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Cardiovascular, respiratory and all-cause (natural) health endpoint estimation using a spatial approach in Malaysia

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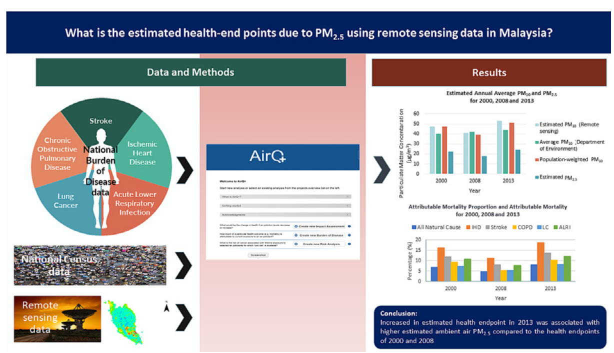
HIGHLIGHTS

- Estimated $PM_{2.5}$ were 22 µg/m^{-3} (2000), 18 µg/m^{-3} (2008) and 24 µg/m^{-3} (2013), exceeding WHO 2005 Air Quality Guideline for $PM_{2.5}$.
- Estimated health endpoints were highest in 2013 compared to 2000 and 2008
- Adhering to the Malaysian Air Quality Standard IT-2 would reduce the Malaysian health endpoint mortality due to $PM_{2.5}$

GRAPHICAL ABSTRACT



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ABSTRACT

In 2016, the World Health Organization (WHO) estimated that approximately 4.2 million premature deaths worldwide were attributable to exposure to particulate matter 2.5 µm ($PM_{2.5}$). This study assessed the environmental burden of disease attributable to $PM_{2.5}$ at the national level in Malaysia. We estimated the population-weighted exposure level (PWEL) of PM10 concentrations in Malaysia for 2000, 2008, and 2013 using aerosol optical density (AOD) data from publicly available remote sensing satellite data (MODIS Terra). The PWEL was then converted to $PM_{2.5}$ using Malaysia's WHO ambient air conversion factor. We used AirQ+ 2.0 software to calculate all-cause (natural), ischemic heart disease (IHD), stroke, chronic obstructive pulmonary disease (COPD), lung cancer (LC), and acute lower respiratory infection (ALRI) excess deaths from the National Burden of Disease data for 2000, 2008 and 2013. The average PWELs for annual $PM_{2.5}$ for 2000, 2008, and 2013 were 22 µg m-3, 18 µg m-3 and 24 µg m-3, respectively. Using the WHO 2005 Air Quality Guideline cut-off point of $PM_{2.5}$ of 10 µg m-3, the estimated excess deaths for 2000, 2008, and 2013 from all-cause (natural) mortality were between 5893 and 9781 (95 % CI: 3347–12,791), COPD was between 164 and 957 (95 % CI: 95–1411), lung cancer was between 109 and 307 (95 % CI: 63–437), IHD was

Abbreviations: IT-2, Interim Target 2; DALY, Disability-adjusted Life Years; DOSM, Department of Statistics, Malaysia.

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between 3 and 163 deaths, according to age groups (95 % CI: 2–394) and stroke was between 6 and 155 deaths, according to age groups (95 % CI: 3–261). An increase in estimated health endpoints was associated with increased estimated PWEL $PM_{2.5}$ for 2013 compared to 2000 and 2008. Adhering the ambient $PM_{2.5}$ level to the Malaysian Air Quality Standard IT-2 would reduce the national health endpoints mortality.

1. Introduction

The World Health Organization (WHO) states that in 2019, 99 % of the world's population lives where ambient air pollution levels exceed WHO's guidelines (WHO, 2023). In Southeast Asia and Western Pacific Region, more than 50 % of city populations are experiencing an increasing trend of annual means of PM_{10} or $PM_{2.5}$ from 2008 to 2013. In addition, most Southeast Asian towns and cities have an annual mean PM level exceeding the WHO Air Quality Guidelines of 10 μg m-3 (WHO Regional Office for Europe, 2006). According to the Malaysian Department of the Environment (DOE, 1996), the percentage of the air emission load by type was motor vehicles, 82 %; power stations, 9 %; industrial fuel burning, 5 %; industrial production processes, 3 %; domestic and commercial furnaces, 0.2 %; and open burning at solid waste disposal sites, 0.8 %. This has not changed much except for power plant sources, where the primary proportion of pollutants emission to the atmosphere in 2017 were from motor vehicles (70.4 %), followed by power plants (24.5 %), industrial (2.9 %), and others (2.1 %) (DOSM, 2018).

Ambient air pollution accounts for an estimated 4.2 million deaths per year globally and has become a significant environmental health risk (WHO, 2016). $PM_{2.5}$ was ranked fifth as the cause of 4.2 million deaths and 103.1 million DALYs and represented 7.6 % of total global deaths and 4.2 % of global DALYs, as reported in the 2015 GBD study (Cohen et al., 2017). The WHO Western Pacific and Southeast Asian regions bear most of the burden, with 1.1 million and 799,000 deaths, respectively. Global deaths attributed to air pollution are mainly due to stroke were 38 % (1,082,750), IHD 36 % (1,078,800), chronic obstructive pulmonary disease (COPD) 14 % (402,350), lung cancer (LC) 8 % (242,250) and acute lower respiratory infection (ALRI) 6 % (169,250) (WHO, 2016).

Ambient air particulate matter (PM) pollution has been associated with an increased risk of premature adult mortalities (Afroz et al., 2003; Atkinson et al., 2014; Crouse et al., 2015; Liu et al., 2016; WHO, 2016). The American Cancer Society (ACS) study (Kaiser et al., 2004) and the Harvard Six-Cities study reported an association between long-term exposure to fine inhalable particles ($PM_{2.5}$) and adult mortality, even after controlling for possible confounders such as age, sex, or cigarette smoking (Pope et al., 2002). In addition, epidemiological studies have shown positive associations between air pollutants such as particulate matter with aerodynamic diameters of less than ten μm (PM_{10}) and 2.5 μm ($PM_{2.5}$) and adverse health outcomes (Liu et al., 2015; Wong et al., 2015; Yorifuji et al., 2016).

Currently, there are 68 Continuous Air Quality Monitoring (CAQM) stations set up throughout Malaysia by the Department of Environment, mainly located on the west coast of Peninsular Malaysia (Air Pollutant Index Management System, 2023). Thus, the number of air monitoring stations is limited to represent population exposure to air pollution levels throughout the nation. In addition, each station can only represent population exposure to ambient air pollution for approximately 5 km (Usmani et al., 2020). As an alternative, remote sensing technology could overcome this problem. Using relevant satellite data and analysis tools, remote sensing data for ambient air monitoring can become an alternative source of ambient air data. However, in Malaysia, very few studies have been conducted to estimate the environmental burden of disease attributable to ambient particulate matter using the spatial method (Mohd Shafie et al., 2022).

This study aimed to estimate the attributable all-natural causes, ischemic heart disease, stroke, lung cancer, bronchitis, and under five years old acute lower respiratory tract infection health endpoints in the Malaysian population for 2000, 2008, and 2013 due to estimated $PM_{2.5}$ using publicly available remote sensing data and available national burden of disease data.

2. Materials and methods

2.1. Site description

Malaysia is a developing country in Southeast Asia undergoing rapid growth in industrial and transportation domains, resulting in increased air pollution, particularly PM_{10} concentrations, during recent decades (Murray et al., 2012). It is a federation of thirteen states and three federal territories (Statoids, 2010). Two federal territories (Kuala Lumpur and Putrajaya) and eleven states are in Peninsular Malaysia, while two other states (Sabah and Sarawak) and one federal territory (Labuan) are grouped as East Malaysia (Government of Malaysia, 2009).

The atmospheric pressure distribution over the region influences the country's tropical climate. The seasonal inter-tropical convergence zone produces two monsoonal seasons, namely the Northeast Monsoon (NEM) (November to February) and the Southwest Monsoon (SWM) (June to August). The two monsoons are divided into interim light and variable wind periods (Sentian et al., 2019). Open burning of solid wastes and forest fires contributed to 3–5 % of the country's air pollution. Since 1994, significant amounts of air pollution have resulted from the transboundary haze, with more frequent trends over the past few years, as reported by the Department of Environment (DOE, 2022).

2.2. Baseline population and mortality data

The dataset used in this study covered all of Malaysia for the years 2000, 2008, and 2013. Mid-year population censuses of Malaysia and the 14 states in Peninsular Malaysia and East Malaysia for 2000, 2008, and 2013 were obtained from the Department of Statistics Malaysia website (DOSM, 2022). However, as these data for 2008 and 2013 were unavailable for Putrajaya, we used data from the Centre for International Earth Science Information Network (CIESIN) (Abdul Shakor et al., 2020). The number of medically certified deaths for the Malaysian population in 2000, 2008, and 2013 was obtained from the Institute for Public Health, National Institutes of Health, Malaysia's database for 2000, 2008, and 2013. The data were for all natural causes (ICD-10 A00-R99), excluding external causes of fatal events unrelated to environmental factors (Chapter XIX ICD-10 S00-T98 and Chapter XX of the ICD-10, V01-Y98), such as road accidents, homicides, suicides, ischemic heart disease (IHD) (ICD10 I20–I25), cerebrovascular disease (stroke) (ICD10 I60-I69), chronic obstructive pulmonary disease (COPD) (ICD10 J40–J44, J47), lung cancer (LC) (ICD10 C33-C34, D02.1-D02.2, D38.1) and acute lower respiratory infection (ALRI) (ICD10 J10-J22, P23, U04).

2.3. Exposure assessment

The data on aerosol products of Level 2 Terra-MODIS (Moderate Resolution Imaging Spectroradiometer) satellite surveillance over Malaysia were obtained from the National Aeronautics and Space Administration's (NASA) Level-1 and Atmosphere Archive and Distribution System (LAADS) Distributed Active Archive Centre (DAAC) website (Abdul Shakor et al., 2020) The aerosol products for MOD04_L2, MOD07_L2, and MOD021km were downloaded for the three studied years at a spatial resolution of 10 × 10 km. Data on aerosol optical depths (AOD), surface temperature (ST), atmospheric stability (KI), and relative humidity (RH) were extracted from the MODIS aerosol products and projected to the World

Geodetic System (WGS) 84 coordinates using Environment for Visualizing Images (ENVI) software version 5.1. Using the Artificial Neural Network (ANN) model from a local study (Kamarul Zaman et al., 2017), mean annual PM_{10} concentration estimations were calculated from the projected outputs in ArcGIS software version 10.6. The calculated PM_{10} concentration estimations were then spatially interpolated using kriging spatial interpolation to fill in the empty pixels and resampled at a resolution of $0.1^{\circ} \times 0.1^{\circ}$. For data validation of the PM_{10} levels, the data were compared with air quality monitoring data from the Department of Environment (DOE) CAQM stations. The remote-sensing image analysis method was described in detail elsewhere (Abdul Shakor et al., 2020; Kamarul Zaman et al., 2017).

We calculated the population-weighted level of PM_{10} concentrations for 2000, 2008, and 2013 for all the states in Malaysia based on methods by Abdul Shakor et al. (2020) and Sun et al. (2013) in Eq. (1), where P is the population and C is its mean annual PM_{10} concentration. The average of the PWEL PM_{10} results is then converted to the $PM_{2.5}$ level using Malaysia's WHO conversion factor, i.e., 0.47 (WHO, 2022).

$$PWEL = \sum(P \times C)/\sum P \tag{1}$$

2.4. Health endpoints estimation

In assessing the mortality or any other adverse health outcome associated with a specific pollutant, the relative risk (RR) function expresses the enhancement of the probability of observing the effect when the pollutant concentration increases. The most popular expressions of the relative risk are the log-linear (Eq. (2)). The health endpoints chosen for $PM_{2.5}$ are based on the WHO's recommendations for the national-level burden of disease assessments (WHO, 2022), which includes all-cause (natural) mortality, cardiovascular mortality, and respiratory mortality in adults and children younger than five years old, using annual average $PM_{2.5}$ concentrations as the exposure indicator.

The calculation parameters inserted into the model include the concentration cut-off value (WHO Air Quality Guideline for $PM_{2.5}$ of 10 μg m-3), $PM_{2.5}$ mean concentration, health endpoint baseline incidence, and the relative risk (RR) (De Marco et al., 2018). For a health endpoint, the RR values, associated with an increase of 10 μg m-3 of the air pollutant concentration, are obtained from the published exposure-response relative risk functions and measure the probability of developing a disease relative to exposure Eq. (2):

$$RR = \exp.[\beta(X - X_0)] \tag{2}$$

where β is a parameter that regulates the rate of RR increment, X (μg m-3) is the measured air pollutant concentration, and X_0 (μg m-3) is the background concentration where no health effect is reported (Ostro, 2004). A relative risk of 1 indicates that there is no increase in risk. The health impact assessment results are presented as per 10 μg m-3 increase in $PM_{2.5}$ levels.

The number of deaths due to the air pollutant can be derived simply from the population at risk, the baseline mortality, and the attributable proportion (AP) calculated from RR (for more details on these calculations, we refer the reader to Burnett et al. (2014) and Ostro (2004). AP can be obtained through the following Eq. (3):

$$AP = \Sigma\{[RR(c) - 1] \times P(c)\} \div \Sigma\{RR(c) \times P(c)\} \tag{3}$$

where relative risk (RR) is the RR for a given health endpoint in category “c” of exposure, obtained from the exposure-response functions derived from epidemiological studies, and P(c) implies the proportion of the population in category “c” of exposure.

The calculation of AP using the AirQ+ model also requires the calculation of the Incidence Rate (IR) of each health-end mortality. Thus, we used age-specific population numbers to determine the age-specific mortality rate. The formula is as follows:

$$\text{Age} - \text{specific incidence rate} = \frac{\text{Age} - \text{specific number of deaths}}{\text{Age} - \text{specific population}} \times 100,000$$

This study used AirQ+ version 2.0 software to estimate the risk of cardiovascular and respiratory-related mortality among the adult age groups due to the long-term impact of $PM_{2.5}$ concentrations in Malaysia. The World Health Organization regional office developed the tool for Europe (Bonn office, Germany) to estimate the potential health effects of various pollutants, including $PM_{2.5}$, PM_{10}, NO_2, O_3, and black carbon. The AirQ+ model has been used in international studies to quantify environmental BOD (WHO Regional Office for Europe, 2019; Miri et al., 2017). The AirQ+ model estimates the AP of mortalities, the attributable excess incidence per 100,000, and the attributable excess cases. The attributable proportion generated from the AirQ+ model can provide helpful information on the health impacts of air pollutants on human exposure in a city or country.

3. Results and discussion

3.1. Baseline mortality and estimated particulate matter data

Table 1 shows the mid-year population census and the number of deaths due to all-natural causes, IHD, stroke, COPD, LC, and ALRI (0–4 years) for 2000, 2008, and 2013. There is an overall increment in the mid-year population census, all-natural causes of mortality, IHD, and stroke in 2000, 2008, and 2013. The numbers of COPD and LC mortalities in 2008 were the lowest compared to those in 2000 and 2013. A goodness-of-fit test was performed to determine if the baseline mortality data differed significantly between the three years (2000, 2008, and 2013). The chi-square test showed no significant differences in mortality cases between the three years ($\chi^2 = 0.199$, $df = 4$).

In Table 2, the estimated annual average PM_{10} for 2000, 2008, and 2013 was 47 μg m-3, 41 μg m-3, and 53 μg m-3, respectively. There was a drop in the estimated PWEL PM_{10} in 2008, leading to a lower estimated $PM_{2.5}$ compared to 2000 and 2013. Both 2000 and 2013 estimated PWEL PM_{10} is higher than the DOE ground station data for the particular year and was twice as high as the WHO Air Quality Guidelines (PM_{10} = 20 μg m-3). All estimated $PM_{2.5}$ concentrations for 2000, 2008, and 2013 exceeded the WHO Air Quality Guideline for $PM_{2.5}$ of 10 μg m-3 (WHO Regional Office for Europe, 2006).

A few factors might contribute to the discrepancy between the DOE data and our study results. First, the remote sensing data represent estimated air pollution in areas where continuous air quality monitoring (CAQM) stations are unavailable. Thus, our method may detect pollution sources producing much higher PM_{10} levels than the national annual PWEL PM_{10}. Second, it was found that the lower PM_{10} level was attributable to higher precipitation and economic slowdown during the 2008 period (Abdul Shakor et al., 2020; NOAA, 2009).

Table 1
National mid-year population census and national mortality cases for 2000, 2008 and 2013.

Year	2000	2008	2013
Mid-year population census	23,494,900	27,567,600	30,213,700
All-cause (natural) mortality[a]	93,232	118,539	128,008
IHD mortality	22,158	22,892	20,295
Stroke mortality	11,290	13,430	22,282
COPD mortality	3949	3156	9376
Lung cancer mortality	2154	2103	3696
ALRI (0-4 years old)	198	231	352

Pearson chi-square ($\chi 2$) = 0.199, df = 4.
[a] Excluding deaths due to accidents.

Table 2
Estimated annual average PM_{10} and $PM_{2.5}$ conversion for 2000, 2008 and 2013 (μg m^{-3}).

Year	2000	2008	2013
Estimated average PM_{10} - remote sensing	47	41	53
Average PM_{10} – Department of Environment (DOE)[a]	40	42	44
Population-weighted PM_{10} (PWEL PM_{10})	47	39	51
Conversion to estimated $PM_{2.5}$	22	18	24

[a] DOE, 2001; DOE, 2009: DOE, 2014.

In this study, we used the PM_{10} conversion factor of 0.47 for Malaysia based on WHO 2016 Ambient Air Pollution conversion factor to calculate the $PM_{2.5}$ as it was available in the AirQ+ version 2.0 software documentation. However, the WHO conversion factor was unavailable for Malaysia in previous AirQ+ software version documentation and had to rely on the regional Western Pacific Region or neighboring countries' conversion factor, which may not be accurate for the country (Ostro, 2004).

3.2. Spatial distribution of estimated PM_{10}

In our study, we adopted the PM_{10} model validation method using an artificial neural network (ANN) from Kamarul Zaman et al. (2017), resulting in R^2 correlation values of 0.6225 with a root mean square error (RMSE) of 14.10 μg m-3. The validation results were comparable to those of other studies (Sinha et al., 2015; Yap and Hashim, 2013: Gupta et al., 2006).

The spatial distributions of the estimated PM_{10} concentrations over Malaysia for 2000, 2008, and 2013 are shown in Fig. 2. Spatial mapping was performed by averaging the daily PM_{10} concentrations in each state. The spatial distribution in 2000, 2008, and 2013 was between 40–70 μg m-3, 0 to 50 μg m-3, and 90–130 μg m-3, respectively. Interestingly, spatial distribution analysis also managed to capture areas with higher or lower PM_{10} estimates than that particular year's annual average, such as areas around Perak and Selangor in 2000, central Peninsular Malaysia and remote parts of Sabah and Sarawak in 2008 and the middle and southern part of Peninsular Malaysia in 2013.

DOE average PM_{10} reports are based on 62 CAQM stations located in Malaysia's residential and industrial areas and open spaces. Each CAQM station represents the population's exposure to ambient air pollution within a 5 km radius (Usmani et al., 2020). As shown in Fig. 1, most CAQM stations are located in the west and southern states of Peninsular Malaysia (37 stations). In contrast, our remote sensing data map is represented by the 3261 pixels covering most of Peninsular Malaysia, Sabah, and Sarawak, including the CAQM station sites. Each of the processed remote sensing pixels in the map represents a 10 × 10 km square of atmospheric column captured by the NASA MODIS satellite. This data map could better represent the population exposure to ambient air pollution compared to when using CAQM stations alone. This study's findings differ from other authors, indicating a downward trend of $PM_{2.5}$ from 2000 to 2013. These differences can be explained by the data types and methods used to calculate average concentrations (Ritchie and Roser, 2022; Health Effects Institute, 2020). Our annual average estimate for PM_{10} was similar to the DOE trend, where 2013 recorded the highest concentration estimate compared to the 2000 and 2008 estimates (DOE, 2001; DOE, 2009: DOE, 2014).

3.3. Assessment of health endpoints using estimated PWEL $PM_{2.5}$

The estimated attributable proportion, premature mortality, and attributable cases per 100,000 people of all (natural) causes, COPD and LC, ALRI, IHD, and stroke cases due to estimated PWEL $PM_{2.5}$ exposure for 2000, 2008, and 2013 are shown in Table 3. The estimated proportion of attributable deaths of all-natural causes, COPD, ALRI, LC, IHD, and stroke, was higher in 2013 than the estimated attributable proportions for 2000 and 2008, demonstrating a potentially higher impact of increasing ambient air $PM_{2.5}$ exposure on patients with those diseases. Therefore, we estimated that 5893 to 9781 attributable deaths from all-natural deaths in the population could have been avoided if our estimated average $PM_{2.5}$ met the WHO AQG of 10 μg m-3 in those years. Similarly, it can be said for other health-end points.

Our proportion estimates for premature mortality due to $PM_{2.5}$ for the above trend were similar to some studies (Faridi et al., 2018; Miri et al., 2016; Brito et al., 2022; Ansari and Ehrampoush, 2019) but dissimilar to others (Hajizadeh et al., 2021; Goudarzi et al., 2017). The difference in weather conditions, such as the occurrence of dust storms in Middle East countries (Hadei et al., 2017b; Hadei et al., 2017a) or higher precipitation in tropical countries such as Malaysia, may contribute to the inconsistency of the attributable proportion from other studies.

We further divided the IHD and stroke health endpoints according to age groups using the available function in the AirQ+ software for better attributable proportions of mortality estimates for different age groups due to ambient air pollution (Table 4). Our study found that the proportion of premature deaths due to ambient air pollution in IHD and stroke was higher after the age of 45 years old. This higher proportion of premature deaths is not surprising, as the risk of death from other causes is higher as age progresses (Heron, 2021; Nowbar et al., 2019; Tas et al., 2013; Woloshin et al., 2008).

The limitation of our study was the simplified methodology to assess the health impact due to ambient air pollution using AirQ+ software. It did not consider calculating exposure to a combination of pollutants (WHO, 2022). The study also did not pinpoint the source of PM_{10}. The remote sensing data depend on the quality of satellite images, satellite image processing software, the algorithm to process it, and the atmospheric condition in a

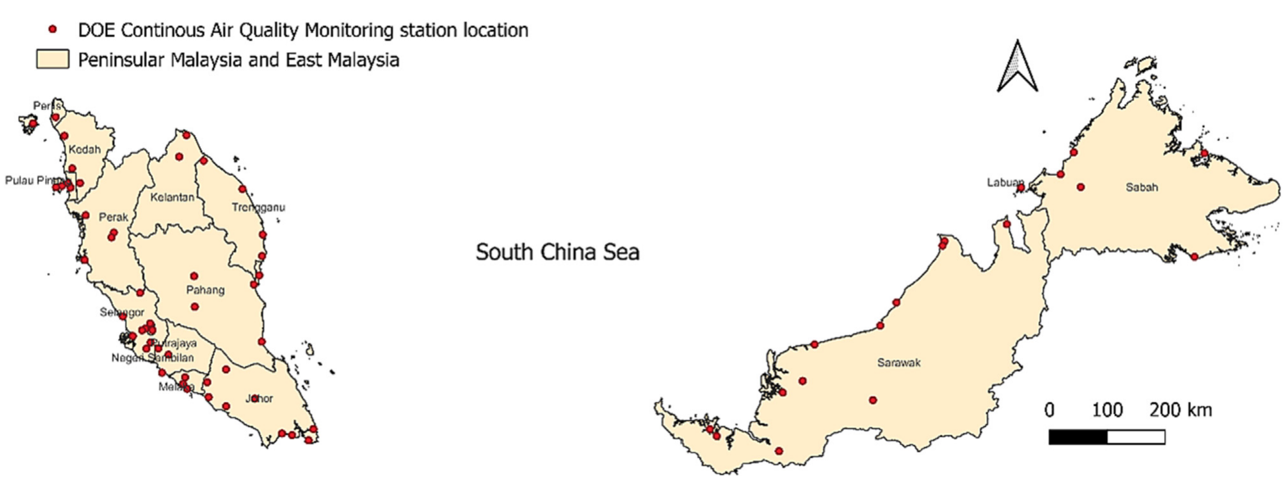

Fig. 1. Map of the states of Malaysia and the location of the Department of Environment continuous air quality monitoring stations.

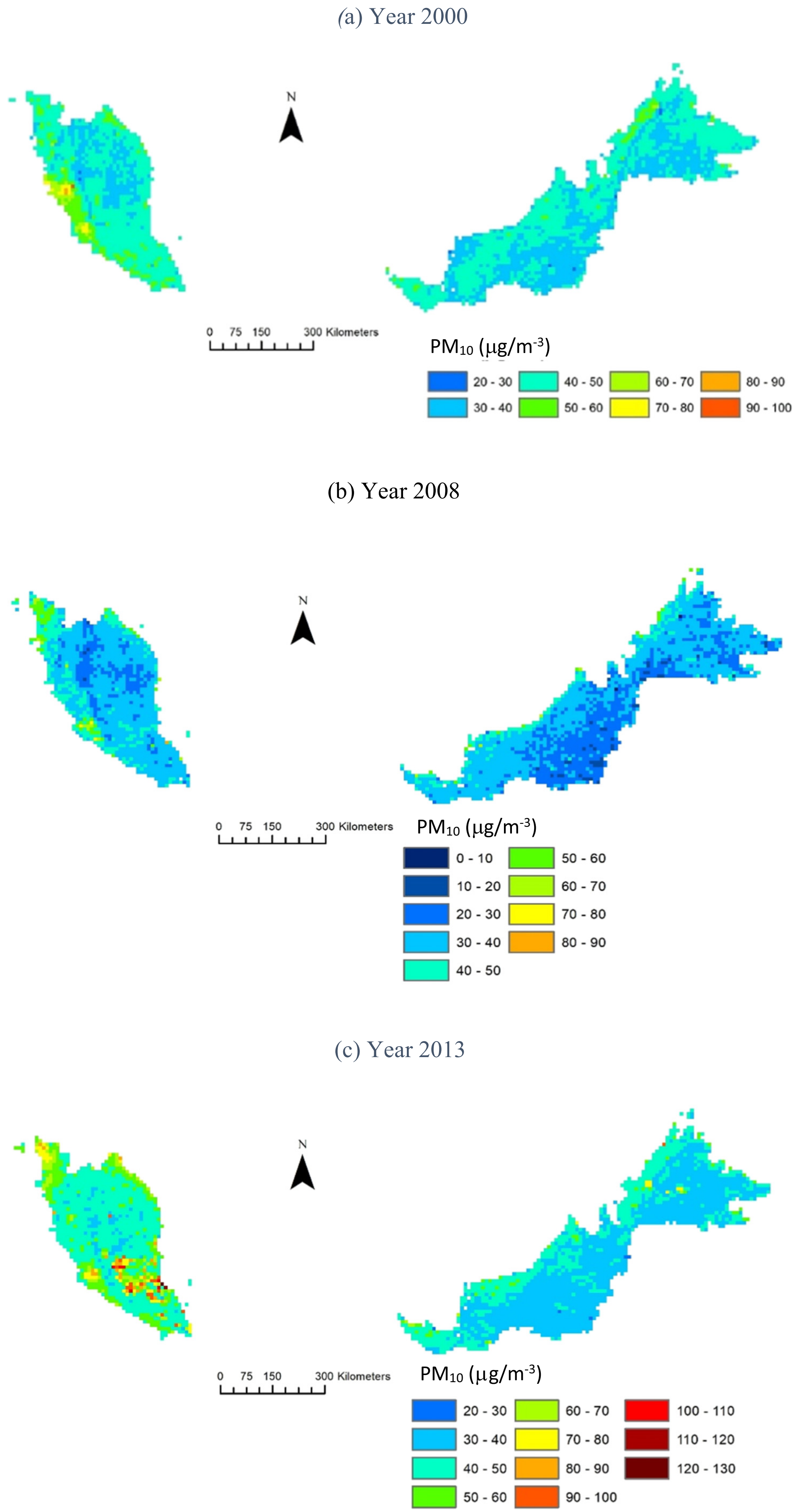

Fig. 2. Spatial distribution of the estimated PM_{10} over Malaysia using 10 × 10 km square resolution for the years (a) 2000, (b) 2008, and (c) 2013.

Table 3
Estimated attributable proportion, attributable mortality and attributable cases per 100,000 people in the year 2000, 2008 and 2013 due to $PM_{2.5}$ exposure for all-cause (natural), COPD, lung cancer, ALRI, IHD and stroke.

Year	2000			2008			2013		
Mortality	Estimated attributable proportion (percent)	Estimated attributable deaths	Estimated Attributable cases per 100,000 people	Estimated attributable proportion (percent)	Estimated attributable deaths	Estimated Attributable cases per 100,000 people	Estimated attributable proportion (percent)	Estimated attributable deaths	Estimated Attributable cases per 100,000 people
All-cause	6.96 (4.60–9.12)[a]	5893 (3890–7721)	64.4 (42.5–84.4)	4.70 (3.09–6.18)	5091 (3347–6696)	44.2 (29.1–58.1)	8.08 (5.34–10.56)	9781 (6470–12,791)	72.9 (48.2–95.4)
COPD	9.25 (5.32–13.82)	341 (196–510)	3.1 (1.8–4.6)	5.20 (3.03–7.61)	164 (95–239)	1.2 (0.7–1.7)	10.37 (6.04–15.29)	957 (558–1411)	5.8 (3.4–8.6)
Lung cancer	7.34 (4.37–10.55)	157 (94–226)	1.4 (0.8–2.0)	5.20 (3.03–7.61)	109 (63–159)	0.8 (0.5–1.1)	8.33 (5.01–11.85)	307 (185–437)	1.9 (1.1–2.7)
ALRI (0-4 years old)	10.75 (7.26–14.48)	21 (14–29)	0.8 (0.5–1.0)	7.71 (5.08–10.57)	18 (12–24)	0.7 (0.5–1.0)	12.13 (8.17–16.32)	43 (29–57)	1.7 (1.1–2.2)
IHD[b]	16.31 (10.81–20.45)	3615 (2395–4531)	32.7 (21.6–40.9)	11.2 (7.34–14.14)	2555 (1675–3228)	18.2 (11.9–23.0)	18.76 (12.49–23.42)	3788 (2522–4729)	23.0 (15.3–29.8)
Stroke[b]	11.77 (4.60–18.01)	1329 (519–2034)	12.0 (4.7–18.4)	8.01 (3.09–12.40)	1062 (410–1645)	7.6 (2.9–11.7)	13.59 (5.34–20.68)	2745 (1079–4096)	16.7 (6.6–25.4)

[a] Values in parentheses are lower and upper limits (95 % CI).
[b] RR from Chen and Hoek, 2020.

particular location to obtain the best retrieval of the AOD on the satellite path. Therefore, areas with less frequent cloud cover, such as the Middle East region, would have better satellite images and AOD retrievals, while tropical regions with frequent cloud cover might not (Mao et al., 2012; Ghotbi et al., 2016). The AirQ+ model selected to quantify the health endpoints associated with $PM_{2.5}$ exposure also has limitation such as the estimates generated by AirQ+ have some uncertainties, as they rely on information from concentration-response functions based on several assumptions and limited evidence for specific diseases (WHO, 2022).

In this study, we managed to estimate the health endpoints due to estimated $PM_{2.5}$ using Malaysian Burden of Disease and remote sensing data at the national level. Prior, no environmental burden of disease assessment was done in Malaysia using the national burden of disease datasets. We used the national burden of diseases mortality datasets for 2000, 2008, and 2013. However, mortality data at the state level were unavailable. Thus, we cannot compare the state-level health endpoints for those years in this study. Our next effort will be to estimate and predict the health endpoints using the mortality data at the state levels when available.

4. Conclusions

This study demonstrated an increased estimated health endpoint in 2013 associated with increased estimated ambient air $PM_{2.5}$ compared to the health endpoints of 2000 and 2008. The assessment also showed potential health benefits to the public in reducing estimated health endpoint mortality, as shown for 2008 compared to the 2013 $PM_{2.5}$ estimated level. Thus, implementing Malaysia Air Quality Standard IT-2 (DOE, 2020) for ambient air $PM_{2.5}$ level by the government in the near future can potentially reduce premature mortality, especially for COPD, IHD, and stroke cases in the Malaysian population.

Remote sensing data are a potentially feasible method to estimate population exposure to $PM_{2.5}$ at the national level, although they have some limitations. It can be used in areas where air quality sampling stations are unavailable. Our findings noted that meteorological factors and economic activity could influence particulate matter levels. Therefore, the use of remote sensing data as an additional tool in addition to the currently available air pollution data from CAQM to estimate the health impact of particulate matter on the Malaysian population at the national level should be considered by future researchers.

CRediT authorship contribution statement

Mohamad Iqbal Mazeli: Conceptualization, Project administration, Funding acquisition, Resources, Data curation, Formal analysis, Investigation, Methodology, Visualization, Writing – original draft. **Muhammad Alfatih Pahrol:** Formal analysis, Validation, Visualization, Writing – review & editing. **Ameerah Su'ad Abdul Shakor:** Formal analysis, Investigation, Validation, Visualization. **Kasturi Devi Kanniah:** Methodology, Writing – review & editing. **Mohd Azahadi Omar:** Data curation, Formal analysis, Methodology, Resources, Validation, Writing – review & editing.

Data availability

Data will be made available on request.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Table 4
Estimated attributable proportion, attributable mortality and attributable cases per 100,000 people according to age group in the year 2000, 2008 and 2013 due to $PM_{2.5}$ exposure for ischemic heart disease and stroke mortality.

Year		2000			2008			2013		
Mortality	Age group	Estimated attributable proportion (percent)	Estimated attributable deaths	Estimated Attributable cases per 100,000 people	Estimated attributable proportion (percent)	Estimated attributable deaths	Estimated Attributable cases per 100,000 people	Estimated attributable proportion (percent)	Estimated attributable deaths	Estimated Attributable cases per 100,000 people
Ischemic Heart Disease	25–29	10.96 (6.70–22.39)[a]	3(2–7)	0.2 (0.1–0.4)	8.27(4.92–17.04)	7(4–14)	0.3 (0.2–0.6)	12.12(7.48–24.61)	16(10–32)	0.5 (0.3–1.0)
	30–34	10.02(6.18–20.99)	32(20–67)	1.8 (1.1–3.7)	7.56(4.55–15.69)	24(14–49)	1.2 (0.7–2.4)	11.09(6.91–23.16)	24(15–50)	0.9 (0.6–2.0)
	35–39	9.26(5.52–18.29)	27(16–53)	1.6 (1.0–3.2)	6.98(4.07–13.86)	34(20–67)	1.8 (1.0–3.5)	10.25(6.19–20.30)	44(27–87)	2.2 (1.3–4.3)
	40–44	8.77(5.12–19.83)	22(13–50)	1.5 (0.9–3.5)	6.59(3.74–14.67)	33(19–73)	1.9 (1.1–4.2)	9.71(5.72–22.07)	71(42–161)	3.8 (2.2–8.6)
	45–49	8.02(4.89–17.37)	111(68–241)	9.2 (5.6–20.0)	6.03(3.59–12.93)	60(35–128)	3.9 (2.3–8.3)	8.88(5.48–19.19)	113(70–245)	6.7 (4.1–14.5)
	50–54	7.23(4.25–16.08)	73(43–163)	8.3 (4.9–18.6)	5.42(3.11–11.93)	93(54–206)	7.3 (4.2–16.1)	8.01(4.77–17.85)	152(91–339)	10.2 (6.0–22.6)
	55–59	6.54(4.02–14.11)	50(30–107)	7.5 (4.6–16.3)	4.90(2.96–10.41)	93(56–198)	9.4 (5.7–19.9)	7.25(4.48–15.72)	163(101–353)	13.4 (8.3–29.1)
	60–64	5.86(3.53–12.07)	162(98–333)	31.1 (18.8–64.2)	4.40(2.60–9.01)	124(73–255)	17.2 (10.1–35.2)	6.49(3.96–13.47)	154(94–318)	16.5 (10.1–34.3)
	65–69	5.22(3.28–10.94)	105(66–220)	27.7 (17.4–58.2)	3.91(2.38–7.98)	110(67–225)	21.8 (13.3–44.5)	5.78(3.67–12.25)	150(95–318)	22.7 (14.4–48.0)
	70–74	4.62(2.83–10.07)	181(111–394)	68.4 (41.8–149.0)	3.46(2.08–7.56)	112(67–244)	30.1 (18.0–65.6)	5.13(3.18–11.22)	125(78–274)	29.1 (18.0–63.6)
	75–79	3.97(2.63–8.69)	84(56–183)	58.7 (38.9–128.5)	2.97(1.94–6.43)	96(63–208)	44.0 (28.7–95.2)	4.40(2.94–9.61)	103(69–226)	35.6 (23.8–77.9)
	80–84	3.33(2.16–6.32)	104(67–196)	117.8 (76.2–223.3)	2.50(1.58–4.64)	70(44–131)	54.3 (34.3–100.9)	3.70(2.41–7.06)	70(46–134)	48.7 (31.8–93.0)
	85+	2.79(1.72–5.64)	58(36–117)	98.7 (60.8–199.4)	2.09(1.27–4.08)	40(24–78)	45.4 (27.6–88.7)	3.10(1.92–6.35)	50(31–103)	40.8 (25.3–83.6)
Stroke	25–29	10.96(6.70–22.39)	6(3–10)	0.3 (0.2–0.5)	6.84(3.31–10.68)	6(3–9)	0.2 (0.1–0.4)	10.27(5.20–15.84)	9(5–15)	0.3 (0.2–0.5)
	30–34	10.02(6.18–20.99)	17(9–26)	0.9 (0.5–1.4)	6.37(3.38–10.00)	10(6–16)	0.5 (0.3–0.8)	9.57(5.26–14.92)	18(10–28)	0.7 (0.4–1.1)
	35–39	9.26(5.52–18.29)	14(8–22)	0.9 (0.5–1.3)	6.04(3.21–9.27)	13(7–19)	0.7 (0.4–1.0)	9.08(4.98–14.03)	24(13–36)	1.2 (0.6–1.8)
	45–49	8.02(4.89–17.37)	50(29–82)	4.2 (2.4–6.8)	5.17(2.84–8.25)	22(12–36)	1.4 (0.8–2.3)	7.78(4.48–12.52)	61(35–98)	3.6 (2.1–5.8)
	50–54	7.23(4.25–16.08)	34(17–55)	3.8 (1.9–6.3)	4.72(2.32–7.72)	37(18–61)	2.9 (1.4–4.7)	10.27(5.20–15.84)	114(58–176)	7.6 (3.9–11.7)
	55–59	6.54(4.02–14.11)	23(13–37)	3.5 (1.9–5.6)	4.29(2.29–6.90)	40(21–64)	4.0 (2.1–6.4)	6.48(3.62–10.27)	108(60–171)	8.9 (5.0–14.1)
	60–64	5.86(3.53–12.07)	68(38–111)	13.1 (7.3–21.3)	3.83(2.04–6.06)	58(31–93)	8.1 (4.3–12.8)	5.76(3.25–9.45)	123(69–201)	13.2 (7.4–21.6)
	65–69	5.22(3.28–10.94)	46(23–75)	12.1 (6.1–19.9)	3.51(1.71–5.81)	57(28–94)	11.3 (5.5–18.6)	5.31(2.71–8.79)	135(69–223)	20.3 (10.4–33.6)
	70–74	4.62(2.83–10.07)	86(46–140)	32.7 (17.5–53.2)	3.09(1.61–4.98)	61(32–98)	16.3 (8.5–26.3)	4.67(2.53–7.67)	137(74–225)	31.8 (17.2–52.3)
	75–79	3.97(2.63–8.69)	40(22–67)	28.2 (15.6–46.9)	2.66(1.46–4.46)	53(29–88)	24.2 (13.3–40.6)	4.04(2.24–6.80)	155(86–261)	53.4 (29.6–89.9)
	80–84	3.33(2.16–6.32)	47(24–80)	53.0 (27.8–90.6)	2.29(1.17–3.91)	46(23–78)	35.2 (18.1–60.1)	3.47(1.83–5.98)	93(49–161)	64.6 (34.1–111.5)
	85+	2.79(1.72–5.64)	26(14–42)	43.9 (23.4–71.9)	1.90(0.99–3.09)	26(13–42)	29.2 (15.3–47.5)	2.88(1.54–4.76)	100(54–166)	81.6 (43.7–135.1)

[a] Values in parentheses are lower and upper limits (95 % CI).

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