Science of the Total Environment 612 (2018) 450–461

Contents lists available at ScienceDirect

Science of the Total Environment

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

Reducing mortality risk by targeting specific air pollution sources: Suva, Fiji

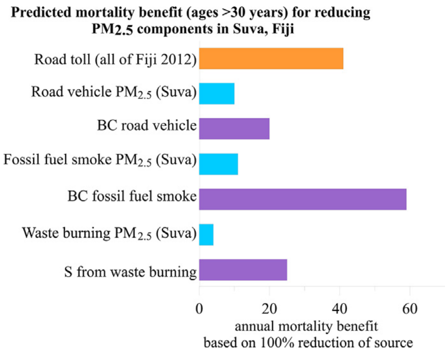
C.F. Isley [a,*], P.F. Nelson [a], M.P. Taylor [a], E. Stelcer [b], A.J. Atanacio [b], D.D. Cohen [b], F.S. Mani [c], M. Maata [c]

[a] *Department of Environmental Sciences, Macquarie University, Sydney, NSW 2109, Australia*
[b] *Centre for Accelerator Science, Australian Nuclear Science and Technology Organisation, Locked Bag 2001, Kirrawee DC, NSW 2232, Australia*
[c] *Faculty of Science Technology and Environment, University of the South Pacific, Laucala Campus, Suva, Fiji*

HIGHLIGHTS

- Determines potential mortality reduction for different particulate matter emission sources
- Risk from black carbon and sulphur content exceed those based on particulate mass.
- Greatest benefits from reducing emission from fossil fuel, vehicles and waste burning

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 26 April 2017
Received in revised form 21 August 2017
Accepted 21 August 2017
Available online xxxx

Editor: D. Barcelo

Keywords:
$PM_{2.5}$ components
Health risk
Fossil fuel
Road vehicles
Black carbon

ABSTRACT

Health implications of air pollution vary dependent upon pollutant sources. This work determines the value, in terms of reduced mortality, of reducing ambient particulate matter ($PM_{2.5}$: effective aerodynamic diameter 2.5 μm or less) concentration due to different emission sources. Suva, a Pacific Island city with substantial input from combustion sources, is used as a case-study. Elemental concentration was determined, by ion beam analysis, for $PM_{2.5}$ samples from Suva, spanning one year. Sources of $PM_{2.5}$ have been quantified by positive matrix factorisation. A review of recent literature has been carried out to delineate the mortality risk associated with these sources. Risk factors have then been applied for Suva, to calculate the possible mortality reduction that may be achieved through reduction in pollutant levels. Higher risk ratios for black carbon and sulphur resulted in mortality predictions for $PM_{2.5}$ from fossil fuel combustion, road vehicle emissions and waste burning that surpass predictions for these sources based on health risk of $PM_{2.5}$ mass alone. Predicted mortality for Suva from fossil fuel smoke exceeds the national toll from road accidents in Fiji. The greatest benefit for Suva, in terms of reduced mortality, is likely to be accomplished by reducing emissions from fossil fuel combustion (diesel), vehicles and waste burning.

---

[*] Corresponding author.
E-mail addresses: isleycynthia1@students.mq.edu.au (C.F. Isley), peter.nelson@mq.edu.au (P.F. Nelson), mark.taylor@mq.edu.au (M.P. Taylor), esx@ansto.gov.au (E. Stelcer), aaz@ansto.gov.au (A.J. Atanacio), david.cohen@ansto.gov.au (D.D. Cohen), francis.mani@usp.ac.fj (F.S. Mani), matakite.maata@usp.ac.fj (M. Maata).

http://dx.doi.org/10.1016/j.scitotenv.2017.08.225
0048-9697/

1. Introduction

It is well established that increased $PM_{2.5}$ (particulate matter with equivalent aerodynamic diameter 2.5 μm or less) concentrations relate to adverse health impacts. Short and long term exposures to even low levels of $PM_{2.5}$ have been associated with all-cause mortality (Kloog et al., 2013; Shi et al., 2016), with no evidence of a threshold below which effects are not observed (Pope and Dockery, 2006; Brook et al., 2010). Hoek et al. (2013) reviewed available studies, finding that the risk of premature mortality due to $PM_{2.5}$ increases by 6% per 10 $\mu g/m^3$ increase in $PM_{2.5}$; 11% for cardiovascular mortality. As coronary heart disease is the leading cause of death in Fiji (Ministry of Health and Medical Services, 2015), health implications of air quality warrant investigation. Associations have been made between $PM_{2.5}$ and diabetes (Potera, 2014; Rao et al., 2015), also a major cause of death in Fiji (Ministry of Health and Medical Services, 2015); deep vein thrombosis and pulmonary embolism (Kloog et al., 2015), as well as dementia, Alzheimer's and Parkinson's (Kioumourtzoglou et al., 2016). Health care access and health education also influence susceptibility to impacts arising from $PM_{2.5}$ exposure (Garcia et al., 2016).

Certain $PM_{2.5}$ constituents are more harmful than others (Bell et al., 2014; Dai et al., 2014; Chung et al., 2015; Kioumourtzoglou et al., 2015; Jia et al., 2017). In a toxicology study, Roper et al. (2017) reported the most significant associations of $PM_{2.5}$ with lung tissue inflammatory response from sampling sites with the lowest $PM_{2.5}$ concentrations; demonstrating that $PM_{2.5}$ concentration alone is not a satisfactory measure of health risk (similarly, Hao et al., 2016). Understanding of the health risk of $PM_{2.5}$ components, and the mechanism for toxicity, is still developing (Huang et al., 2014; Atkinson et al., 2015; Gray et al., 2015; Tong et al., 2015; Weber et al., 2015). Recent research has explored the role of oxidative potential, relating it to cardiovascular and respiratory health impacts (Weber et al., 2015; Lakey et al., 2016; Pei et al., 2016; Sarnat et al., 2016; Weichenthal et al., 2016; Yang et al., 2016). Weber et al. (2015) reported vehicle emissions and biomass burning sources to exhibit higher oxidative potential and hence higher toxicity than other sources. Air pollution control measures should include consideration of components, particularly those with high toxicities, rather than $PM_{2.5}$ mass alone (Liu, 2016). In particular, Eklund et al. (2014) advocate use of black carbon (BC) in air quality regulations, as an indicator of adverse health effects, due to the consistency of observed associations.

The disparate toxicity of $PM_{2.5}$ components is of relevance for the Pacific Islands, where diesel combustion and waste burning contribute significantly to the particulate loading (Periathamby et al., 2009; Mataki, 2011; Owens et al., 2011; Wiedinmyer et al., 2014; Escoffier et al., 2016; Taibi et al., 2016). For Suva, $PM_{2.5}$ levels are within World Health Organization guidelines (7.4 ± 0.3 $\mu g/m^3$ annual average of Wednesdays and Sundays) yet black carbon in $PM_{2.5}$ (2.2 ± 0.1 $\mu g/m^3$) is similar to levels in much larger cities (Isley et al., 2017) highlighting the need for further investigation of air pollutant sources in order to facilitate more effective air quality management. Source contributions to $PM_{2.5}$ for Suva would be typical of dominant of emission contributions across all the Pacific Islands. Similarly, other developing communities in Africa, Asia and South America that share similar climate, burning practices and usage of diesel are likely to be equally affected.

An emissions inventory (Isley et al., 2016) showed diesel vehicle emissions to be the largest source of BC in Suva. Emissions data was difficult to obtain, meaning that sources may have been underestimated. Calculated per-capita BC emissions for Suva were comparable to regions with much lower ambient BC than Suva, indicating that the inventory may not fully represent local emissions (Isley et al., 2016). Further data are required to accurately define emission contributions. Alternatively, elemental concentration data may be used to statistically model sources. This has been attempted by Garimella and Deo (2007); who interpreted elemental concentration data in Suva to provide qualitative conclusions about PM sources. By comparing PM concentrations to the earth's crust, Garimella and Deo (2007) concluded that Suva's PM was dominated by marine aerosols, with possible inputs from automobile exhaust. Source apportionment in Garimella and Deo's (2007) study was constrained by identification of only 5% of total PM mass. This study aims to further that work, using a suite of elements likely to identify a larger proportion of particulate mass; H, Na, Al, Si, P, S, Cl, K, Ca, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, Br, Sr, Pb, N and BC. Because of the well-defined health implications identified above, this study focuses on $PM_{2.5}$. In order to make the study data more specifically applicable to future Fijian air policy and health risk assessments, $PM_{2.5}$ sources will be defined quantitatively using the positive matrix factorisation (PMF) method.

The PMF technique (Paatero and Tapper, 1994; Paatero, 2000b; Paatero, 2000a) identifies statistical groupings of elements (source factors) within total $PM_{2.5}$ mass; which are then related to emission sources using known elemental ratios. Many recent source apportionment studies have used PMF (Belis et al., 2013; Karagulian et al., 2015), particularly due to its differentiation of sources that share common elements. This is an important advantage for Suva, where many combustion sources share BC, H and S.

The objective of this paper is to quantitatively identify source contributions to the total $PM_{2.5}$ burden of Suva's air and to determine the mortality risk presented by these factors. This will enable more effective and targeted air quality policy in Fiji.

2. Method

2.1. Sampling

Sampling was carried out in Suva city centre, at −18.13°S, 178.42°E. On the west coast of the Suva peninsula, the site is located atop a 4-level building, at approximately 18 m height and 20 m elevation. The city markets, Suva bus terminal, Walu Bay industrial area and shipping port activities all lie within 1 km of this site. This site was selected as it is downwind of Suva City and would indicate the sources that people living and working in Suva are exposed to. Meteorological data (Australian Government, 2016) were obtained from instruments co-

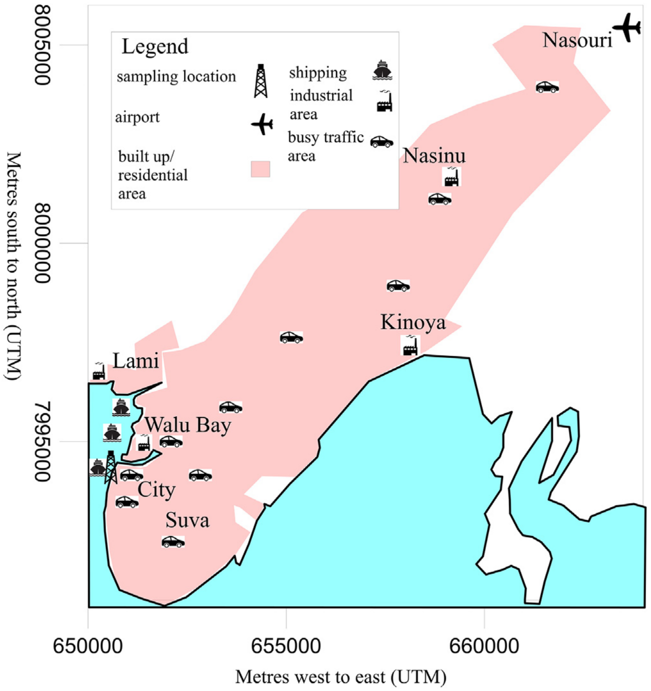


Fig. 1. Sampling locations, showing the $PM_{2.5}$ sampling location in Suva city centre as well as locations of major industries and other emission sources.