AIR QUALITY MODELLING IN CHIANG MAI CITY, THAILAND

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ABSTRACT

The levels of air pollution in Chiang Mai city, Thailand, are higher than in most western cities and are a cause of concern. Within the city, air pollution monitoring stations are few and modelling is potentially an important planning aid. For the present study the use of the ADMS-Urban model was tested using data for Chiang Mai – a tropical city. Pollutant concentrations calculated by ADMS-Urban were compared with concentrations recorded at two monitoring stations. Source information on emission rates, street canyons and meteorological data were inputs to the model. Good correlations were only obtained when corrections were made for the high levels of imported ambient background pollution. The reasons for the limitations in applying the existing ADMS-Urban model to a tropical city are being explored and recommendations for modifications will be made. The model was used to identify 'hot-spots' within the city (along Highways 106 and 108). The results produced are influencing the selection of sites for investigating the potential impacts of air pollution on respiratory health. Schools were located in the hot spot areas and a preliminary respiratory health survey using a standardised questionnaire was later conducted in 4 urban schools in identified "hot spots", and 2 rural schools. The results showed that the prevalence of asthma was similar in all the schools (approximately 5.5%) but the prevalence of rhinitis and atopic dermatitis was higher in the urban schools (24.4% and 12.2%, respectively) than in rural schools (15.7% and 7.2%, respectively).

1. INTRODUCTION

Chiang Mai is the second largest province in the north of Thailand. In 2003, its urban districts have a population of 586,000 (population density of 1363 persons/km^2), and approximately one million people reside outside suburban areas. The city of Chiang Mai is located in a valley at approximately 310 metres above sea level, in a mountainous region. The city has grown rapidly in the past decade with an associated increase in air pollution and respiratory health problems. Sources contributing to air pollution include road traffic, industry, burning of domestic wastes and agricultural burning. Forest fires are also one of the key area sources of air pollution in Chiang Mai. Generally, the atmospheric pollutants which are a cause for concern in Chiang Mai are particulate matter (PM) and ozone (O_3). From the Thai Pollution Control Department (PCD) air quality monitoring, the maximum PM_{10} concentration of 291µg/m^3 and average concentration of 160µg/m^3 were recorded at a roadside monitoring station in Chiang Mai city in February 2004. The highest O_3 concentration was recorded at Chiang Mai Provincial Hall (161 ppb) in 2002 [1]; [2].

The World Health Organisation (WHO) estimated that 800,000 people throughout the world died prematurely from lung cancer, cardiovascular and respiratory diseases caused by outdoor air pollution [3]. Le Tertre et al. [4] commented on the results of recent epidemiological studies, which indicated that ambient air pollution adversely affects human health, even at levels close to, or lower than current national standards. The Ministry of Public Health of Thailand reported that the numbers of persons dying (and death rates) of respiratory diseases in Thailand were 19,888 (32.9 per 100,000 population) in 1997 and 23,417 (37.7 per 100,000 population) in 2001. In 2000, almost 25 million people suffered from respiratory diseases in Thailand (except Bangkok Metropolitan) including 1.38 million in the north of Thailand. Chiang Mai Public Health Office data for 1999 indicated that 42,739 people out of every 100,000 (42.7%) in Chiang Mai suffered from respiratory problems. In comparison, the data for 1994 showed 33,000 of every 100,000 (33%) of the population with impaired respiratory health. Infants, the elderly, and those suffering from chronic respiratory conditions such as asthma, bronchitis, or emphysema are most vulnerable to polluted air.

Air quality modelling was conducted in Chiang Mai, Thailand using ADMS-Urban, a version of the Atmospheric Dispersion Modelling System (ADMS) *versions 1.6 and 2.0*, developed by Cambridge Environmental Research Consultants Ltd. (CERC). ADMS-Urban is a PC-based advanced model of dispersion in the atmosphere of pollutants released from multiple industrial, domestic and road traffic sources in urban areas [5]. ADMS-Urban is widely used for air quality management by local government in the United Kingdom (UK) e.g. Manchester, Nottingham City, and the London Boroughs of Camden, Croydon and Islington. It was also applied in some air modelling studies in China and Hong Kong [6-8]. The main objective of this study was to identify air pollution 'hot-spots' in Chiang Mai and compare pollutant concentrations calculated by ADMS-Urban with those concentrations recorded by two local monitoring stations. The results of the air quality modelling led to the study of respiratory diseases and allergies among children in primary schools in a 'hot spot' area and a suburban area identified by ADMS-Urban. A standardised questionnaire developed for the International Study of Asthma and Allergies in Children (ISAAC) was applied in this study in order to investigate the respiratory health of children.

2. METHODOLOGY

ArcView GIS *version 3.2a*, ArcView Spatial Analyst *version 2.0a* software, and the DMS-Urban programme were employed for the study. Input data were provided by the Thai PCD and entered into ADMS-Urban. The model was then run assuming different scenarios, namely different atmospheric chemistry schemes (i.e. Derwent – Middleton correlation, and Generic Reaction Scheme), different months (February and August, representing dry and wet season months respectively), including with and without diurnal traffic data. The numerical outputs were compared with monitored monthly averages of pollutants in order to validate the model. Subsequently, the scenario that gave the best numerical outputs in comparison to the monitored data was chosen to run the model for 24 hr of meteorological data in order to identify the most likely school 'hot-spots'. In this study, the scenario of the Derwent – Middleton correlation with diurnal traffic data gave the best fit, therefore it was selected to identify the 'hot-spots. Contour plots of different pollutants on the Chiang Mai base map are pictorial outputs. The option of intelligent gridding outputs was chosen. By dividing base maps into many 500m x 500m quadrant cells, fine spatial resolution of pollution maps was produced.

2.1 Model inputs

2.1.1 Traffic data

The detailed Chiang Mai road dataset input into the model was taken from the project on Traffic and Transport Planning in Chiang Mai [9] conducted by the Office of the Commission for the Management of Road Traffic (OCMRT) and Chiang Mai University (CMU) in 2002. The calculation of traffic emissions for each road was not included in the OCMRT study, therefore, the 1999 UK Design Manual for Roads and Bridges (DMRB) database of traffic emissions was applied. The DMRB database contains emission factors depending on vehicle category (light and heavy duty vehicles), average speed and traffic count, for NO_x, CO, PM_{10} and VOC (CERC, 2001). The current dataset in ADMS-Urban *version 1.6* is DMRB 1999, which is the default option in the model. By selecting the DMRB 1999 option, an emission rate for each road source is automatically calculated by ADMS-Urban, when a vehicle count per hour and an average speed are entered into the model. The data entered for each road are: elevation of road; road width (building edge to building edge); canyon height; road geometry; emissions (g/km/s) calculated within ADMS-Urban from vehicle count per hour (light and heavy duty vehicles); average speed (km/hr). In the OCMRT study, one road is divided into 5-15 nodes depending on its length. Each node contains data on the elevation of road, width, building height along the road, traffic volume and speed for each hour from 0600 hrs – 1800 hrs. The traffic information for 430 road sources was entered into the road source option of the model (Figure 1), and the traffic profile (traffic proportion) was also entered into the model.

2.1.2 Point and area sources

The data entered for each source include source type (point or area); source height; source diameter; location (UTM coordinates); exit velocity; flow rate of release; exit temperature of release; source location; and emission rates for each pollutant (g/s or $g/m^2/s$). Although there are over 250 factories in Chiang Mai, most of them are Small and Medium Sized Enterprises (SMEs), the industrial data of 30 key factories were input into the ADMS-Urban programme but data for smaller sources were not entered. Forest fires and agricultural burning were considered to be area source. Areas of agricultural burning were input differently into the model for dry and wet seasons according to harvesting schedules. In addition, forest fires mostly occur in dry season months. Other area sources included in this study were Chiang Mai railway station, airports, petrol stations and sites of domestic waste burning in the municipality area.

2.1.3 Meteorological data

ADMS-Urban applies up-to-date physics using parameterisations of the atmospheric boundary layer structure based on the Monin-Obukhov length (L_{MO}) and the boundary layer height, not Pasquill - Gifford stability parameter, which imprecisely characterises the boundary layer (CERC, 2001). L_{MO} gives a measure of the relative importance of buoyancy generated by heating of the ground and mechanical mixing generated by the frictional effect of the earth’s surface. It represents the depth of the boundary layer within which mechanical mixing is the dominant form of the turbulence generation [10]. The L_{MO} approach uses a continuous scale, and the variation of boundary layer parameters with height is accounted for by the L_{MO} characterisation. Therefore, ADMS-Urban is driven by meteorological input data. Hourly meteorological data employed for modelling were near surface temperature (°C), wind speed (m/s), wind direction (degree clockwise from north), precipitation rate (mm/hr) and cloud cover (oktas). Meteorological data for Chiang Mai were obtained from PCD and Chiang Mai

Meteorological Office. These data are typical for the province of Chiang Mai. As low wind speed conditions were most common, the ADMS model was run under calm conditions.

2.1.4 Background ambient concentrations

ADMS-Urban requires the input of background concentration data for each pollutant. Initially, background concentrations were estimated from annual *minimum* ambient concentrations (2001) but experience showed that the use of these data consistently resulted in an under-prediction of key parameters such as PM_{10}, SO_2 and CO_2, -*cf* air quality data from an ambient and roadside automatic air quality monitoring stations in Chiang Mai. Therefore, annual *average* ambient concentrations for the same year were later input into the model. This resulted in a better match between predicted and measured pollution levels.

2.1.5 Validation

Two sites (receptors) are selected for ADMS to predict concentrations at these points which represent the locations of the air monitoring station in Chiang Mai (ambient and roadside stations). The ambient data represent background concentrations and the roadside data represent city centre concentrations. In order to validate the model, February and August 2001 were selected to be representative of the dry and wet seasons respectively. One month of hourly meteorological data for February and August was used to run the model to predict air quality during these months. The modelled results were compared to the measured parameters and Thai Air Quality Standards over these months. Table 1 shows the ADMS-Urban numerical outputs and data from 2 monitoring stations (ambient and roadside stations) of PM_{10}, NO_2, SO_2 and CO. Run 5 (see Table 1 legend) gave the most satisfactory numerical results compared with the monitored data, especially for ambient NO_2 in February 2001. For CO and PM_{10} in February, the ADMS output differs from the monitored data by less than 30% which is considered acceptable for this modelling exercise. Although, SO_2 results were over-predicted in February, they were judged to be acceptable for August.

Ambient	**ADMS numerical output**					**Monitored**
February 2001	***Run 1***	***Run 2***	***Run 3***	***Run 4***	***Run5***	**Monthly average**
PM_{10} (µg/m^3)	1.99	46.83	46.86	46.62	46.73	34.13
NO_2 (ppb)	12.03	14.33	16.08	15.17	12.95	12.68
SO_2 (ppb)	0.02	2.21	2.21	2.20	2.21	0.88
CO (ppm)	0.20	0.95	0.95	0.94	0.95	1.01

Roadside	**ADMS numerical output**					**Monitored**
February 2001	***Run 1***	***Run 2***	***Run 3***	***Run 4***	***Run 5***	**Monthly average**
PM_{10} (µg/m^3)	4.25	48.43	48.46	47.77	47.86	109.74
NO_2 (ppb)	18.61	19.59	19.04	18.47	16.36	7.44
SO_2 (ppb)	0.09	2.25	2.25	2.24	2.25	11.54
CO (ppm)	0.35	1.06	1.06	1.02	1.03	1.89

Ambient	**ADMS numerical output**					**Monitored**
August 2001	***Run 1***	***Run 2***	***Run 3***	***Run 4***	***Run 5***	Monthly average
PM_{10} (µg/m^3)	1.74	48.43	46.87	46.66	46.58	68.50
NO_2 (ppb)	12.25	19.59	15.92	15.33	12.83	1.42
SO_2 (ppb)	0.02	2.25	2.20	2.22	2.21	2.79
CO (ppm)	0.47	1.06	0.95	0.95	0.94	0.88

Roadside	**ADMS numerical output**					**Monitored**
August 2001	***Run 1***	***Run 2***	***Run 3***	***Run 4***	***Run 5***	**Monthly average**
PM_{10} (µg/m^3)	4.39	48.84	48.92	48.54	48.42	27.97
NO_2 (ppb)	19.69	21.57	19.23	18.88	18.51	5.24
SO_2 (ppb)	0.09	2.25	2.24	2.24	2.25	3.62
CO (ppm)	0.37	1.09	1.09	1.06	1.06	0.70

Table 1 ADMS-Urban numerical outputs and data from monitoring stations of PM_{10}, NO_2, SO_2 and CO

Note:
Different model options;
Run 1 **–** Only background concentrations of CO (110 ppb) and O_3 (0.3 ppb) were included in the model. These concentrations are from average minimum ambient concentrations (2001). No diurnal traffic flow data. The chemistry scheme selected was the NOx-NO_2 correlation (the Derwent – Middleton correlation).

Run 2 – Background concentrations – CO 900 ppb, O_3 19 ppb, NO_2 5.8 ppb, NO_x 9.2 ppb, PM_{10} 45.6 µg/m^3, and SO_2 2.2 ppb[‡] (Runs 2-5) were included but a traffic flow data (time varying emission factors is not included into the model. The chemistry scheme selected was the NOx-NO_2 correlation. Old receptors of ambient and roadside monitoring stations.

Run 3 (CRS1) – Background concentrations were included. No traffic flow data. The chemistry scheme selected was the Chemical Reaction Scheme. Old receptors of ambient and roadside monitoring stations.

Run 4 (CRS3) - Background concentrations were included. No traffic flow data. The chemistry scheme selected was the Chemical Reaction Scheme. New receptors of ambient and roadside monitoring stations.

Run 5 (NO2) - Background concentrations were included. The chemistry scheme selected was NOx-NO_2 correlation. New receptors of ambient and roadside monitoring stations. The 24-hr traffic flow data was included.

3. RESULTS

Figure 1 shows the modelled concentrations of PM_{10} for an area in Chiang Mai in a typical winter day. The pollution 'hot-spots' identified throughout the city are summarised in Table 2. In order to identify schools in the 'hot-spots' located near busy roads (see Figure 1) for a study on *Respiratory Diseases and Allergies among School Children in Chiang Mai,* the modelling of air quality was conducted using the small scale 500mx 500m grid. The model was run for one day in February (24 lines of meteorological data to represent one typical day in dry season) when the worst air pollution normally occurred in Chiang Mai. Numerical outputs of average and maximum pollutant concentrations in 4 schools in 'hot-spots' and 2 schools in non 'hot-spots' are shown in Table 2. In order to compare PM_{10} concentrations from the model with measured values, roadside PM_{10} concentrations were monitored for 24 hours in front of each school. PM_{10} concentrations were monitored at Wat Sripotaram School, S3 (161µg/m^3), Tao Bunruang School, S4 (186µg/m^3), Ban San Pasak School, S5 (241µg/m^3), and Ban Donpin School, S6 (192µg/m^3). All results obtained were much higher than the numerical outputs calculated by ADMS-Urban (Table 2) and the Thai standard for PM_{10} (120µg/m^3). The monitored concentrations of PM_{10} at Ban Korn Tal School, S1 and Wat Sai Moon School, S2 in a non 'hot-spot' were 132 and 210 µg/m^3, respectively (see Table 3). The respirable dust situation in Chiang Mai in January – March 2004 was very serious. The PM_{10} concentrations were measured by the MiniVol^{TM} Portable Air Sampler, which sampled air at 5 litres/minute through a 10µm particle size separator (impactor) and then through a 47mm filter. The PM_{10} sample was caught on the filter which was weighed pre- and post-exposure with a microbalance accurate to one microgram. The MiniVol^{TM} sampler is lightweight, portable and ideal for sampling in remote areas or in locations where no permanent air monitoring site has been established. The respiratory health survey using the International Study of Asthma and Allergies in Childhood (ISAAC) questionnaire was later conducted in 4 urban schools, S3 – S6 in identified "hot spots", and 2 rural schools, S1 and S2 (total 511 children aged 6 – 12). The results showed that the prevalence of asthma was similar in all the schools (approximately 5.5%) but the prevalence of rhinitis and atopic dermatitis was higher in the urban schools (24.4% and 12.2%, respectively) than in rural schools (15.7% and 7.2%, respectively).

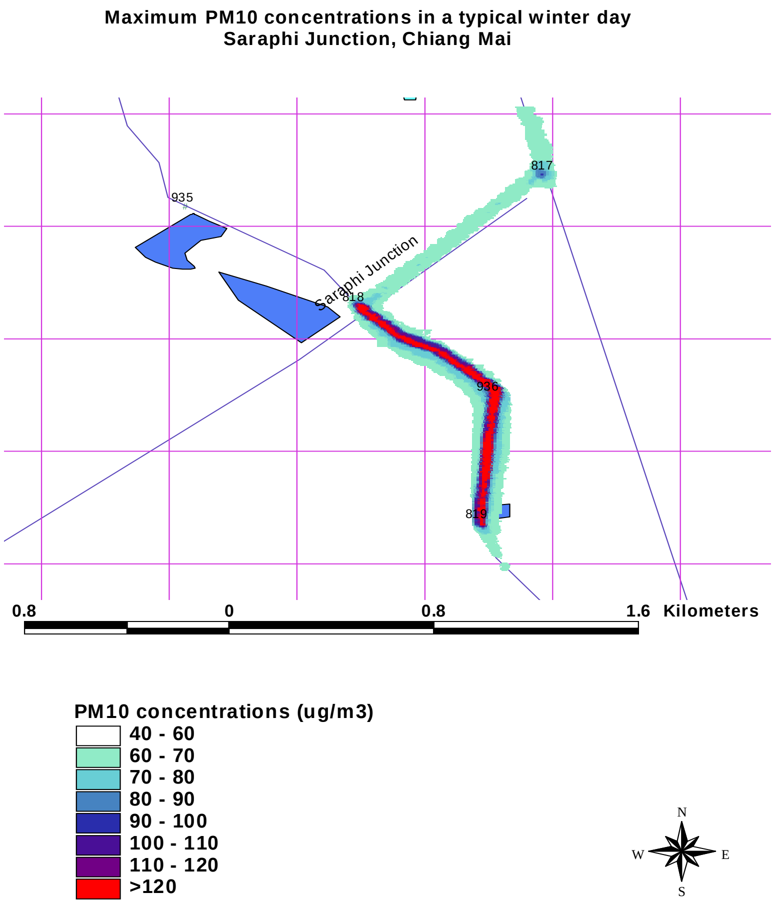
School	X(m)	Y(m)	PM_{10} 24hr ave. µg/m^3	PM_{10} 24hr max. µg/m^3	SO_2 1hr ave. ppb	SO_2 1hr max. ppb	NO_2 1hr ave. ppb	NO_2 1hr max. ppb	CO 1hr ave. ppm	CO 1hr max. ppm
S1 Ban Korn Tal	496798	2090749	45.91	45.91	2.20	2.22	8.85	20.72	0.91	1.00
S2 Wat Saimoon	491458	2065803	46.42	46.42	2.20	2.21	12.02	28.42	0.94	1.07
S3 Wat Sripotaram	504268	2068229	63.16	63.16	2.21	2.23	38.50	151.01	2.29	7.63
S4 Tao Bunruang	492930	2068185	58.62	58.62	2.20	2.22	40.09	111.14	1.42	2.98
S5 Ban San Pasak	493614	2069269	51.76	51.76	2.20	2.22	23.40	74.97	1.14	2.50
S6 Ban Donpin	495271	2071787	58.25	58.25	2.21	2.26	38.81	133.89	1.48	3.60

Note Schools S1 and S2 are located in a non 'hot-spot'; and Schools S3 –S6 in 'hot-spots'.

Table 2 Numerical outputs from the ADMS-Urban model of average and maximum pollutant concentrations in 4 schools in 'hot-spot' and 2 schools in a non 'hot-spot' areas

School site number	S1	S2	S3	S4	S5	S6
School name	Ban Korn Tal	Wat Saimoon	Wat Sri Potaram	Tao Bunruang	Ban San Pasak	Ban Donpin
Date Start Stop	26/02/04 27/02/04	27/02/04 28/02/04	01/03/04 02/03/04	02/03/04 03/03/04	03/03/04 04/03/04	24/02/04 25/02/04
Barometric pressure (mm Hg) Start Stop	758.014 757.864	757.864 757.564	758.614 757.189	755.164 755.839	755.839 755.464	759.665 759.515
Temperature, Start Stop	37.8 30.5	33.5 30.1	25.6 28.2	32.8 31.9	32.5 30.4	20.5 17.5
Time Start Stop	12.51 12.51	13.10 13.10	11.10 11.10	12.51 12.51	13.00 13.00	8.03 8.03
Time period of monitoring (hours)	24	24	24	24	24	24
Rain	No	No	No	No	No	No
Roadside PM_{10} concentration (MiniVol)	132	210	161	186	241	192
Ambient PM_{10} concentration (PCD)	186	204	112	131	162	90

Table 3 Roadside PM_{10} concentrations monitored at 6 selected schools



<u>Figure 1</u> Maximum PM_{10} concentrations in a typical winter day at Saraphi Junction. The small box at the southern end of the PM_{10} plume is Wat Sri Potaram School (S3).

4. Discussion

The use of the ADMS – Urban model for Chiang Mai showed that the accuracy of model predictions was highly dependent on the inputted values of ambient background pollution. ADMS consistently under-predicted PM_{10} concentrations, most likely because actual background concentrations including trans-boundary PM_{10} were not included in the model. Also, other sources such as other factories, road and building construction contributing to the PM_{10} concentrations in Chiang Mai but were not included because of a lack of data. Therefore, in order to produce reasonable results it was necessary to add a background PM_{10} concentration (25.5μg/m^3) to more accurately represent PM_{10} concentrations which may be too low. For SO_2 and CO, the model concentrations appeared lower than the monitored concentrations for both February and August. For NO_2, the model concentrations appeared to be higher than the monitored levels, although the modelled concentration at the ambient station in February (12.03ppb) is slightly lower than the monitored concentration (12.68ppb) because ADMS assumes certain chemical relationships between NO_x and NO_2. In the first run, the Derwent/Middleton Correlation (NO_x-NO_2 correlation) was chosen to model NO_2 concentrations given NO_x emissions. The correlation is based upon UK monitored data under UK meteorological conditions. However, this is possibly not truly representative of Chiang Mai meteorological conditions and the local conversion rates of NO_x to NO_2. The chemistry scheme selected for Run 5 was the NO_x-NO_2 correlation option which appears to give the best results in this study. This option requires more detailed input data such as background NO_x, NO_2, and O_3 concentrations. In February, a dry season month, CO, SO_2 and PM_{10} concentrations resulting from ADMS-Urban modelling were lower than monitored concentrations which may be due to the prevalence of forest fires and rice stalk burning at this time of the year. The emission rates ($g/m^2/s$) derived from annual average emission rates for these sources were used in the model which would predict lower concentrations. In addition, data on SO_2 emissions from industrial combustion of many factories are not available.

In August, (a wet season month), pollutant concentrations are likely to be lower than in the dry season because of higher precipitation rates causing washout of some pollutants e.g. PM_{10}. Emissions of forest fires and burning in rice fields were taken out of the model for this month, but the agricultural burning from orchards was included. Because 'longan' fruit farmers normally burn dry branches and leaves after harvesting around this time of the year. However, the differences of pollutant concentrations were not obvious between dry and wet season in this modelling study. The average concentrations over one month (February 2001) were modelled in comparison to the Thai Air Quality standards. The 24-hr average PM_{10} and 1 hr average SO_2, NO_2 and CO concentrations were calculated by the model using a data set containing hourly meteorological variables over one month. In comparison to the Thai standards, both modelled and monitored PM_{10}, SO_2, NO_2 and CO concentrations recorded in both ambient and roadside sites do not exceed the average standards. In order to make recommendations for further improvement of the ADMS results for Chiang Mai, the limitations in the modelling input data should be addressed. In order to better represent PM_{10} concentrations, further information is required for background, secondary and natural concentrations and sources in and outside the study area. The valley effect should also be taken into consideration due to the mountainous topographic feature of Chiang Mai province.

The asthma prevalence for children in this study is similar to the findings of Trakutivakorn (1999) [11] using the standardised ISAAC questionnaire in Chiang Mai. However, the current prevalence of rhinitis found in this study of 511 schoolchildren in non 'hot-spots' and 'hot-spots' ranged between 15.7% - 24.4% which was higher than 5.7% - 18.5% [11]. For eczema, rash at flexural areas is a typical manifestation of atopic dermatitis and the prevalence of atopic dermatitis (7.2% – 12.2%) was lower than 13% of small children in [11].

5. CONCLUSION

The ADMS – Urban model is a useful tool for modelling atmospheric dispersion of pollutants from multiple sources in urban areas. The results of modelling air quality in Chiang Mai gave pollution maps which could be used to predict the location of air pollution 'hot-spots'. However, the numerical results obtained from the modelling commonly either under- or over-predicted the measured values of different pollutants and seasonal variations. It is likely that in order to improve the accuracy of model predictions, it will be necessary to input both better data and also to make allowance of terrain. The most important of these improvements are likely to come from changes in the better quality of ambient background concentrations.

- Model Hills, an advanced ADMS – Urban option, should be used to model the effect of mountains in Chiang Mai. The terrain file which contains the terrain elevation data is needed. In the UK, the ADMS-Urban model can create *.ter* terrain files from the Ordnance Survey Landform PANORAMA and PROFILE digitalised terrain data for Great Britain. This digitalised terrain data was not available in Chiang Mai.
- It is not recommended to run the model under calm meteorological conditions in Chiang Mai where the value of wind speed is less than 1m/s [10]. The model is sensitive to meteorological data especially wind speed and wind direction variations.
- The conversion rates of NO_x to NO_2 under Chiang Mai meteorological conditions are different to many areas in the UK due to stronger sunlight. The exact conversion rates in Chiang Mai should be investigated.
- ADMS-Urban is a useful tool to identify locations for studying the prevalence of respiratory and allergic diseases. Further statistical analysis of the data is required to establish the role of air pollution and other environmental factors in the incidence of these diseases.

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