University of Southampton

Identifying regional air quality trends from sensor network data

An analysis of PM2.5 measurements in Hampshire

Background and Context

Poor air quality is the UK's greatest environmental health hazard and a particular concern in major cities across the country. It contributes to poor health, such as heart and lung disease, and increased mortality, disproportionately effecting the young, the elderly, and vulnerable populations [1].

In Hampshire, major sources of air pollution include road traffic, shipping and port activities, the airport, and local industry. There are over 30 air quality management areas (AQMAs) in the region where national Air Quality Objectives are locally not being met. The improvement of outdoor air quality is therefore a priority for local authorities who are engaged with local monitoring and have developed air quality action plans [2-5].

This investigation by the University of Southampton aimed to analyse air quality sensor measurements from across Hampshire to:

1. Investigate the extent and severity of air pollution in the region.
2. Identify trends that could lead to targeted interventions and an improvement in quality of the air we breathe.

Our analysis focused on a dataset of measurements of particulate matter smaller than 2.5 μm (PM2.5), the major cause of the negative health effects of poor air quality.

The data was collected from a network of 17 EarthSense Zephyr [6] ambient air quality monitors spread across the region (Figure 1), measured every 15-minutes over the period of January 2023 – March 2024, supplemented with data from DEFRA's Automatic Urban and Rural Network [7] and weather data from the Met Office [8]. We applied statistical and machine learning techniques to identify trends in the data.

Figure 1: Map of the sensor locations.

Key Findings

→ Annual average PM2.5 levels exceed recommended limits

We found that Hampshire's annual average PM2.5 level is 7.5 $\mu g/m^3$ (Figure 2), 50% higher than the World Health Organisation recommended limit [1]. This highlights the pressing nature of this project to help identify and mitigate these high levels of PM2.5.

→ Air pollution isn't localised

All sensors recorded remarkably similar readings, regardless of whether the sensor was located within the city centre or in a more remote location, indicating that PM2.5 pollution affects rural as well as urban areas (Figure 2). Quantifiably, the average standard deviation of all readings on any given day was 3.2 $\mu g/m^3$, whereas the average standard deviation of each sensor's total readings across the entire date range was 5.0 $\mu g/m^3$.

This suggests that the sensor network is potentially missing local hot spots, such as within busy intersections or industrial areas. It also suggests that local interventions on their own will not be enough to substantially reduce the background PM2.5 levels in the region.

→ PM2.5 spikes are often caused by one-off highly polluting events

Several of the largest PM2.5 readings in 2023 and 2024 could be attributed to isolated polluting events, including a forest fire in Longmoor (June 2023) and a factory fire in St Mary's, Southampton (March 2024). These events impacted the whole region and were measured by sensors across the region with hardly any change with proximity to the source. This also means that source apportionment from sensor readings alone is challenging as PM2.5 disperses effectively, obscuring its origin.

We found that, in 2023, major fireworks celebrations had minimal impact on local PM2.5 levels, which is contrary to other reports from elsewhere in the UK which showed an increase in PM2.5 following fireworks displays. It is possible that Hampshire was fortunate to have favourable weather conditions on these days to disperse the pollution but note that this might not always be the case in the future.

→ Daily PM2.5 levels follow a predictable pattern

Averaging the PM2.5 levels according to the time of day, Figure 3 shows a clear trend: PM2.5 readings peak around 9 pm, decrease throughout the night, plateau around the morning rush hour, decrease until about 4 pm, and then rise again to a peak in the evening. This suggests a consistent day-cycle trend driven by human behaviour and the diurnal cycle of the atmosphere.

PM2.5 levels are often higher on weekends, so we can't attribute these peaks solely to rush hour traffic.

Winter months have higher PM2.5 levels than spring and autumn, with summer having the lowest overall levels. Cold winter evenings provide the stable atmospheric conditions for air pollution to accumulate. This exacerbates the potential health impact of pollution emitted at this time such as domestic wood burning.

→ Wind conditions significantly influence background pollution levels

Although the predominant wind direction in the region is from the southwest, we found that when the wind changed direction it strongly influenced air pollution. Polar plots of the average measured concentration dependent on the wind (Figure 4) showed that PM2.5 levels were substantially higher than average when wind blew from the direction of London. In addition to being a source of pollution, weather conditions tend to be more stable when the wind blows from the northeast, which amplifies the impact London pollution has on Hampshire.

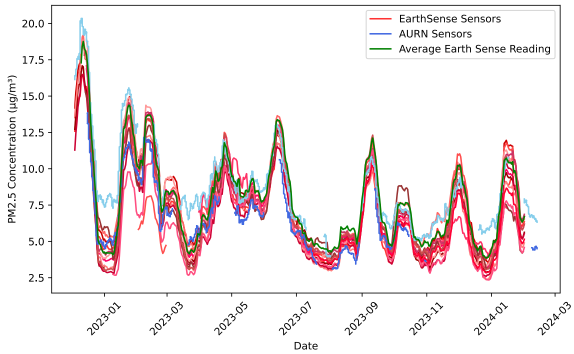

Figure 2: Measurements from all the sensors follow the same trends in time with little regional variation. Peak episodes, such as the one resulting from a large fire in June 2023, were often felt across the region. The annual average PM2.5 level was 7.5 µg/m³ whereas the WHO recommended limit is 5 µg/m³.

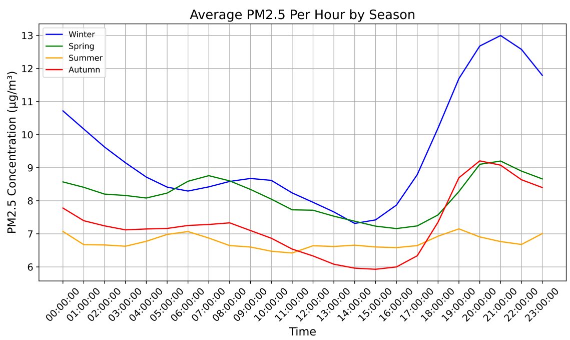

Figure 3: The average PM2.5 concentration as a function of the time of day, separated by season, shows that air pollution is worst in winter evenings.

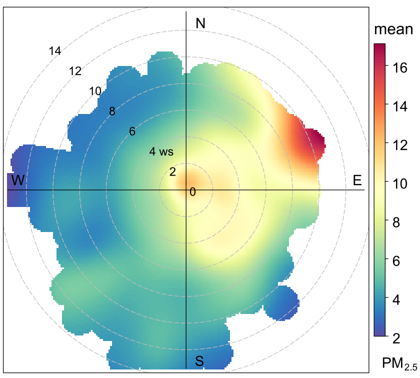

Figure 4: Polar plot showing how the mean PM2.5 concentration across all sensors varies according to wind direction and speed. The yellow and red areas of the plot indicate higher than average concentrations experienced when the wind is still or blowing from the northeast, the direction of London.

Recommendations

→ Local interventions alone are not sufficient to significantly reduce PM2.5 levels in the region, therefore local authorities should actively engage at a national level.

Background PM2.5 levels are largely influenced by activities from outside of the local region and are noticeably worse when the wind is blowing from the direction of London.

Since PM2.5 disperses so widely, collaborating on a national level with other major cities is advised to improve local air quality in Hampshire.

→ Certain weather conditions can exacerbate air pollution. Having clear and accessible notifications of prevention measures during these times can help avoid unnecessary pollution and reduce personal exposure.

Air quality levels are the worst in winter evenings due to cold stable weather conditions preventing the dispersion of air pollution to the atmosphere. Reducing air pollution, such as domestic wood burning, during winter evenings can help alleviate these peaks.

Air pollution can build up during calm wind conditions associated with high pressure weather systems, such as heat waves. It is important to reduce, reschedule, or avoid altogether any polluting activities (such as vehicle traffic, domestic burning, construction, industry emissions) that can cause pollution to build-up during these events.

Awareness of these effects could help vulnerable people in the community to adjust their behaviour to reduce their personal exposure during these peak episodes, such as avoiding strenuous exercise and staying indoors.

→ Large fires and other isolated high-polluting events have significant impact on air quality.

The air pollution resulting from large fires can impact the entire region and must be avoided, particularly during stable weather conditions when air pollution accumulates. The prevention and rapid response to unforeseen disasters and the avoidance of unnecessary burning are likely to be more effective than any other single air pollution reduction policy.

References

[1] Blake, E., & Wentworth, J. (2023). Urban outdoor air quality. Parliamentary Office of Science & Technology, UK Parliament. https://doi.org/10.58248/PN691

[2] Southampton City Council (2024). https://www.southampton.gov.uk/our-green-city/council-commitments/clean-air/improving-air-quality/

[3] Winchester City Council (2024) https://www.winchester.gov.uk/environment/air-quality

[4] Eastleigh Borough Council (2024). https://www.eastleigh.gov.uk/environment/environmental-health/pollution/air-quality

[5] New Forest District Council (2024). https://www.newforest.gov.uk/article/1002/Air-pollution

[6] EarthSense (2024). https://www.earthsense.co.uk/

[7] DEFRA (2019). Automatic Urban and Rural Network (AURN). https://uk-air.defra.gov.uk/networks/network-info?view=aurn.

[8] Met Office (2019). Available at: https://www.metoffice.gov.uk/.

[9] Committee on the Medical Effects of Air Pollutants (COMEAP). Advice on PM2.5 Targets in the Context of WHO Air Quality Guidelines. Department for Environment, Food & Rural Affairs (Defra), 2021.

Authorship

Prof Christina Vanderwel,
School of Engineering,
Faculty of Engineering and Physical Sciences

Mr Oliver Simmonds,
School of Electronics and Computer Science,
Faculty of Engineering and Physical Sciences

Ms Zi Xuan Peng,
School of Mathematical Sciences,
Faculty of Social Sciences

Acknowledgements

We gratefully acknowledge Southampton City Council, Winchester City Council, Eastleigh Borough Council, and the New Forest District Council who provided access to the air quality data measured in their communities funded by DEFRA's Burn Better Campaign.

Funding for this research was provided by the University of Southampton's Low Carbon Comfort Centre of Excellence and the Public Policy|Southampton New Things Fund.

Copyright

To cite this paper, please use: Vanderwel et al., "Identifying regional air quality trends from sensor network data: An analysis of PM2.5 measurements in Hampshire", Public Policy Brief, University of Southampton, October 2024, DOI: 10.5258/SOTON/PP0068

Find out more

Prof Christina Vanderwel
School of Engineering
Faculty of Engineering and Physical Sciences
c.m.vanderwel@soton.ac.uk