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Modeling air quality in Hochiminh city and scenarios for reduction air pollution levels

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Abstract. Air pollution in general, especially air pollution from road traffic in particular in Hochiminh City (HCMC) are at the alarming. Using models to simulate air quality is needed to manage and predict the air pollution levels. Research results have prepared emission inventory of air pollutants from road traffic, industry and domestic sources in HCMC. Besides, TAPOM and FVM models were used to simulate the meteorological conditions and air quality in HCMC.

Emission inventory results from road traffic show that emission from motorcycles account for a significant amount of total load of pollutant emissions from that source. Simulation results of air quality give better results when using emission inventory with traffic emission factors were estimated in HCMC.

In addition, some scenarios to reduce pollution levels in general, especially air pollution from road traffic in particular show that, if reduce 50% number of motorcycles (private transportation) and increase 10 times number of bus (public transportation), air quality will more improve and can reduce traffic jam.

Keywords: Road traffic, emission inventory, models, scenarios.

1. Introduction

Air quality model is an important tool to manage air pollution in urban areas. We can use models to predict impacts in the process of urbanization, such as development of traffic network, the location or expansion of residential and industrial areas, ...

In our country in general and HCMC in particular, the studies aim to simulate air quality was initially implemented and achieved some initial results. Typically there were several research projects at all levels and master thesis. However, one major limitation in almost studies of data on the emission factors (EF) of air pollutants from road traffic was used from neighbour countries. In addition, due to traffic is one of the main source of air pollution generated in HCMC so the simulation results of air quality in that studies had more or less limited accuracy. Therefore, in this study, the authors used results of the study estimated air pollutants EF in real conditions of transportation activities in HCMC, so the simulation results of air quality will get more precision.

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2. Emission inventory for air pollutants

2.1. Emission inventory data

The general methodology for preparation of the emission inventory includes three main steps, identify the sources, sources classification and calculation of emissions. A temporal resolution of 1h is used, and calculations are done for given working day Jan. 19, 2006. As for the spatial resolution, the EI is calculated inside grid used for modeling 35km by 35km with 1 km square cells. Emission calculations are individually done by sources and had value changes according to the each cells.

Three main sources are considered for the emission calculations include: road traffic, industry and domestic activities. Emission estimations are done for parameters of air pollutants NO_x, CO, VOCs and SO_2. In particular, the emissions from road traffic activities using two kind EFs data, EFs from China (used before) and EFs determined in HCMC.

2.2. Methodology and input data

a. Road traffic source

Traffic emissions are calculated using three main groups of activity data: the georeferenced street network, the fleet composition, and temporal and spatial variations of circulation of this fleet. The emissions are computed hour per hour, using hourly emission coefficients in day. In this study, we use EFs of air pollutants was developed in real conditions in HCMC by authors (Ho M.D., 2008) [1,2].

Table1. Road traffic emission factors in Hochiminh City

No.	Pollutants	MC (g/km.veh.)		LDVs (g/km.veh.)		HDVs (g/km.veh.)	
		In HCMC	China (*)	In HCMC	China (*)	In HCMC	China (*)
1	NO_x	0.05 ± 0.02	0.23	1.9 ± 0.9	3.3	19.7 ± 5.2	6.1
2	VOCs	2.34 ± 1.17	11.8	15.02 ± 7.36	0.5	89.92 ± 33.01	6.69
3	CO	21.85 ± 8.67	17	34.8 ± 15.5	16.1	11.1 ± 5.3	14.96

Note: MC (Motorcycle); LDVs (Light duty vehicles); HDVs (Heavy duty vehicles).
(*): EFs from China (DOSTE, 2001)[3].

b. Industry source

Up to now, HCMC has three export processing zones and 12 industrial areas with a total area of 2,354 ha. At present, HCMC has about 1,000 plants, factories and more than 33,000 small-scale production facilities handicrafts. In HCMC, the emission calculation of air pollution load based on the emission factors and the production process of industries that can be applied:

$$G_{in} = \Sigma K_{in}. N_{jn} \text{ (g/year)} \quad (1)$$

Which, G_{in} is emission of pollutant i for sector n (g/year); K_{in} is emission factors of pollutant i for sector n (g/tons of raw materials or products); N_{jn} is amount material or fuel of factory j for sector n (tons/year).

c. Domestic source

Emission inventory from human activities play an important role in modeling air quality. Some main activities generate pollutants such as burning fuel (DO, FO, LPG, coal, etc), building homes, offices (paint and other organic solvents, ...)

2.3. Emission inventory results

Table 2 is the emission inventory results from sources in HCMC, which in road traffic source were divided to two columns, EI-1 is used emission factors in HCMC and EI-2 is used emission factors from China. Results of emission inventory show that, when we used EFs from HCMC, emission load of NO_x and VOCs are lower (89,2% and 43,5%, respectively) but emission load of CO is higher (factor 1.32) value when using EFs from China.

Table 2. Total emission of air pollutants by sources in HCMC

No.	Pollutants	Road traffic (tons/year) (1)		Industry (tons/year)(2)	Domestic (tons/year)(3)
		EI-1	EI-2		
1	NO_x	30.161	33.822	41.310	3.878
2	CO	2.903.064	2.197.008	38.400	358.950
3	VOCs	405.062	931.188	30.900	44.213
4	SO_2	6.422		80.370	7.110

Sources: (1) EMISENS; (2,3) INTEX-B (Zhang Q. và nnk, 2009) [4] .

2.4. Evaluation of the EIs over a specific case study in HCMC

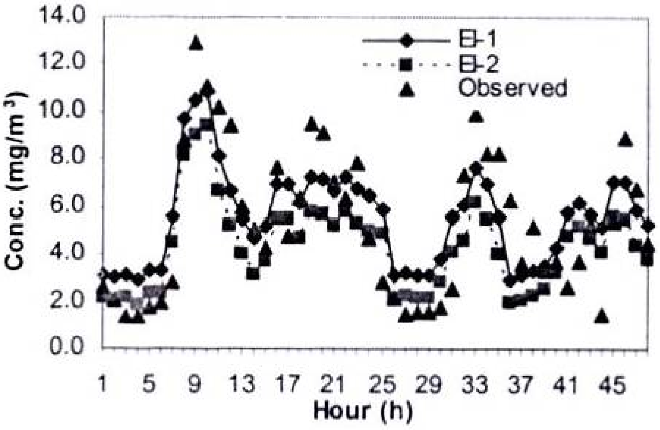
In order to assess the two results of the EIs, an air quality model (AQM) at mesoscale is applied for two days Jan. 19&20, 2006. The goal is to compare the concentrations of CO, NO_x, VOCs and Ozone generated by AQM for both EIs (EI-1 and EI-2) with measurement values.

a. Model description

The models TAPOM (Transport and Air Pollution Model, Martilli A. et al., 2002 & 2003) [5,6] and FVM (Finite Volume Model, Clappier A. et al., 1998) [7] developed at LPAS-EPFL, are used for this study. They are three dimensional Eulerian models using terrain following grid and finite volume discretization. The transport and photochemistry model TAPOM includes the RACM lumped species mechanism chemical solver for gaseous phase (Stockwell et al., 1997) [8]. Meteorological input data for TAPOM is obtains from the model FVM, whose borders can be forced using wind and temperature fields from large scale model results. FVM includes an urban turbulence model which specifically simulates the effects of urban areas on the meteorology [9-14].

b. Comparison of simulated and observed concentrations

A first comparison with primary pollutants is conducts ($[(C_{EI}-C_{ob.})/C_{ob.}]\%$). Simulation results by EI-1 have value is closeer to the measurements, especially for CO, presenting an average percentage difference of 20%, whereas for the simulation results by EI-2, the percentage difference presents 35%. For NO_x, the percentage difference with respect to observations are smaller for EI-1, although not so different from EI-2 results. This indicates a clear underestimation of CO emissions in EI-2, whereas for NO_x both EI-1 and EI-2 generate similar results.



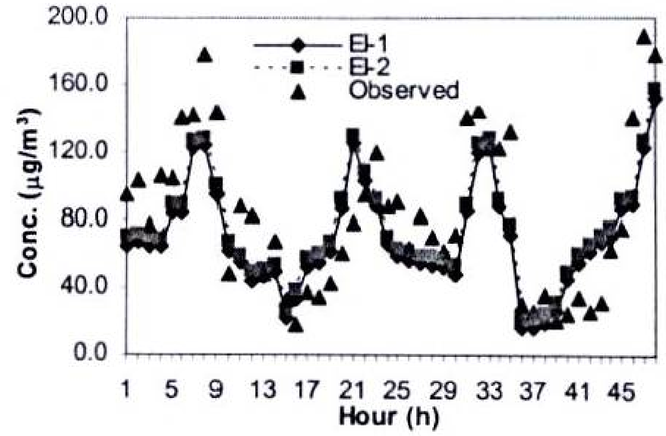


Fig. 1. Comparison CO conc. at HB station (left) and NO_x conc. at BC station (right) on Jan. 19&20, 2006.

Since there is no measuring VOCs data, so we use comparison Ozone concentration as a way to assess the indirect to impact of the change of VOCs emission input data. The average concentration of Ozone in the simulation episode and the measurement values at HB station show that for EI-1, the percentage difference is about 10%, whereas for EI-2, the percentage difference is about 30%. Therefore, we can conclude that the simulation for EI-1 will get reasonable levels of Ozone

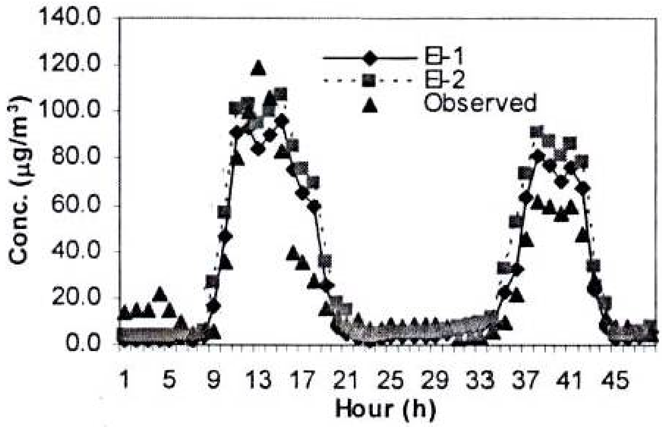


Fig. 2. Comparison O_3 conc. at HB station on January 19&20, 2006.

2.5. Discussion and implications of EI results

a. Distribution of emissions by source and region

Emission inventory and distribution of air pollutants emission from pollution sources in HCMC for spatial and temporal by using GIS method. Domain with dimension of each cell $1km^2$ and have 35 cell for x and y direction is used in this study. Distribution the emission for temporal estimated as equation:

$$E_h = E_a * f_a * f_w * f_d /8760 \quad (2)$$

Which, E_h, E_a are emission load per hour and year, respectively; f_a, f_w, f_d are coefficient of emission distribution for each month, hour in day, respectively; and 8760 is total hours of a year.

The emission load in each cell is gam/km^2.h. Which, the coefficient of emission distribution for each month, week, and hour was estimated for each difference pollution sources.

The most important contribution of CO, VOCs and NO_x in HCMC is attributed from road traffic. A similar relative source strength is found for other developing countries, especially for CO, VOCs and NO_x.

For SO_2, NO_x, CO and VOCs, the 63, 30, 94 and 69 %, of the total road traffic emission, respectively, correspond to motorcycles. This result is entirely reasonable that 95% of the total volume of motor vehicles in HCMC is motorcycles. The most important contribution of CO, VOCs and NO_x in HCMC is attributed from road traffic. A similar relative source strength is found for other developing countries, especially for CO, VOCs and NO_x.

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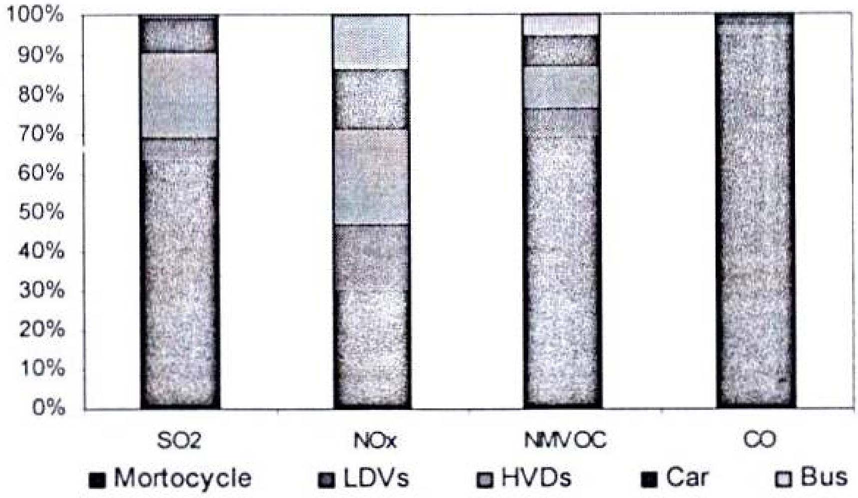


Fig. 3. Distribution of the on-road vehicle emissions in HCMC by type of vehicle and by pollutant.

b. Limitations of the method and discussion

We can state that uncertainties in our EI come from three main sources: First, the quality of the input data we have collected. Second, the extrapolation based on the existing information to fill in the remaining data gaps. Third, some aspects of the methodology itself EMISENS procedure, as it has been developed and initially applied in South American countries and South Vietnam so it has some restrictions to improve. Despite of limitations, all results above allows to conclude that EI with EF from HCMC have more reasonable simulation values than EI with EF from China.

3. Simulation of meteorology and air quality

3.1. Select simulation episode

Episode selected for simulation based on several criteria:

In the dry season (January to April) because during that time cloudy sky, appropriate for FVM model;

Concentration of primary air pollutants are high and stable in the monitoring stations;

Ozone concentration is high in the monitoring stations and often exceed standards (180 ppb);

Based on the criteria above, the period chosen for simulation is Jan. 19 & 20, 2006.

3.2. Settings in the model

To simulate air quality in mesoscale requires precision and resolution of meteorological input data. To get the requirements, FVM model is run by using one way nesting method with 5 domains. Dimension and resolution of domains are selected to simulate meteorology conditions in the study area as follows:

- Domain1 (D1): Dimension of domain 20 x 20 cells, spatial resolution 150km x 150km. This domain covers an area of Southeast Asia and a part of South China Sea;

- Domain 2 (D2): Dimension of domain 20 x 20 cells, spatial resolution 75km x 75km. This domain covers an area of South of Vietnam, Cambodia, Thailand and a part of the South China Sea;

- Domain 3 (D3): Dimension of domain 33 x 33 cells, spatial resolution 16km x 16km. This domain covers an area of the Southern provinces and parts of Central Southern provinces and South China Sea;

- Domain 4 (D4): Dimension of domain 35 x 35 cells, spatial resolution 7km x 7km. This domain covers an area of South Western provinces and HCMC.

- Domain 5 (D5): Dimension of domain 38 x 38 cells, spatial resolution 1km x 1km. Central of this domain coincides with the center of HCMC.

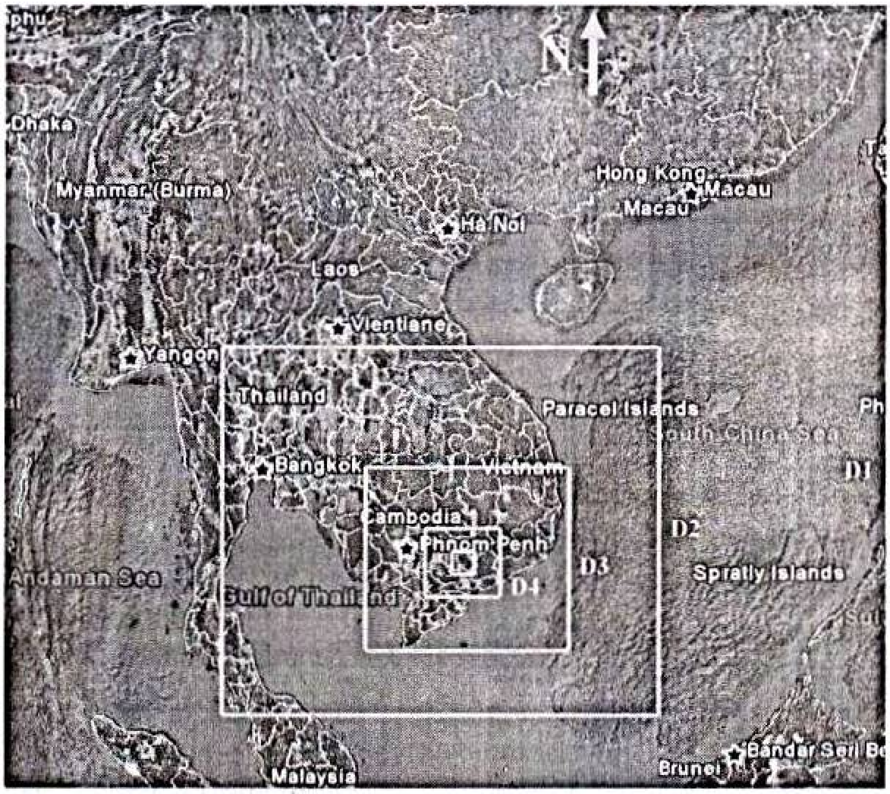


Fig. 4. Domains for meteorological simulation.

3.3. Boundary and initial conditions

This simulation uses 6-hourly data from the NCEP/NCAR (2006) reanalysis dataset for its initial and boundary conditions. Data have 2.5 x 2.5 degree global resolution with 17 pressure levels at times 0Z, 6Z, 12Z and 18Z.

3.4. Topography and land use data

Input data for FVM model also includes topography, land use, characteristics of the soil, roughness, humidity and thermal. All databases is took from USGS with 1km resolution.

4. Results and discussion

4.1. Meteorological simulations

a. Boundary and initial conditions

The model is first applied to a 3.000km x 3.000km grid, aiming to generate adequate boundary and initial conditions for our mesocale domain. A very similar behavior of the wind patterns between the two days of the episode in simulated by the model (in range NE to SE direction). From 5h to 12h, the mainly wind direction often between SE and NE directions, similar behavior of the sea wind. From 12h to 14h, as influenced by sea-continental wind so the mainly wind direction is SE.

b. Mesoscale simulation

Distribution of land use in urban areas in meteorological model is quite complex because they need many information such as density and height building, area of trees and many others information. However, their classification more detailed will get the simulation results closer the measurements. Because the resolution of small domain is 1km x1km to simulate meteorological in mesoscale so they need some corrections for surface data. Databases for the correction is took from USGS and land use in HCMC. Domain D5 is chosen for simulate meteorological as mesoscale in episode of study. Measurement data from Tan Son Nhat (TSN) station was used to compare with the simulation values.

c. Compare simulation result and observed

+ Wind direction and wind speed:

Simulation results from FVM show wind speed depend on the type of surface. On the sea, the wind vector is stable on direction and value, wind speed in lower when come to the continent. Wind direction and wind speed in continent is change a lot and depend on the distribution of the surface thermal. In urban area, wind speed is lower but not clear. Compare with the measurements show wind direction consistent relatively. Comparison between the simulation with measurement values in episode study have correlation coefficient R=0.68 and 0.81 for wind direction and wind speed, respectively.

+ Temperature

Simulation results show the effects of sea to the surface temperature distribution, coastal areas have low an average temperature and temperature variations. When going into the continent, temperature variations and average temperature tends to increase. The highest temperature in domain D5 appear in the center of HCMC, the region have trees and water surface area is low. The model predicts well the time of the day when temperature start increasing due to the sunrise (around 6h – 7h), as well as the time of the maximum value (between 12h – 13h). Comparision between simulation and measurement values in episode study have correlation coefficient R=0.92.

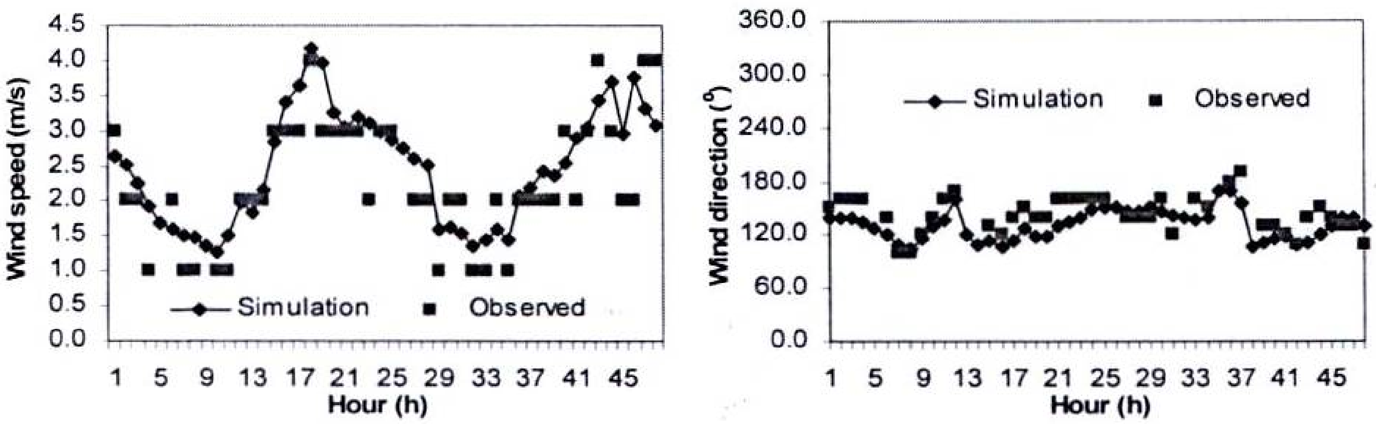


Fig. 5. Comparison wind speed and wind direction between simulation and observed on Jan. 19&20, 2006.

4.2. Air quality modeling

Emission inventory is calculated for 24 hours in Jan. 19, 2006 with 1h temporal resolution and 1km x 1km spatial resolution in domain 35km x 35km. Boundary and initial conditions were prepared with the same databases. A pre-run of one day with the same emissions and wind fields is conducted for all the simulations, in order to provide more realistic initial conditions.

a. Primary air pollutants

The process of transportation and dispersion of primary pollutants in the central of HCMC through have change dispersion toward at times during the day but the trend is moving toward the SE direction in generally, the same with the mainly wind direction in episode of meteorological simulation. Depend on times of day, the distribution of air pollutant concentrations is difference, the peak is in the morning (7-9h) and at night (20-21h).

Both simulated and measured concentrations of CO and NO_x show important morning peak. This peak is related to high emissions from road traffic in the morning rush hour and low mixing height. The intensities of the peaks of both CO and NO_x are good agreement with observations at air quality monitoring station HB and DO. Important nightly peaks of CO and NO_x (around 21h), appear both in the simulation and measurements. This peak is also related to the road traffic and it is sometimes overestimated by the model.

With SO_2 value, the comparison between simulation and measurement show the same pattern.

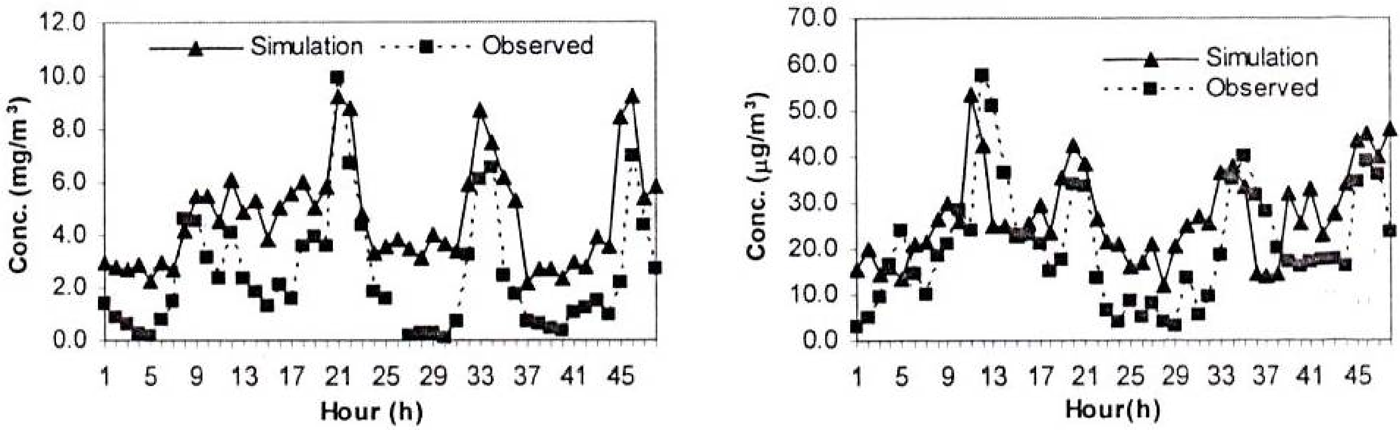


Fig. 6. Comparison CO conc. at DO station (left) and SO_2 conc. (right) at TN station on Jan. 19&20, 2006.

b. Secondary pollutant - Ozone

+ Spatial distribution

The spatial distribution of Ozone is generated depending on the primary pollutant (NO_x & VOCs) concentrations and the meteorological conditions. For this episode, pollutants are pushed by wind coming from SE direction, while Ozone is being formed with maximum values at midday. After midday, wind direction move a little to E direction. At 16h, the maximum Ozone values have dropped and the plume move to E-SE direction. The simulation results show that, the plume of air pollutants is pushed to SE direction in the morning. When the thermal wind is developed, pollutants are then transported eastwards, crossing again the central part of the city. This happens at the same time of maximal solar radiations, thus important peaks of Ozone are generated in town.

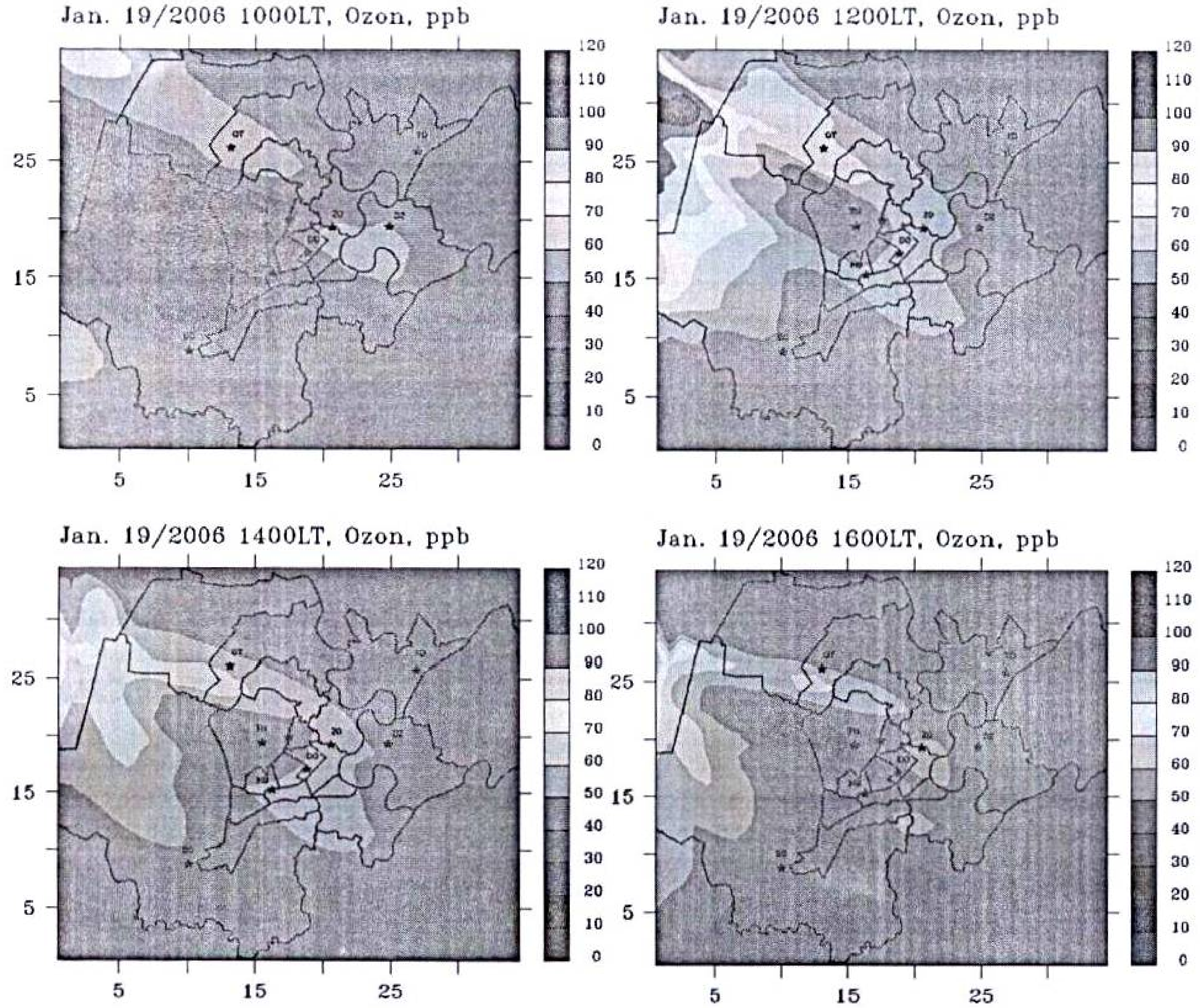


Fig. 7. Map of Ozone concentration (ppb) in domain D5 at 10h, 12h, 14h &16h on Jan. 19, 2006.

+ Comparison with measurement values

The Ozone measurements corroborate the presence of the plume over the city, with high concentration in Jan. 19, 2006 at DO & HB stations (152.3 $\mu g/m^3$, 84.8$\mu g/m^3$, respectively) and lover values in Jan. 20, 2006. This might imply that the city plume remains mainly in the city center on 19 Jan. but is slightly moved towards SE on 20 Jan.. The simulation shows high Ozone levels at the same stations as the measurement values on 19 January, indicating a good reproduction of the plume position.

5. Scenarios to reduce air pollution levels

5.1. Emission scenarios

Due to the road traffic is play important source role to air pollution in HCMC in general, so the proposed scenarios to reduce pollution levels from this source is necessary. Two types of transportation means special interested is motorcycle and bus. Scenarios to reduce air pollution levels is based on two major criteria: (a) change the number of types of transportation and (b) change the type of fuel used.

HCMC has 3.584 streets with total road length about 3.670 km, the area of pavement is 36 million m^2, so the ratio of road area density and city area only about 1.8% (km/km^2), much lower than the common standard of developed countries 10-20%.

Area for a motorcycle travel is 10 - $12m^2$, while area of a seat on the bus only $2m^2$ area of road . With about 4 million motorbikes will account for approximately 40 million m^2 travel. But, HCMC only build a new or adding about 1% of road surface every year.

In addition, fuel consumption indicator for a passenger is 0.015 liters/km when using motorcycles and 0.0044 liters/km when using the bus. Thus, when used as a means of transport, motorcycles have a fuel consumption higher than 3.4 times of the bus.

Therefore, only increase the bus and reduce the motorcycle volumes can solve traffic congestion in the status of the current tight line, save fuel and reduce pollution.

a. *Change the number of vehicle types*

Some scenarios to reduce air pollution levels from road traffic was proposed as follows:

- Scenario 1 (Scen1): reduce 50% of motorcycle volume travel throughout the city at the same time so the load of pollutants emission from motorcycles will decrease 50%.

- Scenario 2 (Scen 2): reduce 50% of the motorcycle volume, at that time to fill the demand for travel ½ rest of the people to increase the volume of bus 10 times of the current number. Besides, change small size buses (35-40 seats: B35-B40) for the types are commonly used (55-80 seats: B55-B80). The new size means in accordance with the existing road traffic in HCMC where the whole city has only 14% of the road 12 meters width (convenient for the bus B55-B80), 51% of the road from 7-12m width and 35% of the road width less than 7m. In addition, efficiency buses must be from 80-100% (currently 40-45% for the large buses).

- Scenario 3 (Scen 3): reduce 50% of the motorcycle volume, at that time to fill the demand for travel ½ rest of the people to increase the volume of bus 05 times higher than the current number. Efficiency buses have at least 80% (currently 40-45%).

b. *Change the type of fuel*

Change using clean fuel (LPG, CNG, ..) instead of fuel being used is one of the solutions not only get economical benefit but also contribute to reduce air pollution from road traffic source.

Using CNG (Compressed Natural Gas) costs only about 50-60% of the transport than gasoline, oil, but reducing to 35% of C_xH_y, 60% CO and 10% NO_x, ... emitted into the environment. With some other benefits such as anti-abrasion, increased engine life, reduced maintenance costs.

Comparison with gasoline, motorcycle run on 40% gas saving fuel costs and environmental pollution levels reduced over 70%.

5.2. Simulation results air quality in the scenarios

With 03 scenarios as mentioned above show the emission load calculated is a different amount of emission load at the first of study (base case). Depending on the air pollutants and scenarios that emissions of air pollutants are increase or decrease.

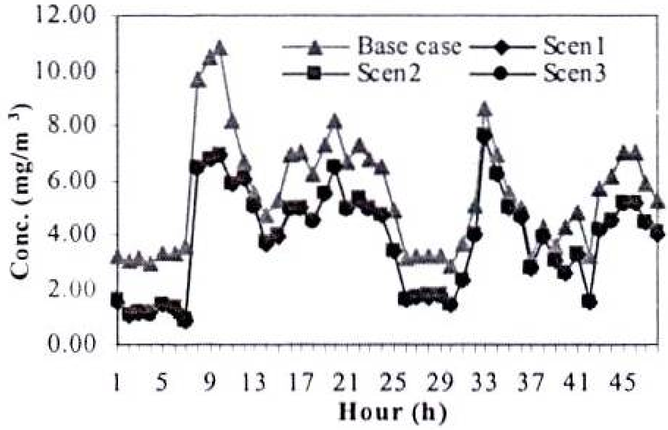
a. Concentrations of primary pollutants

Simulation results of air quality in 3 scenarios above mentioned with primary pollutants concentrations comments as follows:

- NO_x concentration: In scenario 1, light decrease with the initial concentration (base case). However, in scenarios 2 and 3, concentrations of NO_x increase with the base case value simulation (1.2 times and 1.1 times higher for Scen2 and Scen3, respectively) because of NO_x emissions load in scenarios 2& 3 increase with the value calculated emissions load initially.

- CO concentrations significantly reduced in 3 scenarios with base case simulation value, this completely reasonable when the load emissions calculated of CO in the 3 scenarios are lower (only 53-54%) emissions load in the first calculation.

- SO_2 concentration from simulation results in 03 scenarios are light decrease with results simulation by the initial load because SO_2 emissions load calculated in 3 scenarios are reduced by 69-74%.



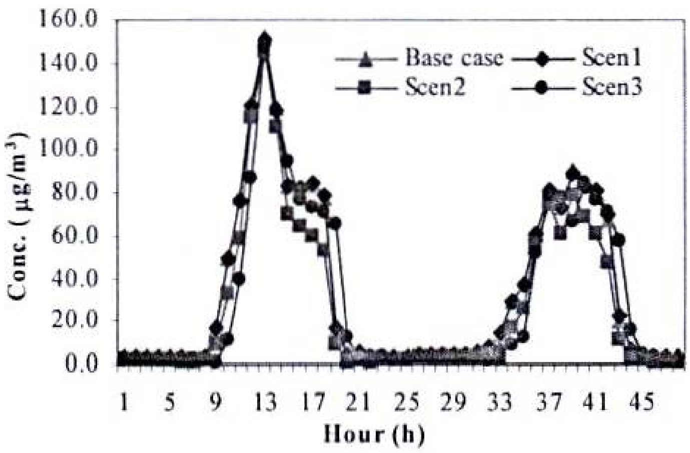


Fig. 8. Comparison CO conc. at HB station (left) and Ozone conc. at DO station on Jan. 19&20, 2006.

b. Concentration of secondary pollutants

Concentrations of secondary pollutant Ozone from 3 scenarios simulation are lower with the simulation results of the first emissions calculated. Comparison of Ozone concentrations simulated from 03 scenarios and base case simulation were implemented at air quality monitoring stations DO and HB.

5.3. Support method

Besides on the propose of scenarios to reduce air pollution levels from road traffic by changing the number and type of vehicles and fuel used, the support method to reduce air pollution from road traffic should be also of interest:

- Propose to do inspection and control emissions periodically for other means of transportation 1 times per year. For motorcycles, due to for the high volumes so in initially can be required for category of motorcycle with capacity engine $\leq$ 50 cm^3. These motorcycles have high pollution emission levels will be required to upgrade, maintenance or replacement of spare parts, the engine or forbidden travel.

- Encourage, extensive propaganda and strongly in the people about the consequences of the motorcycle explosion, the long-term risk to the development of the city and next living generations.

- Implement solutions "2 needs" that need a strong method in the general planning, transportation planning and need quick investment for transport projects especially public transportation network.

- Restriction of cars travel into the central city during the morning rush hours (7 – 9h) and evening (20 - 21h). These are times with high concentration of air pollutants in simulation and measurement.

Conclusion

Research results obtained in this study is to develop the emissions data of air pollutants from major of air pollution sources in HCMC, especial for transportation source. Besides, TAPOM and FVM models were used to simulate the meteorological conditions and air quality in HCMC. Episode was chose for simulation on January 19&20 2006, in the dry season of year.

Emission inventory of air pollutants from road traffic show that emission load of motorcycles account for a significant amount of total emission of that source. Air quality simulation get better results when using emission inventory calculated from the emission factors developed in HCMC compared with case using the emission factors from China.

FVM and TAPOM models are chose to simulate meteorology and air quality in HCMC. The simulation episode for research results show that, there are not so difference between simulation and measurement values. Particular, at air quality monitoring station HB, CO conc. is 5% difference between simulation and measurement. For others parameters NOx, SO_2 and Ozone comparison results between simulation and measurement has similar results.

Besides, based on the simulation results and current statue of air pollution in HCMC with air pollution from road traffic plays an important role in air pollution in general, the authors proposed some scenarios to reduce air pollution levels in general and air pollution from road traffic in particular. The simulation results from scenarios show that, if reduce 50% number of motorcycles and increase 10 times number of buses, concurrently, change all the present buses (B55-B80) to small size buses (25-30 seats), air quality will be improve and can be reduce traffic jam in rush hour.

All simulation results above can help us to understand about air pollution in HCMC in general and air pollution from road traffic in particular. Based on this study, we can develop research further about meteorological conditions and air quality in longer period to get more precision results.

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