ASSESSMENT OF POPULATION EXPOSURE TO PM2.5 AND LONG-TERM MORTALITY IN MALAYSIA

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ABSTRACT: Studies have shown that exposure to high levels of suspended particulate matter <2.5 microns in diameter ($PM_{2.5}$) are harmful to human health and is associated with increased morbidity and mortality. As there are limited numbers of continuous air quality monitoring stations in Malaysia and most of them are located in urban and industrialized areas, remote sensing and geographic information system (GIS) technology can be utilized to estimate the $PM_{2.5}$ concentrations to cover the whole country. This study aimed to assess the long-term mortality among Malaysians due to exposure to estimated $PM_{2.5}$ concentrations using remote sensing and GIS application. Satellite data was used to estimate annual PM_{10} concentrations for year 2013 with spatial resolution of 5 x 5 kilometers using a validated Artificial Neural Network (ANN) model from a local study based on aerosol optical depth (AOD). The estimated PM_{10} concentrations was overlaid with high resolution population data, to determine the population-weighted exposure level (PWEL) of PM_{10} for 16 states in Malaysia. $PM_{2.5}$ was estimated by multiplying the PWEL of PM_{10} by 0.65. Mortality data which was excluded for deaths due to accidents and injury was used to determine the number of premature deaths for each state by using AirQ+ model (developed by World Health Organization, WHO). Annual PWEL of $PM_{2.5}$ concentrations for whole Malaysia was 36 $\mu g/m^3$ which was higher than WHO's Air Quality Guideline (AQG). The highest PWEL of $PM_{2.5}$ was in Putrajaya (46 $\mu g/m^3$) and lowest were in Sabah and Sarawak. The total number of premature deaths associated with long term exposure to $PM_{2.5}$ in whole Malaysia was 14,525 (95%CI: 9,665-18,891). The state with highest number of premature deaths was estimated in Selangor at 3,034 (95%CI: 2,032 – 3,924) as it has high density population and have among the highest level of PWEL to $PM_{2.5}$ in Malaysia. Wilayah Persekutuan Labuan recorded the lowest number of premature deaths compared to other states. In terms of population at risk, the highest number was estimated in Perlis which was at 96.6 (95%CI: 64.62-125.04) premature deaths per 100,000 population. Results also showed that reduction of annual $PM_{2.5}$ levels by 5 $\mu g/m^3$ could prevent 3,587 (18%) premature deaths. Remote sensing and GIS are useful tools which could enable estimation of $PM_{2.5}$ concentration from satellite sources. The combination of these tools and health impact assessment software have enabled the estimation of burden of disease due to air pollution which could assist decision-makers in developing appropriate interventions to reduce $PM_{2.5}$ concentration and protect health of the population. **(411 words)**.

1. INTRODUCTION

WHO reported that air pollution is responsible for 6.7% of all mortality worldwide with 2.6-4.4 million premature deaths per year were estimated (WHO, 2003). Many studies done about health impacts of air pollution around the world (Shin et al, 2008; Burnett et al., 2014). Particulate matter is one of the most important determinants which have evidence in causing health effects on human. Short- and long-term exposure to high levels of suspended particulate matter <2.5 microns in diameter ($PM_{2.5}$) are related to various health outcomes such as cardiovascular and respiratory disease and eventually associated with premature mortality (Cesaroni et al. 2014; Klepac et al., 2018).
With this matter, the need to study the epidemiology of air pollution and health impact assessment has become more essential to help environmental policy makers to quantify the burden of air pollution to the country. Therefore, it is important to assess the population exposure to the particulate matter in the spatial and temporal manner. As there are limited numbers of continuous air quality monitoring stations in Malaysia and most of them are located in urban and industrialized areas, remote sensing and geographic information system (GIS) technology can be utilized to estimate the $PM_{2.5}$ concentrations to cover the whole country from reliable source of satellite data.
This study aimed to estimate long-term mortality among Malaysians using estimated $PM_{2.5}$ concentrations exposure for year 2013 using remote sensing application and health impact assessment tool.

2. MATERIALS AND METHODS

2.1 Site description

Malaysia is a country part of the Southeast Asia which have total land area of 329,613 km^2. It consists of 13 states and three federal territories. This group of states separated by South China Sea into Peninsular Malaysia and Malaysia Borneo Island. Two of the federal territories which are Kuala Lumpur and Putrajaya are located on Peninsular Malaysia and the other one is Labuan which is located on the Borneo Island. Kuala Lumpur is the capital city of Malaysia.

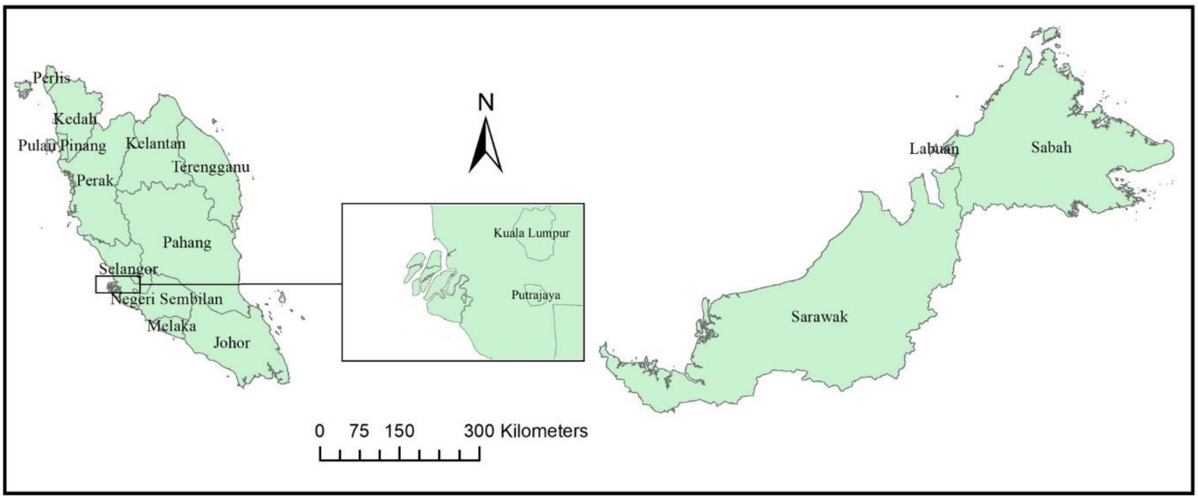

Figure 1. Study area

2.2 Air quality data

The satellite data used for this study were downloaded from aerosol product of MODIS obtained from the Level-1 and Atmosphere Archive & Distribution System (LAADS) Distributed Active Archive Center (DAAC) website produced by National Aeronautics and Space Administration (NASA). Aerosol product for MOD04, MOD07 and MOD021 for the whole year 2013 were downloaded. Multiple output for Aerosol Optical Depths (AOD), surface temperature, atmosphere stability and relative humidity were projected to coordinate system WGS84 by using ENVI software. All the outputs were then calculated to obtain annual average concentration of PM_{10} by using GIS software. The PM_{10} estimation method were done by using Artificial Neural Network (ANN) formula from a local study (Zaman et al., 2017). The map of annual average of PM_{10} value for whole Malaysia was then multiplied by 0.65 (standard conversion factor by WHO) to obtain value of $PM_{2.5}$. The map was then interpolated at resolution of 5km x 5km using Kriging interpolation method to match gridded population distribution data.

2.3 Mortality data

Mortality records for year 2013 were obtained from Department of Statistics, Malaysia (DOSM). All-natural cause mortality for all age ranges were obtained and the death from accidents and injury were excluded. The coding for the mortality was adhered to the International Classification of Disease, Tenth Revision (ICD-10) by the World Health Organization (WHO) for the health outcomes

2.4 Population data

The country's population was 28,334,135 in 2010 with growth population of 1.54 percent per year according to DOSM. However, to obtain the detailed population distribution, population data were downloaded from the Center for International Earth Science Information Network (CIESIN) website that contained spatial information of the population of the country. Population count gridded data of the World version 4 (GPWv4) were derived for year 2013 in view of the provided data only consists data for 5-year intervals starting from year 2000 and later. The gridded population data were downloaded with 5 kilometers resolutions to match the map of annual average of $PM_{2.5}$ concentrations.

2.5 Population weighted exposure level (PWEL) to $PM_{2.5}$

In view of the population distribution and $PM_{2.5}$ concentration were not concordant in an area, the PWEL calculation was proposed to measure population exposure (Ivy et al, 2008). In this calculation, the pollutant concentration weighs proportionally to number of populations that are being exposed. The gridded population layer for year 2013 and $PM_{2.5}$ concentration layer was overlaid to analyze the population exposure levels in various concentration ranges using GIS spatial information analysis function. Calculation of PWEL were done in all 16 states using the population exposure equation as follows:

$$\text{PWEL} = \Sigma(P_i \times C_i) / \Sigma P_i \quad (1)$$

Where Pi is the population unit of a grid and Ci is its $PM_{2.5}$ concentration that being exposed to the population unit in a grid.

2.6 AirQ+ health impact assessment software

AirQ+ software is a tool to evaluate the impact of air pollution with burden of disease such as particulate matters based on concentration-response function from previous systematic review and meta-analysis of epidemiological studies. In order to calculate long term mortality in this software, the following input data such as mean of pollutants concentration (this study used value from PWEL $PM_{2.5}$ from each state), total population in a state at risk (all age) of all-cause mortality, cut off value of $PM_{2.5}$ pollutant for consideration (annual mean of 10 µg/m^3 as recommended by WHO air quality guideline) and relative risk (RR) values for mortality from annual $PM_{2.5}$. This study used RR value from Health Risk of Air Pollution in Europe (HRAPIE) project by WHO which recommended that the RR value is 1.062 (CI 95% 1.04 – 1.083) for all-cause mortality for age more than 30 years from $PM_{2.5}$ pollutant (WHO,2013). In view of data limitations, this study used mortality data from all ranged for the health impact assessment calculation.

3. RESULTS

3.1 PWEL to PM10 in states of Malaysia

Table 1 showed the difference of estimated annual $PM_{2.5}$ concentrations and its PWEL value after spatial distribution of population in a state were take into account. It should be noted that all of the annual concentrations of $PM_{2.5}$ in all states were higher than10 µg/m^3, which is value recommended by WHO air quality guideline. The highest PWEL of $PM_{2.5}$ was in Putrajaya (46 µg/m^3) and lowest were in Sabah and Sarawak. Majority of states showed decreased value of $PM_{2.5}$ after PWEL were calculated except for Selangor. This showed that more population in Selangor were exposed to high concentration of $PM_{2.5.}$ As for Pulau Pinang and Melaka, the PWEL value were decreased more than 30% from the actual level. This showed that more population of the states exposed with the low level of $PM_{2.5}$ concentrations compare to the annual average value.

Table 1. Annual average concentrations and PWEL of PM2.5 in 16 states of Malaysia.

State name	Annual average concentrations of PM2.5 (µg/m^3)	PWEL of PM2.5 (µg/m^3)	Differences
Putrajaya	47	46	-1
Kuala Lumpur	46	37	-9
Selangor	33	36	+3
Perlis	44	35	-8
Kedah	38	32	-6
Terengganu	32	32	0
Labuan	29	30	0
Pahang	33	30	-3
Johor	34	27	-8
Perak	30	26	-4
Kelantan	31	26	-5
Negeri Sembilan	35	26	-9
Pulau Pinang	36	25	-11
Melaka	33	23	-10
Sabah	26	22	-4
Sarawak	26	22	-4

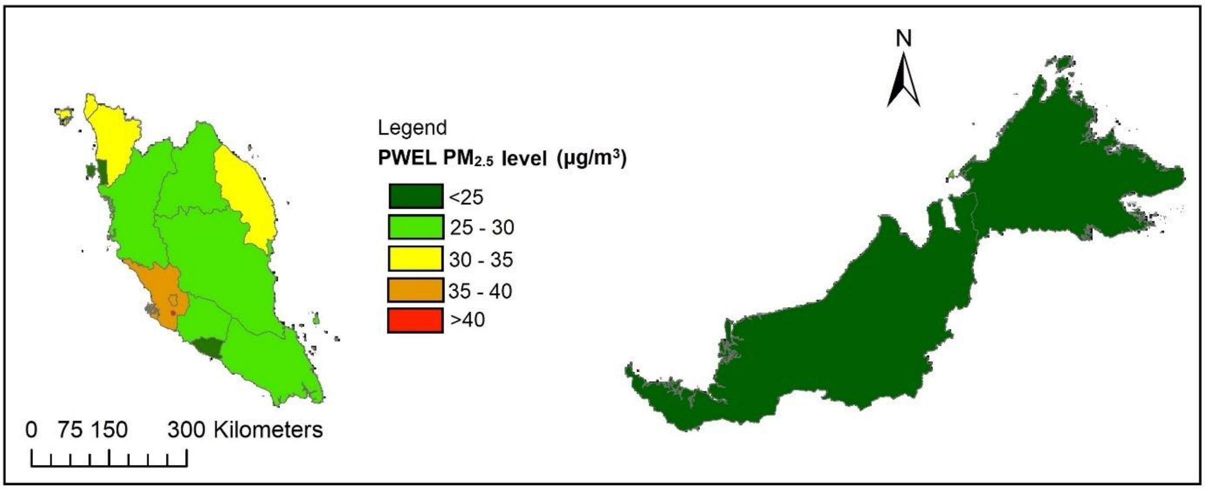

Figure 2. Spatial distribution of PWEL of $PM_{2.5}$ in 16 states of Malaysia in 2013.

3.2 Long-term premature death based on AirQ+ software

Using AirQ+ software, health impacts from $PM_{2.5}$ concentration over year 2013 were calculated. The total number of premature deaths associated with long term exposure to $PM_{2.5}$ in whole Malaysia was 14,525 (95%CI: 9,665-18,891) as shown in Table 2. The state with highest attributable number of premature deaths was estimated in Selangor at 3,034 (95%CI: 2,032 – 3,924) as it was driven by both of its highest population (19.54% population ratio) and have among the highest level of PWEL to $PM_{2.5}$ in Malaysia. Wilayah Persekutuan Labuan recorded the lowest attributable number of premature deaths compared to other states as it has low population and low exposure level to $PM_{2.5}$ concentration. In terms of population at risk, the highest number was estimated in Perlis which was at 96.6 (95%CI: 64.62-125.04) premature deaths per 100,000 population. Results also showed that reduction of annual $PM_{2.5}$ levels by 5 $\mu g/m^3$ could prevent 3,587 (18%) premature deaths.

Table 2. Attributable proportion, total attributable premature deaths and total attributable premature deaths per 100,000 population due to long-term exposure to $PM_{2.5}$ in 2013.

State name	Attributable proportion % (95% CI)	Total attributable premature death (95% CI)	Attributable premature death per 100,000 population
Putrajaya	19.47 (13.17-24.95)	31 (21-39)	38.6 (26.1-49.47)
Kuala Lumpur	14.99 (10.05-19.37)	1052 (705-1359)	61.04 (40.91-78.86)
Selangor	14.48 (9.69-18.72)	3034 (2032-3924)	51.39 (34.41-66.45)
Perlis	13.96 (9.34-18.07)	234 (156-303)	96.6 (64.62-125.04)
Kedah	12.4 (8.27-16.09)	1488 (993-1932)	72.96 (48.66-94.7)
Terengganu	12.4 (8.27-16.09)	766 (511-995)	68.84 (45.91-89.35)
Labuan	11.34 (7.54-14.74)	27 (18-35)	29.52 (19.64-38.38)
Pahang	11.34 (7.54-14.74)	880 (586-1144)	56.08 (37.33-72.93)
Johor	9.72 (6.45-12.68)	1645 (1091-2145)	47.34 (31.41-61.74)
Perak	9.18 (6.08-11.98)	1458 (966-1902)	59.56 (39.48-77.74)
Kelantan	9.18 (6.08-11.98)	895 (593-1168)	53.15 (35.23-69.38)
Negeri Sembilan	9.18 (6.08-11.98)	545 (361-712)	50.86 (33.71-66.39)
Pulau Pinang	8.63 (5.71-11.27)	796 (527-1040)	47.86 (31.69-62.53)
Melaka	7.52 (4.97-9.85)	343 (227-449)	40.05 (26.46-52.42)
Sabah	6.96 (4.6-9.12)	575 (379-753)	15.91 (10.51-20.85)
Sarawak	6.96 (4.6-9.12)	756 (499-991)	28.63 (18.9-37.51)
Total/Average	-	14525 (9665-18891)	51.15 (34.06-66.48)

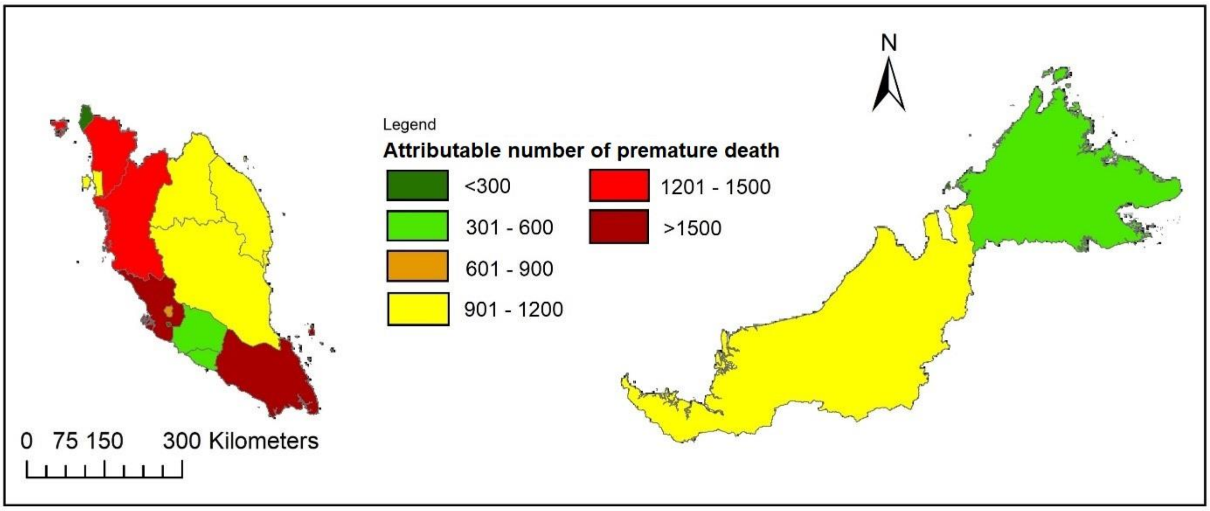

Figure 3. Spatial distribution attributable number of premature death due to long-term exposure of $PM_{2.5}$ in 16 states of Malaysia in 2013 using AirQ+ software.

Figure 2 and 3 illustrate the spatial distribution of PWEL of $PM_{2.5}$ concentration and attributable number of premature deaths estimated in all 16 states of Malaysia for year 2013. The higher PWEL of $PM_{2.5}$ concentration was located at Selangor, Terengganu and northern Malaysia (Kedah and Perlis) compared to Sabah and Sarawak which low $PM_{2.5}$ concentration. Compared to figure 3 that illustrated the number of attributable premature deaths is more concentrated along the west coast of the peninsular Malaysia. This reflects that the number of attributable premature deaths were influenced by the number of populations of a state and $PM_{2.5}$ concentration.

4. DISCUSSIONS AND CONCLUSION

GIS and remote sensing applications in environmental health provides utilization of air data combination with health data. Aerosol data from NASA provides measurement of $PM_{2.5}$ from satellite source over Malaysia which readily available from year 2000 until now. Satellite-based $PM_{2.5}$ concentration provide better estimates of population exposure more spatially. This will give environmental researcher to study more on air pollution and its impact on human exposure. From the GIS software, environmental researchers are able to produce air pollution map, make analysis and measure the burden of air pollution in the future. The spatial features in GIS are good for data management in storing and displaying information that can be understand between environmental and health agencies. The combination of these tools and health impact assessment software have enabled the estimation of burden of disease due to air pollution which could assist decision-makers in developing appropriate interventions to reduce $PM_{2.5}$ concentration and protect health of the population.

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