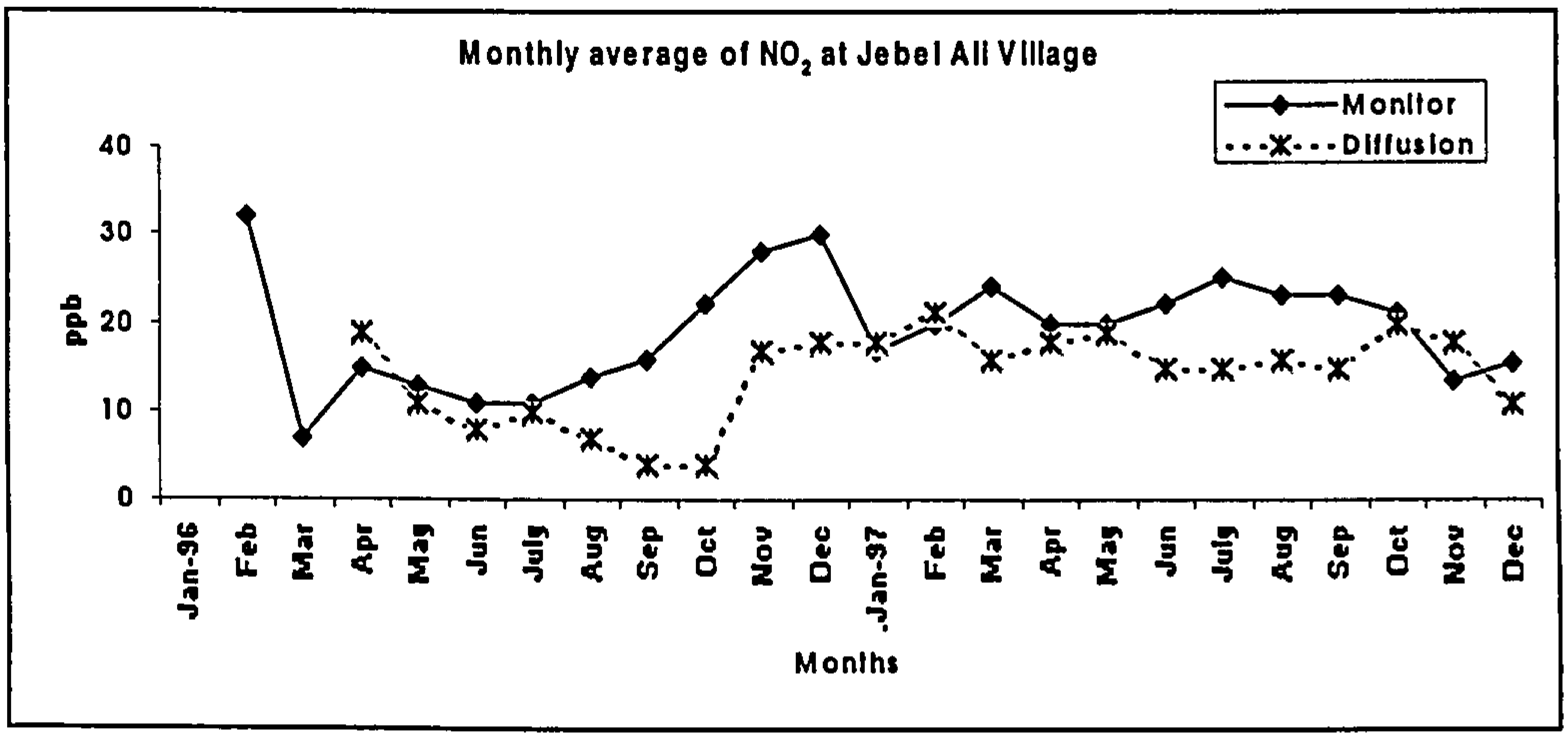


Figure 5.4 and Figure 5.5 shows the results of monthly average NO_2 at Deira station and Jebel Ali Village which were collected by using diffusion tubes and plotted together with the monthly average from the monitoring network during 1996-1997. Both Figures indicate that in general there is a similarity in monthly results of NO_2 concentration between diffusion tubes and monitoring instruments at both Deira and Jebel Ali village stations. However, the monthly NO_2 average at Deira appears slightly higher than the monthly average of NO_2 at Jebel Ali village. At the same

time, as can be seen from both Figure 5.4 and Figure 5.5, the NO_2 concentrations are significantly higher during winter months compared with summer months.

Sadly, the results from the Jebel Ali village station were somewhat corrupted due to the stand for the diffusion tubes being used as a washing line by local workers, thus covering the actual diffusion tube face.

A further test of the usefulness of diffusion tubes comes from a study conducted in Sefton Bootle, Liverpool, in 1998-9 (see Fig 5.6).

Fig 5.6 Concentration of NO_2 in ppb at St. Joan Bootle, together with monitoring instrument data during 1998-1999.

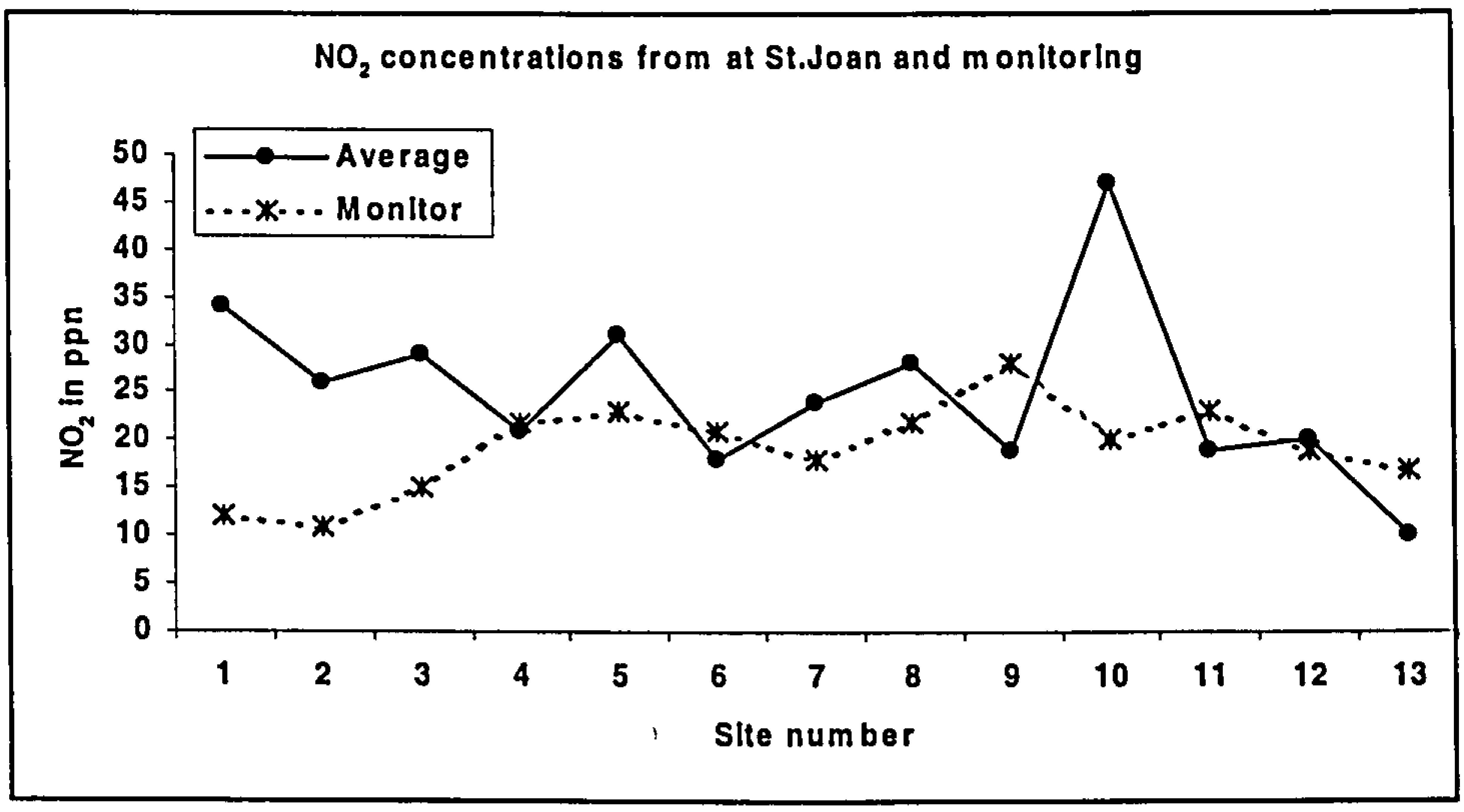


Figure 5.6 shows concentration of NO_2 in ppb, which was collected during a two-week period at St Joan of Arc primary school on Rimrose Road, Bootle. These were analysed at a laboratory of the Geography Department at the University of Liverpool, together with data of the same period taken from a monitoring instrument. As can be seen from (Fig 5.6), there is agreement between the NO_2 averages of both data sets. On the other hand, there are several runs of disagreement, which are underlined in the table. Again diffusion tubes were installed at the same locations as network monitoring equipment and also in this instance the results produced some

agreement, but also some disagreement in the average NO_2 concentration. However, it has been discovered that in those instances of divergent results there was a high incidence of a minus reading from the network monitor, which can only indicate a fault in the machine as this location is situated next to a busy road.

Summary;

1. There is a similarity of the results for the three types of blanks.
2. High values were sometimes recorded for field blanks for an unknown reason (possibly leakage) but these were still very small compared to any signal. The highest blank was 1.60 in nanomoles of the lowest value of 5 nanomoles from diffusion sample.
3. The values from the Liverpool laboratory blanks are similar to those from the Dubai laboratory blanks.
4. It was decided to use a use global blank as a standard blank value.
5. There is a similarity in many of the monthly results of NO_2 concentration between diffusion tubes and monitoring instruments at both Deira and Jebel Ali village stations.
6. At the same time there is a similarity in some of he NO_2 concentrations results between the present survey and NO_2 concentrations, which was collected at St Joan of Arc primary school on Rimrose Road, Bootle. The months that are not similar are probably due to some error with the monitoring instruments or the fact, for this experiment only that the length of time between the exposure and analysis of the diffusion tubes was long.

Chapter Six

Results of the Diffusion Tube Study

6.1 Introduction

The experiment measuring NO_2 by using diffusion tubes ran from the beginning of 1996 to the end of 1997. All nitrogen dioxide data in this chapter are in ppb by volume. The results were statistically analysed using average, standard deviation and coefficient of variation. Histograms were used to show the distribution of the gas concentration. In addition, graphs and regression analysis have been used, where the results from one site are compared against all other sites to test for any relationship which might exist between the sites.

6.2 The NO_2 concentration measured by diffusion tubes

Table 6.1 shows the number and names of the site locations throughout Dubai City where diffusion tubes were collected during 1996 and 1997.

Table 6.1 The site location in Dubai City

LOCATION	SITES
L1	Two sample site at Dubai Municipality
L2	Golf Club
L3	Airport
L4	Mushrif Park
L5	Al Safa Park
L6	Umm Ahrir roundabout
L7	Al Nahda roundabout
L8	Fish roundabout
L9	Bu Khadrah roundabout
L10	Jebel Ali municipality
L11	Jebel Ali Village

The diffusion tubes were exposed in Dubai City for two weeks. However, due to sampling difficulties, such as losing the tubes by destruction or removal from the sites by visitors, this period may vary from one to two weeks longer or shorter, by a small degree.

6.3 The effects of missing data

Some measurement values are missing for different reasons e.g. removal and destruction of the diffusion tube at the site during fieldwork. Other reasons included loss of the tubes in the transportation process from Liverpool to Dubai, or vice versa. The final results from the diffusion tube show that the missing data occurred at several sites during the sample period. For instance there is substantial missing data at L3 (Airport).

To test the effect of the missing the average and coefficient of variation COV% were compared between sites with and without missing data. The result shows that there was no difference in the final results. In other words, there was similarity in total results either calculated with the missing data or without between the means, standard division and COV% of NO_2.

Fig 6.1 Concentration of NO_2 at the Airport

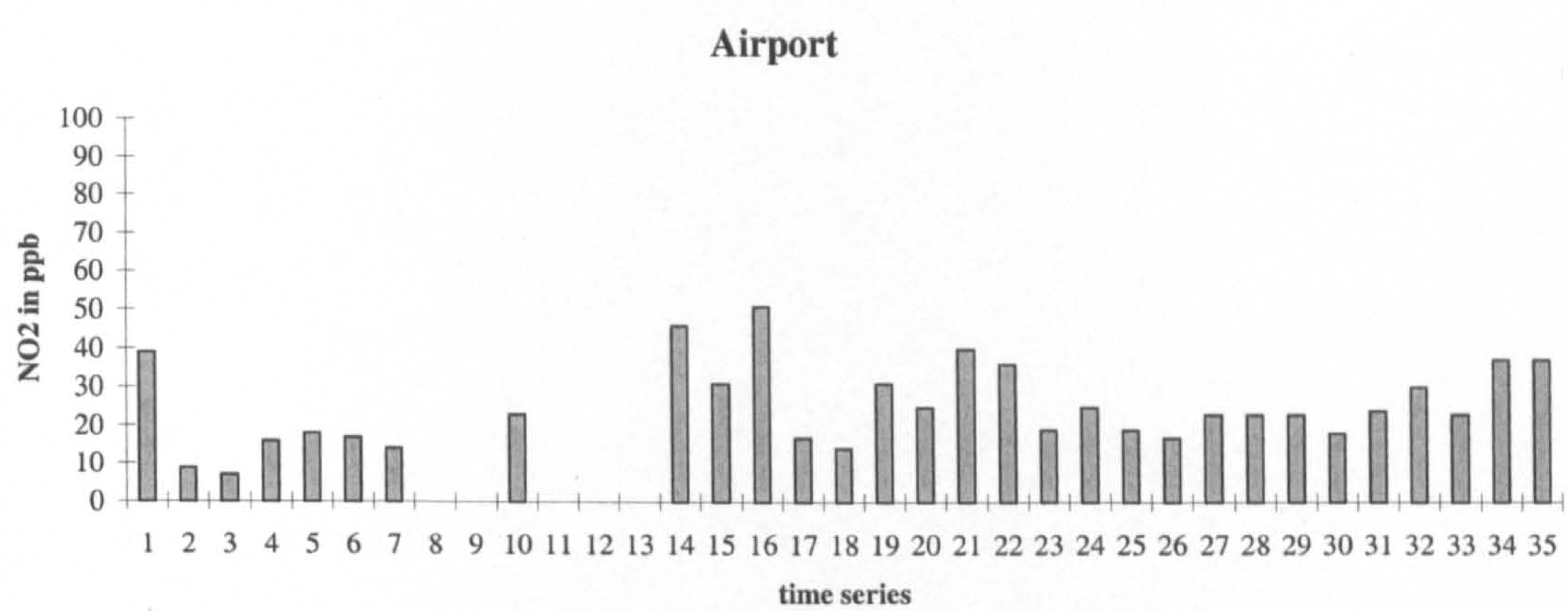


Figure 6.1 shows the airport site, which has the highest number of the missing data compared with all other locations, due to re-building the airport area, which made difficulties for the person who was responsible for changing the diffusion tubes at the airport. The sample site was relocated to the airport periphery, but close to the highway.

The mean concentration of NO_2 is 25 ppb and the COV% is 43 which is slightly high in comparison with other sites.

On the other hand, the highest mean of NO_2 concentration values were found near the roundabouts in the urban area, which were affected by high traffic density (see Fig 6.2 below). The mean values of NO_2 concentration for the roundabouts ranged from 38 ppb to 48 ppb, with Umm Ahrir roundabout recording the highest average of NO_2 concentrations, ranging between 24ppb and 76ppb. The Umm Ahrir roundabout is located in an urban area with a very busy road. Bu Khadrah roundabout shows the lowest average of NO_2 concentration in comparison with other roundabouts (see Table 6.2). Bu Khadrah roundabout is located south-east of Dubai City, in a suburban area and with busy traffic in particular during Wednesday and Friday, for more see details chapter 3.

Table 6.2 The Mean, S.D, COV%, and value range from the roundabouts

SAMPLE SITE	AVERAGE	S.D	COV%	RANGE
L6-Umm Ahrir Roundabout	**48**	**11**	**24**	**24-76**
L7-Al Nahda Roundabout	**43**	**12**	**27**	**25-66**
L8- Fish Roundabout	**45**	**12**	**27**	**25-75**
L9- Bu Khadrah Roundabout	**38**	**11**	**24**	**26-57**

Fig 6. 2 Concentration of NO_2 from different roundabout sample sites

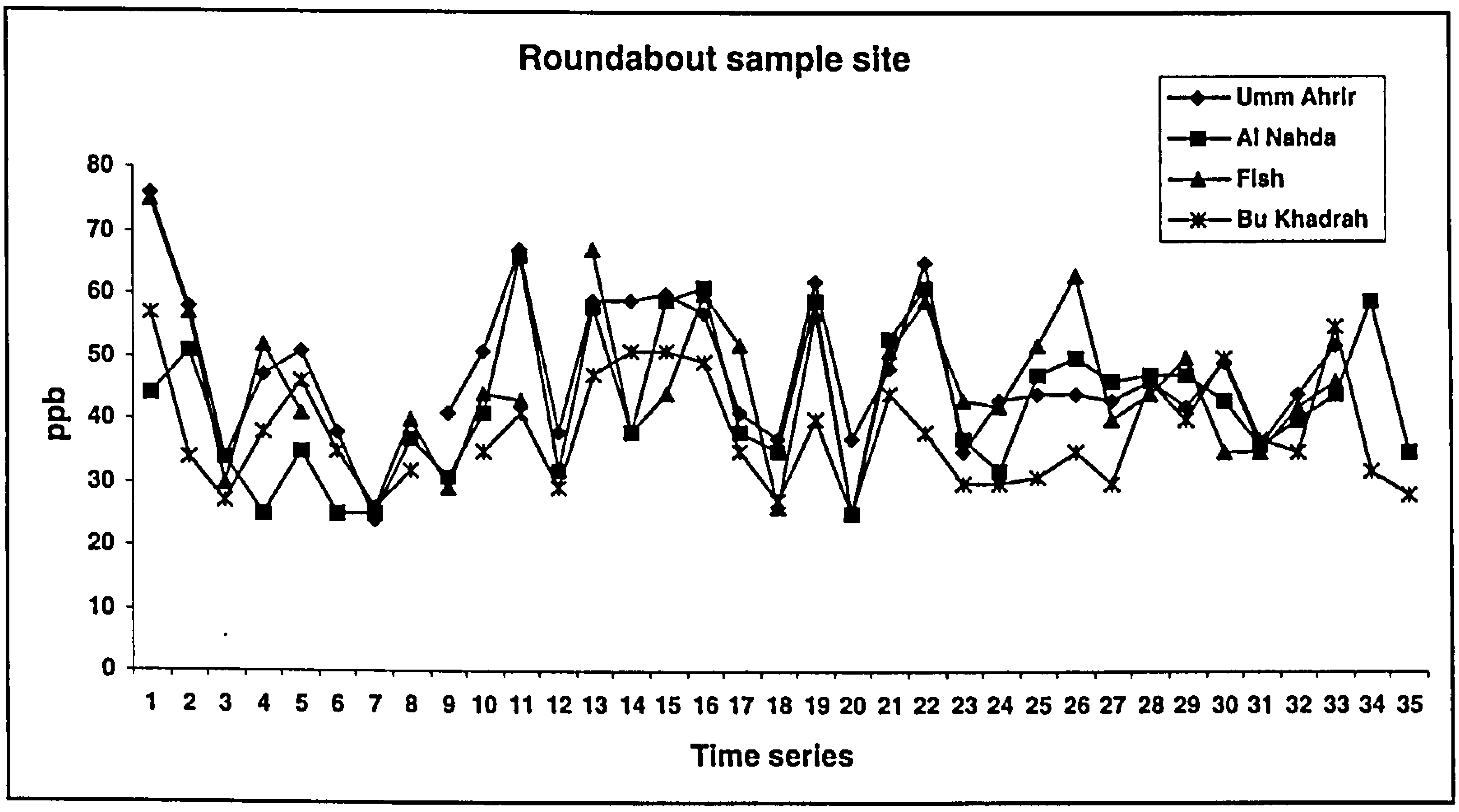


Figure 6.2 shows the concentration of NO_2 at four different roundabouts in Dubai City. As can be seen from Figure 6.2 three of the roundabouts L6, L7 and L8 recorded the highest concentration of NO_2, while L9 had a slightly lower concentration compared to the other three roundabouts. However, there is similarity in the peaks and dips between the four site concentrations.

On the contrary, the commercial and urban area L1 (Dubai Municipality), urban and residential area L2 (Al Safa Park), and the urban area near to high traffic L3 (Airport) shows low concentrations of NO_2. The average concentration of NO_2 ranged from 23 ppb to 26 ppb.

The low results of NO_2 concentrations were also found in the industrial area L10 (Jebel Ali Port) and urban, resident and have low traffic density but close vicinity to power station such as L11 (Jebel Ali village). The mean of NO_2 concentration at L10 was found to be16 ppb, while the mean NO_2 concentration at L11 was found to be 21 ppb.

Summary;

In general, measurement of NO_2 was conducted throughout Dubai City, the sample sites were carefully selected to represent different locations, which might be influenced by the sources of NO_2. The sample sites included the airport, industrial and power plant areas, high traffic density areas, commercial areas, and suburban areas with low traffic density such as national parks. Changing the sample location twice at the Airport caused a higher COV% 43. The change happened after several runs of experiments when the site was moved from the area between landing and takeoff to the airport periphery and close to a busy road. There is no evidence that the missing data affected the final result of the diffusion tubes.

6.4 Data variability

Fig 6.3 Coefficient of variation of diffusion tube data.

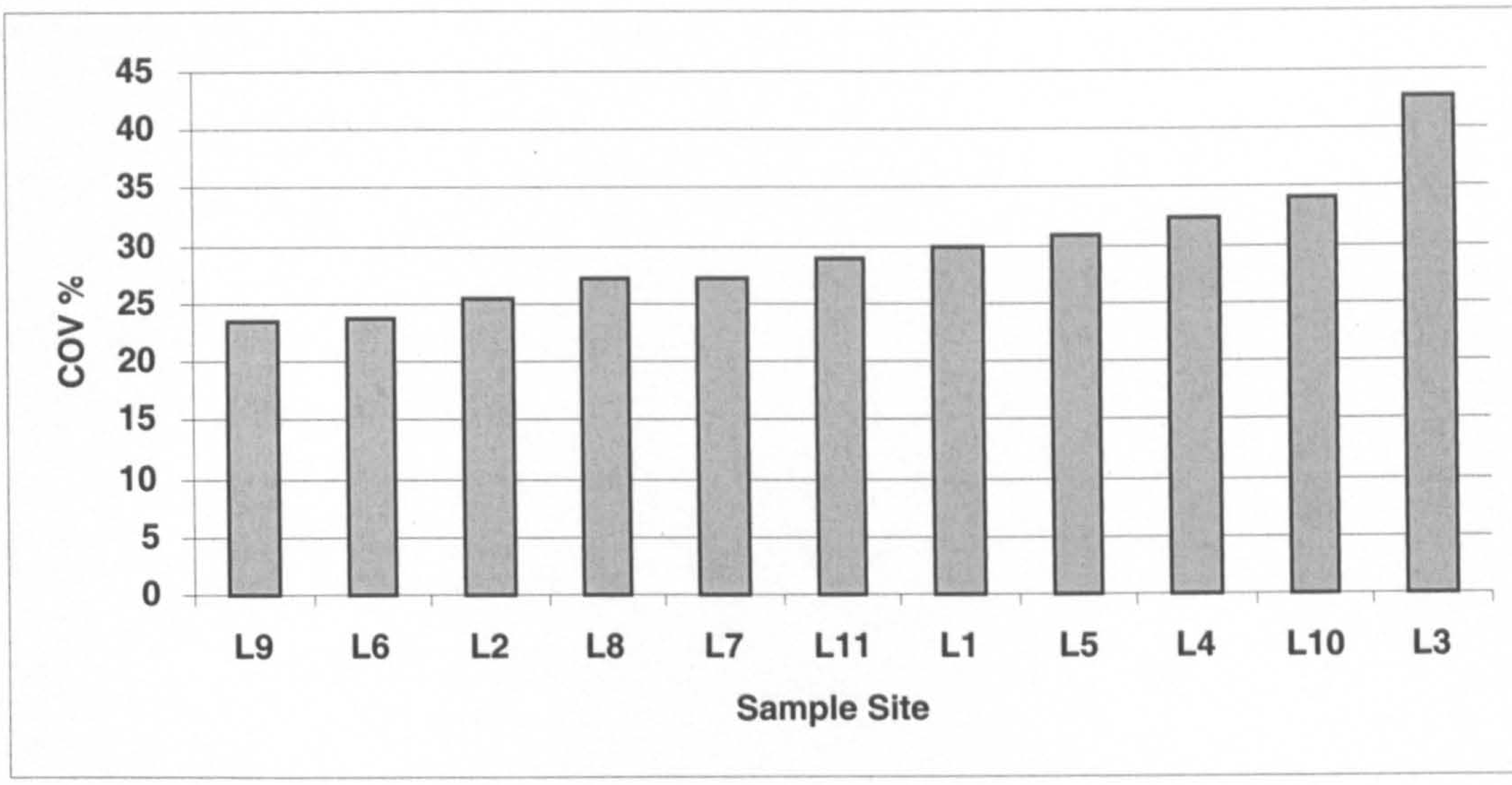


Figure 6.3 shows the coefficient of variation COV% of NO_2 concentration throughout the sites in Dubai City. As can be seen from Figure 6.3 there is little variation between the eleven sites. However, the highest percentage of 43% was found at L3 (Airport), where the values ranged from 7ppb to 46ppb. The second highest percentage of 34% was found at L10 (Jebel Ali village), where the values ranged from 4ppb to 30ppb.

Mushrif Park (L4) was 32 %, the value ranged between 4 ppb and 21 ppb. Which is high concentration compared with all other sites. The concentration in Mushrif Park was obtained, because the whole area located far away from the main sources of NO_2. At the same time Mushrif Park is near to the desert, which has typical hot weather for seven months of the year (hot and humid in the summer, cold and dry in winter).

On the other hand, it is clear that the sites which have highest level of NO_2 e.g. roundabouts (L6, Umm Ahrir roundabout, L7 Al Nahda roundabout, L8 Fish roundabout and L9 Bu Khadrah roundabout) have the lowest value of COV%.

6.5 Frequency distribution

Fig 6.4 Histogram Distribution of NO_2 in ppb for all measurment across all sites.

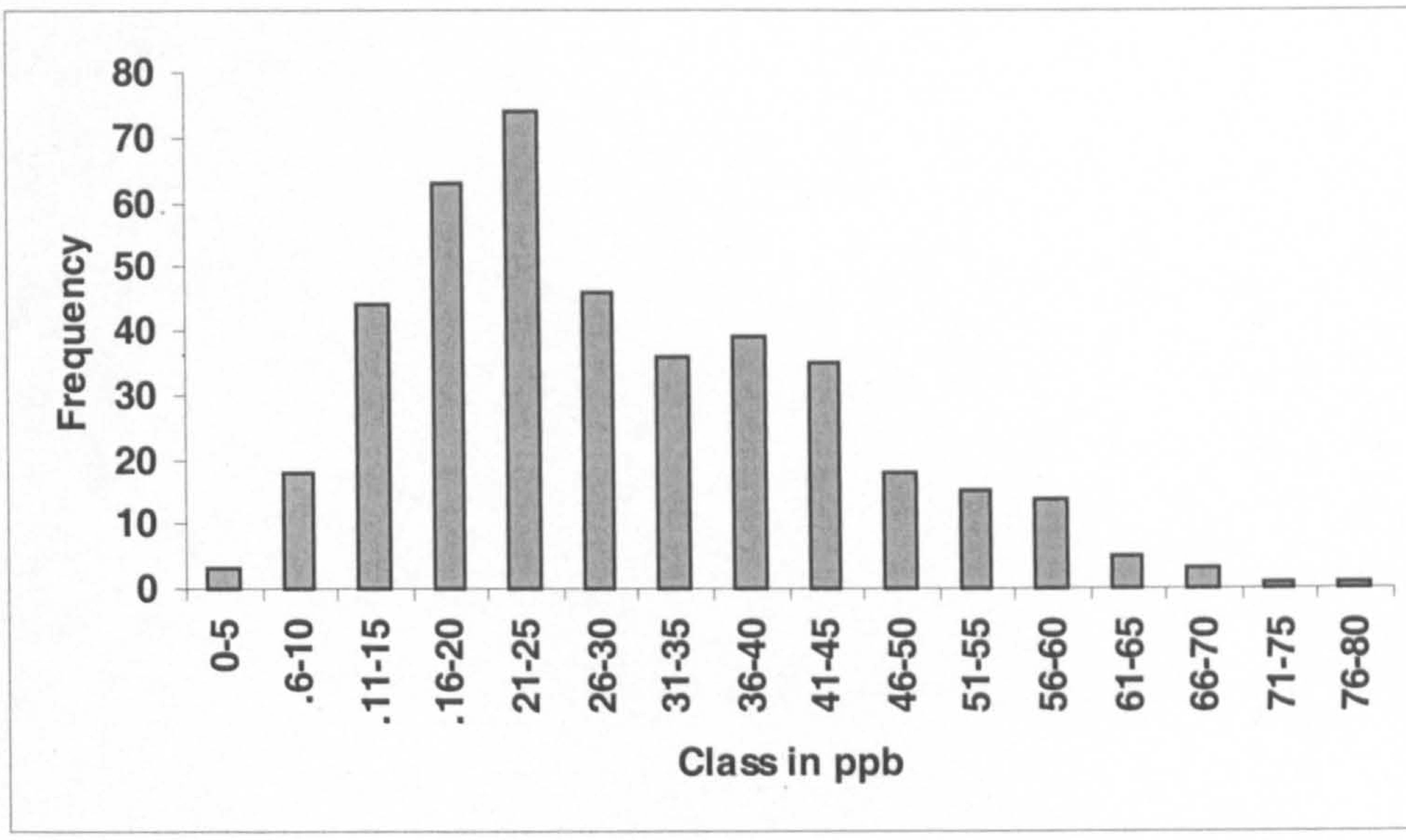


Figure 6.4 shows histogram distribution with a mean of 27.7 ppb, a median of the class interval of 26-30 ppb and a modal value in the class interval of 21-25 ppb. This indicates that the data have a positive skewed non-normal distribution. The reason for this may be due to plotting NO_2 concentrations from non-similar sources, e.g. the values for the sites adjacent to the roundabout are expected to be higher than the values from outside the city centre. The skew is 0.7. Thus the skewed distribution shown in Figure 6.4 may result from a combination of several normal distributions. This is supported by the distributions observed at each site (below) which are less skewed.

Fig 6.5 Mushrif Park sites

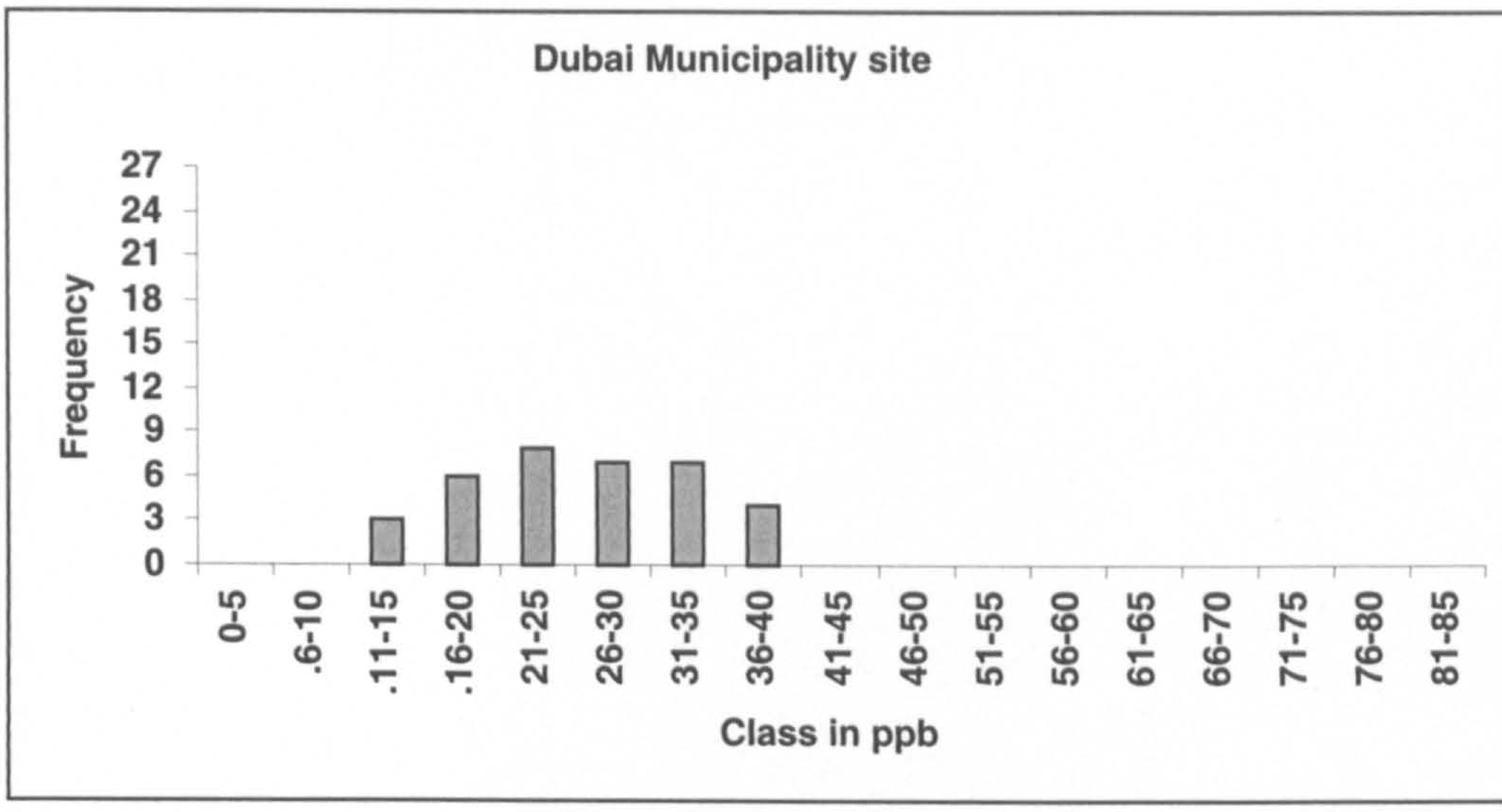


Fig 6.6 The roundabout sites.

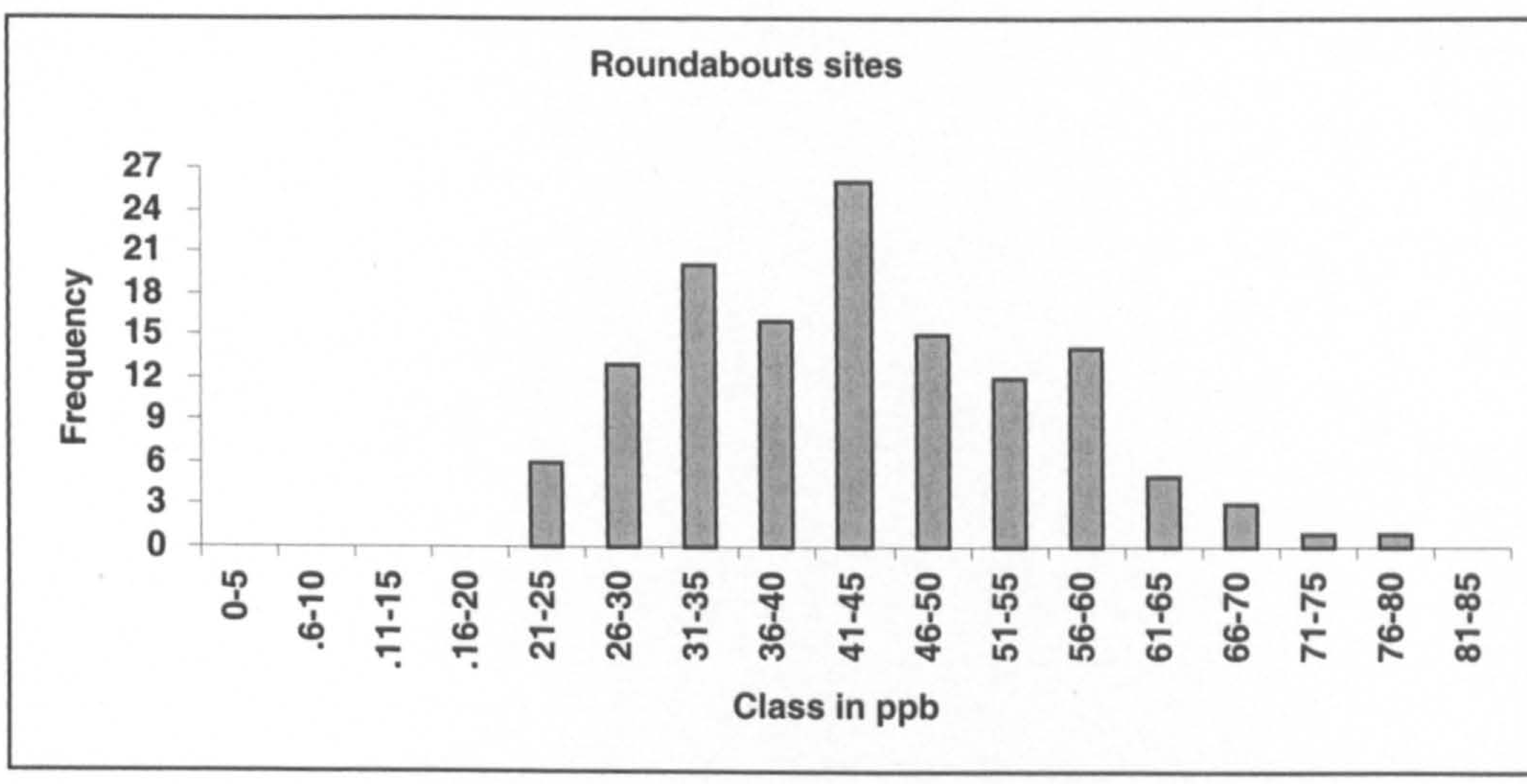


Fig 6.7 Dubai municipality site.

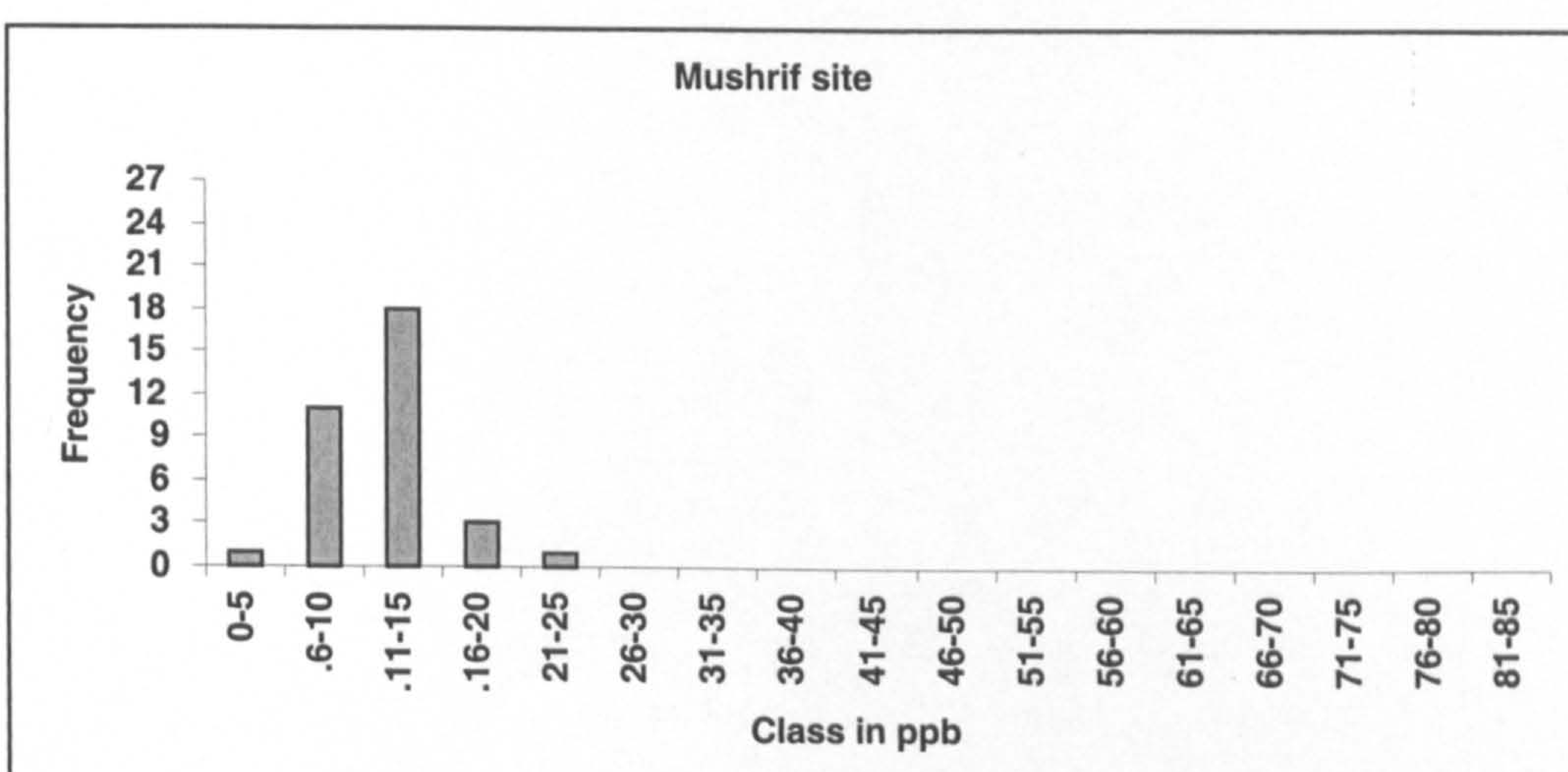


Figure 6.5 shows the result of the data which were collected from Mushrif Park in Dubai City. It indicates that this Park is the cleanest place in Dubai with the low concentrations of NO_2. This could be due to either the fact that Park is not effected by human activities or being far away from sources of NO_2.

Figure 6.6 shows the result of the data collected from all the roundabout sample sites, Umm Ahrir, Al Nahda, Fish and Bu Khadrah roundabouts. It is clear from the Figure 6.6 that the values of NO_2 are concentrated in the class interval of 41-45 ppb. However, this group has no values recorded in the class interval of 0-5 ppb and the class interval of 16-20 ppb. At the same time, this class represents the highest values of NO_2.

Figure 6.7 shows the most typical concentrations that could be found in Dubai City. This typical concentration was recorded from Dubai municipality site which is surrounded by buildings and is located nears a busy area. The value of NO_2 concentration shows the similar magnitude in each of ppb classes.

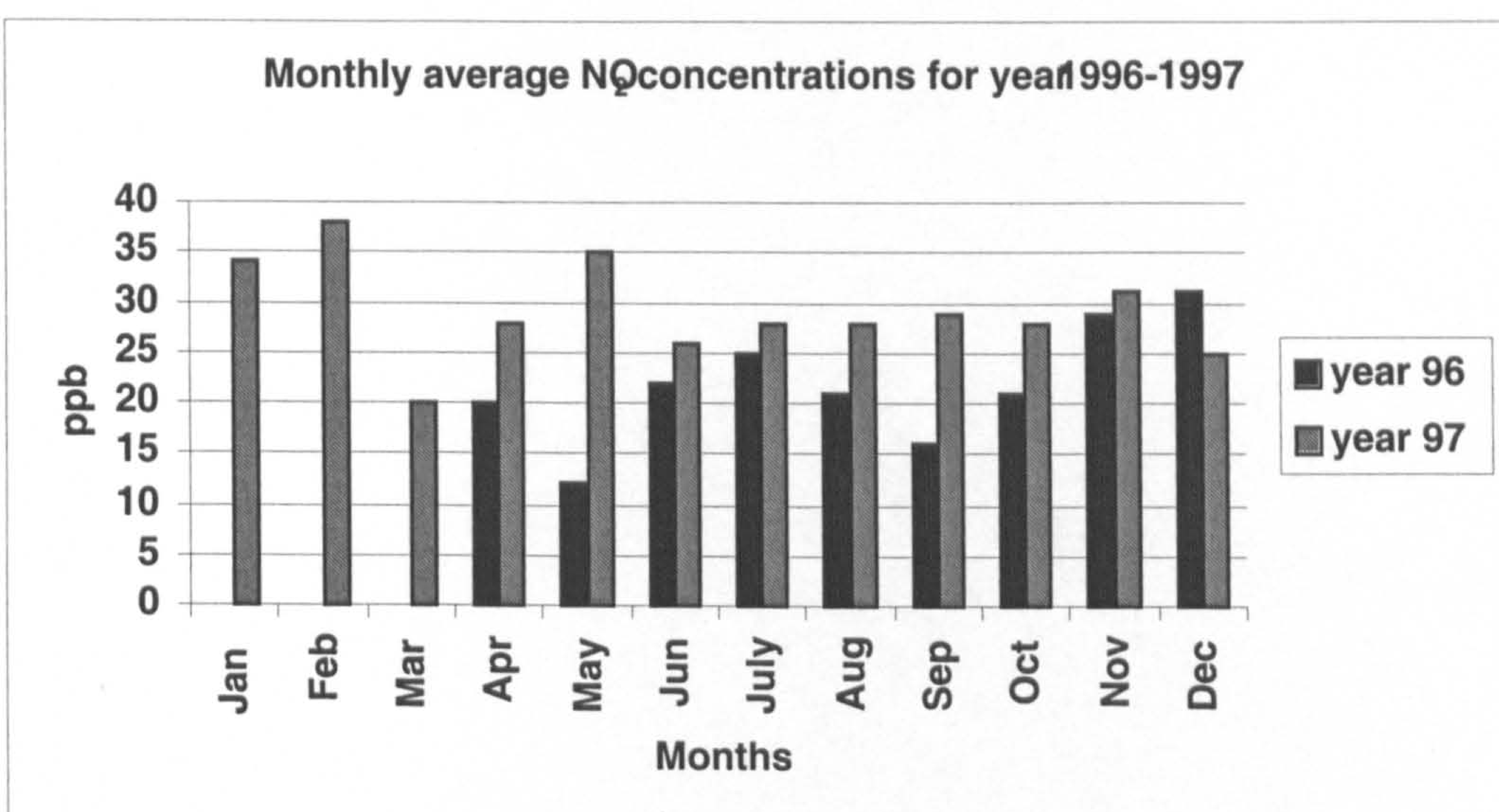
Summary;

There are significant differences in the NO_2 concentration distribution between sites in Dubai City, as the sites are located in different part of Dubai. Although the combined data set for all NO_2 concentration measurements is positively skewed at each site, the distribution is approximately normal. It was found that the lowest level of NO_2 was recorded in location far away from the city centre and close to the desert e.g. Mushrif Park, while the highest levels were found at the roundabout sites. Two or more separate populations may be present due to meteorological conditions or seasonal differences of wind direction or wind pattern. Another possible reason for this difference may be the varying temperatures between daytime and nighttime, during the two weeks of sampling.

6.6 Temporal variability

The monthly average of the NO_2 concentrations during year 1996 together with the monthly average of year 1997 are represented in Figure 6.8. As can be seen from Figure 6.8 there is a significant seasonal pattern occurs in the NO_2 concentrations during the experiment period. Average winter months NO_2 concentration is higher than summer months NO_2 concentrations. During 1996 the lowest NO_2 concentrations occur during summer months in May and September, the monthly average is 12ppb in May and 16ppb in September. While winter months of November and December shows the higher NO_2 concentration. The monthly average is 29ppb and 31ppb. During 1997 there is little variation for NO_2 concentration between the summer months, while the winter months also reveal to high concentrations.

Fig 6.8 Monthly average of NO_2 concentration during year 1996-1997

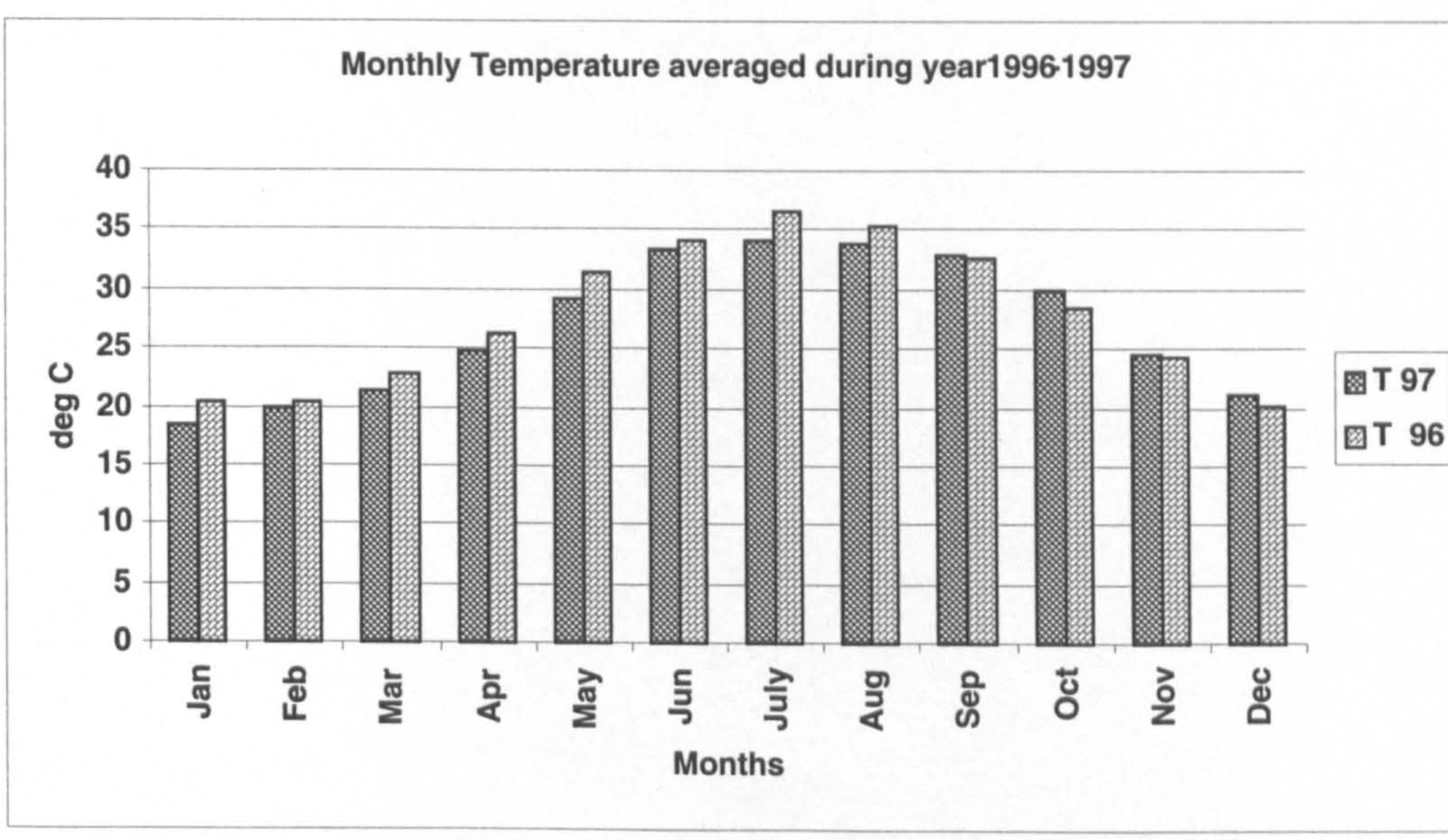


At the same time Table 6.3 was created from the monthly average for NO_2 concentrations together with monthly average of meteorological parameters. Tables 6.3 show that the monthly average of different meteorological parameter shows no significant monthly variations occurs between 1996 and 1997. However, there is less pattern during 1996 than year 1997. For more details see Figure 6.9.

Table 6.3 monthly NO_2 concentration and monthly meteorological parameters

MONTH	YEAR 1996				YEAR 1997			
	NO_2	T °C	RH %	Wind speed knots	NO_2	T °C	RH %	Wind speed knots
Jan		20	73	7	34	19	68	6
Feb		20	73	7	38	20	66	7
Mar		23	72	9	20	21	67	7
Apr	20	26	59	7	28	25	61	6
May	12	31	47	6	35	29	53	7
Jun	22	34	55	8	26	33	55	7
July	25	37	46	7	28	34	61	8
Aug	21	35	54	7	28	34	64	7
Sep	16	33	65	7	29	33	63	6
Oct	21	29	58	6	28	30	58	6
Nov	29	24	59	7	31	24	67	6
Dec	31	20	64	6	25	21	66	6

Fig 6.9 Monthly average of Temperature during 1996-1997



6.7 Correlation analysis

In order to determine whether the NO_2 concentration from one site could be used to predict the NO_2 concentration at another site, the correlation between two selected sites and all the sites has been calculated. The two sites selected are Dubai Municipality and Jebel Ali.

Dubai municipality is representative of a site in busy areas, but is not close to the kerbside. Jebel Ali Port is representative of the sites in an industrial area, located west, on the edge of the Emirate of Dubai and far from the city centre.

The distances in (km) between Dubai municipality and the other sites have been calculated together with the distance between Jebel Ali Port and the other sites. These are presented below in Table 6.4. The information, which is shown in Table 6.4 has been used together with data in Table 6.5 and Table 6.6 to created Figures 6.10 and 6.11.

Table 6.4 Distance (km) between Dubai municipality and Jebel Ali port and the sites

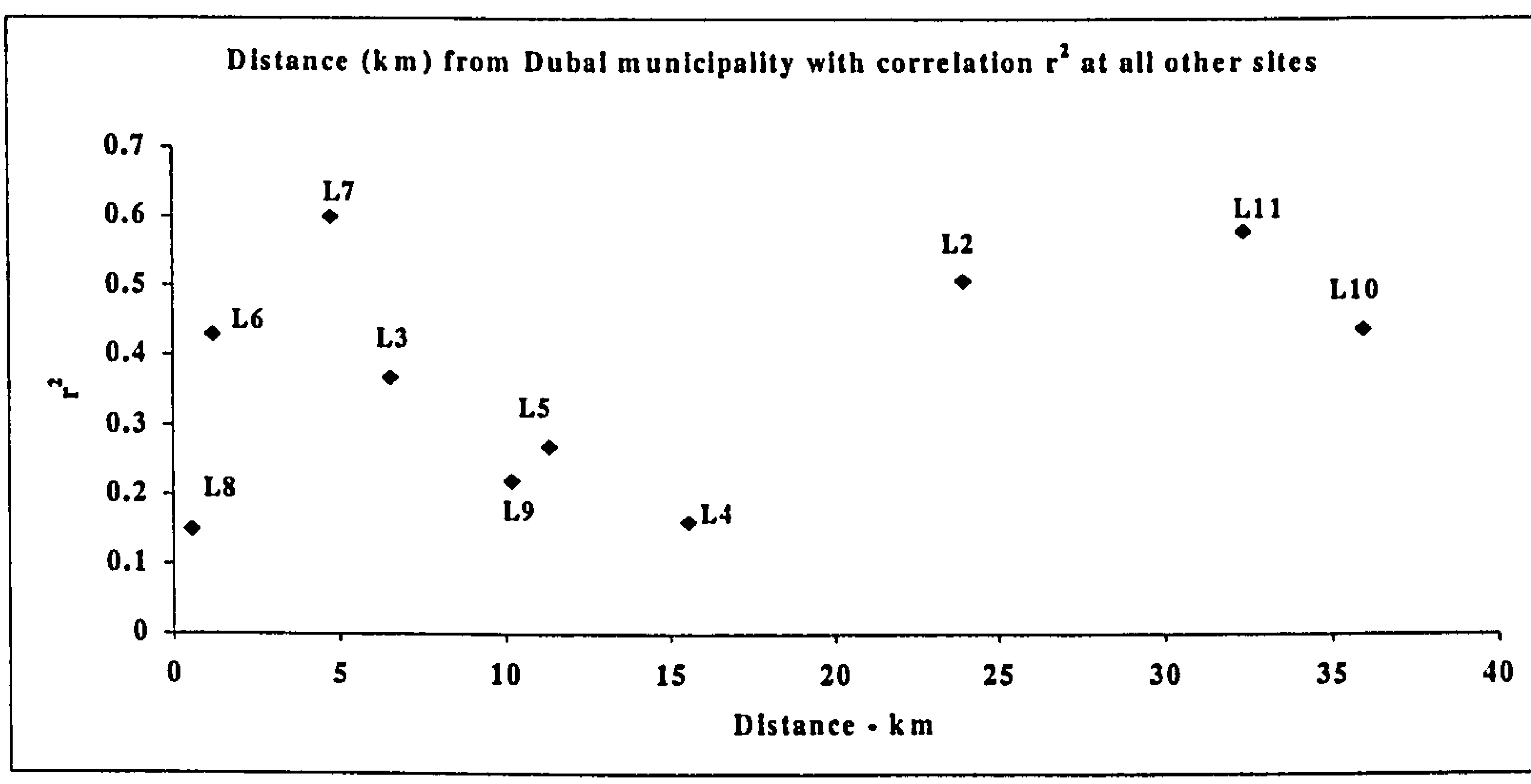
SITE	L1	L2	L3	L4	L5	L6	L7	L8	L9	L10	L11
Dubai municipality	_	24	6.6	15.6	11.4	1.2	4.8	0.6	10.2	36	32.4
Jebel Ali port	36	12	37.2	40.6	24.6	34.8	39.6	36.6	38.8	_	4.2

Table 6.5 shows r^2 values at Dubai municipality against the other 10 sites. Figure 6.10 shows the r^2 value as calculated between the data at the Deira site and the other 10 diffusion tube sites, plotted with their distance from Deira.

Table 6.5 Correlation r^2 between Dubai municipality and the other sites

LOCATIONS	r^2	RELATIONSHOP
L2 Golf Club	0.52	Significant positive relationship
L3 Airport	0.37	Significant positive relationship
L4 Mushrif Park	0.16	Significant positive relationship
L5 Al Safa	0.27	Significant positive relationship
L6Umm Ahrir roundabout	0.43	Significant positive relationship
L7 Al Nahda roundabout	0.61	Significant positive relationship
L8 Fish roundabout	0.15	Significant positive relationship
L9 Bu Khadrah roundabout	0.22	Significant positive relationship
L10 Jebel Ali Port	0.44	Significant positive relationship
L11 Jebel Ali village	0.58	Significant positive relationship

Fig 6.10 Distance in (km) from Dubai municipality against r^2 from the other sites



There is a significant and strong positive relationship between Dubai municipality and sites far from city centre i.e. L7 (Al Nahda roundabout) $r^2 = 0.61$, L11 (Jebel Ali village) $r^2 = 0.58$, and L2 (Golf Club) $r^2 = 0.52$ and a substantial correlation occurs at L10 (Jebel Ali Port) $r^2 = 0.44$ and L6 (Umm Ahrir roundabout) $r^2 = 0.43$. On the other hand there were weak correlations but significant with L9 (Bu Khadrah roundabout) $r^2 = 0.22$ and L4 (Mushrif Park) $r^2 = 0.16$. Figure 6.10 shows that NO_2

for most cases there is high correlation of concentrations between sites close to Dubai municipality.

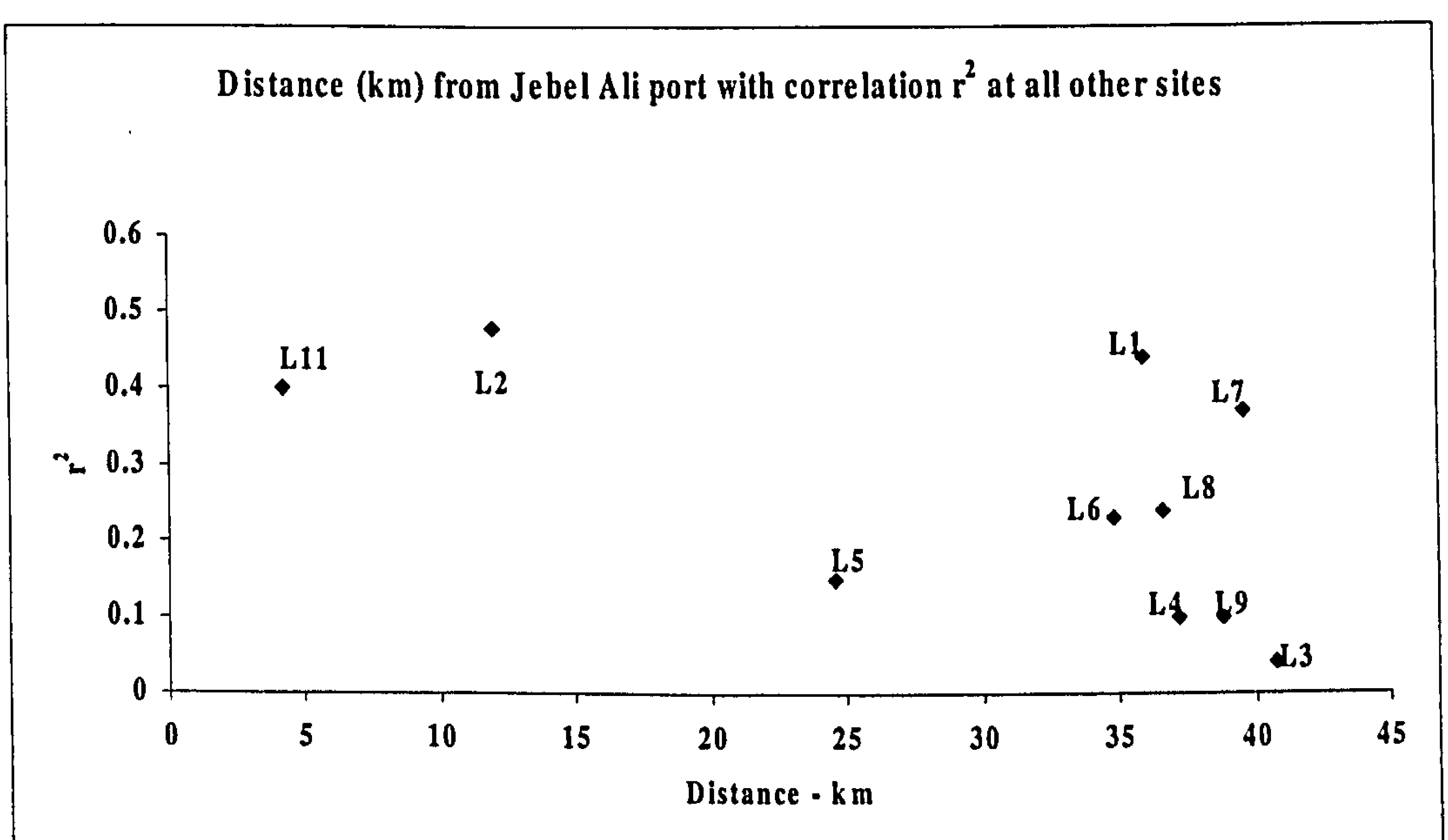
Table 6.6 shows r^2 values at Jebel Ali Port against the other 10 sites. Figure 6.11 shows the r^2 distributions in km and NO_2 based on the distance at Jebel Ali Port.

Table 6.6 Correlation r^2 between Jebel Ali port and the other sites

LOCATIONS	r^2	RELATIONSHOP
L1 Dubai municipality	0.44	Significant positive relationship
L2 Golf Club	0.48	Significant positive relationship
L3 Airport	0.10	Significant positive relationship
L4 Mushrif Park	0.46	Significant positive relationship
L5 Al Safa	0.15	Significant positive relationship
L6Umm Ahrir roundabout	0.23	Significant positive relationship
L7 Al Nahda roundabout	0.37	Significant positive relationship
L8 Fish roundabout	0.03	No Significant relationship
L9 Bu Khadrah roundabout	0.10	Significant positive relationship
L11 Jebel Ali village	0.40	Significant positive relationship

There is a significant and substantial positive relationship between Jebel Ali port and sites close by, and a significant but weak positive relationship between Jebel Ali port and far sites i.e. L4 (Mushrif Park) $r^2 = 0.46$, L11 (Jebel Ali village) $r^2 = 0.40$ and L1 (Dubai municipality) $r^2 = 0.44$ and L2 (Golf Club) $r^2 = 0.48$.

Fig 6.11 Distance in (km) from Jebel Ali municipality against r^2 from the other sites



At the same time Figure 6.11 shows that between close sites to Jebel Ali Port there are correlation, while the sites far away from Jebel Ali showed no correlation.

Summary;

During the experimentation period of 1996-1997 a significant seasonal pattern of NO_2 concentrations was found. The average NO_2 concentration for winter months is higher than for the summer months, particularly during November and December, when the higher NO_2 concentrations occurred. However, the monthly average meteorological conditions reveals no significant variations between the years 1996 and 1997.

The correlation of average NO_2 concentration with the distance from two sites, i.e. Dubai Municipality and Jebel Ali, were tested. The reason were to determine whether the NO_2 concentration from one site could be used to predict the NO_2 concentration at another sites.

Chapter Seven

Analysis of Ozone Variation

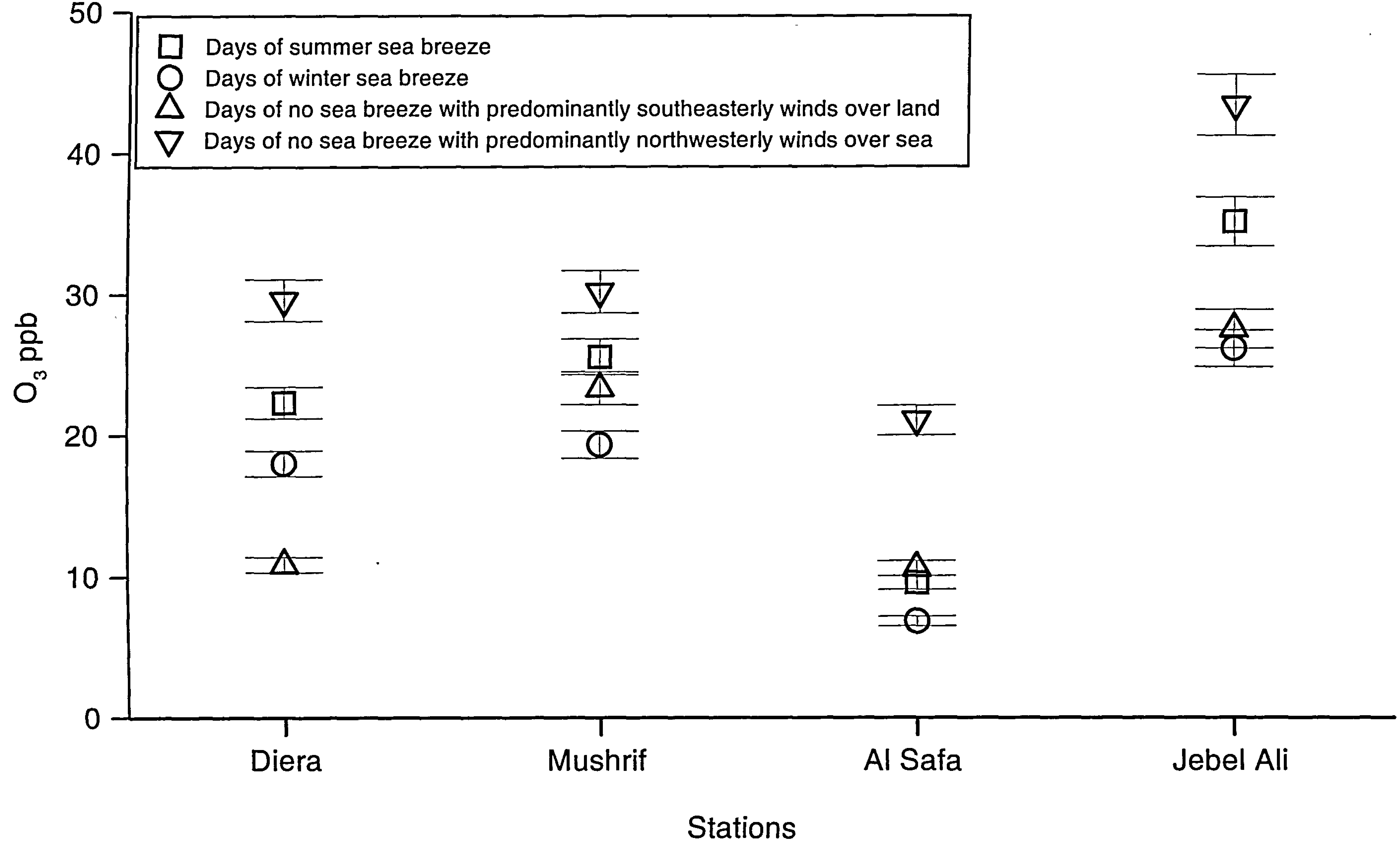
7.1 Introduction

The gas monitoring data from the Dubai Municipality network has been analysed statistically. This study tests the hypothesis that there is no difference in the pollution levels between the different monitoring sites during each of the different day types of wind pattern. The average daily O_3 concentrations for different day types of wind pattern are presented, followed by details of hourly variability of O_3 concentrations. The experimental data were subdivided into average concentration for daytime and nighttime for the four day types (see Fig 7.2), which are compared. This is followed by a more detailed analysis of hourly average data by day type. The hourly average of NO_2 and NO concentrations at Deira and Jebel Ali village stations during the four different day types of wind pattern are also presented

The meteorological data such as wind direction, wind speed, temperature and vapour pressure from Dubai International Airport have been analysed statistically.

Correlations were calculated between different meteorological variables and O_3 concentrations by using average hourly data during different day types of wind pattern. Finally, two days were selected as case studies and are representative examples of hourly O_3 concentrations. The examples are of a summer sea breeze circulation and a day of no sea breeze with a northwesterly wind blowing from the Arabian Gulf.

Fig 7.1 The average of O_3 concentrations for different day types of wind pattern



7.2 The variation of diurnal distribution of ozone concentration

The hourly average O_3 concentration during 24 hours at four different stations located in the coastal zone area at the Emirate of Dubai was analysed. The characteristic of each station was studied in terms of an investigation into the main factors which might affect ozone concentration during daytime and nighttime. Ozone distribution during night hours and day hours was measured to study the effect of the sea breeze circulation on overall levels of O_3.

Figure 7.1 was constructed from hourly average data, which shows average O_3 concentration for composite days of sea breeze at four stations throughout Dubai City, to illustrate the overall picture of ozone concentrations. The standard error of O_3 concentration for each data point is shown by the vertical bar.

In general Figure 7.1 shows a significant variation between the four stations and a significant variation during different days of sea breeze and days of no sea breeze at the experimental area in Dubai. Al Safa station recorded constantly low O_3 concentrations, Jebel Ali village station has constantly high O_3 concentrations, while Deira and Mushrif stations both showed similar ozone concentrations patterns.

At the same time, during days of no sea breeze with northwesterly winds NSBNW, when the speed ranged from 13 to 16 knots, the average O_3 concentrations reaches the highest values. During days of winter sea breeze WSB the average of O_3 concentration showed the lowest level.

Jebel Ali village station, which is located close to the largest industrial area in Dubai, mostly recorded the highest O_3 concentrations during different day types of wind pattern. The biggest variation of O_3 concentration occurred during days of no sea breeze, when the values of the prevailing northwesterly winds NSBNW reached 45ppb. However, the average of O_3 concentration showed small variations between days of winter sea breeze WSB and days of no sea breeze with prevailing southeasterly winds NSBSE, when the values ranged between 25ppb and 27ppb.

Al Safa station which is located in an area of Al Safa national park and surrounded by a residential area, showed the lowest average of O_3 concentrations during days of summer sea breeze SSB and during days of no sea breeze, when the values of the prevailing southeasterly winds NSBSE ranged between 9ppb and11ppb.

Deira station, which is located close to a busy city centre commercial area showed a clear pattern of O_3 concentrations during different day types of sea breeze and days of no sea breezes. The lower value of O_3 concentration recorded during days of no sea breeze with the prevailing southeasterly winds NSBSE varied from 11ppb to 13ppb, while the high concentrations recorded during days of no sea breeze with the prevailing northwesterly winds NSBNW varied from 28ppb to 31ppb.

Mushrif station, which is located inside the Mushrif National Park close to the desert, showed little variation between the highest and lowest levels of O_3 concentrations during different day types of wind pattern. The highest concentration recorded during days of no sea breeze with the prevailing northwesterly winds NSBNW varied from 29ppb to 32ppb, while the lowest concentrations recorded during days of winter sea breeze WSB ranged from 18ppb to 21ppb.

Furthermore, the highest average of O_3 concentration occurred mainly during days of no sea breeze with the prevailing northwesterly winds NSBNW, however, the values were observed to vary between the four stations. At Jebel Ali village station the values were 45ppb, while at Al Safa station the values were 21 ppb, and values ranged between 29ppb and 30ppb at Deira and Mushrif stations.

The lowest average of O_3 concentrations often occurred during days of winter sea breeze WSB, and the lowest winter O_3 average was observed at three stations Jebel Ali village, Al Safa and Mushrif. For more details see Figure 7.1.

Fig 7.2 The average of O_3 concentration during daytime and nighttime

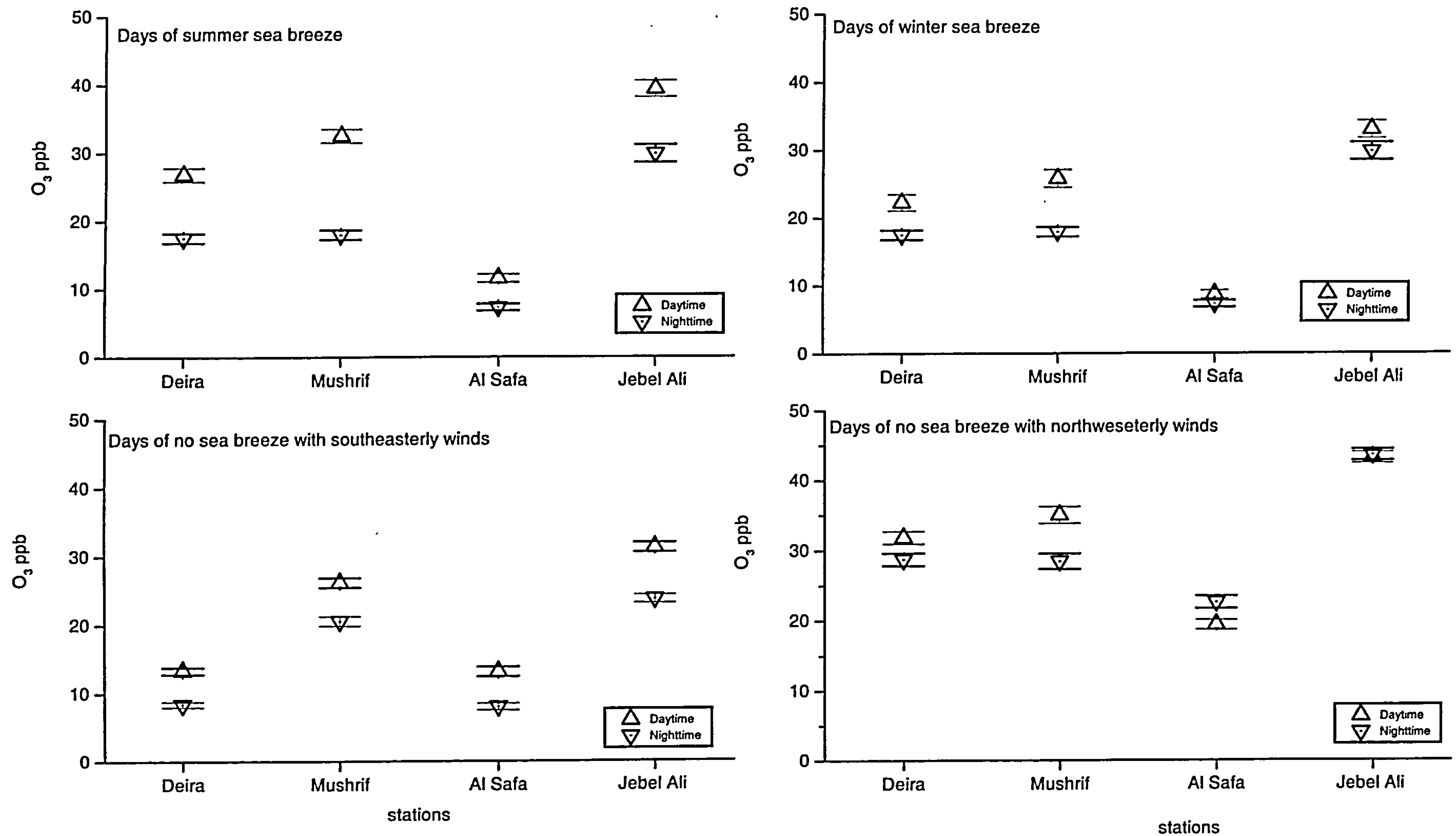


Figure 7.2 shows the average of O_3 concentration during daytime and nighttime during different days types of wind pattern. It is clear that the average of O_3 concentration varies significantly at the four stations during daytime and nighttime.
In general, Figure 7.2 clearly showed that the concentrations of O_3 during daytime are always higher than the O_3 concentrations during nighttime, during the different four days types of wind pattern. The exceptions was at Al Safa station, when the O_3 concentrations were higher during nighttime than daytime, these differences occurred during NSBNW winds. The highest nighttime value was 22 ppb, and lowest daytime value was 20 ppb.

It was noticed that the average O_3 at two stations (Jebel Ali village and Al Safa) showed no patterns between daytime and nighttime concentrations, especially during day types of winter sea breeze and during no sea breeze with prevailing northwesterly winds. The value at Al Safa station was 8ppb, and at Jebel Ali village station the value was 43ppb.
The emission from local sources at these two stations, such as traffic activity and industrial activity, might be the reason of the increase the level of the pollution.

In contrast, the average of O_3 concentrations at Deira and Mushrif stations during three different day types of sea breeze SSB, WSS and NSBNW, showed the same patterns during 24 hours. This is that the daytime concentration at Deira station is always lower than at Mushrif station; however, nighttime O_3 concentrations in both stations were observed to be similar.

Fig 7.3 The daytime hourly average of O_3 concentrations by day types

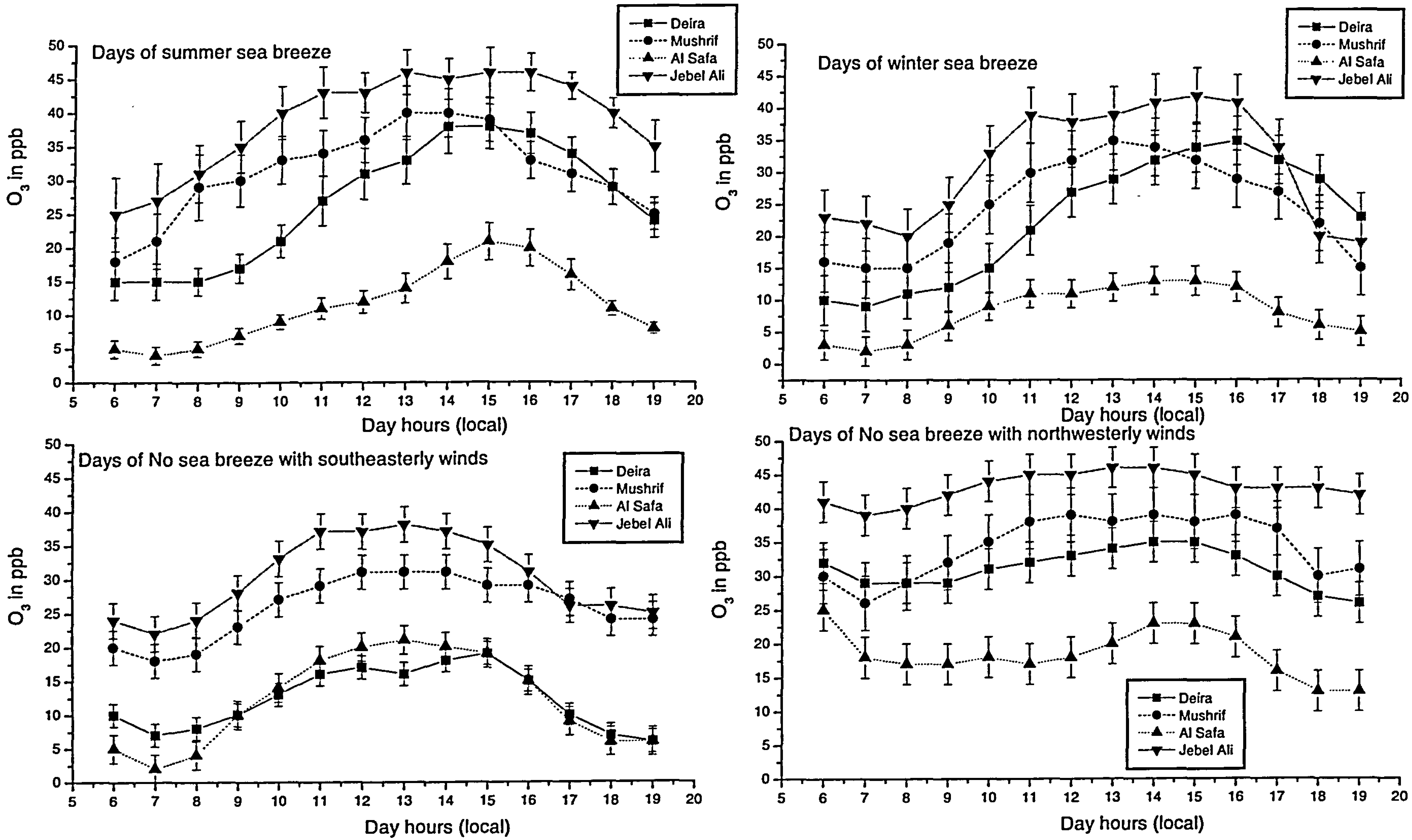


Figure 7.3 shows the distribution of ozone concentration during the day hours, from 06:00 to 19:00 local time, including days of sea breeze and days of no sea breeze at the four stations.

In general, the diurnal variations of O_3 concentrations increased from sunrise until midday-afternoon. Hourly average of daytime O_3 concentrations was greatest during days of no sea breeze with northwesterly winds NSBNW, followed by days of summer sea breeze SSB (see Fig 7.3 d, 7.3 a), while the O_3 concentrations were almost the same during days of winter sea breeze WSB and days of no sea breeze with southeasterly NSBSE winds (see Fig 7.3 c, 7.3 b). It must be noted that, not only the high O_3 concentrations were not expected during days of no sea breeze while both winds northwesterly and southeasterly winds were blowing, but also the small diurnal variation of O_3 during daytime was not expected. At the same time, the daytime peak was also not expected while these two winds were blowing. However, during days of NSBSE winds the peak in daytime occurred between 13:00 and 15:00 local time. While during days NSBNW winds the O_3 concentrations were observed to be higher at all the times and between all the four stations. With a small peak of O_3 between 14:00 and 16:00 local time (Fig 7.3d).

At 07:00 local time the diurnal variation of O_3 levels shows the lowest concentrations during days of SSB and WSB, and days of NSBSE winds. The lowest concentration recorded at Al Safa station around 2ppb, at Deira station the values ranged between 7ppb and 15ppb, at Mushrif the values were ranged between 15ppb and 20ppb, and the value was 25ppb at Jebel Ali village station.

The significant increases of O_3 concentrations occurred from 08:00 local time until late afternoon 3-4 hours after midday. The peak daytime levels occurred roughly around 15:00 local time during days of sea breeze.

Days of NSBNW winds showed relatively high concentrations of O_3 levels at all the stations. The values were 25ppb at Al Safa stations, between 29ppb and 33ppb at Deira and Mushrif, followed by 44ppb at Jebel Ali village station.

The maximum daytime O_3 concentration showed a little variation within each station during different day of sea breeze. However, the daytime O_3 concentrations varied between the four stations during each type of sea breeze, (see Table 7.1) Jebel Ali village station showed the maximum O_3 concentration which varied between 46ppb to 38ppb during different day types of sea breeze. Variations of O_3 concentration were observed at each station. Days of SSB and NSBNW winds showed the highest records between al the four days types of sea breeze for maximum O_3 concentrations. (For more details see Table 7.1 below).

Table 7.1 The peak of daytime O_3 concentration at the four different stations

STATIONS/DAYS	MAXIMUM O_3 CONCENTRATION IN PPB			
	SSB	WSB	NSBNW	NSBSE
Deira	38	35	36	20
Mushrif	40	35	39	33
Al Safa	21	11	23	22
Jebel Ali village	46	43	46	38

Fig 7.4 The nighttime hourly average of O_3 concentrations by day types

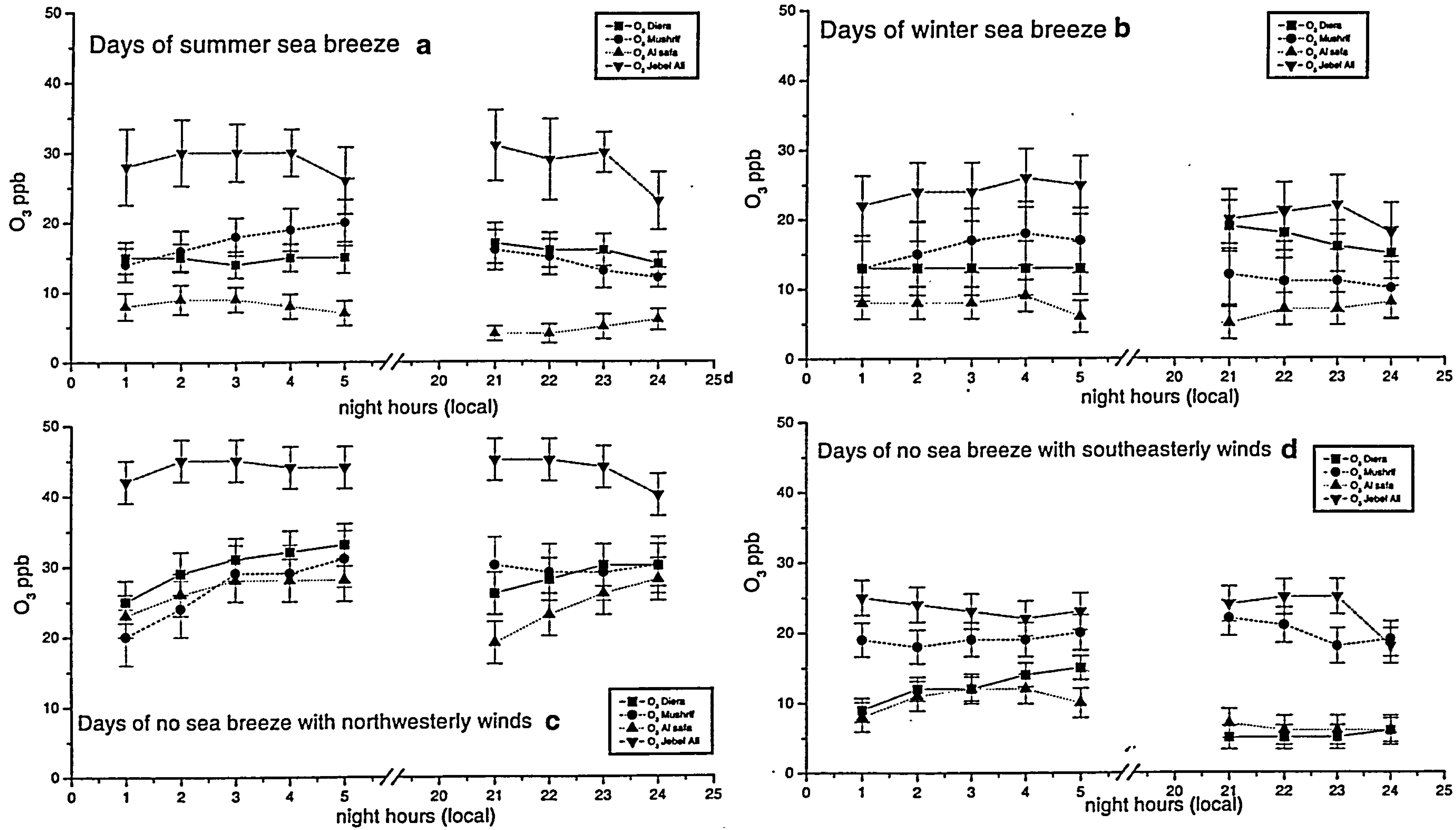


Figure 7.4 shows the distribution of ozone concentration during the night hours, from 19:00 to 05:00 local time. The plots of O_3 concentration at night begin from immediately after sundown until sunrise next day, including different day types of sea and no sea breezes. It is clear that O_3 remains in the atmosphere, and does not decrease to zero levels during night hours for the four categories of day types of sea breeze.

In general, the ozone level seemed to be low during the night hours (Fig 7.4) compared to the O_3 level during day hours (Fig 7.3). In contrast, during days of SSB (Fig 7.4a) and days of WSB (Fig 7.4b), the O_3 concentration ranged between 7ppb and 27ppb. The lowest levels of the night hour's concentration occurred at Al Safa station, while the highest levels occurred at Jebel Ali village station. However, the two stations, at Deira and Mushrif showed different patterns of O_3 concentrations during the night hours, which may be related to their location, or might be due to the circulation of the sea/land breeze.

Nevertheless, in (Fig 7.4a) and (Fig 7.4b) it is clear that at 19:00 local time the concentration of O_3 concentration at Deira station tend to be higher than the concentration of O_3 at Mushrif station. The values at Deira station ranged between 20ppb and 18ppb, while at Mushrif stations the value ranged between 14ppb and 13ppb. In contrast, roughly three hours before the end of the night hours the concentration of O_3 at Mushrif station tend to by higher than the O_3 concentration at Deira station.

The concentration of O_3 during the night hours of different day types of no sea breeze seems to be complicated. Figure (7.4c) and Figure (7.4d) showed that during the night hours O_3 concentrations were higher during days of NSBNW winds than days of NSBSE winds. The greatest difference between day types of night hour's O_3 concentration recorded appeared at Jebel Ali village station Figure (7.4d) where the values ranged between 40ppb and 45ppb. While the three stations Al Safa, Mushrif and Deira, however, little variation in the nighttime O_3 concentration occurred during days of NSBNW winds. Moreover, during the beginning of the night period at 19:00 local time, the constant levels of ozone occurred at those three stations. The values roughly ranged between 25ppb to 30ppb. However, a small increase of night oncentrations was recorded by the end of each night, when value reached up to34ppb.

In contrast, Figure (7.4c) showed that the night time O_3 concentration was much lower and constant at the four stations, with the overall night values of less than 25 ppb. However, by the beginning of the night period, Jebel Ali village and Mushrif stations showed higher levels of O_3 than Deira and Al Safa stations. The similar patterns of O_3 levels between Jebel Ali village and Mushrif might be related to their location, due to both stations relatively located on the edge of Dubai utilization areas, or because NO is produced less during night hours near those stations.

Fig 7.5 The average hourly O_3 concentration at transition periods of day/night during days of sea breeze

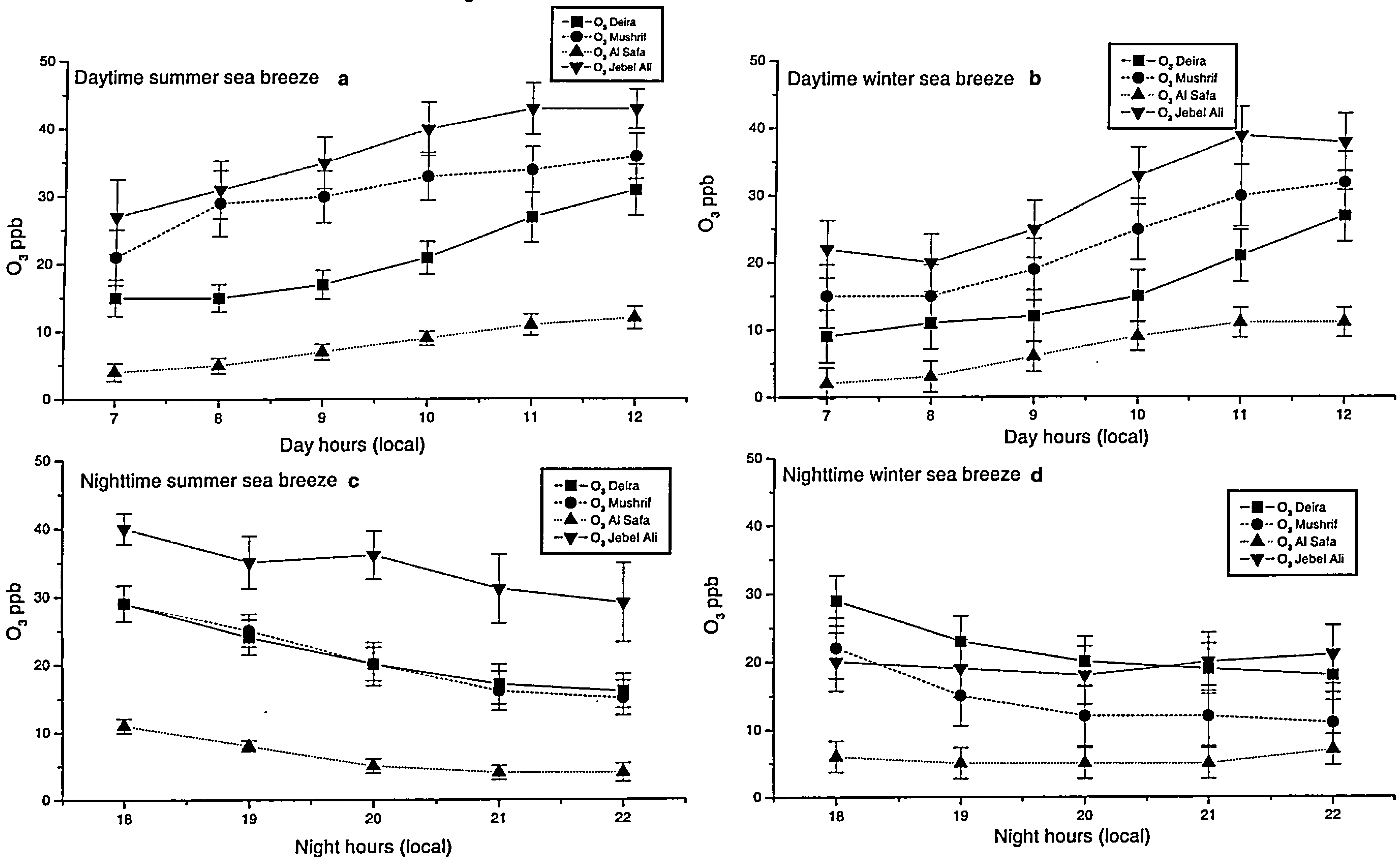


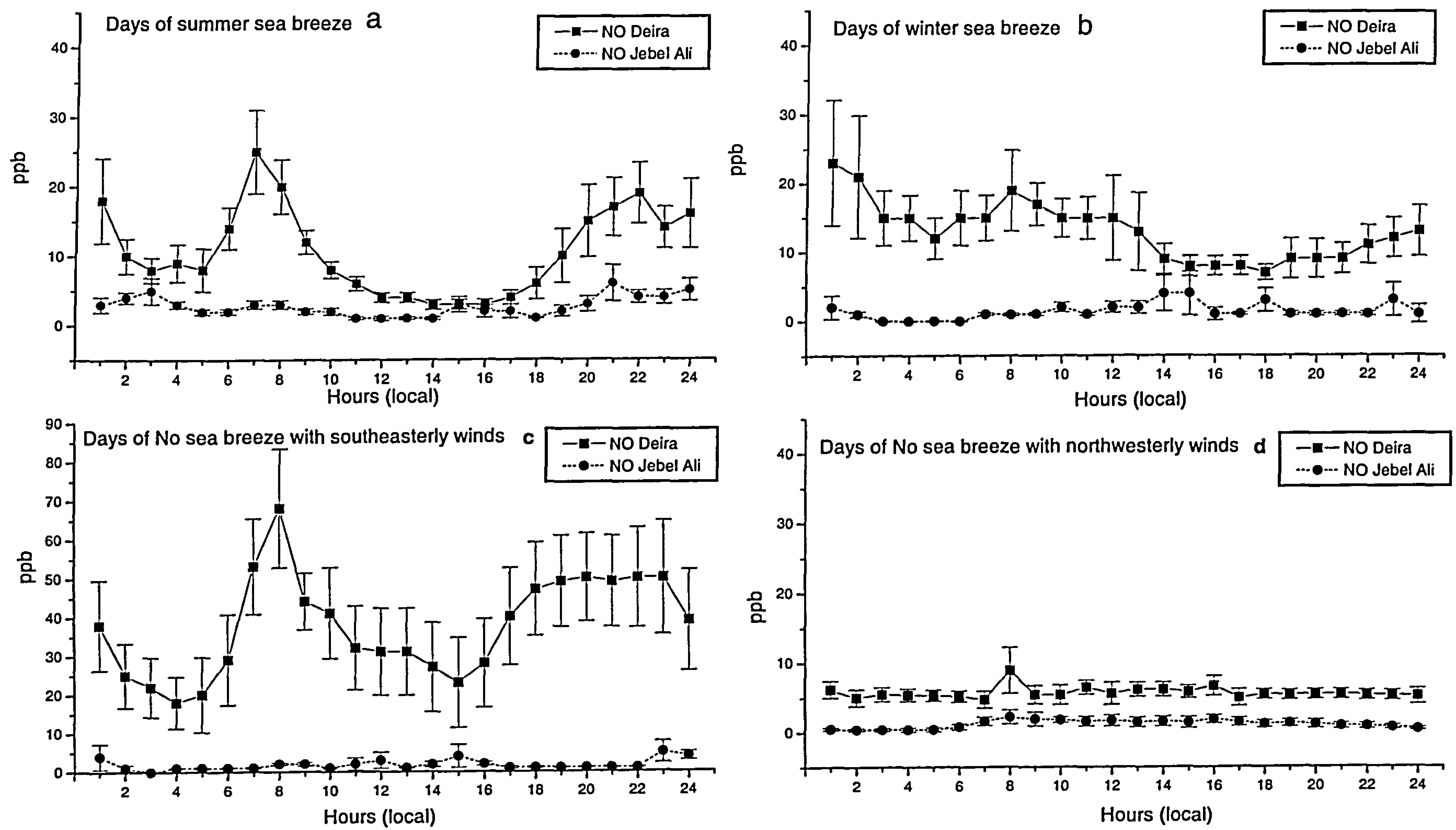
Figure 7.5 shows the transition period and the distribution of O_3 concentration during daytime and nighttime for two days of summer sea breeze and winter sea breeze. The transition period shows a correlation with the circulations of the sea breeze, which are defined as thermal transitions due to the different temperature of air masses over the land and the sea. The first transition occurred during the daytime period, which was observed between 07:00 and 12:00 local time,. (see Fig 7.5a and 7.5b). The second transition occurred during the nighttime period, which was observed between 18:00 and 22:00 local time (see Fig 7.5c and 7.5d).

In general, during the daytime the transition of the sea breeze shows higher O_3 concentration during days of summer sea breezes, more than during days of winter sea breeze. At the same time the increase of O_3 concentration was exhibited earlier during days of SSB than days of WSB. Figures (7.5a and 7.5b) showed that from 08:00 local time the O_3 concentration increased rapidly, and it was calculated that 4ppb O_3 was produced for each degree (1°C). Furthermore, obviously the O_3 was produced faster at Jebel Ali village station than any other station, from 4ppb to 5ppb per one hour, whereas the O_3 concentration at Al Safa station shows a slower increase of 1ppb to 2ppb per one hour. The temperature during summer sea breeze ranged between 31°C and 39°C in particular from 07:00 to 12:00 local time, and increased rapidly by 3° per hour.

It is worth noting here before continuing with the rest of the figures that in UAE there is one hour difference for sunrise between summertime and wintertime.

Figure 7.5b shows the transition period during days of winter sea breeze. It is clear from the graph that the O_3 concentrations were increasing at 08:00 local time, which is correlated with developments of sea breeze. During winter months the temperature ranged between 16°C and 23°C from 07:00 to 12:00 local time, increased by 2° per one hour. O_3 concentrations were also observed to increase by 4 ppb per one hour during days of WSB. Figure (7.5c) shows the nighttime transition period during days of summer sea breeze. It is clear that the O_3 concentration decreases before sunset, although the concentrations show lower values during this period. The average of O_3 concentrations at Deira and Mushrif stations shows a similar decreasing trend. The nighttime temperature recorded was between 34°C and 35°C.

Fig 7.6 The hourly average NO at Deira and Jebel Ali stations



7.3 The distribution of NO_2 and NO during different day types of wind pattern

The average concentration of nitrogen dioxide (NO_2) and nitric oxide (NO) were analysed. These two pollutants were only measured at two stations Deira and Jebel Ali village during years 1996 and 1997.

Figure 7.6 shows the diurnal distribution of NO during different day types of sea breeze at two stations Deira and Jebel Ali village. In general there is no variation of NO concentration at Jebel Ali village during different day types of wind pattern, and values do not exceed 1.5ppb during different day types of wind pattern. However, Deira shows significant patterns of NO concentration during different day types of wind pattern. Figure 7.6a and 7.6c clearly show that the levels of NO concentrations during days of SSB and NSBSE winds reveal more significant variation than days of WSB. At Deira station the maximum average of NO concentrations occurred at 07:00 local time and during the night period particularly after 17:00 local time, which might be directly attribute to the morning and evening rush hours. In addition, the daytime averages of NO concentrations were higher than nighttime.

Figure 7.6 a and 7.6 b shows the concentrations of NO during days of SSB and WSB, when the NO concentration might be increased and controlled by the influences of the sea breeze circulation. In spite of that, during days of NSBSE winds the emission from local sources might affect the NO distribution throughout the 24 hours, due to the absence of sea breeze circulation Figure (7.6c).

Fig 7.7 The hourly avearage of NO_2 concentration at Deira and Jebel Ali stations

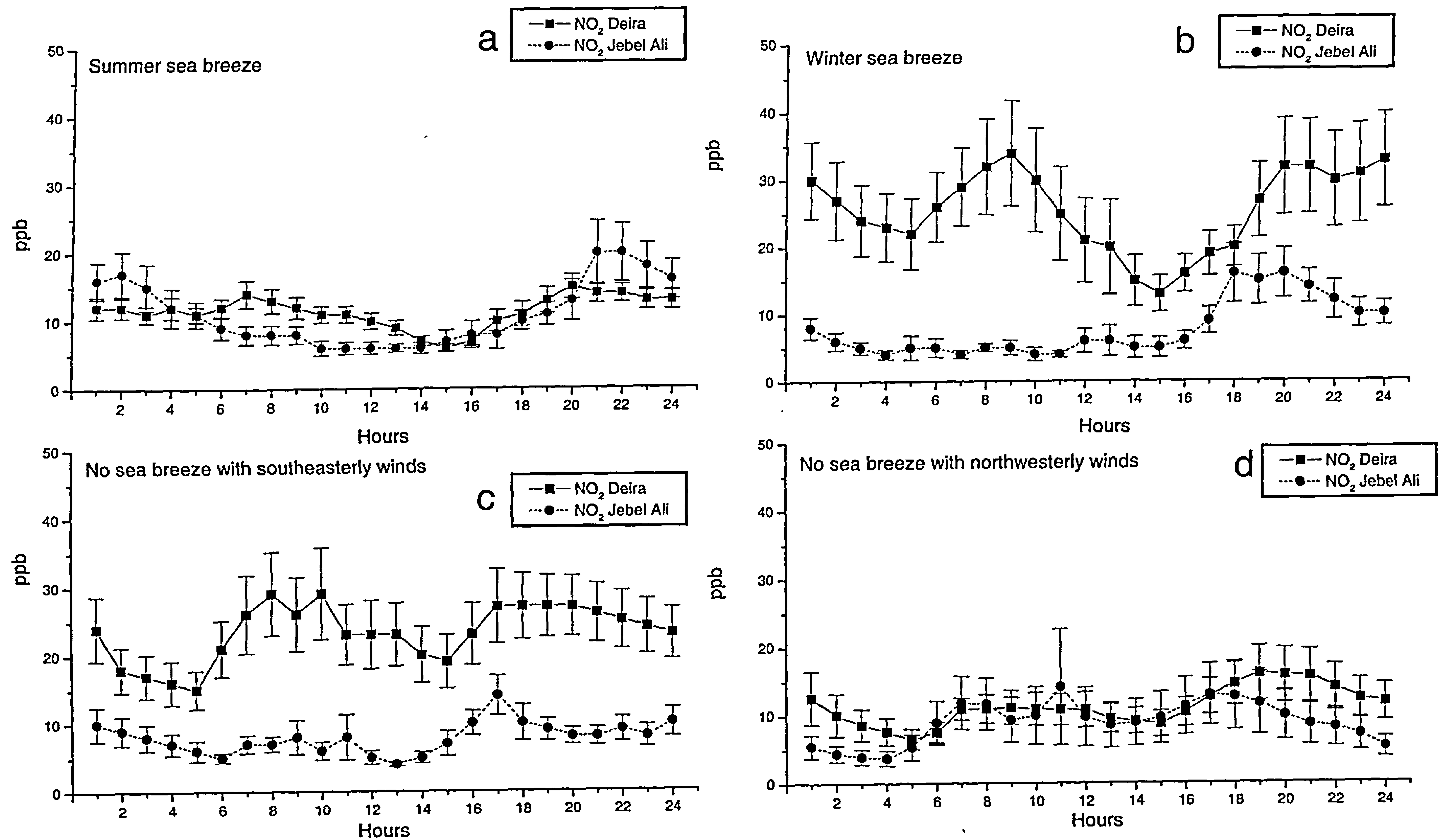


Figure 7.7 shows the diurnal distribution of NO_2 during different day types of wind pattern at the two stations, Deira and Jebel Ali village. In general, the average of NO_2 showed a significant pattern throughout 24 hours during days of winter sea breeze and days of no sea breeze with southeasterly winds.

In contrast, lower levels and less variation of NO_2 concentration were recorded during days of summer sea breeze and days of no sea breeze with northwesterly winds, when the overall concentrations were less than 20ppb. However, during the nighttime period high NO_2 concentrations were found particularly after 17:00 local time. Deira station recorded the biggest variation of NO_2 concentration during days of winter sea breeze and days of no sea breeze with southeasterly winds when the values ranged between 15ppb and 35ppb.

7.3.1 Gas hodograph

In this part of the study a diagram a hodograph was used to illustrate the diurnal distribution of O_3 and NO_2 during summer and winter sea breezes, based on wind direction and level of concentration. However, the sense of rotation i.e. clockwise or anticlockwise of the wind through the day must be taken into account for a conventional hodograph that plots wind speed and wind direction.

As has been mentioned before only two stations in the Emirate of Dubai Jebel Ali village and Deira measured nitrogen dioxide. Therefore, the comparison of NO_2 and O_3 will only be made at those two stations.

Fig 7.8 The average hourly concentrations NO_2 and O_3 during days of summer sea breeze

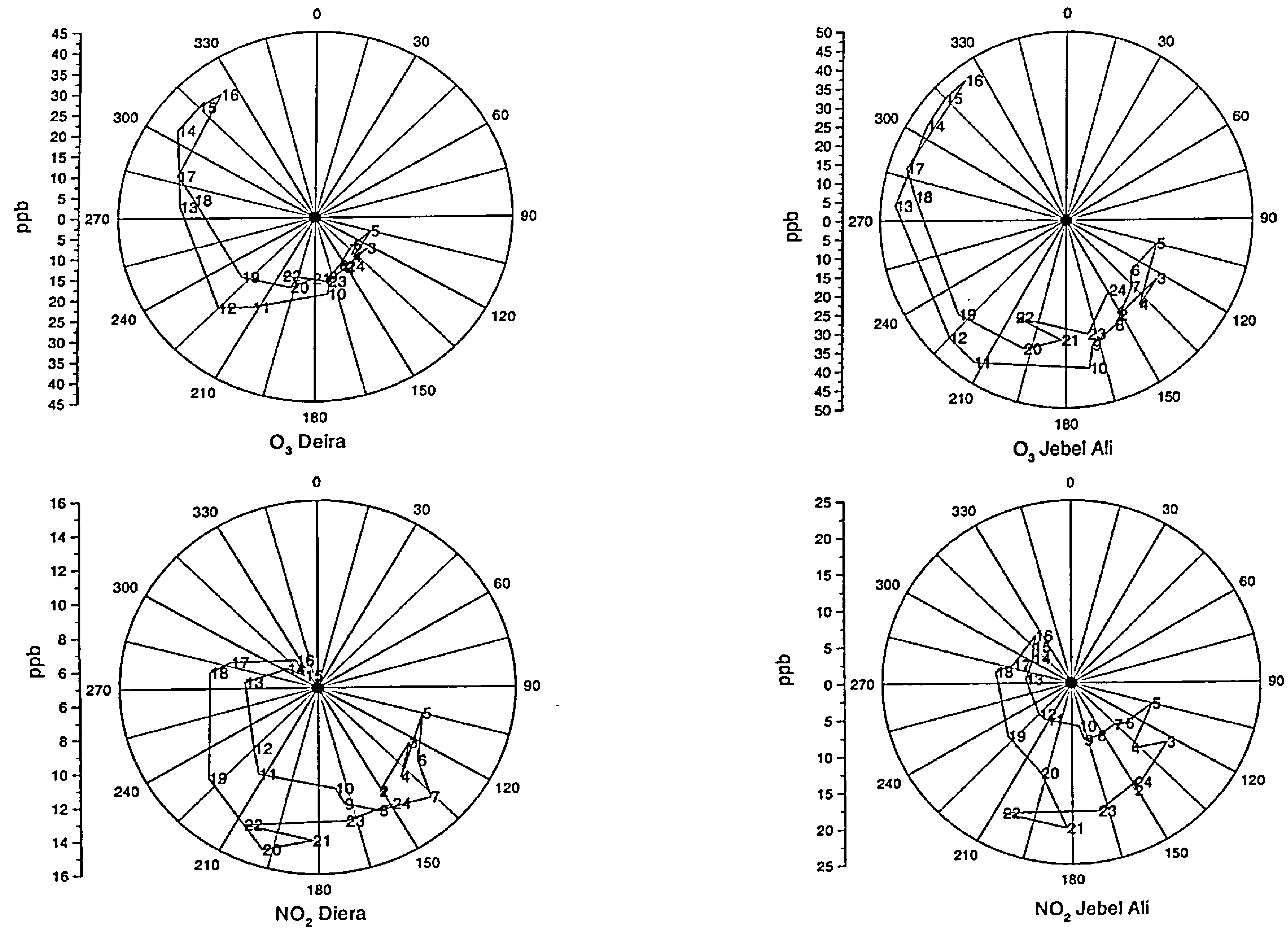


Figure 7.8 showed that during SSB the highest average of O_3, which was recorded, between 14:00 and 16:00 local time, was associated with winds blowing from the northwest between 304° and 324°. The value reached 46ppb at Jebel Ali village stations, while at Deira station the value reached 38ppb. However, the lowest average of O_3 was recorded during nighttime, which was associated with wind blowing from southeast to south between 120° and 160°.

On the other hand, the highest average of NO_2 was recorded during nighttime and as is clearly seen from Figure 7.8 the high concentrations were associated with southerly winds between 160° and 190°. The values reached 20ppb at Jebel Ali village station, while at Deira station the value reached 15ppb. However, the lowest average of NO_2 was recorded during the daytime, which was associated with wind blowing from northwesterly 330°.

Fig 7.9 The average hourly concentration NO_2 and O_3 during days of winter sea breeze

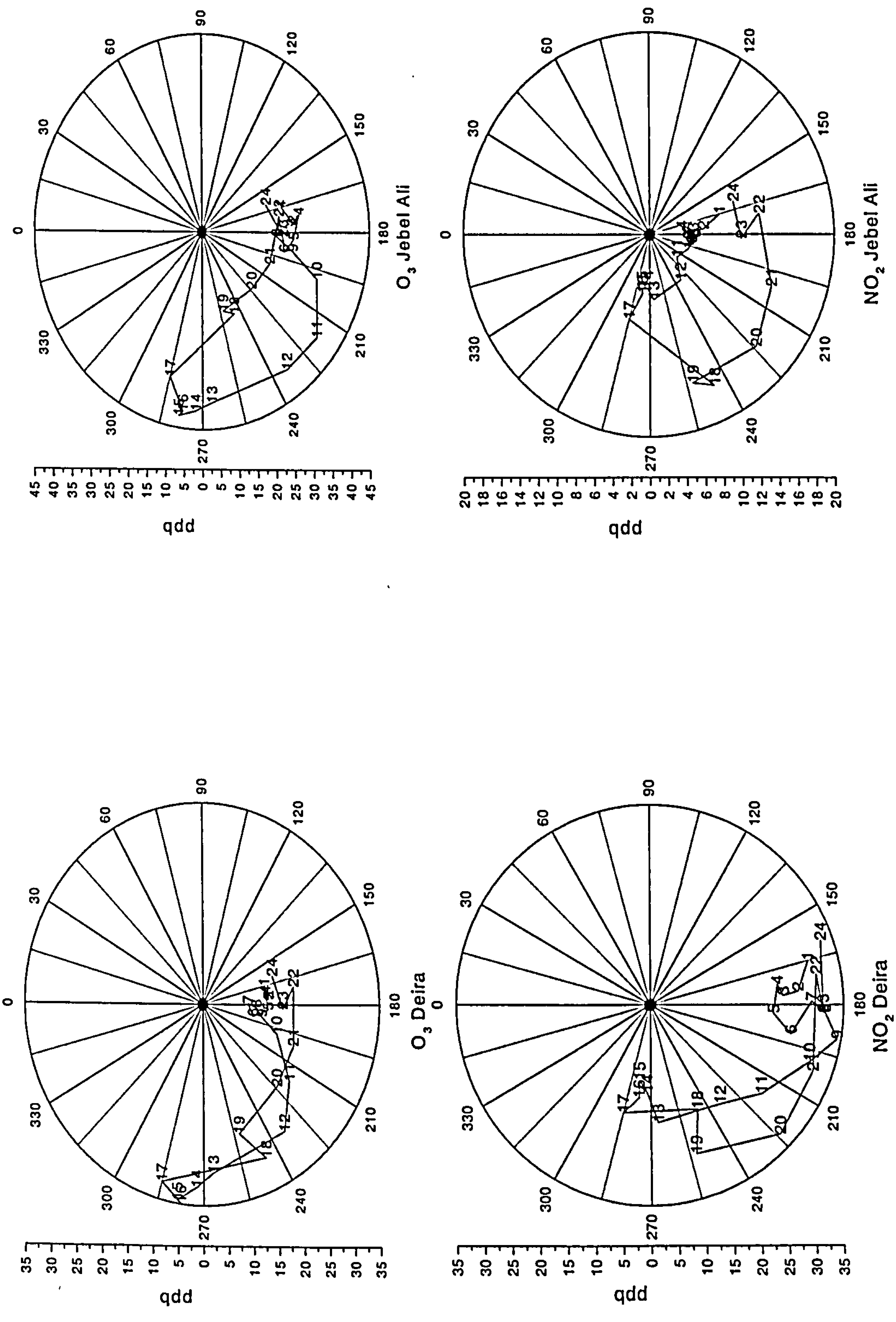
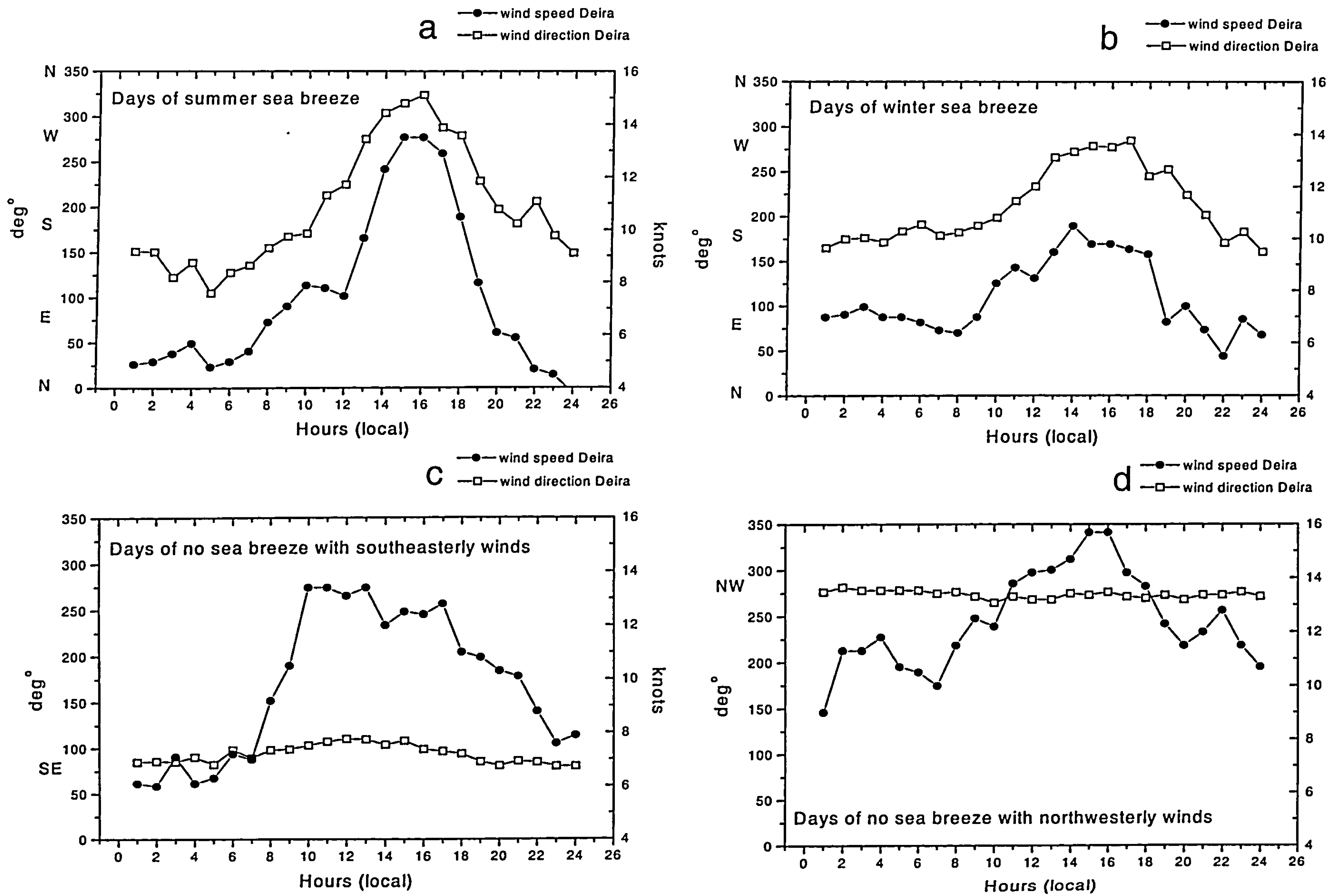


Figure 7.9 showed that during WSB the predominant southwest to westerly winds were clearly associated with high NO_2 and O_3. The highest average of O_3 concentration, which was recorded between 14:00 and 16:00 local time, was associated with wind blowing from the west between 273° and 279°. The value reaches 42ppb at Jebel Ali village stations, while at Deira station the value reached 35ppb. The lowest average of O_3 was recorded during the nighttime with wind blows from southwest to westerly. The nighttime was also the period of highest average of NO_2. At the same time the average of NO_2 concentration during WSB is higher than SSB and, in particular, at Deira station the emission of NO_2 is overall higher than Jebel Ali village station. The values reached 33ppb at Deira station, while at Jebel Ali village station the value reached 16ppb.

Fig 7.10 Diurnal variation of hourly average wind direction and wind speed



7.4 The diurnal variation of weather conditions

Different variables of meteorological parameters were analysed to determine the effect of weather conditions on pollution levels during different days of wind pattern. To obtain a better understanding of meteorological variations, these variables included wind direction, wind speed, temperature and vapour pressure.

Figure 7.10 showed the diurnal variation of wind directions and wind speed during different day types of wind patterns. Figures (7.10a and 7.10b) showed the significant change of the wind direction and association with wind speed during days of SSB and WSB. As can be seen from Figures (7.10a and 7.10b) the wind direction was observed clearly to blow from the land during early morning until around 10:00 local time, and was associated with minimum speeds from 4 to 6 knots.

However, Figure 7.10a shows a very clear ascending and descending of the wind speed between midday and late afternoon, which is associated with significant change of wind direction. As is mentioned in Figure 7.10a during SSB the wind speed increases from 7 to 13 knots between 12:00 and 15:00 local time, which is the time of full development of sea breeze circulation, as well as descending during late afternoon between 16:00 and 20:00 local time from13 to 5 knots. This reduction in wind speed is associated with a second change of wind direction this time from the Arabian Gulf back to the land between 300° and 150 ° this completes the sea breeze daily cycle.

In contrast, Figure (7.10c) illustrates the constant southeasterly winds, which blow from the land, while Figure (7.10d) illustrates the constant northwesterly winds, which blow from the Arabian Gulf. However, there is diurnal variation of wind speeds during NSBNW and NSBSE.

Fig 7.11 Diurnal variation of hourly average temperature and vapour pressure for different day types

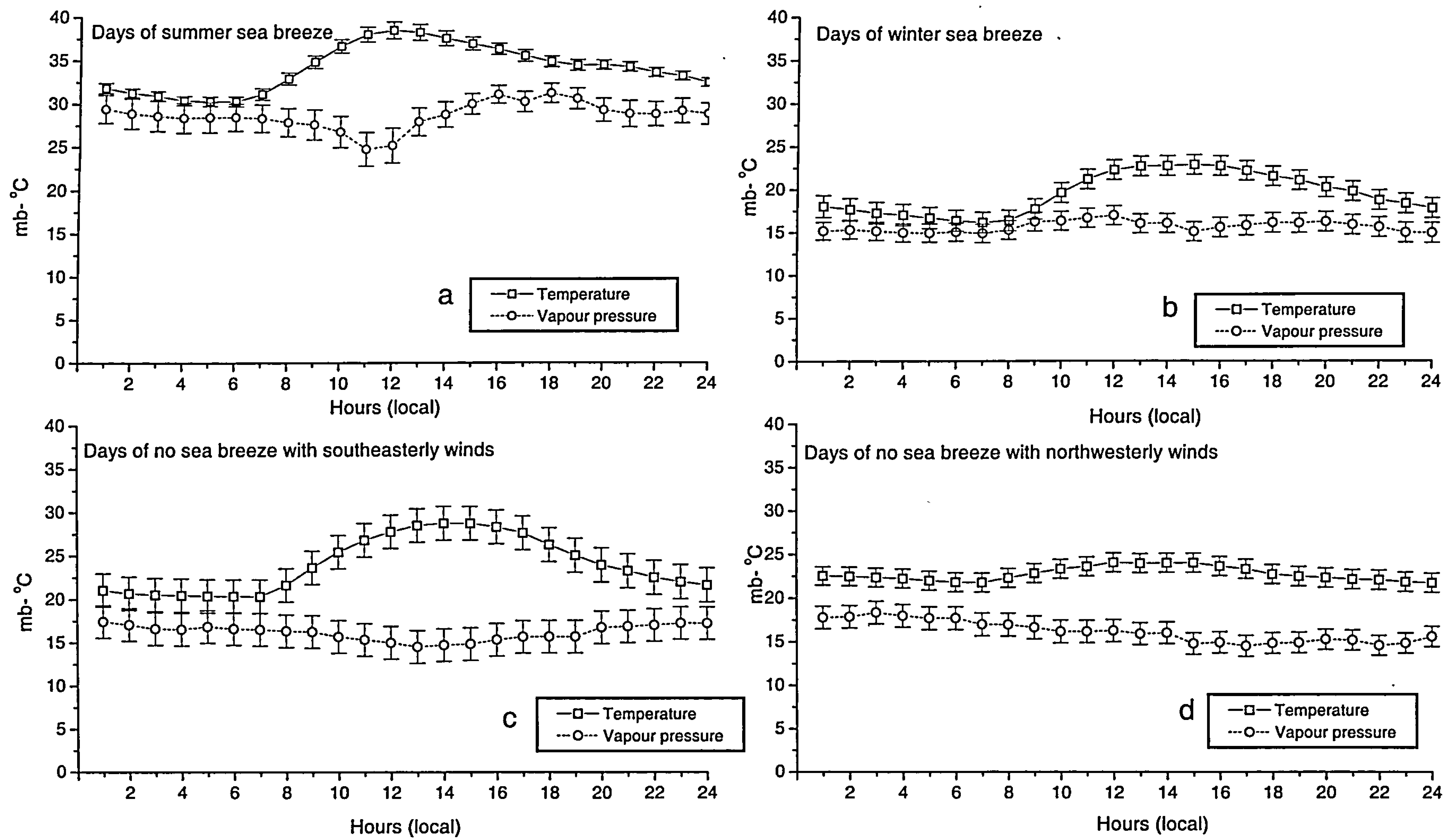


Figure (7.10c) shows the increase of wind speed during NSBSE from 7 to 13 knots between 07:00 to 10:00 local time, with clear variation of wind speeds during midday to late afternoon, and a decrease again to 8 knots during the evening period.

Figure (7.10d) shows the highest speed during the four different days of wind pattern. As clearly can be seen from Figure (7.10d) high wind speed was recorded throughout the 24 hours of northwesterly winds, with speeds ranging from 10 to 16 knots. The maximum wind speed was recorded during early afternoon between 14:00 to 16:00 local time.

Figure 7.11 shows the diurnal distributions of air temperature and vapour pressure during different days types of sea breeze. It is clear from Figure 7.11 that the temperatures varied significantly during the three different day types of wind pattern, SSB, WSB and NSBSE. During days of NSBNW the air temperature was constant between 20°C and 23°C throughout 24 hours, which means that cold weather conditions predominate during days of northwesterly winds.

Figure (7.11a) shows the diurnal distribution of vapour pressure, between 10:00 and 13:00 local time, there is a reduction in vapour pressure during days of SSB. This is may be because of the wind direction, as the wind blows from the land during that hour of the day. Also might be to the boundary layer as growing rapidly and may dilute the water vapour concentrations.

7.5 Correlation analysis of ozone variation

Experiments have been undertaken to check the relationship of ozone and different parameters e.g. wind direction, wind speed, temperature, dust and relative humidity. Also the relationship of ozone and different gases concentrations e.g. NO_2, NO and SO_2 has been checked. The statistical significance of the correlations has been tested at the 5% level. N = refers to 24 daily avearges of differnt days of day daypes which were carefully selacted. For more details see chapter three.

Tables 7.2, 7.3, 7.4 and 7.5 show the correlation between O_3 and NO_2 during different day types of sea breeze at two stations Deira and Jebel Ali.

Tables 7.2 Correlation (r^2) between O_3 and NO_2 during days of summer sea breeze

STATIONS	r^2	RELATIONSHIP	N
Deira	0.70	Significant negative relationship	432
Jebel Ali	0.37	Significant negative relationship	432

Tables 7.3 Correlation (r^2) between O_3 and NO_2 during days of winter sea breeze

STATIONS	r^2	RELATIONSHIP	N
Deira	0.58	Significant negative relationship	336
Jebel Ali	0.25	Significant negative relationship	336

Tables 7.4 Correlation (r^2) between O_3 and NO_2 during days of no sea breeze with northwesterly

STATIONS	r^2	RELATIONSHIP	N
Deira	0.60	Significant negative relationship	192
Jebel Ali	0.04	No Significant relationship	192

Tables 7.5 Correlation (r^2) between O_3 and NO_2 during days of no sea breeze with southeasterly winds

STATIONS	r^2	RELATIONSHIP	N
Deira	0.31	No Significant relationship	144
Jebel Ali	0.16	No Significant relationship	144

As can be seen from the above tables, that during three days of SSB, WSB and NSBNW winds, there was a clear strong positive correlation between O_3 and NO_2 at Deira station. However, weak correlation occurred during southeasterly winds at

Jebel Ali. The weak correlation dominated the relation of O_3 and NO_2 during the four different day types of sea breeze.

Tables 7.6, 7.7, 7.8 and 7.9 show the correlation between O_3 and NO during different day types of sea breeze at two stations Deira and Jebel Ali.

Tables 7.6 Correlation (r^2) between O_3 and NO during days of summer sea breeze

STATIONS	r^2	RELATIONSHIP	N
Deira	0.47	Significant negative relationship	432
Jebel Ali	0.32	Significant negative relationship	432

Tables 7.7 Correlation (r^2) between O_3 and NO during days of winter sea breeze

STATIONS	r^2	RELATIONSHIP	N
Deira	0.41	Significant negative relationship	336
Jebel Ali	0.00	No relationship	336

Tables 7.8 Correlation (r^2) between O_3 and NO during days of no sea breeze with northwesterly winds

STATIONS	r^2	RELATIONSHIP	N
Deira	0.04	No Significant relationship	192
Jebel Ali	0.01	No Significant relationship	192

Tables 7.9 Correlation (r^2) between O_3 and NO during days of no sea breeze with southeasterly winds

STATIONS	r^2	RELATIONSHIP	N
Deira	0.58	Significant negative relationship	144
Jebel Ali	0.04	No Significant relationship	144

From the above tables, it can be seen that during days of SSB and NSBSE the strong correlations between O_3 and NO were found at Deira station. However, O_3 concentration at Jebel Ali station indicated a weak correlation with NO only for summer sea breeze.

Tables 7.10, 7.11, 7.12 and 7.13 show the correlation between O_3 and SO_2 during different day types of sea breeze at two stations Deira and Jebel Ali.

Tables 7.10 Correlation (r^2) between O_3 and SO_2 during summer sea breeze

STATIONS	r^2	RELATIONSHIP	N
Deira	0.15	Significant negative relationship	432
Jebel Ali	0.57	Significant positive relationship	432

Tables 7.11 Correlation (r^2) between O_3 and SO_2 during winter sea breeze

STATIONS	r^2	RELATIONSHIP	N
Deira	0.03	No Significant relationship	336
Jebel Ali	0.08	No Significant relationship	336

Tables 7.12 Correlation (r^2) between O_3 and SO_2 during no sea breeze with northwesterly winds

STATIONS	r2	RELATIONSHIP	N
Deira	0.06	No Significant relationship	192
Jebel Ali	0.04	No Significant relationship	192

Tables 7.13 Correlation (r^2) between O_3 and SO_2 during no sea breeze with southeasterly winds

STATIONS	r^2	RELATIONSHIP	N
Deira	0.02	No Significant relationship	144
Jebel Ali	0.00	No relationship	144

Viewing the above tables, it can be seen that during days of SSB Jebel Ali station showed a strong correlation between O_3 and SO_2. However, during all different days of sea breeze Deira station shows only a weak correlation between O_3 and SO_2.

Tables 7.14, 7.15, 7.16 and 7.17 demonstrate the correlation between O_3 and temperature during different day types of sea breeze at the four stations.

Tables 7.14 Correlation (r^2) between O_3 and Temperature during days of summer sea breeze

STATIONS	r^2	RELATIONSHIP	N
Deira	0.67	Significant positive relationship	432
Mushrif	0.73	Significant positive relationship	432
Al Safa	0.37	Significant positive relationship	432
Jebel Ali	0.76	Significant positive relationship	432

Tables 7.15 Correlation (r^2) between O_3 and Temperature during days of winter sea breeze

STATIONS	r^2	RELATIONSHIP	N
Deira	0.92	Significant positive relationship	336
Mushrif	0.92	Significant positive relationship	336
Al Safa	0.49	Significant positive relationship	336
Jebel Ali	0.65	Significant positive relationship	336

Tables 7.16 Correlation (r^2) between O_3 and Temperature during days of no sea breeze with northwesterly winds

STATIONS	r^2	RELATIONSHIP	N
Deira	0.32	Significant positive relationship	192
Mushrif	0.54	Significant positive relationship	192
Al Safa	0.08	No Significant relationship	192
Jebel Ali	0.30	Significant positive relationship	192

Tables 7.17 Correlation (r^2) between O_3 and Temperature during days of no sea breeze southeasterly winds

STATIONS	r^2	RELATIONSHIP	N
Deira	0.26	No Significant relationship	144
Mushrif	0.92	Significant positive relationship	144
Al Safa	0.49	No Significant relationship	144
Jebel Ali	0.69	Significant positive relationship	144

From the above tables it is clear that Al Safa station had constantly weaker correlation, while Mushrif station had constantly stronger correlation during different day types of sea breeze. However, both Deira and Jebel Ali had different correlations for different days types of sea breeze. In other words, during SSB and WSB there was a clear strong correlation at Deira between O_3 and temperatures and a weak correlation during days of NSBSE and NSBNW. On the other hand, during SSB, WSB and NSBSE there was a strong correlation between O_3 and temperatures at

Jebel Ali. However the same station showed a weak correlation during days of NSBNW.

Tables 7.18, 7.19, 7.20 and 7.21 give the correlation between O_3 and wind direction during different day types of sea breeze at the four stations. It should be mentioned here that during this survey the wind direction on the four different day types of wind pattern did not reach the north (0^o) and therefore it was possible to calculate the correlation between O_3 and the wind direction for those locations.

Tables 7.18 Correlation (r^2) between O_3 and wind direction during days of summer sea breeze

STATIONS	r^2	RELATIONSHIP	N
Deira	0.90	Significant positive relationship	432
Mushrif	0.64	Significant positive relationship	432
Al Safa	0.69	Significant positive relationship	432
Jebel Ali	0.81	Significant positive relationship	432

Tables 7.19 Correlation (r^2) between O_3 and wind direction during days of winter sea breeze

STATIONS	r^2	RELATIONSHIP	N
Deira	0.87	Significant positive relationship	336
Mushrif	0.59	Significant positive relationship	336
Al Safa	0.28	Significant positive relationship	336
Jebel Ali	0.32	Significant positive relationship	336

Tables 7.20 Correlation (r^2) between O_3 and wind direction during days of no sea breeze with northwesterly winds

STATIONS	r^2	RELATIONSHIP	N
Deira	0.00	No relationship	192
Mushrif	0.25	Significant negative relationship	192
Al Safa	0.38	Significant positive relationship	192
Jebel Ali	0.02	No Significant relationship	192

Tables 7.21 Correlation (r^2) between O_3 and wind direction during days of no sea breeze with southeasterly winds

STATIONS	r^2	RELATIONSHIP	N
Deira	0.53	Significant positive relationship	144
Mushrif	0.64	Significant positive relationship	144
Al Safa	0.54	Significant positive relationship	144
Jebel Ali	0.68	Significant positive relationship	144

From the above tables, it can be shown that there was a clear strong correlation between the O_3 and wind direction during two different days of sea breeze SSB and NSBSE. However, during WSB a weak correlation occurred at Al Safa station only.

Tables 7.22, 7.23, 7.24 and 7.25 demonstrate the correlation between O_3 and wind speed during different day types of sea breeze at the four stations.

Tables 7.22 Correlation (r^2) between O_3 and wind speed during days of summer sea breeze

Stations	r^2	Relationship	N
Deira	0.86	Significant positive relationship	432
Mushrif	0.74	Significant positive relationship	432
Al Safa	0.81	Significant positive relationship	432
Jebel Ali	0.79	Significant positive relationship	432

Tables 7.23 Correlation (r^2) between O_3 and wind speed during days of winter sea breeze

STATIONS	r^2	RELATIONSHIP	N
Deira	0.70	Significant positive relationship	336
Mushrif	0.82	Significant positive relationship	336
Al Safa	0.56	Significant positive relationship	336
Jebel Ali	0.60	Significant positive relationship	336

Tables 7.24 Correlation (r^2) between O_3 and wind speed during days of no sea breeze with northwesterly winds

STATIONS	r^2	RELATIONSHIP	N
Deira	0.29	Significant positive relationship	192
Mushrif	0.73	Significant positive relationship	192
Al Safa	0.73	Significant negative relationship	192
Jebel Ali	0.29	Significant positive relationship	192

Tables 7.25 Correlation (r^2) between O_3 and wind speed during days of no sea breeze with southeasterly winds

STATIONS	r^2	RELATIONSHIP	N
Deira	0.15	No Significant relationship	144
Mushrif	0.92	Significant positive relationship	144
Al Safa	0.49	Significant positive relationship	144
Jebel Ali	0.56	Significant positive relationship	144

As can be seen from the tables above that there was a strong correlation between O_3 and wind speed at the four stations during days of SSB and WSB. During days of NSBNW winds a weak correlation was constantly occurring at three stations Deira, Al Safa and Jebel Ali. However, only Mushrif station recorded a strong correlation. On the other hand during days of NSBSE winds a strong correlation occurred at two stations Mushrif and Jebel Ali, while a weak correlation was recorded at both Deira and Al Safa stations.

Tables 7.26, 7.27, 7.28 and 7.29 show the correlation between O_3 and relative humidity during different day types of sea breeze at the four stations.

Tables 7.26 Correlation (r^2) between O_3 and relative humidity during days of summer sea breeze

STATIONS	r^2	RELATIONSHIP	N
Deira	0.47	Significant negative relationship	432
Mushrif	0.60	Significant negative relationship	432
Al Safa	0.21	Significant negative relationship	432
Jebel Ali	0.37	Significant negative relationship	432

Tables 7.27 Correlation (r^2) between O_3 and relative humidity during day of winter sea breeze

STATIONS	r^2	RELATIONSHIP	N
Deira	0.95	Significant negative relationship	336
Mushrif	0.49	Significant negative relationship	336
Al Safa	0.51	Significant negative relationship	336
Jebel Ali	0.70	Significant negative relationship	336

Tables 7.28 Correlation (r^2) between O_3 and relative humidity during days of no sea breeze with northwesterly winds

STATIONS	r^2	RELATIONSHIP	N
Deira	0.03	No Significant relationship	192
Mushrif	0.51	Significant negative relationship	192
Al Safa	0.22	Significant positive relationship	192
Jebel Ali	0.11	No Significant relationship	192

Tables 7.29 Correlation (r^2) between O_3 and relative humidity during days of no sea breeze with southeasterly winds

STATIONS	r^2	RELATIONSHIP	N
Deira	0.29	No Significant relationship	144
Mushrif	0.93	Significant negative relationship	144
Al Safa	0.50	No Significant relationship	144
Jebel Ali	0.72	Significant negative relationship	144

As can be seen from the tables above that during days of SSB and NSBNW winds a weak correlation occurred at three stations Deira, Al Safa and Jebel Ali. However, Mushrif station showed a strong correlation during these two days. On the other hand, during WSB only Mushrif station showed a weak correlation, while all other stations showed a strong correlation between O_3 and relative humidity. During days of NSBSE winds a weak correlation between O_3 and humidity occurred only at Al Safa station. However all other stations recorded a strong correlation between O_3 and humidity.

Tables 7.30, 7.31, 7.32 and 7.33 show the correlation between O_3 and dust during different day types of sea breeze at two stations Deira and Al Safa.

Tables 7.30 Correlation (r^2) between O_3 and dust during days of summer sea breeze

STATIONS	r^2	RELATIONSHIP	N
Deira	0.34	Significant positive relationship	432
Al Safa	0.56	Significant positive relationship	432

Tables 7.31 Correlation (r^2) between O_3 and dust during days of winter sea breeze

STATIONS	r^2	RELATIONSHIP	N
Deira	0.34	Significant positive relationship	336
Al Safa	0.59	Significant positive relationship	336

Tables 7.32 Correlation (r^2) between O_3 and dust during days of no sea breeze with northwesterly winds

STATIONS	r^2	RELATIONSHIP	N
Deira	0.16	Significant positive relationship	192
Al Safa	0.00	No relationship	192

Tables 7.33 Correlation (r^2) between O_3 and dust during days of no sea breeze with southeasterly winds

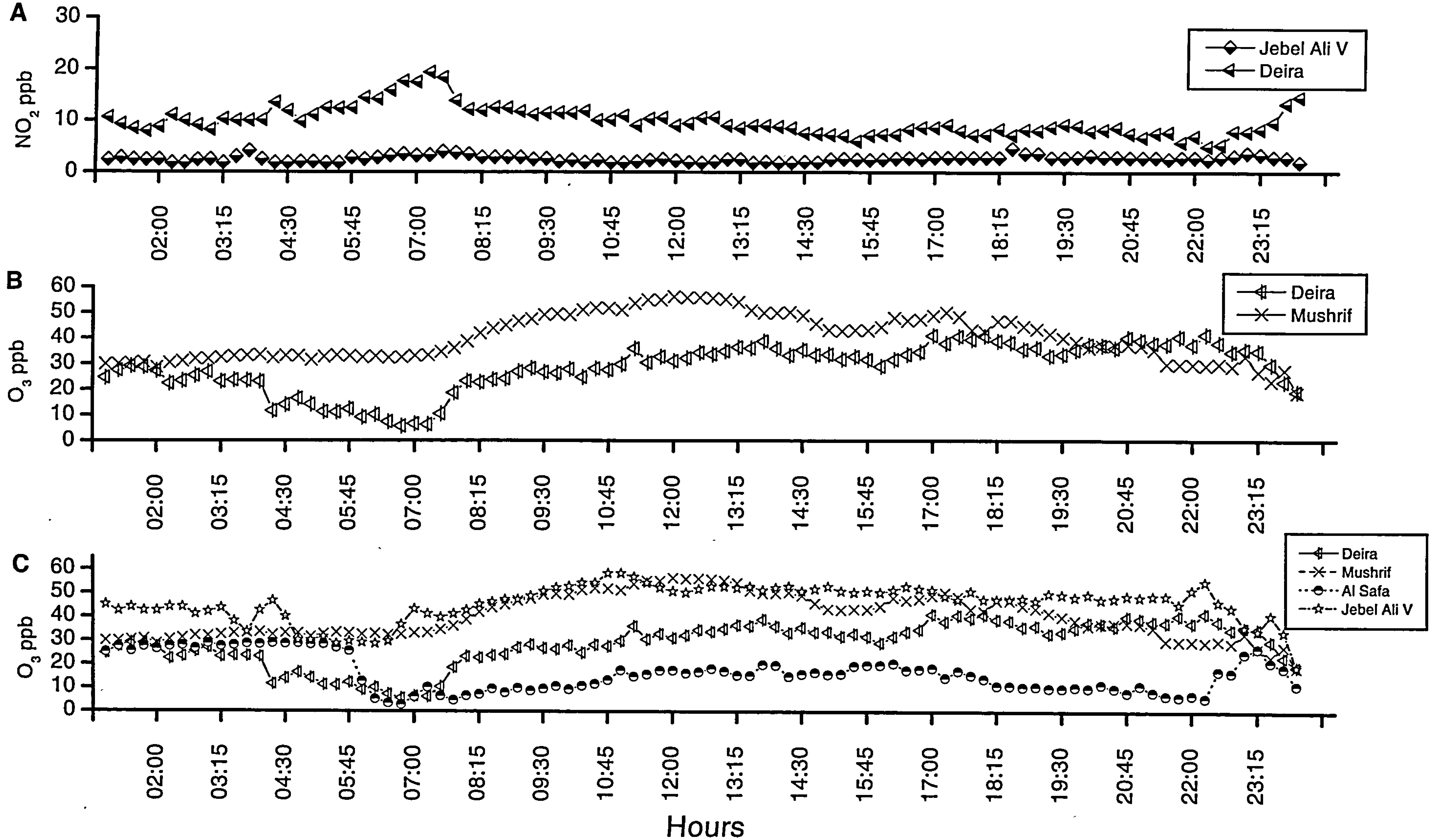
STATIONS	r^2	RELATIONSHIP	N
Deira	0.22	No Significant relationship	144
Al Safa	0.28	Significant positive relationship	144

As can be seen from the above tables that Al Safa station showed a strong correlation between O_3 and dust during days of SSB and WSB. However, at Deira station the correlations were always weak during different days of sea breeze.

7.6 Case Study

In order to test whether the calculated day types of hourly averages truly represent the daily patterns, two days were selected according to wind types and ozone levels. The 3rd June 1997 illustrates a day with summer sea breeze, while the 28th February represent a day of no sea breeze with northwesterly winds and for both days complete meteorological and pollutant data sets are available. The four stations which measured O_3 on the selected days for a 24 hour period are represented.

Fig 7.12 Concentration of O_3 and NO_2 during a day of summer sea breeze 3[rd] June 1997



7.6.1 First case study

Figure. 7.12, shows the case study day of summer sea breeze SSB. It can be seen that at Al Safa station a drop in O_3 concentration was recorded during the early morning after sunrise 06:00-07:00 local time. This is due to the early summer rush hour when the levels of NO_2 increased. Figure 7.12a indicates that Al Safa and Deira are the locations which are most affected by traffic density. By 07:00 local time O_3 levels rise, which at Deira station can be attributed to the photochemical reaction of increased traffic emissions, while it probably reaches Jebel Ali village by being transported by sea breeze circulation. Between 07:00 and 07:30 local time, the sea breeze develops, which is most obvious at the stations in Jebel Ali and Deira. Sea breeze circulation is established earlier at Jebel Ali, which can be explained by the meteorological station in Jebel Ali village being in very open terrain and close to the coast, which immediately sees the changes in the wind speed and wind direction. Deira station however, is surrounded by buildings and the roughness of the city decreases the wind speed and therefore prevents the strong or onshore winds from reaching Deira as soon as Jebel Ali. The maximum value for O_3 concentration measured 40-50 ppb and appeared at 13:00 local time, which deviates slightly from the monthly pattern for days of summer sea breeze in that it is approximately one hour earlier. However, the values peaked earlier at Jebel Ali with 59ppb at 10:45 local time. Generally it can be said that the values of O_3 increase until 11:30 local time and then remain at a constant high until 22:30 local time. Al Safa station constantly provided the lowest values of O_3 concentration, between 5-25 ppb, but higher levels were recorded in the night time than during the day.

Deira and Mushrif Park stations may be affected by sea breeze circulation and Deira station are dominated by the city, and hence a closer examination of these was undertaken, whereby measurements taken every 15 minutes were plotted. The station at Mushrif Park is located south of the Deira station and it can hence be seen that these two stations are both affected by sea breeze circulations. Figure 7.12b shows during summer sea breeze SSB that the Deira station is more obviously affected by sea breeze circulation, as is obvious by the increase of O_3 concentrations during the establishment of sea breeze circulation between 07:00 and 07:45 local time.

Meanwhile the O_3 concentration at Mushrif Park station reached higher levels at nighttime, which increased further during the daytime. The levels of O_3 at Mushrif Park increase during the day, but remain quite constant between 35ppb and 55ppb throughout the day, while the nighttime levels are also constant between 30ppb and 35ppb. This indicates that a source and precursors of O_3, mainly from Deira affect this area. The lack of a decrease in the levels of O_3 concentration at Mushrif Park can be explained by the lack of a sink for O_3.

Figure 7.12c represents the NO_2 concentration at Deira and Jebel Ali village stations during a day of summer sea breeze SSB, the 3rd June 1997. During SSB Jebel Ali village is not affected by any sources of NO_2, as the levels are below 5 ppb, while Deira is affected by traffic density and here concentrations reach a peak of 18ppb of NO_2 at 06:30 to 07:30 local time, during the rush hour. At the nighttime there is another increase of NO_2 concentration, reaching 15ppb, which might be attributed to the evening rush hour.

Fig 7.13 Concentration of O_3 and NO_2 during a day of no sea breeze with a northwesterly wind at 28th February 1997

7.6.2 Second case study

On the 28th February 1997 (Fig. 7.13), with the absence of sea breeze all four stations are equally affected by the northwesterly winds. As usual the highest levels of O_3 were recorded at Jebel Ali village, ranging between 39ppb and 50 ppb, and the lowest at Al Safa between 20ppb and 25ppb. At Mushrif Park a drop was recorded between 01:00 and 02:30 local time. This means that the O_3 concentration pattern of 28th February 1997 corresponds to the pattern for the hourly average day types of days of no sea breeze with northwesterly winds at all the four stations.

Figure 7.13b shows the concentration of O_3 at the 28th February 1997 during day of no sea breeze with northwesterly wind NSBNW at Deira and Mushrif Park stations, the measurements were taken at 15-minute intervals. The two stations show the same pattern over a 24-hour period. As both stations are in concordance with each other at a persistently high level of O_3 ranging between 29ppb and 45ppb. During the early morning, between 01:00 and 02:30 local time there are increases, especially noticeable at Mushrif park station. Throughout these 24 hours the stations were affected by transported O_3, probably from a different industrial region in the Arabian Gulf by northerly winds.

Figure 7.13c represents the NO_2 concentrations at Deira and Jebel Ali village stations during NSBNW winds, the 28th February 1997. It can be seen that the NO_2 concentration was higher during the nighttime, ranging between 20ppb and 25ppb, than during the daytime from 11ppb to 18ppb. This takes place in the winter and it must be borne in mind that in a hot country, such as the Emirate of Dubai, people go out more in winter and therefore use their cars more, which might increase NO emissions. This also corresponds to the results found in the monthly averages of NO during days of summer and winter sea breeze and days of no sea breeze with northwesterly winds.

Fig 14 The meteorological conditions during 3rd of June and 28th of February 1997

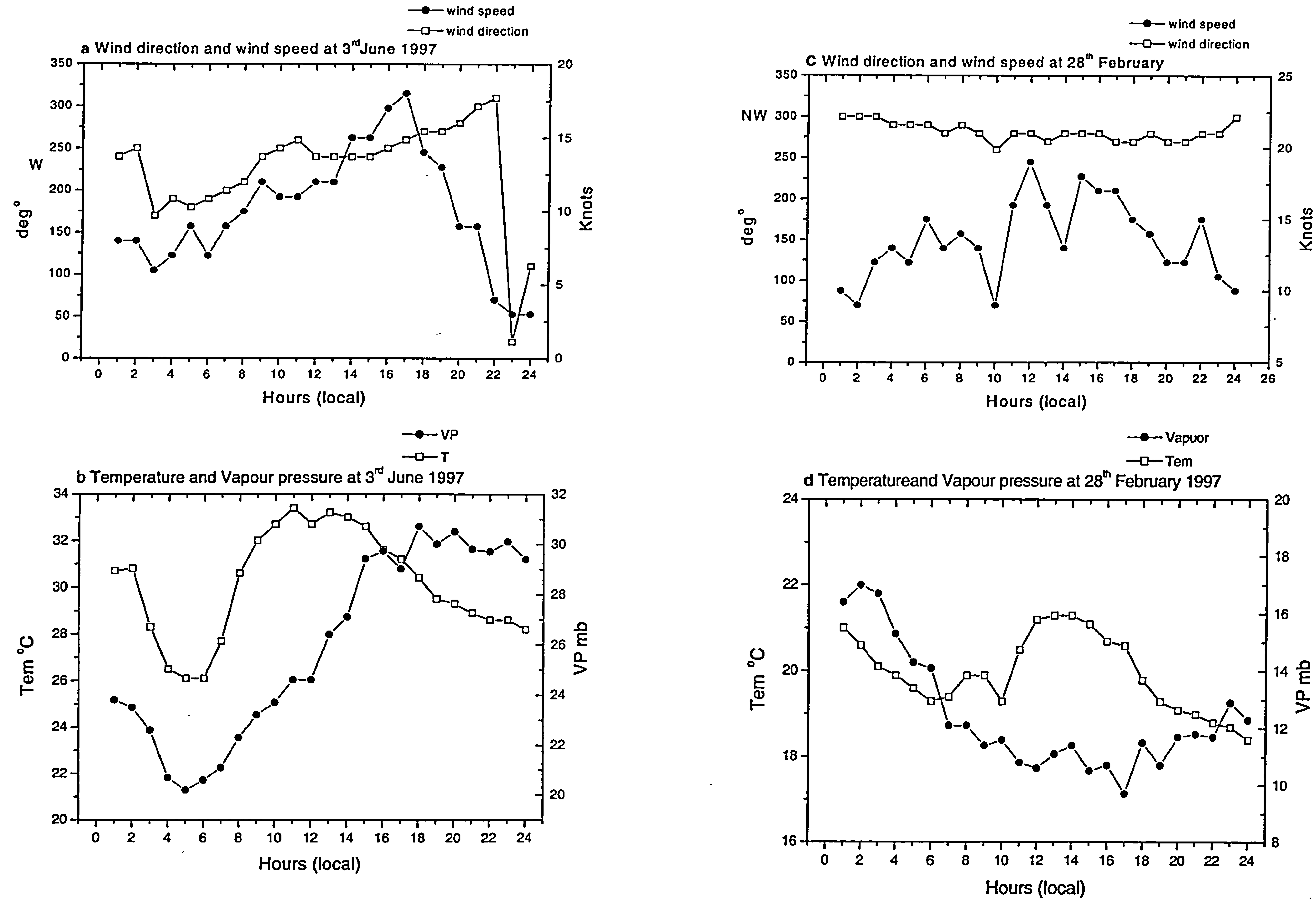


Figure 7.14 represents meteorological data, such as wind direction, wind speed, temperature and vapour pressure at Deira and Jebel Ali village stations.

In Figure 7.14b, during summer sea breeze SSB on the 3rd June 1997, the maximum air temperature was at around midday at 35°C with a minimum at 05:00 local time, which might be associated with land-sea breeze and the overall average recorded was above 30°C. The vapour pressure refers to the pressure exerted by the water vapour molecules in a given volume of air. As can be seen from (Fig7.14b) around 05:00 local time the lowest value were recorded at 20 mb which is might be associated with blowing of land breeze.

In Figure 7.14d during the 28th February 1997 the air temperature remained constant around 20°C throughout the day, while the vapour pressure ranged from 17 mb in the nighttime, at around 02:00 local time, to 10 mb in the afternoon at around 17:00 local time. The lower value in the afternoon is due to the lower moisture content in the northwesterly wind in winter as less water evaporates from the sea in the cooler temperatures.

Figure 7.14a shows the wind direction and wind speed during summer sea breeze SSB at 3rd June 1997. It can be seen from Figure 7.14a that during early morning before sunrise the wind turned from west to south between 250° and 150°, with constant in wind speed between 5 and 4 knots. The concentrations of O_3 at this time of the day were constant at the four stations. Around 07:00 local time the concentrations of NO_2 recorded were the highest levels as the morning rush hours starts. 2 to 2 ½ hours after sunrise which around 08:00 local time when the air temperature becomes warmer than the air above the Arabian Gulf, the wind starts to veer from southerly to westerly 180° to 250° from the land to the Arabian Gulf. The concentrations of O_3 were increased at the four stations. This is associated with wind speed as rapidly increases from 5 to 11 knots. The fully developed of the sea breeze circulation occurred at about midday, which was noticed by the maximum of O_3 concentrations during the midday at Jebel Ali village and Mushrif Park stations. The maximum of O_3 concentrations were recorded around 1-2 hours after midday at Deira and Al Safa stations, this was associated with the wind veering from 240° to 260° and maximum wind speed were between 11 and 18 knots. During nighttime the wind direction was observed to back from northerly to southerly from 300° to 150° between 22:00 and 24:00 local time. The O_3 concentrations were constant high during the late afternoon and nighttime. The speed decreased rapidly from 18 to 3 knots associated with wind direction changes from the Arabian Gulf to the land.

Figure 7.14c shows the wind direction and wind speed during a day of no sea breeze with northwesterly wind NSBNW at 28th of February 1997. It can be seen from Figure 7.14c that the winds blow constantly from northwest between 300° and 320°, which is associated with high concentrations of O_3 during the 24 hours. The wind speed varied during the day with the maximum speed observed during daytime at 20 knots.

Summary;

The hourly average O_3 concentration were observed to vary diurnally at four different stations located in the coastal zone area of the Emirate of Dubai. Al Safa station recorded consistantly low O_3 concentrations, Jebel Ali village station has consistantly high O_3 concentrations, Deira and Mushrif stations both have concentrations between what found at the other two stations. The highest average O_3 concentrations occurred mainly during days of no sea breeze with the prevailing northwesterly winds from the Arabian Gulf. The concentrations of O_3 during daytime are always higher than the O_3 concentrations during nighttime, during the four different days types of sea breeze. The emission from local sources such as traffic activity and industrial activity, might be the reason for the increase in the level of the pollution during the day along with insolation. The transition periods during days of summer and winter sea breeze shows a correlation with the circulations of the sea breeze. At the same time, during the daytime through transition to the sea breeze the O_3 concentration increases higher during both days of summer sea breezes and winter sea breeze. The results of NO and NO_2 showes that there is very little variation of NO concentration at Jebel Ali village during different day types of wind pattern. However, Deira shows significant patterns of NO and NO_2 concentration during days of winter sea breeze and days of no sea breeze with southeasterly winds. On the other hand, the meteorological parameters show significant patterns. Wind direction changes are significant and are associated with wind speed variations as is expected during days of summer and winter sea breeze. Temperatures were also observed to vary significantly during different day types of sea breezes and no sea breeze when the wind is blowing from the land. The results of two days of case studies- the 3rd June 1997 illustrates a day with summer sea breeze, while the 28th February represent a day of no sea breeze with northwesterly winds from the Arabian Gulf.

It was found that both case studies fitted the pattern seen in the average day type data.

Chapter Eight

Discussion and Conclusion

8.1 Introduction

In this chapter the results of the diffusion tube survey and network monitoring data will be discussed. The results of the tube survey will be discussed according to seasonal variation and according to local site variation. The method of using diffusion tubes has proven its usefulness by producing results which to test against the results from the network monitoring stations run by the Dubai Municipality and to extend the network. In this discussion it will be attempted to find the link between the results of the diffusion tube study with those of the Dubai Municipality. Finally, the distribution of O_3 during daytime and nighttime will be discussed, using the secondary pollutant data collected by the Dubai Municipality's network monitoring stations. The discussion will deal with the picture which emerges from the data from these four stations.

8.2 Background

This is the first thoroughly documented, in depth analysis of ambient NO_2 concentrations that has been carried out in the Emirate of Dubai. The analysis is based on two surveys of air quality; the monitoring network of the Dubai Municipality data, and the present study based on passive diffusion tube samplers. The passive diffusion tube sampler survey measured two-week averages of pollutant concentrations over a two years period from January 1996 to December 1997. Samplers were located at eleven sites, including an urban area with high traffic density, suburban areas with low traffic density, as well as commercial and industrial areas. One important point to be taken into account at the start of the survey was to ensure that all tubes at all sites would be changed and replaced on the same days.
In order to understand the pollution phenomenon in Dubai, it was at first necessary to establish the background information, which was achieved by means of diffusion tube sampling. As there have not been many such studies in this region, it is worthwhile to compare the results from two different techniques, i.e. network monitoring stations and diffusion tubes. One outstanding advantage of using diffusion tube sampling is its cost effectiveness, which means that many sites can be included in the study, in order to get as complete a picture of the pollution levels as possible. Furthermore, this technique is very simple to implement, so that sampling can be conducted by persons without any scientific training, which was important for this study, as volunteers were used to replace the sampling tubes.

The results of this survey clearly indicate that the overall NO_2 concentration throughout the Emirate of Dubai is low. However, the levels of NO_2 have been found to be slightly higher near to the city centre and in sites with high traffic density. On the other hand, the results of the present study are in agreement with results from network monitoring sites, which are run by the Environmental Office of Dubai Municipality, particularly with the data from the Deira site (Dubai Municipality). Also there is agreement with the Sefton MBC group, who conducted an investigation in Bootle, Merseyside.

8.3 Seasonal variation

It is interesting at this stage to illustrate whether there are significant pattern differences between summer months and winter months or not. Although theft and vandalism corrupted the data for January-March 1996, it can still be postulated that this is the case, as it is evident in the 1997 data. In finding high levels of NO_2 in the winter months, this is consistent with the results of Bower *et al.* (1987) and Williams *et al.* (1988), However, it contrasts with Madany *et al.* (1993), although Bahrain State and the Emirate of Dubai share the same arid, hot and humid climate. Their climates differ only in the sense that Bahrain is an island and therefore more humid and not affected by the heat storage of a landmass like the Empty Quarter just south-east of Dubai. Both have roughly the same temperatures, since in the Emirate of Dubai it is regulated effected by the sea breeze and a local wind, which ventilate the area. The difference might be explained in terms of Boundary Layers. Bahrain being an island has a marine boundary layer, while Dubai's has an urban boundary layer influenced by sea-land breeze circulation.

8.4 Localised variation

8.4.1 High NO_2 concentrations during winter months

Possible explanations for the high levels of NO_2 during the winter might be weather conditions, a seasonal increase of NO_2 emissions or other external factors controlling NO_2 levels in Dubai City.

1. Weather conditions; many researchers believe that temperature influences levels of NO_2. However, this research seems to show no such relation. As can be seen in chapter 6 Figure 6.9 there is no significant pattern of variation in the average temperature, but a steady increase and fall, which is in stark contrast to the monthly average of NO_2 pattern in chapter 6 Figure 6.8. Although this research, like Madany's in the state of Bahrain, was conducted in a hot country, the results are in disagreement. Whereas Madany finds temperature to be the single most important meteorological factor leading to the high NO_2 concentrations in summer, the results from Emirate of Dubai show low concentrations of NO_2 during the high summer temperatures. Bower *et al.* (1991a) stated that a reason behind high levels NO_2 in the U.K. in winter are weak winds and a shallow mixing layer, which are unable to disperse a large concentration of pollution, and termed this condition as atmospheric stagnation. Due to a lowering of the inversion layer, the mixing layer decreases (i.e. becomes shallower), which affects the levels of pollution through poor dispersion. Power station and space heating Activity increases during the winter, which increases the pollution levels near the ground surface. Angius *et al.* (1995) point out that vehicular traffic and emissions from building heating systems have been identified as the main sources of pollutants particular in winter months. NO_2 is largely a secondary pollutant, formed by oxidation of primary emission of NO

and the effects of emissions and meteorology (which could tend to lead to higher levels in winter) outweigh those of atmospheric chemistry (which would lead to increased NO_2 levels in summer, due to enhanced photochemical activity).

2. Seasonal increase of NO_2 emissions: in other studies there does not seem to be a seasonal increase in traffic density, which discounts this possibility. It is plausible that this is a similar mechanism applies in Dubai, that there are not seasonal changes in traffic density.
3. Other external factors: Could the seasonal variation in sea breeze and wind trajectory effect the variation in NO_2 concentration?

8.4.2 Traffic density is the major sources of NO_2 in Emirate of Dubai

A major source of NO_2 concentration is traffic density. The highest levels of NO_2 pollution were found at roundabouts, which was to be expected. Madany *et al.* (1993) also found the highest NO_2 readings in a narrow and congested street in the capital of Bahrain, and that the highest NO_2 concentrations were attributed to the increase in the number of automobiles since the 1970's. Likewise, in the Emirate of Dubai the number of automobiles increased from 206,070 in 1996 to 269,544 in September 1999, which represents a similar rate of increase as that mentioned by Madany for the years 1985-1989. This is coupled with spatial factors, such as the highest concentration of vehicles within a relatively small area, as represented by the Deira site and the four different roundabout sites. The high concentration of NO_2 near roundabouts can be explained by the greater traffic density and higher emissions, due to the lower average speed as well as there not being any turbulence generated by the flow of traffic (Laxen and Noordally, 1987). According to (Lenner,

1987) the NO_2 in car engine exhaust is formed when the exhaust gases pass through the exhaust systems where oxidation of NO will take place if oxygen is present NO_2 is formed at low engine speed. At the Fish roundabout the geography of tall buildings along the dual carriageway contributes to the raised levels of NO_2 recorded at this location.

8.4.3 Airport

The investigation carried out in the airport location suggests that air-traffic does not contribute to elevated levels of NO_2, as a low concentration averaging 25ppb was found here. This suggests that the airport is not a significant contributor to NO_2 pollution in Dubai City.

Other researchers such as Williams *et al.* (1988) who carried out an investigation in Greater London also supported this conclusion, and Madany *et al.* (1993) obtained the same result in Bahrain State.

8.4.4 National park (Mushrif Park)

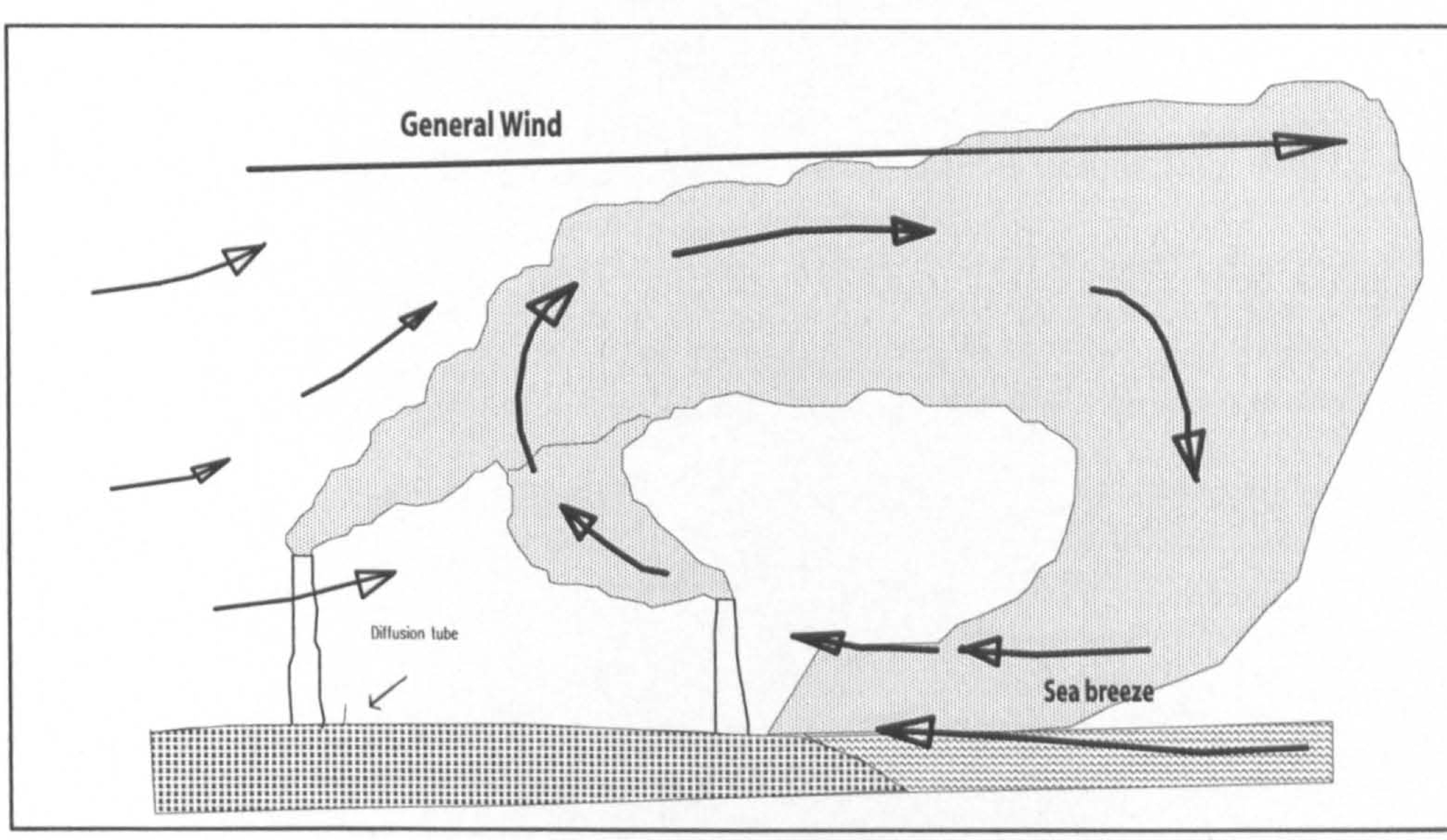
The suburban area of Mushrif Park has the lowest average of NO_2 concentration over the year of 11ppb, with values ranging between 4ppb and 21ppb. This result is obviously different from Al Safa Park where the average values were found to be 24ppb. This could be related to the characteristics of this area, because Al Safa Park is situated in a residential area, while Mushrif Park is far away from the city centre, close to the desert and does not have dense traffic.

8.4.5 Industrial Area

The study also revealed unexpectedly low concentrations of NO_2 in the industrial location of Jebel Ali municipality and the residential of area Jebel Ali village. Both have low traffic density, but are in close proximity to the power station.

Although this seems to indicate that the power station is not a major contributor to NO_2 pollution in the Emirate of Dubai, it is of course possible that these results emerged due to the location of the test tubes near ground level (see Fig 8.1). As it can be seen from Figure 8.1, the pollution will rise away from the diffusion tubes, if the wind blows from the land and therefore renders it impossible to measure accurately. As the wind carries it up, the pollution is diluted and transported over the sea, where it will help form other gases. The polluted air mass does return by sea breeze circulation, but there will no longer be the original concentration of NO_2, as these have been transformed.

Fig 8.1 Influence of sea breeze on ground levels pollution (Forsdyke, 1970)



Unfortunately the available data makes it very difficult to extrapolate satisfactory results, but we can hypothesise that the presence of NO_2 concentration at Jebel Ali

Village might indeed be caused by the power station. This area might be affected due to its raised location, but the effect is kept to a minimum in NO_2 levels by the north-westerly sea breeze dispersing the pollution.

8.4.6 Correlation

When calculating the correlation between the site at Dubai Municipality with all other sites, it was found that with a greater distance between the sites, the correlation was stronger and closer sites show a weak correlation, when measured over a period of two weeks. In order to explain this, meteorological factors, such as temperature and wind direction, or sinks of NO_2 must be taken into consideration. The site of Dubai Municipality is in the city centre and those sites which are nearest to it will be the most affected with pollution from high traffic density. The weak correlations may be due to the high temperature during the daytime, which leads to faster destruction of NO_2, as it is photolyzed. The strong correlations might be explained by the pollution being transported by the sea breeze circulation from the municipal centre.

8.5 Discussion of ozone

8.5.1 Distribution of pollutant concentrations during the daytime

Especially in the coastal area it is quite complicated to explain the diurnal variation in the levels of O_3, because there are so many contributing factors, such as photochemical reaction, weather conditions and topography. The concentrations of O_3 are generally high during the daytime, because the photochemical reactions usually take place under the following meteorological conditions: high temperature, high isolation, relatively low wind-speed (2-5 m/s), unaffected by the presence of land-sea breeze circulation.

The low values found near the ground level in the early hours of the day are caused by the morning rush hour and the boundary layer depth increasing as the sun rises. As the emissions of primary pollutants (such as NO, NO_2, SO_2 and CO) increase, they enrich those already trapped under the inversion layer since the previous day. Combined with the sunlight the NO is photolyzed into NO_2, thus preventing the creation of O_3. Another contributing factor may be the land-breeze circulation, as this changes from sea breeze to land breeze between 04:00 and 05:00 local time. According to Lalas *et al.* (1983) and Nester (1995) the reversal of the breeze flow brings back air that is rich in pollutants from the previous day and is then enriched with additional NO from the rush-hour, which leaves the ambient air without O_3 and with increased levels of NO_2. Furthermore, the stagnant air and low wind speed during the early morning aids the build-up of primary pollutants, as the ambient air becomes saturated with HCs and NO_x from ground level pollution. This can be seen in Figures. 7.6 a, b and c at the Dubai Municipality monitoring station at Deira. At Jebel Ali however, the values of NO and NO_2 are not as striking, which can probably be attributed to the much lower traffic density at this station. Stagnant air leads to the establishment of sea breeze, which then transports the pollution all over the coastal area. This is also associated with the increase of solar radiation after sun-rise, which helps in the formation of O_3 and dilutes the primary pollutants. During the early afternoon the levels of O_3 reach their peak due to a local photochemical reactions as a result of increased solar radiation and the establishment of the sea breeze circulation. Conversely the higher wind-speeds and turbulence dilute the NO and NO_2, as can be seen in Figures. 7.6 and 7.7. After 15:00 local time, the O_3 levels begin to fall (see Chapter7, Fig. 7.3.a and b) and the NO_2 concentration drops to its lowest point (see Chapter 7, Figs. 7.7.a and b), as the wind direction changes from sea to land and the wind-speed of the sea breeze drops (Figs.7.10.a and b). Also the sun begins to set, although without significantly lowering the temperature and thus keeping it favourable for the production of O_3 (see Chapter 3, Table 3.1 and 3.2). Nester (1995) similarly found in Athens that at midday, when the wind-speed and turbulence reached their maximum, the NO levels dipped.

8.5.2 Higher average of O_3 during nighttime

At nighttime the O_3 levels rise within the background level (20-30 ppb), or stay below it, but never fall to zero, which is in contrast to the results from studies conducted elsewhere, e.g. in Athens (Lalas *et al.,* 1983). The notable exception is Jebel Ali station during days of no sea breeze with westerly winds (Fig 7.4d), where levels were considerably above the average background values of 30 ppb, which nonetheless shows a similar fall in ozone concentration to the other measuring stations.

According to Steinberger and Ganor (1980) during the nighttime the levels of ozone increase from stratospheric ozone, however only a very small amount of O_3 is transported from the stratosphere, as it is far away from the ground level concentrations and there are other contributing factors as well. For instance, after sunset there is a layer of air maintaining a very high concentration of O_3 which was produced during the daytime and trapped under the inversion layer, while O_3 concentrations near the ground are low, as no more O_3 is generated. By the beginning of the evening rush hour the O_3 is destroyed by the increase of NO, and due to the lack of sunlight, NO_2 can no longer be photolyzed and thus no further O_3 is produced.

8.5.3 Highest level of O_3 on days with no sea breeze and northwesterly winds.

Ozone concentrations were highest during days with no sea breeze and prevailing north-westerly winds blows onshore - Shamal winds – and high, during days of summer and winter sea breeze, but low during days of no sea breeze with prevailing southerly winds blows offshore.

In accordance with the first case, during days of no sea breeze with north-westerly winds the highest ozone concentrations are observed. It can be argued that this result, Although only six day, were observed in the two years, this result represents source of O_3 outside the Emirate of Dubai. A possible source could be the north-west of The Arabian Gulf. It is well known that there are several industrial areas in Qatar, Bahrain and in the eastern part of Saudi Arabia. The present study found that the northerly winds during days of no sea breeze might transported the pollution from the heavy petroleum industrial area in Saudi Arabia, especially those winds associated with highest speeds. With its maximum speed of about 16 knots, it can be estimated that these winds would only take two days to approach Dubai, which is nearly 500 km from that part of Saudi Arabia.

The second case, high ozone concentration during days of summer and winter sea breeze, might prove the study hypothesis that the air mass can be transported offshore and then back inshore as a result of the land and the sea breeze circulations. As these days are characterised with normal sea breeze circulation and a moderate wind speed, the pollution created from local sources during day times such as car traffic and industrial areas would be returned to the same areas at late afternoon. In addition to the summer sea breeze, which only act as a transmission factor for pollution, there are the favoured weather conditions, such as high temperature and high relative humidity also increases the ozone concentrations.

8.5.4 Significant variation during days with no sea breeze, but constant southeasterly winds

Due to the constant wind and the absence of a sea breeze one might expect to find a uniformly unvaried pattern over 24 hours, but the results presented a daytime peak. The curve of the diurnal variation in O_3 concentration was roughly the same as for the total solar radiation. Furthermore the air temperature was increased, especially during the daytime, by the wind coming from the land hence blowing over the Empty Quarter.

8.5.5 The variations between the stations and days of different types of sea breeze

Unlike in Athens (Güsten and Heinrich, 1988), there are difference in the results obtained between sites that cannot be caused by a difference in height above sea level, as all the stations are at roughly the same height.

Deira is a typical urban site, close to the metropolitan area and affected by high traffic density, where we find a pronounced maximum in O_3 in the early afternoon. Concentrations in the early morning are low, as the pollutants generated by the emissions of NO_2 and NO during the early morning traffic destroy O_3.

Mushrif Park is located 15 Km downwind from Deira and therefore far from the source of precursors of O_3. Here the high level of O_3 is related to that in Deira from where it is transported by the sea breeze, the flow of which takes approximately half an hour to reach Mushrif Park. There is no local source of O_3, apart from the persistently high temperature during the summer speeding up the generation of O_3 and, coupled with the absence of a sink for O_3 in the area, this causes the constantly higher level of O_3 at Mushrif Park. Figure. 7.14 illustrates the strong positive relationship between O_3 and temperature at Mushrif station during summer and winter sea breeze.

The station at Jebel Ali village has showed the most interesting O_3 values, as it provides the highest recorded levels, in spite of the absence of a source for O_3 in the area.

Since Deira has the higher traffic density, one might expect it to also show higher pollutant concentrations such as NO, NO_2 and O_3. However, higher levels have consistently been recorded at Mushrif Park (see Fig. 7.2). The corresponding daytime and nighttime patterns in Figures. 7.2 (a), (b) and (d) can be explained in three ways, which might also be combined.

1. During the rush hour there is an increase in NO_x and HCs, which causes raised levels of O_3 after approximately 09:00 local time. At the same time the sea-breeze circulation is established and the pollution is transported all over Dubai by the sea breeze. During this transport the precursors NO_x and HC are diluted, but the O_3 concentration is already generated, which leads to increased O_3 concentration in Mushrif Park due to the continuing sea-breeze circulation, which brings the pollutants to Mushrif Park. This explanation is based on the assumption that all the transported pollution at Mushrif Park comes from Deira. However, pollution from Jebel Ali Port and beyond might contribute as well. We cannot clearly identify the sources of transported pollution, but assume that beside the local source (i.e. Deira) there is also a regional one as at in i.e. Jebel Ali Port and beyond.
2. Due to the high traffic density, more ozone will be destroyed during morning and evening rush hours at Deira than at Mushrif Park, where we have practically no traffic.
3. Mushrif Park might have higher temperatures, since it is located in the desert, but unfortunately we have no separate data for this location. As was seen in Jebel Ali Port, higher temperatures speed up the production of O_3 (see Fig. 7.5).

The station at Al Safa showed continuously low levels of O_3, although one might expect it be similar to Deira. As has been mentioned in chapter three, to the east is an open land which stretches up to approximately 6 km, after which there is an industrial area (cement factory and heavy industrial area).

The results from this site might suggest that dust particles can be an important sink for NO_x, oxidants, and free radicals (Zhang *et al.*, 1994). The decrease in nitrogen oxides and the lowering of the peroxy radicals that occur in the presence of dust must result in a decrease in production of O_3. Alternatively, it is possible that the monitoring station which is located close an the irrigated area, which would give high levels of water vapour in the air, which can act as sink for ozone concentrations (Zhang *et al.*, 1994).

8.6 Conclusion

1. Temporal variation in the monthly average of NO_2 concentration shows higher concentrations in the winter than in the summer.
2. Unexpectedly low concentrations of NO_2 are found in the industrial location of Jebel Ali municipality and the residential of area Jebel Ali village. This means that the power station is not a major contributor to ground level NO_2 pollution in its immediate viscinity. The spatial pattern of NO_2 concentrations through the Dubai Emirates also fails to indicate a major impact of the power station.
3. The levels of primary and secondary pollution such as NO_2 and O_3 in Emirates of Dubai are presumably dependent on the sea breeze circulation.
4. The major source of NO_2 in Emirates of Dubai is traffic, and the highest levels of NO_2 pollution at ground level were observed at roundabouts and in sites close to the city centre.
5. During different day types of wind pattern Al Safa station regularly recorded low O_3 concentrations, Jebel Ali village station regularly recorded high O_3 concentrations, while Deira and Mushrif stations both show similar intermediate O_3 concentrations.
6. At the same time, during days of no sea breeze with northwesterly winds NSBNW when the speed ranged from 13 to 16 knots, the average of O_3 concentrations reaches the highest values. During days of winter sea breeze WSB the average of O_3 concentration showed the lowest level.The level of O_3 recorded during nighttime might be related to local source during daytime, and then was trapped under the inversion layer.

7. During days of no sea breeze with prevailing northwesterly winds the levels of O_3 reaches it highest concentrations due to external factors which may be transporting the pollution from north-west of the Arabian Gulf.

8. During days of summer and winter sea breeze, which are characterized by normal sea breeze circulations and moderate wind speeds, there is enhancement of the pollution generated by local sources, mainly from traffic.

9. It is important to note that the value of NO_2 concentrations throughout the Emirate of Dubai are below the annual National Air Quality standard for NO_2 of 50ppb which has been set in USA and Canada. However, because of continuous increase in vehicular and industrial areas, all these result will probably change in the future.

8.8 Further work

The results of this study highlight some areas of key uncertainty, relating to local mesoscale meteorology.

1- There is uncertainty about the structure of air flow over the Emirate of Dubai from different directions e.g. southeasterly from the open desert area, northwesterly from the coastal zone and the Arabian Gulf. This could be addressed using surface meteorological tower and upper air data to monitor wind direction, wind speed and temperature.

2- There are no data to evaluate the internal boundary layer over the Dubai. Measurement of the depth of the boundary layer, assessment of the horizontal transport paths over mesoscale domains, and characterisation of the structure of atmospheric turbulence up to 7-8 km inland are needed for better understanding of the pollution climatology.

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