Atmospheric Environment 99 (2014) 168–174

Contents lists available at ScienceDirect

Atmospheric Environment

journal homepage: www.elsevier.com/locate/atmosenv

Short term association between ambient air pollution and mortality and modification by temperature in five Indian cities

Hem H. Dholakia [a,*], Dhiman Bhadra [b], Amit Garg [a]

[a] Public Systems Group, Indian Institute of Management, Ahmedabad 380015, Gujarat, India
[b] Production and Quantitative Methods Group, Indian Institute of Management, Ahmedabad 380015, Gujarat, India

HIGHLIGHTS

- We model PM_{10}-mortality relationships for five Indian cities across climate zones.
- Higher relative health benefits for pollution reduction in cleaner cities.
- No significant modification effect of temperature on PM_{10}-mortality association.
- The effect observed in this study is similar to those observed in other countries.

ARTICLE INFO

Article history:
Received 27 March 2014
Received in revised form
25 September 2014
Accepted 26 September 2014
Available online 28 September 2014

Keywords:
Particulate matter
PM_{10}
Health effect
Temperature-pollution interactions
Time-series
GAM

ABSTRACT

Indian cities are among the most polluted areas globally, yet assessments of short term mortality impacts due to pollution have been limited. Furthermore, studies examining temperature – pollution interactions on mortality are largely absent. Addressing this gap remains important in providing research evidence to better link health outcomes and air quality standards for India. Daily all-cause mortality, temperature, humidity and particulate matter less than 10 microns (PM_{10}) data were collected for five cities – Ahmedabad, Bangalore, Hyderabad, Mumbai and Shimla spanning 2005–2012. Poisson regression models were developed to study short term impacts of PM_{10} as well as temperature – pollution interactions on daily all-cause mortality. We find that excess risk of mortality associated with a 10 $\mu g/m^3$ PM_{10} increase is highest for Shimla (1.36%, 95% CI = −0.38%–3.1%) and the least for Ahmedabad (0.16%, 95% CI = −0.31%–0.62%). The corresponding values for Bangalore, Hyderabad and Mumbai are 0.22% (−0.04%–0.49%), 0.85% (0.06%–1.63%) and 0.2% (0.1%–0.3%) respectively. The relative health benefits of reducing pollution are higher for cleaner cities (Shimla) as opposed to dirtier cities (Mumbai). Overall we find that temperature and pollution interactions do not significantly impact mortality for the cities studied. This is one of the first multi-city studies that assess heterogeneity of air pollution impacts and possible modification due to temperature in Indian cities that are spread across climatic regions and topographies. Our findings highlight the need for pursuing stringent pollution control policies in Indian cities to minimize health impacts.

1. Introduction

Short term health impacts of air pollution have been extensively studied for developed countries using time series and case-crossover studies (Lee et al., 2014; Li et al., 2013; Samet et al., 2000; Samoli et al., 2008; Schwartz, 2004). These findings have played an important role in determining air quality standards in the respective countries. For instance, the U.S. Environmental Protection Agency (USEPA) reviews health research every five years to recommend revisions to National Ambient Air Quality Standards, as mandated by the Clean Air Act (Bell et al., 2003; USEPA, 1970). However, epidemiological studies, to inform air pollution policy, are largely limited in the context of developing countries such as India (Balakrishnan et al., 2011).

Indian cities today are among the most polluted areas in the world and it is estimated that outdoor air pollution leads to approximately 670,000 deaths annually (Lim et al., 2013). In India, the Central Pollution Control Board (CPCB) set up under the Air Act of 1981 (MoEF, 1981), is mandated with setting and reviewing the National Ambient Air Quality Standards (NAAQS). Current

* Corresponding author.
E-mail addresses: hemdholakia@iimahd.ernet.in (H.H. Dholakia), dhiman@iimahd.ernet.in (D. Bhadra), amitgarg@iimahd.ernet.in (A. Garg).

http://dx.doi.org/10.1016/j.atmosenv.2014.09.071
1352-2310/

standards, for particulate matter set by the CPCB (CPCB, 2009) are much higher than those recommended by the World Health Organization (Krzyzanowski and Cohen, 2008). In addition, unlike other countries (Bell et al., 2003; Dominici et al., 2007), the CPCB does not take into account findings from health literature when deciding on air quality standards (Balakrishnan et al., 2011). A periodic review of epidemiological evidence informs policy makers about current health risks associated with air pollution and sets the agenda towards finding a balance between reducing health impacts and the costs of implementing further air pollution controls (Dominici et al., 2004).

One potential reason for the lack of tight coupling between ambient air quality standards and health outcomes may be limited epidemiological evidence in the Indian context. A comprehensive review of air pollution and health in Asia found only three time-series studies that examine the short term impacts of air pollution on mortality for the cities of Delhi and Chennai (Balakrishnan et al., 2011; HEI, 2010; Rajarathnam et al., 2011).

However, studies for other cities are needed for at least two important reasons. The first reason is that for a country like India, cities vary widely in terms of development pathways, sources and levels of pollution and policy responses to curb pollution. This presents challenges for generalization of findings from single city studies to the whole country. Second, a changing climate may likely alter pollution levels and subsequently modify health risks over time (Jacob and Winner, 2009; Ren et al., 2006; Tagaris et al., 2009). Consequently, temperature and pollution interactions for cities that lie in different climatic regimes may be quite different. An understanding of these health risks would play an important role in shaping policy to thwart air pollution.

To address the aforementioned research gaps, we use a time-series approach using semi-parametric Poisson regression to study the short term mortality impacts of particulate matter (PM_{10}) as well as temperature – pollution interactions for five cities – Ahmedabad, Bangalore, Hyderabad, Mumbai and Shimla. Being situated in different climactic zones of India, we hope that the observations derived from our findings on these cities will give a fairly good idea about the environment–mortality interaction patterns prevalent in India as a whole.

2. Methods

2.1. Mortality data

Daily all-cause mortality data were collected from the birth and death registers of the municipal corporations of Ahmedabad, Bangalore, Hyderabad, Mumbai and Shimla. For most cities, information on age and cause of death were not available. Table 1 summarizes the climactic characteristics and topography of the above cities.

India is divided into five climate zones namely – hot and dry, warm and humid, composite, temperate and cold. The rationale for choosing these cities was that they are each representative of a different climate zone. In addition to climate zone, these cities represent varied topography – plains, plateau, coastal areas and hilly regions. Air pollution levels vary from city to city based on sources of pollution and policy measures. Additionally, different weather patterns may modify pollution related health risks leading to wide spatial heterogeneity. Thus our choice of cities provides a snapshot of differential health risks across India.

Table 1
Cities distributed by climate zone.

Climate zone	Representative cities	Topography
Hot and dry	Ahmedabad	Plains
Cold	Shimla	Hilly regions
Temperate	Bangalore	Plateau
Composite	Hyderabad, Lucknow	Plains
Warm and humid	Mumbai	Coastal areas

2.2. Weather and PM_{10} data

Daily data on maximum and minimum temperature, relative humidity and dew point temperature were collected from the Indian Meteorological Department (IMD). The IMD has a record of daily weather variables since the year 1948. Daily measurements of PM_{10} were collected from the Central Pollution Control Board (CPCB) database. These included background monitors in residential, industrial and other areas designated as ‘sensitive’. Under the National Ambient Air Quality Monitoring Program (NAMP) the CPCB monitors four criteria pollutants i.e. Sulphur Dioxide (SO_2), Oxides of Nitrogen (NO_x), Total suspended particles (TSP) and particulate matter less than 10 microns (PM_{10}) for 342 stations located in 127 cities across India.

Typically two measurements are taken per week for each station implying that 100–120 observations are available per year. These measurements are made available through the CPCB website and the values reported are a 24-hr average. Every city has a different number of air quality monitors that range from one in Shimla to nine in Hyderabad. For a given year, if any monitor had less than 75% of recorded observations (i.e. less than 90 observations), then it was not used in the analysis. Scatterplots of daily mortality, PM_{10} concentrations and temperature for the different cities are shown in the supplementary material.

To create a population level exposure series for particulate matter, we used the centering approach described by Schwartz (2000). For each monitor, the mean (overall observations) of that particular monitor was subtracted from each observation. This demeaned data was then divided by the standard deviation of that particular monitor to get a standardized series for that monitor. This process was repeated for all monitors in a given city. The standardized series across all monitors was averaged to get one single series. Finally, this single series was multiplied by the standard deviation of all monitors taken together and the mean of all monitors taken together was added back to each observation (Schwartz, 2000). The resultant series was the final exposure series used in the regression model.

After creating the final exposure series, we dropped all observations where pollution data was not available (i.e. complete case analysis). For this dataset, the final exposure series for PM_{10} was shifted (lagged) by one observation. This would relate the deaths on a given day to a PM value roughly three days prior (i.e. for instance deaths on June 4 are associated with pollution value measured on June 1; deaths on June 7 are associated with pollution value measured on June 4 and so on).

2.3. Analytical models

We adopted a semi-parametric regression framework to develop the exposure – response relationship between air pollution and mortality for the sampled cities (Balakrishnan et al., 2011; Peng et al., 2006; Rajarathnam et al., 2011). The logarithm of daily expected deaths was modelled as a function of daily air pollution measurements in the presence of other confounding variables such as temperature and humidity. We assumed deaths to follow an over-dispersed Poisson distribution i.e. $E(Y_t) = \mu_t$ and $\mathrm{Var}(Y_t) = \phi\mu_t$ where ϕ is the over–dispersion parameter. This is an accepted assumption for pollution studies (Dominici et al., 2004). Smooth functions were used to control for effects of daily temperature,