The natural environment as a disaster hazard—the growing global health threat

Gerard Finnigan,

School of Medicine and School of Humanities and Social Sciences, Deakin University, Waurn Ponds, Australia

Abstract

Introduction: The earth's natural ecosystems and physical environment in which communities live are rapidly deteriorating and in turn, increasing the risk of premature morbidity and mortality to people worldwide. Hydrometeorological hazards are concentrating contaminants from the damaged environment and exposing large populations of vulnerable people to serious health and life threating diseases. This study performed a retrospective health risk assessment on two recent disaster events where such impacts unfolded, namely the 2015 south east Equatorial Asia smoke haze disaster and the 2016 Melbourne thunderstorm asthma epidemic. The primary objective was to test if the characterisation of health risk warranted earlier and more effective risk reduction activities prior to the disasters occurring.

Method: The study used a two stage process to perform a retrospective health risk characterisation assessment. Using the framework developed by UNISDR Health Aspect in Disaster Risk Assessment (2017), a thematic and targeted word literature review was performed to identify the level of risk knowledge prior to each event. A risk characterisation matrix was then developed and applied to characterise the health risk of each hazard event.

Results: The 2015 south east Equatorial Asia smoke haze disaster risk assessment was characterised as 'extreme' health risk and the 2016 Melbourne thunderstorm asthma epidemic was characterised as 'high' health risk.

Conclusion: To reach the goal of the Sendai Framework for Disaster Risk Reduction 2015-2030 requires strategies and plans to urgently address the catastrophic level of premature mortality risk posed by exposure to environmental contaminants and conditions. Innovative approaches and partnerships are necessary to mitigate the risk from the deteriorating health of the environment and natural ecosystems, along with disaster risk response initiatives that eliminate or reduce exposure of vulnerable people to these contaminants on a large scale.

Introduction

Human activity has so affected the earth's natural systems and physical environment, it now poses a serious threat to human health and risk of premature death worldwide (Steffen et al., 2018; Landrigan et al., 2017; Whitmee et al., 2015). Human behaviour has harmed the planets ecosystems and physical environment causing deforestation, freshwater degradation, ocean acidification, environmental pollution and biodiversity loss, which are singularly and cumulatively causing morbidity and shortened human life expectancy (Corvalen et al., 2005; McMichael et al., 2006; McMichael and Bennett, 2016; Whitmee et al., 2015).

The IPCC (2014) reported the burden of disability-adjusted life years in 2010 from air pollution was 7.6% of all disability-adjusted life years lost, a figure higher than all twelve other risk factors examined, including those of malnutrition, smoking and high blood pressure. The World Health Organization (WHO) estimated that exposure to 'unhealthy environments' caused 12.6 million deaths in 2012, with South East Asia and Western Pacific having the highest burden of 7.3 million deaths (WHO, 2016). A more recent analysis published in the Lancet reported that environmental pollution was responsible for the premature death of at least nine million people in 2015, representing 16% of all deaths worldwide for that year and this rate is expected to grow significantly each year (Landrigan et al., 2017).

While the relationship between the environment, development and human health is well recognised (Corvalen et al., 2005; Smith and Ezzati, 2005) less attention has concentrated on the relationship between deteriorating environmental conditions and the risk of premature mortality and morbidity from disaster hazards. Reporting on health impacts from disasters has typically concentrated on injury, disability and mortality caused from acute trauma as a direct effect of the hazard (Leaning and Guha-Sapir, 2013). For example, the 2015 yearly analysis of disaster mortality and impact published by the Centre for Research on the Epidemiology of Disasters (CRED), reported the Gorkha Earthquake as the disaster which caused the highest mortality, killing an estimated 8,831 people (Guha-Sapir et al., 2016). For the following year, CRED reported the Ecuadorian 7.8 magnitude earthquake was responsible for the highest mortality, with 676 people killed followed by Hurricane Matthew, which caused 546 deaths in Haiti and 49 deaths in the USA (CRED, 2016).

This data contrasts starkly with two different disasters that occurred in 2015 and 2016 respectively, which have not yet been included on the CRED EM DAT system. In 2015, the factors of climate, environmental land management and human behaviour combined to enable 230 fires to burn for three months, covering many countries across south-east equatorial Asia in a blanket of thick smoke (Marlier et al., 2015; NASA Earth Observatory, 2015; Samsuddin et al., 2018). One study which modelled all-cause mortality from the smoke exposure estimated at least 103,000 (95% CI, 26,300-174,300) excess deaths occurred across Indonesia, Malaysia and Singapore as a direct consequence of the smoke exposure (Koplitz et al., 2016). Another study estimated excess all-cause mortality due to short-term exposure of the smoke from the fires at 11,880 (95% CI, 6153-17,270) deaths (Crippa et al., 2016).

A different disaster occurred on the 21st November 2016 in Melbourne, Australia, when convergent environmental factors pushed extreme concentrations of fractured grass pollen, fungal spores and tree and weed pollen into the city by severe thunderstorms (Thien et al., 2018). Within 30 hours, the state health care system was overwhelmed by unprecedented demand from patients in respiratory distress (Inspector General for Emergency Management, 2016). In that timeframe, over 3,365 patients presented to hospital emergency departments with respiratory symptoms and 1428 presented with nil diagnosis (Davies et al., 2017). Over 3,867 more people presented at State public hospital emergency departments (based on a three-year average); there was a 992% increase in asthma-related admissions to hospitals in the suburbs of Melbourne and Geelong (524 more patients based on a three-year average). Furthermore, a 30-fold increase in asthma-related intensive care admissions (based on a three year average) and a six-fold increase in home visits by the National Home Doctor service were reported (VDHSS, 2017). From 6-pm until midnight on the 21st November, 643 patients contacted the ambulance requiring a ‘code 1’ or ‘most severe’ response (VDHSS, 2017, p.2). The death of ten people was determined to be caused by the thunderstorm event (Lindstrom et al., 2017).

In view of the sheer scale of health impact of these two disaster events, a retrospective disaster health risk assessment was performed, using the United Nations International Strategy for Disaster Risk (UNISDR) public health risk assessment guidance framework (UNISDR, 2017). The primary purpose of the study was to determine if the magnitude of health risk from either of these events could have reasonably been predicted, based on scientific information available at the time the event occurred. The study further hoped to identify any gaps or deficit in disaster risk reduction knowledge or its application that may have contributed to the lack of risk reduction planning before the events.

Understanding and identifying system deficits and knowledge barriers will be essential to support global initiatives to advance disaster risk reduction strategies and plans and prevent premature mortality in the future. Given the pace of deterioration to natural ecosystems and the physical environment in which many communities live, urgent action will be necessary and instrumental to achieve targets set by the Sendai Framework for Disaster Risk Reduction 2015-2030 (SFDRR). These include the targets of substantially reducing disaster mortality, the people affected and economic losses caused from disasters (UNISDR, 2015). The knowledge gained from this study will further support initiatives to address all four priority areas of action of the SFDRR (UNISDR, 2015) along with regional action plans created to aid implementation of the SFDRR (AMCDRR, 2018).

Disaster risk reduction initiatives that address the interrelationship between the health of the environment and human health will prove critical in reaching 15 separate targets across five Sustainable Development Goals (SDG). These include SDG 3, on healthy lives and promote wellbeing; SDG6 on access to clean water and sanitation; SDG 11 on sustainable cities and communities; SDG 12 on responsible consumption and production and SDG15 on sustainable forests, desertification, degradation and biodiversity loss (United Nations, 2019). Article 8 of the Paris Agreement also recognises the role of sustainable development in reducing such disaster risk and loss and highlights cooperation and action needed to for ‘comprehensive risk assessment and management’ and for ‘resilient communities, livelihoods and ecosystems’ (UNFCCC, 2015, p.12).

Lastly, knowledge on evidence-based improvements for disaster risk reduction strategies, plans and systems will be necessary to support the broad and inclusive framework of the International Health Regulations (2005) designed to prevent and respond to public health threats which cross international borders (Fidler and Gostin, 2006; UNISDR, 2017, p.5; WHO, 2008).

Methodology

The study employed a two-step process. The first step involved performing a retrospective health risk assessment of each disaster event. The second step applied the results of the retrospective health risk assessments to a semi-quantitative novel health risk matrix. This enabled a crude assessment of the health risk characterisation for each hazard event to be established.

Step 1. Health Risk Assessment

The retrospective health risk assessment was performed using the UNISDR (2017) 'Health Aspect in Disaster Risk Assessment' guidelines as a framework to investigate the hazard in terms of health consequences (UNISDR, 2017, p.3). The comprehensive framework recommends four assessment categories including: i) Identifying the characteristics of a hazard and its associated health consequences; ii) Evaluating the exposure of individuals and populations to likely hazards (identifies the nature or mechanism of exposure and dose-response characteristics); iii) Analysing the context vulnerabilities and capacities associated with the hazard (this assesses context and vulnerability factors associated with the human population and environment in which they live, along with the capacity of the health system to respond) and iv) Characterising the public health impact (considers the possible health impact, including direct and indirect consequences).

A thematic and targeted word literature search collected information on each hazard and event (equatorial Asia smoke haze; allergens in thunderstorm asthma outbreaks). Databases searched included CINAHL (via EBSCOhost), PubMed, EMBASE (including Medline), Web of Science and SCOPUS. The search of grey literature was performed to capture documents from government authorities and non-government organisations involved in the emergency disaster response. Search criteria limited dates to those publications published before each disaster event, namely before June 2015 for equatorial Asia smoke haze and before November 2017 for thunderstorm asthma.

Step 2. Health Risk Characterisation

A semi-quantitative health risk assessment matrix was constructed using Standards Australia (ISO 3100:2009) health and safety risk matrices (SASNZ, 2009) and environmental health impact assessment matrix guidelines from the West Australian Department of Health (GOWA, 2010). The matrix tested the probability of event occurrence, expressed in frequency per time/year, against the relative human health impact, expressed as mortality/disability/hospitalization/evacuation counts. The information collected in response to the four health risk assessment categories for the equatorial Asia smoke haze event and Melbourne thunderstorm asthma epidemic event was applied to the matrix to determine the risk characterisation for each separate hazard event.

Results

1. 2015 Equatorial Asia Smoke Haze Disaster

Disaster Event Synopsis

Between June and October 2015, large-scale fires in Sumatra and Kalimantan Indonesia burned in excess of 2.6 million hectares of forest, peat and other land (Glauber et al., 2016). The nature and duration of the fires produced a thick smoke haze which was spread across the region by prevailing winds, directly affecting Brunei, Indonesia, Malaysia, Singapore, Thailand, Vietnam, Cambodia and the Philippines (Marlier et al., 2015; NASA Earth Observatory, 2015; Samsuddin et al., 2018).

Concentrations of airborne particulate and especially PM2.5, known to cause serious health effects, measured over 24-hour intervals, reached levels five times higher the WHO guidelines and 3.9 times greater than US EPA standards (Latif *et al*., 2018; Sharma and Balasubramanian, 2017). One conservative estimate calculated 185 million people were exposed to particulate matter (PM10) higher than WHO 24hr guidelines, and 217 million people were exposed to particulate matter (PM2.5) higher than WHO 24hr guidelines for 50% of the period between September and October 2015 (Crippa et al., 2016).

While the full spectrum of human health impact (including mental and physical disability) was not determined, one model measuring adult excess mortality estimated 103,000 excess deaths (95% CI, 26,300-174,300) occurred across Indonesia, Malaysia and Singapore (Koplitz et al., 2016). Another study measuring excess all-cause mortality due to short-term exposure to the particulate matter (PM2.5) estimated 11,880 excess deaths (95% CI, 6153-17,270) from short-term exposure to the smoke haze (Crippa et al., 2016).

Step 1. Applying the Health Risk Assessment Framework

i) Characteristics of the Hazard

Smoke haze pollution across equatorial Asia has been recognized as an annual problem for at least two decades and whose impact is dependent on environmental and climatological factors (Betha et al., 2013; Betha et al., 2014; Nicol, 1998; Reid et al., 2013; Miettinen et al., 2011). However the smoke generated from uncontrolled forest and peatland fires under certain natural climate cycles has been shown to contain high concentrations of particulate matter, including PM10 and PM2.5 , whose short and long-term exposure has been strongly associated with all-cause mortality and respiratory morbidity (Betha et al., 2014; Johnson et al, 2012; Marlier et al., 2013).

Drought conditions increase the frequency and intensity of wildfires across equatorial Asia during positive phases of El Nino Southern Oscillation (ENSO) and the Indian Ocean Dipole (IOD) (van der Werf et al., 2008; van der Werf et al., 2010; Reid et al., 2013; Tacconi, 2016). One study indicated smoke haze from Borneo was 30 times greater in El Nino conditions compared to La Nina conditions (van der Werf et al., 2008).

ii) Exposure of individuals and populations

There have been at least three previous historical smoke haze disaster events involving equatorial Asia, occurring in 1997 (Frankenberg et al., 2005; Heil and Goldammer, 2001; Kunii et al., 2002; WHO, 1998); 2005 (Norela et al., 2013; Sahani et al., 2014) and 2013 (Bertha et al; 2014; Ho et al., 2014). During the June 2013 event, the Malaysian Prime Minister declared an emergency when the air quality index reached a valve (API 750) more than two and half times that considered hazardous to human health (API 300) (New Straits Times, 2013; Betha et al., 2014).

Land, biomass and wildfires release a complex mixture of particulate matter and toxic gases, polycyclic aromatic hydrocarbons, inorganic ions, trace elements and endotoxins (Risen et al., 2011; See et al., 2007) and which include primary pollutants, some of which react within the mixture to form secondary pollutants (such as ozone) (Risen et al., 2013; Risen et al., 2015, p.1029). Landscape fires are an important contributor to airborne contamination through emissions of PM2.5 and ozone (Johnston et al., 2012; Reid et al., 2016; Liu et al., 2015). Impact assessments from landscape fires related to deforestation and land clearing is estimated to cause more than 300,000 premature deaths globally per year (Johnston et al., 2012).

These contaminants, mixed with ambient air can enter the human body either directly through inhalation, absorption via skin, indirectly through ingestion or via the trans-placental route, where they potentially damage tissue cells or initiate or aggravate a disease process (Ruckerl et al., 2011; Csavina et al., 2012). When ambient air is contaminated for long periods, without an intervention to reduce or eliminate exposure to the contaminated air, very high population exposure rates occur.

Epidemiological studies have identified vulnerable populations at higher risk of deleterious health impacts from exposure to PM2.5 including people with pre-existing respiratory and cardiovascular disease, people over 65 years of age, populations from lower socio-economic groups, children, infants and unborn foetuses (Ross, 2009; Ruckerl et al., 2011). Others suspected of higher risk include people with chronic inflammatory diseases (diabetes and obesity) and people with genetic polymorphisms (Cascio, 2018, p.589).

iii) Context, vulnerabilities and capacities

Indonesia is the world's fourth most populous country, with approximately 252 million people (World Bank Group, 2018). Despite being the second largest economy in south east Asia, with GDP per capita that has grown from $857 per annum to $3,603 in 15 years, 28 million people live below the poverty line and 40% of the population remain bordering on the line (World Bank Group, 2018). Rates of maternal mortality and proportion of stunting of children under five years of age remain some of the highest in the world and the Indonesian health system is vulnerable to large scale public health emergencies (Campbell et al., 2013). The WHO (2010) created three density thresholds to help inform discussions about the necessary size and skill mix of health professionals (total number of midwives, nurses, and physicians) to meet fundamental health needs per 10,000 population. There were three thresholds recommended of 22.8, 34.5, and 59.4 skilled health professionals per 10,000 population purposively selected to highlight the variation in health workforce availability. In 2010, Indonesia's Health care worker density was recorded at 16.1 per 10,000 population, requiring at least a 78% increase in health professionals to meet the minimum WHO standard of 22.8 per 10,000 (Campbell et al, 2013, p.60).

iv) Public health impact

The global burden of disease study (Wang et al., 2016) study estimated that in 2015, mortality from PM2.5 in ambient air caused 7.6% of global deaths, a rise of 20%, from 3.5 (95%UI, 3.0- 4.0 million) million people in 1990 to 4.2 (95%UI, 3.7- 4.8 million) million people in 2015 (Cohen et al et al., 2017).

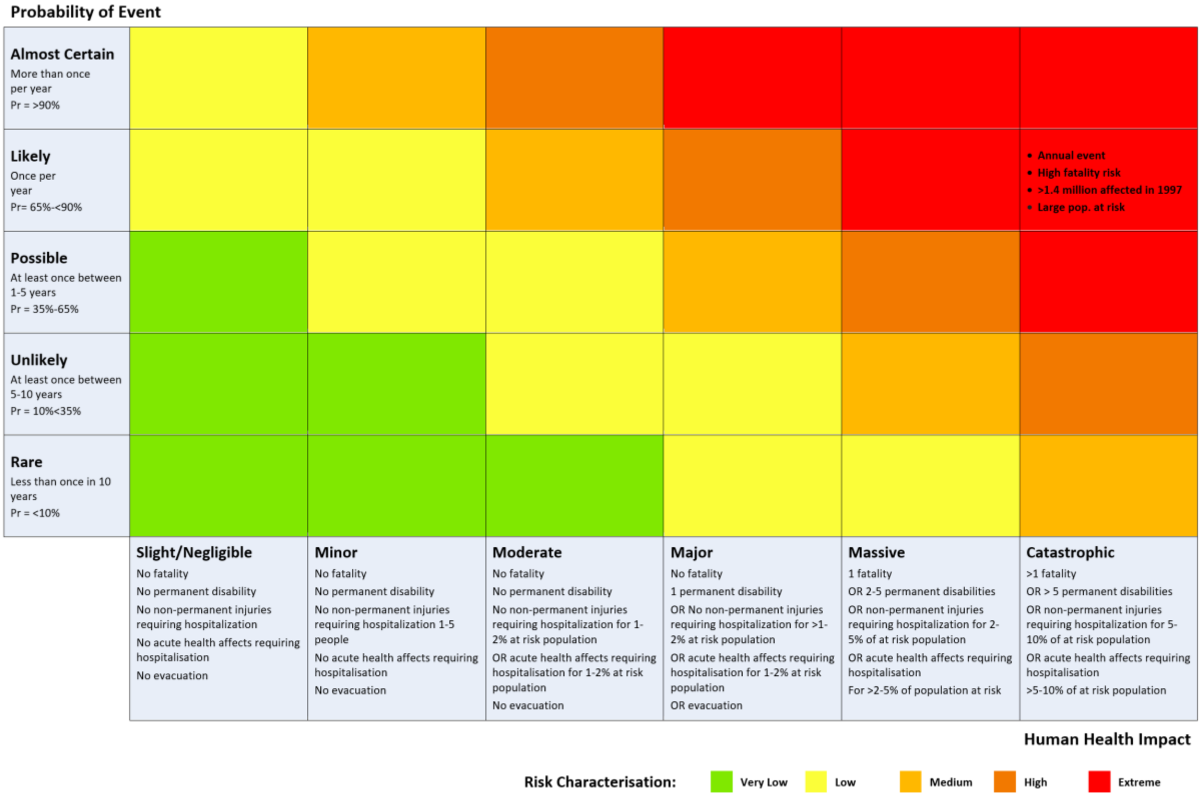
The public health impact from exposure to air pollution is profound and ranked as one of the leading causes of the total global disease burden and the leading cause of pollution-related deaths (Cohen at al., 2017, Lelieveld et al., 2015; WHO, 2009). The number of deaths attributable to particulate matter (PM 2.5) contaminated in ambient air is estimated to have risen from 3.5 million (95%CI 3.0-4.0 million) in 1990 to 4.2 million (3.7-4.8 million) in 2015 (Landrigan et al., 2017). Current trends in mortality caused from exposure to air pollution are expected to increase by 50%, and analyses have shown a doubling of mortality rates under a 'business as usual' case scenario (Lelievald et al., 2015).

More specifically exposure to wildfire smoke is estimated to cause 339,000 deaths (95% CI, 260,000–600,000) annually (Johnston et al., 2012). Systematic reviews of epidemiological evidence have shown strong associations between exposure to wildfire smoke and all-cause mortality (Youseff et al., 2014; Liu et al., 2015). Similarly, studies on morbidity risks from lower respiratory infections, chronic obstructive pulmonary disease, lung cancer, ischemic heart disease and stroke from exposure to wildfire smoke which have shown increased associations are supported by more recent systematic reviews (Haikerwal et al., 2015; Casico, 2018).

From a purely experiential viewpoint, the public health effects in equatorial Asia from the 1997 fires and smoke haze affecting Indonesia, Singapore, Malaysia, Brunei and Thailand (Hu et al., 2018) were reported to include 527 haze-related deaths; 298,125 cases of asthma; 58, 095 cases of bronchitis and 1,446,120 cases of acute respiratory illness (Kunii et al., 2002; Hu et al., 2018, Sastry, 2002). Children, the elderly and people with pre-existing respiratory illness were the most severely affected people across the population (Heil and Goldammer, 2001).

Step 2. Testing the Health Risk Characterisation

Figure 1. Health Risk Matrix – 2015 Equatorial Smoke Haze



Source: Standards Australia ISO 3100:2009(SASNZ, 2009) and West Australian Department of Health (GOWA, 2010).

2. 2016 Melbourne Thunderstorm Asthma Epidemic

Disaster Event Synopsis

On 21st and 22nd November 2016, the largest thunderstorm asthma event ever recorded occurred in the State of Victoria, Australia (Inspector General for Emergency Management, 2016). Over the two day period, there were 12,723 presentations to state public hospital emergency departments, 3,867 more than expected, based on the three-year average (VDHSS, 2017). Within 30 hours of the thunderstorm occurring, emergency services received 2666 phone calls, 962 with breathing difficulty; 3365 patients with respiratory symptoms and 1428 with nil diagnosis presented to emergency departments (Davies et al., 2017). A further 35 patients were admitted to intensive care and nine deaths were reported to the coroner (Davies et al., 2017). In the large and highly resourced urban health service areas of Melbourne and Geelong, there were 9,909 presentations to public hospital emergency departments (3,643 more than expected based on a three-year average) and a 30-fold increase in asthma-related admissions to hospital (VDHSS, 2017, p.3)

In two days, there were 1,626 more calls to the Emergency Services Telecommunications Authority than forecast; a six-fold increase in home visits by the National Home Doctor service; a 48% increase in phone calls to the Nurse-On-Call service a and 2.5-fold increase in attendance to Supercare Pharmacies (VDHHS, 2017).

Step 1. Applying Risk Assessment Framework

i) Characteristics of the Hazard

For more than 30 years, thunderstorms have been recognised as part of a mechanism to trigger sudden and rapidly occurring outbreaks of acute and severe asthma across communities in different parts of the world (Marks et al., 2001). The published literature reports 22 outbreaks of thunderstorm asthma events globally since 1983, associated with sudden onset of acute and severe asthma in Australia (Bellomo et al., 1992; Egan, 1985; Erbas et al., 2012; Girgis et al., 2000; Howden 2011), the United Kingdom (Packe and Ayres, 1985; Wallis et al., 1996; Higham et al., 1997; Johnson and Sears, 2006), Italy (D’Amato et al., 2016), Canada (Wardman et al., 2002; Dales et al., 2003), Iran (Forouzan et al., 2014), and Kuwait (Bousquet et al., 2017). More specifically, outbreaks of thunderstorm asthma occurring near Melbourne, Australia, in the month of November had been reported on at least five other occasions, including in 1984 (Egan, 1985), 1987 and 1989 (Bellamo et al., 1992), 2003 (Erbas et al., 2012) and 2010 (Howden et al., 2011).

Marks and Bush (2007, p.531) proposed a model of four necessary conditions for a thunderstorm asthma event to occur. These included i) high concentrations of allergenic material, such as grass pollen or fungal spores; ii) a thunderstorm outflow that sweeps up the grass pollen and/or fungi and concentrates the material near ground level in a population centre; iii) Formation of respirable particles (<10 µm), for example, by the action of water in rupturing pollen grains to release starch granules or germinating fungal spores; and iv) exposure of individuals who are sensitized to the relevant allergen and have a propensity for airway narrowing, that is, untreated airway hyperresponsiveness, to an air mass containing a high concentration of respirable allergenic particles.

ii) Exposure of individuals and populations

Thunderstorms are capable of collecting and fracturing pollen and rapidly pushing high concentrations of the fractured allergens ahead of the storm in large outflow air masses (Taylor and Jonsson, 2004). People in the path of the air mass are exposed and inhale a high dose of air filled with allergens, that are small enough to get past the nose and throat and reach deeply into the lungs (Marks and Bush, 2007; VDHHS, 2017). Those vulnerable to health effects must either i) be sensitised to the allergen, and or, ii) suffer from allergic rhinitis (hay fever) with or without asthma, and or iii) being exposed to open air and not taking preventative medication for asthma (Davies et al., 2017, p.12)

Of most significance, is that up to 40% of people presenting to emergency departments with respiratory difficulties during a thunderstorm asthma event have not previously experienced asthma (Davidson et al., 1996; Davies et al., 2017; Girgis et al., 2000). Similarly, the prevalence of hay fever and asthma in Asian migrants increase significantly with the length of stay in Australia, and after ten years up to 60% of south east Asian born immigrants develop hay fever and 15% have symptoms of asthma (Leung et al., 1994; Leung, 1996).

iii) Context, vulnerabilities and capacities

The Australian federal government funds a universal public health insurance program providing free or subsidised access to health care for Australian citizens and many residents. The total health expenditure in the years 2013–2014 represented 9.8 per cent of gross domestic product (GDP), or $4,115 per capita (Mossialos et al., 2016, p.11). The average growth rate in real domestic spending per capita is 2.42%, which compares with the United Kingdom at -0.88% and the United States at 1.24% (Mossialos et al., 2016, p.7). In 2013, there were 3.39 physicians per 1000 population, which compares with the United Kingdom at 2.77 and the United States at 2.56 (Mossialos et al., 2016, p.7).

A recent study compared the health system performance of 11 high-income countries based on an analysis of 72 indicators (Schneider, 2017). The study concluded Australia's health system was the second highest overall behind the United Kingdom, with the top ranking in the domains of health outcomes, administrative efficiency and second-ranked in the 'care process' (Schneider, 2017).

The first national asthma strategy was developed by the Australian National Asthma Council in 1999 and was quickly followed by a National Asthma Action Plan (NACA, 2018). For over twenty years, funded by the

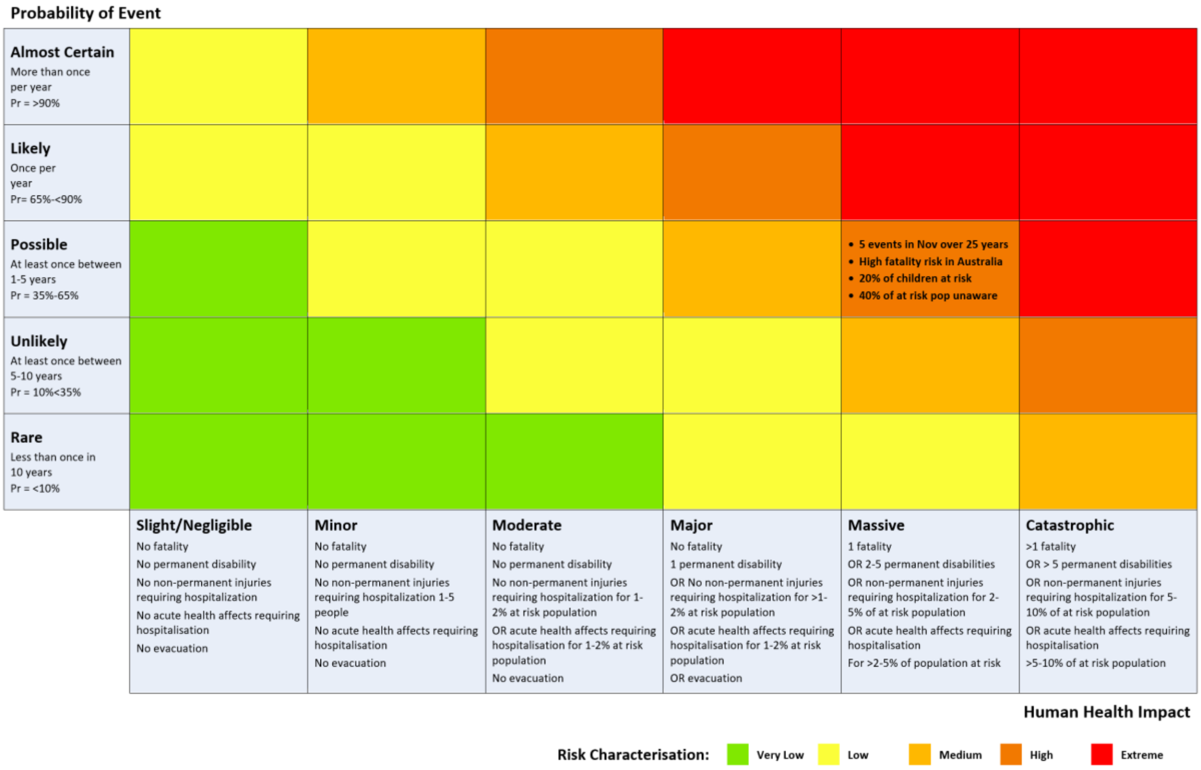
Australian government, and supported by network partners, the Asthma Council has led the process of re-developing successive national asthma strategies, supporting community-wide asthma initiatives and developing clinical management and best practice guidelines (NACA, 2018).

iv) Public health impact

Australia has one of the highest asthma mortality rates in the world (Davies et al., 2017). Dropping from a peak of 964 deaths in 1989, asthma caused 421 deaths in 2015 and 455 deaths in 2016 (NACA, 2018). The prevalence of asthma in children is also among the highest in the world, with up to 20.5% of children affected at some point in their childhood (VDHHS, 2017). In the State of Victoria, approximately 17% of people have allergic rhinitis, with research indicating that 70-90% of asthmatics also have allergic rhinitis and approximately 50% of people with allergic rhinitis have asthma (VDHSS, 2017, p.12). While there had been no deaths recognised in Australia from thunderstorm asthma before 2016, three deaths were reported in children (<17years of age) from the eastern region of the United Kingdom between 2001 and 2006, following thunderstorm asthma events (Anagnostou et al., 2012).

Step 2. Testing the Health Risk Characterisation

Figure 2. Health Risk Matrix – 2016 Melbourne Thunderstorm Asthma Epidemic



Source: Standards Australia ISO 3100:2009(SASNZ, 2009) and West Australian Department of Health (GOWA, 2010).

Discussion

The health risk assessment approach used in this study to retrospectively test both hazards reveals the Equatorial smoke haze would have been characterised at an 'extreme' level of health risk and the thunderstorm asthma event at 'high' level of health risk. Notwithstanding the methodological limitations of using health risk matrices previously well defined (Vatanpour et al., 2015), it is challenging to draw any other conclusion of the risk characterisation, given the historical frequency of each event and the size of each respective vulnerable population. The magnitude of people at risk meant that any significant event would produce a large and possibly catastrophic level of morbidity and mortality.

Arguably, the most perplexing element in each of these disaster events was the missed opportunity to implement strategies, actions or controls to reduce or mitigate the health impact on vulnerable people living in affected communities. Not only had the health risk been historically well defined and recognized, but actions to reduce the risk of harm been explored or implemented in other localities over a decade before each disaster occurred. In the circumstance of thunderstorm asthma, a risk management initiative was implemented 16 years earlier, in a different State of Australia in the regional town of Wagga Wagga, New South Wales. An 'early warning system' approach had been successfully established through a collaboration between the Bureau of Meteorology, who monitored thunderstorms, the local University who monitored pollen counts, and the local health service who warned the community of impending risk of asthma when pre-conditions occurred (Girgis et al., 2000). In the circumstance of the Equatorial smoke haze, recognition of the need to address the hazard and major health and economic risks was highlighted in the 2002 ASEAN Agreement on Transboundary Haze Pollution (ASEAN Secretariat, 2002). The agreement was the first of its kind and aimed to mitigate and prevent haze pollution through national-to-local activities and increase regional and international cooperation (Nazeer and Furuoka, 2017).

The extreme and high characterisation of health risk for these hazards and the relative absence of effective risk reduction plans before each disaster raise serious questions for disaster risk management and emergency response sectors. The most compelling: how have two decades of published research and scientific commentary, specifically relating to each hazard, their risks and vulnerable populations, failed to translate into meaningful action to reduce morbidity and mortality risk? Of equal importance, how had effective plans and actions previously implemented to reduce the threat of mortality and morbidity not been considered necessary or applicable despite such high and extreme levels of health risk?

While specific answers to these questions are beyond the scope of this study, valuable lessons can be learned to assist national and regional efforts in implementing the SFDRR and achieving targets of the SDG's. In particular is the knowledge gained to help implement priority areas of action, including priority one, 'understanding disaster risk' and priority four, 'enhancing disaster preparedness for effective response and to build back better in recovery, rehabilitation and reconstruction' (UNISDR, 2015, p.14).

'Priority 1. Understanding disaster risk'

Hazard risk assessment approaches and methods developed by member States should consider and interpret the changing dynamic nature of risk caused by any significant deterioration to natural ecosystems or physical environment within a local area. As illustrated by these disaster events, as the physical environment changed, the health and mortality risk from known and unknown hazards contained within the environment rapidly increased. In both disasters in this study, the magnitude of change to the environment was not matched with the necessary re-calibration of risk to vulnerable populations and as such, corresponding preparedness or response plans were not implemented. Hazards present in the deteriorated physical environment that expose vulnerable populations through air or water or soil need to be recognized and monitored. Where indicated, new risk adjustment strategies will be required to escalate disaster risk reduction plans, actions and emergency measures to protect the community from new or escalating environmental risks. Methods and approaches will be necessary to measure the ongoing and changing level of risk over time of the physical environment (air, water, soil) as an integral part of the overall local and national risk reduction strategy.

Similarly local, national and regional disaster risk assessments should materially be linked to disaster response or action plans that effectively prevent and mitigate the hazard risk for vulnerable populations. In both disaster events in this study, the risk from the hazards were comprehensively understood and recognised. However the link between the knowledge of the hazards, the health risk and an appropriate scalable response plan to reduce or eliminate the risk for vulnerable people was missing. All effort should be made to deliberately link local and national hazard identification with preparedness and response strategies and plans. This will provide invaluable information and capacity building opportunities to strengthen future local, national and regional cooperation and collaboration efforts.

Arguably, one of the most difficult challenges facing nations implementing the SFDRR is grappling with the measurement of disaster mortality. The technical guidance developed to support the monitoring and reporting of progress targets is clear where injury and death are time bound and fit within a narrow lens of death from acute physical trauma, drowning or poisoning (UNISDR, 2017). In both disaster events in this study, attribution of death from the hazard was not straightforward, despite unequivocal medical and scientific knowledge of the causal link between hazard exposure and mortality risk. At the heart of this challenge, is demonstrating mortality risk across a time continuum, where the health effect is not detected for weeks, months or years after the hazard exposure in the disaster event. In some circumstances, the presence and acuity of illness is not apparent until after an insidious or cumulative threshold of exposure has been reached, after which point the mortality risk becomes significant. In the case of pregnant women, the mortality risk from exposure to environmental contaminants is not equal for the pregnant women compared to the growing foetus/unborn infant. Such mortality risk and attribution of mortality from disasters requires improved recognition and management. Greater attention, technical discourse and agreement is urgently needed to manage and accurately report deaths caused from disasters exposing people to environmental hazards. Without accurate measurement, the prioritization of hazards and actions to manage population risk will be misconstrued, to the great cost of otherwise preventable deaths. The case in point is represented in this study. Despite both the smoke haze disaster and thunderstorm asthma epidemic meeting the classification and criteria for reporting on the EM DAT system, the estimated deaths and people affected from these disasters have not been counted or currently included in the EM DAT reports, analyses or discussion (CRED, 2018a; CRED, 2018b).

A further challenge facing local agencies developing disaster risk profiles will be performing vulnerability assessments for different environmental hazards and the corresponding action plans to protect people identified at risk. In the case of the thunderstorm asthma epidemic, 40% of those people affected had no prior history of asthma, and as such, did not know they were at heighted risk. In the smoke haze disaster, people with diabetes, heart disease and COPD were at higher risk, which represented a very large proportion of the population. Cardiovascular disease, diabetes, chronic obstructive pulmonary diseases (COPD) and cancers have become an emerging pandemic globally with disproportionately higher rates in developing countries (Terzic and Waldman, 2011). In 2015, non-communicable diseases (NCDs) accounted for 71% of the deaths due to exposure to environmental contaminants (Wang et al., 2016). At a global level, 92% of all mortality attributed to environmental contamination occurs in low and middle-income countries, with the highest number of deaths in south east Asia (3.2 million deaths- includes India) and western Pacific (2.2 million- includes China) (Landrigan et al, 2017). By 2020, NCD's are estimated to account for 80 percent of the global burden of disease, causing seven out of every ten deaths in developing countries (Mathers and Loncar, 2006; WHO 2016). As such, improved technical guidance will be required to develop accurate and specific vulnerability profiles for specific hazards across large populations and particularly for 'at risk groups' whom are unaware of their level of risk. Such profiles will prove invaluable because of the direct application and use for disaster preparedness and response plans to mitigate risk for each vulnerable group.

'Priority 4. Enhancing disaster preparedness for effective response…'

At a regional level, institutional cooperation efforts should seek to specifically address transboundary environmental hazard risks and prepare for the potential of cascading disaster risk from contaminated air, water or soil. Guidelines and tools are needed to recognize the transportability of mortality risk for vulnerable populations in one locality, from hazards contained within the physical environment in a different geographic locale. As the smoke haze disaster demonstrated, the capacity to manage the hazard and reduce the risk to vulnerable populations may not be possible or even effective, even though the threat to vulnerable people from the hazard intensifies. National and local risk assessments that identify cross-border environmental hazards require links with innovative contingency response plans, where mortality risk can be effectively managed by evidence-based exposure prevention approaches. National plans that seek to reduce risk through multi-faceted early warning systems should embrace the opportunity to build capacity of local authorities and engage local communities to manage in-situ environmental monitoring and data collection and reporting.

Preventing catastrophic premature mortality from environmental contamination will require sophisticated approaches that can link different monitoring systems and act collectively to: i) monitor health risk in real or near-real time; ii) create the essential nexus between environmental hazard exposure and human health risk; and iii) report patient continuum of care. Such systems are necessary for the health service to respond to people in need of life saving care, and to act to prevent and protect other vulnerable groups from hazard exposure and premature mortality risk. Managing environmental hazard risks requires innovative exposure prevention approaches that act as the foundation of health risk reduction strategies. In the circumstance of the smoke haze and asthma epidemic, the health service disaster response plans were geared toward the treatment and care of casualties, as distinct from strategies that reduce or eliminate human exposure and downstream health impacts. Emergency health and medical disaster response approaches need to recognise the two-tailed human health risk from disaster events and act to respond to those people in need of medical care but also prevent exposure and protect others at risk.

Conclusion

To succeed in substantially reducing global disaster risk and loss of life and livelihoods, requires urgent attention to address potential catastrophic levels of risk from exposure to environmental hazards. The two disaster events examined in this study demonstrate the transportability of risk through the environment and across national boundaries, to expose large populations of people to grave health risks at a rapid pace.

National and regional risk reduction strategies and plans should be underpinned by bi-modal approaches, where the capacity to alter or affect the hazard itself is not available to disaster response agencies and partners. As observed in both these study examples, the ability to mitigate the hazard at its source was not available for governments, risk management agencies or disaster response organisations.

Risk reduction strategies need to restore health to the physical environment and mitigate current damage to natural ecosystems, as well as concentrate on eliminating hazard exposure to vulnerable people. Hazards identified as high-risk in risk assessment methods must be manifestly linked to disaster response strategies, plans and actions. Such initiatives, which have proved elusive for the disaster management agencies involved in complex hazard response and mitigation (CRED/UNISDR, 2016) will be necessary to achieve specific targets contained within five different Sustainable Development Goals, including SDG3, SDG6, SDG11, SDG12 and SDG15 (United Nations, 2019).

To address this growing global health risk, multi-sectoral and multi-disciplinary integrated disaster risk reduction approaches are required, implemented through new and innovative partnerships between, institutional collaborations and the community. The healthcare sector is universally trained to manage acute injury and trauma from hazards associated with disaster events. Reducing the risk of premature mortality from hazards whose health risk involves insidious cumulative exposure, or whose health effect is latent, represents a much greater challenge to manage. A major innovation in disaster health management is required, that integrates surveillance of the physical environment with human healthcare information systems and concentrates on public health protection.

Lastly, urgent research is needed to understand the efficacy of interventions to reduce exposure to environmental contaminant risks and the role the changing dynamics of the physical environment play, in increasing or reducing these risks. Understanding the relationships between the environment, exposure to contaminants during disaster events and specific disease outcomes will be vital for effective risk reduction approaches in the future (Cascio, 2018).

References

Anagnostou, K., Harrison, B., Iles, R., & Nasser, S. (2012). Risk factors for childhood asthma deaths from the UK Eastern Region Confidential Enquiry 2001–2006. *Primary Care Respiratory Journal*, *21*(1), 71.

Asian Ministerial Conference on Disaster Risk Reduction (AMCDRR). (2018). *Action Plan 2018-2020 of the Asia regional plan for implementation of the Sendai framework for disaster risk reduction 2015–2030*. Retrieved at: https://www.preventionweb.net/files/56219_actionplan20182020final.pdf

Bellomo, R., Gigliotti, P., Treloar, A., Holmes, P., Suphioglu, C., Singh, M. B., & Knox, B. (1992). Two consecutive thunderstorm associated epidemics of asthma in the city of Melbourne. The possible role of rye grass pollen. *The Medical Journal of Australia*, *156*(12), 834-837.

Betha, R., Pradani, M., Lestari, P., Joshi, U. M., Reid, J. S., & Balasubramanian, R. (2013). Chemical speciation of trace metals emitted from Indonesian peat fires for health risk assessment. *Atmospheric Research*, *122*, 571-578.

Betha, R., Behera, S. N., & Balasubramanian, R. (2014). 2013 Southeast Asian smoke haze: fractionation of particulate-bound elements and associated health risk. *Environmental science & technology*, *48*(8), 4327-4335.

Bousquet, J., O'Hehir, R. E., Anto, J. M., D'Amato, G., Mösges, R., Hellings, P. W., ... & Sheikh, A. (2017). Assessment of thunderstorm-induced asthma using Google Trends. *Journal of Allergy and Clinical Immunology*, *140*(3), 891-893.

Campbell, J., Dussault, G., Buchan, J., Pozo-Martin, F., Guerra Arias, M., Leone, C., ... & Cometto, G. (2013). A universal truth: no health without a workforce. *Geneva: World Health Organization*.

Cascio, W. E. (2018). Wildland fire smoke and human health. *Science of the Total Environment*, *624*, 586-595.

Centre for Research on the Epidemiology of Disasters (CRED). (2018a) EM DAT. The International Disaster Database. General Classification. Retrieved from: https://www.emdat.be/classification#Meteorological

CRED. (2018b) EM DAT. The International Disaster Database. Criteria. Retrieved from: https://www.emdat.be/explanatory-notes

CRED. (2016). 2016 Preliminary data: human impact of natural disasters. *CRED Crunch*, (45).

CRED. (2016b). Heat Waves and Health. CRED Crunch Issue No. 46. Retrieved from http://cred.be/sites/default/files/CredCrunch46.pdf

Centre for Research on the Epidemiology of Disasters/United Nations International Strategy for Disaster Reduction (CRED/UNISDR). (2016). Poverty and death: Disaster mortality 1996–2015.

Cohen, A. J., Brauer, M., Burnett, R., Anderson, H. R., Frostad, J., Estep, K., ... & Feigin, V. (2017). Estimates and 25-year trends of the global burden of disease attributable to ambient air pollution: an analysis of data from the Global Burden of Diseases Study 2015. *The Lancet*, 389(10082), 1907-1918.

Corvalan, C., Hales, S., McMichael, A. J., & Butler, C. (2005). *Ecosystems and human well-being: health synthesis*. World Health Organization.

Crippa, P., Castruccio, S., Archer-Nicholls, S., Lebron, G. B., Kuwata, M., Thota, A., ... & Spracklen, D. V. (2016). Population exposure to hazardous air quality due to the 2015 fires in Equatorial Asia. *Scientific reports*, *6*, 37074.

Csavina, J., Field, J., Taylor, M. P., Gao, S., Landázuri, A., Betterton, E. A., & Sáez, A. E. (2012). A review on the importance of metals and metalloids in atmospheric dust and aerosol from mining operations. *Science of the Total Environment*, *433*, 58-73.

Dales, R. E., Cakmak, S., Judek, S., Dann, T., Coates, F., Brook, J. R., & Burnett, R. T. (2003). The Role of Fungal Spores in Thunderstorm Asthmaa. *Chest*, *123*(3), 745-750.

Davies, J. M., Erbas, B., Simunovic, M., Al Kouba, J., & Milic, A. (2017). Literature review on thunderstorm asthma and its implications for public health advice.

Davidson AC, Emberlin J, Cook AD, Venables KM, Accident, T. R., & Emergency Trainer Association. (1996). A major outbreak of asthma associated with a thunderstorm. *BMJ*, *312*, 601-604.

D'amato, G., Vitale, C., D'amato, M., Cecchi, L., Liccardi, G., Molino, A., ... & Annesi-Maesano, I. (2016). Thunderstorm-related asthma: what happens and why. *Clinical & Experimental Allergy*, *46*(3), 390-396.

Demaio, A., Jamieson, J., Horn, R., de Courten, M., & Tellier, S. (2013). Non-communicable diseases in emergencies: a call to action. *PLoS currents*, *5*.

Egan, P. (1985). Weather or not. *The Medical Journal of Australia*, *142*(5), 330.

Erbas, B., Akram, M., Dharmage, S. C., Tham, R., Dennekamp, M., Newbigin, E., ... & Abramson, M. J. (2012). The role of seasonal grass pollen on childhood asthma emergency department presentations. *Clinical & Experimental Allergy*, *42*(5), 799-805.

Fidler, D. P., & Gostin, L. O. (2006). The new International Health Regulations: an historic development for international law and public health. *The Journal of Law, Medicine & Ethics*, *34*(1), 85-94.

Field, R. D., Van Der Werf, G. R., Fanin, T., Fetzer, E. J., Fuller, R., Jethva, H., ... & Worden, H. M. (2016). Indonesian fire activity and smoke pollution in 2015 show persistent nonlinear sensitivity to El Niño-induced drought. *Proceedings of the National Academy of Sciences*, *113*(33), 9204-9209.

Fifth Assessment Report of the Intergovernmental Panel on Climate Change, in Smith, K.R., A.Woodward, D. Campbell-Lendrum, D.D. Chadee, Y. Honda, Q. Liu, J.M. Olwoch, B. Revich, and R. Sauerborn, 2014: Human health: impacts, adaptation, and co-benefits. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Field, C.B., V.R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel,A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L.White (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 709-754.

Forouzan A, Masoumi K, Haddadzadeh Shoushtari M, Idani E, Tirandaz F, Feli M, et al. An overview of thunderstorm-associated asthma outbreak in southwest of Iran. J Environ Public Health 2014; 2014:504017.

Forouzanfar, M. H., Afshin, A., Alexander, L. T., Anderson, H. R., Bhutta, Z. A., Biryukov, S., ... & Cohen, A. J. (2016). Global, regional, and national comparative risk assessment of 79 behavioural, environmental and occupational, and metabolic risks or clusters of risks, 1990–2015: a systematic analysis for the Global Burden of Disease Study 2015. The Lancet, 388(10053), 1659-1724.

Frankenberg, E., McKee, D., & Thomas, D. (2005). Health consequences of forest fires in Indonesia. *Demography*, *42*(1), 109-129.

Girgis, S. T., Marks, G. B., Downs, S. H., Kolbe, A., Car, G. N., & Paton, R. (2000). Thunderstorm-associated asthma in an inland town in south-eastern Australia. Who is at risk?. *European Respiratory Journal*, *16*(1), 3-8.

Glauber, A. J., Moyer, S., Adriani, M., & Gunawan, I. (2016). The cost of fire: an economic analysis of Indonesia's 2015 fire crisis. *The World Bank http://pubdocs. worldbank. org/en/643781465442350600/Indonesia-forest-fire-notes. pdf (Accessed 15 June 2016)*.

Government of Western Australia (GOWA). Department of Health. (2010). Health Risk Assessment Guidelines: health risk assessment process for risk assessors for use within the scoping stages of environmental and health impact assessments. GOWA, Perth, Western Australia.

Guha-Sapir, D., Hoyois, P., & Below, R. (2016). Annual disaster statistical review 2015: the numbers and trends. CRED: Brussels; 2016.

Haikerwal, A., Akram, M., Del Monaco, A., Smith, K., Sim, M. R., Meyer, M., ... & Dennekamp, M. (2015). Impact of fine particulate matter (PM 2.5) exposure during wildfires on cardiovascular health outcomes. *Journal of the American Heart Association*, *4*(7), e001653.

Heil, A., & Goldammer, J. (2001). Smoke-haze pollution: a review of the 1997 episode in Southeast Asia. *Regional Environmental Change*, *2*(1), 24-37.

Higham, J., Venables, K., Kupek, E., Bajekal, M., & Kopek, E. (1997). Asthma and thunderstorms: description of an epidemic in general practice in Britain using data from a doctors' deputising service in the UK. *Journal of Epidemiology & Community Health*, *51*(3), 233-238.

Ho, R. C., Zhang, M. W., Ho, C. S., Pan, F., Lu, Y., & Sharma, V. K. (2014). Impact of 2013 south Asian haze crisis: study of physical and psychological symptoms and perceived dangerousness of pollution level. *BMC psychiatry*, *14*(1), 81.

Howden, M. L., McDonald, C. F., & Sutherland, M. F. (2011). Thunderstorm asthma—a timely reminder. *The Medical Journal of Australia*, *195*(9), 512-513.

Hu, Y., Fernandez-Anez, N., Smith, T. E., & Rein, G. (2018). Review of emissions from smouldering peat fires and their contribution to regional haze episodes. *International Journal of Wildland Fire*, *27*(5), 293-312.

Inspector-General for Emergency Management. (2016). Review of response to the thunderstorm asthma event of 21-22 November 2016: Final Report. 2017.

Johnston, F. H., Henderson, S. B., Chen, Y., Randerson, J. T., Marlier, M., DeFries, R. S., ... & Brauer, M. (2012). Estimated global mortality attributable to smoke from landscape fires. *Environmental health perspectives*, *120*(5), 695.

Johnston, N. W., & Sears, M. R. (2006). Asthma exacerbations· 1: epidemiology. *Thorax*, *61*(8), 722-728.

Koplitz, S. N., Mickley, L. J., Marlier, M. E., Buonocore, J. J., Kim, P. S., Liu, T., ... & Pongsiri, M. (2016). Public health impacts of the severe haze in Equatorial Asia in September–October 2015: demonstration of a new framework for informing fire management strategies to reduce downwind smoke exposure. *Environmental Research Letters*, *11*(9), 094023.

Kunii, O., Kanagawa, S., Yajima, I., Hisamatsu, Y., Yamamura, S., Amagai, T., & Ismail, I. T. S. (2002). The 1997 haze disaster in Indonesia: its air quality and health effects. *Archives of Environmental Health: An International Journal*, *57*(1), 16-22.

Landrigan, P. J., Fuller, R., Acosta, N. J., Adeyi, O., Arnold, R., Baldé, A. B., ... & Chiles, T. (2017). The Lancet Commission on pollution and health. *The Lancet*.

Latif, M. T., Othman, M., Idris, N., Juneng, L., Abdullah, A. M., Hamzah, W. P., ... & Sahani, M. (2018). Impact of regional haze towards air quality in Malaysia: a review. *Atmospheric Environment*.

Leaning, J., & Guha-Sapir, D. (2013). Natural disasters, armed conflict, and public health. *New England journal of medicine*, *369*(19), 1836-1842.

Lelieveld, J., Evans, J. S., Fnais, M., Giannadaki, D., & Pozzer, A. (2015). The contribution of outdoor air pollution sources to premature mortality on a global scale. *Nature*, *525*(7569), 367.

Leung, R. C., Carlin, J. B., Burdon, J. G., & Czarny, D. (1994). Asthma, allergy and atopy in Asian immigrants in Melbourne. *The Medical Journal of Australia*, *161*(7), 418-425.

LEUNG, R. (1996). Asthma and migration. *Respirology*, *1*(2), 123-126.

Lindstrom, S. J., Silver, J. D., Sutherland, M. F., Treloar, A., Newbigin, E., McDonald, C. F., & Douglass, J. A. (2017). Thunderstorm asthma outbreak of November 2016: a natural disaster requiring planning. *The Medical Journal of Australia*, 207(6), 235-237.

Liu, J. C., Pereira, G., Uhl, S. A., Bravo, M. A., & Bell, M. L. (2015). A systematic review of the physical health impacts from non-occupational exposure to wildfire smoke. *Environmental research*, 136, 120-132.

Marks, G. B., Colquhoun, J. R., Girgis, S. T., Koski, M. H., Treloar, A. B. A., Hansen, P., ... & Car, N. G. (2001). Thunderstorm outflows preceding epidemics of asthma during spring and summer. *Thorax*, *56*(6), 468-471.

Marks, G. B., & Bush, R. K. (2007). It's blowing in the wind: new insights into thunderstorm-related asthma. *Journal of Allergy and Clinical Immunology*, *120*(3), 530-532.

Marlier, M. E., DeFries, R. S., Voulgarakis, A., Kinney, P. L., Randerson, J. T., Shindell, D. T., ... & Faluvegi, G. (2013). El Niño and health risks from landscape fire emissions in southeast Asia. *Nature climate change*, *3*(2), 131.

Marlier, M. E., DeFries, R. S., Kim, P. S., Koplitz, S. N., Jacob, D. J., Mickley, L. J., & Myers, S. S. (2015). Fire emissions and regional air quality impacts from fires in oil palm, timber, and logging concessions in Indonesia. *Environmental Research Letters*, *10*(8), 085005.

Mathers, C. D., & Loncar, D. (2006). Projections of global mortality and burden of disease from 2002 to 2030. *PLoS medicine*, *3*(11), e442.

Miettinen, J., Shi, C., & Liew, S. C. (2011). Deforestation rates in insular Southeast Asia between 2000 and 2010. *Global Change Biology*, *17*(7), 2261-2270.

Mossialos, E., Wenzl, M., Osborn, R., & Sarnak, D. (2016). *2015 international profiles of health care systems*. Canadian Agency for Drugs and Technologies in Health.

McMichael, A. J., Woodruff, R. E., & Hales, S. (2006). Climate change and human health: present and future risks. *The Lancet*, *367*(9513), 859-869.

McMichael, A. J., & Bennett, C. M. (2016). Global environmental change and human health. In *The Ashgate Research Companion to the Globalization of Health* (pp. 119-138). Routledge.

NASA Earth Observatory. (2015). Smoke blankets Sumatra. Retrieved from https://earthobservatory.nasa.gov/IOTD/view.php?id=86681&eocn=image&eoci=related_image

National Asthma Council of Australia (NACA). (2018). Asthma Mortality Statistics. Retrieved from https://www.nationalasthma.org.au/living-with-asthma/resources/health-professionals/reports-and-statistics/asthma-mortality-statistics

Nazeer, N., & Furuoka, F. (2017). OVERVIEW OF ASEAN ENVIRONMENT, TRANSBOUNDARY HAZE POLLUTION AGREEMENT AND PUBLIC HEALTH. *International Journal of Asia-Pacific Studies*, *13*(1).

New Straits Times. (2013). Malaysia PM declares emergency in Muar and Ledang, API surpasses 750. Retrieved from http://www.asiaone.com/health/malaysia-pm-declares-emergency-muar-and-ledang-api-surpasses-750

Nichol, J. (1998). Smoke haze in Southeast Asia. A predictable recurrence. *Atmospheric Environment*, *32*, 2715-2716.

Norela, S., Saidah, M. S., & Mahmud, M. (2013). Chemical composition of the haze in Malaysia 2005. *Atmospheric environment*, *77*, 1005-1010.

Noy, I. (2016). A Global Comprehensive Measure of the Impact of Natural Hazards and Disasters. *Global Policy*, *7*(1), 56-65.

Packe GE, Ayres JG. Asthma outbreak during a thunderstorm. Lancet 1985; 2: 199-204.

Reid, J. S., Hyer, E. J., Johnson, R. S., Holben, B. N., Yokelson, R. J., Zhang, J., ... & Holz, R. E. (2013). Observing and understanding the Southeast Asian aerosol system by remote sensing: An initial review and analysis for the Seven Southeast Asian Studies (7SEAS) program. *Atmospheric Research*, *122*, 403-468.

Reisen, F., Meyer, C. M., McCaw, L., Powell, J. C., Tolhurst, K., Keywood, M. D., & Gras, J. L. (2011). Impact of smoke from biomass burning on air quality in rural communities in southern Australia. *Atmospheric Environment*, *45*(24), 3944-3953.

Reisen, F., Meyer, C. M., & Keywood, M. D. (2013). Impact of biomass burning sources on seasonal aerosol air quality. *Atmospheric environment*, *67*, 437-447.

Reisen, F., Duran, S. M., Flannigan, M., Elliott, C., & Rideout, K. (2015). Wildfire smoke and public health risk. *International Journal of Wildland Fire*, *24*(8), 1029-1044.

Ross, M. A. (2009). Integrated science assessment for particulate matter. *US Environmental Protection Agency: Washington DC, USA*, 61-161.

Rückerl, R., Schneider, A., Breitner, S., Cyrys, J., & Peters, A. (2011). Health effects of particulate air pollution: a review of epidemiological evidence. *Inhalation toxicology*, *23*(10), 555-592.

Taylor, P. E., & Jonsson, H. (2004). Thunderstorm asthma. *Current allergy and asthma reports*, *4*(5), 409-413.

Sahani, M., Zainon, N. A., Mahiyuddin, W. R. W., Latif, M. T., Hod, R., Khan, M. F., ... & Chan, C. C. (2014). A case-crossover analysis of forest fire haze events and mortality in Malaysia. *Atmospheric Environment*, *96*, 257-265.

Samsuddin, N. A. C., Khan, M. F., Maulud, K. N. A., Hamid, A. H., Munna, F. T., Ab Rahim, M. A., ... & Akhtaruzzaman, M. (2018). Local and transboundary factors' impacts on trace gases and aerosol during haze episode in 2015 El Niño in Malaysia. *Science of the Total Environment*, *630*, 1502-1514.

Sastry, N. (2002). Forest fires, air pollution, and mortality in Southeast Asia. *Demography*, *39*(1), 1-23.

Schneider, E. C. (2017). *Mirror Mirror 2017: International Comparison Reflects Flaws and Opportunities for Better US Health Care*. Commonwealth Fund.

Secretariat, A. S. E. A. N. (2002). ASEAN agreement on transboundary haze pollution. Re-trieved at: http://haze. asean. org.

See, S. W., Balasubramanian, R., Rianawati, E., Karthikeyan, S., & Streets, D. G. (2007). Characterization and source apportionment of particulate matter≤ 2.5 μm in Sumatra, Indonesia, during a recent peat fire episode. *Environmental science & technology*, *41*(10), 3488-3494.

Sharma, R., & Balasubramanian, R. (2017). Indoor human exposure to size-fractionated aerosols during the 2015 Southeast Asian smoke haze and assessment of exposure mitigation strategies. *Environmental Research Letters*, *12*(11), 114026.

Smith, K. R., & Ezzati, M. (2005). How environmental health risks change with development: the epidemiologic and environmental risk transitions revisited. *Annu. Rev. Environ. Resour.*, *30*, 291-333.

Standards Australia/Standards New Zealand (SASNZ). (2009). AS/NZS ISO 3100:2009, Risk Management-Principles and guidelines, November 2009.

Steffen, W., Rockström, J., Richardson, K., Lenton, T. M., Folke, C., Liverman, D., ... & Donges, J. F. (2018). Trajectories of the Earth System in the Anthropocene. *Proceedings of the National Academy of Sciences*, *115*(33), 8252-8259.

Tacconi, L. (2016). Preventing fires and haze in Southeast Asia. *Nature Climate Change*, *6*(7), 640.

Taylor, P. E., & Jonsson, H. (2004). Thunderstorm asthma. *Current allergy and asthma reports*, *4*(5), 409-413.

Terzic, A., & Waldman, S. (2011). Chronic diseases: the emerging pandemic. *Clinical and translational science*, *4*(3), 225-226.

Thien, F., Beggs, P. J., Csutoros, D., Darvall, J., Hew, M., Davies, J. M., ... & Byrne, T. (2018). The Melbourne epidemic thunderstorm asthma event 2016: an investigation of environmental triggers, effect on health services, and patient risk factors. *The Lancet Planetary Health*, *2*(6), e255-e263.

Van der Werf, G. R., Dempewolf, J., Trigg, S. N., Randerson, J. T., Kasibhatla, P. S., Giglio, L., ... & Dolman, A. J. (2008). Climate regulation of fire emissions and deforestation in equatorial Asia. *Proceedings of the National Academy of Sciences*, *105*(51), 20350-20355.

Van der Werf, G. R., Randerson, J. T., Giglio, L., Collatz, G. J., Mu, M., Kasibhatla, P. S., ... & van Leeuwen, T. T. (2010). Global fire emissions and the contribution of deforestation, savanna, forest, agricultural, and peat fires (1997–2009). *Atmospheric Chemistry and Physics*, *10*(23), 11707-11735.

Vatanpour, S., Hrudey, S. E., & Dinu, I. (2015). Can public health risk assessment using risk matrices be misleading? *International journal of environmental research and public health*, *12*(8), 9575-9588.

Victorian Department of Health and Human Services (VDHHS). (2017). Chief Health Officer. The November 2016 Victorian epidemic thunderstorm asthma event: an assessment of the health impacts. Department of Health and Human Services, Victorian State Government, Australia (2017)

Wardman, A. E., Stefani, D., & MacDonald, J. C. (2002). Thunderstorm-associated asthma or shortness of breath epidemic: a Canadian case report. *Canadian respiratory journal*, *9*(4), 267-270.

Wallis, D. N., Webb, J., Brooke, D., Brookes, B., Brown, R., Findlay, A., ... & O'Donnell, C. (1996). A major outbreak of asthma associated with a thunderstorm: experience of accident and emergency departments and patients' characteristics. *Bmj*, *312*(7031), 601-604.

United Nations. (2014). *World Urbanization Prospects: The 2014 Revision-Highlights*. UN.

United Nations. (2019). *Sustainable Development Goals*. Retrieved at: https://www.un.org/sustainabledevelopment/sustainable-development-goals/

United Nations Framework Convention on Climate Change (UNFCCC). (2015). *Paris Agreement.* Retrieved at: https://unfccc.int/sites/default/files/english_paris_agreement.pdf

United Nations International Strategy for Disaster Risk (UNISDR). (2017). E. Health Aspect in Disaster Risk Assessment, In, Words into action guidelines: National Disaster Risk assessment, Special Topics. UNISDR.

UNISDR, U. (2015). Sendai framework for disaster risk reduction 2015–2030. In *3rd United Nations World Conference on DRR*. Sendai, Japan: UNISDR.

Wang, H., Naghavi, M., Allen, C., Barber, R. M., Carter, A., Casey, D. C., ... & Dandona, L. (2016). Global, regional, and national life expectancy, all-cause mortality, and cause-specific mortality for 249 causes of death, 1980–2015: a systematic analysis for the Global Burden of Disease Study 2015. *The Lancet,* 388(10053), 1459-1544.

Whitmee, S., Haines, A., Beyrer, C., Boltz, F., Capon, A. G., de Souza Dias, B. F., ... & Horton, R. (2015). Safeguarding human health in the Anthropocene epoch: report of The Rockefeller Foundation–Lancet Commission on planetary health. *The Lancet*, *386*(10007), 1973-2028.

World Bank Group (2018). The World Bank in Indonesia. Accessed at http://www.worldbank.org/en/country/indonesia/overview

World Health Organization (WHO). (1998). Report of the Biregional Workshop on Health Impacts of Haze-Related Air Pollution. *Manila, Philippines: WHO*.

World Health Organization. (2008). *International health regulations (2005)*. World Health Organization.

World Health Organization (WHO). 2009. *Global Health Risks: Mortality and Burden of Disease Attributable to Select Major Risks. WHO.* Geneva, Switzerland.

World Health Organization (WHO). (2010). Achieving the health-related MDGs. It takes a workforce. *WHO, Geneva, February*.

World Health Organization. (2016). Global action plan for the prevention and control of non-communicable diseases 2013–2020. Geneva: WHO; 2013. *Public Health England.*

World Health Organization (WHOb). (2016). An estimated 12.6 million deaths each year are attributable to unhealthy environments. Retrieved from http://www.who.int/mediacentre/news/releases/2016/deaths-attributable-to-unhealthy-environments/en/

Youssouf, H., Liousse, C., Roblou, L., Assamoi, E. M., Salonen, R. O., Maesano, C., ... & Annesi-Maesano, I. (2014). Non-accidental health impacts of wildfire smoke. *International journal of environmental research and public health*, *11*(11), 11772-11804.