Research brief

Source apportionment of fine atmospheric particles using positive matrix factorization in Pretoria, South Africa

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Outdoor and indoor air pollution have been regarded as a serious issue in South Africa, with the emissions of various air pollutants and their resulting concentrations in the atmosphere being a major source of concern. For example, nearly 80% of the global population was subjected to air pollution levels that surpassed the World Health Organization (WHO) air quality guidelines in 2011. Pollution from a variety of sources has had a significant effect on air quality, posing a direct threat to the critical roles the environment plays in preserving and sustaining life by absorbing harmful ultraviolet radiation, warming the surface, and controlling the earth's temperature. Particulate matter (PM) suspended in the air for hours or days can travel a long distance, making it a long-range transported pollutant that is influenced by particle size, chemical composition, and other physical and biological characteristics. $PM_{2.5}$ (particles smaller than 2.5 µm) has received a lot of attention recently because of the negative impact it has on human health, i.e., its potential to penetrate human lungs. Furthermore, epidemiological studies have revealed a connection between PM and a variety of health problems. Source apportionment is an important air quality management tool for providing information about source contributions required for pollution abatement strategies. However, not many studies have applied air mass backward trajectory modelling with source apportionment model analysis to investigate the sources of PM.

Daily 24-hour $PM_{2.5}$ samples were collected every third day on the roof top of HW (6th floor) Snyman South Building at the School of Health Systems and Public Health (SHSPH), Prinshof Campus, University of Pretoria, from April 2017 to April 2018. At the Air Quality Laboratory of SHSPH, gravimetric analyses of $PM_{2.5}$ filters were carried out using a 1µg sensitivity microbalance (Mettler Toledo, XP6) under climate-controlled conditions (temperature and relative humidity were maintained at 21± 0.5 °C and 50 ± 5%, respectively) before and after sampling. Black carbon (BC), UVPM (a proxy for organic carbonaceous particulate matter absorbing UV light at 370 nm), the elemental composition of aerosol particles on all filters were determined using an XEPOS 5 energy-dispersive X-ray fluorescence (EDXRF) spectrometer (Spectro Analytical Instruments GmbH, Germany) at the Department of Chemistry and Molecular Biology, Atmospheric Science Division, University of Gothenburg. The Environmental Protection Agency's program EPAPMF5.0 was used to conduct the source apportionment study. The geographical origin of air masses passing through Pretoria, South Africa, was used as a proxy for long-range transport of air pollutants from distant sources and their composition. The Hybrid Single Particle Lagrangian Integrated Trajectory (HYSPLIT) program was used to generate backward trajectories for the 1-year sampling campaign.

A total of 147 $PM_{2.5}$ filter samples were obtained (with 25 duplicate samples), over a 122-day period for the 1-year sampling campaign. The average daily $PM_{2.5}$ concentration was 21.1 µg/m³. The daily mean concentration in this study was higher than the South African National Ambient Air Quality Standards (20 µg/m³) and the WHO yearly air quality guideline (10 µg/m³). The WHO daily air quality guideline for $PM_{2.5}$ (25 µg/m³) was found to be exceeded on 27% (33 days) of the sampling campaign days, with the most exceedance occurring during the winter season. The $PM_{2.5}$ mean concentrations for weekdays (88days; 20.7 µg/m³) and weekends (34days; 22.1 µg/m³) did not differ significantly from each other ($p > 0.05$). This may be attributed to other sources contributing to the pollutant levels apart from traffic, as it is expected that less traffic will be less over the weekend compared to weekdays.

The mean $PM_{2.5}$ level for this study is significantly higher than the $PM_{2.5}$ levels from the other two cities of this bigger project, Cape Town (13.3 µg/m³) and Thohoyandou (10.9 µg/m³). In comparison with other African countries, the mean $PM_{2.5}$ level were similar to the studies in Nairobi (21 µg/m³) and Accra (22.7 µg/m³) but lower to what were reported in Quagadougou (86 µg/m³) and Cairo (80 µg/m³) and Egypt (70 µg/m³.) The annual mean concentration for trace elements showed S had the highest average concentration of all the elements determined, followed

by Si, Fe, K, and Ca, in that sequence. The weekly variation showed that the highest concentrations of the elements were recorded on Thursdays and lowest on Mondays for K, Pb, and Cl; Tuesday for S; and weekends for Fe, Ca. The concentrations of Pb and Cl display variation during weekdays, indicating variability in their sources, while the concentration of K, Ca, Fe, and S do not display significant variation within the weekdays, thus indicating some consistency for their possible sources. Most of the species concentration followed the seasonal pattern (winter > autumn > spring > summer) observed for $PM_{2.5}$.

The total daily $PM_{2.5}$ elemental composition dataset from the sampling campaign were used in the PMF model. Five to seven factors were investigated, but the seven factors output was presented. The mean $PM_{2.5}$ concentrations of the seven sources (i.e., are local and anthropogenic in origin) were named; fossil fuel combustion, soil dust, secondary sulphur, vehicle exhaust, road traffic, base metal/pyrometallurgical, and coal burning. Fossil fuel was found to be the major contributor with 22% of elemental mass in $PM_{2.5}$ concentrations on a yearly average. Coal combustion came in second, accounting for 18% of the total $PM_{2.5}$ mass. The combined contribution of soil dust and road traffic amounts to 4.0 $\mu g/m^3$ (22% of the total $PM_{2.5}$). Seasonal behaviour has been discovered in the known sources. When compared to other seasons, the contribution of secondary sulphur, vehicle exhaust, base metal/pyrometallurgical, and coal burning to $PM_{2.5}$ concentration levels was found to be significantly higher during winter. In comparison to other seasons, levels of fossil fuel, soil dust, and road traffic were higher in autumn ($p < 0.001$ for all tests).

Apart from local sources, air pollutants transport and regional sources have a significant impact on Pretoria's air quality. Five transport cluster pathways were identified in this study. Long-rang transport (LRT) and local sources characterized these pathways. Cluster 1 North Limpopo (NLP) is a local source from the northern province of Limpopo, which is associated with a high concentration of $PM_{2.5}$ due to anthropogenic activities happening in the area, which include coal power stations, mining, domestic fuel burning, agriculture, and veld fires. Cluster 2 Eastern Inland (EI) has its origin from the Indian Ocean while clusters 3, 4, and 5 (Short Indian Ocean SIO, Long Indian Ocean LIO, and South Westerly-Atlantic Ocean, respectively) depicts LRT sources. About 78% of the days in which the WHO and SA standard were exceeded were of local source origin (cluster NLP and EI), while only 22% was attributed to LRT sources.

To effectively develop $PM_{2.5}$ reduction strategies, the sources of PM and their contributions, as well as the contribution from each source, must be understood using a combination of transport cluster analysis. The later provides additional information on the pathway through which the sources originated.

Reference

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