Air Quality, Atmosphere and Health
https://doi.org/10.1007/s11869-020-00867-x

Air pollution and its health impacts in Malaysia: a review

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Received: 12 January 2020 / Accepted: 30 June 2020
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Abstract

Air pollution is strongly tied to climate change. Industrialization and fossil fuel combustion are the main contributors leading to climate change, also being significant sources of air pollution. Malaysia is a developing country with a focus on industrialization. The preference of using private cars is a common practice in Malaysia, resulting in the after-effects of haze and transboundary air pollution. Hence, air pollution has become a severe issue in Malaysia in recent times. Exposure to air pollutants such as ozone and airborne particles is associated with increases in hospital admissions and mortality. For the past few years, the focus of the research is moving towards air quality and the impacts of air pollution on health in Malaysia. In this study, we establish the definition of air pollution, the motivation to study it, and its impacts and sources of air pollution and climate change. We discuss the air quality monitoring system in Malaysia and compare Malaysian ambient air quality standards with global standards. We also look comprehensively on the health impacts of air pollution globally and in the Malaysian context. We discuss where the health impact studies in Malaysia are lacking and what are the gaps in the research. The role of the Malaysian government concerning air pollution and its impacts is discussed. Lastly, we look into the future work and research opportunities with a focus on engineering, estimation, predictive models and lack of research projects.

Keywords Air pollution · Health · Air quality · Haze · Climate change

Introduction

Air pollution is the driving force behind climate change, and it is considered to be one of the biggest environmental challenges faced by humanity in the twenty-first century (Matson 2001). The primary motivation behind air pollution studies is the health impacts involving air pollution. The air pollution has severe and harmful effect on health, and it has become a serious global threat to human health and welfare (Kampa and Castanas 2008). Ninety-two percent of the world's population breathes dirty air, and which has caused 6.5 million deaths worldwide (11.6% of all global deaths) (WHO 2016a). Numerous cardiovascular and respiratory diseases caused by air pollution contribute enormously to loss of life. Cardiovascular diseases (CVD) are the leading cause of deaths worldwide. As estimated, 17.9 million die due to CVD each year, which amounts to 31% of all deaths. Similarly, CVDs are the leading cause of death in Malaysia with a mortality rate of 35% (WHO 2016b). Air pollution and CVD are highly linked as 60–80% of air pollution–related deaths are due to CVD (WHO 2017).

Figure 1 shows the health effects of air pollution, especially ground-level ozone and fine particles in the form of a pyramid, highlighting the magnitude and severity of these effects. This pyramid is provided by the Benefits Mapping and Analysis Program (BenMAP) by the United States Environmental Protection Agency (EPA) (EPA 2020b). The "pyramid of effects" shows how pollutants are related to incidence and severity. At the bottom, asthma attacks and cardiac effects are less severe and affect a larger population. Towards the tip of the pyramid, heart attacks and hospital admissions are more severe and affect a smaller proportion of the population.

Another motivation for studying air pollution and its health impacts is the annual monetary value of health burden. Global examples of economic burden state that the

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Published online: 22 July 2020

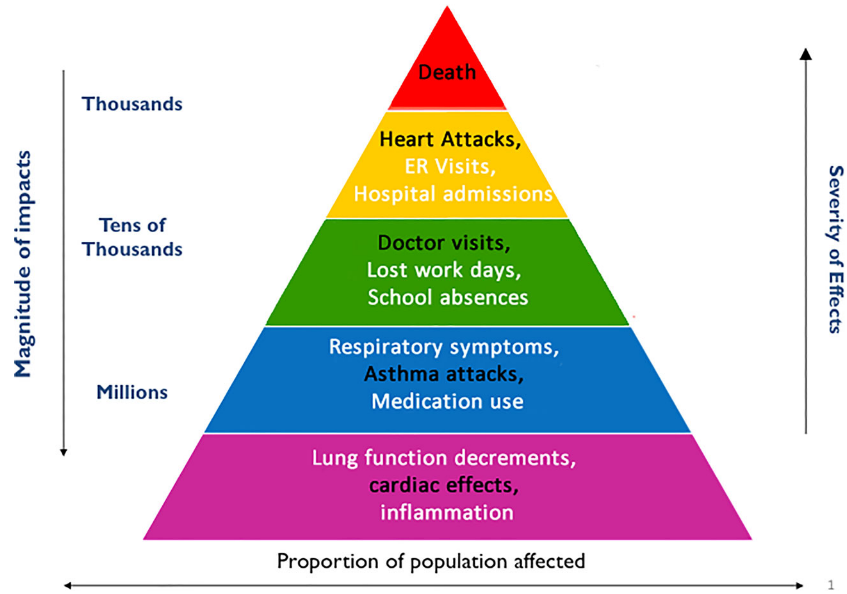


Fig. 1 A "Pyramid of Effects" from air pollution

annual monetary value of health burden was estimated over $8972 million for chronic exposure and $1057 million for acute exposure in Seoul, South Korea (Lee et al. 2011a), and in the United States of America over $60.1 million in New York and $1.1 million in Syracuse are spent on human health effects associated with PM yearly (Nowak et al. 2018). In the context of Malaysia, the national healthcare expenditure was around 4.6% of GDP in 2015 (Yorulmaz and Mohamed 2019) and the average annual economic loss due to the inpatient health impact of haze was valued at MYR273,000 ($65,934) (Othman et al. 2014). During the haze episodes of 2005, 2006, 2008 and 2009, the economic loss due to inpatient costs was $91,000 annually and $4789 for each haze day (Latif et al. 2018), and the total economic cost of the 2013 haze episode was estimated at MYR 1494.4 million (Shahwahid 2016). The average annual economic loss due to the inpatient health impact of haze was valued at MYR273,000 (Othman et al. 2014).

Vision/Wawasan 2020 was introduced by the Malaysian government in 1991 to achieve a self-sufficient industrialized nation by the year 2020. The commitment to achieve the Vision/Wawasan 2020, along with the rapid economic growth, has contributed to the degradation of the urban environment and air quality. Industrialization and haze episodes combined, air pollution is affecting the daily lives of people in Malaysia, Indonesia and Singapore (Latif et al. 2018). The air pollution in Malaysia is affecting ecosystems, forest species, agricultural crops (Ishii et al. 2004) and human health (Afroz et al. 2003). Tourism is known to contribute substantially to socioeconomic development and growth. Malaysia is ranked 25th in the world for tourism and is known for its rainforests, exotic beaches and multicultural influences. The impact of tourism on Malaysia's socioeconomic development and growth is achieved through the degradation of the environment and has an incremental effect on environmental pollution (Azam et al. 2018).

The goal of this study is to offer a review on air pollution and its health impacts in Malaysia. The most relevant related work appears in Afroz et al. (2003). However, our study differs from the previous papers by providing an updated and comprehensive investigation of the air pollution and its health impacts in Malaysia. The main contributions of this study include the investigation of climate change in Malaysia and comparison of air quality standard in Malaysia with the global standards, the comparison of air quality evaluation, prediction, spatial distribution, transboundary air pollution, and haze with the global trends of air pollution studies. A comprehensive comparison of health impacts of air pollution is presented that highlights the research gaps in this field. We also discuss the role of government in reducing air pollution and creating public awareness. The comprehensive future work is also presented at the end of the paper. Other related works include the impact of regional haze towards air quality in Malaysia (Latif et al. 2018) and also the impacts, management issues and future challenges of air pollution in Malaysia (Awang et al. 2000).

Sources of air pollution

Air pollution is a result of a complex mixture containing thousands of pollutants (Seinfeld and Pandis 2016). The mixture includes suspended liquid and solid particles, majorly comprising of particulate matter (PM), and several gases such as volatile organic compounds (VOCs), ozone (O_3), carbon monoxide (CO) and nitrogen oxides (NO_2).

This constitution of toxic particles and gases varies according to the sources of emissions and geographical locations (Li et al. 2019). The shape, size, number, chemical composition, surface area, toxicity and solubility are also variable and dependent on these factors. Many processes cause air pollution, such as fossil fuel combustion in automotives (airplanes, trucks, cars and other engines) and power plants, industries and household heating systems. This emission of chemicals and toxic gases react with the sunlight in ways that multiply the toxicity of the substance (Fig. 2).

Air pollution comes from mobile, stationary, area and natural sources. Mobile sources include buses, cars, planes and trains. The stationary sources include the oil refineries, power plants, industry and other types of factories. The area sources include the agricultural cities and wood burning. The natural sources include the dust (wind), wildfires and volcanoes (NPS 2020).

Climate change in Malaysia

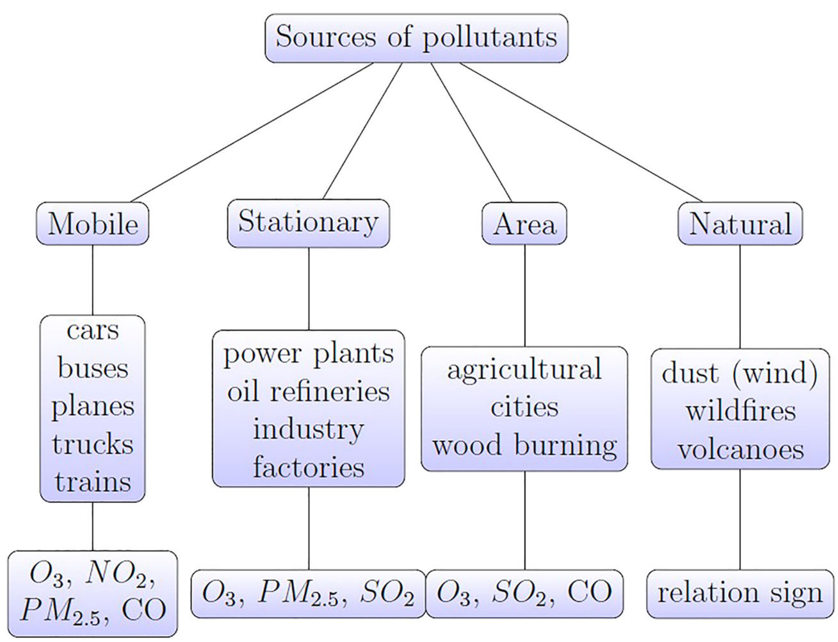
Climate change is a long-term alteration in Earth's climate system generated from human activities. Numerous activities cause climate change, such as air pollution, population growth and industrialization, that damage the Earth's atmosphere and aggregate the atmospheric composition (Mustafa et al. 2012). Another significant environmental issue that harms the environment is transboundary haze, and it is affecting Southeast Asia (SEA) since 1983. SEA is facing challenging natural disasters like tsunami and floods that are caused by climate change. In Malaysia, forest fire, air pollution from industrial activities, and motor vehicles result in changes in the atmosphere (Aghamohammadi and Isahak 2018). There is an increase in motor vehicles, and these motor vehicles emit over 75% of total emissions in Malaysia, which contribute to climate change (Mustafa et al. 2012; Brohi et al. 2018). Global warming is one of the effects of climate change, and the primary source of global warming is the production of greenhouse gases from industrial activities, burning and vehicular traffic.

Malaysia is exposed to the risk of global warming and its effects are seen in various ways (Ahmad and Hossain 2015). Studies also show variability in rainfall and rise in the average annual temperature, rise in the average sea level and extreme weather events (Tang 2019). Depending upon the greenhouse emissions in the twenty-first century, the average temperature in Malaysia can rise from 3 to 5 °C (Ahmad and Hossain 2015). Along with these effects, seven sectors are also vulnerable due to climate change, which are forestry, agriculture, biodiversity, coastal and marine resources, water resources, energy, and public health (Tang 2019).

Air quality monitoring in Malaysia

Malaysia is divided into three federal territories and thirteen states. The air quality monitoring in Malaysia was carried out through a private company known as Alam Sekitar Malaysia Sdn Bhd (ASMA) until 2017. ASMA was appointed by the DOE and the Malaysian Meteorological Department (METMalaysia), and it was responsible for collecting, processing, analysing and distributing air pollutant

Fig. 2 Sources of the pollutant



measurements. There are 66 air quality monitoring stations across Malaysia, 14 manual sampling (high volume sampler) stations were operated by METMalaysia, and ASMA operated 52 continuous air-quality monitoring (CAQM) stations (DOE 2013b). The DOE has increased the number of CAQM stations to 68 (DOE 2020a). The location-wise details of the CAQM stations are provided in Fig. 3.

Under the new Environmental Quality Monitoring Programme (EQMP), the DOE is closely monitoring the environmental parameters. The new system provided by private contractor Transwater gathers and stores real-time data on river, sea and air conditions. The monitoring stations under the new system have advanced measuring tools for calculating air pollutant index (API), and it can detect tiny particles of 2.5μm in diameter.

According to DOE, the CAQM stations are chosen based on the following parameters: (a) results of past and current monitoring, (b) representativeness, (c) accessibility, (d) whether support services like power and telephone line are available, (e) security and (f) effects of any specific topography (DOE 2020b). In the coming section, we talk about what is the Malaysian ambient air quality standard and compare its guidelines and standards from the United States of America (USA), WHO and European Union (EU).

API

Air pollutants have a severe and harmful effect on health. API is a number that determines the level of air quality within a region. The API in Malaysia is calculated using 6 major pollutants with 24-h running averages of PM_{10} and $PM_{2.5}$, 8-h running averages of CO and O_3 and 1-h running average of SO_2 and NO_2.

Table 1 shows the Malaysian ambient air quality standard (MAAQS). It includes the interim targets for 2015, 2018 and 2020. The API calculated using these standards are used in many studies in Malaysia. Table 5 shows a summary of air pollution-related studies in Malaysia. The last column of Table 5 highlights whether the study is using data provided by DOE or not.

Table 2 provides a comparison between the MAAQS and ambient air quality standards (AAQS) of the USA, WHO and EU. It is clear that the AAQS of the EU and WHO follow the same guidelines and targets. The MAAQS lags behind WHO and EU standards in $PM_{2.5}$ and PM_{10}, but it is the same as the USA for $PM_{2.5}$ 24 h and slightly higher for 1 year. The MAAQS is on par with other agencies in table for O_3, higher for SO_2 and NO_2. This comparison reveals that there is ample room for improvement in MAAQS in almost each air pollutant.

Air quality in Malaysia

In Malaysia, industrial expansion has turned the quality of air from healthy to worse. As a result of industrial growth, many harmful particles are introduced into the atmosphere. To address this issue, the Malaysian Department of the Environment (DOE) in 1989 has formulated air quality guidelines and, in 1993, introduced an air quality measuring index system which is called the Malaysian Air Quality Index (MAQI). Later on in 1996, for the sake of regional and global harmonization, a new system was adopted by the government know as air pollution index (API). API follows the pollutant standard index (PSI), which is used in the United States air monitoring system. PSI has improved

Fig. 3 Air quality monitoring stations in Malaysia

Table 1 Ambient air quality standard—Malaysia (DOE 2013a)

Air pollutant(s)	Averaging time	Ambient air quality standard		
		Interim target-1 (2015) $\mu g/m^3$	Interim target-2 (2018) $\mu g/m^3$	Standard (2020) $\mu g/m^3$
Nitrogen dioxide (NO_2)	1 h	320	300	280
	24 h	75	75	70
Sulphur dioxide (SO_2)	1 h	350	300	250
	24 h	105	90	80
*Carbon monoxide (CO)	1 h	35	35	30
	8 h	10	10	10
Ground-level ozone (O_3)	1 h	200	200	180
	8 h	120	120	100
Particulate matter $<$ 10 micron (PM_{10})	1 year	50	45	40
	24 h	150	120	100
Particulate matter $<$ 2.5 micron ($PM_{2.5}$)	1 year	35	25	15
	24 h	75	50	35

*mg/m^3

the old Malaysian air quality standard. In order to control the concentration of these air pollutants, the DOE has set target values for 2015, 2018 and 2020 which are provided in Table 1. In the coming sections, we will discuss various studies in the field of air quality in Malaysia and discuss how they relate to global studies.

Air quality evaluation

Air quality evaluation is a relatively older trend in Malaysia. The investigation of the concentration of PM_{10} in outdoor and indoor air pollution in industrial and residential areas in Selangor was done by Sulaiman et al. (2005). The study shows that the concentration of PM10 was found lower in outdoor pollution as compared with indoor air pollution. Furthermore, Sadullah et al. (2003) studied and investigated the concentrations of sulphur dioxide (SO_2) and carbon monoxide (CO) from vehicular traffic in the closed and opened area in Ipoh, Malaysia. The result indicates that the concentration of SO_2 and CO is lower in open than in closed areas. Additionally, a study was conducted on the variability of $PM_{2.5}$ in the industrial area in Klang Valley (Amil et al. 2016). The study concluded that the annual concentrations of $PM_{2.5}$ exceeded the guideline set by the

Table 2 Ambient air quality standard—Malaysia VS global

Air pollutant	Averaging time	Malaysia (DOE 2013a)	USA (EPA 2020a)	WHO (2005)	EU (UNION E 2006)
NO_2	1 h	280$\mu g/m^3$	100 ppb	200 $\mu g/m^3$	200 $\mu g/m^3$
	24 h	70 $\mu g/m^3$	–	–	–
	1 year	–	53 ppb	40 $\mu g/m^3$	40 $\mu g/m^3$
SO_2	1 h	250 $\mu g/m^3$	75 ppb	500 $\mu g/m^3$*	–
	24 h	80 $\mu g/m^3$	–	20 $\mu g/m^3$	–
CO	1 h	30 mg/m^3	35 ppm	–	–
	8 h	10 mg/m^3	9 ppm	–	–
O_3	1 h	180 $\mu g/m^3$	–	–	–
	8 h	100 $\mu g/m^3$	0.070 ppm	100 $\mu g/m^3$	100 $\mu g/m^3$
PM_{10}	1 year	40 $\mu g/m^3$	–	20 $\mu g/m^3$	20 $\mu g/m^3$
	24 h	100 $\mu g/m^3$	150 $\mu g/m^3$	50 $\mu g/m^3$	50 $\mu g/m^3$
$PM_{2.5}$	1 year	15 $\mu g/m^3$	12.0 $\mu g/m^3$	10 $\mu g/m^3$	10 $\mu g/m^3$
	24 h	35 $\mu g/m^3$	35 $\mu g/m^3$	25 $\mu g/m^3$	25 $\mu g/m^3$

*10-min mean

World Health Organization (WHO). Similarly, the study by Ahamad et al. (2019) investigates the issues with reducing ozone in three different locations in Klang Valley, Shah Alam, Cheras and Petaling Jaya. The result shows that the daily level of ozone was different at Shah Alam location than at Cheras and Petaling Jaya.

Moreover, Rahman et al. (2015) examine the trend of O_3, CO, PM_10 and NO_2 in Klang valley. The result shows that the hourly trend of pollutants was below and daily trends exceeded the standard given by Malaysian Ambient Air Quality Guidelines (MAAQG). The patterns of major pollutants were studied by Latif et al. (2014) in Malaysia. The result demonstrates that the yearly concentration of PM_10 exceeds the guideline standard given by WHO. Additionally, the time series model was proposed by Awang et al. (2013) to evaluate the level of O_3 in 2009 from Jerantul, Kajang, Seberang Perai and Bakar Arang stations in Malaysia. The study concludes that the level of ozone in Kajang and Seberang Perai exceeds the limited guideline provided by MAAQG, while at Kajang station, the ozone level was found the lowest.

Air quality evaluation is also important to understand the impacts of air pollution, most importantly for tourist destinations as they attract foreign revenue and have a major impact on economy of a country. A study is done for Langkawi island, which is one of the well-known tourist destinations of Malaysia (Halim et al. 2018). Statistical methods were used to analyse meteorological factors and air pollutants. Concentrations of all pollutants other than PM_{10} were found to be lower than WHO recommended levels. Tropical weather, vehicle emissions and biomass burning were considered as the primary influencers of yearly average concentrations of PM_{10}. In a similar study (Wui et al. 2018), the authors argued that air pollution studies in the past were focused on the west peninsular of Malaysia. The authors aimed to fill the said gap and provide variability statistics of PM_{10} concentrations of 5 sites in urban areas of Sabah, Malaysia. Daily and weekly cycle patterns of responses towards NO_2, CO, ozone and SO_2 variations were examined. The authors found that the rush hours are associated with peaks of PM_{10} levels and concentrations for weekdays have higher PM_{10}, CO and NO_2 in comparison with weekends.

The study by Mohtar et al. (2018) investigates the variability level of NO_2, O_3, SO_2, CO and PM_10 due to season variation in Klang, Cheras, Shah Alam and Petaling Jaya. The result reveals that the concentrations of pollutants differ due to local and regional factors at the locations. A research on exploring sources that contribute to PM_10 emissions in Malaysia during southwest monsoon was carried out by Fujii et al. (2017). The result shows that Indonesian peatland fires (IPF) were the major contributer of PM_10. They added that reducing IPF will improve air quality in Malaysia. The distribution of particle number concentration (PNC) and particle mass concentration in Bachok were investigated by Dominick et al. (2015). The study suggests that the variation of PNC was influenced by particle size and relative humidity, wind speed, pressure and temperature.

Another challenge for air pollution studies is that measuring air pollution requires devices for detecting air pollutants, and these devices are expensive. Due to this reason, Gunawan et al. (2018) applied Arduino Uno Controller and additional of four more cheap sensors to detect and measure the level of particulate matters ($PM_{2.5}$ and PM_{10}), ozone (O_3) and carbon monoxide (CO) in Malaysia. The detected pollutant was compared with existing monitoring stations' devices (continuous air quality monitoring stations) by the Department of Environment (DOE) Malaysia. The result shows that the system is reliable and efficient.

The air quality evaluation studies in Malaysia are following the global trend in this field, but there is still room for air quality evaluation–based studies like early warning systems (Xu et al. 2017), and evaluation of air quality standards (Chen et al. 2016).

Air quality prediction

Air quality prediction can help minimize the harmful effects of air pollution and can be used to give a heads-up to people in that area. A study was carried out by Afzali et al. (2017) to predict the concentration of nitrogen dioxide (NO_2), particulate matter (PM_{10}) and sulphur dioxide (SO_2) produced by 45 industrial points in Johor, Malaysia, using AERMOD model. Quantile plots (Q-Q plot) were applied to assess the performance of the predicted and observed pollutant. The result shows that the AERMOD model performed well. Koo et al. (2020) used various state-of-the-art methods, i.e. artificial neural network, ARMA and ARIMA, and several fuzzy time series models to predict the API of Kuala Lumpur. A brief but comprehensive comparative study found that Singh fuzzy time series model is the most efficient and accurate forecasting model. Similarly, Tan et al. (2016) predict the monthly concentration of ozone (O_3) in Malaysia using six years of data (2003–2008). A statistical method, multiple linear regression and principal component analysis were applied. The result shows good agreement between the predicted and observed pollutant.

There are very few studies done in Malaysia for air quality prediction in comparison with global air quality prediction trends. The researchers in Malaysia can opt for studies using machine learning (Kang et al. 2018), deep learning (Li et al. 2016) and time series models (Zhu and Lu 2016) for prediction of air quality and major air pollutants, which will help understand and plan for future in Malaysia.

Air quality and vehicle emissions

Air pollution in urban areas is mostly generated from vehicle emissions, and lack of interest in the public transport system has led to an increasing number of private cars in Malaysia (Brohi et al. 2018). The authors discussed the government's initiatives on public transport and smart cities. The authors concluded that inappropriate infrastructure, weather, and security are the significant barriers in Malaysia's move towards eco-friendly mobility practices. The air pollution index (API) is a general way to define the quality of air in Malaysia. API is calculated by using multiple air pollution data sets.

A study (Alyousifi et al. 2017) was conducted to describe the random patterns in API data. The authors used data from Klang city, Malaysia, for three years (2012–2014). Using a five-stage Markov chain, they portrayed five separate air pollution states. The study found out that the risk of unhealthy events is small but remains notably troubling. The increase of population and motor vehicles leads to heavy traffic congestions in an urban city; these motor vehicles produced air pollution into the atmosphere. A study was conducted by Ling et al. (2010) to investigate the relationship and trend of urban growth and air pollution level in Kuala Lumpur, Malaysia. The result shows a strong association between urban land uses and hazardous days in Kuala Lumpur.

There are very few studies done in Malaysia for vehicle emissions considering it is the major source of air pollution in urban areas. The global trend in vehicle emissions and air quality is monitoring on-road air quality and measuring vehicle emissions (Smit et al. 2019), ways to reduce vehicle emissions (Xiao et al. 2019) and evaluation of impact of policies and restrictions on vehicle emissions (Davis 2017).

Spatial distribution of air pollution

Urban commercial, industrial and settlement area development has contributed to increasing the atmospheric pollution risk. In order to control air pollution, it is important to understand the spatial distribution of air pollutants. The spatial distribution of major air pollutants, i.e. particulate matter, NO_2 and ozone are usually studied to understand the link between their concentrations and various parameters. There have been multitude of studies looking at spatial distribution of air pollution in Malaysia, and the studies in this section are following the global trend of spatial distribution studies (Chen et al. 2018).

A study (Sulaiman et al. 2017) was conducted to investigate the spatial distribution between ozone concentration and land use types. The authors used the remote sensing technique to extract land use types, and the GIS approach was used to show ozone concentrations. The results of the study showed that the Shah Alam area had exceeded the maximum allowable concentration of new Malaysian air quality standard. The authors concluded that the government of Malaysia should monitor and control the land use to make sure the ozone production does not exceed the regulation standards.

Another major air pollutant is particulate matter (PM). Particulate matter comes from transportation and temperature; wind speed can contribute to the particulate matter as well. A study (Zahid et al. 2018) was carried out in residential and educational areas in Shah Alam to determine PM levels. The results of the study showed that the particulate matters ($PM_{2.5}$ and PM_{10}) were below the Malaysian Ambient Air Quality Guidelines' acceptable levels. The authors concluded that there is a significant correlation between traveled particles and PM produced by traffic vehicles. Particulate matter (PM_{10}) levels are seasonally significant in urban areas of Malaysia, hence the valid concern for its impacts on human health. SENTIAN et al. (2018) analysed the temporal and spatial characteristics of PM_{10}. The series dataset used in the study came from 20 air quality monitoring stations across Malaysia. The authors found that the trend of decrease in concentrations of PM_{10} across 11 monitoring stations and seven monitoring stations showed no substantial trends. The authors argued that despite the decreasing concentration trend over a long period, small episodes of high concentrations related to transboundary pollution during events like El Niño need special attention to protect the wider population.

Furthermore, research on impact of meteorological condition on $PM_1 0$, $PM_2 .5$, CO_2 and CH_4 was conducted at Bachok Marine Research Station in two different locations in monsoon, Southwest and Northeast by Othman and Latif (2020). The result shows that the level of $PM_1 0$ and $PM_2 .5$ when offshore winds covered Bachok Marine Research Station area was found two times higher than the normal. Similarly, exploration of the variability of O_3, CO, SO_2 and NO_2 due to seasonal variation in southeast and northeast monsoon was conducted by Ahmad et al. (2018). The result indicates that there is a decrease in air pollution during the northeast monsoon season compared with the southeast. The spatial variation of the hourly concentration of ozone (O_3) in Klang Valley was investigated by Ahamad et al. (2014). The study shows that dispersion characteristics and local emission of pollutants were influenced by the exceedance of ozone.

Moreover, the influence of meteorological condition on NO_2 and $PM_1 0$ was investigated by Dominick et al.

(2012) in Shah Alam, Kuching and Johor Bahru. The result indicates that there is a significant association between wind speed and NO_2, while the negative association was found between wind speed, relative humidity and PM_10. An overview of the trend of air pollution was explored by (Makmom Abdullah et al. 2012) in Klang Valley. The result shows that Kuala Lumpur and Shah Alam were found with unhealthy air pollution throughout 2001–2009. Additionally, the variability of PM_10 in Klang valley in the monsoon season was investigated by Juneng et al. (2011). The result revealed that meteorological parameters influence the concentration of PM_10. The trend of air pollution in Nilai, Kajang and Banting stations was explored by Latif et al. (2011). The highest concentration was found at Kajang for NO_2 and O_3 pollutants. Similarly, the trend of air pollution in Klang valley was investigated (Azmi et al. 2010). The concentration of NO_2, CO and NO_2 was higher at Petaling Jaya station.

A study was conducted to identify the factors that contribute to air pollution and predict the concentration of the air pollution index in Malaysia (Isiyaka and Azid 2015). The study shows that bush burning, traffic emissions, constructions and industrial activities are the major sources of air pollution, and the developed predictive model performed well. Furthermore, an anomaly detection of PM_{10} and the factors that determine the anomalies of the pollutant were conducted by Shaadan et al. (2015) in Kuala Selangor, Petaling Jaya and Klang. The result indicates that the variation of wind speed, location, season, the background of the station, weekends, and weekdays contribute significantly to affecting PM_10 anomalies. In addition, the temporal and spatial variation of CO, SO_2, O_3 and NO_2 pollutants in three different monitoring stations in Malaysia was studied by Mutalib et al. (2013). The result demonstrates that motor vehicles and industrial activities are the major sources of air pollution.

Transboundary air pollution and haze episodes in Malaysia

Nightmare is that air pollution has no boundaries as toxic air can travel from one place to another with the wind current. One of the major example of transboundary air pollution in SEA is haze. Haze is known as a phenomenon where visible light is scattered in the atmosphere due to sufficient concentration of aerosols, reducing the visual range (Seinfeld and Pandis 1998). Haze formation is highly related to emissions of pollutants, gas-to-particle conversion and meteorological conditions (Sun et al. 2006; Watson 2002). Haze is composed of a higher concentration of PM_{10}, the metal Fe ions from the dry fallouts, and Zn from the wet fallouts (Norela et al. 2013).

The past few years have seen frequent episodes of haze in Malaysia, as shown in Table 3. These episodes have made the management of PM_{10} pollution a critical task for Malaysia. The authors Ng and Awang (2018) used air pollutants and meteorological parameters to do 1-day-ahead prediction of PM_{10} concentrations. The authors created three models, and their comparison revealed that PM_{10} concentrations could be explained by using humidity, wind speed, wind direction, carbon monoxide, temperature and ozone as main parameters. Episodes of haze are one of the significant concerns in Malaysia as they are one of the dangerous sources of air pollution and have a severe effect on human health. A study (Jaafar et al. 2018) was conducted to determine the composition of airborne agents during the $PM_{2.5}$ haze episode. The results showed that $PM_{2.5}$ concentration dropped due to rainfall and a decrease in temperature which is inline with the work done by Tai et al. 2010. The authors emphasized the need for attention on $PM_{2.5}$ as it has adverse effects on human health and pointed out the need for forecasting the emissions so it can be ensured that the emissions do not exceed proposed standards.

The effect of haze from the 2015 wildfire on air pollution and population exposure in Malaysia was studied by Mead et al. (2018). The result shows there is a significant effect of haze on air quality, and more than 60% of the population were exposed to hazardous air quality in Malaysia. The variability of ozone in Klang Valley was investigated (Latif et al. 2012). Low concentration was found from June to August, while the highest from January to April. A study by Dominick et al. (2012) examined the source and spatial variation of air pollution in Malaysia. The study shows that PM_10 was the major contributor to the differences in air pollution, and the highest concentration was found on CO.

Haze increases the toxicity of pollution, which causes deaths in severe cases. Table 4 shows the data collected for 2000–2007 of the rapid rise in the mean values for all the pollutants in the Klang Valley, but PM has increased three times, which is the higher value comparatively. However, on non-haze days, it was observed that values were from normal to low. There is also a need for the forecasting of haze and $PM_{2.5}$, so it can help understand the exceeded emissions and plan accordingly for future (Jaafar et al. 2018).

It is proven that the toxic wind current from one place to another also plays a major role in poor air quality (Sani 1988). In the study, the researcher did not include only Selangor as a focus area but also included other cities that were contributing to the pollution and raising the API (Mabahwi et al. 2018). Another study was performed to determine the API trend in Malaysia from 2010 to 2015. The analysis of air pollution in a study shows that due to haze episodes, the API level reached 663 on 23 June 2013 at Sekolah Menengah Teknik Muar in Johor, which is an

Table 3 Haze episodes in Malaysia

Period	Episode severity	Period	Episode severity
September 1982	Major (Schweithelm and Glover 1999; Sham 1984)	2010	Slight
April 1983	Major (Awang et al. 2000)	2011	Slight (DOE 2013c)
August 1990	Major (Awang et al. 2000)	2012	Slight (DOE 2013c)
June, October 1991	Major (Awang et al. 2000)	2013	Major (DOE 2013c)
1994	Major (Awang et al. 2000)	2014	Moderate (DOE 2013c)
1997	Major (Latif et al. 2018)	2015	Major (Latif et al. 2018)
2005	Major (Latif et al. 2018)	2019	Major
2006	Moderate (DOE 2013c)		

emergency level and has high risk on health (Rani et al. 2018).

Transboundary emissions are a big part of air pollution and haze episodes in Malaysia, whether in the form of peat fires blown from Indonesia or the air masses from Indo-China. Peat fires in Samatra affect the Peninsular Malaysia and Kalimantan, which mainly affects East Malaysia. As a result of this practice in 2005, a state of emergency was announced at Port Klang. The API for that time span was more than 500, which is an extreme level and hazardous for all living beings.

To study the transboundary air pollution, a study was conducted by Khan et al. (2019) in urban areas of Kuala Lumpur to evaluate the levels of particle number concentrations (PNCs) and inputs of PNCs (local and transboundary). The authors also evaluated the potential deposition rate of PNCs in the human respiratory system. Trajectory modeling was used to identify that PNC $100 < cm_3$ was influenced by air masses from the Indo-China region. Five potential parameters were extracted, i.e. transportation emissions, aged traffic emissions, industrial emissions, diverse sources and secondary origin source together with meteorological factors. The results found that CO, NO, NO_2 and SO_2 showed a positive and significant correlation to PNC, while O_3 was negatively correlated with PNC counts. The leading causes of air pollution are open burning, emissions from vehicles, and industry. A study (Ismail et al. 2017) was conducted to find out the necessary parameters of pollutants that are causing air quality problems. The authors also investigated the air quality patterns in Northern Malaysia using air quality data of 12 air monitoring stations. The results showed that due to transboundary pollution, 2005 and 2006 showed different patterns. Also, SO_2, NO_2 and O_3 were found to be significant contributors to air quality problems.

In Table 5, we present recent air pollution–related studies in Malaysia. The inclusion criteria were that the studies must be on air pollution in Malaysia, and they should be recent (2010–2020). The key results are presented in the table, as well as the information about the dataset. Most of the studies are using the air quality dataset provided by DOE.

Health impact of air pollution

Air pollution is one of the major causes of death every year. According to yearly mortality statistics by the World Health Organization (WHO), tobacco use causes 7 million deaths; AIDS causes 1.2 million deaths; tuberculosis causes 1.1 million deaths; and malaria causes 0.7 million deaths (WHO 2017). In the same year, there were 6.4 million deaths attributed to air pollution worldwide, with 4.2 million deaths due to ambient air pollution and 2.8 million

Table 4 Summary of the environmental data for haze and non-haze days in the Klang Valley during 2000–2007 (Sahani et al. 2014)

Parameters	All days		Haze days		Non-haze days	
	Mean	CV	Mean	CV	Mean	CV
$PM_{10} (\mu g/m^3)$	55.5	0.41	134.5	0.44	53.1	0.29
NO_2 (ppb)	21.0	0.21	26.8	0.14	20.8	0.21
SO_2 (ppb)	4.5	0.31	5.2	0.25	4.5	0.31
CO (ppm)	0.8	0.38	1.5	0.47	0.8	0.25
O_3 (ppb)	54.3	0.32	70.6	0.35	53.8	0.31

Table 5 Summary of air quality studies in Malaysia

Year	Key result(s) and recommendation(s)	Dataset	DOE data
2020 (Mohyeddin et al. 2020)	- CS1: Regional sources of pollutants originated from the central region of China and areas along coastal Vietnam influenced the monitoring site - CS2: Daily land–sea breeze event, strong diurnal effect and closely linked to the local source of pollutants from areas along the east coast of Peninsular Malaysia was associated	(CS1) 25–27 Jan. & (CS2) 3–5 Jun. 2016	✓
2020 (Koo et al. 2020)	- Singh fuzzy time series model outperformed Artificial Neural Network, ARIMA and TBATS for prediction of API	2012–2017	✓
2019 (Ahamad et al. 2019)	- Titration, wind profiles and land use are main challenges in ozone mitigation - Historical database on ozone and NOx distribution is insufficient - Internet of Things can help mitigate challenges in ozone mitigation	2014	✓
2018 (Halim et al. 2018)	- PM10 is the dominant air pollutant - meteorological variables were statistically significant in influencing the distribution of the air pollutants - Air quality was influenced by traffic emissions - Detailed emission source information is necessary involving land use studies and emissions inventories	1999–2011	✓
2018 (Wui et al. 2018)	- PM_{10} exhibited strong correlations with NO_2 and CO - PM_{10} levels show two peaks in morning and evening rush hours	2012	✓
2018 (Ahmad et al. 2018)	- CO, O_3, PM_{10}, NO_2 and wind speed are responsible for the variation in the two monsoon seasons - Motor vehicles, boat engines, aircraft, industrial activities, power plants and construction sites are the major factors contributing to the seasonal variation	1999–2011	✓
2018 (Zahid et al. 2018)	- AQI residential ¿ AQI educational - Significant correlation of PM2.5 with medium vehicles	-	×
- Educational area has correlation with all types of heavy, medium and small vehicles			
2018 (SENTIAN et al. 2018)	- High PM_{10} in Malaysia corresponded to the biomass burning in neighbouring countries - Small but significant decrease in trends of PM_{10} over long-term period	1997–2015	✓
2018 (Gunawan et al. 2018)	- Portable air quality measurement system using Arduino Uno and low-cost sensors proved to be reliable and efficient	-	×
2018 (Mead et al. 2018)	- 60% of population was exposed to unhealthy air quality conditions - 40% of the population was exposed to PM_{10} concentrations higher than $100 \mu g m^{-3}$	1st Sep.–30th Nov. 2015	✓
2018 (Mohtar et al. 2018)	- O_3 and PM_{10} frequently exceed MAAQS - PM_{10} associated with tropical biomass burning during southwest monsoon	2005–2015	✓

Table 5 (continued)

Year	Key result(s) and recommendation(s)	Dataset	DOE data
	- Main contributors of SO_2 are power stations and Shipping emissions		
2017 (Afzali et al. 2017)	- Weather Research and Forecasting model predictions have good agreement with observed values	2010	✓
	- Coupled model can consider different meteorological conditions and various distribution patterns of sources		
2017 (Alyousifi et al. 2017)	- Standard of air quality in Klang falls in healthy category	2012–2014	✓
	- Discrete-time Markov chain predicted small possibility of API over 100		
2017 (Sulaiman et al. 2017)	- Ozone in Klang valley is affected by seasonal variations and physical activity	2014	✓
	- Land use gives impact concentration of ozone		
	- Shah Alam has exceeded the maximum allowable concentration in MAQS		
2017 (Shafie and Mahmud 2017)	- 99% were very sensitive and were aware on traffic pollution and its effects	-	×
	- Support in public for incentive schemes for public transport use		
2017 (Fujii et al. 2017)	- 30% of $PM_{2.5}$ concentration was from Indonesian peatland fire	-	×
	- Reduction the Indonesian peatland fires burden would drastically improve the air quality		
2016 (Amil et al. 2016)	- Fine particles are very significant (triple (2.8-fold) the WHO annual guideline) in the ambient air of the Petaling Jaya	Aug. 2011–Jul. 2012	✓
	- Sources and Chemical constituents of $PM_{2.5}$ influenced by gaseous and meteorological parameters		
2016 (Tan et al. 2016)	- Good agreement between the monthly predicted and observed O_3 using multiple linear regression and principal component analysis	-	×
2015 (Isiyaka and Azid 2015)	- Discriminate analysis based on clusters developed by hierarchical agglomerative cluster analysis gave 87% accuracy PM_{10}, SO_2 and NO_2	2000–2004	✓
2015 (Shaadan et al. 2015)	- PM_{10} anomalies are affected by seasonal (monsoon), wind speed, location, background of station and weekend-weekdays variations	2005–2010	✓
2015 (Rahman et al. 2015)	- PM_{10} levels remain highly concentrated during the south-west monsoon	2007–2011	✓
	- Hourly trends of PM_{10}, NO_2, CO and O_3 were below MAAQG standard		
	- 24-h PM10 values were above MAAQG standard		
2015 (Dominick et al. 2015)	- Daily patterns of particles are influenced by local activities	-	×
	- Wind trajectory plays important role in the variability of particles		
	- Smaller size particles (PM_1 and particle diameters (0.27–0.43 μm)) influenced meteorological parameters		
2014 (Latif et al. 2014)	- The transport of air pollutants is influenced by wind direction	1997–2011	✓
	- Motor vehicle emissions contribute to diurnal variations of major air pollutants		

Table 5 (continued)

Year	Key result(s) and recommendation(s)	Dataset	DOE data
2014 (Azid et al. 2014a)	- CH_4, $NmHC$, THC, O_3 and PM_{10} are the most significant - PCA-ANN showed predictive ability with limited parameters	2005–2011	✓
2014 (Azid et al. 2014b)	- Artificial neural network provided better API prediction than multiple linear regression	2005–2007	✓
2014 (Ahamad et al. 2014)	- O_3 exceedance in Klang valley is strongly influenced by dispersion characteristics and local pollutant emission	2008–2010	✓
2013 (Mutalib et al. 2013)	- Spatial pattern recognition (S-ANN) shows better prediction and classification compared with discriminant analysis in discriminating between the regions	2000–2010	✓
2013 (Awang et al. 2013)	- Time series analysis was used to assess trend and status of ozone - Urban areas have high concentration of O_3 in comparison with industrial, sub urban and background areas	2009	✓
2012 (Dominick et al. 2012)	- NO_2 has a reverse relationship with wind speed - PM_{10} has positive relationship with ambient temperature but a negative relationship with relative humidity and wind speed	2007–2009	✓
2012 (Makmom Abdullah et al. 2012)	- 5% unhealthy days and severe acidified rain in places around Klang valley	2001–2009	✓
2012 (Latif et al. 2012)	- Wind direction influences O_3 during monsoon - 47% of the high O_3 days are associated with the localized circulation - 32% and 22% are associated with mid-range and long-range transport across the South China Sea from the northeast - Further investigation is required to confirm NMHCs influence on O_3	2004–2008	✓
2012 (Dominick et al. 2012)	PM_{10} is the main contributor to API - CO is major influencer in main air pollutant on high concentrations of PM_{10}	2008–2009	✓
2011 (Juneng et al. 2011)	- Surface air temperature, humidity and wind speed dominate the fluctuation of PM_{10} - Regression models provide better predictions with foreign hotspot counts and synoptic weather conditions	2003–2006 ✓	
2011 (Latif et al. 2011)	- Average concentrations of PM_{10}, SO_2, NO_2, O_3 and CO are below permissible level - NO_2 and O_3 show increasing long-term air quality trends	1996–2006	✓
2010 (Azmi et al. 2010)	- Traffic flow leads to high concentrations of PM_{10}, SO_2, NO_2 and CO - Ambient temperature and wind speed may influence the concentration of PM_{10}	1997–2006	✓
2010 (Ling et al. 2010)	- Significant relationship between # of unhealthy days and urban land uses	-	×

attributed to indoor air pollution. If not controlled aggressively, the projection of deaths from ambient air pollution in 2060 is 6–9 million. Additionally, ambient air pollution is categorized as an important risk factor for neurodegenerative diseases in adults and neurodevelopmental disorders in children (WHO 2017).

Various medical specialty reports have consistently highlighted a relation between particulate air pollution and not only the aggravation of cardiovascular and respiratory illnesses but also a drastically rising number of deaths among older people. These associations are reportedly unlikely to be elaborated by any confounder; they mainly represent cause and effect. However, the nature of the urban particulate cloud is where the explanation lies. It may contain up to 100,000-nm-sized particles per milliliter, in what may be a gravimetric concentration of only 100–200 $\mu g/m_3$ of pollutant (Seaton et al. 1995). It also suggests that such ultra-fine particles can provoke alveolar inflammation, with the release of mediators capable of causing aggravation of lung disease and increasing blood clots formation. This explains the increasing number of cardiovascular deaths associated with urban pollution.

Since sulphur dioxide has generally decreased in concentration globally (EPA USEPA 2020) and in Asia (Asia 2020), attention has shifted to ozone, nitrogen dioxide and particulates. From a global perspective, millions of people living in rural areas in developing countries consume biomass fuels in concentrations that are, by magnitude, higher than recently observed in developed countries. Over 2 million children die due to acute respiratory infections that are caused by these exposures (Moraga et al. 2017).

Eighty percent of premature deaths are due to stroke and coronary heart disease (CHD), also attributed to air pollution, making it the most common cause of premature death from air pollution in Europe (EU 2016). The mechanisms by which cardiovascular disease is caused by air pollution are observed to be identical to those causing respiratory disease.

Cardiovascular diseases account for 60–80% of air pollution–related deaths (Bourdrel et al. 2017). Hence, the contribution of air pollution to heart disease is presented in the 2016 report of air quality in Europe (Paper 2017). The report covered 41 European countries. The report indicates that air pollution caused 444,000 premature deaths from stroke and coronary heart disease. According to the 2013 figures, air pollution caused 416,000 premature deaths in the European Union (Paper 2017).

Table 6 presents a comprehensive comparison of health-related studies globally and in Malaysia. We looked into the major diseases and conditions that are linked with air pollution and the air pollutants that are associated with these diseases. We then compared the studies done in the Malaysian context and marked the combinations of diseases and pollutant, where there is a research gap. The comparison shows that although health impact studies are gaining popularity in Malaysia in recent years, there is still ample room to study various diseases and conditions with major air pollutants in Malaysia.

Health impact of air pollution in Malaysia

Malaysia is a developing country with a focus on industrialization and a huge trend to use private cars (Mohamad and Kiggundu 2007). Hence, air pollution has become a severe issue in Malaysia in recent times. For the last few years, the research focus is moving towards finding the impact of air pollution in Malaysia.

Studies have shown that air pollution has a significant effect on human health. For example, Qureshi et al. (2015) investigate the relationship between environmental indicators, air pollution and health in Malaysia using a two-stage least square regression method. The environmental indicators include urban population, combustible renewables and waste, nuclear energy and alternative, industry, and fossil fuel energy consumption while carbon dioxide (CO_2) used as an air pollutant. The study shows that environmental indicators and air pollution have substantial impact on direct and indirect Malaysian health services via life expectancy, fertility rate and infant mortality rate. Additionally, a study by Mabahwi et al. (2015) shows that air pollution has an impact on Selangor residents.

Furthermore, a study by Norbäck et al. suggests that air pollution significantly associated with headache, nasal and dermal system, rhinitis, and ocular among high school students in Johor Bahru, Malaysia (Norbäck et al. 2017). Similarly, a comparative study was conducted among 62 bus drivers and 62 administrative staff by Kavitha et al. (2011) to explore the association between PM, biomarkers and health impact among drivers in Klang Valley, Malaysia. The result shows that traffic emissions are the primary source of pulmonary inflammation among bus drivers, and the prevalence of phlegm and cough was found lower among administrative staff compared with bus drivers.

Indoor and outdoor air quality can significantly affect the health of school-going children. A study (Othman et al. 2019) was conducted in schools located in Kuala Lumpur City Centre, to determine the chemical dust compositions and $PM_{2.5}$ concentration. Higher health risks were found in outdoor dust exposure with a comparison with indoor dust exposure due to industry and traffic emissions. The authors also suggested that school activities are the major contributor to the indoor contributions of $PM_{2.5}$. The authors suggested that detailed investigations of indoor air quality and ventilation systems are needed in schools in major urban areas. In another study of 1952 schoolchildren, Abidin et al. (2014) investigated the effects of indoor and outdoor air pollution. The study used a questionnaire, including questions on asthma symptoms and other environmental risk factors. NO_2 and PM_{10} were found to be associated with a two-fold increase in asthma symptoms among the students. The sources that influence

Table 6 Air pollution (AP) and the adverse health effects

Disease/condition	Study	Trace metals	NO_X	NO	NO_2	CO	PM	PM_{10}	$PM_{2.5}$	BC	$Benzene$	O_3	SO_2
Cancer	Global	(Liu et al. 2014; Shi et al. 2011)			(Turner et al. 2019; Turner et al. 2017; Lavigne et al. 2017)				(Turner et al. 2019; Guo et al. 2016; Lavigne et al. 2017)		(Turner et al. 2017)		
	Malaysia	(Othman and Latif 2020; Othman et al. 2019)			×				×		×		
Acute exposure	Global						(Cho et al. 2009)		(Lee et al. 2011b)				
	Malaysia						×		×				
Asthma	Global	(Gent et al. 2009)	(Middleton et al. 2010)		(Perez et al. 2012; Deng et al. 2016)	(Middleton et al. 2010)	(Borrego et al. 2009)	(Alotaibi et al. 2019)			(Perez et al. 2012)		
	Malaysia	(Abidin et al. 2014)	×		×	×	×	×			×		
Asthma ER visits	Global										(Buchdahl et al. 2000; Thompson et al. 2001)	(Buchdahl et al. 2000; Thompson et al. 2001)	
	Malaysia										×	×	
Asthma hospitalizations	Global				(Lee et al. 2002)	(Lee et al. 2002)	(Lee et al. 2002; Lin et al. 2002)				(Lee et al. 2002)		(Lee et al. 2002)
	Malaysia				×	×	×				×		×
Birth outcomes	Global			(Brauer et al. 2008)	(Brauer et al. 2008)			(Brauer et al. 2008)	(Brauer et al. 2008)	(Brauer et al. 2008)			
	Malaysia			×	×			×	×	×			
Chronic exposure	Global								(Lee et al. 2011b)				
	Malaysia								×				
Cardiovascular	Global	(Bell et al. 2014; Kioumourtzoglou et al. 2014)		(Alexeeff et al. 2018)	(Dons et al. 2014; Alexeeff et al. 2018)	(Liu et al. 2018)	(Feng and Yang 2012)	(Meier-Girard et al. 2019)	(Rich et al. 2019; Ghosh et al. 2015; Lee et al. 2014)	(McCracken et al. 2010; Dons et al. 2014; Alexeeff et al. 2018)		(Devlin et al. 2012)	(Newell et al. 2018)
	Malaysia	×		×	(Tajudin et al. 2019)	×	×	×	×	×		(Tajudin et al. 2019)	(Tajudin et al. 2019)

Table 6 (continued)

Disease/condition	Study	Trace metals	NO_X	NO	NO_2	CO	PM	PM_{10}	$PM_{2.5}$	BC	$Benzene$	O_3	SO_2
Mortality	Global	(Watanabe et al. 2011)	(Johansson et al. 2017)	(Johansson et al. 2017)	(Johansson et al. 2017; Beelen et al. 2007; Cesaroni et al. 2012; Guerreiro et al. 2016)	(Liu et al. 2018)			(Kheirbek et al. 2016)	(Johansson et al. 2017)		(Guerreiro et al. 2016)	
	Malaysia	(Sahani et al. 2014)	×	×	×	×			×	×		×	
Oxidative stress	Global				(Dons et al. 2014)					(Dons et al. 2014)			
	Malaysia				×					×			
Blood pressure	Global								(Lamoureux et al. 2013)				
	Malaysia								×				
Breast cancer	Global				(Shekarrizfard et al. 2015)								
	Malaysia				×								
Prostate cancer	Global				(Shekarrizfard et al. 2015)								
	Malaysia				×								
Respiratory	Global	(Saini-Eidukat and Triplett 2014)			(Ribeiro et al. 2019; Beelen et al. 2007)		(Requia et al. 2016; Barnett et al. 2005; Wu et al. 2018)		(Buckeridge et al. 2002)		(McNabola et al. 2007)		
	Malaysia	(Kavitha et al. 2011)			×		×		×		×		

Table 6 (continued)

Disease/condition	Study	Trace metals	NO_X	NO	NO_2	CO	PM	PM_{10}	$PM_{2.5}$	BC	$Benzene$	O_3	SO_2
Respiratory hospital	Global	(Bell et al. 2014)			(Barnett et al. 2005)							(Luong et al. 2018)	(Goudarzi et al. 2016)
admissions	Malaysia	(Tajudin et al. 2019)			(Tajudin et al. 2019)							(Tajudin et al. 2019)	(Tajudin et al. 2019)
Cardiopulmonary	Global						(Cho et al. 2009)						
	Malaysia						×						
Morbidity	Global								(Kheirbek et al. 2016)				
	Malaysia								×				
Preeclampsia	Global		(Wu et al. 2009)						(Wu et al. 2009)				
	Malaysia		×						×				
Preterm birth	Global		(Wu et al. 2009)						(Wu et al. 2009)				
	Malaysia		×						×				
Pregnant women	Global								(Askariyeh et al. 2019)				
	Malaysia								×				
Premature death	Global		(Hou et al. 2016)										
	Malaysia		×										
Rhinitis	Global	(Ishii et al. 2004)		(Hwang et al. 2006)	(Burte et al. 2018)	(Deng et al. 2016)		(Hwang et al. 2006)			(Hwang et al. 2006)	(Hwang et al. 2006)	
	Malaysia	(Norbäck et al. 2017)		×	(Norbäck et al. 2017)	×		×			×	×	

the indoor and outdoor environments in an office were examined in an earlier study by Othman et al. (2016). The study found that the health assessment values were higher than the acceptable limit for both sampling stations, hence, indicating the potential health effects in this setting to indoor occupants.

Urbanization in Malaysia is increasing rapidly, and it poses risks to the health of residents. Daily hospitalizations due to cardiovascular and respiratory diseases and air pollutants data were used in the study (Tajudin et al. 2019) to estimate the relative risk (RR) of air pollutants in Kuala Lumpur. The authors observed that NO_2 and O_3 had immediate effects on cardiovascular hospitalizations, and SO_2 and NO_2 had a delayed effect on cardiovascular and respiratory hospitalizations. The authors argued that immediate and delayed hospitalizations could be caused by exposure to trace gases.

Exposure to air pollution has been linked to various respiratory diseases. Mabahwi et al. claimed that previous scholars had found a crucial link between air pollution and respiratory diseases. However, there is a lack of studies with regional context, i.e. Malaysia (Mabahwi et al. 2018). Air pollution index was used along with self-reported health data to find a correlation between respiratory diseases and air pollution. The researchers found out that acute respiratory infection (ARI) was not conclusively related to air quality.

In a 31-day study (Jie 2017), the author investigated the relation between air pollution and cardiovascular and respiratory mortality. The author conducted his study in Klang Valley, Malaysia, in August 2015. In the study, data of people who died in the hospital was collected, and Spearman's correlation was used to model the relationship of said data with air pollutant concentration data. The study found that PM_{10} exceeded the Malaysian Ambient Air Quality Guidelines (MAAQG) on different days. It was also found that the temperature also has a direct correlation with PM_{10} concentrations. The author concluded that the variability of PM_{10} was not found to be the reason of in-patient mortalities, and this outcome could be due to relatively low PM_{10} concentrations in air as well as limited influence area of haze episode in 2005.

The health impact of air pollution studies in Malaysia is following the global trend, but these studies are far behind in the various pollutants and diseases/conditions. The air pollution and health data is abundantly available in Malaysia due to efforts of DOE, Department of Statistics (DOS) and MOH. The DOE is providing the dataset for air pollution from its CAQM stations, MOH is providing dataset of hospitalizations and DOS is providing data on mortality in Malaysia. Hence, there is extensive opportunities for research in the field of air pollution and its health impacts.

Moreover, epidemiological studies usually use the location of residence to indicate the exposure to environmental agents. The dataset with residence location as an exposure indicator is easy to collect and monitor, and it applies to various studies (Tajudin et al. 2019; Mabahwi et al. 2018; Jie 2017). The utility, validity and accuracy of residence location as an exposure indicator are disputed due to concerns relating to aggregate exposures from mobile, non-point and point sources as well as multiple exposure pathways (Huang and Batterman 2000). There is a need for personal-level, site-specific, quantitative assessment of pollution exposures which are needed to cater to the risk of uncertainty by verifying the exposure levels among the different parts of the population. Researchers in Malaysia can follow the footsteps of various studies around the world which use on personal-level air pollution exposure (Glasgow et al. 2016; Gariazzo et al. 2016; Larkin and Hystad 2017).

In Table 7, we present the recent health impact of air pollution studies in Malaysia. The inclusion criteria were that the studies must be on the health impact of air pollution in Malaysia, and they should be recent (2010–2020). The key results are presented in the table, as well as the information about the diseases the studies focus on.

Role of government

Department of Environment (DOE) has played a significant role in keeping a record of the air and took necessary measures to create awareness among people about keeping the air clean. Along with DOE, the Ministry of Health (MOH) has played a vital role in raising awareness for air pollution and harms associated with it. MOH has mentioned on their website the measure required for haze days as well as the long-term exposure health risks associated with the pollutants. Long-term exposure in haze causes abortions, birth defects and infant death. This particulate matter thickens the arteries and causes heart diseases. However, the horrors haze brings are not only limited to these diseases.

DOE established the Clean Air Action Plan (CAAP) (2010–2020) in 2011. To improve the quality of air, the CAAP targeted five strategies, i.e. (1) motor vehicle emission control, (2) control forest and land fires to prevent haze pollution, (3) reduce emissions from industries, (4) build institutional capabilities and capacity, and (5) strengthen participation and awareness of public (DOE 2011).

DOE is using major pollutants to calculate the API. The API denotes the air quality and its risks. In order to overcome significant damage, DOE has planned policies for outdoor emissions. Along with MOH, the DOE is working on reducing air pollution and its impacts on the environment. The government plans to reduce air pollution concentrations in every interim. In order to achieve this

Table 7 Summary of health impact of air pollution studies in Malaysia

Study	Key findings	Diseases
2020 (Othman and Latif 2020)	- Road dust was vehicle emissions/traffic activity, and major source of bioaccessible fraction was soil dust - Low risk from non-carcinogenic and probable risk from carcinogenic elements, with higher health risks for children compared with adults	Hazard quotient and cancer risk
2019 (Tajudin et al. 2019)	- Immediate effect of NO_2 and O_3 found for cardiovascular hospitalizations - No immediate effect for respiratory hospitalizations - Delayed effect of SO_2 and No_2 found for cardiovascular and respiratory hospitalizations	Cardiovascular and respiratory hospitalizations
2019 (Othman et al. 2019)	- Hazard quotient (HQ) value for non-carcinogenic trace metals was < 1 - Cancer risk (CR) value for carcinogenic elements was below the acceptable limit No significant risk to school child health	Hazard quotient and cancer risk
2018 (Mabahwi et al. 2018)	- ARI incidence was not clearly related to the air quality - Significant relationship between exposure to air pollution and ARI incidence found 2/5 study areas	Acute respiratory infection (ARI)
2017 (Norbäck et al. 2017)	- Ocular and throat symptoms and fatigue can be a risk factor for school going children due to Xylene, benzaldehyde, formaldehyde and NO_2 - Benzene indoor and outdoor levels were often higher than the EU standard of 5 $\mu g/m^3$	Rhinitis, ocular, throat and dermal symptoms, headache and fatigue
2017 (Jie 2017)	- For 2005 haze episode, respiratory and cardiovascular mortality not attributed to the change in the concentration of PM_{10}	Cardiovascular and respiratory mortality
2017 (Koplitz et al. 2016)	- 100 300 excess deaths across Indonesia, Malaysia and Singapore in 2015 haze episode, more than double in comparison with 2006 haze episode - Proposed framework can rapidly identify areas where land use management would yield the greatest benefit to human health by reducing or avoiding fires	-
2016 (Othman et al. 2016)	- Hazard quotient value was slightly higher than acceptable limits - Excess life time carcinogenic risk (ELCR) value for both sampling stations was higher than the acceptable limit - PM_{10} can significantly affect the indoor air quality and occupant health	Lung and skin cancer
2015 (Qureshi et al. 2015)	- Environmental indicators and air pollution have a substantial impact on direct and indirect Malaysian health services via life expectancy, fertility rate and infant mortality rate	Malaysian health services
2015 (Mabahwi et al. 2015)	Majority of residents suffer ARI during haze episode in 2013	Respiratory
2014 (Abidin et al. 2014)	- Asthma and dry cough were significantly higher among urban schoolchildren - Secondhand smoke, mould and the presence of new furniture at home were also linked to asthma symptoms	Asthma
2014 (Sahani et al. 2014)	- Natural and respiratory mortality was significantly associated with haze episodes - Haze exposure showed immediate and delayed effects on mortality	Mortality

Table 7 (continued)

Study	Key findings	Diseases
2014 (Othman et al. 2014)	- Inpatient cases increased by 2.4 per 10,000 populations each year (31% increase from normal days) due to haze - Average annual economic loss is estimated at $91,000 USD	Inpatient cases
2011 (Kavitha et al. 2011)	- The bus drivers showed higher concentration of interleukin-6 and tumour necrosis factor and were at a higher risk of getting respiratory illnesses	Respiratory

target, the government has formulated many guidelines for vehicle emission, indoor air quality, and haze proactive steps. In the following sections, we will discuss the steps taken by the DOE to monitor air pollution and create awareness about its harms. In awareness, we will also discuss the public perception of the steps taken by the government of Malaysia.

Employees' protection guidelines against harmful effects of Haze

The Department of Occupational Safety and Health Malaysia has provided "Guidelines for the Protection of Employees against the Effects of Haze at Workplaces" (SAFETY DOO and MALAYSIA HD 2019). In this standard, the government has focused on the employer and emphasized taking appropriate measures during haze episodes in terms of safety and risk assessment for the employees. As the main element in the haze is PM_{10}, so the values for PM_{10} and precautionary measures to be taken accordingly for that number are also explained in this guideline (SAFETY DOO and MALAYSIA HD 2019).

Approved facility

The approved facility is a place where people can register their vehicles for carrying out smoke emission tests via a smoke meter and trained personnel at the facility conduct this test. This test is recognized by DOE. The DOE has introduced this step to enforce the environmental laws and regulations and take corrective actions for the vehicle to prevent emitting unnecessary smoke into the air. Moreover, the DOE has strictly prohibited open burning of any kind.

Awareness

The awareness of air pollution can also make a difference in its impacts on human society. A study on public awareness and perception of traffic emission in Kuala Lumpur, Malaysia, was conducted using questionnaires (Shafie and Mahmud 2017). The result indicated that 99% of the participants were aware of traffic air pollution and its impact on health. Additionally, the respondents suggested that vehicular traffic is the primary source of air pollution, yet Malaysia still has a culture of using private cars instead of public transport (Chin et al. 2019). Similarly, the majority of respondents in a study conducted by Chin et al. (2019) preferred environmental actions that do not involve individual effort and segments of the population, i.e. people with three or more cars in a household are willing to pay personally for environmental protection. This sentiment was also echoed by another study (Bazrbachi et al. 2017), which concluded that on average, a private passenger is willing to pay RM 4.99 (USD 1.55) per trip. The study also stated that people with previous health issues were found more likely to shift to public transport. In general, people are well aware of air pollution and its adverse effects on human health, and they have responded positively towards the air quality in Malaysia (Bazrbachi et al. 2017; Chin et al. 2019; De Pretto et al. 2015).

MOH and DOE usually release media statements and guidelines in real time for any air pollution and health-related phenomenon. The studies of the general perception of people towards air pollution and awareness suggest that the government's awareness programme is working adequately (Shafie and Mahmud 2017; Bazrbachi et al. 2017; Chin et al. 2019; De Pretto et al. 2015). Also, Malaysians are more concerned about waste management than maintaining air quality, and their strong environmental awareness level does not translate into better environmental behaviour (Mei et al. 2016). However, there is still an extensive range of issues due to the poor air quality, which are to be addressed. Using the values provided by API, scientists, researchers and other concerned authorities can come up with a strategy to solve issues related to pollution and make a concrete plan to control air pollution. A study to emphasize adding construction engineers in the air pollution awareness campaigns was done so that the construction companies should include preventive measures for pollution in their projects (Begum and Pereira 2008).

Future work

The governments around the world are investing in monitoring stations, but as discussed in the section (3), Malaysia has 66 air quality monitoring stations. Traffic is the primary cause of air pollution, but these air quality monitoring stations are mostly based in schools. Hence, they cannot capture the major risk areas where the air pollution level is high. Picking an optimum location for the air quality monitoring stations can help future studies. The future work for air pollution and its health impacts include engineering, predictive models, and lack of research projects.

Engineering

The price of portable outdoor air quality sensors varies from 1000$ to 5000$. There has been some advancement in reducing the price of air quality sensors. However, reliable air quality sensors that can measure meteorological data and all major pollutants, i.e. PM_{10}, $PM_{2.5}$, NO_2, NO, O_3, SO_2 and CO, are still out of reach for general public and researchers. Some work in this regard has already been presented (Gunawan et al. 2018), but the high air quality sensor prices present the opportunity of research and development in the field of engineering and computer science, especially using the Internet of Things (Azlan and Azrul 2019).

Estimation and predictive models

Air quality prediction can help minimize the harmful effects of air pollution and can be used to give a heads-up to people in that area. The problem of expensive air quality sensors and lack of monitoring stations leads us to a significant research opportunity in land-use regression (LUR) models. LUR models are used to estimate pollution (Larkin et al. 2017; Lee et al. 2017) and the air pollution exposure (Beelen et al. 2013). The LUR models estimate air pollutant concentrations using predictable pollution patterns. Malaysia lacks data for road and industrial emissions, which can be estimated by using LUR models (Liu et al. 2019). In Addition to LUR, a dispersion model (DM) is also used for the assessment of long-term air pollution. The combination of DM and LUR also presents the potential for improving estimates of air pollution (Korek et al. 2017). The data generated by air monitoring stations, air quality sensors and LUR models are in the form of time series. Hence, the availability of these time series datasets opens up the avenue to research and development of time series models for air pollution and its health impacts in Malaysia, as done globally (Yin et al. 2017; Nhung et al. 2018; Arroyo et al. 2019). These time series models are robust and give high accuracy in their prediction.

Machine learning is used nowadays for prediction in various fields with high precision (Pham et al. 2018; Jones et al. 2016). There has been some work in air quality prediction in Malaysia (Azid et al. 2014a; Azid et al. 2013), but it can be extended, and the accuracy can be improved upon as it has globally (Cabaneros et al. 2019; Ma et al. 2019). There is also very little research on the prediction of the health impact of air pollution. Time series models and machine learning algorithms, i.e. K-nearest neighbors algorithm (KNN), decision trees, neural networks, among others, can be highly successful in modeling and predicting the health impact of air pollution.

Lack of research projects

Malaysia also needs to work on highly successful projects to quantify the health impacts of air pollution and reduce uncertainty surrounding the health impacts of air pollution in Malaysia. Projects like the European Study of Cohorts for Air Pollution Effects (ESCAPE) (Beelen et al. 2014), TRANSPHORM (Wang et al. 2014), "Study of Cohorts for Air Pollution Effects" (Gruzieva et al. 2014) and "Health risks of air pollution in Europe" (HRAPIE) (Henschel and Chan 2013) provide an excellent template to follow in a Malaysian context. These projects have estimated air pollution and its impact on human health as well as a climate with high precision and helped raise awareness in public and government on how to handle this challenge. These environmental centric projects are facilitated by pollution abatement financing (Lovei 1995; EPA 2001). The focus of these projects includes cardiovascular and respiratory diseases in adults, pregnancy outcome and birth cohort studies, and cancer incidence and mortality.

Conclusion

Air pollution has become a significant problem in Malaysia due to industrialization, a huge trend of using private cars, and haze episodes. The primary motivation to study air pollution and its health impacts is the loss of health as the exposure to air pollutants such as ozone and airborne particles is associated with increases in hospital admissions and mortality. The other motivations include the monetary burden of health burden, impact on ecosystems, forest species, and agricultural crops.

The current study looked into the air quality standard and monitoring in Malaysia and how it compares with the global standards. We looked into air pollution–related studies in Malaysia and compared them with the global trends in the fields of air quality evaluation, prediction, vehicle emissions, spatial distribution of air pollutants and the important issue of haze and transboundary air pollution.

The health impacts of air pollution are discussed and compared with global studies. The comparison showed that studies in Malaysia are far behind the global trends. various associations of air pollutants and diseases remain a research gap in Malaysia.

We looked into the steps taken by the government in reducing air pollution and creating public awareness. The studies showed that the general perception of public towards air quality is positive. The public prefers actions that do not require individual effort and are willing to pay for environmental protection, but are not prone to using public transport. In the end, we discussed major future research opportunities in the fields of engineering, estimation and prediction models, and lack of research projects.

Funding information This research is funded by Taylor's University under the research grant application ID (TUFR/2017/004/04) entitled as "Modeling and Visualization of Air-Pollution and its Impacts on Health".

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