Research brief
$PM_{2.5}$ chemical composition and geographical origin of air masses in Cape Town, South Africa

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Various indoor and outdoor air pollutants are linked in epidemiology studies to the symptoms, hospital admissions and development of numerous health outcomes — even with the spread and increase of Covid-19's morbidity and mortality and other disease mortality. Most of these epidemiology studies were conducted in the developed world and very few in Africa. An epidemiology study in Cape Town reported that exposure to outdoor PM_{10}, NO_2 and SO_2 levels during 2001–2006 posed a much higher risk to die from cardiovascular and respiratory diseases than reported in developed countries, even though the outdoor levels were on average similar to those in European cities. Another study in Cape Town observed adverse effects on cardiovascular disease hospital admissions during 2011–2016 – with stronger effects on days warmer than 20.3 °C. The South African studies did not investigate $PM_{2.5}$ as this air pollutant is not currently monitored in Cape Town. The daily and yearly $PM_{2.5}$ South African national ambient air quality standard came into effect on 29 June 2012. It is widely accepted that $PM_{2.5}$ is more hazardous to human health than PM_{10}. Very few studies in Africa reported on $PM_{2.5}$ levels. No study ever reported on $PM_{2.5}$ levels in Cape Town.

$PM_{2.5}$ filters samples were collected manually over 24 hours and every third day at an urban background, located on the roof of a house in the suburb of Kraaifontein, Cape Town during April 2017 and April 2018. In addition to the 24-hour filter samples, four composite filter samples were collected over four consecutive weeks during September 2017 and January 2018 to determine the anion and elemental composition of $PM_{2.5}$. After gravimetric analysis, reflectance measurements were performed. Elemental levels and anion levels of the composite samples were determined by Inductively Coupled Plasma-Optical Emission Spectrometry and Ion Chromatography, respectively. The geographical origin of air masses that passed Cape Town was applied as surrogates for long-range transported air pollution from distant sources and its composition, as done in other studies. The Hybrid Single Particle Lagrangian Integrated Trajectory software was used.

In total, 146 24-hour $PM_{2.5}$ filter samples (including 25 duplicate samples) were collected on 121 days during the 1-year study period. The mean $PM_{2.5}$ level of 13.4 $\mu g.m^{-3}$ was lower than the yearly South African National Ambient Air Quality Standard (SA NAAQS) (20 $\mu g.m^{-3}$). The levels exceeded the daily World Health Organization air quality guideline (25 $\mu g.m^{-3}$) on 14 occasions. These exceedances indicate that the population of Cape Town may experience various health outcomes due to outdoor $PM_{2.5}$ exposure, as indicated previously. The mean and maximum were higher than those reported in rural areas of South Africa, but lower than those reported in Pretoria or the South African towns located in the Vaal Triangle and Highveld air pollution priority areas. The mean level in this study was lower than the mean in 499 cities of 24 countries (37.5 $\mu g.m^{-3}$). The maximum level in this study was 39.1 $\mu g.m^{-3}$, which is generally lower than those reported in cities from other African countries.

The mean soot level was 1.38 $m^{-1} \times 10^{-5}$. Very few studies in Africa reported soot levels. The mean soot levels in Pretoria were higher and varied between 2.3 $m^{-1} \times 10^{-5}$ during April 2017 to April 2018 and 0.02 $m^{-1} \times 10^{-5}$ during May 2018 to Apr 2019. The mean soot level in Thohoyandou, a town located in a rural area, was lower: 0.69 $m^{-1} \times 10^{-5}$ during April 2017 to April 2018. A review concluded in 2017 that atmospheric black or elemental carbon is a risk factor for hospital admissions and mortality.

The largest fraction of $PM_{2.5}$ was due to anionic and metallic species ranging from 31 to 54% of mass and 27–51% of mass, respectively. Na and Cl^- were the most abundant constituents. The Atlantic Ocean and Indian Ocean are the most probable sources of Na and Cl^-. The lowest Fe and Zn level was 1.2 $\mu g.m^{-3}$ and 0.03 $\mu g.m^{-3}$, respectively. A large European cohort epidemiology study reported an increase of 3% in natural-cause mortality per 500 $ng.m^{-3}$ increase in Fe or per 20 $ng.m^{-3}$ increase in Zn. The observed Fe and Zn levels, if assumed to be experienced citywide in Cape Town, may thus pose a significant risk to human health.

Zn:Al ratios indicate the relative contribution of local road dust to $PM_{2.5}$ levels. Al is predominantly from natural sources, whilst Zn is mainly from tire wear, but also from solid waste or biomass burning and industrial emissions. The mean Zn:Al ratio in this study was 2.17.

The lowest SO_4^{2-} and NO_3^- level was 0.8 $\mu g.m^{-3}$ and 0.6 $\mu g.m^{-3}$, respectively. A review concluded that natural-cause mortality increased by 15% and 17% per 1 $\mu g.m^{-3}$ increase in SO_4^{2-} and NO_3^-, respectively. The observed SO_4^{2-} and NO_3^- levels, if assumed to be representative of levels in Cape Town, may thus

pose a significant risk to human health. The inorganic carbon fraction ranged from 7.0–14.2% of mass.

Four geographical origins of air masses were identified: Atlantic-Ocean-SW, Atlantic-Ocean-SSW, Atlantic-Ocean-WSW and Indian-Ocean. Air masses emanating from the Atlantic Ocean dominated in winter (87%), summer (73%), spring (77%) and the entire year (71%). In autumn, 51% of the air masses emanated from the Indian Ocean, with 29% in the entire study period. The median 24-hour $PM_{2.5}$ and soot levels did not differ significantly by the geographical origin of air masses.

Recommendations are that all the $PM_{2.5}$ samples are analysed for chemical composition to perform source apportionment and health risk assessment studies.

Reference

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