Available online at www.sciencedirect.com
SCIENCE DIRECT
Science of the Total Environment 367 (2006) 559–572
Science of the Total Environment
An International Journal for Scientific Research into the Environment and its Relationship with Humankind
www.elsevier.com/locate/scitotenv

Intraurban variations of PM_{10} air pollution in Christchurch, New Zealand: Implications for epidemiological studies

J. Gaines Wilson [a,b,*], Simon Kingham [a], Andrew P. Sturman [a,b]

[a] GeoHealth Laboratory, Private Bag 4800, University of Canterbury, Christchurch, New Zealand
[b] Centre for Atmospheric Research, University of Canterbury, Christchurch, New Zealand

Received 25 March 2005; received in revised form 12 August 2005; accepted 25 August 2005
Available online 21 October 2005

Abstract

Epidemiological studies relating air pollution to health effects often utilise one or few central monitoring sites for estimating wider population exposures to outdoor particulate air pollution. These studies often assume that highly correlated particulate concentrations between intraurban sites equate to a uniform concentration field. Several recent studies have questioned the universal validity of this assumption, noting that in some cities, the uniformity assumption may lead to exposure misclassification in health studies. Few studies have compared central fixed site concentrations to intraurban population background sites using actual monitored data in cities with higher levels of pollution. This research examines daily concentration variations in particulate matter less than 10 μm in diameter (PM_{10}) at the neighbourhood scale over two winter months in Christchurch, New Zealand, a city with high winter pollution concentrations. Daily concentrations of PM_{10} data were collected for two winter months at ten background monitoring sites within 9.3 km of the central fixed monitoring site typically used for estimating exposure in epidemiological studies. Results indicate that while the correlation between PM_{10} concentrations measured at the central monitoring site and most background sites is strong ($r>0.76$), absolute daily concentration differences between the central monitoring site and population background sites were substantial (mean 90th percentile absolute difference=17.6 μg m^{-3}). In Christchurch, a central monitoring site does not therefore appear to accurately depict wider area population exposures to PM_{10}. Local intraurban variations in particulates should be well understood before applying central monitoring site concentrations as proxies for population exposure in epidemiological studies.

Keywords: Exposure misclassification; Spatial epidemiology; Coefficient of divergence; Exposure assessment; Cohort studies

1. Introduction

Air pollution, especially particulate matter (PM) air pollution, has received considerable attention over the past 15 years, primarily due to health effects associated with personal exposure variations (e.g., Dockery and Pope, 1994; Pope et al., 1991; Schwartz and Dockery, 1992). The prevailing approach for estimating exposure to air pollution at a coarse spatial resolution is the application of an arithmetic mean concentration value from one or few central monitoring stations to the entire population of the study area (e.g., Dockery et al., 1993; Pope et al., 2002, 1992; Samet et al., 2000; Wong et al., 2001; Zanobetti et al., 2003). This method assumes that the spatial distributions of certain pollutants, especially particulate concentrations, are distributed homogeneously within large urban areas. Early concentration

* Corresponding author. GeoHealth Laboratory, Private Bag 4800, University of Canterbury, Christchurch, New Zealand. Tel.: +64 3 364 2987x4842; fax: +64 3 364 2907.
E-mail address: j.wilson@geog.canterbury.ac.nz (J.G. Wilson).

0048-9697/$ - see front matter © 2005 Elsevier B.V. All rights reserved.
doi:10.1016/j.scitotenv.2005.08.045

variability studies in the United States supported this assumption, finding homogeneous distributions of particulates across intraurban (*within*-city) areas (Burton et al., 1996; Suh et al., 1997; Wilson and Suh, 1997). However, several recent studies suggest that in some cities there may be greater spatial variation than previously reported and that the ecological method of particulate exposure assessment may misclassify personal exposures when variability is high (Briggs, 2000; Ito et al., 2004; Kim et al., 2005; Pinto et al., 2004; Wilson et al., 2005; Zhu et al., 2002). Further, exposure misclassifications due to the selection of monitoring sites and sampling frequencies have been shown to significantly alter the magnitude of health outcomes in epidemiological studies (Ito et al., 1995). Consequently, the study of air pollution exposures at the intraurban scale has been identified as a priority area for future work (Brunekreef and Holgate, 2002; Jerrett et al., 2005; Kukkonen et al., 2001; Sajani et al., 2004).

This paper has several aims related to intraurban variations in particulate matter air pollution less than 10 μm in diameter (PM_{10}) in a city with high levels of winter air pollution, including: (i) to describe the nature of PM_{10} intraurban concentration homogeneity between all study sites in a dense monitoring network; (ii) to investigate the validity of the intraurban homogeneity assumption in Christchurch, New Zealand by comparing relative and absolute daily concentrations between ten population exposure monitoring sites and a central monitoring site; and (iii) to discuss the wider implications of exposure misclassification for epidemiological studies due to spatial heterogeneity of intraurban particulate concentrations.

2. Air pollution and intraurban uniformity

Air pollution in Christchurch has been reported for well over a century (Gray, 1889) and has been systematically monitored since the 1950s (Wilkinson, 1959). Christchurch is a mid-latitude city with a population of 330,000 located on the Canterbury Plains about 70 km east of the Southern Alps (172°W, 43°S) and just north of eroded remains of a late Tertiary volcanic complex known as Banks Peninsula or the Port Hills. Christchurch's mid-latitude location in the southern hemisphere is in a climate significantly influenced by the interaction between the eastward propagating low and high pressure systems and the Southern Alps massif (Sturman and Tapper, 1996). Cold air drainage from the Southern Alps converging with more localised cold air drainage winds originating from the slopes of Banks Peninsula is thought to generate zones of stagnant air, enhancing the strength of temperature inversions on cold winter nights (Kossmann and Sturman, 2004). The main source of winter particulate air pollution in Christchurch is domestic heating, with approximately 48% of Christchurch homes burning coal or wood in the main living area as a source of heat on a typical winter's night and/or day (Lamb, 2003). Domestic heating sources contribute 11.2 t out of the total 13.6 t (82%) of PM_{10} discharged on a typical winter's day (Scott and Gunatilaka, 2004). Ambient 24-h averages of PM_{10} exceed national ambient air quality guidelines of 50 μg m^{-3} an average of more than 30 times every winter and may reach up to 400 μg m^{-3} in 1-h maximum concentrations (Aberkane et al., 2004).

In Christchurch, multi-site monitoring studies of intraurban variations in particulate air pollution are limited. The most recent monitoring studies utilising more than four monitoring stations in Christchurch were published in the early 1980s. Sturman (1982) studied daily smoke concentration data for winter months (May through August) at 12 to 13 sites (non-concurrently) in Christchurch. A strong gradient between the city centre and the suburbs was observed, related to the distribution of emissions. The highest areas of concentration were in the east to northeast of the city centre, where population densities were highest. Relative daily variations were small and most of the spatial variation between sites was found in outlying areas of the urban area. In a follow-on study based on the same pollution data set, local wind systems were found to be a major contributor to spatial concentrations and dispersion patterns of smoke (Sturman, 1985). More recently, Kossmann and Sturman (2004) studied meteorological conditions at five air pollution monitoring sites and noted significant variations in air pollution and wind characteristics over relatively small distances related to the complex and dynamic relationship between airflow and air pollution patterns over the city. Concentration variations between intraurban sites were not reported in detail.

Several studies have been conducted internationally on spatial variations in particulates at the intraurban scale, with mixed conclusions about local uniformity (Wilson et al., 2005). Burton et al. (1996) measured PM_{10}, $PM_{2.5}$ and coarse particles ($PM_{10-2.5}$) at eight sites in Philadelphia, finding high correlations between sites and low concentration variations, concluding that concentrations at a central monitoring site could be used to characterize exposure concentrations across the city, as well as in other similar cities in the northeastern United States. Suh et al. (1997) measured