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REVIEW ARTICLE

Haze and health impacts in ASEAN countries: a systematic review

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Abstract

Seasonal haze episodes and the associated inimical health impacts have become a regular crisis among the ASEAN countries. Even though many emerging experimental and epidemiological studies have documented the plausible health effects of the predominating toxic pollutants of haze, the consistency among the reported findings by these studies is poorly understood. By addressing such gap, this review aimed to critically highlight the evidence of physical and psychological health impacts of haze from the available literature in ASEAN countries. Systematic literature survey from six electronic databases across the environmental and medical disciplines was performed, and 20 peer-reviewed studies out of 384 retrieved articles were selected. The evidence pertaining to the health impacts of haze based on field survey, laboratory tests, modelling and time-series analysis were extracted for expert judgement. In specific, no generalization can be made on the reported physical symptoms as no specific symptoms recorded in all the reviewed studies except for throat discomfort. Consistent evidence was found for the increase in respiratory morbidity, especially for asthma, whilst the children and the elderly are deemed to be the vulnerable groups of the haze-induced respiratory ailments. A consensual conclusion on the association between the cardiovascular morbidity and haze is unfeasible as the available studies are scanty and geographically limited albeit of some reported increased cases. A number of modelling and simulation studies demonstrated elevating respiratory mortality rates due to seasonal haze exposures over the years. Besides, evidence on cancer risk is inconsistent where industrial and vehicular emissions are also expected to play more notable roles than mere haze exposure. There are insufficient regional studies to examine the association between the mental health and haze. Limited toxicological studies in ASEAN countries often impede a comprehensive understanding of the biological mechanism of haze-induced toxic pollutants on human physiology. Therefore, the lack of consistent evidence among the reported haze-induced health effects as highlighted in this review calls for more intensive longitudinal and toxicological studies with greater statistical power to disseminate more reliable and congruent findings to empower the institutional health planning among the ASEAN countries.

Keywords Air pollution · ASEAN · Biomass burning · Forest fire · Haze · Health impact

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Introduction

The Association of Southeast Asian Nations (ASEAN), which is formed in 1967, is a political alliance among ten Southeast Asian countries including Malaysia, Singapore, Thailand, Brunei, Indonesia, the Philippines, Myanmar, Laos, Vietnam and Cambodia to work on a common interest in a broad variety of fields, including science and technology, to accelerate social and environmental sustainability in the region (Nesadurai 2008). Seasonal biomass burning-induced haze episodes in this region has drawn much international attention in view of the growing threat to the regional air quality and

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public health (Betha et al. 2014; Ho et al. 2014; Sastry 2002). Large quantities of airborne particulate matter with unique chemical composition from the smoke emissions are transported by prevailing transboundary winds and subsequently transformed into recurrent regional haze episodes that plagued many parts of the ASEAN countries (Ho et al. 2014; Marlier et al. 2015; Odihi 2001; Reddington et al. 2014; Van der Werf et al. 2008; Wang et al. 2004). The resulting thick haze usually engulfs at least six of the ten ASEAN countries such as Indonesia, Malaysia, Brunei, Thailand, Singapore and the Philippines (Ho et al. 2014). The severity and prevalence of such transboundary haze are often intensified during very dry weather conditions associated with El Nino-Southern Oscillation (ENSO) phenomenon and positive Indian Ocean Dipole (pIOD) conditions (Anaman and Ibrahim 2003; Koplitz et al. 2016; Sastry 2002). Hence, such disastrous seasonal haze episodes accentuated a concerted inter-regional concern in view of the elevating social and economic cost of public and environmental health among the ASEAN countries. One of such prominent mitigation measures is the ratification of the ASEAN Agreement on Transboundary Haze pollution (AATHP) by all the ASEAN member countries with Indonesia being the last country to deposit the ratification documents in 2015 (Sunchindah 2015). Studies have proved that about 90% of soot exuded from biomass burning is lower than 2.5 μm in size and have a high probability of penetration deep into the lower respiratory tract (Pavagadhi et al. 2013; Ward 1990). In certain studies, prolonged exposure of $PM_{2.5}$, which is defined as minute particles less than or equal to 2.5 μm in aerodynamic diameter, is reckoned to increase the risk of developing lung cancers (Abba et al. 2012; Betha et al. 2013; Khan et al. 2016). However, very few studies have investigated the long-term chronic effects of episodic haze exposure, even though many people of ASEAN nation are regularly exposed for extended periods (Johnston et al. 2012; Reid et al. 2016). Short-term, but high level of exposures, often leads to acute fatal effects such as increased fatalities and asthma attacks whereas long-term mild exposures result in chronic effects such as cancer that can be only detected after an extended period of time. Therefore, such limited information on the type, prevalence and severity of health impacts often hinders the effectiveness of the institutional planning to upgrade the public health status during severe haze episodes. This situation can only be compensated with long-term prospective or surveillance studies which are deemed to be expensive and labour intensive.

Meanwhile, contemporary studies apt to be retrospective where the researchers are mainly utilizing inadequately available administrative health records from various institutions for further interpretation. As a result, a reliable and rigid conclusion on the adverse health impacts and their association with haze is often unattainable. To the current knowledge of the authors, there are very limited numbers of studies directly evaluating the public health impacts of transboundary haze in ASEAN region despite a growing mutual concern of enhancing the regional community health care. However, a proper understanding and synthesis of the existing knowledge on the health impacts of transboundary haze is required to serve as a baseline data to guide the future public health responses effectively. Besides, such understanding is also indispensable to articulate extensive epidemiological studies with new methods revealing associations that were previously indiscernible. A recently published review paper by Reid et al. (2016) has documented various health impacts of wildfire smoke exposure from the available literature without any geographical restrictions. This paper reported a consistent association for both respiratory morbidity and mortality during haze episodes. In Reid et al.'s study, the discussion consists only 9.43% of studies published for ASEAN region from the total number of 53 studies included in that review. Hence, the aforementioned review is inconclusive for the potential haze-induced morbidity for these developing countries and more research is needed for more efficient future public health planning. With such consideration, this study aimed to review the plausible health impacts of the biomass burning-induced seasonal haze exposures, their prevalence and significance among different ASEAN countries from the available literature.

Methodology

A literature search was conducted from March to April 2017 using six electronic databases across the environmental and medical disciplines such as Web of Science, Science Direct, Scopus, PubMed and the World Health Organization (WHO) publication databases such as WHOLIS and WHO IMSEAR to obtain research evidences on the health impacts of haze in ASEAN countries. A Boolean search using a combination of keywords including 'haze', 'forest fire', 'biomass burning', 'health impacts', 'public health' and 'ASEAN' was conducted without any restrictions on time period to retrieve peer-reviewed original research articles from each of the databases. All types of quantitative studies that empirically assessed the relationship between the haze phenomenon and public health impacts were eligible for inclusion in this review. However, the literature search was limited to research articles published in English, available in open source and also retrievable in full-text format. Unpublished articles were not considered in this review.

The search strategy yielded a total of 384 articles from Web of Science ($N = 158$), Science Direct ($N = 52$), Scopus ($N = 87$), PubMed ($N = 42$) and another 45 additional articles from WHO databases. The total number of 384 retrieved articles also includes studies published outside of the ASEAN region, irrelevant studies and duplicates which were screened and

removed in few stages as shown in Fig. 1. Finally, about 21 original articles were identified for a full-text review after discarding the duplicates, irrelevant articles and those that assessed only the exposure without any association with the health through title and abstract screening. Ten articles comprising of review papers, case reports, general lecture, editorials and articles with no proper statistical analyses were excluded from this list after the full-text review. References and citations of the finalized eligible articles were checked and nine articles were added to ensure the inclusion of all the relevant articles in this review. From the remaining original articles ($N = 20$), the information pertaining to the health impacts of haze in ASEAN countries were extracted for expert judgement. All the studies included in this review were published between the years 1995 and 2017. Article selection and information extraction from each study was conducted by two independent reviewers. The flow chart of paper selection is illustrated in Fig. 1.

Results

The extensive search strategy yielded 20 eligible studies out of 384 retrieved articles which are mainly conducted in five ASEAN countries (Singapore, Malaysia, Indonesia, Brunei and Thailand) with Singapore having the highest number of health related studies on haze as presented in Fig. 2. No epidemiological studies evaluating the health impacts of haze were obtained from the rest of the countries such as the Philippines, Vietnam, Myanmar, Cambodia and Laos.

The selected studies varied by study location, study time frame, study sample, assessment approach, types and level of exposure, adjustment for confounding factors and the type of health outcomes as provided in Table 1.

All the reviewed studies were published between the years 1995 and 2017. Out of these, eight studies used a comparative analysis on the prevalence of different types of health impacts before, during and after the exposure (Betha et al. 2014; Frankenberg et al. 2005; Hashim et al. 1998; Mott et al. 2005; Odihi 2001; Pongpiachan et al. 2015; Sulong et al. 2017; Tan et al. 2000). Three studies utilized time-series analysis to investigate the associations between annual variations of PM_{10} levels during haze episodes and mortality among the vulnerable populations (Marlier et al., 2013; Sahani et al. 2014; Sastry 2002). Two studies modelled the hospitalization data to elucidate the respiratory responses among the vulnerable populations during the haze episodes (Anaman and Ibrahim 2003; Chew et al. 1995). One study compared the emission sources of haze episode and the number of mortality in the equatorial Asia between two events of similar

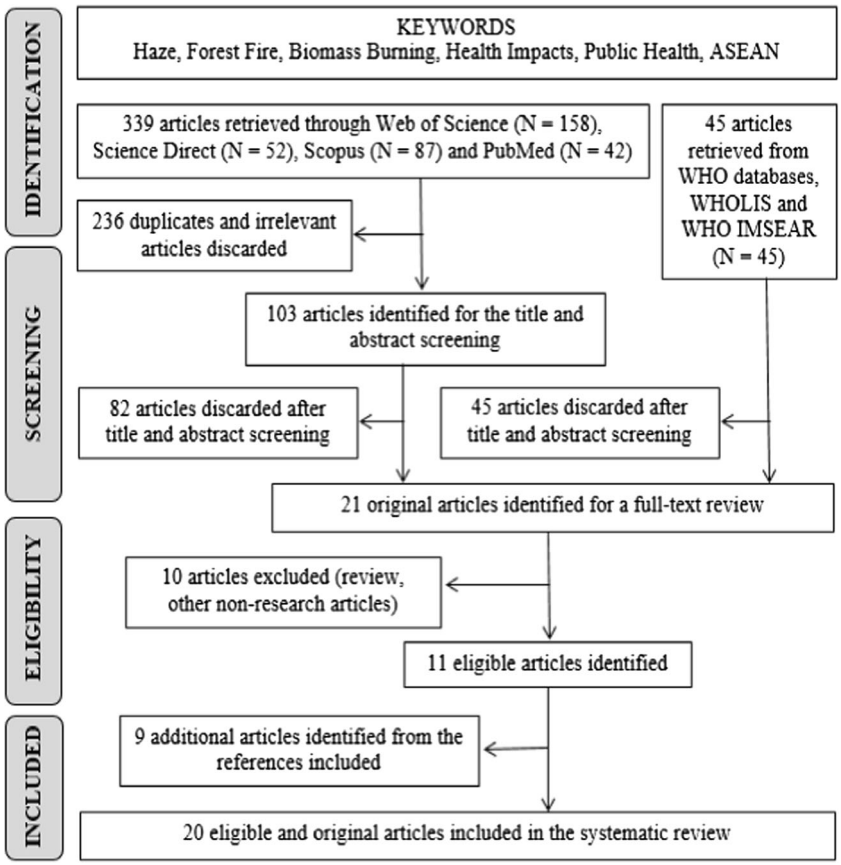

Fig. 1 Flow chart of paper selection

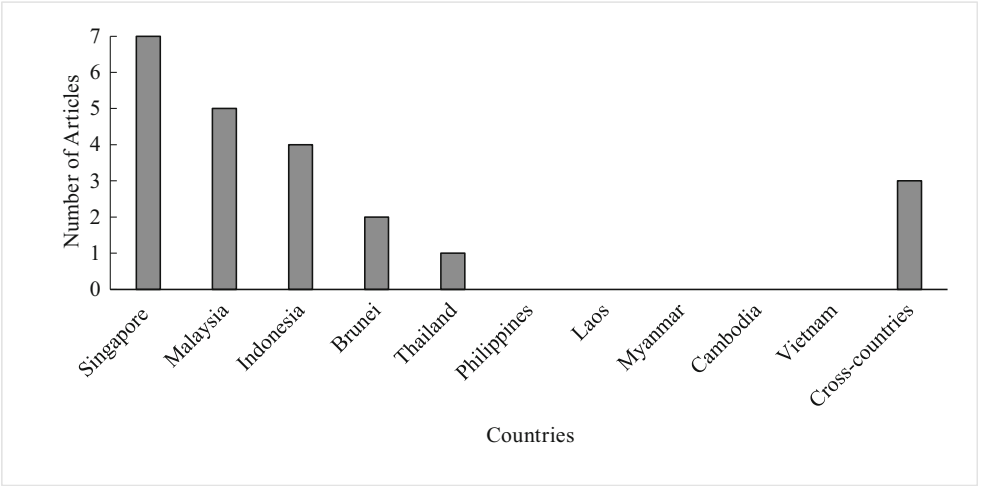

Fig. 2 Total number of research articles on health impacts associated with haze in ASEAN countries

magnitude occurring under similar meteorological conditions by employing advanced modelling techniques (Koplitz et al. 2016). Two mix method studies identified the dominant physical and psychological symptoms of haze in Brunei and Singapore using random samples (Ho et al. 2014; Odihi 2001). In addition, two toxicological studies in Singapore demonstrated the catastrophic health impacts of particulate matter exposure on human bodies (Pavagadhi et al. 2013; Tan et al. 2000). Meanwhile, two studies evaluated the addition impacts of haze on mortality by utilizing cross-country data (Crippa et al. 2016; Koplitz et al. 2016). In terms of prevalence of haze induced health impacts in ASEAN countries, respiratory morbidity is the highly reported disease and this is followed by mortality and physical symptoms respectively as shown in Fig. 3.

The potential public health impacts of haze were divided into physical impacts and psychological impacts. The physical impacts are further divided into physical health effects and toxicological studies that explicitly describe the laboratory studies which are conducted to elucidate the biological mechanisms of the pollutants present in the haze.

Physical impacts of haze in ASEAN countries

Physical health effects

This section comprehensively discusses various reported physical health effects of haze such as physical symptoms, respiratory morbidity, cardiovascular morbidity, mortality and cancer risk in different ASEAN countries.

Physical Symptoms Inconsistent evidences were identified among the reported physical symptoms of haze exposure in the reviewed studies. Both Tan et al. (2000) and Ho et al. (2014) observed higher frequency of mouth or throat discomfort cases among the subjects during the haze period in Singapore (Ho et al. 2014; Tan et al. 2000). Odihi (2001) reported that cases related to conjunctivitis did not have any significant increase during the haze exposure period in Brunei (Odihi 2001). Besides this, Ho et al. (2014) also encountered other most common physical symptoms such as nose discomfort (64.1%), eye discomfort (60.7%), headache (50.3%) and breathing difficulty (40.3%) as the prevailing cases among the haze inflicted population in Singapore (Ho et al. 2014). Yeo et al. (2014) reported two exacerbated atopic dermatitis cases that were aggravated within 3 weeks of exposure during 2013's haze episode in Singapore (Yeo et al. 2014).

Respiratory Morbidity A significant association was found between the haze exposure and impairment of lung functions, although the variations can be seen according to the age, gender, residential area and patient's medical history. Chew et al. (1995) reported increased asthma hospitalizations due to chronic PM_{10} exposure and particulates with an aerodynamic diameter of 10 μm, which was 20% higher than the annual average moving trend in Singapore (Chew et al. 1995). Hashim et al. (1998) compared pulmonary functions of 107 primary school children before, during and after the haze episodes in Malaysia. The children, particularly girls, experienced significant reductions in pulmonary function parameters during and after the haze episode when compared to the pre-episode period. A residual impact of the haze on children's pulmonary functions was found even though a partial recovery was identified after the haze episode ended (Hashim et al. 1998). Emmanuel (2000) identified a significant increase of respiratory diseases such as rhinitis (26%), asthma (19%) and upper respiratory tract illness (URTI) (12%) using computerized health surveillance data during the peak haze periods in Singapore (Emmanuel 2000). Odihi (2001) surveyed households in Brunei and ascertained that bronchial disorders such as asthma, bronchitis and emphysema had a statistically significant increase whilst conditions such as pneumonia and acute upper respiratory infections (AURI) did not have any significant increase during the exposure period. They also

Table 1 Findings on the health impacts of haze from the reviewed studies

Article	Country/study area/time frame	Study sample	Exposure assessment method	Exposure levels	Adjustment for confounding factors	Key findings
Physical impacts: physical health effects						
Physical symptoms						
Tan et al. (2000)	Singapore/Dieppe and Kranji/June–Dec 1997	30 respondents aged between 19 and 24 years old	Spirometry and venous blood sampling during and after the haze	Mean daily concentration of PM_{10} was 125.4 ± 44.9 μg/m^3 and SO_2 was 78.7 ± 31.2 μg/m^3	PM_{10}, SO_2, O_3, NO_2, CO, gender, age, smoking habit, subject's activities and time period stratification	• The frequency of mild throat discomfort admitted to by the subjects at blood sampling sessions was 8% (haze period) compared with 7.2% (post-haze period).
Odihi et al. (2001)	Brunei/Brunei-Muara (BM) and Temburong (T) districts/Sept 1997 and Jan–June 1998 (haze) and Jan–June 1997 and Sept 1998 (after haze)	Households: 218 (BM) and 41 (T)	Household survey and focused group discussions (FGD)	Not reported	Age, work, gender and residential area	• Cases related to conjunctivitis did not have any significant increase during the exposure period.
Ho et al. (2014)	Singapore/21–26 June 2013	298 respondents recruited by snowball sampling	Cross-sectional design and online self-administered questionnaire survey	Self-report of perceived PSI values as dangerous	Age, gender, marital status, ethnicity, occupation, medical record	• Five most common physical symptoms such as mouth or throat discomfort (68.8%), nose discomfort (64.1%), eye discomfort (60.7%), headache (50.3%) and breathing difficulty (40.3%) were the prevailing cases among the haze inflicted population.
Yeo et al. (2014)	Singapore/Ulu Pandan Constituency/25 June 2013–11 July 2013	72 consultations with 69 patients with three seen twice	Consultation clinics during the haze period	PSI = 401 on 21 June 2013 $PM_{2.5}$ = 251–300 μg/m^3 on 20 June 2013	$PM_{2.5}$, age, gender, day of the week and hour of the day	• Three cases of dermatitis reported from which two with an exacerbation of atopic dermatitis during the haze episode
Respiratory morbidity						
Chew et al. (1995)	Singapore/Sep–Oct 1994	Children less than 12 years old.	Modelling based on the hospitalization data	Highest modelled PM_{10} levels up to a threshold of 158 μg/m^3	PM_{10}	• An increase in emergency room attendances for acute childhood asthma in two large general hospitals in Singapore
Hashim et al. (1998)	Malaysia/Kuala Lumpur/July–Nov 1997	107 school children aged between 7 and 11 years old	Pulmonary function assessments once prior, once during and twice after the haze exposure	Mean PM_{10} prior = 82.0 μg/m^3, during = 194.1 μg/m^3 and twice after 76.9 and 53.6 μg/m^3.	PM_{10}, gender, time period stratification	• Significant reductions (mean 18%) in pulmonary function among children during and after the episode when compared to the pre-episode period. • The mean reduction in % predicted FEV1 and FVC and % FEV1/FVC during the haze were lower among the girls (21, 19 and 8% respectively) than among the boys (16, 10 and 5% respectively).

Table 1 (continued)

Article	Country/study area/time frame	Study sample	Exposure assessment method	Exposure levels	Adjustment for confounding factors	Key findings
Emmanuel (2000)	Singapore/1997	Computerized patient care system's data of Ministry of Health	Computerized routine surveillance of disease conditions during haze period	PM_{10} = 50–150 μg/m^3	PM_{10}, SO_2, O_3, NO_2, CO, temperature, relative humidity, rainfall, wind speed and time period stratification	• A significant increase of 12% of upper respiratory tract illness (URTI), 19% of asthma and 26% of rhinitis during the peak haze period
Odihi et al. (2001)	Brunei/Brunei-Muara (BM) and Temburong (T) districts/Sept 1997–Jan–June 1998 (haze) and Jan–June 1997–Sep-t 1998 (after haze)	Households: 218 (BM) and 41 (T)	Household survey and focused group discussions (FGD)	Not reported	Age, work, gender and residential area	• Bronchial disorders such as asthma, bronchitis and emphysema had a statistically significant increase whilst conditions such as pneumonia and AURI did not have any significant increase during the exposure period. • Respiratory illnesses of haze were higher among young (1–5 years) and the elderly (above 60 years). • Higher proportion of urban population and outdoor workers were more adversely affected compared to their counterparts
Anaman and Ibrahim (2003)	Brunei/Brunei-Muara District/Jan–June 1998	Public health centre's data where the study area consists of two thirds of the entire population of Brunei	Time-series econometric model: trend-type model assessing linear and log-linear dose–response relationship	PSI is not reported.	Temperature and humidity	• Dose–response functions of the respiratory diseases such as asthma, bronchitis, emphysema, influenza, pneumonia and AURI, show a significant relationship to the levels of PSI. • The societal costs of respiratory diseases increased with increasing PSI and relative humidity but decreased with increasing temperature.
Frankenb-erg et al. (2005)	Indonesia/1993 and 1997	Interview of 7200 households in 321 enumeration areas in Indonesia	Population-based longitudinal surveys before (1993) and during (1997) haze episodes	Mean TOMS aerosol index ≥ 2.0	Age, gender, health status, time and subject's occupation	• One third of adult respondents over 30 years old reported coughing as the major health issue during 1997 haze episode.
Mott et al. (2005)	Malaysia/Kuching, Sarawak/1 Jan 1995–31 Dec 1998	Hospitalization record (190,016) from seven hospitals on cardiorespiratory diseases	Time-series analyses of hospitalizations before, during and after the forest fire period	API is shown in graphical form.	Age, gender, race and time period stratification	• Significant increase of respiratory hospitalizations, particularly due to asthma, was observed in the 19–39 and 40–64 years age categories during fire period and an increase of 50 and 42% hospitalizations during the same time periods in 1995, 1996 and 1998 among those aged 40–64 years and above 65 years old.

Table 1 (continued)

Article	Country/study area/time frame	Study sample	Exposure assessment method	Exposure levels	Adjustment for confounding factors	Key findings
						• Survival analyses highlighted that elderly, above 65 years old with prior hospitalizations, were more likely to be re-admitted during the follow-up and control periods.
Yeo et al. (2014)	Singapore/Ulu Pandan Constituency/25 June 2013–11 July 2013	72 consultations with 69 patients with three seen twice	Consultation clinics during the haze period	PSI = 401 on 21 June 2013 $PM_{2.5}$ = 251–300 μg/m^3 on 20 June 2013	$PM_{2.5}$, age, gender, day of the week and hour of the day	• Most of the consultations (61.1%) were for conditions related with haze associated respiratory symptoms such as upper respiratory tract illness and breathlessness. • The ageing population above 60 years old is identified as the most vulnerable group to the exposure.
Cardiovascular morbidity						
Sastry (2002)	Malaysia/Kuala Lumpur/1994–1997	Mortality data on cardiovascular causes	Modelling of mortality counts	PM_{10} > 210 μg/m^3 (13 days)	PM_{10}, age, temperature, visibility, seasonality and time period stratification	• Less infant deaths from cardiovascular causes whereas the death risk from cardiovascular causes for individuals aged between 65 and 74 years is twice as high on days following a haze episode.
Mott et al. (2005)	Malaysia/Kuching, Sarawak/1 Jan 1995–31 Dec 1998	Hospitalization record (190,016) from seven hospitals on cardiorespiratory diseases	Time-series analyses of hospitalizations before, during and after the forest fire period	API is shown in graphical form.	Age, gender, race and time period stratification	• Increased hospitalizations for ischemic heart disease (IHD)
Mortality						
Sastry (2002)	Malaysia/Kuala Lumpur/1994–1997	Mortality data	Modelling of mortality counts	PM_{10} > 210 μg/m^3 (13 days)	PM_{10}, age, temperature, visibility, seasonality and time period stratification	• Increased mortality both linearly and with discrete levels of PM_{10} exposure, mainly for those aged between 65 and 74 years old. • The associated relative mortality risk is 1.07 following a high air pollution day with an average increase in PM_{10} concentrations of 245.33 μg/m^3.
Marlier et al. (2013)	Southeast Asia/1997–2006	No data	Combined satellite data with atmospheric models to estimate pollutant concentrations and corresponding regional mortality.	$PM_{2.5}$ = 50–200 μg/m^3 O_3 = 25–50 ppb	$PM_{2.5}$, O_3 and time period stratification.	• Adult cardiovascular disease mortality during high fire years increase up to 10,800 (6800–14,300) annual deaths from $PM_{2.5}$ exposure and an additional 4100 (2300–5900) annual deaths from O_3.

Table 1 (continued)

Article	Country/study area/time frame	Study sample	Exposure assessment method	Exposure levels	Adjustment for confounding factors	Key findings
Sahani et al. (2014)	Malaysia/Klang Valley/1 Jan 2000–31 Dec 2007	Mortality data from the Department of Statistics.	A case-crossover study design to model the effect of PM_{10} concentration on the mortality	Mean concentration and the highest concentration of PM_{10} was 134.5 and 481.1 $\mu g/m^3$ respectively.	PM_{10}, NO_2, SO_2, CO, O_3, age, gender, humidity, temperature and visibility	• Higher risk of respiratory mortality among all male residents and elderly males above 60 years during acute exposure events. • A 41.4% increase of mortalities was found among the children under 14 years old after 2 days of exposure to the haze days. • Higher risk of mortalities among females aged between 15 and 59 years old also occurred after 5 days of constant exposure.
Koplitz et al. (2016)	Equatorial Asia/Singapore, Malaysia and Indonesia/Sep–Oct 2006 and 2015	No data	Modelling of premature mortality using the adjoint of the GEOS–Chem, chemical transport model and Global Fire Assimilation System (GFAS) based on two haze events in 2006 and 2015.	Mean smoke exposure: A) 2015 Sin: 27 $\mu g/m^3$ Ind: 19 $\mu g/m^3$ Mal: 14 $\mu g/m^3$ B) 2006: Sin: 10 $\mu g/m^3$ Ind: 8 $\mu g/m^3$ Mal: 6 $\mu g/m^3$	$PM_{2.5}$ and fire source locations	• An excess of 100,300 mortalities across Indonesia, Malaysia and Singapore is identified in 2015 compared to 2006. • Regional smoke-related mortality was 2.7 times higher in 2015 than in 2006
Crippa et al. (2016)	Singapore and Indonesia (Pekanbaru in Sumatra)/Sep–Oct 2015	No data	Regional simulations of WRF-Chem model to assess air quality conditions.	Highest concentration of PM_{10} in Indonesia is 600 $\mu g/m^3$ and of $PM_{2.5}$ in Singapore is 200 $\mu g/m^3$.	$PM_{2.5}$ and PM_{10}	• A total of 11,880 fatalities occurred as a result of short-term exposure to extreme PM concentrations in both Singapore and Indonesia. • About 75,600 estimated premature mortalities to occur each year due to chronic exposure.
Cancer						
Betha et al. (2013)	Indonesia/Pulang Pisau, Kalimantan/19 Sep–12 Oct 2009	No data	Human Health Risk Assessment: Hazard identification and exposure assessment	$PM_{2.5}$ concentration ranged from 235 to 7817 $\mu g/m^3$.	$PM_{2.5}$ bound with trace metals (Al, Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb, Ti, V and Zn).	• Four or five individuals out of 1000 can be affected by cancer after being exposed to 70% of $PM_{2.5}$-bound carcinogenic trace metals emissions. • The estimated excess lifetime cancer risk (ELCR) was much higher than the acceptable level (1×10^{-6}). • The concentration of particulate-bound carcinogenic metals such as cadmium (39 ng/m^3) and nickel (249 ng/m^3) in the exchangeable fraction exceeded the WHO guideline values by several factors.

Table 1 (continued)

Article	Country/study area/time frame	Study sample	Exposure assessment method	Exposure levels	Adjustment for confounding factors	Key findings
Betha et al. (2014)	Singapore/20 June–28 July (haze) and 12 Sep 12–2 Oct 2013 (non-haze)	No data	Multiple Path Particle Dosimetry model to estimate the deposition of the particulate-bound elements in the respiratory system between haze and non-haze days and health risk assessment.	$PM_{2.5}$ concentrations up to 329 μg/m^3 during haze days compared to those during the non-haze period.	Size of PM, trace metals (B, Ca, K, Fe, Al, Ni, Zn, Mg, Se, Cu, Cr, As, Mn, Pb, Co, and Cd) and time period stratification.	• Higher deposition (MMAD: 0.69 ± 0.19 μm) of inhaled bioavailable fraction of the carcinogenic trace metals in $PM_{2.5}$ in both tracheobronchial and pulmonary regions during the hazy days. • Excessive lifetime carcinogenic risk (ELCR) due to haze-induced $PM_{2.5}$ exposure is $18 \pm 1 \times 10^{-6}$ and increased significantly ($P < 0.05$) compared to the exposure to urban air ($12 \pm 2 \times 10^{-6}$).
Pongpiachan et al. (2015)	Northern Thailand/before haze: 2012 (28 Nov–22 Dec 22) and after haze: 2013 (23 Feb–20 March)	Pre-school children (< 5 years old)	Excess cancer risk (ECR) assessment	Average PAH congener for both monitoring periods was 63 ± 181 pg/m^3 and was higher before haze.	PAH congeners and time period stratification.	• The average ECR Northern Thailand for a lifetime of 70 years ranged from 6.1×10^{-8} (after haze) to 6.0×10^{-6} (before haze). • Biomass-burning source may play a minor role in cancer risk due to human exposure to $PM_{2.5}$-bound PAHs in northern provinces of Thailand
Sulong et al. (2017)	Malaysia/Kuala Lumpur/June–Aug 2015 (pre-haze); Sept–Oct 2015 (haze) and Nov 2015–Jan 2016 (post-haze)	No data	Human Health Risk Assessment: lifetime average daily doses and carcinogenic health risks	$PM_{2.5}$ concentrations: Pre-haze: 24.5 ± 12.0 μg/m^3. Haze: 72.3 ± 38.0 μg/m^3. Post-haze: 14.3 ± 3.58 μg/m^3.	$PM_{2.5}$, age, trace metals (Cr, Mn, Ni, Cd, As, Pb and Co) and time period stratification.	• The highest ELCR estimation during haze by adult group for which it increased from 1.92×10^{-5} (non-haze) to 2.27×10^{-5} (haze) where 2 to 3 individuals in 100,000 are likely to develop cancer.
Physical impacts: toxicological studies						
Tan et al. (2000)	Singapore/Dieppe and Kranji/June–Dec 1997	30 respondents aged between 19 and 24 years old.	Spirometry and venous blood sampling during and after the haze.	Mean daily concentration of PM_{10} was 125.4 ± 44.9 μg/m^3 and SO_2 was 78.7 ± 31.2 μg/m^3	PM_{10}, SO_2, O_3, NO_2, CO, gender, age, smoking habit, subject's activities and time period stratification.	• An elevated white blood cell count during the haze period with maximal association on zero and one lag day for PM_{10} and 3 and 4 lag days for SO_2 which contributes to the pathogenesis of the cardiorespiratory morbidity.
Pavagadhi et al. (2013)	Singapore/NUS/21–23 Oct 2010	Culture of human epithelial respiratory cell lines (A549)	Assessment of cell viability and cytotoxicity, and caspase-3/7 activation assay	$PM_{2.5}$ concentrations on: 21: 133 μg/m^3 22: 110 μg/m^3 23: 78 μg/m^3	$PM_{2.5}$, PAH, trace metals and days	• Cell viability had a 2.5-fold decrease whilst the cell death increased by 1.9-fold due to the direct exposure towards water-soluble metals and PAHs bound with $PM_{2.5}$. • Low levels of glutathione and caspase-3/7 that result in oxidative stress and apoptotic death which leads to the pulmonary inflammation.

Table 1 (continued)

Article	Country/study area/time frame	Study sample	Exposure assessment method	Exposure levels	Adjustment for confounding factors	Key findings
Psychological impacts						
Ho et al. (2014)	Singapore/21–26 June 2013	298 respondents recruited by snowball sampling	Cross-sectional design and online self-administered questionnaire survey	Self-report of perceived PSI values as dangerous	Age, gender, marital status, ethnicity, occupation, medical record	• Highest intrusion score (mean = 0.96, SD = 0.63) that represent recurrent thinking about haze such as negative feelings associated with reminder of haze, dreams about haze and recurrent mental pictures of haze among the study population. • Moderate mean hyper-arousal score (mean = 0.85, SD = 0.74) that represent irritability, easily startled responses, insomnia, poor concentration, on guard of haze and physical reactions after reminders of haze was recorded. • The mean avoidance score (mean = 0.71, SD = 0.5) was the lowest where the study population was less concern about the avoidance of feelings, reminders, recollections and discussion about the haze. • No significant differences among the gender and scores on psychological stress

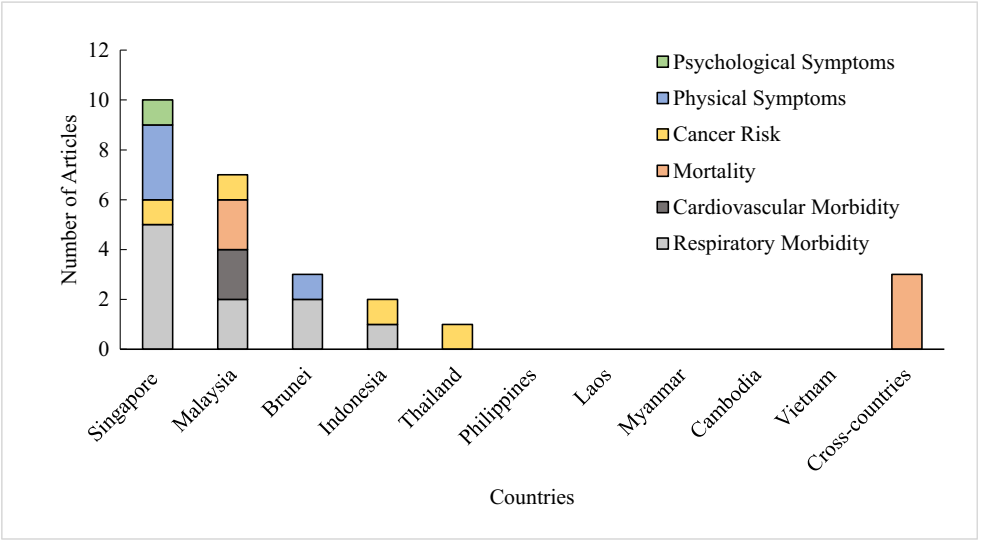

Fig. 3 Different types of haze-induced health impacts reported in research articles in ASEAN countries

ascertained a non-uniform relationship of health impacts among different age groups as the injurious effects of haze skewed towards the young and the elderly. Moreover, a higher proportion of urban population and outdoor workers were more adversely affected compared to their counterparts. The urban environment presents a complex urban metabolism including constructions, development and maintenance activities that amplify the anthropogenic emissions exposure during the haze episodes. Furthermore, increased dose of inhaled pollutants during social and economic activities in the city centres aggravate the respiratory conditions of the urbanites (Odihi 2001). Besides, Anaman and Ibrahim (2003) used time-series econometric models to demonstrate dose–response functions between the respiratory diseases and Pollutant Standard Index (PSI) during the 1998 haze-related air pollution episode in Brunei. The results showed a significant increase of respiratory cases with increasing PSI levels during the haze episode in Brunei (Anaman and Ibrahim 2003). Frankenberg et al. (2005) conducted two population-based longitudinal surveys before and during the haze episodes and reported that one third of adult respondents over 30 years old recorded coughing as the major health issue during the 1997 haze episode in Indonesia (Frankenberg et al. 2005). Mott et al. (2005) through the time-series analyses between the pre- and post-haze periods had observed a statistically significant increase in respiratory hospitalizations, specifically those for chronic obstructive pulmonary disease (COPD) and asthma in the 19–39 and 40–64 years age categories in Kuching, Malaysia. They also identified that elderly people above 65 years old with previous hospitalization records were more vulnerable to be re-hospitalized during the follow-up period after exposed to the haze in 1997 (Mott et al. 2005). Similarly, Yeo et al. (2014) observed a higher number of haze related respiratory illnesses, mainly the upper respiratory tract illness and breathlessness during community-led atmospheric haze clinics in Singapore. The ageing population of Singapore above 60 years old was identified as the most vulnerable group to the exposure from their patronage to the haze clinics (Yeo et al. 2014).

Cardiovascular Morbidity Limited number of studies reported the risk of cardiovascular morbidity due to haze exposure. Sastry (2002) witnessed less cardiovascular related infant deaths compared to the other age categories in his retrospective study in Kuala Lumpur, Malaysia. However, death risk from cardiovascular causes for the elderly above 65 years old is twice as high after the direct exposure to the severe haze episodes (Sastry 2002). In agreement to the previous findings, Mott et al. (2005) observed increasing records of hospitalizations for ischemic heart disease (IHD) among the individuals aged between 40 and 64 years based on the historical data due to prolonged exposure to the forest fires in Kuching, Malaysia in 1997 (Mott et al. 2005).

Mortality A statistically suggestive increase in haze related mortality among the specific vulnerable population was found in this region. In Malaysia, Sastry (2002) reported a rise in mortality in both linearly and with discrete levels of PM_{10} exposure during 1997 Southeast Asian wildfire with an upward shift detected mainly for those aged between 65 and 74 years old (Sastry 2002). The study by Marlier et al. (2013) combined satellite data with atmospheric models and observed higher frequencies of regional mortality due to cardiovascular diseases during high fire incidences between 1997 and 2006 in Southeast Asia (Marlier et al. 2013). On the other hand, Sahani et al. (2014) used a case-crossover study design to estimate the mortality risk resulting from the exposure of PM_{10} during the haze episodes in Klang Valley, Malaysia between 2000 and 2007. Daily mortality data resulting from respiratory diseases during the haze days when PM_{10}

concentration exceeding 100 μg/m^3 were used to examine the incidence and lag effects of deaths according to age and gender categories. They identified an incremental risk of respiratory mortality among all male residents, especially elderly males above 60 years during acute exposure events. At the same time, a 41.4% increase of mortalities was found among the children under 14 years old after 2 days of exposure during the haze episode. Similar delayed effect was discovered when the highest number of mortalities among the females aged between 15 and 59 years old occurred after 5 days of constant exposure (Sahani et al. 2014). By comparing the population-weighted smoke exposure data of $PM_{2.5}$ between 2006 and 2015 haze events, Koplitz et al. (2016) found that the year 2015 recorded an excess of 100,300 mortalities across Indonesia, Singapore and Malaysia compared to the year 2006 (Koplitz et al. 2016). Their results unveiled that regional smoke-related mortality in 2015 was more than double of the 2006 haze event that enveloped the Equatorial Asia. By employing high-resolution regional atmospheric model in combination with satellite-derived fire emissions data, Crippa et al. (2016) demonstrated a total of 11,880 fatalities occurred as a result of short-term exposure to extreme $PM_{2.5}$ concentrations in both Singapore and Indonesia. Furthermore, the study also predicted about 75,600 additional premature deaths to occur every year due to continuous exposure to the pollutant concentrations as experienced in 2015 haze event (Crippa et al. 2016).

Cancer Risk Two studies demonstrated that carcinogenic pollutants present in haze have the potential to cause cancer by performing Excessive Lifetime Cancer Risk (ELCR) assessments based on the concentrations of compounds determined through particulate sampling whereas one study did not find a significance association with cancer risk. Betha et al. (2013) estimated that 0.4–0.5% of individuals can be affected by cancer after being inadvertently exposed to the carcinogenic trace metals present in $PM_{2.5}$ emissions from the Indonesian peat fires. The study found that the concentration of particulate-bound carcinogenic metals such as cadmium and nickel in the exchangeable fraction exceeded the standards set by World Health Organization (WHO) which can lead to adverse health outcomes (Betha et al. 2013). Similarly, Betha et al. (2014) estimated the deposition fractions of carcinogenic trace metals in PM_{10} in the simulated human respiratory system using a human airway deposition model known as Multiple Path Particle Dosimetry (MPPD) model. They identified higher deposition of inhaled bioavailable fraction of the carcinogenic trace metals in $PM_{2.5}$ in both tracheobronchial and pulmonary regions of the simulated respiratory system during the hazy days in Singapore. However, they found that the mean concentrations of carcinogenic metals in various particulate matter fractions ($PM_{2.5}$ until $PM_{0.2}$) are lower during the haze period compared to the non-haze period. But, sample calculations of health risk assessment still showed a significant increase of excessive lifetime carcinogenic risk to individuals who are constantly exposed to biomass burning-impacted aerosols in Singapore (Betha et al. 2014). On the contrary, Pongpiachan et al. (2015) highlighted that the biomass-burning source may play a minor role in cancer risk due to human exposure to $PM_{2.5}$-bound PAHs in northern provinces of Thailand (Pongpiachan et al. 2015). In a recent study, Sulong et al. (2017) estimated highest excess lifetime cancer risk among the adult group (above 18 years old) in Kuala Lumpur during haze period compared to pre- and post-haze periods of 2016.

Toxicological studies

In spite of very limited toxicological studies, the existing evidences support the feasible respiratory health effects of particulate matter exposure during the haze episodes. Tan et al. (2000) investigated the relationship between biomass burning-induced severe air pollution and peripheral leucocyte counts for phagocytosis of PM_{10} in humans during the 1997 Southeast Asian transboundary haze in Singapore. The researchers observed an immediate elevation of leucocyte counts in 30 subjects due to PM_{10} exposure and a slight delayed effect for SO_2 exposure. It was speculated that this response is due to the pathogenesis of the cardiorespiratory morbidity and could conceivably initiate other vascular events related to acute air pollution (Tan et al. 2000). In another approach, Pavagadhi et al. (2013) evaluated the toxicological profile of the $PM_{2.5}$ samples collected during a severe regional smoke haze episode in Singapore using a human epithelial lung cell line (A549) for a period of 48 h. The results indicated that the cell viability decreased by 2.5-fold whereas the cell death increased by 1.9-fold due to the direct exposure towards water-soluble metals and polycyclic aromatic hydrocarbons (PAHs) bound with $PM_{2.5}$ in the haze. They also found very low levels of glutathione and caspase-3/7 in the cells that can lead to the increased numbers of reactive oxygen species (ROS) that results in oxidative stress and apoptotic death which eventually leads to the pulmonary inflammation after a chronic exposure to haze (Pavagadhi et al. 2013).

Psychological impacts of haze in ASEAN countries

There is only one study by Ho et al. (2014) that examined the immediate psychological symptoms of haze among individuals in Singapore. They identified highest mean intrusion score (mean = 0.96 ± 0.63) that represent recurrent thinking and negative feelings about haze including reminder, dreams and mental pictures of haze among the study population. Moderate mean hyper-arousal score (mean = 0.85 ± 0.74) was recorded for the feeling of irritability, poor concentration, insomnia and other successive physical reactions after the

reminders of haze. The mean avoidance score (mean = 0.71 ± 0.5) was the lowest where the study population was less concerned about the avoidance of feelings, recollections, reminders and discussion about the haze. However, they identified no significant differences between the genders and scores of psychological stress. In conclusion, the findings suggest that the haze crisis is associated with very mild to moderate psychological stress only (Ho et al. 2014).

Discussion

This section discusses the overall findings of the review with some critical aspects, recommendations and suggestions that need to be taken into serious consideration for the improvement of future studies. In terms of physical symptoms, various symptoms were reported based on the self-perceived data (interviews and questionnaire) in both Singapore and Brunei. Yet, there were no specific symptoms recorded in all the reviewed studies except for throat discomfort (Ho et al. 2014; Tan et al. 2000). In certain cases, physical symptoms are the earliest indicators of the associated deleterious effects of haze on human physiology. The exacerbation of certain symptoms is directly proportional to the air pollution levels based on the depth of transport of hazardous pollutants into human bodies. Hence, ASEAN countries need to precisely report the association between predominating physical symptoms and pollutant concentrations to deduce the threshold dose that could serve as the baseline data for public health intervention practices in the region. Moreover, not all the studies explicitly analysed and reported the influence of other confounding factors such as study sample's working environment or medical history on the incidence of those physical symptoms.

The review highlighted that the majority of the studies showed a significant increase of respiratory morbidity, especially with the aggravation of asthma (Anaman and Ibrahim 2003; Chew et al. 1995; Mott et al. 2005; Odihi 2001). The findings also suggested a higher risk of respiratory illnesses among the children (Chew et al. 1995; Hashim et al. 1998; Odihi 2001) and elderly people (Mott et al. 2005; Odihi 2001; Yeo et al. 2014). However, the influence of gender, socioeconomic status, working exposure (indoor or outdoor) and the geographical influence (upwind or downwind countries from the source of emission) on the amplification of respiratory morbidity is not fully explored in all of these studies. These findings are in agreement with Delfino et al. (2008) (southern California) and Johnston et al. (2014) (Sydney, Australia) who observed increased asthma problems among children and elderly people after the forest fire incidents in their respective countries of different climates. Ironically, some major haze-inflicted countries such as Indonesia, Thailand and the Philippines are lacking in epidemiological studies to associate the respiratory ailments with haze exposures. Hence, more experimental studies that relate both air monitoring and respiratory morbidity assessments are required as most of the respiratory problems are directly originating from the inhalation of polluted air. On the other hand, studies on the cardiovascular morbidity demonstrated an increasing risk in Malaysia, especially among the elderly people based on pre-existing hospitalization and mortality records over the years (Mott et al. 2005; Sastry 2002). Although the findings recorded some positive relationships, regional studies are still very scarce and geographically limited to reach a general conclusion between haze and cardiovascular diseases for ASEAN region.

Mounting modelling and simulation evidences (Koplitz et al. 2016; Sahani et al. 2014; Sastry 2002) reported a convincing association between mortality and haze exposure whereas a cross-country study between Singapore and Indonesia predicted mushrooming number of premature mortalities to occur each year due to chronic exposures (Crippa et al. 2016). In agreement to this, multi-year studies which are conducted in different climate zones such as Europe (temperate) and Madrid, Spain (sub-tropical) produced same observations on elevated mortality counts in smoke-affected regions (Faustini et al. 2015; Linares et al. 2015). In the reviewed studies, possible reasons for the observed higher risk of mortality among children and elderly people are poor or impaired immune system and pre-existing health implications that address them as more susceptible populations (Sastry 2002; Sahani et al. 2014). In spite of the vitality of the multi-year studies that assess the long-term fatal impact of haze exposure, more comparative studies that analyse the mortality before and after the exposure are still needed to provide more authentic agreement on the mortality causes. Besides, the carcinogenic effect of metal-bound particulate matter exposure is consistent in both Indonesia (Betha et al. 2013) and Singapore (Betha et al. 2014). However, human exposure to haze-induced $PM_{2.5}$-bound PAHs in northern provinces of Thailand (Pongpiachan et al. 2015) is expected to be lesser carcinogenic compared to vehicular and industrial emissions. It should be noted that the cancer risk of haze in the aforementioned studies is mere estimation based on equations and more laboratory toxicological studies are still needed to comprehensively evaluate the role of air-borne carcinogens in the development of cancer cells. In fact, the body of evidence based on the toxicological studies is relatively small for a generalization despite their importance in identifying the biological mechanism of particulate matter in human bodies. Other ASEAN countries, by emulating the initiatives of Singapore, should shift the scope of their research towards more toxicological studies for a strategic intervention in tackling the mounting health impacts of haze. With the growing concern on lab animal's experimentation, future toxicological studies can investigate the impact of particulate matter in haze on human health using urine, blood samples, biochemical

tests, cell culture assays and mathematical or computer models (Balls 1994; Hendriksen 2002; Höfer et al. 2004).

In terms of psychological symptoms, the impacts have not sufficiently studied and also incomparable to reach a consensual conclusion, although some symptoms were recorded in a single study in Singapore (Ho et al. 2014). But, the conclusions derived from this study (Ho et al. 2014) have higher potential for bias due to study population selection through a non-random sampling method. Moreover, the study evaluated the acute psychological symptoms of a short-term exposure with a list of pre-prepared specific symptoms in the questionnaire. Since the study samples composes of young individuals below 29 years old, the other factors that might be associated with the psychological impacts such as the academics, family, physical activities and financial turmoil are not clearly differentiated from the haze-induced psychological stress. In general, the other ASEAN countries also need to take initiatives to study the mental well-being of the public during such environmental crisis as it may impede their performance and productivity in every aspect. With such knowledge, necessary mitigations can be devised at the community level to enhance their mental health during the haze episodes.

The review also emphasized the existence of many gaps to be addressed in the future studies to obtain a complete apprehension of the health implications due to haze exposure.

- Firstly, the review highlighted that countries such as the Philippines which was more likely to be affected by seasonal haze episodes do not produce any public health studies during the haze phenomenon (Mott et al. 2005; Sastry 2002). Hence, the present review calls for more research to be conducted in these countries to decipher the typical diseases brought by poor regional air quality for better public health planning.
- Secondly, the aforementioned studies mostly attempted to analyse the aggravation of the existing physical health impacts without addressing the incidence of new cases during the intense exposure period. The reason for such problem could be addressed to the lacking of longitudinal studies that closely monitor the long-term health impacts of susceptible populations in the haze-inflicted region which are also indispensable for more evidence-based prevention and control strategies.
- Thirdly, future studies in ASEAN region should focus more on conducting toxicological studies that explore the synergistic effects of particulate matter of various aerodynamic sizes with the other dominant air pollutants, carcinogenic metals and PAHs which can be transported deep into the bloodstream to cause severe fatal effects. Meanwhile, the lack of concentration response functions via proper toxicological studies produces a big factor of uncertainty in health impact estimates. The reviewed studies tend to present either a statistical estimation of dose–response functions (Anaman and Ibrahim 2003) or health impacts of particulates in haze based on WHO's standards (Betha et al. 2013). Therefore, proper dose–response functions via experimental studies are prudential to elucidate the harmful or lethal effects of exposure levels for strategic health interventions.
- Fourthly, identification of specific biomarkers as the potential indicators of the biological mechanisms of haze-induced toxicity is very important in this region.
- Fifthly, large cohort studies with stronger statistical power are also needed in haze afflicted ASEAN countries to provide a valid and unbiased justification on the incidence of health impacts.
- Sixthly, future studies need to clearly address and communicate the influence of confounding factors such as study areas (topography, geographical setting and upwind or downwind country), residential areas (urban or rural) and the working environment (indoor or outdoor) on the intensification of haze-induced diseases to omit all the possible variances that can be caused in the results.
- Lastly, integrated quadruple helix collaboration, as adapted from Ahonen and Hämäläinen (2012), between academia, government, industries and societies is essential where the academic institutions need to devise more scholarly studies to communicate the health impacts and to alert the other stakeholders to work on adaptation, mitigation and prevention strategies to improve the public health in ASEAN region. Furthermore, such scientific knowledge will become valuable input and tool for the policy-makers to make the right policy choices aiming at sustainable healthcare solutions.

Increasing haze-associated health impacts often impose a heavy burden on the socio-economic dynamics of a nation. However, a very limited number of regional studies have evaluated the socio-economic impact of haze-induced diseases (Anaman and Ibrahim 2003; Othman et al. 2014). In one of such studies, Othman et al. (2014) used cost of illness (COI) approach and estimated the economic value of inpatient health during each haze episodes between 2005 and 2009 in Selangor, Malaysia. This study discovered that the incremental change in inpatient rates (2.4 inpatient cases per 10,000 persons each year) incur higher annual expenses (MYR 0.273 million) for the Malaysian healthcare system. Other than this, the loss of productivity of economic sectors reduced leisure activities that impede tourism, risk of accidents due to obscured visibility and shut down of schools also leads to a substantial loss of socio-economic values of a country during severe haze episodes (Anaman and Looi 2000; Othman and Shahwahid 1999; Othman et al. 2014). Hence, rigorous attention needs to be given to evaluate the economic burden of haze associated diseases via more scholarly studies to devise pragmatic measures to control haze occurrences in the region.

Conclusion

Notwithstanding that haze episodes have become a recurrent seasonal phenomenon among the ASEAN nations since 1997, the number of public health studies is still scarce in major haze-affected countries. Among the health impacts, a consistent association was found among the respiratory morbidity, especially on the aggravation of asthma, and mortality during the haze episodes. It should be taken into serious consideration that the current knowledge discussed in this review is derived from a very limited number of studies which are restricted to ASEAN countries only. In addition, extensive variations are present in the assessments of the included studies in terms of study samples, sample size, duration, controlled confounding factors and methodologies that restrict the employment of other collative approaches such as meta-analysis. Hence, a statistically sound analysis is not feasible in this review. Besides, limited number of studies reported only few types of the diseases under each category where the prevalence and significance of each type of diseases during the haze episodes remain inconclusive. Despite limited research evidences, more intensive studies are still needed to reach a strong and valid agreement between the patterns of other diseases during the exposure. Particularly, Singapore is paradigmatic in initiating toxicological studies on biological mechanism of hazardous pollutants of haze in which the rest of the countries are still lagging behind. In fact, long-term exposure assessments need to establish veritable evidences for the susceptible populations for a sound health planning. Besides, the impact of haze on social life and economy also needs to be studied comprehensively in the areas that have been majorly affected by haze episodes. Integrated collaboration between the major stakeholders such as academia, government, industries and societies is crucial to strategically minimize the health impacts of haze in ASEAN region. On top of that, collaboration and networking among researchers in ASEAN countries are vital to brainstorm new knowledge on the composition of transboundary haze, forecasting and modelling techniques as well as the impact of haze toward human health and social life.

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