Traffic Air pollution Assessment and Sustainable Transportation: The Case for Abu Dhabi City

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Abstract:
The Environmental Research and Wildlife Development Agency (ERWDA) is implementing an Air Quality Management Study to determine the impact of current and future development activities on the quality of ambient air in Abu Dhabi Emirate. The Norwegian Institute for Air Research (NILU) and its agent in Abu Dhabi, Dome Oilfield Equipment & Services (DOME) are undertaking this Abu Dhabi Air Quality Management Study on behalf of ERWDA.

One part of this project is to identify hot spots and to quantify the source contributions to impact on air quality. The NILU developed air quality management system AirQUIS has been used to collect existing data on emissions to air from sources such as industry, traffic, power plants and hospitals. The GIS based AirQUIS system combines the latest sensor and monitor technologies with data acquisition; data base developments, quality assurance, statistical and numerical atmospheric dispersion models and advanced computer platforms for data processing, as well as distribution and dissemination of data and model results.

Based on existing data on meteorology, traffic load and emissions from industry in Abu Dhabi, numerical dispersion models have been used to calculate concentration levels of nitrogen dioxides in Abu Dhabi city. The results show that, with the contribution from traffic emissions alone, the EU one-hour air quality guideline for NO_2 of 200 µg/m^3 is exceeded inside Abu Dhabi city. On the other hand, the EU air quality guideline for 6-month average NO_2 of 50 µg/m^3 is not exceeded in Abu Dhabi city with the emissions from traffic alone. Including industrial sources, the guidelines are exceeded in an impact area outside the city centre between the bridges.

1. Introduction

The Environmental Research & Wildlife Development Agency (ERWDA) as part of its efforts to ensure sustainable balance between economic growth and healthy environment has signed a contract (on Sept 8, 2003) with the Norwegian Institute for Air Research (NILU) to conduct an Air Quality Monitoring and Management Study for the Emirate of Abu Dhabi that will last 18 months.

This initiative comes as part of ERWDA's continuous efforts to protect the environment for generations to come, especially under the major development the emirate is witnessing in all economical, social and technological aspects. This industrial and social boom is bound to have effects on the surrounding environment such as jeopardizing the quality of the air we breathe and subsequently impacting the human health, since it has been directly related to irritation of respiratory system and respiratory problems in children, people with asthma, and other sensitive populations.

The project is subdivided into four distinct stages, the first of which constituted baseline data collection and assessment in collaboration with a multi-disciplinary, multi-sectoral technical team representing Abu Dhabi Municipality, Al-Ain Municipality, Abu Dhabi National Oil Company (ADNOC), Abu Dhabi Water and Electricity Agency (ADWEA) and Abu Dhabi Police Department. Based of the said assessment and collected data, tender document was compiled and a successful bidder was chosen.

The second stage (current) is comprised of analysis of the emissions and dispersion of flue gases from industrial stacks (point and area stationary sources) and the emissions from vehicular traffic (on-road and off-road mobile sources) in the Emirate by using internationally approved air dispersion models. Also, recommendations should be included for the specifications, optimum number and locations of fixed and mobile Air Quality Monitoring Stations to effectively and comprehensively monitor the major industrial and residential areas of Abu Dhabi.

The outcome of the previous stage will steer the implementation of the third one, which comprises the purchase, construction and operation of a Central Network System, and a fully equipped and functional Air Quality Management System.

The continuous operation and manipulation of the installed state-of-the-art system comprise the fourth and last stage of this project. Experience will be built throughout the previous stages and will continue throughout the life of the project to ensure maximum utilization of this invaluable planning and prediction tool.

Transport is a key factor in modern economies. However, there is a permanent contradiction between society, which demands ever more mobility, and public opinion, which is becoming increasingly intolerant of chronic delays and the poor quality of some transport services. As demand for transport keeps increasing, the transport system needs to be optimized to meet the demands of enlargement and sustainable development. A modern transport system must be sustainable from an economic and social as well as an environmental viewpoint.

An efficient and flexible transport system is essential for our economy and our quality of life. Very often the current transport system poses significant and growing threats to the environment and human health, and even defeats its own objectives ('too much traffic kills traffic'). The drastic growth in road transport and aviation is the main driver behind this development.

The sector is the fastest growing consumer of energy and producer of greenhouse gases in the EU. Technology and fuel improvements have resulted in marked decreases of emissions of certain pollutants. Yet urban air quality in most European cities is still poor. Roads and railways are cutting natural and agricultural areas in ever-smaller pieces, threatening the existence of wild plants and animals. Traffic noise causes human health problems, and over 100 people die on the EU's roads every day on average.

Transport policies increasingly recognise the need to restrain transport growth and to improve the market shares of the various transport modes. Fair and efficient pricing, better targeted investments, and spatial planning are some of the policy tools that can help to achieve this.

1.1 Measures to reduce NO_X emissions from road transport

Nitrogen oxide emissions from road transport in EU-15 countries increased by about 20 % from 1980 to 1990 and then fell, so that by 2000 they essentially returned to the 1980 levels. That the emission did not continue to increase in line with traffic growth was mainly due to the introduction of three-way catalyst converters to cars in the late 1980s and early 1990s. Although many Member States had encouraged the penetration of cars with catalyst converters before 1990, Directive 91/441/EEC made it effective in all Member States. Emission standards for heavy-duty vehicles, as demanded by Directive 91/542/EEC, Stage I, also contributed to the emission reduction although to a lesser extent. Without these measures, nitrogen oxide emissions by traffic in the EU would have been 50 % higher in 1998.

After 1995, the effects became apparent with the introduction of stricter emission standards for both heavy-duty vehicles (91/542/EEC, Stage II) and passenger cars (94/12/EC). It is expected that these will lead to further reductions in the near future.

The gradual increase in sales of diesel passenger cars in some European countries contributed further to a reduction in nitrogen oxide emissions, which was significant in Austria, Belgium, Germany, France and the Netherlands. Increased use of diesel across the EU caused a drop in emissions of 2 to 4 % in the 1990s.

2. AirQUIS, an integrated air quality management system

NILU has developed an air quality management system AirQUIS, which integrates both air quality measurements and modelling. The system has been established and operated in more than 30 cities and urban areas worldwide.

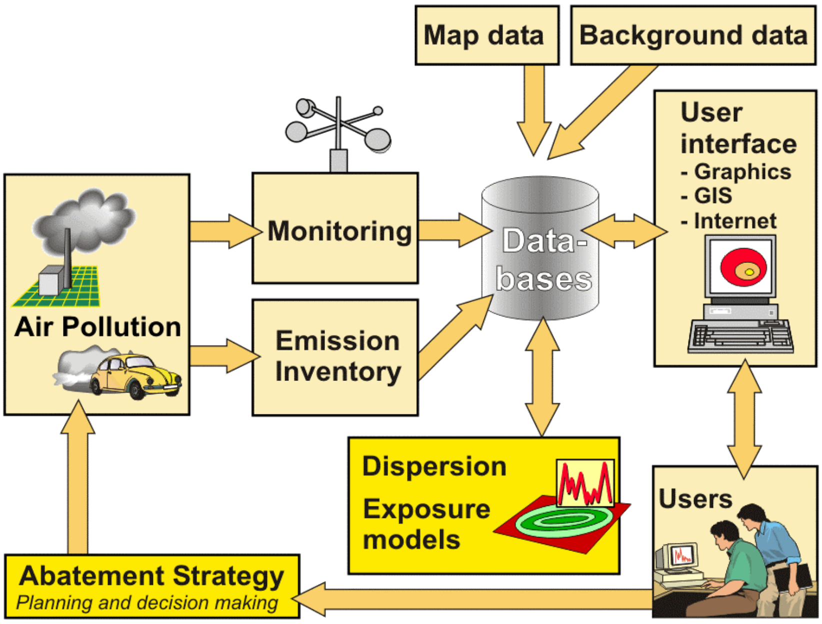


Figure 1: The modules of an integrated air quality management system.

The AirQUIS system is modular and consists of the modules described below.

2.1 On-line measurement system

The AirQUIS measurement module consists of modern on line sensors for selected air pollution indicators according to local standards and indicators. The air quality monitoring stations are equipped with a modern digital data logger unit to collect and store data at each site. Hourly average data is transferred as raw data via modem and telephone lines to the central computer unit with frequency specified by the user.

2.2 Automatic data acquisition system

To collect air quality and meteorological data from various measurement stations to the central database, NILU has developed a robust and stable data acquisition system, ADACS, to obtain high frequency of operation. In addition to automatic data transfer, this module contains aggregation and scaling functionality as first level of quality control.

2.3 The databases

The development of an associated database or metadata is important to all modern environmental monitoring and information systems. The AirQUIS data base system consist of several databases, which serve as main storage platforms for:

- On-line collected ambient air quality data.

- Calculated fields of emissions, concentrations and exposure.
- Historical data with trends, background information (land use, population).
- National and international regulations, air quality limits or guideline values.
- Information on the support and decision-making processes.

The databases contain information that enables an evaluation of the actual state of the environment and it includes data for establishing trend analyses, warnings and the undertaking of countermeasures in case of episodic high pollution.

2.4 The Air Emission Inventory Database

The sources of air pollution are divided in three categories:

- **Point sources;** single activities like industries, energy production etc., that are linked to single stacks, are treated as point sources.
- **Line sources;** moveable sources like road traffic, air flights and shipping are treated as line sources in the emission database.
- **Area sources;** home heating/cooling, public and private services, open burning, windblown dust etc., are treated as area sources.

The emission module calculates all combinations of emissions in an area, such as total emissions of a component in selected areas or divided into source categories in a selected time period.

The emission data are easily accessed through search for area or region, line or point data sets. The specific industry can also be accessed through advanced search functionality on type of industry. The user can also have the functionality to find/edit information on emission sources by searching by polygon/rectangle on geographical areas via the map.

2.5 Air Quality modelling

The NILU developed source oriented numerical dispersion model EPISODE calculates spatial distribution of hourly concentration of selected indicators, such as SO_2, NO_2 and suspended particles. The NILU models ROADAIR and CONTI-LENK are used to estimate sub grid concentrations close to roads within the square grid. A puff-trajectory part of the model is used to calculate the influence of point sources.

To obtain a good description of the wind field in a complex terrain, NILU has included a terrain influenced wind field model. This model is fast and can on hourly basis perform inhomogeneous wind fields as input to the dispersion models for emissions to the atmosphere.

The models have been presented for evaluation, discussions and model comparisons within the European Environmental Agency (EEA). The models are already part of the models approved by Norwegian Authorities. They have also been used in several countries in Europe.

2.6 Exposure

AirQUIS has an Exposure or Abatement Module, which in an efficient way can perform analysis of different scenarios to improve air quality. This module has global functionality to select source by category or in areas direct from the map. Different recommended measures to reduce air pollution can easily be evaluated due to population exposure and cost-benefit or cost-efficiency analyses. A priority list of the selected measures can be developed, taking into account air pollution exposure, health aspects and related costs.

2.7 Surveillance and Management

The AirQUIS emission inventory system and advanced dispersion models can compare measurement data to model estimates. Model results give spatial concentration distributions as a total or for individual source categories. In this way the system can be used as a tool for evaluating and comparing different measures to reduce air pollution. The models may also estimate exposures of the population, materials and ecosystems.

Based on defined abatement options and scenarios, cost-benefit analyses can be used to evaluate the best possible options to reduce the air pollution load seen from an economic point of view. The results of such analyses again may lead to the development of Action plans.

2.8 Information to the public

Information of air quality in urban areas has been issued to the public on a daily basis described in terms of "very good", "good", "poor" etc. Information to the public is given to the public as text, graphs, maps, SMS-messages, e-mail etc, and updated on hourly basis.

3. Atmospheric dispersion models

The AirQUIS-EPISODE model is the main dispersion model used in the PC-based Air Quality Information System AirQUIS (Bøhler and Sivertsen, 1998[1]), which has been developed at NILU during recent years. This Air Quality Management System (AQMS) is part of NILUs support for Air Quality Management (AQM) and is more fully described in http://www.nilu.no/aqm. The modelling system covers air pollution on all scales; traffic in street canyons and along roads, industrial emissions and gridded pollution from diffusive sources and household etc. within the urban areas and on a regional scale.

The AirQUIS-EPISODE model is a combined 3D Eulerian/Lagrangian air pollution dispersion model for urban and local-to-regional scale applications (Slørdal, Walker and Solberg, 2003[2]). The model is typically used to calculate air pollution concentration in cities and urban areas from several simultaneous emission sources such as road traffic, domestic (home) heating and industry.

The model calculates ground level hourly average concentrations as gridded values (using one or more user defined grids) and/or at individually placed receptor points. The model also calculates hourly dry and wet deposition values for the same geographical locations. Since the output from the model consists of hourly data, it can be used as a basis for calculating long term concentration averages or total deposition values. It also contains a statistical module for calculating the N highest daily or hourly values during the simulation period which can be used for defining percentiles.

The Eulerian part of the AirQUIS-EPISODE model consists of the numerical solution of the atmospheric (mass) conservation equation of the pollutant species in a three-

[1] Bøhler, T. and Sivertsen, B. (1998) A modern air quality management system used in Norway. Kjeller, Norwegian Institute for Air Research (NILU F 4/98).
[2] Slørdal, L.H., Walker, S.E., Solberg, S. (2003) The urban air dispersion model EPISODE applied in AirQUIS$_{2003}$. Technical description. Kjeller, Norwegian Institute for Air Research (NILU TR 12/2003).

dimensional Eulerian grid. The Lagrangian part of the model consists of separate subgrid-models for line- and point-sources. The line source model is an integrated Gaussian type of model, while the point source model is a Gaussian segmented plume/puff trajectory model. The meteorological data which are being used in AirQUIS-EPISODE is calculated in a separate meteorological pre-processor. This meteorological pre-processor is based on advanced atmospheric boundary layer similarity theory (Gryning, Holtslag, Irwin and Sivertsen, 1987[3]; Bøhler, 1996[4]).

Calculations of NO_2 are based on using photochemical equilibrium between the three fast-cycle compounds NO, NO_2 and O_3. For more comprehensive photochemical calculations, the model contains a newly developed and simplified photochemistry scheme for cities and urban areas (Walker, Solberg and Denby, 2003[5]). This scheme is based on the more comprehensive EMEP photochemistry scheme (Anderson-Sköld and Simpson, 1999[6]; Simpson, 1993[7]). The new scheme contains 45 compounds and about 70 chemical reactions as compared to the EMEP scheme's 70 compounds and about 150 reactions.

[3] Gryning, S.E., Holtslag, A.A.M., Irwin, J.S., and Sivertsen, B. (1987) Applied Dispersion Modelling Based on Meteorological Scaling Parameters. *Atmos. Environ.*, *21*, 79-89.
[4] Bøhler, T. (1996) MEPDIM. The NILU meteorological processor for dispersion modelling. Version 1.0. Model description. Kjeller, Norwegian Institute for Air Research (NILU TR 7/96).
[5] Walker, S.E., Solberg, S. and Denby, B. (2003) Development and implementation of a simplified EMEP photochemistry scheme for urban areas in EPISODE. Kjeller, Norwegian Institute for Air Research (NILU TR 12/2003).
[6] Anderson-Sköld, Y. and Simpson, D. (1999) Comparison of the chemical schemes of the EMEP MSC-W and IVL photochemical trajectory models. *Atmospheric Environment*, **33**, 1111-1129.
[7] Simpson, D. (1993), Photochemical model calculations over Europe for two extended summer periods: 1985 and 1989. Model results and comparisons with observations, *Atmospheric Environment*, **27A**, No. 6, 921-943.

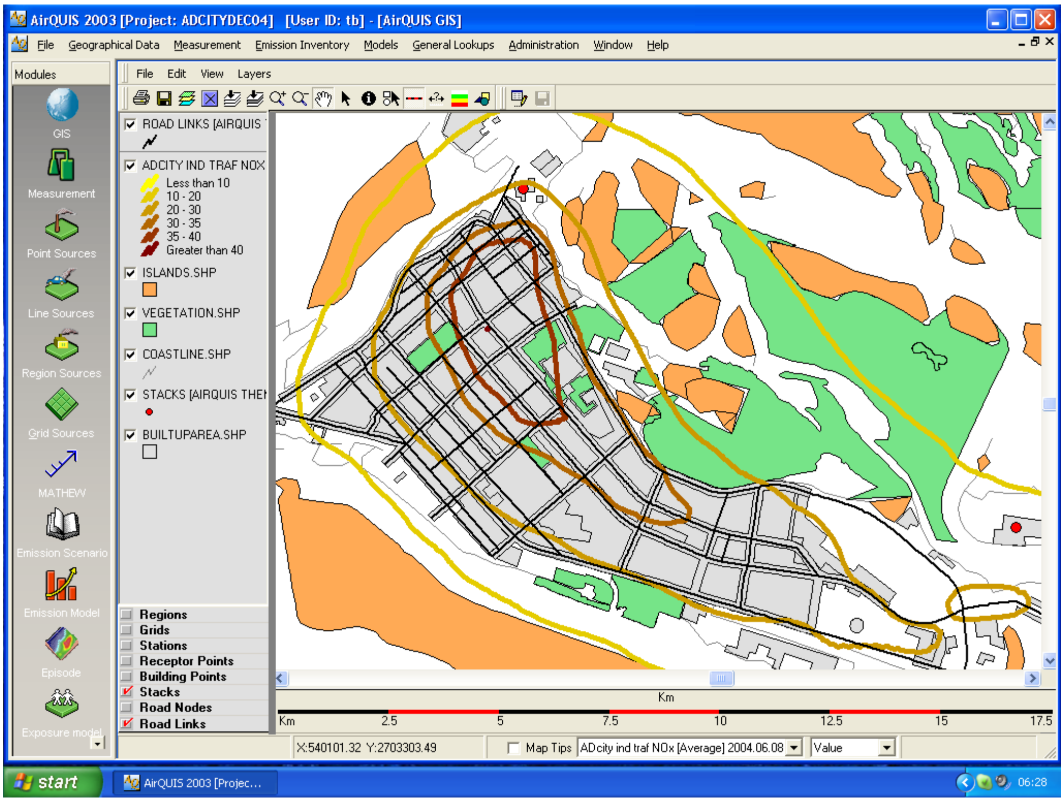


Figure 2: AirQUIS integrated GIS Module for presentation of modelling results.

4. Emission inventory in Abu Dhabi

The Norwegian Institute for Air Research (NILU) has carried out two major studies in Abu Dhabi related to air quality management:

- The first study was to provide Abu Dhabi National Oil Company (ADNOC) with the required pre-FEED and FEED, which included the necessary services to achieve a state of the art, professional, air quality monitoring and management system. This study contained collection of all existing information on emissions from ADNOC sources.
- The Environmental Research and Wildlife Development Agency (ERWDA) is implementing an "Abu Dhabi Air Quality Management Study" to determine the impact of current and future development activities on the quality of ambient air in Abu Dhabi Emirate. The emission inventory in this study was focused on non-ADNOC sources like traffic load, hospitals and power plants.

The following section provides an overview of the findings of the data review exercise for various emission data provided so far including stationary, area and line sources.

4.1 Power and Desalination Plants

The Abu Dhabi Water and Electricity Authority (ADWEA) has nine main power and desalination plants in the Emirate of Abu Dhabi, located in Al Ain, Mina Zayed, Abu Dhabi City, Al Mirfa, Madinat Zayed, Al Taweelah, Umm Al Nar.

Based on the average fuel gas consumption, emission data were established using the EPA's AP-42 Methodology based on fuel combustion/consumption rates provided. In addition, stack monitoring was performed on selected stacks to evaluate the validity of using standard emission factors.

4.2 Oil & Gas Industries (ADNOC & its Group Companies)

The majority of air emission sources from ADNOC and its group of companies generated from refining, gas processing, petrochemicals, exploration and production. Eleven companies were identified as main air polluting and seven companies were identified as minor air polluting when compared with previous activities are support services and maritime transportation.

The majority of the air emission in Exploration and Production activities arises from the use of fuel or from controlled flaring and venting, which is necessary for safe operation. Considerable amount of the emissions are hydrocarbons, consisting predominantly of methane. The remaining emissions, principally NO_X, SO_X and CO, are produced during the fuel combustion. CO_2 is not included because CO_2 is a greenhouse gas and its impact is on a global and not regional scale.

It is concluded from identifying existing ADNOC (Oil & Gas) data, there are more than eight hundred air emission sources distributed existing in ADNOC oil of companies. The majority of the air pollution sources of the eleven ADNOC main air polluting companies have been identified and identification of sources is missing for the other seven ADNOC minor contributors to air pollution. But the amount of available physical parameters and emission data per source is low, especially for two major companies, ADCO and ZADCO there is no information for any air emission individual sources.

4.3 Traffic data for Abu Dhabi City

NILU has received from ERWDA the Abu Dhabi Master Transportation Plan Technical Memorandum 2.2.1.& 2.2.4 belonging to the Abu Dhabi Municipality and Town Planning Department, which contain traffic flow data for 1999 for 155 measuring points, located at 78 of the signalised intersections on the island. The data provides the ability to track changes in traffic volumes through various time periods. Hourly (for weekdays only) and monthly/seasonal changes in traffic flow have been accessed and presented in this Technical Memorandum using the TCC data.

Figure 3 shows the hourly variation in traffic flow for an average Thursday and Friday, estimated and for a weekday, given in the Technical Memorandum 2.2.1.

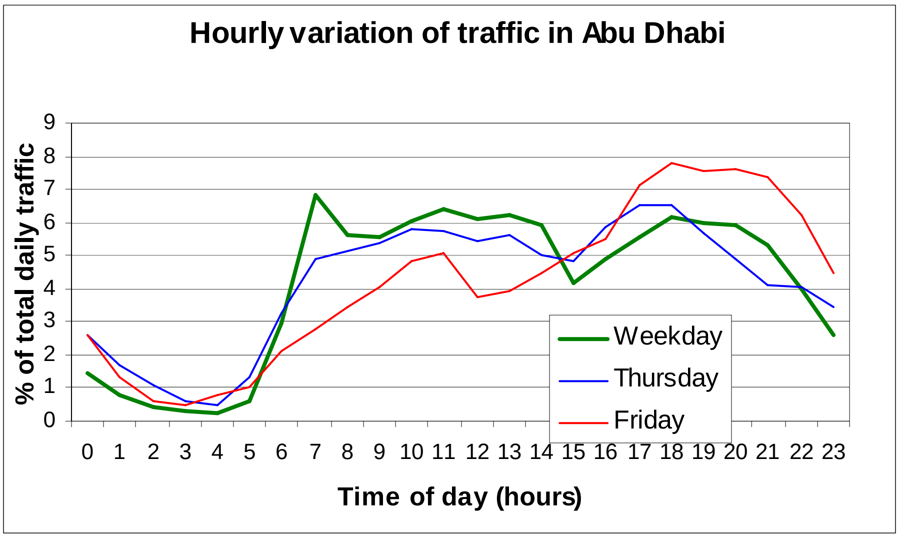


Figure 3: Hourly variation of traffic in Abu Dhabi.

Annual daily traffic (ADT) is needed as input to dispersion modelling. Based on the traffic countings described above and local experience, an estimated traffic network load for Abu Dhabi city was established as presented in figure 4. Figure 4 shows high traffic load on the major roads inside Abu Dhabi city, such as East Road, Airport Road and Salaam Street with estimated total daily traffic up to 90000 vehicles per day. In the central city of Abu Dhabi, the daily traffic load varied between approx. 50000 to 80000 vehicles per day.

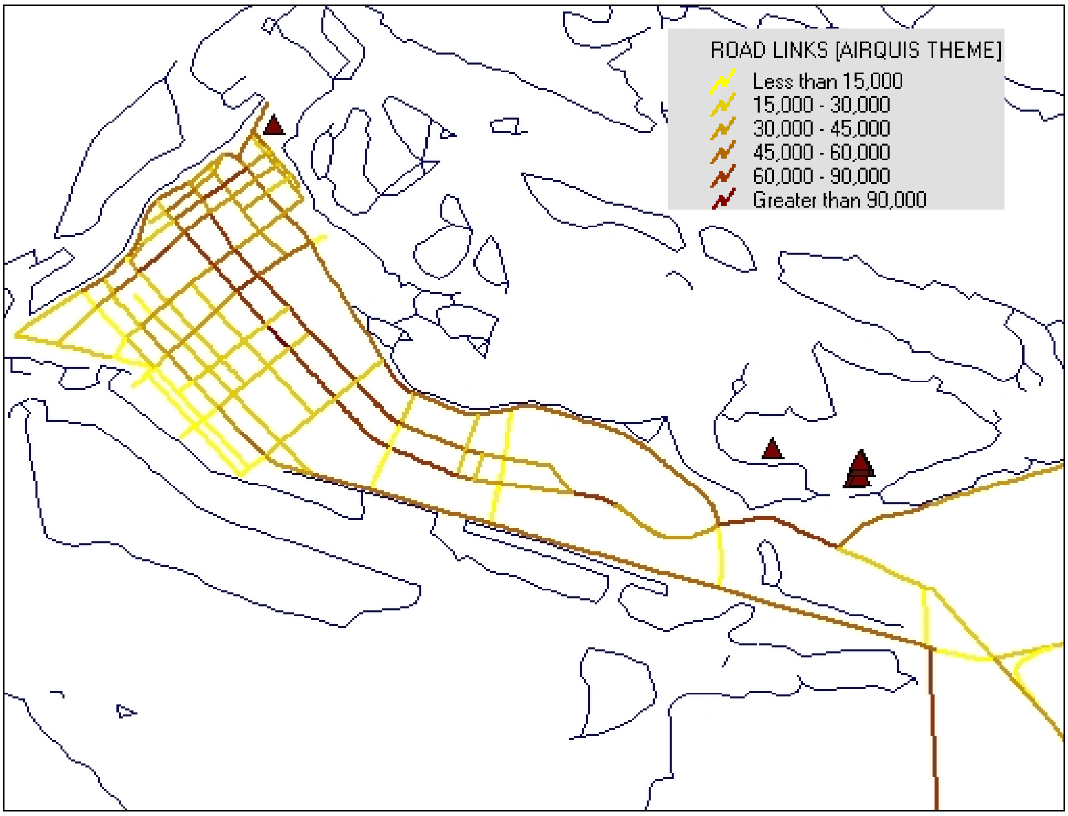


Figure 4: Estimated Annual Daily Traffic (ADT) for Abu Dhabi city based on traffic countings.

5. Atmospheric dispersion modelling of air quality

The NILU developed EPISODE model has been used to carry out dispersion calculations to describe the total impact of air pollution from all source categories in the Emirate of Abu Dhabi. The calculations describe the contribution from all sources such as industry, power plants and traffic and cover the most important components.

In this presentation focus is given to the contribution from traffic to the total impact of air pollution in Abu Dhabi city to describe the importance of traffic as the major source to air pollution in cities.

The wind rose for the modelled period, from 01/01/2001 to 30/06/2001, is given in figure 5. As the figure shows, the wind was blowing predominantly from west-northwest.

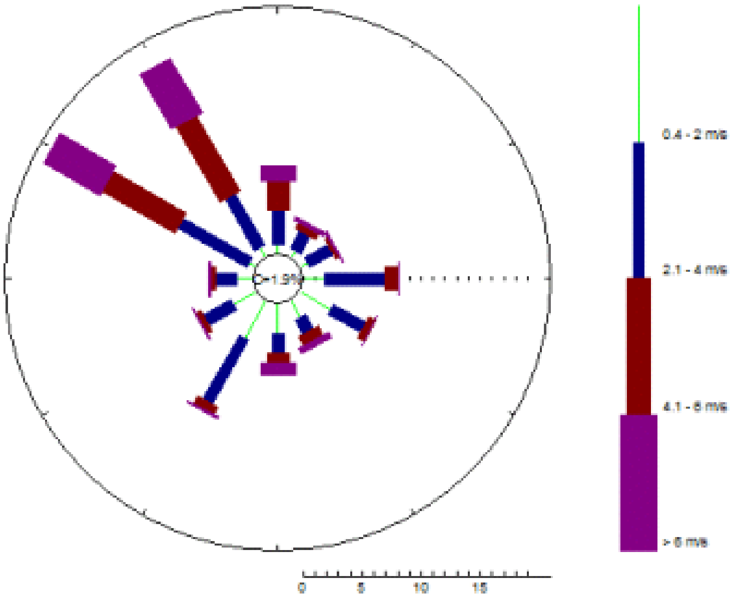


Figure 5: Wind rose for the modelled period. The meteorological station was placed between the Maqta and Mussafah Bridges in Abu Dhabi city.

5.1 Estimated impact of nitrogen oxides from traffic in Abu Dhabi city

Daily average traffic (ADT) has been estimated for the major roads in Abu Dhabi city based on the traffic countings as described above. The impact emissions from traffic has been calculated hour by hour, by using daily and weekly variations of traffic load and standard emission factors for vehicle fleet for Europe with pre-catalyser technology.

The average impact of NO_X and nitrogen dioxides (NO_2) from traffic calculated for a 6-month period is given in figure 6. It shows that the 6-month average NO_2-concentrations in the centre of Abu Dhabi city are between 30 and 38 µg/m^3 and the NO_x-concentrations are above 100 µg/m^3.The average level on the whole peninsula for NO_2 is above 20 µg/m^3 and above 5 µg/m^3 for NO_x. For comparison, the proposed air quality guideline for 6-month average NO_2 is 50 µg/m^3.

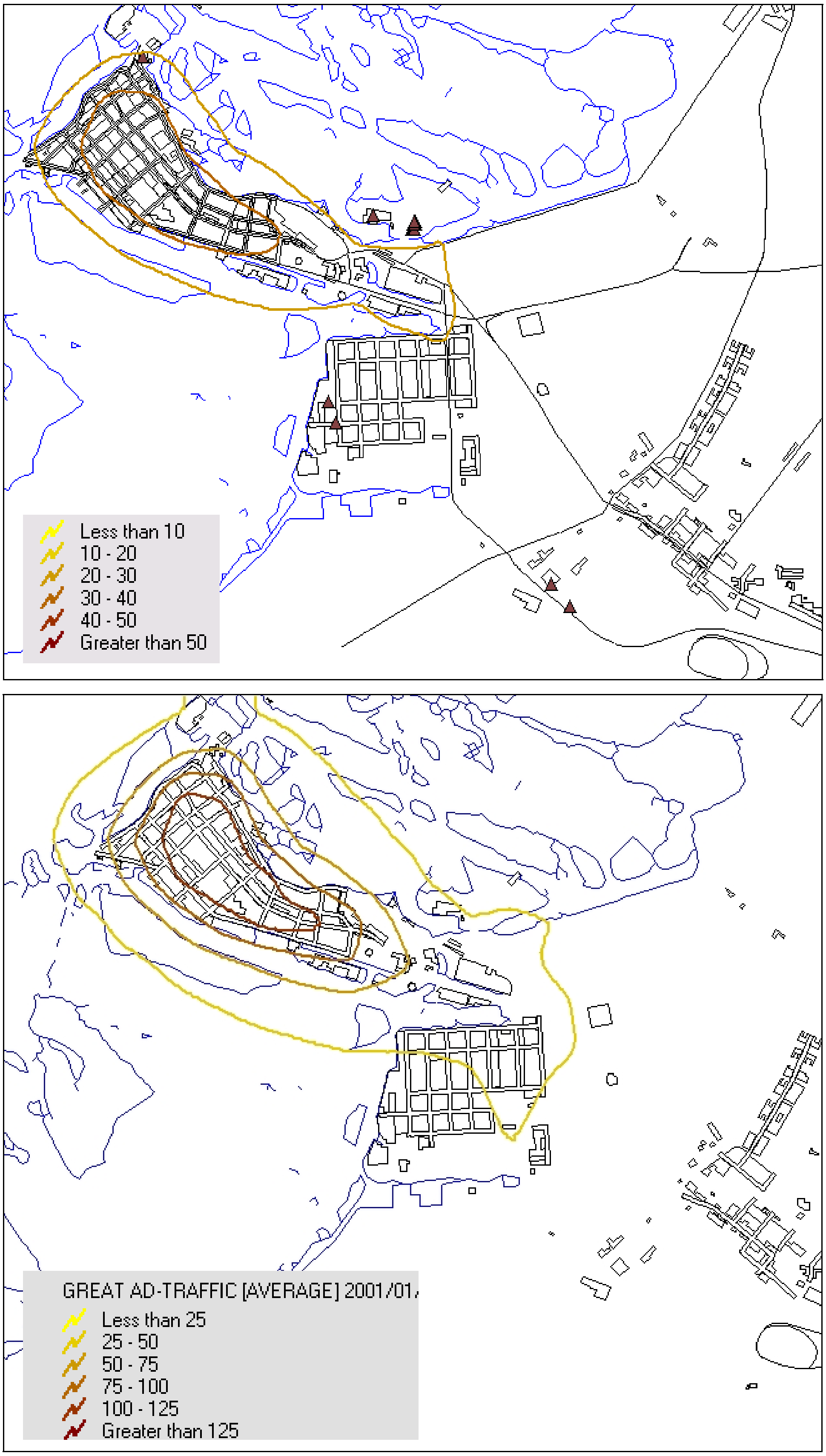


Figure 6: Average NO_2 (top figure)/NO_X (bottom figure) concentrations ($\mu g/m^3$) from traffic emissions in Abu Dhabi city for a 6-month period.

The highest one-hour impact of nitrogen dioxides from traffic calculated for a 6-month period is given in figure 7 below. It shows that during hours with high impact, NO_2-concentrations up to approx. around 250-270 µg/m^3 occurred in the centre of Abu Dhabi city. For comparison, the proposed one-hour air quality guideline for NO_2 is 200 µg/m^3.

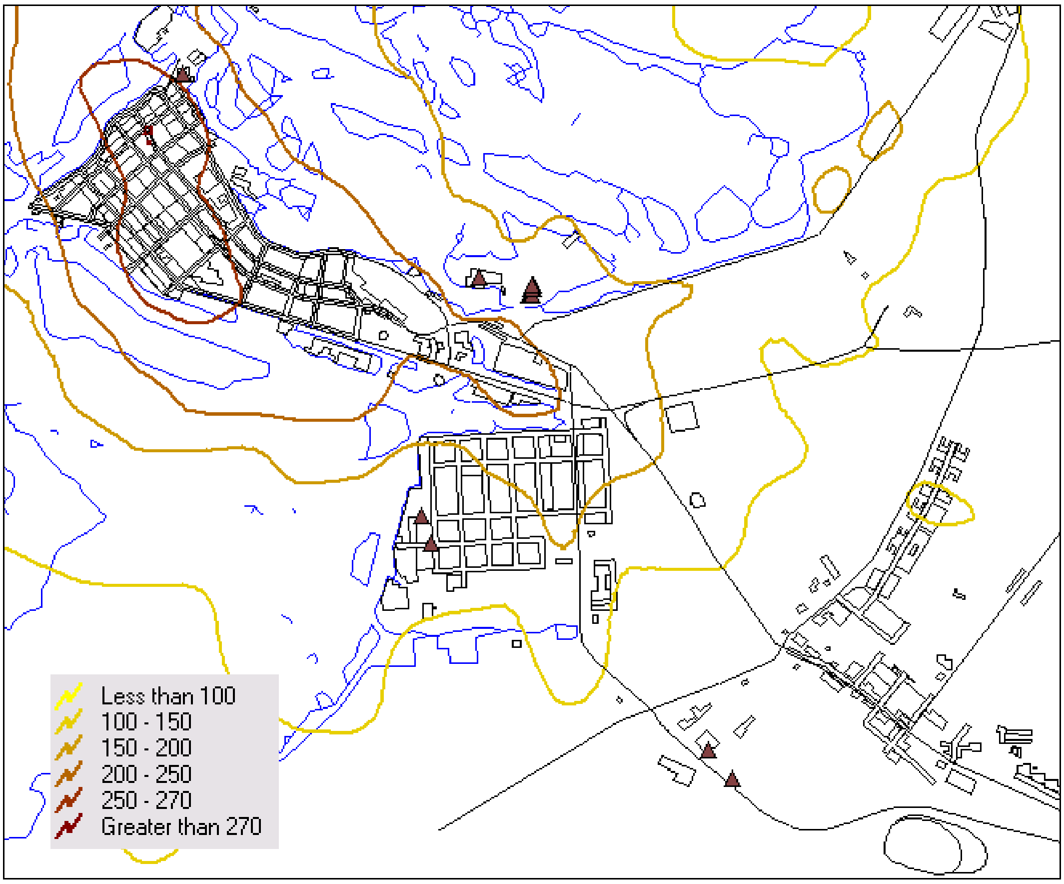


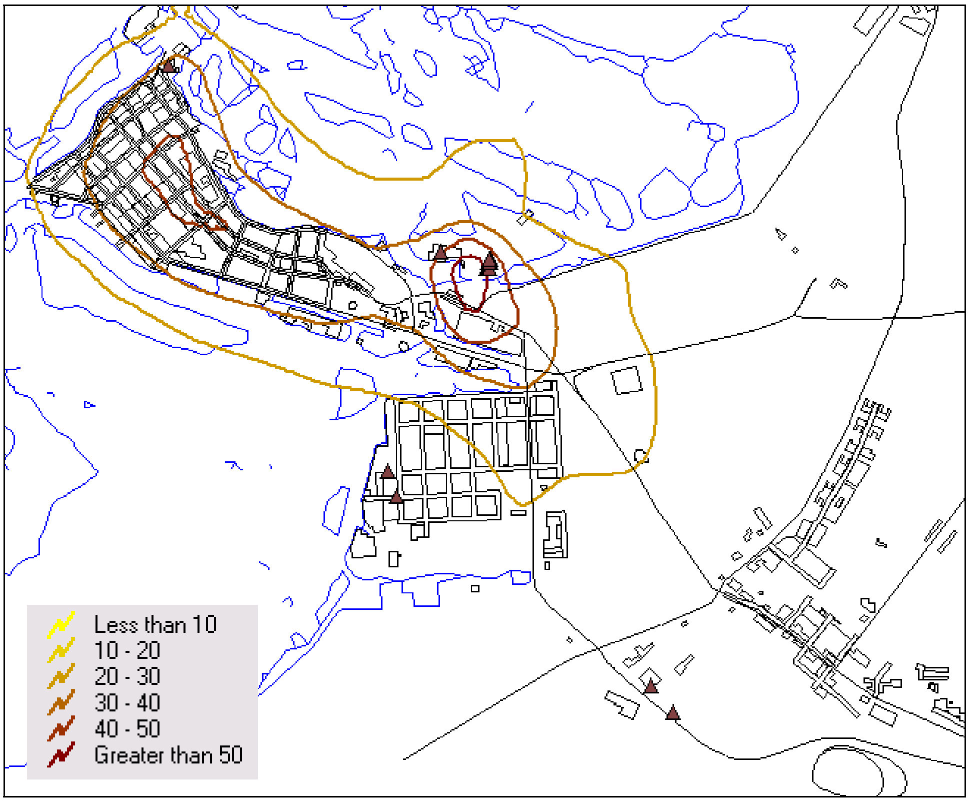
Figure 7: Typical maximum one-hour average NO_2 concentrations (µg/m^3) from traffic emissions in Abu Dhabi city.

5.2 Estimated impact of nitrogen oxides from traffic and industry in Abu Dhabi city

The daily NO_X-emissions from the industry are approx. 270 tons/day. Similar, the daily emissions in Abu Dhabi city from traffic is approx. 70 tons/day. It is important to note that the emissions from traffic are emitted at ground level, impacting immediately on the air quality at ground level, while the emissions from the industry are emitted through stacks at a height of about 30 m and with a given flow velocity and temperature which contribute to the elevation and dilution of the emitted flow before it reaches the ground.

The average impact of NO_X and nitrogen dioxides (NO_2) from traffic and industry calculated for a 6-month period is given in figure 8 below. It shows that the 6-month average NO_2-concentrations in the centre of Abu Dhabi city are around 30 - 40 µg/m^3 and the NO_x-concentrations are around 125 µg/m^3, while the average level on most of the peninsula is above 30 µg/m^3 for NO_2 and above 50 µg/m^3 for NO_x. In addition, an impact area located between the bridges exceeds the proposed air quality guideline for 6-month average NO_2 of 50 µg/m^3.

The maximum one-hour averaged concentrations of NO_2 with emissions from traffic and industry are given in figure 9. Compared with the traffic only calculations, these calculations gave similar hourly maximum concentration levels in Abu Dhabi city, where the proposed one hour air quality guideline for NO_2 of 200 µg/m^3 were already exceeded with the contribution of the traffic emissions alone is not significantly further aggravated by emissions from the industry. However, outside Abu Dhabi city peninsula and between the bridges, the results show a significant increase in maximum hourly values of NO_2. When we compare the model results with the contribution from traffic alone with emissions from the industry and traffic sources, the area of exceedance of the one-hour air quality guideline for NO_2 expands from the Abu Dhabi city peninsula to about 15 km, including Mussafah area. This confirms that in highest impact areas of nitrogen dioxides, the major contributor is traffic, while point sources like power plants will give high impact in maximum impact areas downwind from the stacks.



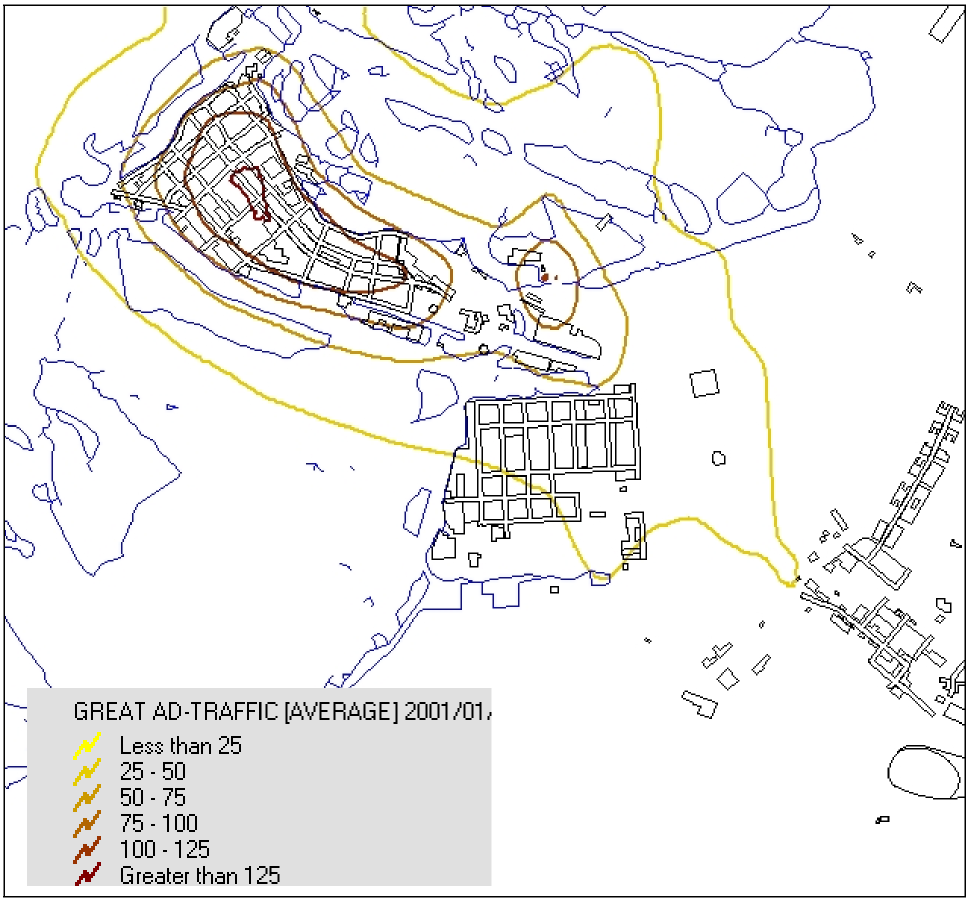


Figure 8: Average NO_2 (top figure)/NO_X (bottom figure) concentrations (µg/m^3) from traffic and industrial emissions in Abu Dhabi city for a 6-month period.

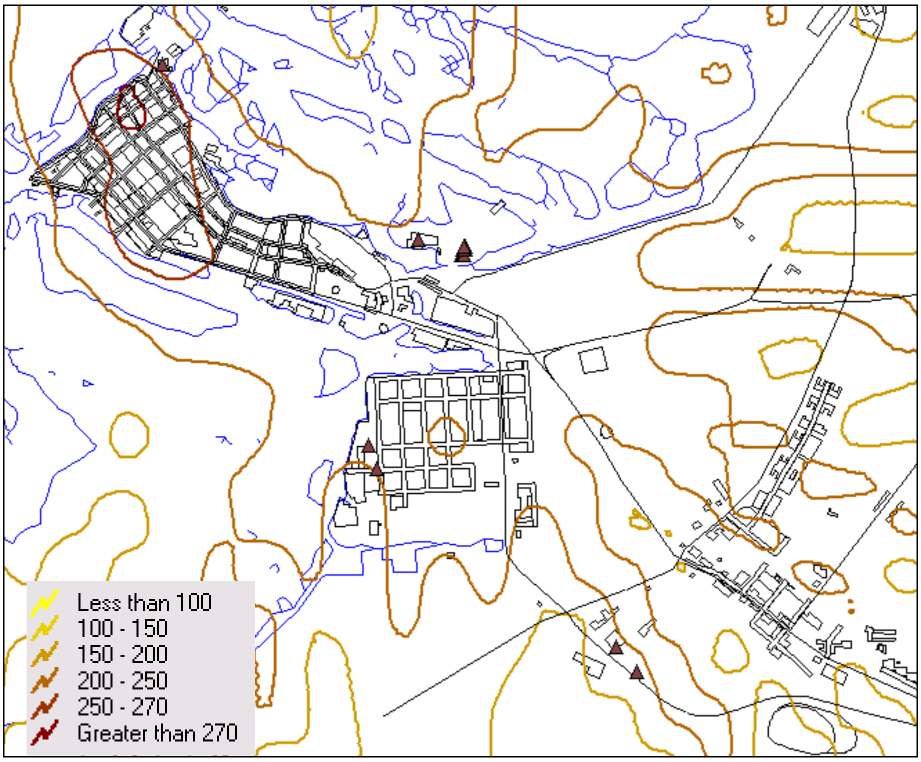


Figure 9: Typical maximum one hour average NO_2 concentrations (µg/m^3) from traffic and industrial emissions in Abu Dhabi city.

6. Conclusions and recommendations

6.1 Conclusions

An efficient and flexible transport system is essential for our economy and our quality of life. But the current transport system poses significant and growing threats to the environment and human health, and even defeats its own objectives (‘too much traffic kills traffic’). The drastic growth in road transport and aviation is the main driver behind this development.

The GIS based Air Quality Management System AirQUIS presented in this paper is one step towards obtaining the adequate and relevant information in order to select the right actions in the process of city planning.

NILU has used the NILU developed air quality management system AirQUIS to carry out atmospheric dispersion modelling to describe the impact of air pollution from traffic. These calculations shows that inside the Abu Dhabi city, due to emission conditions and prevailing wind, traffic is the main contributor to impact of nitrogen oxides inside Abu

Dhabi city. The EU one-hour air quality guideline for NO_2 of 200 $\mu g/m^3$ is exceeded inside Abu Dhabi city with the emissions from traffic alone. However, point sources from industry will give increased impact downwind of prevailing wind directions. Their contribution, added to the contribution from traffic, can lead to exceedance of the EU Air Quality Guidelines in areas outside the city centre where these guidelines were not exceeded with the contribution from traffic alone.

6.2 Recommendations

To obtain a sustainable development of the Abu Dhabi city it is crucial to implement similar emission standards for heavy-duty and light vehicles as in the EU Member States. This means that through regulations and restrictions on emissions from the transport sector, such as three-way catalyst converters to cars will lead to reduced impact from traffic which together with an efficient and flexible transport system will improve the environment and our quality of life.