



Health impacts of the Southeast Asian haze problem – A time-stratified case crossover study of the relationship between ambient air pollution and sudden cardiac deaths in Singapore

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ABSTRACT

Objectives: To investigate the association between air pollution and out-of-hospital cardiac arrest (OHCA) incidence in Singapore.

Design: A time-stratified case-crossover design study.

Setting: OHCA incidences of all etiology in Singapore.

Participants: 8589 OHCA incidences reported to Pan-Asian Resuscitation Outcomes Study (PAROS) registry in Singapore between 2010 and 2015.

Main outcome measures: A conditional Poisson regression model was applied to daily OHCA incidence that included potential confounders such as daily temperature, rainfall, wind speed, Pollutant Standards Index (PSI) and age. All models were adjusted for over-dispersion, autocorrelation and population at risk. We assessed the relationship with OHCA incidence and PSI in the entire cohort and in predetermined subgroups of demographic and clinical characteristics.

Results: 334 out of 8589 (3.89%) cases survived. Moderate (Risk ratio/RR = 1.1, 95% CI = 1.07–1.15) and unhealthy (RR = 1.37, 95% CI = 1.2–1.56) levels of PSI showed significant association with increased OHCA occurrence. Sub-group analysis based on individual demographic and clinical features showed generally significant association between OHCA incidence and moderate/unhealthy PSI, except in age < 65, Malay and other ethnicity, traumatic arrests and history of heart disease and diabetes. The association was most pronounced among cases age > 65, male, Indian and non-traumatic. Each increment of 30 unit in PSI on the same day and previous 1–5 days was significantly associated with 5.8–8.1% increased risk of OHCA ($p < 0.001$).

Conclusions: We found a transient effect of short-term air pollution on OHCA incidence after adjusting for meteorological indicators and individual characteristics. These findings have public health implications for prevention of OHCA and emergency health services during haze.

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¹ This author takes responsibility for all aspects of the reliability and freedom from bias of the data presented and their discussed interpretation.

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What is already known on this subject?

- Impact of air pollution on respiratory morbidities has been well established but the health impact on cardiovascular disease, specifically out-of-hospital cardiac arrest (OHCA), has recently gained recognition.
- Transboundary haze which occurs in Southeast Asia due to forest fires has posed numerous environmental health problem.
- Understanding the relationship between ambient air pollution due to transboundary haze in Southeast Asia and OHCA is of great public health interest.

What this study adds?

- Our study found that exposure to higher Pollutant Standards Index was associated with an increased short-intermediate term risk of having OHCA in Singapore, especially for cases who were over age 65, male, Indian ethnicity, and occurring in inter-monsoon periods.
- This is the first study linking the Southeast Asian haze to cardiovascular outcomes to our knowledge, and these results may have public health implications for the region.

1. Introduction

Transboundary haze in Southeast Asia due to forest fires is a major environmental health problem, exacting a large economic and health toll on the region. Cardiovascular disease (CVD) is the leading cause of death worldwide according to the World Health Organization [1]. Out-of-hospital cardiac arrest (OHCA), or sudden cardiac death, is the most disastrous presentation of cardiovascular disease and imposes heavy burden worldwide in terms of premature death or disability [2]. Understanding the relationship between ambient air pollution and OHCA is of great public health interest.

The impact of air pollution on all-cause mortality is well established [3], and was estimated to have caused three million premature deaths globally in 2012 alone [4]. While health impacts on respiratory morbidity is intuitive and well-understood [5], air pollution as an important determinant of CVD has recently gained recognition. A 2010 update to a scientific statement from the American Heart Association concluded that the evidence for association of particulate matter (PM) exposure was moderate for heart failure and stroke, and inconclusive for arrhythmia and cardiac arrest [6]. Indeed, associations of air pollution with OHCA have been observed in Rome, Italy [7], Victoria, Australia [8] and Indianapolis, Indiana [9] but not in Seattle, Washington [10,11] or Stockholm, Sweden [12]. These mixed findings may reflect different PM composition from different sources or variations in methodology. A 2016 meta-analysis of 20 studies found an overall significant association, with pooled risk ratios of individual pollutants ranging from 1.02 to 1.04 [13].

Singapore is a small, densely-populated island city-state situated in the Southeast Asian (SEA) region, and experiences recurrent large-scale transboundary haze caused by industrial scale slash-and-burn agricultural practices in neighboring countries. It is hence susceptible to wide day-to-day fluctuations in ambient air pollutant levels over decades. Singapore also has robust disease surveillance capabilities for conditions such as OHCA. These characteristics make Singapore an optimal natural population laboratory to study short-intermediate term health impacts arising from the SEA haze problem.

The objective of this study is to investigate the association between ambient air pollution and OHCA occurrence using a time-stratified case-crossover design while adjusting for other meteorological parameters

such as ambient temperature and rainfall and individual characteristics. It is hypothesized that exposure to increased Pollutant Standards Index (PSI) is associated with increase in number of OHCA cases. Other research questions are whether the effect is highest on same day of exposure or after lagged terms of a few days, and whether the risk is different in various subgroups. Findings may inform public health policies relating to measures to reduce air pollutants as well as those to mitigate their effect on susceptible subgroups of the population.

2. Materials and methods

2.1. Setting

Singapore is an urbanized island city-state situated at the southernmost tip of continental Asia and peninsula Malaysia with a population of 5.5 million over a land area of 719.1 km² [14]. Singapore has a gross domestic product of 295.7 billion dollars [15] and a life expectancy of 82.1 years. Singapore has a mixed health-care system [16], where the public healthcare system is funded through a system of compulsory savings, subsidies, and price controls [17]. There are an estimated 2000–2300 OHCA cases in Singapore per year (unpublished internal data from Singapore Civil Defence Force). Survival to hospital discharge rate for OHCA cases in Singapore was around 2–3% between 2010 and 2012 [18]. Singapore is 1.5 degrees north of the equator, with a climate that is classified as tropical rainforest climate (Köppen-Geiger classification system). As a result of its geographical location and maritime exposure, its climate is characterized by uniform temperature and pressure, high humidity, abundant rainfall and no true distinct seasons.

2.2. Southeast Asian haze situation

The SEA haze situation describes a series of large-scale air pollution episodes that occurs regularly, and has been recorded since 1972 [19]. These haze events have caused adverse health and economic impact, notably in Indonesia, Singapore [20] and Malaysia. The haze has been attributed to forest fires due to illegal industrial-scale slash-and-burn agricultural practices in the region, such as from the Indonesian islands of Sumatra and Borneo [21]. Clearing peatlands using fire, while illegal, is attractive to businesses because it is faster and cheaper compared to using machinery [21].

The haze situation exacerbates recurrently in Singapore, usually coinciding with the dry season from July to September, which is also when the southwest monsoon operates, which shifts haze towards Singapore.

This transboundary haze has been implicated in damages amounting to an estimated of US\$ 4.5 billion for the fire episodes in 1997 alone, due to long-term health damage, reduced crop yield, reduced visibility, preventive expenditures, accidents, loss of life, evacuations, and the loss of confidence of foreign investors [22]. Following severe land and forest fires in 1997–1998, member states of the Association of Southeast Asian Nations (ASEAN) signed the ASEAN Agreement on Transboundary Haze Pollution (AATHP) in 2002 to monitor, prevent and mitigate land and forest fires to control transboundary haze pollution through concerted national efforts and international cooperation.

2.3. Study population and outcome data – the Pan-Asian Resuscitation Outcomes Study

We performed a time-stratified case-crossover design on all reported OHCA cases to PAROS registry from 2010 to 2015 (2015 was partial data) in Singapore. The primary outcome variable is the occurrence of an OHCA. National OHCA data was obtained for the whole of Singapore, from the Pan-Asian Resuscitation Outcomes Study (PAROS). PAROS is a prospectively collected, multi-center registry to provide baseline information on OHCA epidemiology, management and outcomes. Data definitions follow the Utstein recommendations [23] and collaboration with the Cardiac Arrest Registry to Enhance Survival (CARES) [24] in the United States enabled the development of a common taxonomy and data dictionary to allow valid comparisons with global data [25]. Data was extracted from emergency dispatch records, ambulance patient case notes, and emergency department (ED) and in-hospital records. We included OHCA of all etiology brought in by EMS or presenting at EDs, as confirmed by the absence of pulse, unresponsiveness and apnea.

2.4. Environmental data

The primary exposure variable was 24-hour average Pollutant Standards Index (PSI). PSI is an air quality index, which is used to indicate the level of pollutants in the air. This was based on a scale devised by the United States Environmental Protection Agency to provide a way for news agencies to report daily air quality. PSI has been used in several countries including the United States, Brunei Darussalam and Singapore. In Singapore, the National Environment Agency (NEA) classifies 24-hour PSI into ranges of good (0–50), moderate (51–100), unhealthy (101–200), very unhealthy (201–300) and hazardous (>300) [26].

PSI is computed based on six air pollutants: fine particulate matter with aerodynamic dynamic smaller than 2.5 µm (PM_{2.5}), PM₁₀, sulphur dioxide (SO₂), carbon monoxide (CO), ozone (O₃) and nitrogen dioxide (NO₂). For each pollutant, a sub-index is calculated from a segmented linear function that transforms ambient concentrations onto a scale extending from 0 through 500 [27]. PSI is then computed to be the maximum of the six sub-indices. PM_{2.5} is the major pollutant released by forest fires [28], and the World Health Organization guideline level for 24-hour mean PM_{2.5} is 25 µg/m³ [4].

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