NILU: OR 35/2008

NILU: OR 35/2008
REFERENCE: E-107016
DATE: JUNE 2008
ISBN: 978-82-425-1972-6 (print)
978-82-425-1974-0 (electronic)

Model test for applying AirQUIS in Ho Chi Minh City

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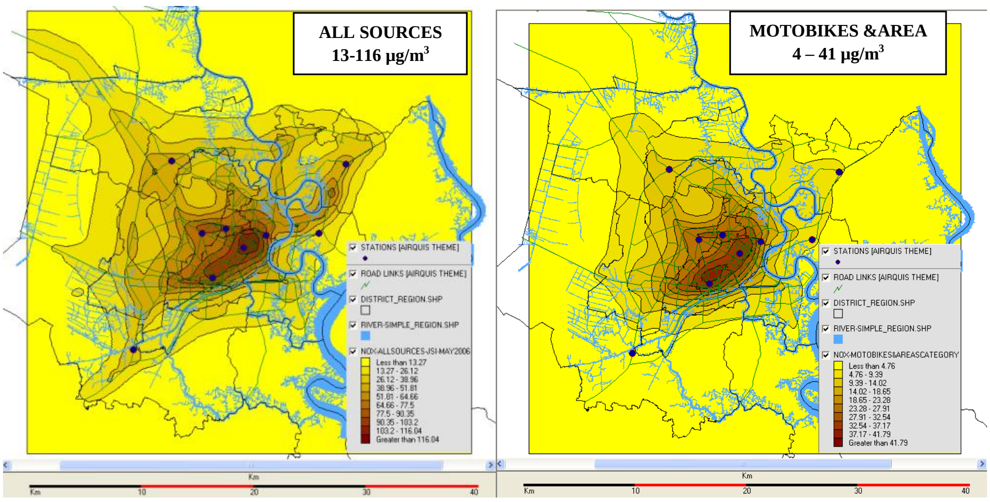


Contents

Summary

The NILU developed dispersion models which are part of the AirQUIS planning tool, has been tested and improved for applications in Ho Chi Minh City (HCMC). A number of parameters and approaches have been applied in order to find the most suited model, which also reflects spatial and time variations in NOx concentrations measured in HCMC

The Ho Chi Minh City Environmental Protection Agency (HEPA) under DONRE is operating an air quality monitoring and assessment system in HCMC. Air pollution dispersion models have been installed as part of the GIS based database and planning tool. This system is based on the NILU developed AirQUIS system.

The models have been operated for a number of different meteorological situations. The model results were further verified against measurement data and NOx concentrations were selected as the main component for these tests.

Different variables in the model; such as mixing heights, stability parameterisation and wind data were checked. Some adjustments were implemented in order to obtain an operational model for HCMC. The model was also run to estimate NO_2 exposure based on population statistics for the city.

In further applications of the model concentration estimates will be used to evaluate different source's relative importance to the total exposure, impact assessment and to perform optimal abatement planning.

Model test for applying AirQUIS in Ho Chi Minh City

1 Introduction

Emissions from vehicles, cars, trucks, industries and home cooking are potential sources for air pollution in Ho Chi Minh City (HCMC) Vietnam. Many of the sources have limited air emission control systems as well as poor maintenance. A "bottom-up" detailed emission inventory has been developed for HCMC based on the NILU developed AirQUIS emission model. Evaluations of emission factors for some of the sources have been important in the total evaluation process.

Dispersion models linked to population distribution information have been developed to estimate the exposure to people from individual source groups. The relative importance of the different sources has further been estimated based on total exposure evaluations.

In order to test and verify the dispersion models in AirQUIS measurement data for meteorology and air quality have been selected based on measurements performed in HCMC during 2007. Different periods have been tested, and the aim has been to present the model performance for a variety of dispersion conditions, dispersion parameterisation and different application modules for the use of the model features.

1.1 The first test programme

A test programme for verifying the models was developed. It included the following three phases:
First phase:

1. Check all emission factors Nox.
2. Analyse total emissions, emissions from line sources, point and areas.
3. Verify background concentrations to be used in the model.
4. Verify meteorological input data. Select two weeks winter/dry season (February 2007) and two weeks representative for the summer/wet season (August). Run statistics on meteorological data.
5. Present NOx and NO_2 concentrations for same period, run time plot and statistics including concentrations as functions of wind directions (Breuer diagramme9.

Second phase:

1. Run model for all sources (new background)
   a) winter
   b) summer
2. Compare with measurement data in receptor points
3. Run receptor point concentrations for individual source groups; point, line area
4. Run concentration distributions (km scale) for NOx both periods
5. Assess and discuss the results

Third phase:

1. Prepare improvement programme: initial spread, wind speeds, building heights, turbulence, vertical diffusion etc..
2. Run model for receptor points and total area with different options

2 Early model test results

2.1 The model

The first model tests were based on the AirQUIS model as it was delivered by NILU to HCMC (version 2.0.330).
A first dataset was selected based on measurements and input data for one week; 1 to 8 February 2007.
The receptor point at Doste (air quality and meteorological measurements) was selected.
The model grid was based on:

- 10 vertical layers
- 40 x 40 cells, 1 km2 each.

The vertical cell height was as given in the following table.

Table 1: Layers specification in AirQUIS model for HCMC.

Layer number	**Vertical cell Height**
1	14
2	14
3	43
4	72
5	109
6	154
7	180
8	344
9	441
10	1016

2.2 Background concentrations

The model would require that background concentrations of NOx and/or PM_{10} was specified.

- For NOx we selected to use an average of 15µg/m^3 as the background for the whole city. This value was based on the regional NOx concentration.
- For PM_{10} the first model testing of AirQUIS used measurement data at District 2 as the background for model calculation.

2.3 Model testing results for PM_{10}

The first model tests for HCMC have shown that the AirQUIS models are performing well for PM_{10} emissions. The main reason for this is that the regional background of PM_{10} as observed at the District 2 site plays an important role on the kilometre scale concentration distribution all over the city of HCMC.

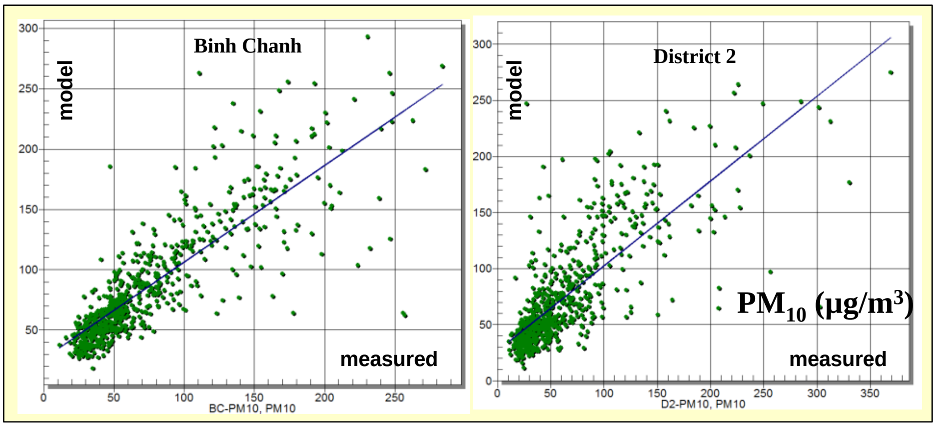


Figure 1: Model estimated PM_{10} concentrations versus measured concentrations at two sites in HCMC, February 2007.

The concentrations produced by the model matched the observed concentrations well as seen from Figure 1. However, too much of the time variations in the PM_{10} concentrations in HCMC was due to the measured concentrations at District 2, so it would be difficult to estimate the local contribution from the sources inside the city itself.

We will therefore return to the estimation of spatial distributions of PM_{10} later in order to understand the model performance better. Further studies of emission factors and the influence of varying the emission factors are also needed.

In the following evaluation we will use data on NOx as an inert gas, in order to study the model performance.

2.4 The first model test of NOx concentrations

Already in the first model tests for NOx concentrations, the model proved to be very sensitive to traffic emissions along roads close to the receptor points. The model generally overestimates the concentrations at the receptor points.

We therefore prepared a schedule for further testing and modification of model input data, emission factors and the effects of initial turbulence along the traffic stream. We believed that the model for NOx and NO_2 impact in HCMC will perform satisfactory in the near future, and that this again can be used for impact assessment and planning.

In the first model results we saw that we had to re-investigate a number of features such as:

- Check the road width and the position of the receptor point to make sure that the receptor points are not located within the road width.
- Check the raw data of meteorology in this period to identify the frequency of stable atmospheric conditions (could there be an over estimate for HCMC?)

The first concentration plots of NOx as shown in Figure 2, clearly show the strong overestimation of concentrations at the Doste station.

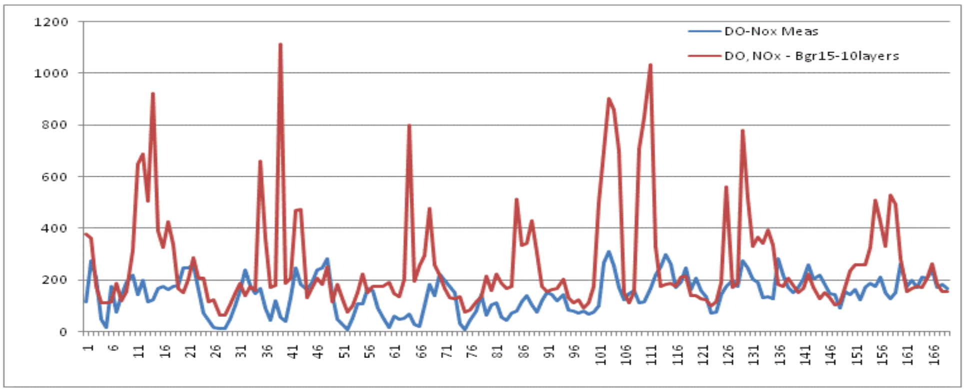


Figure 2: Model results versus measured concentrations of NOx at the Doste station 1-8 February 2007. (test date 24 September 2007).

We had adjusted the exact position of the receptor point compared to the nearby road (Dien Bien Phu). We had found that the distance from the Doste receptor point to the road is 10m, while the road width of Dien Bien Phu Street at that point is 12m. It means that the receptor point had to be moved out of the road. We thus moved the Doste receptor point 10m far away from the road with the new (X,Y) coordinate is (X=684422, Y=1192228).

The results are shown in Figure 2.

Very high concentrations were estimated in the receptor point at Doste, when the wind was blowing along the road as seen from Figure 3.

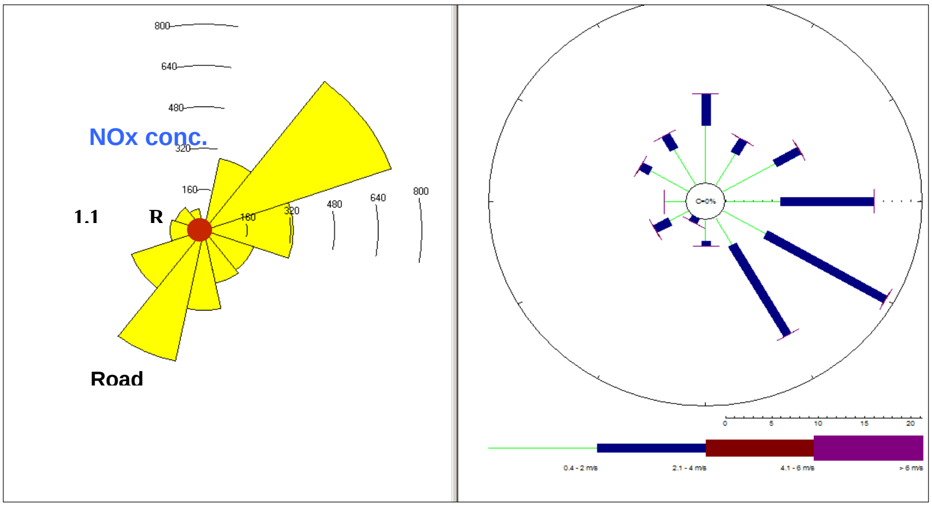


Figure 3: Model estimated NOx concentrations at receptor near road, together with the wind frequency distribution for the same period.

The effects of dispersion parameters during wind along the road was discussed, and it was decided to investigate the sensitivity of changing these parameters in order to increase the vertical and horizontal spread of individual plumes from traffic emissions.

3 Dispersion parameters testing

3.1 Increased values of horizontal initial spread

On 26 September we changed the following input parameters:

- Change Sigma Y(0) = 3m to Sigma Y(0)=10m
- Change KST = 4 to KST = 3

The initial horizontal dispersion was increased form 3m to 10.

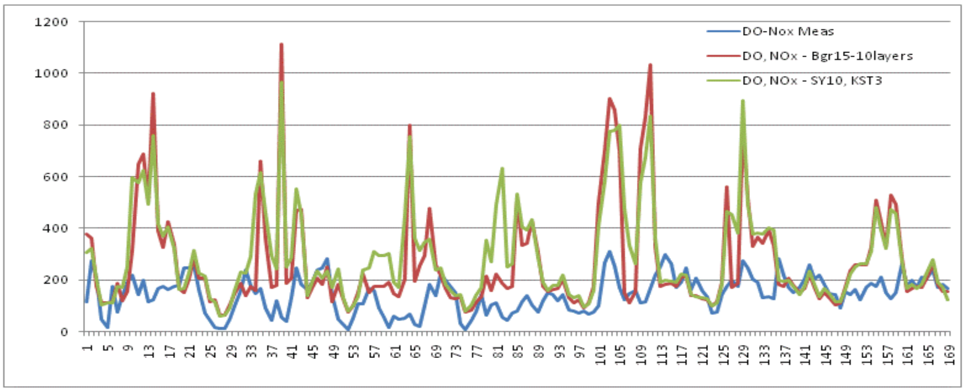


Figure 4: Model results versus measured concentrations of NOx at Doste statioon 1-8 February 2007. (test date 26 Sep 2007).

From Figure 4 we see that the concentrations estimated with the model are still over estimated at the Doste site. The peak concentrations have been reduced using an increased initial horizontal spread of the plumes. However, at peak concentrations we still over estimated by a factor 4.

3.2 Increased vertical spread

On 3 October 2007 we changed the vertical initial dispersion from 3m to 10 m. We kept the stability parameter in the model at KST = 3. The new model results together with previous runs are presented in Figure 5.

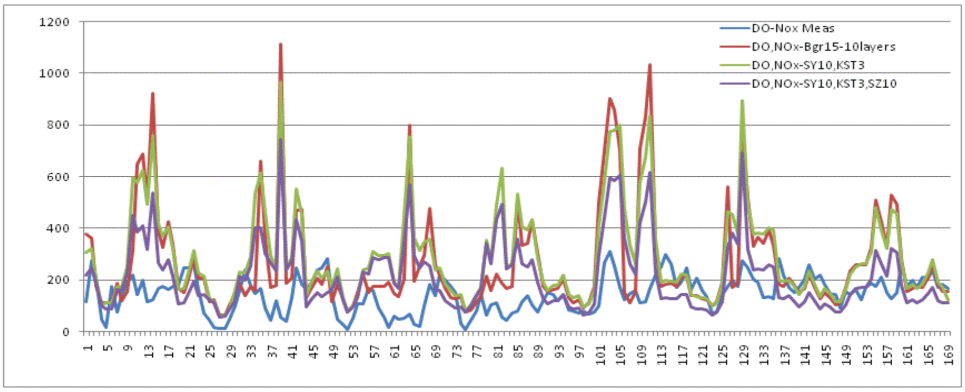


Figure 5: Model results versus measured concentrations of NOx at Doste station 1-8 February 2007. (test date 3 October 2007).

3.3 August 2006 test period

In order to test the model performance for another measurement period, we had selected one week in August 2006, during the rainy season in HCMC. The measured data were again taken from the Doste station, but also data from Binh Chanh and the ZOO station were used in these tests. The results from Doste is shown in Figure 6.

As seen from Figure 6 there is also in August an overestimate by the model with a factor 0.4 to 4. The peak concentrations are during this period not as well matched in time with measurements as during February 2007. This seemed to be a result of the receptor point exact location compared to the plume direction governed by the measured wind direction at the tower at Doste.

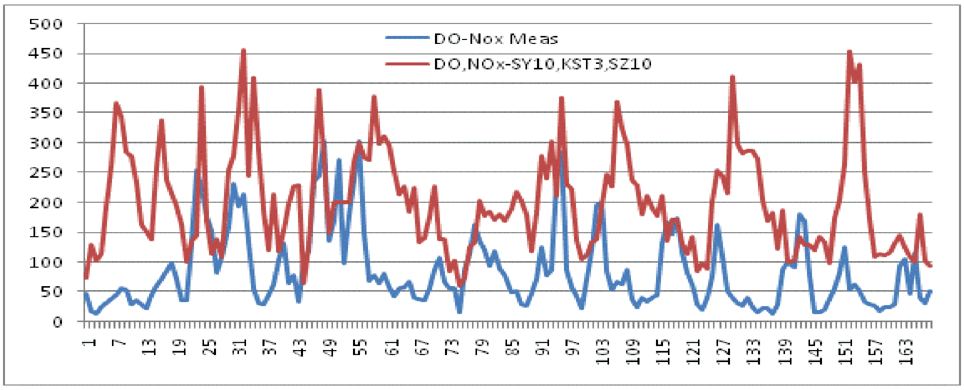


Figure 6: Model result versus measured concentrations of NOx at doste site August 2006. (Test date 3 Oct 2007).

In order to test the sensitivity of the exact location we wanted to evaluate the measured concentrations versus the kilometre square average concentration estimated buy the model.

3.4 Kilometre scale model concentrations versus measured

The kilometre scale model result versus measurement concentrations at Doste is presented in Figure 7.

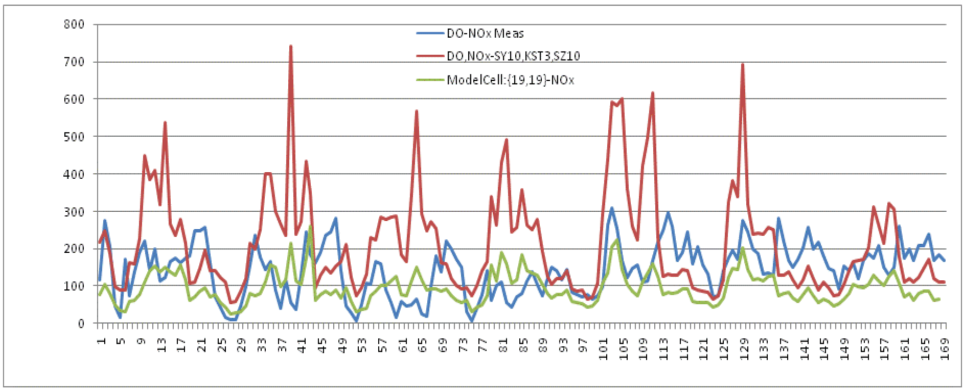


Figure 7: Model estimated km scale NOx concentrations for the grid around Doste (km scale: green line and receptor point: red line) versus measured concentrations (blue line) at the Doste station for February 2007. (Test date 3 Oct 2007).

The green line, which is the model estimated cell concentration seem to match very well the measured concentrations. The conclusion was that the exact location of the receptor point give a model result that is too sensitive to individual plume concentrations. The model seem to work well with the gridded average concentrations.

4 Changing stability classifications

4.1 Classification codes

On 9 October 2007 we changed the "Episode" code.
The stability classes (KST) now will depend on the stability result from AirQUIS according to the following classes:.

Stability.	KST	Class
1	3	Unstable
2	4	Neutral
3	5	Light Stable
4	6	Stable

The updated results from model results from Doste station is presented in Figure 8 below.

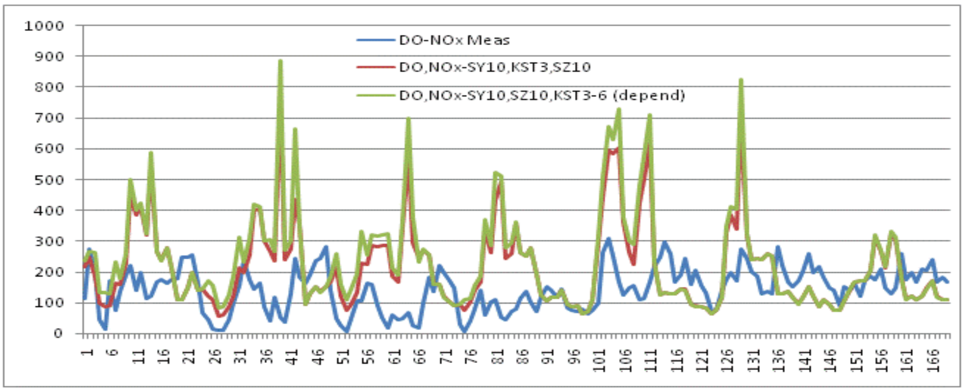


Figure 8: Model estimated NOx concentrations at Doste versus measured concentrations at the Doste station for February 2007. (Test date 9 Oct 2007).

The difference in concentrations between the two approaches are not significant, and would not solve the problem of overestimation compared to the measurement data.
We also tested another approach by setting the KST value at fixed value = 3 and only increased the dispersion coefficient beyond a distance of 300 m.

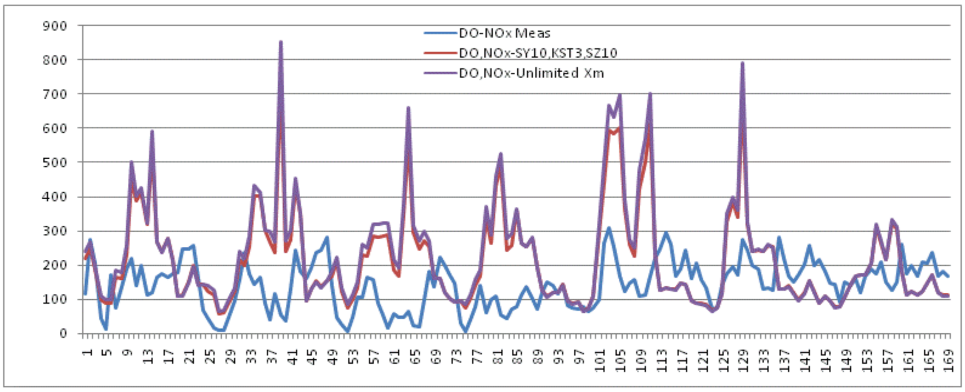


Figure 9: Model estimated NOx concentrations at Doste versus measured concentrations at the Doste station for February 2007. (Test date 11 Oct 2007).

4.2 Increased parameterisation of dispersion

On 11 October 2008 we also changed the dispersion parameters using a parameterisation which has been used by the NILU Gaussian type models for several years. However, we increased the horizontal and vertical spread by a factor ten in order to verify whether the model responded to a considerable change in dispersion..

The horizontal and vertical spread is given by the standard deviation of the concentration distribution;

- $\sigma y = ax^p$ with a = 3 (the normal value is 0.31)
- $\sigma z = bx^q$ with b= 0.7 (the normal value is 0.07)

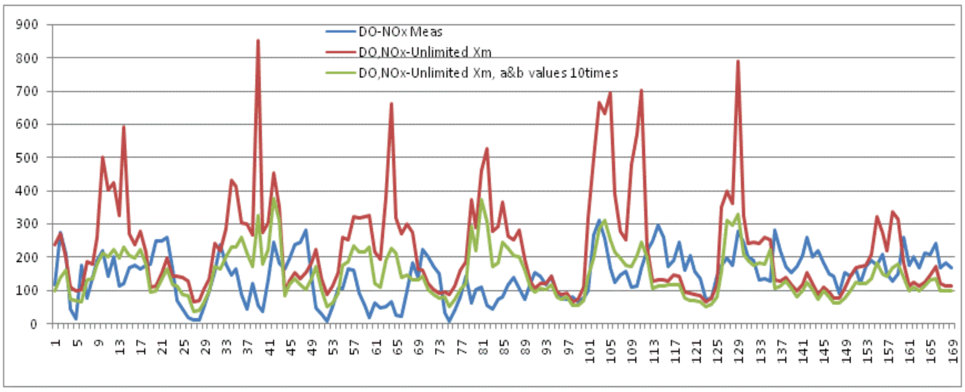


Figure 10: Model estimated NOx concentrations at Doste using a strongly enhanced dispersion (green curve) and old dispersion (red curve) versus measured concentrations (blue line) at the Doste station for February 2007. (Test date 11 Oct 2007).

The strongly increased dispersion parameters reduced the concentrations significantly. The green line in Figure 10 indicates that the concentrations estimated by the model at the receptor point “Doste” was close to the values that was measured at this site.

This again told us that the dispersion and dilution of pollutants especially from traffic sources assumed in the original model formulation was too small.

5 First results presented – parameters changed

On 12 October 2007 the preliminary results were presented for the modelling group at NILU. Several parameters in the model were discussed such as:

- The number of layers used in the wind field model in Matthew, and the application for HCMC.
- The model for HCMC should be further tested using 4 stability classes and alternative sigma values
- Present further tests on sensitivity and variability and document the results

The sensitivity in changing other selected parameters was tested, such as:
Site latitude 60^o → 10^o
Site longitude 11^o → 106^o
Wind field layer dimension 40m → 10m
Number of wind field layers 30 layers → 60 layers
Changed the PIN = 0.02 to 0.002

5.1 Estimates with original dispersion parameters

The values of the parameters in the sigma dispersion parameters was changed back to the original ones.

The changes in concentration estimates in the receptor point did not change much as long as the dispersion parameters were the same.

5.2 Dispersion parameters from rough surface data

Again we tried to modify the dispersion by assuming rough surface data using among other parameters thos presented by McElroy & Pooler.

- The fixed value of KST = 3 was changed back to KST with 4 classes 3,4,5,6
- Changed a and b values from the Smooth Surface condition to Rough Surface condition. Only one stable class was used for rough surface conditions.

The results are presented in Figure 11.

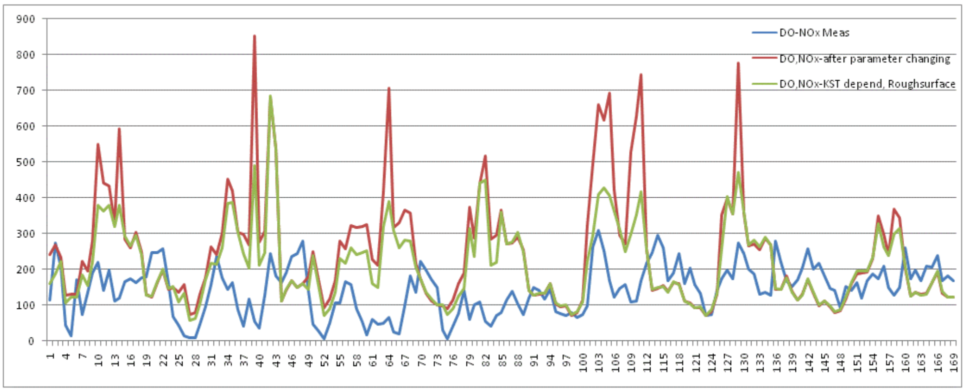


Figure 11: Model estimated NOx concentrations at Doste using new dispersion parameters for rough surface conditions (green curve) and old dispersion (red curve) versus measured concentrations (blue line) at the Doste station for February 2007.(Test date 23 Oct 2007).

The model result using rough surface dispersion conditions (green line) showed some significant changes. The peak concentrations were almost halved the values given from previous model testing. Again we demonstrated the sensitivity of the spread.

We will thus in the following go further into the parameterisation if the dispersion and search support from John Irwin, who visited NILU in November 2007.

6 New input to the traffic dispersion model

Based on further discussions concerning the NILU application and modifications of the traffic dispersion model based on the US-EPA model "Hiway II" we compiled new input data for the dispersion of pollutants from traffic. A number of different approaches were tested again as presented in the following.

Some of the parameters that were evaluated were:

1) The values of KST (stability classification) were estimated based on boundary layer parameters such as L and z_0 ; KST= f(L,z_0)
2) The "Drag Wind Speed" (WSP) as used in Hiway2 was applied based on the equation:

$$U_C = C\, u^{0.164} \cos^2 \phi$$

3) The dispersion parameters were based on the values of drag wind speed:

$$\sigma_{z_O} = 3.57 - 0.53\, U_C$$

The classification of stability was changed from 3 NILU classes to 6 classes as given by the Pasquill stability categories.

The results of the first estimates are presented in Figure 12.

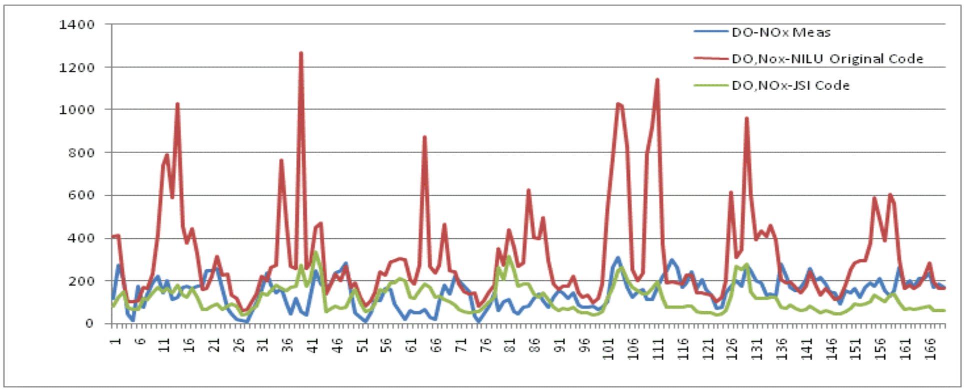


Figure 12: Model estimated NOx concentrations at the Doste site using new dispersion parameters based on drag wind speeds (Hiway2) (green curve) and old dispersion (red curve) versus measured concentrations (blue line).
(Database: February 2007, Test date 28 Nov 2007).

We see that the model results using the drag wind speed based dispersion parameters (green line Figure 12) now are much better correlated with the measured concentrations, and the level is on the average equal to the measured concentration levels at the Doste site.

6.1 Final modifications of the model

Based on the first good quality results a number of parameters were evaluated before the final selection for model applications in HCMC was decided upon.

First we changed the number of wind field layers from 60 to 30 layers. The concentrations estimated did not change much. In the final model applications we used 60 layers in the model.

Next we tested the sensitivity in varying the wind field layer height. Changing from 10m back to 40m gave very high peak concentrations again, so we decided to keep the layer height at 10m.

The final results of model estimated NOx concentrations at the receptor point Doste is presented in Figure 13 below.

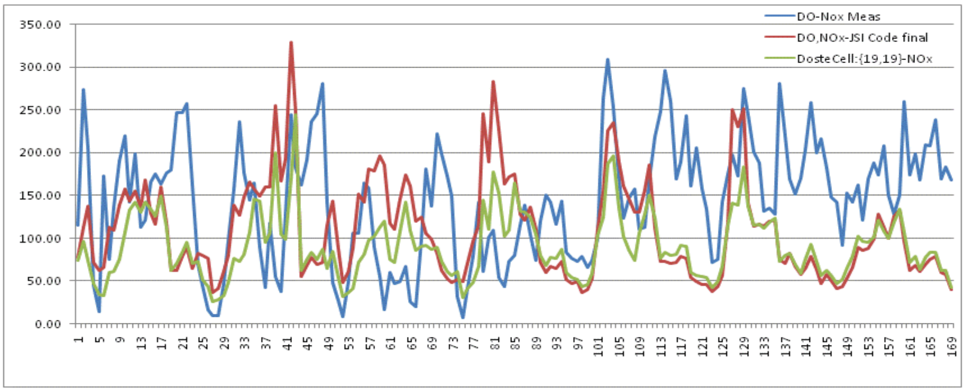


Figure 13: Model estimated NOx concentrations ***at Doste*** *using final input data concerning boundary layer parameterisation and model layers (Hiway2) (red curve) versus measured concentrations (blue line. The green line shows the model estimated average km-scale grid cell concentrations.*
(Data base: February 2007, Test date 30 Nov 2007).

The estimated NOx concentrations in the receptor point at Doste follow largely the measured concentration distribution in time, even if some of the peak values does not match exact at the right hour. The correlation coefficient is thus quite low. However, the average level of model estimated concentrations are close to that measured.

The kilometre scale grid average concentrations are lower than the receptor point concentration, which was to be expected.

The final model concept was also tested on another data period. We have selected one week of August 2006, and the results are presented in Figure 14.

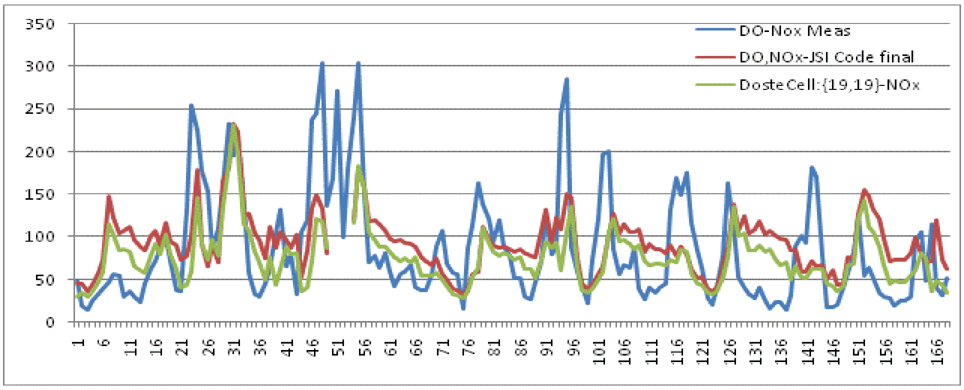


Figure 14: Model estimated NOx concentrations at Doste using final input data concerning boundary layer parameterisation and model layers (Hiway2) (red curve) versus measured concentrations (blue line. The green line shows the model estimated average km-scale grid cell concentrations.
(Data base: August 2006, Test date 30 Nov 2007).

During the week in August 2006 the estimated NOx concentrations also match fairly well the measured concentrations. The peak concentrations seem to be somewhat underestimated compared to the measurements. However, on the average the model results compared well with the measurements.

Based on all the model test results and the final results presented in Figures 13 and 14 we have decided to apply this last version of the model in the further estimates of concentration distributions and exposure of NOx in the population of HCMC.

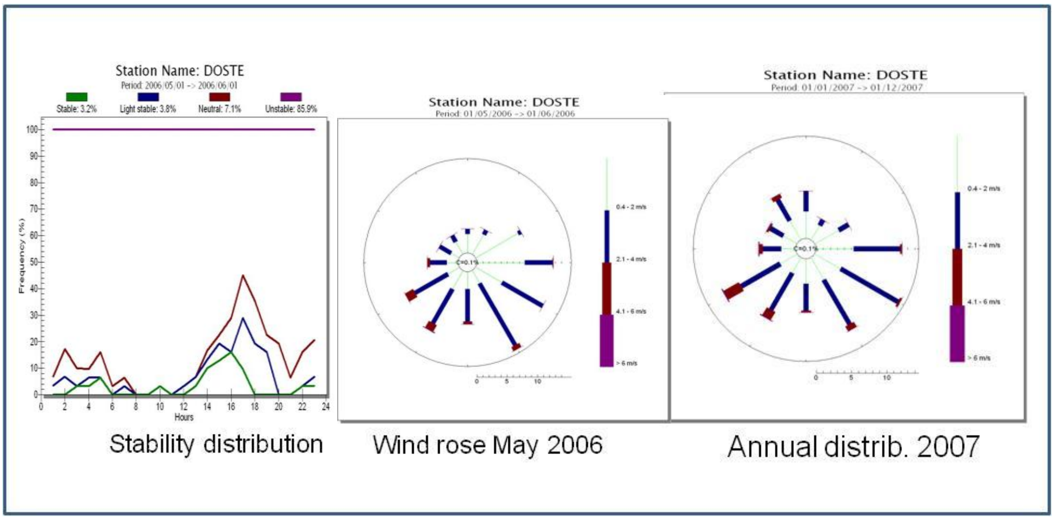
As the average concentrations match the measurement data this version of the model will be well suited to estimate long term (monthly and annual) average impact of pollution as a basis for predictions of future impact and the impact of mitigation measures in HCMC. The model results have also been verified using data from other stations in HCMC. It remains to verify this last version of the model for PM_{10}. The initial studies as presented in Figure 1 indicate, however, that the estimated PM_{10} concentrations in HCMC will be strongly dependent upon the assumptions of background or is work

7 Exposure estimates

Based on the model results achieved from the model tests and verifications presented above we have proceeded to perform the first estimates of concentration distributions, and population exposures.

7.1 Input data meteorology

We have selected meteorological input data from a statistical analyses of data from every month of 2007. The predominant wind directions for February to April are from around south east, in June to September from around south west while in October to November the wind was most often from north west. On the annual average the wind directions are fairly well spread from around south east, south west and some from north east. During the month of May 2006 the frequency distribution of wind directions were very close to the typical annual average. We therefore selected May 2006 wind frequency distributions as input to modelling the annual average concentration distribution in HCMC.



7.2 NOx to NO_2 ratio

The air quality limit values for Vietnam are specified for NO_2, while our model estimates are given for NOx. In order to evaluate the number of people living in areas where NO_2 concentrations may be exceeded we have measured concentration ratios between NOx and NO_2 to estimate NO_2 concentrations.

The NO_2 / NOx ratios in % is presented in the table below based on measurements at 5 monitoring stations during 2007.

	BC	**D2**	**ZO**	**DO**	**TN**
NOx	62.8	26.9	32.2	117.0	26.6
NO2	29.4	18.1	17.3	85.3	14.6
NO2/NOx(%)	47	67	54	73	55

Based on these data the ratio NO_2/NOx ratio varied between 0.47 and 0.73. At urban background station the ratio was 0.54. To evaluate the exceeding of 40 µg/m^3 as the annual average NO_2 limit value for Vietnam we have estimated the number of people living in areas where the NOx concentration exceeded 74 µg/m^3

7.3 Source categories

The dispersion model have been applied for estimating the contribution from different source categories in HCMC. Meteorological data for May2006 was used to represent the annual average wind speed and wind direction distributions. The source categories are:

- Point sources
- Motorbikes plus areas sources estimated for motorbikes only.
- Light trucks
- Heavy trucks
- Buses

In additions estimates were performed for all sources available in the emission inventory.

The original emissions from light trucks was very high while the number of light trucks is very much lower than motorbikes. We had to modify the distribution and evaluate the distribution of light trucks and cars on different type of roads. Instead of 4 Vehicle Classes, we therefore had to look at 5 classes as presented below.

Road Vehicle Classes (RVC)		
ID number	Road Vehicle Class (RVC) Name	Heavy Duty (0 = not heavy duty, 1= heavy duty)
1	Xe tai nang - Heavy trucks	1
2	Xe tai nhe - Light trucks	1
3	Xe buyt - Buses	1
4	Xe gan may - Motorbikes	0
5	Xe Oto - Cars	0

We have changed the data for line sources in AirQUIS and imported the updated data as input for AirQUIS. This also applies to the distribution of cars and light trucks. Based on the traffic counting of 2006 which has been done by HEPA, the ratio between Cars and Light trucks are different from different Road class as shown in the Table below.

oad Classes		Vehicle Classes	Ratio (%)
ID number	Road Class Name		
1	National Road - Quoc lo	Light Trucks	80
		Cars	20
2	Province Road - Tinh lo	Light Trucks	70
		Cars	30
3	Main Road - Duong noi thi chinh	Light Trucks	55
		Cars	45
4	Minor Road - Duong noi thi phu	Light Trucks	45
		Cars	55
5	Industrial Area Road - Duong trong KCN	Light Trucks	50
		Cars	50

The ADT (Annual Daily traffic) for 118 main roads in HCMC were collected from 2003 to 2005. Statistic information from Department of Transportation and Public Works in HCMC, however, show that the number of vehicles increases about 15% for the last 3 years. To come closer to the real number of vehicles in HCMC as of 2007 we have increased the ADT numbers by 15% for the 118 main roads that have been counted.

7.4 Contribution from different vehicles

Estimates of the distribution of the average concentrations for each hour of the day has been estimated for the Doste site to evaluate the sensitivity of the daily variation of traffic density flows and emissions of NOx.

The average diurnal variation for 5 vehicle classes is presented in Figure 14.

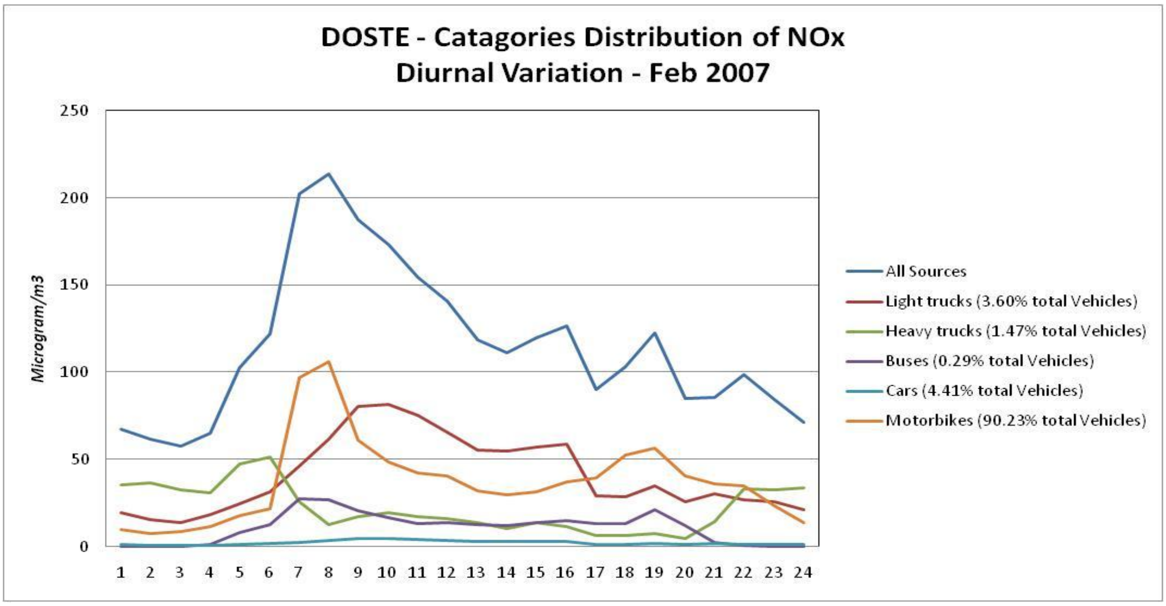


Figure 14: The average diurnal variation of NOx concentrations at Doste presented for 5 vehicle classes and for the total traffic flow (February 2007).

The highest concentrations of NOx were estimated during the morning rush hour around 08:00 hrs. The main sources during these hours are light trucks and motor bikes. The most distinct time variation, demonstrating the importance of the rush hours, are shown in the contribution from motor bikes. Contributions from light trucks is clearly a day time phenomenon.

The contributions from heavy trucks are only significant during night time hours between 21:00 and 07:00 hrs. The reason for this is that heavy trucks are not allowed on these roads during day time.

7.5 Average concentration distributions

Based on the annual average wind distributions as presented above, using the dispersion model verified for HCMC, we have estimated the "annual average" concentration distribution of NOx over the city of Ho Chi Minh.

The emission inventory consists of 118 main roads, where data have been collected based on manual counting of traffic density flows as well as diurnal variations of traffic flows along all these roads. Side roads have been converted into area sources (Sivertsen et.al, 2005). Area source emissions have been estimated based on the population distribution in each of the Wards of HCMC.

A total of 70 different industries have been evaluated, which has lead to identification of 125 individual stacks in HCMC. Emission factors for point and line sources have been based on a study of different emission factors collected from Asian studies

Two examples of results are presented in Figure 15; the annual average NOx concentration distribution for all sources available in the emission inventory, and the concentrations related to emissions of NOx from motorbikes in HCMC.

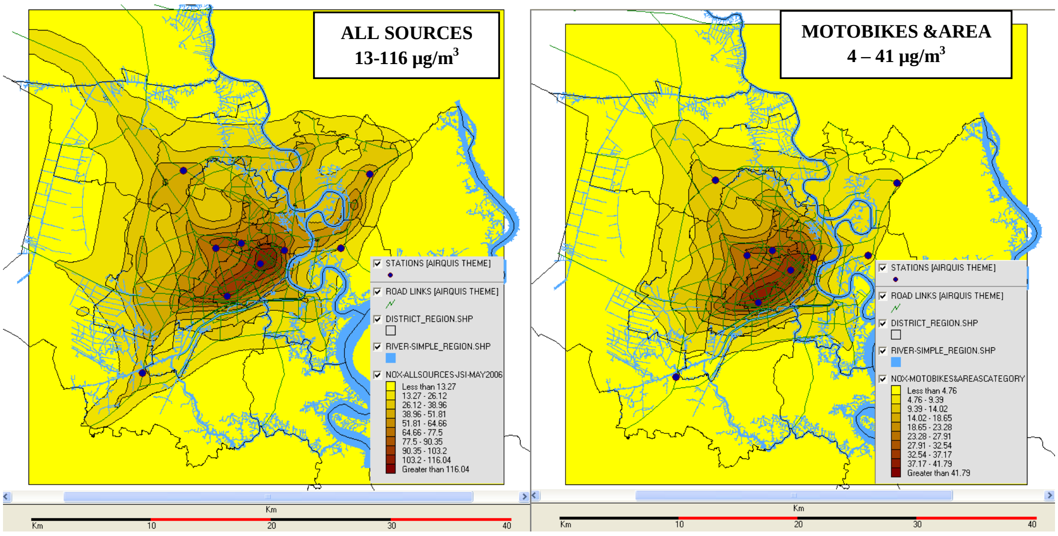


Figure 15: Annual average NOx concentrations estimated for all sources and for emissions from motor bikes in HCMC.

The highest average concentrations of NOx were estimated over the city centre. In the maximum impact area the average concentrations exceeded 100 µg/m^3. Concentrations above 50 µg/m^3 covered an area of about 50 km^2.

The contributions of NOx concentrations from motorbike emissions was between 35 and 45 µg/m^3 in the centre areas of HCMC.

8 Relative contributions to the population exposure

Based on data for the population distribution in HCMC we have estimated the number of people exposed to concentrations above given limit values. The relative importance of different sources to the population exposure has been based on person-weighted average concentrations (PW) calculated by the following formula:

$$C\,(PW) = \{\, \Sigma\, (N(x,y)*C(x,y,i)\,)\}/N(tot)$$

where N represents the total number of persons in the area (x,y).
C(x,y,i) represents the average concentration of compound i in area (x,y).

The NOx concentrations calculated as annual average concentrations in each square kilometre of HCMC are taken as input to these estimates.

As an example the relative contribution of NOx from each of six source groups are presented in Figure 16.

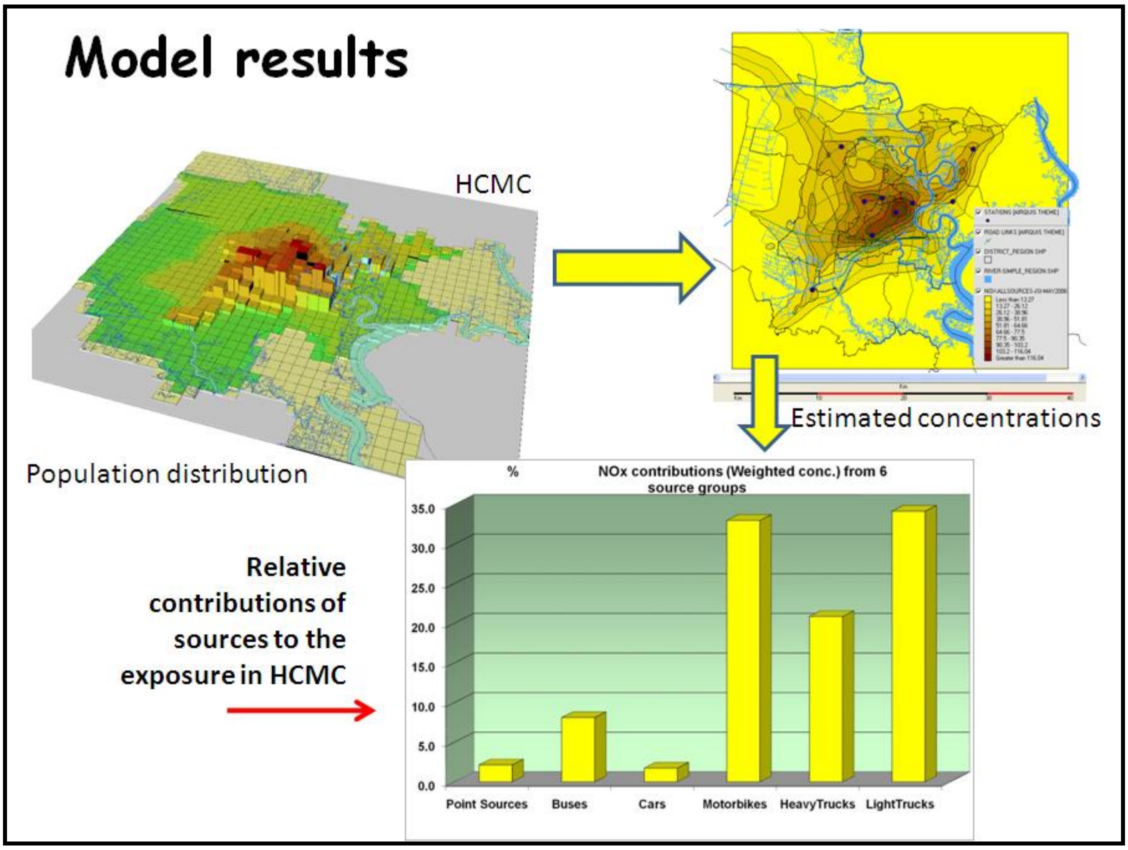


Figure 16: Population distribution and NOx concentration distributions from model estimates represented the input for estimating the relative contributions of sources to the exposure of NOx in HCMC.

These estimates show that about 32% of the contribution to the NOx exposure is due to emissions for motorbikes in HCMC. Another 33% of the contributions are from light trucks and 20 % is from heavy trucks.

Emissions from buses represent 20% of the exposure, while cars and point sources (industries) only represented less than 2 % each inside the city.

9 Aknowledgement

The authors want to thank Dr Bruce Denby and Sam-E. Walker at NILU for valuable discussions, modifications and support as well as John S Irwin for his analyses and evaluation of the “Hiway” model and parameterisation of dispersion.

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P.O. Box 100, N-2027 Kjeller, Norway
Associated with CIENS and the Environmental Research Alliance of Norway
ISO certified according to NS-EN ISO 9001

REPORT SERIES SCIENTIFIC REPORT	REPORT NO. OR 35/2008	ISBN 978-82-425-1972-6 (print) 978-82-425-1974-0 (electronic) ISSN 0807-7207	
DATE	SIGN.	NO. OF PAGES 20	PRICE NOK 150,-
TITLE Model test for applying AirQUIS in Ho Chi Minh City		PROJECT LEADER Bjarne Sivertsen	
		NILU PROJECT NO. E-107016	
AUTHOR(S) Vo Thanh Dam and Bjarne Sivertsen		CLASSIFICATION * A	
		CONTRACT REF.	
REPORT PREPARED FOR NILU and HEPA/DONRE HCMC, Vietnam			
ABSTRACT The NILU developed dispersion models which are part of the AirQUIS planning tool, has been tested and improved for applications in Ho Chi Minh City (HCMC). A number of parameters and approaches have been applied in order to find the most suited model, which also reflects spatial and time variations in NOx concentrations measured in HCMC			
NORWEGIAN TITLE Test av spredningsmodeller for anvendelse i Ho Chi Minh City, Vietnam.			
KEYWORDS AirQUIS	Dispersion modelling	Ho Chi Minh City	
ABSTRACT (in Norwegian)			

** Classification* *A* *Unclassified (can be ordered from NILU)*
B *Restricted distribution*
C *Classified (not to be distributed)*