Health Benefit Modeling and Optimization of Air Pollution Control Strategies

Nadhirah Nordin[1*], M. Rafee Majid[2] and Ho Chin Siong[3]
[1*] Research Assistant, UTM-Low Carbon Asia Research Centre, Faculty of Built Environment, Universiti Teknologi Malaysia, Johor Bahru, Malaysia. Email: *nadhirahnordin24@gmail.com*,
[2] Associate Professor, UTM-Low Carbon Asia Research Centre, Faculty of Built Environment, Universiti Teknologi Malaysia, Johor Bahru, Malaysia. Email: *rafee@utm.my*
[3] Professor, UTM-Low Carbon Asia Research Centre, Faculty of Built Environment, Universiti Teknologi Malaysia, Johor Bahru, Malaysia. Email: *ho@utm.my*
*Corresponding author

ABSTRACT

In recent years, Malaysia is experiencing issues of continuous air pollution and transboundary air pollution. The issues are especially felt in areas that record high economic growth and rapid urbanization such as Iskandar Malaysia, a developing economic-growth corridor in Southeast Asia. This has led to increased rate of Particulate Matter emissions, which further led to increased in the rate of respiratory-related health incidences. Many epidemiological studies have proven that particulate matters in the ambient air are associated with adverse health effects. This will eventually affect the existing and future economy of Iskandar Malaysia, where the exposed population may loss their work days and face increased medical spending as well as reduced in their health. This study focuses on quantifying health and economic benefits from the reduction level of ambient Particulate Matter with a size of 10 micrometers or less in diameter (PM_{10}) by using the Environmental Benefits Mapping and Analysis Program (BenMAP), a model which is developed by USEPA. Health impact functions are used to quantify the relationship between a change in the PM_{10} level and a change in the related health effects among the exposed population. Up to date, there are three air monitoring stations that are located in the Iskandar Malaysia region and are operated by the Department of Environment (DOE). The samples for this research include a continuous monitoring data on the daily mean of PM_{10} for 2010, the 2010 Malaysian Census Data and the number of PM_{10} related health cases which are specifically focused in the Iskandar Malaysia region. The final outcome of the modeling compares the co-benefits of air pollution reduction between the baseline scenario and the control scenario for PM_{10} level in Malaysia. The results of this study are useful in eventually optimizing and improving the existing policies and strategies for controlling air pollution and PM_{10} emission level in Iskandar Malaysia.

KEYWORDS
Air pollution, particulate matter emission, PM_{10}, health benefits, BenMAP

1.0 Introduction

The issue of air pollution has long been discussed globally and had proven to have impact on the exposed population. Malaysia is one of the developing countries in Asian region that is not excluded from experiencing serious issues related to air pollution. Recent activities on major development in Malaysia have led to a growing concern on the ambient air quality environment. As to date, Iskandar Malaysia is one of the region that undergoes rapid on-going major developments in Malaysia which also contributes to the deteriorating level of air quality in its ambient surroundings. The current population in the region is exposed to the deteriorating ambient air quality and is a potential threat to the current and future populations' health of Iskandar Malaysia.

The purpose of this research is to explore substantially on the health and monetized benefits of the emission reduction scenario in the air pollution level among the exposed population of Iskandar Malaysia. This study focused on air particles which has the size of smaller than 10 μm in aerodynamic diameter (PM_{10}). PM_{10} has been a recent concern where epidemiological studies have proved that continuous exposure on air pollution especially particles of less than 10μm in size affects the health of the population's exposed. Many epidemiological works around the world continuously associates PM_{10} to serious adverse health effects including daily mortality which consists of all-cause, cardiovascular disease and respiratory disease (Dai et al. 2004; Hwang et al.,2002) and is also associated with higher prevalence of respiratory symptoms (Hong et. al, 2001). Hwang et al. (2007) reported that lung cancer incidence and mortality rates in women increased up to 65% and 27% when a higher PM_{10} concentration was applied. Furthermore, a study done by Iwai et al. (2005) reported that a significant correlation was observed between SPM (Suspended Particulate Matter) and ischemic heart disease or hypertensive heart disease in both males and females. As study by Pan et al. (2007) proved that symptoms such as asthma, emergency department visits, hospital admissions for respiratory and cardiovascular disease decreases when a clean-energy-use scenario (decreased in PM_{10} concentrations) was implemented and compared to the baseline scenario.

Many studies regarding PM_{10} health effects have been done in countries in the Asian region such as in China, Japan and Thailand. But, only a number of studies have been done regarding the level of PM_{10} and the associated health effects in Malaysia. A research project report by UKM Pakarunding (2004) discussed on the associations of PM_{10} increments with the significant Relative Risks (RR) outcomes for respiratory and cardiovascular morbidity. This research typically adapts a reduced PM_{10} level and the reduced number of PM_{10} –related health cases as well as its monetized benefits through the Environmental Benefits and Mapping Analysis program (BenMAP) developed by US EPA. To date, there are currently no studies done yet regarding this particular field in Malaysia which is adapting a thoroughly different environment by using this program.

Like other developing countries, Malaysia has developed its own National Air Quality Monitoring Program that is mainly governed by Alam Sekitar Malaysia Bhd. (ASMA) and the Department of Environment (DOE). So far, ASMA has established monitoring stations to capture particles that contribute to air pollution such as CO, SO_2, O_3 and PM_{10} in both the Peninsular Malaysia as well as in the West Malaysia of Sabah and Sarawak. Focus has been to only capture PM_{10} and other particles but less research is done on its contribution to serious health effects among the exposed population in Malaysia.

The DOE monitoring station that are within Iskandar Malaysia's vicinity are located in Pasir Gudang, Johor Bahru and Tampoi. Since this research uses the population data input that is based on the 2010 Malaysia Census Data, all the other data inputs such as PM_{10} monitoring data and health incidence data are based on the year 2010. This research only uses the PM_{10} monitoring data available for the year 2010 that only includes Pasir Gudang and Johor Bahru stations. To address the needs to conduct this research, Figure 1 illustrates the daily mean of PM_{10} monitoring data for 2010 in both stations as well as the recommended guidelines of daily mean of PM_{10} by World Health Organization (WHO), US Environmental Protection Agency (US EPA) and the guideline set by DOE Malaysia. This shows alarming trends of PM_{10} in both stations where PM_{10} exceeded the recommended WHO guideline for daily mean of PM_{10} and even though Malaysia's and US EPA's recommended guidelines for PM_{10} daily mean is higher, PM_{10} level is still at an alarming rate because it exceeded the WHO daily mean guideline for PM_{10}. The occurrence of PM_{10} daily mean that exceeded Malaysia and US EPA guidelines on June and October 2010 shows the incident of trans boundary haze that occurred in Malaysia and neighboring countries. Thus, there is an urgent need to conduct this research in Iskandar Malaysia region before the matter gets worst.

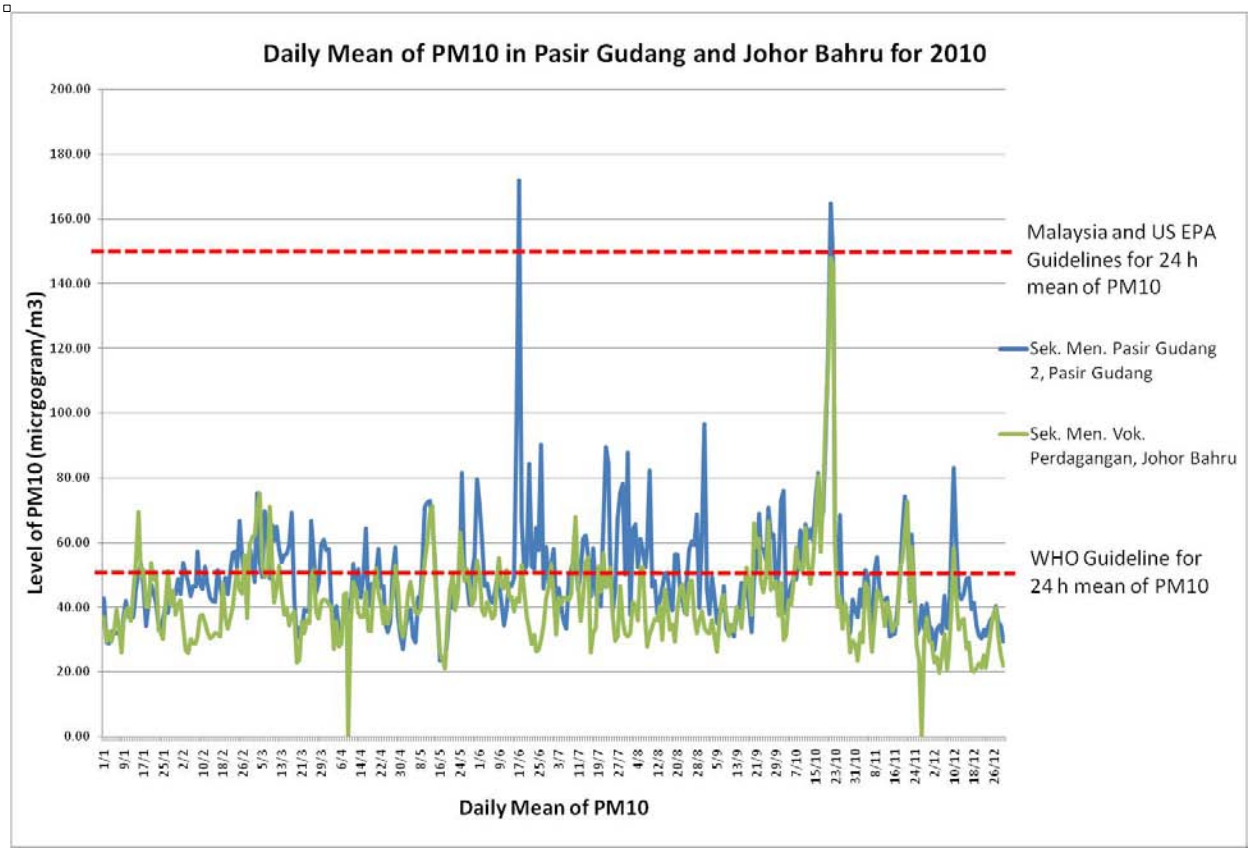

Figure 1 : Daily Mean of PM10 in Pasir Gudang and Johor Bahru stations for 2010

2.0 Method

2.1 BenMAP Operation

BenMAP is used to estimate the number of avoidable deaths and the monetized value of each of the health cases avoided and to illustrate the economical and health benefits of a PM_{10} reduction scenario analysis. Figure 2 shows a thoroughly framework of the policy analysis approach in BenMAP. There are three major stages involved in BenMAP analysis which are producing the air quality surface, constructing health impact configuration and evaluating the economic costs which involves aggregating, pooling and valuating the reduced health cases. All of these stages will be completed in order to conduct the analysis step to obtain the results. This paper will explain the research's current progress up to the methodology stage.

The relationship between a change in the concentration of a pollutant level (PM_{10}) and the change in the incidence of a PM_{10}-related health effects are quantified by using health impact functions (He et al., 2010) obtained from previous epidemiology studies that are done in Asia. Figure 2 shows the variables needed in a health impact function for a certain health incidence and are also called concentration-response functions (CRF). As to date, the current health impact functions that are available in epidemiology studies are mostly done in the developed countries like U.S., Europe and in some Asian countries. So the health impact function for each of the health incidence that will be analysed in this research will refer to health impact functions in studies that are done in Asian countries preferably developing countries. This will reduce the uncertainty of this research where health impact functions of similar environment should be used to make the study feasible. The health impact functions are chosen from various studies on the PM_{10}-related health effects and will be adjusted according to Iskandar Malaysia's suitability based on the current baseline incidence rate of health effects and current level of PM_{10}.

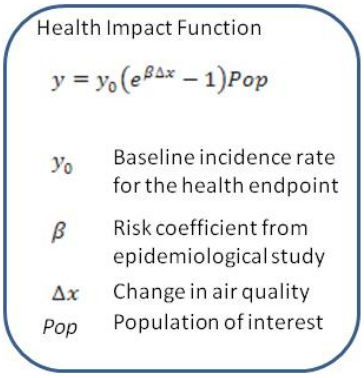

Figure 2: Variables needed in a health impact function for a certain health incidence

Economic costs for these incidence changes can then be estimated by multiplying the changes in incidence by an estimated unit value for the health endpoint (He et al., 2010). These are obtained by using valuation functions from other related epidemiology studies that are done in Asia. The significance of economic benefits in the PM_{10} reduction scenario analysis are proven by Chen et. al. (2007), where the implementation of low carbon energy scenarios could reach an economic benefits up to U.S.$507.31 million to U.S.$1.49 billion in 2010.

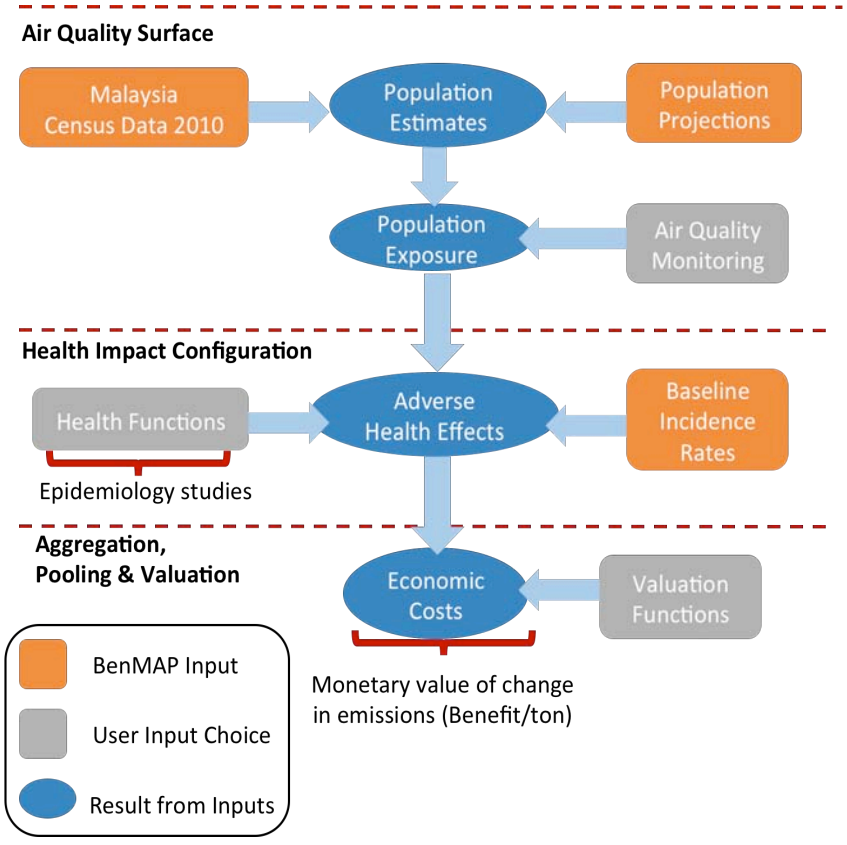

Figure 3: BenMAP Policy Analysis Approach

2.2 Data Apportionment

Based on the previous Figure 3, the three major stages can be divided into five distinct phases. The first phase in operating BenMAP involved loading externally created data in the format that BenMAP recognizes. The second and third phase involved in producing population estimates and population exposure. The fourth phase involved in configuring the health impacts and the last phase is obtaining the economic costs and benefits from the previous results of the health impacts analysis.

All the data inputs will be adjusted according to formats that BenMAP recognizes. The data input includes grid definitions, pollutants to be analyze, monitor datasets, incidence and prevalence datasets, population datasets, health impact functions and valuation functions from epidemiologic studies. Grid

definitions are consists or irregular and regular shape files where it illustrates the boundary of Iskandar Malaysia as well as square grids to cover the Iskandar Malaysia region. These square grids are needed in order to show current population estimates and to produce population exposures as well as illustrating the results of the analysis in BenMAP in the future. Figure 4 illustrates the estimates for population based on Malaysia Census Data for 2010 at the district level which has been tallied with each grid.

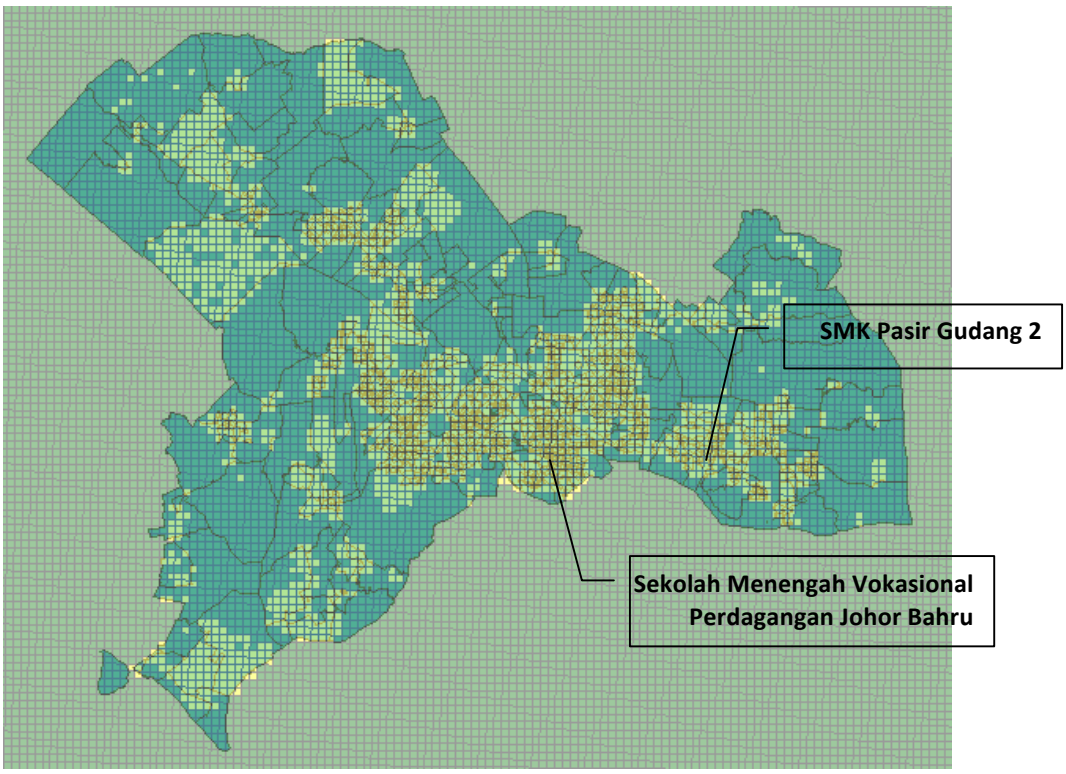

Figure 4: Population estimates based on Malaysia Census Data 2010 for Iskandar Malaysia region and the location of DOE monitor station available for PM_{10} in 2010

2.2.1 Population Estimates

BenMAP inputs are associated with the existing data on population estimates by which, in Malaysia, the population data used is the Malaysia Census Data for 2010. Since this research later on will represent a comparison between the PM_{10} emission reduction scenario and the Business as Usual (BaU) scenario, so population projection data are not needed for the analysis and only existing population data for the year 2010 are used. The data are arranged in Excel format according to the BenMAP User's Manual for 2012. Since the population census are distributed based on smaller districts in Iskandar Malaysia, so the population grid are produced based on the number of people living in each grid to tally with the total number of people living in a certain district.

2.2.2 Population Exposure

In order to obtain population exposure, PM_{10} monitoring data are obtained and prepared in the format that BenMAP recognizes. The monitoring data are obtained from DOE stations in Johor Bahru and Pasir Gudang. Even though there are limited numbers of monitoring station in Iskandar Malaysia, BenMAP have the ability to average the monitoring data for the whole region by using the Voronoi Neighbor Averaging (VNA) process. According to the BenMAP Users Manual for 2012, VNA process first identifies the set of monitors that surround each grid cell center and calculates the inverse-distance weighted average for the neighboring monitors (in this case, the neighboring monitors

are in Johor Bahru and Pasir Gudang). So the interpolation of the monitoring data points for each grid across the region can be done.

The variables in the monitoring data are consists of metrics, seasonal metrics, statistic (annual metric) and values. The metric used for PM_{10} reduction scenario analysis in this research is calculated in Daily Average Values in BenMAP. Seasonal metrics are calculated based on the average values of PM_{10} in each month so that makes 12 values of seasonal metrics for 12 months in 2010. Since PM_{10} are observed daily, a value of 365 (days per year) are obtained from DOE data and this data are prepared in Excel files and in the format that BenMAP recognizes. This step can also be illustrated by using maps. Based on the sample research analysis provide by US EPA for BenMAP analysis, the statistic (annual metrics) are left blank since we calculate an average mean of PM_{10} for each month as well as the value of PM_{10} for 365 days per year.

2.2.3 Adverse Health Effects

This step involves input data of baseline incidence rate which is related to the current number of health effects per person in a certain population per unit of time associated with the level of PM_{10} in the Iskandar Malaysia region. Table 1 shows the list of health effects that increases with an increased in PM_{10} level according to the epidemiologic studies done in the Asian countries which will be used in the analysis of this research in the future. Based on the previous Figure 2 on health impact functions, this research analysis will use the beta coefficient for each health endpoint in the list of studies stated below. These health effects are identified based on International Classification for Diseases (ICD-10) codes by WHO to ease the research process analysis and data obtaining process in the future.

Table 1: List of health effects that are related to increased in PM_{10} level

ICD-10 codes	*Health Effects*	*List of studies related to analyzing increased level of PM_{10}*
For respiratory diseases		
J40 – J42	*Bronchitis*	*Chen (2006); Hu (2001); Kan et. al. (2004); Mead & Brajer (2005); Pan et al. (2007)*
J43	*Emphysema*	*Agarwal et. al. (2006)*
J44	*Other obstructive pulmonary diseases (COPD)*	*Agarwal et. al. (2006); Jang et. al. (2006); Ko et. al. (2007); Pan et. al. (2007); Yang et. al. (2007)*
J45 - J46	*Asthma*	*Agarwal et. al. (2006); Jang et. al. (2006); Kan & Chen (2003); Pan et. al. (2007); Bell et. al. (2008)*
For cardiovascular diseases		
I20 – I25	*Ischemic heart disease*	*Iwai et. al. (2005); Lee et. al. (2003)*

Source: Various epidemiological studies

The health effects data have rates that vary by race, ethnicity, gender, and age group. But for the purpose of this research, since the aim is only to quantify the monetized benefits and reduced health benefits when a PM_{10} reduction scenario analysis is implemented, so there is no need to specifically do an analysis that considers all these parameters and only conducting an analysis that generally considers all of the parameters. This paper only reviews up until the methodology section for this research because it is somewhat a time consuming process in acquiring this type of data for Iskandar Malaysia region from Ministry of Health Johor, and so the analysis can be done once the data are obtained from MOH Johor.

2.2.4 Economic Costs

Aggregation, pooling and valuation stage will be done in BenMAP to obtain the monetized benefits for the PM_{10} reduction scenario analysis. Based on the BenMAP Manual Case Study for Mumbai (2006), aggregation refers to spatial combination of results from smaller areas to a larger ones, pooling refers to the mathematical combination of two or more results of health impact function into a single result, and valuation refers to applying unit values to incidence results to obtain the monetized benefits. In this stage, valuation function from epidemiologic studies are also needed in order to calculate the economic value for the each of the reduced health endpoint from the reduction scenario analysis. Completion for the previous stage which is conducting the health impact functions for each health endpoint is necessary in order to proceed to this last stage of BenMAP PM_{10} reduction scenario analysis.

4.0 Conclusion

To conclude, this research will help policymakers to propose a comprehensive framework in improving the air quality control measures for minimizing costs and maximizing benefits in the health and economy aspects. Evaluation on the current air quality strategies and policy can be done to measure the effectiveness of government initiatives by referring to the results of this research in the future. The outcome of this research will further improve the policy framework for ambient air quality in Malaysia especially in Iskandar Malaysia region in the present time as well as in the future. It will also help policymaker formulate new policies and reduce the number of cases on PM_{10} – related health effects among the exposed population and will further contribute to the increased level of public health and air quality ambient surrounding in Iskandar Malaysia. For the monetized benefits aspects, the analysis will further focused on the reduction of health effects that contributes to the economy of the study region such as the number of lost work days, hospital admissions related to respiratory and cardiovascular symptoms and emergency room visits.

Acknowledgments

The authors gratefully acknowledge the funding support for this work provided by Ministry of Education, Malaysia and Universiti Teknologi Malaysia (UTM) under Others Grant of VOT Number R.J1300000.7301.4B145 and Japan International Cooperation Agency (JICA) under the scheme of SATREPS Program (Science and Technology Research Partnership for Sustainable Development) for the project Development of Low Carbon Scenario for Asian Region.

References

Abt Associates Inc. (2006). 'BenMAP Environmental Benefits Mapping and Analysis Program, Case Study: Mumbai'.

Abt Associates Inc. (2012). 'BenMAP Environmental Benefits Mapping and Analysis Program User's Manual'.

Agarwal R, Jayaraman G, Anand S and Marimuthu P. (2006). 'Assessing respiratory morbidity through pollution status and meteorological conditions for Delhi.' *Environ Monit Assess*. No 114: 489-504.

Dai H, Song w, Gao X, et al. (2004). 'Study on relationship between ambient PM_{10}, $PM_{2.5}$ pollution and daily mortality in a district in Shanghai', *Journal of Hygiene Research*, No. 33: 39-49.

Davidson, K., Hallberg, A., McCubbin, D., & Hubbell, B. (2007). Analysis of PM2.5 using the Environmental Benefits Mapping and Analysis Program (BenMAP). *Journal of Toxicology and Environmental Health. Part A*, *70*(3-4), 332–346. doi:10.1080/15287390600884982

He, K., Lei, Y., Pan, X., Zhang, Y., Zhang, Q., & Chen, D. (2010). Co-benefits from energy policies in China. *Energy*, *35*(11), 4265–4272. doi:10.1016/j.energy.2008.07.021

Hong CY, Chia SE, Widjaja D, et al. (2004). 'Prevalence of respiratory symptoms in children and air quality by village in rural Indonesia', *Journal of Occupational Environmental Medicine*, No. 46: 1174-1179.

Hu W, Wei FS, Teng EJ, et. al. (2001). 'The impact of air pollution on respiratory health of children and their parents'. *China Environ Sci*. No 20:425-428.

Hwang SS, Cho SH and Kwon HJ (2002). 'Effects of the severe Asian dust events on daily mortality during the spring of 2002, in Seoul, Korea', *J Prev Med Pub Health*, No 38: 197-202.

Hwang SS, Lee JH, Jung GW, et al. (2007). 'Spatial analysis of air pollution and lung cancer incidence and mortality in 7 metropolitan cities in Korea', *J Prev Med Pub Health*, No 40: 233-238.

Iwai K, Mizuno S, Miyasaka Y, et al. (2005). 'Correlation between suspended particles in the environmental air and causes of disease among inhabitants: Cross-section studies using the vital statistics and air pollution data in Japan', *Environ Res*, No 99: 106-117.

Jang AS, Kim BY, Lee CH, et. al. (2006). 'Hospital visits and admissions in patients with asthma, COPD and cardiovascular diseases according to air pollutants'. *J Asthma Allergy Clin Immunol*. No. 26: 233-238.

Kan H, Chen B. (2003). 'A case crossover analysis of air pollution and daily mortality in Shanghai'. *J Occup Health*. No. 45:119-124.

Kan HD, Chen BH, Chen CG, et. al. (2004). 'An evaluation of public health impact of ambient air pollution under various energy scenarios in Shanghai, China. *Atmos Environ*. No 38: 95-102.

Ko FW, Tam WW, Wong T, et. al. (2007). 'The temporal relationship between air pollutants and hospital admissions for chronic obstructive pulmonary disease in Hong Kong'. *Thorax*. No 62: 780-785.

Lee JT, Kim H, Hong YC, et. al. (2003). 'Air pollution and hospital admissions for ischemic heart diseases among individuals 64+ years of age residing in Seoul, Korea.' *Arch Environ Health*. No 58: 617-623.

Pan X, Yue W, He K & Tong S. (2007). 'Health benefit evaluation of the energy use scenarios in Beijing, China.' *Sci Total Environ.* No 374: 242-251.

UKM Pakarunding. (2004). A Research Project Report A Study of Health Impact and Risk Assessment of Urban Air Pollution in the Klang Valley, Malaysia.

WHO Air Quality Guidelines for particulate matter, ozone, nitrogen dioxide and sulfur dioxide (2005)

Yang CY & Chen CJ. (2007). 'Air pollution and hospital admissions for chronic obstructive pulmonary disease in a subtropical city: Taipei, Taiwan.' *Journal of Toxicology and Environmental Health A.* No 70: 1214-1219.