Blue Mountains and Lithgow
Ambient Air Quality Monitoring

Final Report 1st June 2019 - 31st May 2020
19 November 2020

Participating Organisations:
Blue Mountains City Council
Blue Mountains Conservation Society
Blue Mountains Union and Community
Doctors for the Environment
Environment Protection Authority
Lithgow Environment Group
Lithgow City Council
Nepean Blue Mountains Local Health District
Department of Planning, Industry and Environment
Western Sydney University

ACRONYMS

AM	Arithmetic Mean
AQM	Air Quality Monitoring
BMCC	Blue Mountains City Council
BMCS	Blue Mountains Conservations Society
BMUC	Blue Mountains Union and Community
CI95	95% Confidence Interval
CO	Carbon monoxide
DPIE	Department of Planning, Industry and Environment
EPA	Environment Protection Authority
GM	Geometric Mean
KOALA	Knowing Our Local Ambient Air Quality
LCC	Lithgow City Council
NBMLHD	Nepean Blue Mountains Local Health District
AAQ NEPM	Ambient Air Quality National Environment Protection Measure
PM	Particulate matter
$PM_{2.5}$	Particles with a mass median aerodynamic diameter of 2.5μm
PM_{10}	Particles with a mass median aerodynamic diameter of 10μm
ppm	Parts per million
pphm	Part per hundred million
QUT	Queensland University of Technology
WSU	Western Sydney University

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BACKGROUND

The Blue Mountains and Lithgow Air Watch project was a 12-month community-initiated research project supported by the NSW Environment Protection Authority (EPA) and the NSW Department of Planning, Industry and Environment (DPIE), as well as local stakeholders.

The purpose of the project was to provide a better picture of air quality in the Blue Mountains and Lithgow region and help inform future initiatives to protect air quality. This was done by gathering data across the greater Blue Mountains to observe the potential impacts of natural (bushfires and dust storms) and anthropogenic (traffic, wood smoke, construction, industry etc.) sources on air quality in the region.

The design of the NSW air quality monitoring networks is guided by the National Environment Protection (Ambient Air Quality) Measure (AAQ NEPM). It sets the minimum monitoring requirements based on population thresholds within a certain air shed or community. The minimum number of stations required for NEPM in Sydney is eight, DPIE currently operate 19 stations.

Previous air quality monitoring in the Blue Mountains and Lithgow area was undertaken in the late 1990s. The closest current NSW DPIE Air Quality Monitoring (AQM) Network stations are located in Penrith, St Marys and Richmond. The next closest AQM station is Bathurst, a distance of approximately 160 km.

The project was initiated by the Blue Mountains Conservation Society (BMCS), Blue Mountains Union and Community (BMUC), Doctors for the Environment and the Lithgow Environment Group. Representatives from these community groups and from the Blue Mountains City Council (BMCC), Lithgow City Council (LCC), Western Sydney University (WSU), Nepean Blue Mountains Local Health District (NBMLHD), DPIE and the EPA formed the Project Steering Committee.

The project included the collection of local air quality data over twelve months between 1st June 2019 and 31st May 2020 using:

- one (1) temporary compliance air quality monitoring station located at Katoomba; and

- twelve (12) low cost air quality sensors, known as KOALAs (Knowing Our Ambient Local Air-Quality), located at Katoomba, Lithgow, Springwood and Wentworth Falls (Figures 1 and 2).

The locations of the temporary compliance air quality monitoring station and the KOALAs were selected by the community representatives in the steering committee. Katoomba, Lithgow and Springwood townships were selected to get an indication of background air quality in different parts of the Blue Mountains and Lithgow area. Wentworth Falls along Boddington Hill was selected to provide an indication of air quality along a transport corridor. The KOALAs were placed in local schools and businesses and were looked after by volunteer hosts.

Figure 1: KOALA low cost air monitoring sensor (QUT)

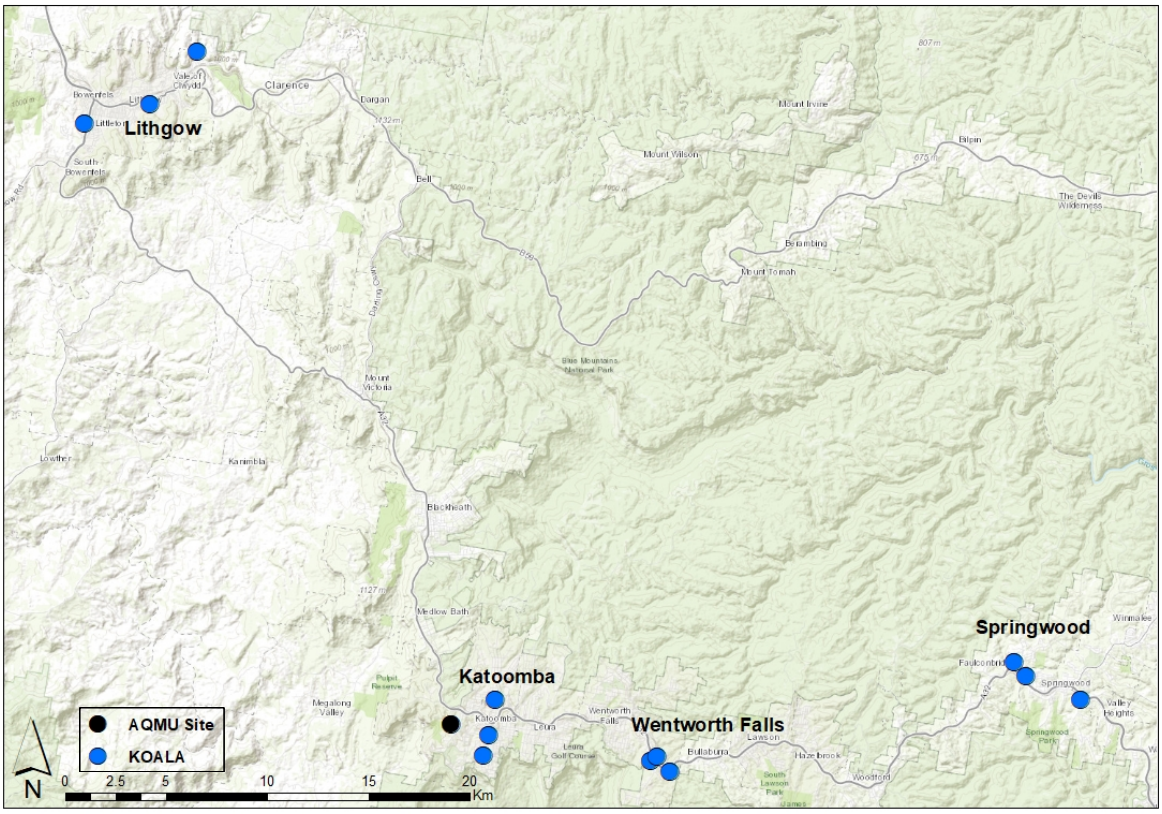

Figure 2: Location of KOALAs, Blue Mountains and Lithgow

The KOALAs were developed by the Queensland University of Technology (QUT). They measure concentrations of particles less than of 10 microns (PM_{10}) and less than 2.5 microns ($PM_{2.5}$) in diameter, as well as carbon monoxide (CO), in real time. The data was uploaded to a dedicated website maintained by QUT (http://bluemountains.sensors.net.au/).

The compliance air quality monitoring station in Katoomba was equipped with reference instruments for monitoring the quality of air for assessment in relation to the health-based air quality standards set out in the National Environment Protection (Ambient Air Quality) Measure (AAQ NEPM). The data from the Katoomba station (Figure 3) was used to assess baseline air quality over the 12 months, and for the validation of the KOALAs pre and post the study period.

Figure 3: Location of Katoomba Compliance Station, Air Services Australia, Valley Road

The scope of the project was to:

- Compare Compliance Station data against the health-based air quality standards and establish a baseline for Katoomba;
- Analyse PM_{10}, $PM_{2.5}$ and CO concentrations within and between the Blue Mountains and Lithgow townships using KOALAs;
- Identify potential sources of air pollutants that may be impacting the Blue Mountains and Lithgow townships; and
- Report and make recommendations where appropriate based on these findings.

METHODOLOGY

The KOALAs are solar powered, low cost, air quality monitors designed by the QUT's International Laboratory for Air Quality and Health (2019) (Figure 4). The units are fitted with:

- Plantower PMS1003 detector for $PM_{2.5}$ and PM_{10} particulates
- Aphasense CO-B4 gas sensor for carbon monoxide
- Temperature and humidity sensor
- Data logger
- 3G sim for telemetry
- Solar panel and battery

Figure 4: KOALA fitted with Carbon Monoxide and Particulate Sensors

Low cost sensors are indicative instruments that do not have the same accuracy, precision or stability as more sophisticated compliance instruments. Performance of low cost sensors therefore may decline over-time.

The particle sensors work on the principle of light scattering. Put simply, an air stream containing particles is passed through a laser beam, and the concentration of particulate matter is calculated according to the degree of light scattering. The degree of scattering is calculated as a mass measurement in micrograms per cubic metre of air (μg/m^3). The particle sensor has a range of error of +/-10 μg/m^3 (Plantower 2016). The Alphasense CO-B4 CO sensor is an electrochemical sensor that picks up changes in electrical charge when gas comes into contact with the detection unit. The change is then calculated as a measure of carbon monoxide in parts per million (ppm).

The KOALAs are not compliance instruments, and therefore the data cannot be compared directly to the health-based air quality standards set out in the AAQ NEPM (Dept. of the Environment 2016). The KOALAs can be, valuable tools for the detection of any local air pollution sources, assessing variability within and between discrete locations, and as tools for community education and awareness around management of air quality.

The Katoomba Compliance Station was operated and maintained by the DPIE's Climate and Atmospheric Science Branch.

The Katoomba site was located at a latitude of 33° 42' 37"S, longitude of 150° 17' 59"E and an elevation of 1045.9 metres (DPIE 2019). Air quality parameters monitored at the station include:

- Ozone (O_3)
- Oxides of nitrogen (NO, NO_2 and NOx)
- Carbon monoxide (CO)
- Sulphur dioxide (SO_2)
- Particles less than 10 micron (PM_{10})
- Particles less than 2.5 micron ($PM_{2.5}$)
- Visibility
- Wind speed, wind direction and sigma theta
- Ambient temperature
- Relative humidity

Ambient air quality data collection methods at the site were compliant with Schedule 3 of the AAQ NEPM. Monitoring data from the Katoomba Compliance Station was compared to the air quality standards in the AAQ NEPM (DPIE, 2020).

The AAQ NEPM was established to create a nationally consistent framework for the monitoring and reporting of air quality. The AAQ NEPM provides health-based standards that also take into account environmental, social and economic considerations (NEPC, 2011). The criteria pollutants and standards set out in the AAQ NEPM is provided in Table 1. More information on the establishment of and monitoring in relation to the AAQ NEPM can be accessed through the National Environment Protection Council website (2020).

Table 1: Ambient Air Quality National Environment Protection Measure

Pollutant	Averaging period	National Standard (NEPM)	NEPM (max allow exceedance)
Carbon monoxide	8 hours	9.0 ppm	1 day a year
Nitrogen dioxide	1 hour	0.12 ppm	1 day a year
	1 year	0.03 ppm	
Photochemical oxidants (as ozone)	1 hour	0.10 ppm	1 day a year
	4 hours	0.08 ppm	1 day a year
Sulphur dioxide	1 hour	0.20 ppm	1 day a year
	1 day	0.08 ppm	1 day a year
	1 year	0.02 ppm	
Particles as PM_{10}	1 day	50 µg/m^3	
	1 year	25 µg/m^3	
Particles as $PM_{2.5}$	1 day	25 µg/m^3	
	1 year	8 µg/m^3	

(source: https://www.legislation.gov.au/Details/F2016C00215)

Meteorological data, including, temperature, humidity, wind speed and direction was collected at the Katoomba Compliance Station. Rainfall data was sourced, where available, from the nearest Australian Bureau of Meteorology (BOM) monitoring station. Information on scheduled hazard reduction burns and bushfires in the surrounding area was sourced from the NSW Rural Fire Service (https://www.rfs.nsw.gov.au/)

Data Analysis

KOALA data was downloaded and transformed into hourly averages in R version 3.5.2. The databases were established in Microsoft Excel, with analysis and graph preparation undertaken in STATA Version 15 and Microsoft Excel.

The data from the KOALAs were not compared against the AAQ NEPM because the sensors do not comply with the requirements for compliance monitoring.

Validation Monitoring

The KOALAs were co-located at the Katoomba Compliance Station before (16th to 28th April 2019) and after (2nd to 16th June 2020) project deployment for validation testing. The results of the testing indicated that the KOALAs tracked well with the Compliance Station instruments in response to shifts in air quality indicators. However, as would be expected with low cost sensors, they did not have the accuracy and precision of the reference instruments. The data from the validation monitoring is presented in Appendix A.

RESULTS & DISCUSSION

Katoomba Compliance Monitoring Station

Air quality in Katoomba between 1st June 2019 and 31st May 2020, outside of fire events, complied with the AAQ NEPM standards (Table 2). Between October 2019 and February 2020, smoke from bushfires adversely impacted on local air quality in the region.

Prior to, and after the bushfire period, criteria air pollutants were consistently below their respective AAQ NEPM standards (Table 2, Appendix A), with concentrations of sulphur dioxide, nitrogen dioxide and ozone at the limit of detection of the instrument. The low levels of air pollutant concentration observed indicate that baseline air quality in Katoomba is generally very good.

During the bushfire period, there were 42 exceedances of the daily $PM_{2.5}$ standard of 25 µg/m^3 (Table 3). The bushfires significantly contributed to the annual $PM_{2.5}$ concentration of 16 µg/m^3, which is double the annual standard of 8 µg/m^3, as shown in Tables 2 and 3. The annual average $PM_{2.5}$ concentration with exceptional events (mainly bushfires during summer) removed was 4.9 µg/m^3 which is more indicative of general air quality in the Katoomba area. For the full set of monthly data results please refer to Appendix B.

For the other criteria pollutants monitored at the Katoomba Compliance Station during the bushfire period, 34 exceedances were recorded for daily PM_{10} (24-hour standard of 50 µg/m^3), along with 34 exceedances for O_3 (4-hour standard of 10 pphm) (Table 3). There were also increases in airborne concentrations of CO, SO_2 and NO_2, as well as decreased visibility as measured by the nephelometer (Table 2).

Elevated PM_{10} concentrations due to dust storms were also recorded on a few days in the summer period at the Katoomba compliance station. A full list of the exceptional events during the study period is provided in Appendix C.

Although outside of the study period, during the commissioning in May 2019, data collected indicate hazard reduction burns can also be a major contributor to airborne particulates. Details of the May 2019 snapshot during the commissioning period is provided in Appendix D.

Table 2: Monthly Averages for Ambient Air Pollutants, Katoomba Compliance Station, June 2019 to May 2020.

	$PM_{2.5}$ (µg/m^3)	PM_{10} (µg/m^3)	CO (ppm)	O_3 (pphm)	SO_2 (pphm)	NO_2 (pphm)	NEPH^ (Mm^{-1})
June 19	3.44	5.04	0.09	2.49	-0.01	0.11	18
July 19	2.86	4.52	0.09	2.78	0.02	0.07	10
Aug 19	3.26	5.30	0.07	2.98	0.03	0.07	15
Sept 19	3.60	6.71	0.02	3.07	0.02	0.05	15
Oct 19*	6.14	12.76	0.10	3.27	0.02	0.09	24
Nov 19*	16.98	29.27	0.18	3.34	0.03	0.09	76
Dec 19*	109.64	118.91	0.90	3.79	0.11	0.51	614
Jan 20*	38.47	55.97	0.48	3.30	0.07	0.25	NA
Feb 20*	6.74	14.39	0.14	2.45	0.08	0.18	45
March 20	3.14	7.08	0.12	2.12	0.02	0.16	26
April 20	4.57	8.71	0.10	2.40	0.04	0.12	18
May 20	3.08	4.83	0.11	2.24	0.03	0.17	14
Annual	16.83	22.79	0.20	2.85	0.04	0.16	93
Annual NEPM	8	25		8	2	3	
24 hour NEPM	25	50			8		
NEPM 8 hour			9				
NEPM 4 hour				10			
NEPM hourly					20	12	
DPIE Guide							210

* Active bushfires in NSW during this period
^ Nephelometer measures visibility and is compared with the NSW air quality indicator as there is no NEPM standard.

Table 3: Number of Exceedances for Criteria Air Pollutants Recorded at Katoomba Compliance Stations, June 2019 to May 2020

	$PM_{2.5}$	PM_{10}	CO	O_3	SO_2	NO_2	NEPH
1-hour*	392	412			0	0	626
24-hour	42	34					
4-hour				34			
8-hour			0				

* For 1-hour average $PM_{2.5}$ and PM_{10}, data is compared with the NSW interim reporting standard as there is no NEPM standard. Nephelometer data is compared with the NSW air quality indicator.

KOALA Low Cost Sensor Particulate Data

Similar to the data from the Katoomba compliance station, the real-time particulate data from the KOALAs reflected the increased emission of particulates and carbon monoxide during the bushfire season, which peaked in December 2019 (Figures 5 and 6), and during the May 2019 hazard reduction burn, which is presented in Appendix D. The study found that the bushfires were the largest contributor to particulates and CO in the Blue Mountains and Lithgow area during the study period, with Lithgow and Katoomba, located closest to the Gospers Mountain and Ruined Castle fires.

Outside of the bushfire period, particulate concentrations were very low, and did not vary widely between the townships. A small increase in PM_{10} particulate concentrations was observed in the Autumn months for Lithgow, Katoomba and Wentworth Falls, which is likely due to dust storm activity during this period (Figure 6).

Across the seasons, Springwood appeared to trend higher in comparison to the other townships across the seasons (Figure 7). However, the colocation data indicates that the Springwood KOALAs (K70-K72) trended higher in comparison to the other KOALAs (Appendix A). The KOALA particle sensors can operate within an accuracy range of ±10 $\mu g/m^3$, and the median, 25th and 75th percentile range for each township, indicated by the graphs in Figure 7, which were within this range of each other (Figure 7).

The PM_{10} and $PM_{2.5}$ data was modified by transforming any measurement over 500 $\mu g/m^3$ to a maximum value of 500 $\mu g/m^3$ which is the upper limit of detection for the KOALAs. Although the sensor may have recorded higher values during pollution events, it exceeded the upper limit of detection of the instrument. Therefore, the reading is considered out of range.

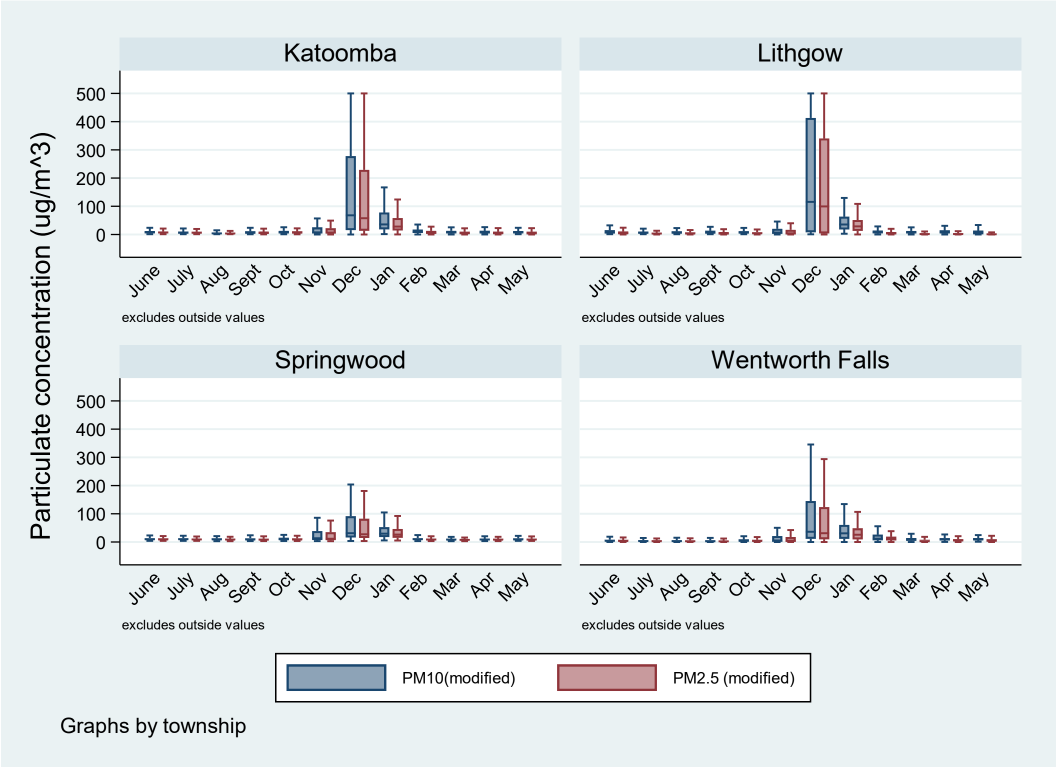

Figure 5: Comparison of Particulate Concentrations by Township, 1st June 2019 to 31st May 2020

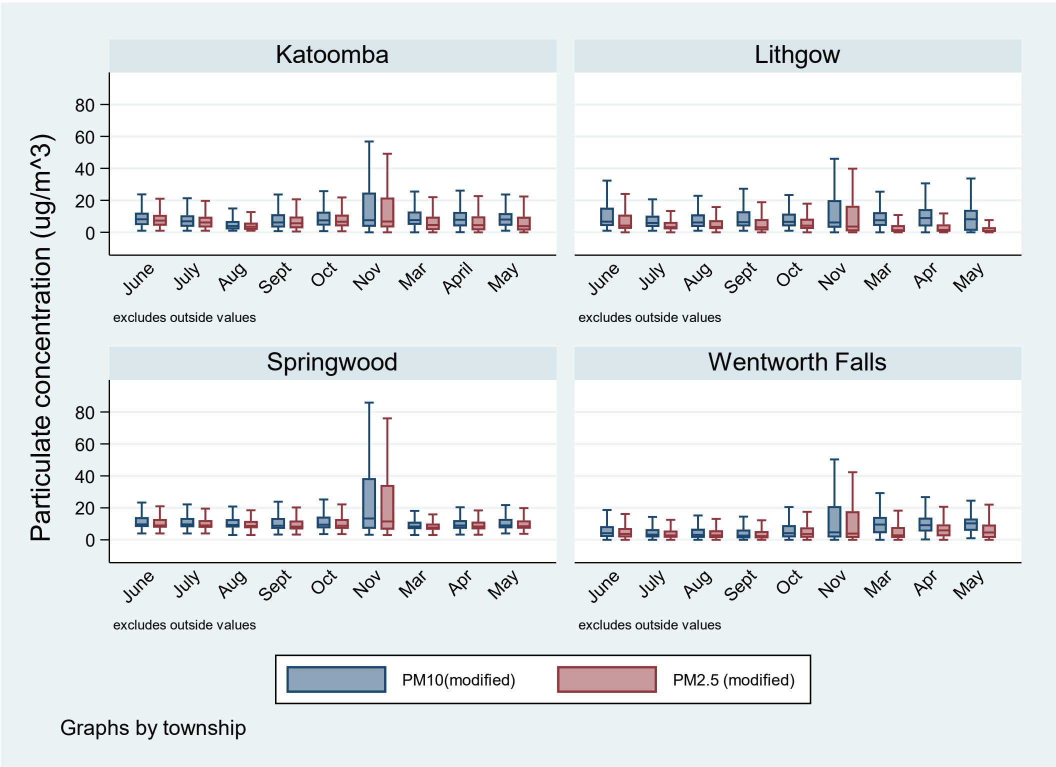

Figure 6: Comparison of Particulate Concentrations by Township summer data excluded, 1st June 2019 to 31st May 2020.

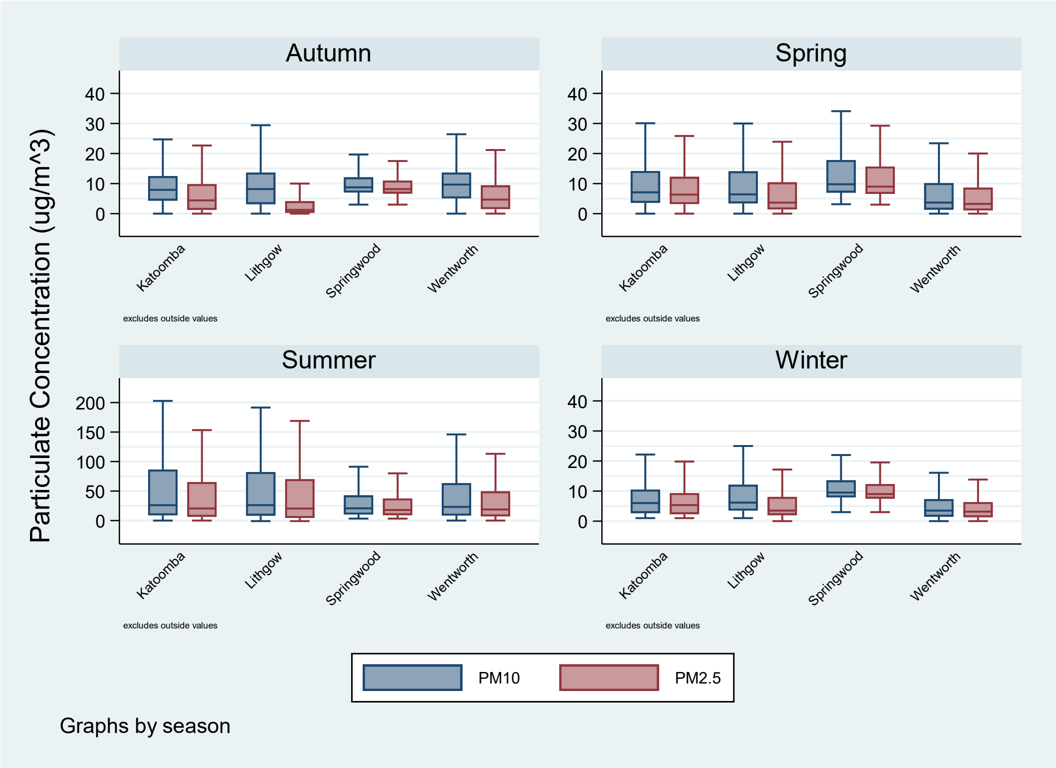

Figure 7: Seasonal Comparison of $PM_{2.5}$ and PM_{10} by Township, 1st June 2019 to 31st May 2020. (Note change in scale for summer)

A bimodal peak between morning and afternoon was observed for the hourly averaging of airborne particulates during autumn, winter and spring. The effect was most pronounced for Lithgow and Springwood, with a morning peak around 7am, and an evening peak between 7pm and 8pm (Figure 8). The timing of the peaks suggests that the use of heating devices such as solid fuel heaters may be a source of the elevated $PM_{2.5}$ concentrations. Due to the intensity and duration of bushfires in the summer, data from the months of December to February were omitted from this calculation because the data obscured the potential impact from other sources (Figure 8). The large change in $PM_{2.5}$ concentrations during summer can be seen in the comparison of hourly $PM_{2.5}$ for each season in Figure 9.

The potential for traffic impacts was looked at by analysing weekday and weekend separately to see if there were shifts in patterns that is typical of traffic activities. There was no observed difference in the weekday/weekend PM and CO concentrations. The summer data was omitted to remove the influence of bushfires in the analysis. There was also little variation between the Wentworth Falls KOALAs located along the transport corridor and the KOALAs in the other townships.

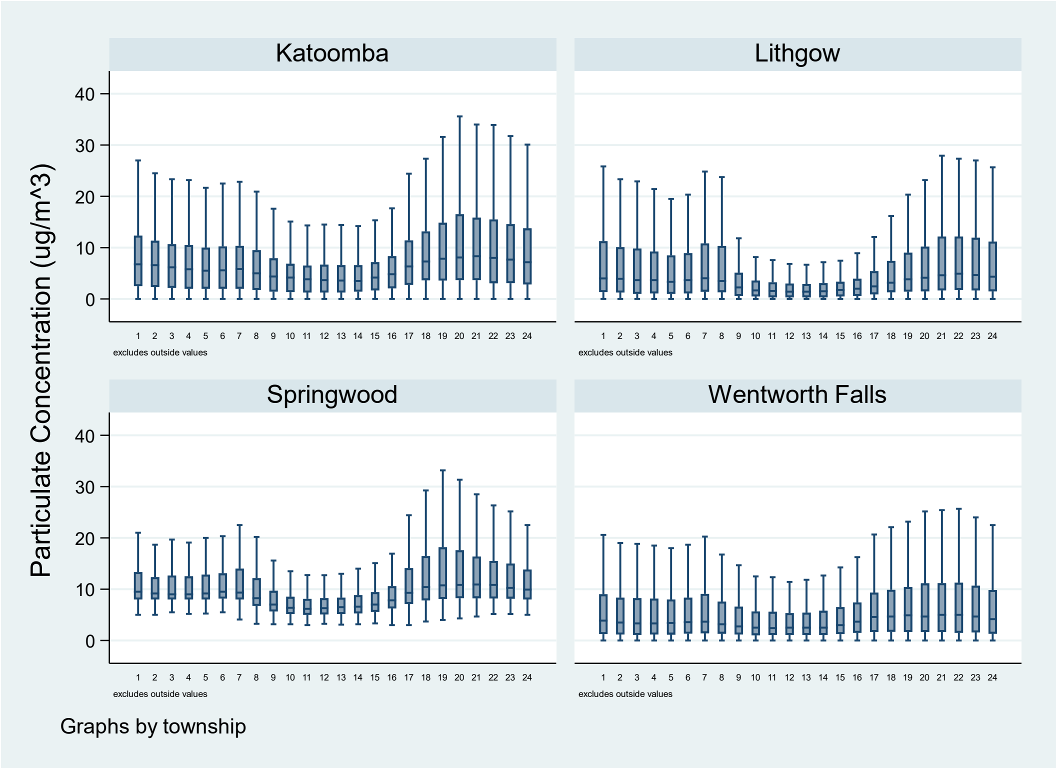

Figure 8: Daily (Diurnal) PM$_{2.5}$ by Township
1st June 2019 to 31st May 2020 summer data excluded

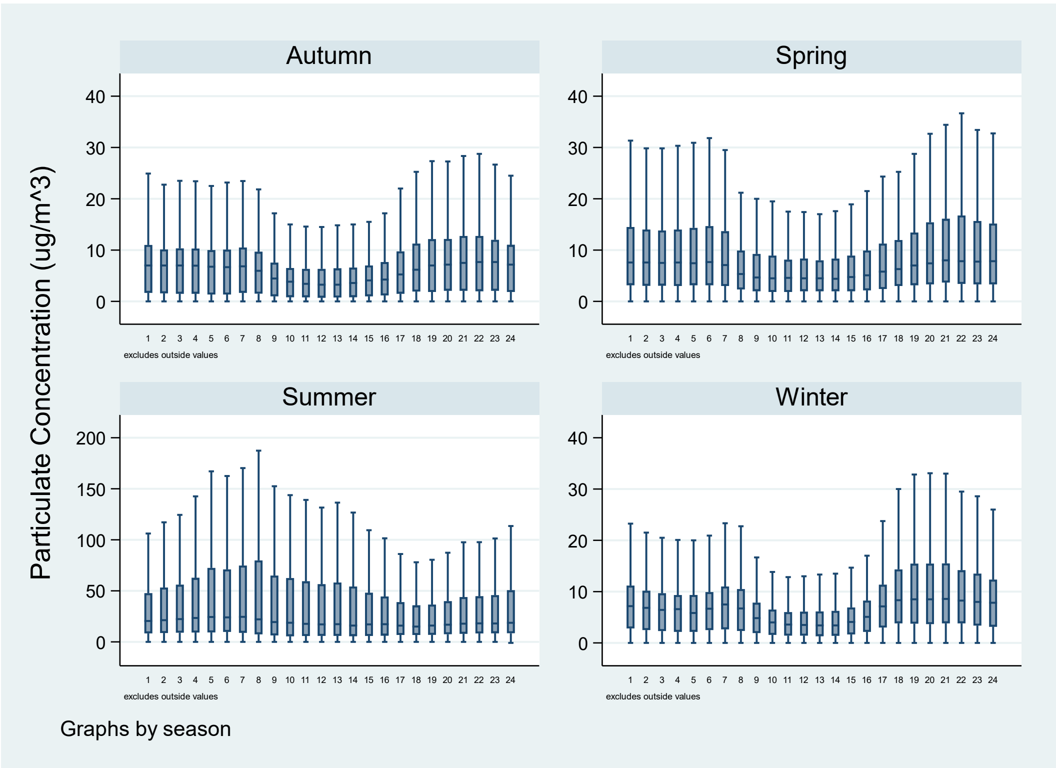

Figure 9: Daily (Diurnal) PM2.5 by Season,
1st June 2019 to 31st May 2020. (Note scale change for summer)

KOALA Low-cost Sensor Carbon Monoxide Data

Carbon monoxide is produced when materials are burned, including events such as bushfires and hazard reduction burns, combustion of fossil fuels, and operation of solid fuel, gas and kerosene stoves and heaters.

The CO concentrations recorded by the KOALAs followed a similar pattern to that for particulate matter. Peak CO concentrations were observed between October 2019 to February 2020 (bushfire period), with the highest concentrations recorded in December 2019 (Figures 10 and 11). Outside of the bushfire period, the CO concentrations were extremely low and at the limit of detection for the sensor, measuring less than 0.1 ppm (100 parts per billion).

Similar to $PM_{2.5}$, a bimodal peak in hourly CO concentrations occurred in the morning around 7am, and evening between 7pm and 9pm (Figure 12). The pattern was consistent across all townships, and more pronounced during the winter period (Figure 13). The timing of the CO peaks, as with $PM_{2.5}$, suggests that the use of heating sources such as solid fuel stoves may be contributing to the localised CO exposure, albeit at very low concentrations. The summer data was also omitted from the annual township daily CO graph due to fire activity obscuring the hourly fluctuations (Figure 12), which can be seen in Figure 13 where the bimodal peak is absent in summer.

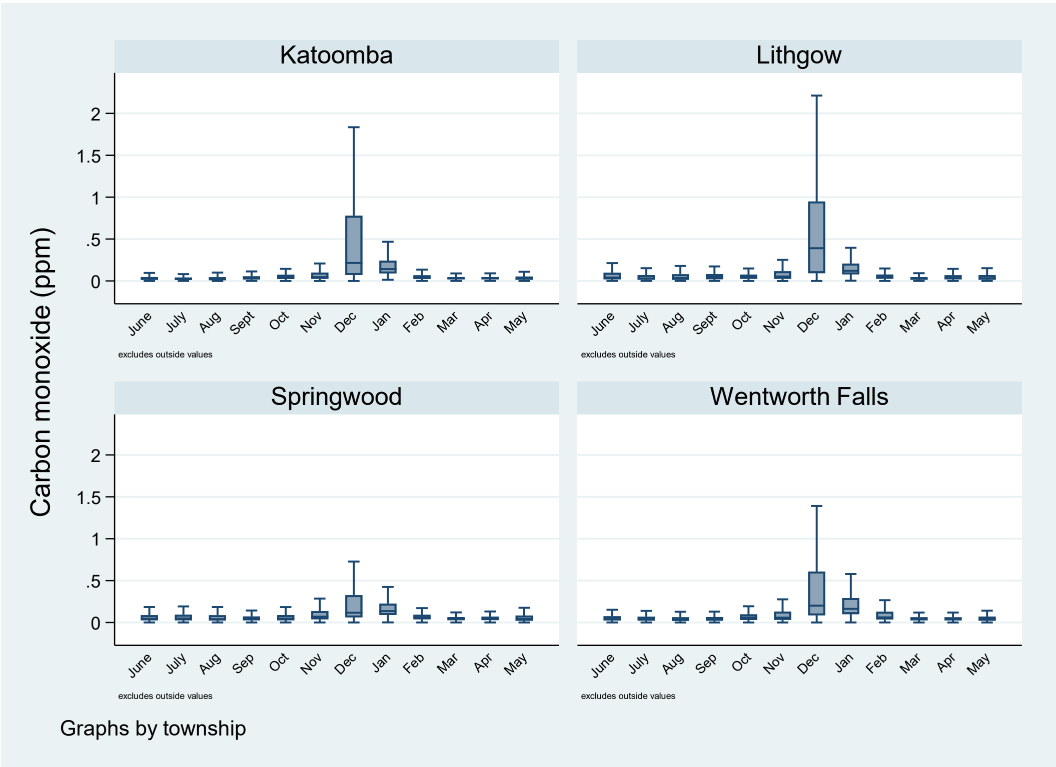

Figure 10: Comparison of Carbon Monoxide by Location and Month, 1st June 2019 to 31st May 2020.

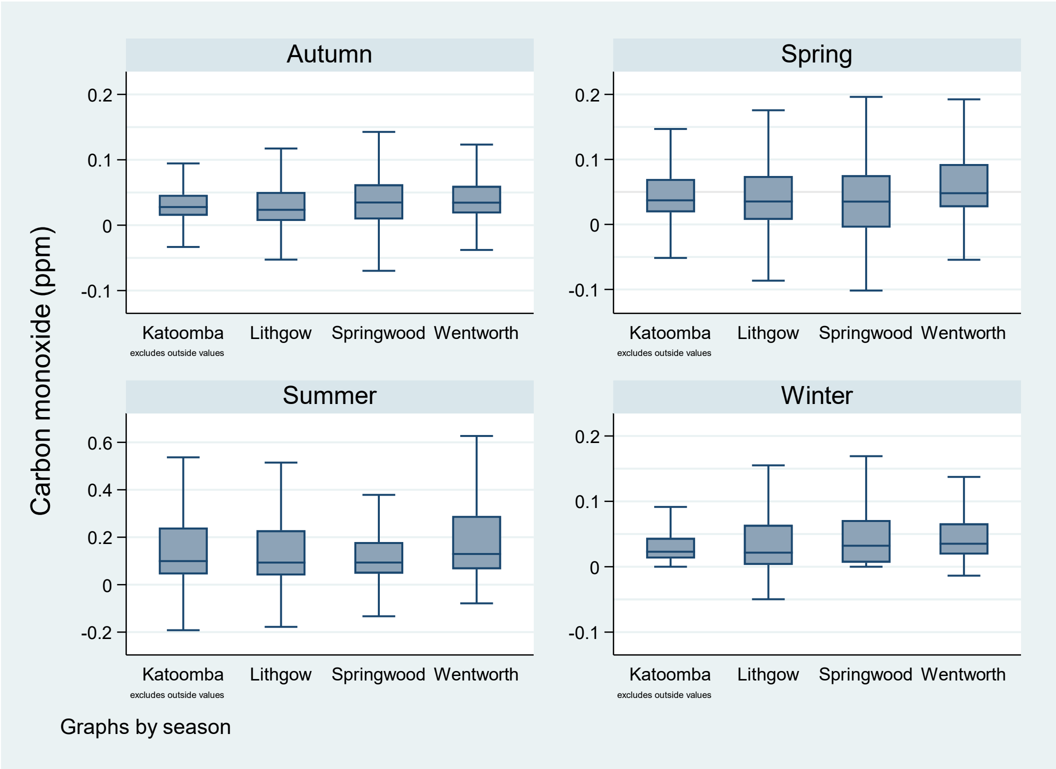

Figure 11: Comparison of Hourly Carbon Monoxide by Season, 1st June 2019 to 31st May 2020 Note scale change summer

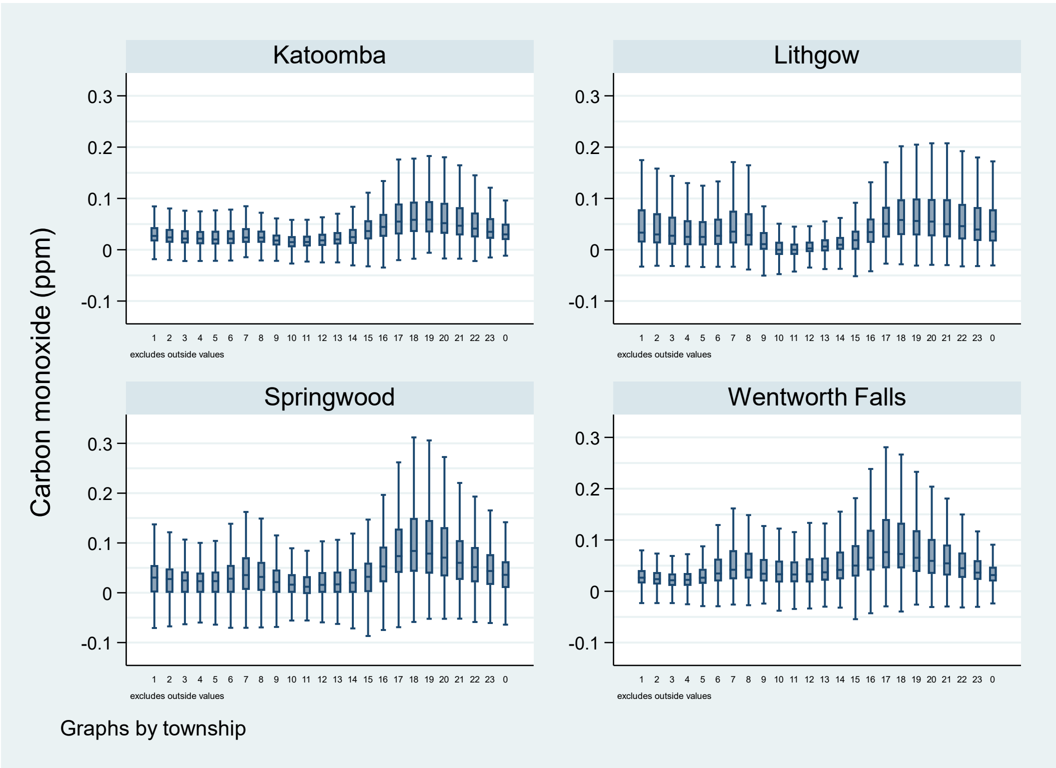

Figure 12: Daily (Diurnal) CO by Township
1st June 2019 to 31st May 2020 Summer data excluded

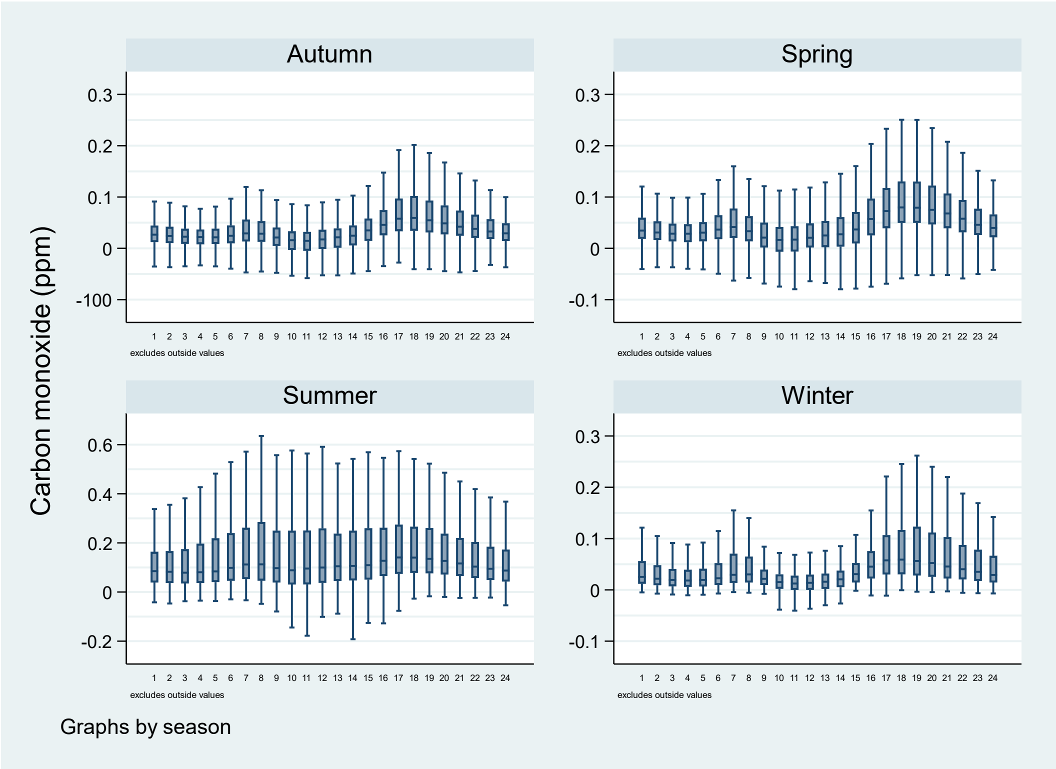

Figure 13: Daily (Diurnal) CO by Season
1st June 2019 to 31st May 2020

Outside values, also referred to as outliers, have been omitted to improve legibility of the graph.

FINDINGS

The work undertaken for this project is of critical importance to the Blue Mountains and Lithgow communities because it is the first 12-month baseline study of ambient air quality in the region to be undertaken since the 1990s. In addition, the project also captured the vital air quality data from the exceptional 2019 and 2020 bushfire season which burnt over 5.5 million hectares of land in NSW. This data will be critical in developing greater understanding of the health impacts, and management of bushfire smoke in relation to human and ecosystem health.

The results from the 12-month project between the 1st June 2019 and 31st of May 2020 indicate that outside of the exceptional bushfires of 2019-2020, the air quality in Katoomba (compliance station) was generally very good, and compliant with the AQ NEPM standards. During the bushfire period, PM_{10} and $PM_{2.5}$ frequently exceeded their respective 24-hour standards of 50 μg/m^3 and 25 μg/m^3, as well as 34 exceedances of ground level O_3 concentrations. Other sources of emissions in Katoomba such as industrial and transport were not discernible, with SO_2, NO and NO_2 readings typically at the limit of detection for the instruments (outside of fire events).

The findings indicate that the 2019-2020 bushfires had the greatest impact on local air quality in the Blue Mountains region. This data indicates that air quality during the bushfire period represented a potential public health risk, and actions were undertaken at the time to alert residents to the potential health risks associated with exposure to bushfire smoke, and measures that could be undertaken to reduce personal exposure.

The Katoomba Compliance Station air quality data from this project is available for public use and can be accessed through the DPIE website.

Given the air quality is very good in the Blue Mountains region, outside of exceptional air pollution events such as bushfires and dust storms, there are no specific recommendations for the Blue Mountains and Lithgow area arising from the project.

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Appendix A: Colocation (Validation) Data

The KOALAs were co-located at the Katoomba Compliance Station from the 16th to 28th April 2019 (pre-study period colocation), and from the 2nd to 16th June 2020 (post-study period colocation), for validation testing. The results of the testing indicated that the KOALAs tracked well with the Compliance Station instruments in response to shifts in air quality indicators ($PM_{2.5}$, PM_{10} and CO). However, as would be expected with low cost sensors, they did not have the accuracy and precision of the reference instruments. As a result, the data from KOALAs should only be used for indicative purposes to observe differences in air quality within and between township locations, which may be influenced by human and natural activities.

Particulate Monitoring

Table A1 provides a comparison of the hourly $PM_{2.5}$ KOALA data with the DPIE Compliance Station tapered element oscillating microbalance (TEOM) during the two-week colocation periods (pre and post-study period). The difference between the $PM_{2.5}$ geometric means (GM) calculated for each sensor to compare their accuracy in relation to a reference standard instrument (TEOM).

During the pre-study period colocation period the mean KOALA $PM_{2.5}$ concentrations varied from -0.4 µg/m^3 (K61) to 9.3 µg/m^3 (K64) relative to the TEOM (Table A1; Figure A1), and between -1.3 µg/m^3 (K69) and 12.2 µg/m^3 (K67) during the post-study period colocation (Table A1; Figure A1). Based on the findings from the pre-study period colocation, the particulate sensor for K64 was replaced prior to deployment.

The trend for PM_{10} measurements was similar to $PM_{2.5}$ during the pre-study period colocation (Figure A1), but varied greater in comparison to $PM_{2.5}$ during the post-study period colocation (Figure A2).

The particulate sensors for some of the KOALAs required maintenance and/or replacement during the monitoring, and the full details for maintenance of the sensors can be found in Appendix E.

The difference between the particulate measurements by the KOALAs and TEOM is expected given the different detection mechanisms. Low cost particulate sensors that use light scatter as a detection method (photometers), such as the KOALAs, do not have the accuracy and precision of gravimetric instruments. The reduced accuracy and precision can occur for number of reasons. Firstly, low cost sensors are not fitted with heaters or dryers, and events such as fog or haze may result in the overestimation of particulate levels due to fine droplets registering as particles. The sensors may also be influenced by differences in the physical and chemical makeup of aerosols in the real world versus the type of test dust used to calibrate the sensor, as well as non-linearity of sensor response when there are very high particulate concentrations (Grimm & Eatough 2009; Jayaratne et al. 2018; Kelly et al. 2017).

The potential effect of moisture (humidity) on the sensors was observed during the pre-study period colocation; KOALA $PM_{2.5}$ and PM_{10} displaying a moderate correlation with humidity levels of R_s=0.680 and R_s=0.709 respectively, and a weaker correlation ranging between R_s=0.406 and R_s=0.570 during the post-study period colocation.

Table A1: Comparison Daily KOALA $PM_{2.5}$ Data Versus DPIE Compliance Station Katoomba, April 2019 and June 2020.

Instrument Reference	Project Location	Hourly $PM_{2.5}$ (µg/m^3)					
		Number of samples	**KOALA (Pre) April 2019***	**Difference to Compliance Station**	**Number of samples**	**KOALA (Post) June 2020 ***	**Difference to Compliance Station**
K61	Lithgow	279	3.8 (3.2 - 4.5)	-0.4	281	5.0 (4.2 - 6.1)	0.8
K62	Lithgow	286	8.6 (7.8 - 9.5)	4.4	286	5.9 (5.1 - 6.8)	1.7
K63	Lithgow	288	5.5 (4.9 - 6.2)	1.3	264	4.4 (3.5 - 5.4)	0.2
K64	W. Falls	287	14.8 (13.7 - 16.2)	9.3	NA	NA	NA
K98	W. Falls	NA	NA	NA	250	4.3 (3.4 - 5.5)	0.1
K65	W. Falls	286	9.1 (8.3 - 10.0)	4.9	285	5.7 (4.8 - 7.8)	1.5
K66	W. Falls	230	10.0 (9.0 - 11.2)	5.8	290	14.4 (13.4 - 15.5)	10.2
K67	Katoomba	289	12.2 (11.4 - 13.1)	8.0	287	16.4 (15.1 – 17.9)	12.2
K68	Katoomba	283	4.8 (4.3 - 4.5)	0.6	289	4.4 (3.8 - 5.0)	0.2
K69	Katoomba	286	7.9 (7.2 - 8.6)	3.7	243	2.9 (2.4 - 3.6)	-1.3
K70	Springwood	288	10.2 (9.6 - 10.8)	6.0	288	8.2 (7.7 - 8.8)	4.0
K71	Springwood	287	11.7 (11.0 - 12.3)	7.5	276	15.2 (14.0 - 16.7)	11.0
K72	Springwood	287	13.1 (12.2 - 14.1)	8.9	285	15.5 (14.2 - 16.9)	11.3
Mean ALL			9.2 (8.5 - 9.9)			7.6 (7.3 – 8.0)	3.4
Compliance Station			4.2 (3.8 - 4.5)	NA		4.2 (3.8 - 4.5)	NA

*Geometric Mean and 95% Confidence Intervals

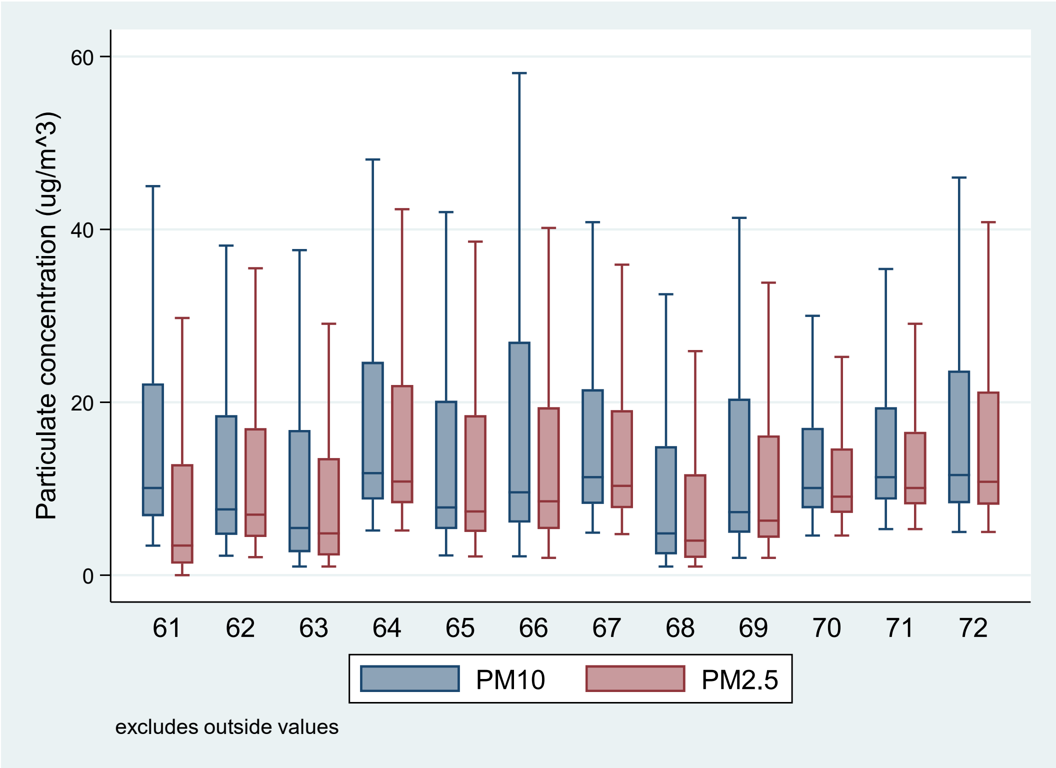
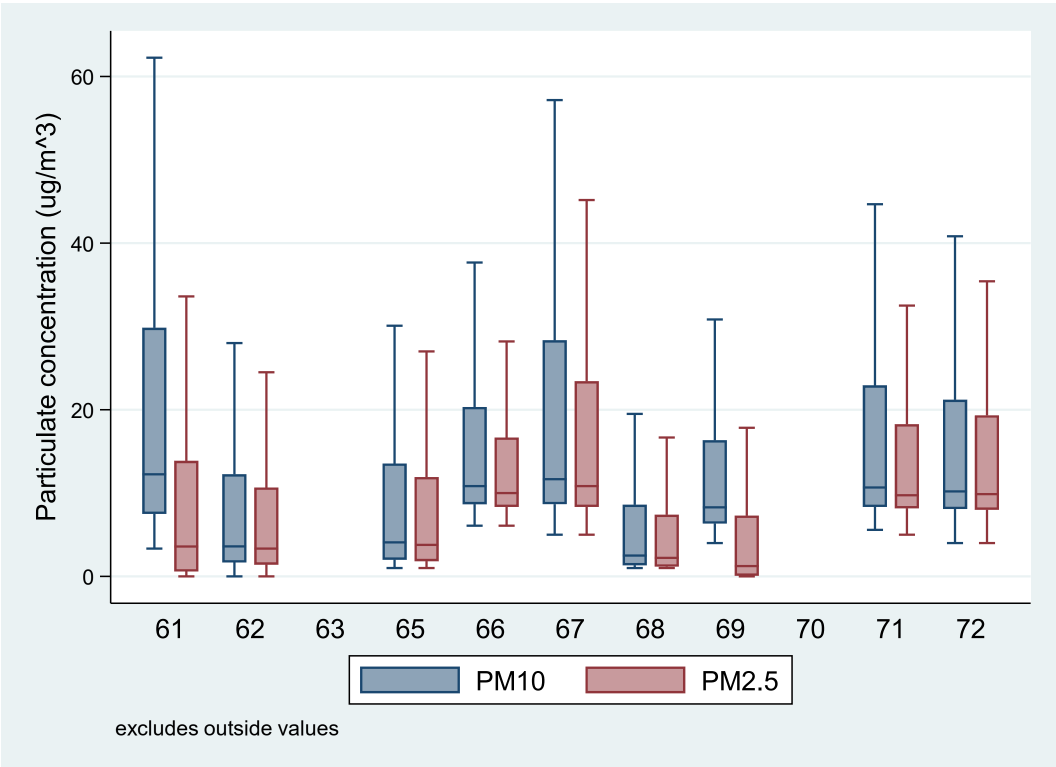


Figure A1: Comparison of Real-Time PM_{10} and $PM_{2.5}$ for KOALAs (16th to 28th April 2019)



Note KOALAs 63 and 70 are not included as the sensors were replaced during or prior to the second colocation

Figure A2: Post-study period comparison of Daily $PM_{2.5}$ and PM_{10} for KOALAs (2nd to 16th June 2020)

Carbon monoxide

The ambient CO levels in Katoomba during both the pre and post-study period colocation were at the limit of detection for both DPIE Compliance Station and the KOALAs, measuring typically less than 50 ppb (0.05 ppm) during pre-study period colocation (Figure A3) and below zero during post-study period colocation (Figure A4). Carbon monoxide concentrations trended well between the KOALAs during the colocation periods, with exception of K62 and K70, which were adjusted prior to deployment. For post-study period colocation K62 and K70 continue to monitor carbon monoxide lower in comparison to the other KOALAs. However, it must be noted that the sensors were measuring at the limit of their detection capability and greater variability would be expected, and K70 had an ant infestation during this period with the sensor reading zero (Figure A8).

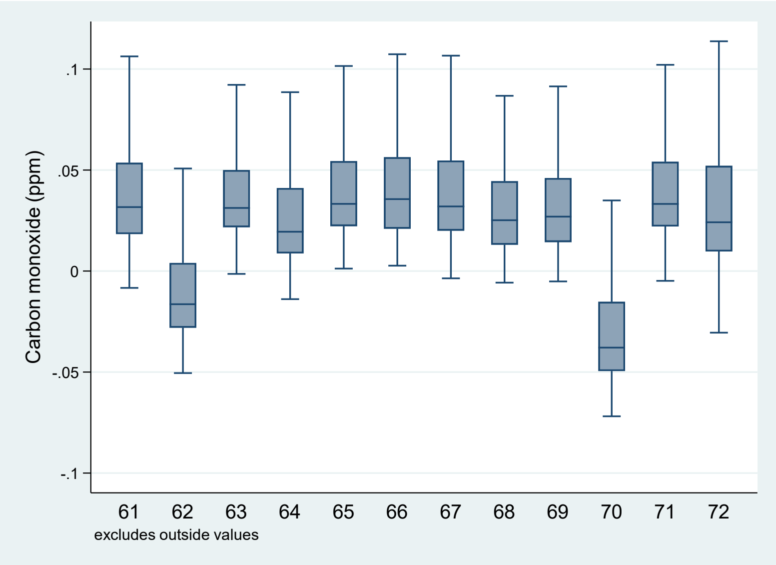


Figure A3: Comparison of Carbon Monoxide (ppm) readings for KOALAs (16th to 28th April 2019)

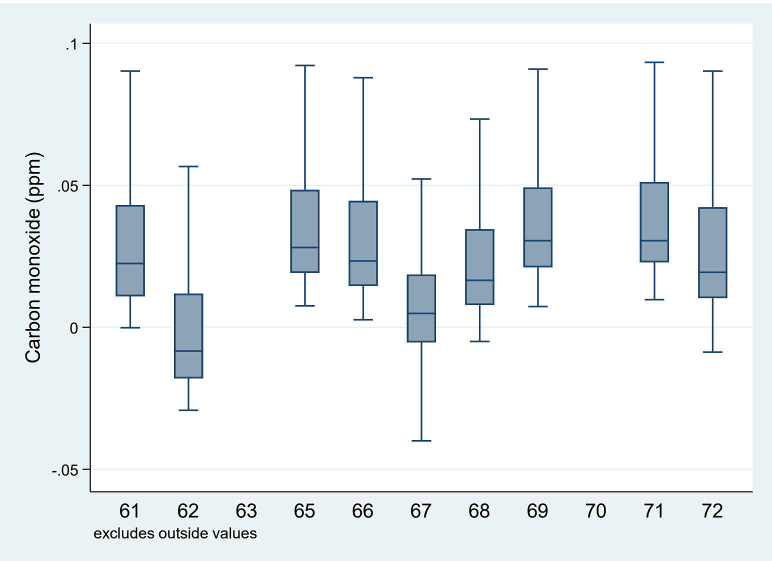


Figure A4: Comparison of Carbon Monoxide (ppm) readings for KOALAs (2nd to 16th June 2020). Note KOALAs 63 and 70 are not included as the sensors were replaced during or prior to the second colocation.

KOALAs Co-located at Katoomba DPIE Compliance station for entirety of study

Two KOALA units were co-located at the Katoomba Compliance Station for the entirety of the study as another test of sensor drift. It was found that the two sensors did not drift from each other or compliance measurements for both CO and $PM_{2.5}$ measurements (Figures A5-A7).

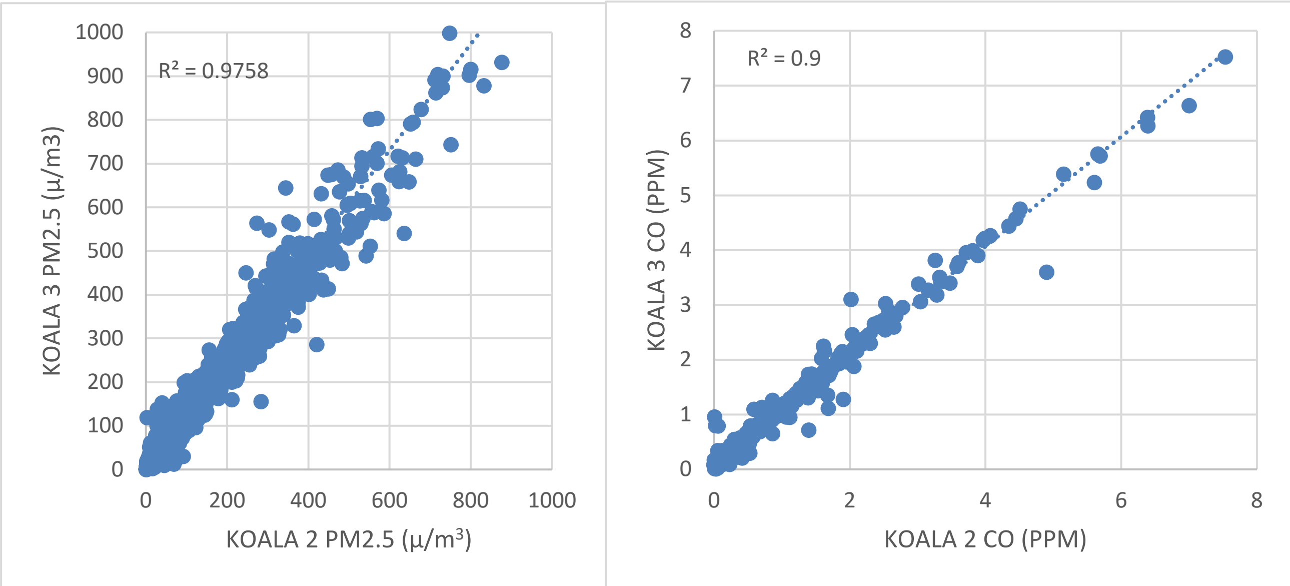


Figure A5: Comparison of KOALA 2 and KOALA 3 $PM_{2.5}$ (left) and CO (right) during entirity of study

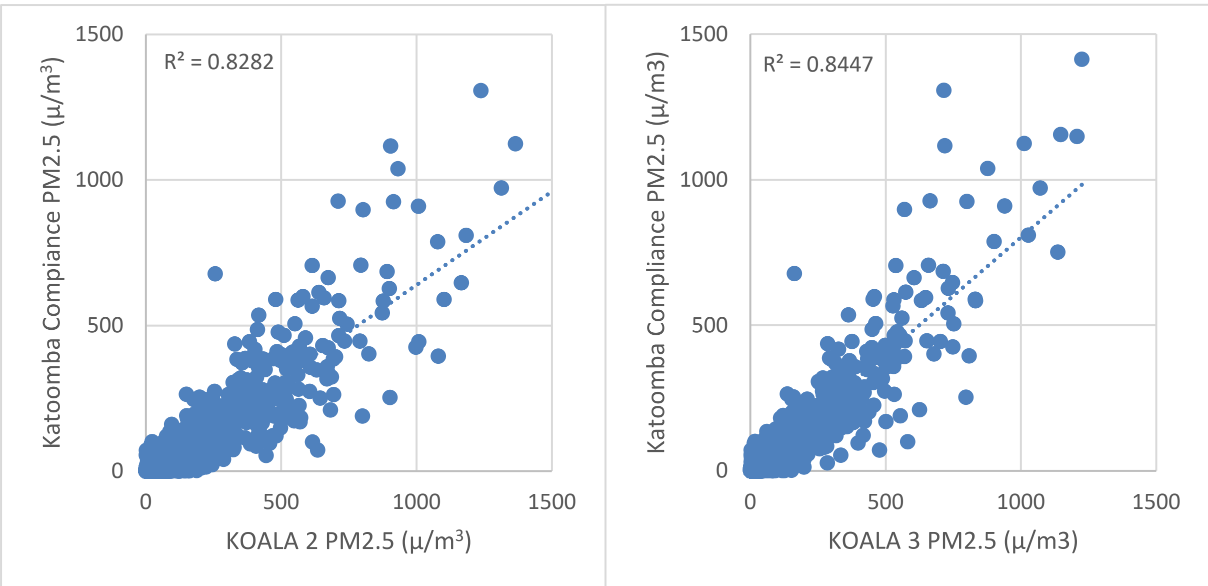


Figure A6: Comparison of KOALA 2 (left) and KOALA 3 (right) and the Katoomba Compliance Station for $PM_{2.5}$

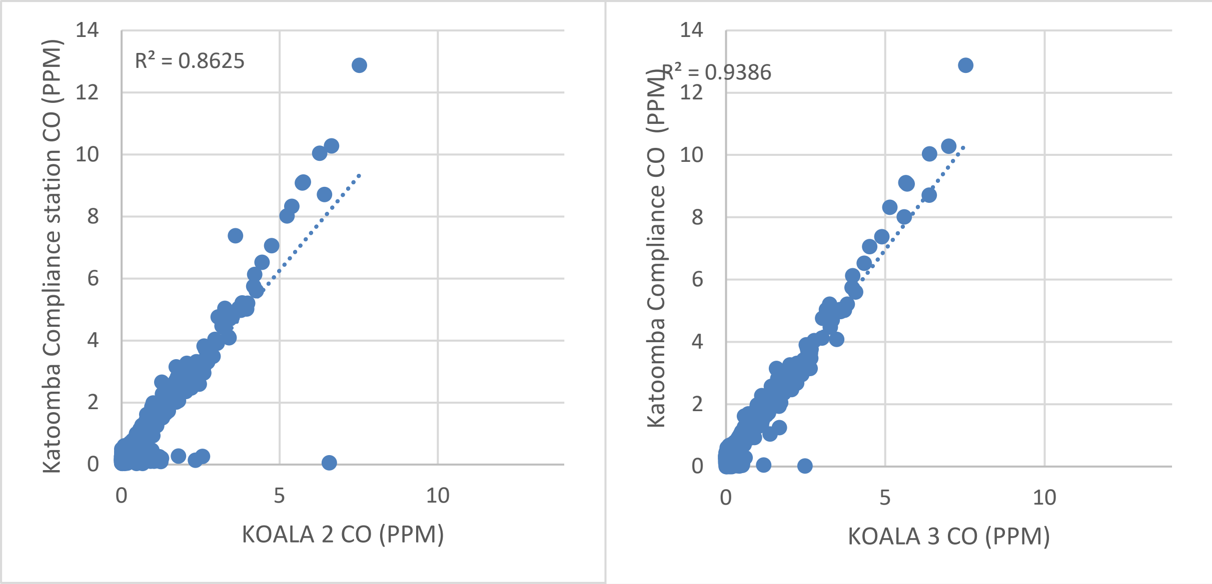


Figure A7: Comparison of KOALA 2 (left) and KOALA 3 (right) and the Katoomba Compliance Station for CO

Appendix B: DPIE Compliance Station Results – 1st June 2019 - 31st May 2020

Table B1: Comparison of Air Quality Data for the Katoomba DPIE Compliance Station 2019-2020,

Station	PM_{10} 24 hour average (µg/m^3)	$PM_{2.5}$ 24 hour average (µg/m^3)	CO 8 hour rolling average (ppm)	NO 1 hour average (pphm)	NO_2 1 hour average (pphm) *	O_3 1 hour average (pphm)	SO_2 1 hour average (pphm) *
June 2019 Average (median) n= Geometric mean (GSD n=) Minimum to maximum	5 (5) n=30 4 (1.7) n=30 1-9	3 (3) n=30 3 (1.8) n=30 <1-7	0.1 (0.1) n=669 0.1 (1.4) n=517 <0.1-0.9	0.12 (0) n=687 NA^ <0.01-1.10	0.12 (0) n=687 NA^ <0.01 - 1.80	2.5 (2.5) n=663 0.9 (1.2) n=690) 1.1-3.5	<0.1 (0) n=670 NA^ <0.01-0.40
July 2019 Average (median) n= Geometric mean (GSD n=) Minimum to maximum	5 (4) n=31 4 (1.6) n=31 2-10	3 (3) n=31 3 (1.6) n=31 <1-5	0.1 (0.1) n=712 0.1 (1.6) n=434 <0.1-0.5)	0.03 (0) n=712 NA^ <0.01-0.80	0.07 (0) n=712 NA^ <0.01 - 1.40	2.8 (2.8) n=712 2.8 (1.1) n=744 1.8-3.8	0.01 (0) n=712 NA^1.3 <0.01-0.50
August 2019 Average (median) n= Geometric mean (GSD n=) Minimum to maximum	5 (5) n=31 5 (1.7) n=31 1-12	3(3) n=31 3 (2.0) n=31 <1-10	0.1 (0.1) n=712 0.1 (1.3) n=415 <0.1-0.8	0.02 (0) n=712 NA^ <0.01-0.5	0.07 (0) n=712 NA^ <0.01-1.5	2.9 (3.0) n=712 2.9 (1.1) n=744 <0.1-3.8	0.2 (0) n=712 NA^ <0.01-0.70
September 2019 Average (median) n= Geometric mean (GSD n=) Minimum to maximum	7 (7) n=30 5 (2.2) n=30 <1-20	4 (3) n=30 3 (2.5) n=30 <1-13	0.01 (0) n=690 NA^ <0.1-0.2	0.02 (0) n=690 NA^ <0.01-0.5	0.05 (0) n=690 NA^ <0.01-1.2	3.1 (3.1) n=644 3.0 (1.1) n=668 1.9-4.4	0.01 (0) n=690 NA^ <0.01-0.80
October 2019 Average (median) n= Geometric mean (GSD n=) Minimum to maximum	13 (9) n=31 9 (2.3) n=31 2-46	6 (5) n=31 4 (2.5) n=31 <1-26	0.1 (0.1) n=678 NA^ <0.1-0.5	0.02 (0) n=695 NA^ <0.01-0.70	0.09 (0) n=695 NA^ <0.01-1.2	3.3 (3.1) n=695 3.1 (1.3) n=722 1.8-8.3	0.02 (0) n=696 NA^ <0.01-0.70

^ too many null values to calculate geometric mean (GSD)

Station	**PM_{10}** 24 hour average (µg/m^3)	**$PM_{2.5}$** 24 hour average (µg/m^3)	**CO** 8 hour rolling average (ppm)	**NO** 1 hour average (pphm)	**NO_2** 1 hour average (pphm) *	**O_3** 1 hour average (pphm)	**SO_2** 1 hour average (pphm) *
November 2019							
Average (median) n=	29 (16) n=30	17 (7) n=30	0.2 (0.1) N=681	0.01 (0) n=659	0.10 (0) n=659	3.3 (3.1) n=681	0.03 (0) n=678
Geometric mean (GSD n=)	19 (2.5) n=30	9 (3.1) n=30	0.2 (1.9) n=627	NA^	NA^	3.2 (1.4) n=706	NA^
Minimum to maximum	4-118	2-113	<0.1-3.0	<0.01-0.20	<0.01-1.40	1.6-11.6	<0.01-2.6
December 2019							
Average (median) n=	112 (77) n=27	103(66) n=27	0.9 (0.5) n=744	0.04 (0) n=605	0.27 (0.10) n=605	3.8 (3.2) n=711	0.11 (0) n=692
Geometric mean (GSD n=)	64 (3.3) n=27	47 (4.6) n=27	0.5 (3.2) n=739	NA^	NA^	3.3 (1.7) n=711	NA^
Minimum to maximum	6-447	2-436	0-8.1	0-2.5	0-8.6	0.6-10.9	0-1.6
January 2020							
Average (median) n=	56(30) n=31	38(20) n=31	0.5 (0.3) n=735	0.02 (0) n=626	0.27 (0.10) n=623	3.3 (3.1) n=672	0.05 (0) n=704
Geometric mean (GSD n=)	36 (2.3) n=31	23(2.4) n=31	0.4 (2.0) n=735	NA^	NA^	3.0 (1.6) n=672	NA^
Minimum to maximum	6-379	4-363	0.1-7	0-1.6	0-8.6	0.5-8.3	0-1.4
February 2020							
Average (median) n=	15(11) n=29	7(9) n=26	0.1 (0.1) n=672	0.04 (0) n=629	0.18 (0.18) n=630	2.5 (2.2) n=611	0.07 (0) n=634
Geometric mean (GSD n=)	9(3.2) n=27	4(3.5) n=25	0.1 (01.5) n=621	NA^	NA^	2.2 (1.5) n=611	NA^
Minimum to maximum	0-92	0-39	0-0.7	0-0.8	0-2.4	0.7-6.5	0-4.3
March 2020							
Average (median) n=	7.0 (5.3) n=29	3.1 (2.7) n=29	0.1 (0.1) n=730	0.04 (0) n=675	0.16 (0.10) n=675	2.1 (1.9) n=652	0.01 (0) n=675
Geometric mean (GSD n=)	5.6 (2.0) n=29	2.7 (1.7) n=29	0.1 (1.2) n=730	NA^	0.16 (1.9) n=533	2.0 (1.4) 652	NA^
Minimum to maximum	1.2-21.5	0.7 – 7.5	<0.1-0.2	0-0.7	0-1.7	0.5-4.8	0-0.6

^ too many null values to calculate geometric mean (GSD)

Station	PM_{10} 24 hour average (µg/m^3)	$PM_{2.5}$ 24 hour average (µg/m^3)	CO 8 hour rolling average (ppm)	NO 1 hour average (pphm)	NO_2 1 hour average (pphm) *	O_3 1 hour average (pphm)	SO_2 1 hour average (pphm) *
April 2020l							
Average (median) n=	8.7 (8.5) n=31	4.6 (4.2) n=30	0.11 (0.10) n=712	0.02 (0) n=672	0.12 (0.10) n=672	2.4 (2.4) n=686	0.03 (0) n=672
Geometric mean (GSD n=)	8.1 (1.5) n=31	4.2 (1.6) n=30	0.11 (1.2) n=693	NA^	0.18 (1.9) n=348	2.4 (1.2) n=686	NA^
Minimum to maximum	2.5-15.3	1.0-10.5	<0.10-0.20	0-0.5	0-3.0	0.4-4.0	0-2.5
May 2020							
Average (median) n=	4.8 (4.6) n=31	3.2 (2.9) n=30	0.11 (0.10) n=744	0.04 (0) n=711	0.16 (0.10) n=712	2.2 (2.3) n=666	0.02 (0) n=712
Geometric mean (GSD n=)	3.7 (2.3) n=31	2.3 (2.5) n=30	0.12 (1.3) n=713	NA^	0.18 (2.0) n=481	2.2 (1.9) n=666	NA^
Minimum to maximum	0.4-12.5	0.2-11.2	<0.10-0.30	0-0.3	0-1.9	0.4-3.1	0-1.9
NSW Air Quality Standard	50 (µg/m^3)	25 (µg/m^3)	9 (ppm)	-	12 (pphm)	10.0 (pphm)*	20 (pphm)

^ too many null values to calculate geometric mean (GSD)

Appendix C: List of exceptional events during study period

Date	Site	PM10	PM2.5	Parameter	Main source
22/05/2019	KATOOMBA	55.08	45.18	PM10/PM2.5	Hazard Reduction Burning
23/05/2019	KATOOMBA	85.82	72.91	PM10/PM2.5	Hazard Reduction Burning
30/10/2019	KATOOMBA		26.52	PM2.5	Bushfire
1/11/2019	KATOOMBA		27.42	PM2.5	Bushfire
17/11/2019	KATOOMBA		25.46	PM2.5	Bushfire
18/11/2019	KATOOMBA		36.96	PM2.5	Bushfire
21/11/2019	KATOOMBA	121.67	114.71	PM10/PM2.5	Bushfire
22/11/2019	KATOOMBA	58.21	39.24	PM10/PM2.5	Bushfire
23/11/2019	KATOOMBA	65.01	46.81	PM10/PM2.5	Bushfire
26/11/2019	KATOOMBA	86.94		PM10	Mix Dust and Burning
28/11/2019	KATOOMBA		34.26	PM2.5	Bushfire
29/11/2019	KATOOMBA	51.52	31.29	PM10/PM2.5	Bushfire
8/12/2019	KATOOMBA	122.25	111.08	PM10/PM2.5	Bushfire
9/12/2019	KATOOMBA	309.86	295.36	PM10/PM2.5	Bushfire
10/12/2019	KATOOMBA	84.85	67.59	PM10/PM2.5	Bushfire
11/12/2019	KATOOMBA	131.40	122.02	PM10/PM2.5	Bushfire
12/12/2019	KATOOMBA	72.18	65.30	PM10/PM2.5	Bushfire
13/12/2019	KATOOMBA	50.51	46.07	PM10/PM2.5	Bushfire
14/12/2019	KATOOMBA	76.48	65.61	PM10/PM2.5	Bushfire
15/12/2019	KATOOMBA	80.63	70.08	PM10/PM2.5	Bushfire
16/12/2019	KATOOMBA	72.33	65.30	PM10/PM2.5	Bushfire
17/12/2019	KATOOMBA		28.28	PM2.5	Bushfire
18/12/2019	KATOOMBA	254.90	249.48	PM10/PM2.5	Bushfire
19/12/2019	KATOOMBA	103.94	94.98	PM10/PM2.5	Bushfire
20/12/2019	KATOOMBA	256.06	248.65	PM10/PM2.5	Bushfire
21/12/2019	KATOOMBA	211.93	198.20	PM10/PM2.5	Bushfire
22/12/2019	KATOOMBA		28.71	PM2.5	Bushfire
23/12/2019	KATOOMBA	267.64	257.74	PM10/PM2.5	Bushfire
24/12/2019	KATOOMBA	173.38	164.05	PM10/PM2.5	Bushfire
25/12/2019	KATOOMBA	87.09	81.10	PM10/PM2.5	Bushfire
26/12/2019	KATOOMBA	446.78	435.92	PM10/PM2.5	Bushfire
31/12/2019	KATOOMBA	56.65	36.14	PM10/PM2.5	Bushfire
1/01/2020	KATOOMBA	125.07	117.71	PM10/PM2.5	Bushfire
2/01/2020	KATOOMBA		29.51	PM2.5	Bushfire
4/01/2020	KATOOMBA	89.29	71.46	PM10/PM2.5	Bushfire
5/01/2020	KATOOMBA	378.99	362.60	PM10/PM2.5	Bushfire
7/01/2020	KATOOMBA		32.87	PM2.5	Bushfire
8/01/2020	KATOOMBA	75.12	66.78	PM10/PM2.5	Bushfire
11/01/2020	KATOOMBA	78.52	62.39	PM10/PM2.5	Bushfire
12/01/2020	KATOOMBA	54.85	44.13	PM10/PM2.5	Bushfire
23/01/2020	KATOOMBA	249.61	39.79	PM10/PM2.5	Widespread dust storm
24/01/2020	KATOOMBA	70.62		PM10	Mix Dust and Burning
2/02/2020	KATOOMBA	91.79	39.03	PM10/PM2.5	Mix Dust and Burning
4/02/2020	KATOOMBA		25.34	PM2.5	Bushfire

Appendix D: May 2019 Hazard Reduction Burn Data

Air quality in Katoomba during the commission period (May 2019) was significantly impacted by hazard reduction burns undertaken in the mid Blue Mountains, during which the health based air quality standard for $PM_{2.5}$ of 25 µg/m^3 (24-hour average) and PM_{10} standard of 50 µg/m^3 (24-hour average) were exceeded between 21st and 24th May 2019 (Figure C1). Carbon monoxide levels also peaked during this period but did not exceed the national standard for air quality of 9.0 ppm (8-hour average). Outside of the hazard reduction burns, daily particulate concentrations were typically less than 10 µg/m^3.

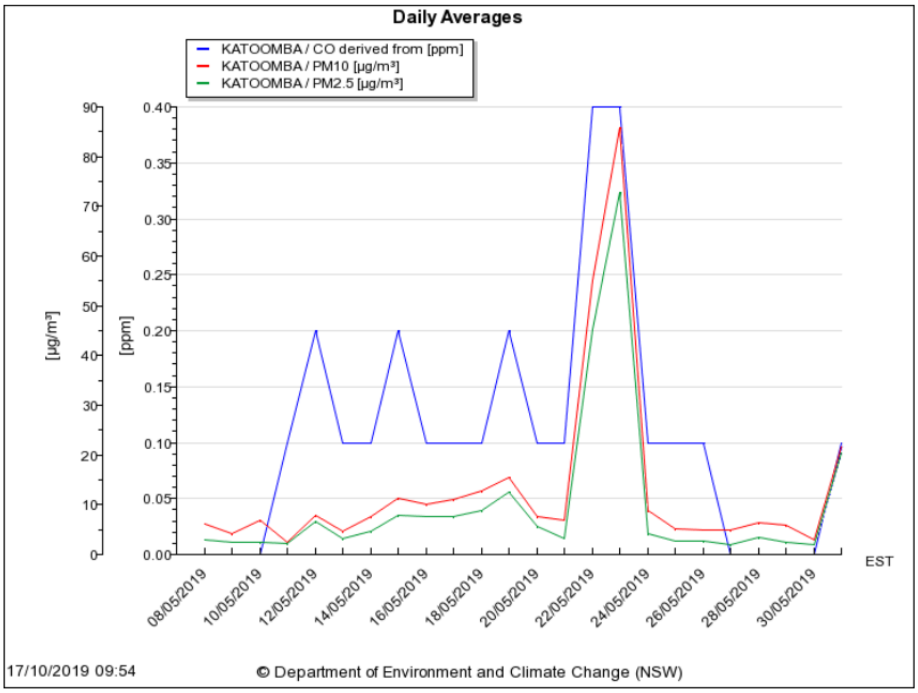


Figure D1: Time Line of Daily $PM_{2.5}$, PM_{10} and Carbon Monoxide Daily Averages from Katoomba Compliance Station, 14th to 31st May 2019

Low cost air quality sensors, known as KOALAs (Knowing Our Ambient Local Air-Quality) were located at Katoomba, Lithgow, Springwood and Wentworth Falls. During May 2019, the PM_{10} and $PM_{2.5}$ measurements were higher for Springwood, in comparison to Katoomba, Lithgow and Wentworth Falls (Figure C2). The biggest impact on local air quality during this period were the hazard reduction burns which were closest to the trio of KOALAs located in Springwood, the $PM_{2.5}$ peaks from which can be seen in Figure C3. CO levels followed a similar pattern to particulates (Figure C4).

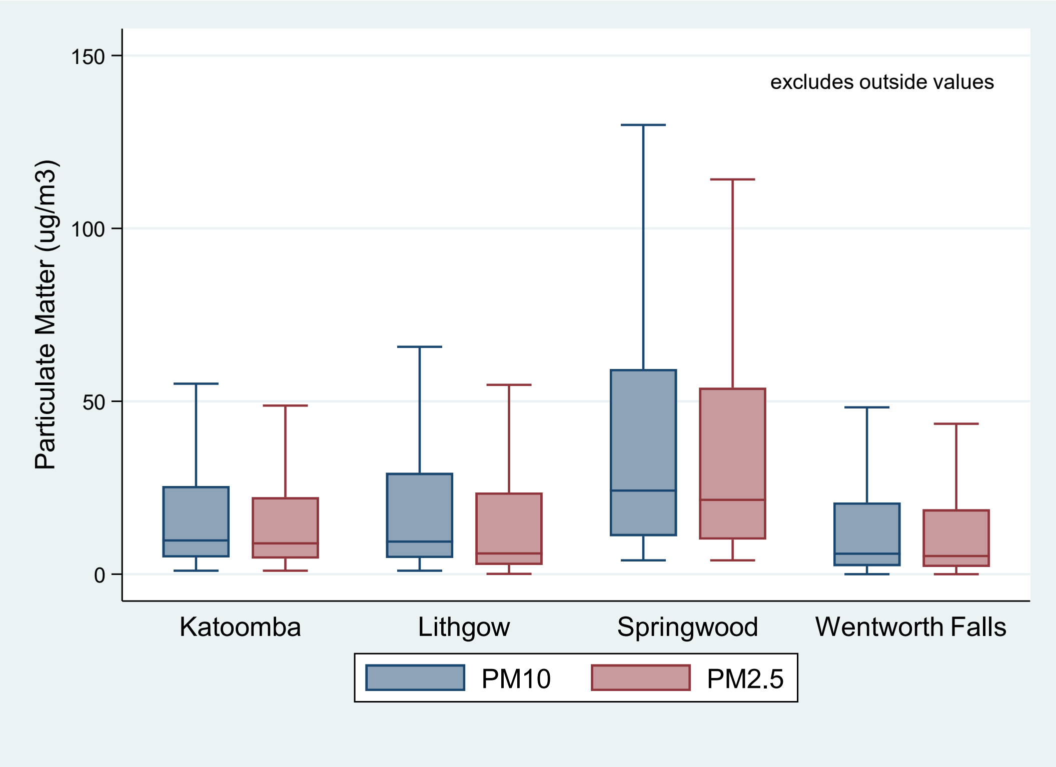
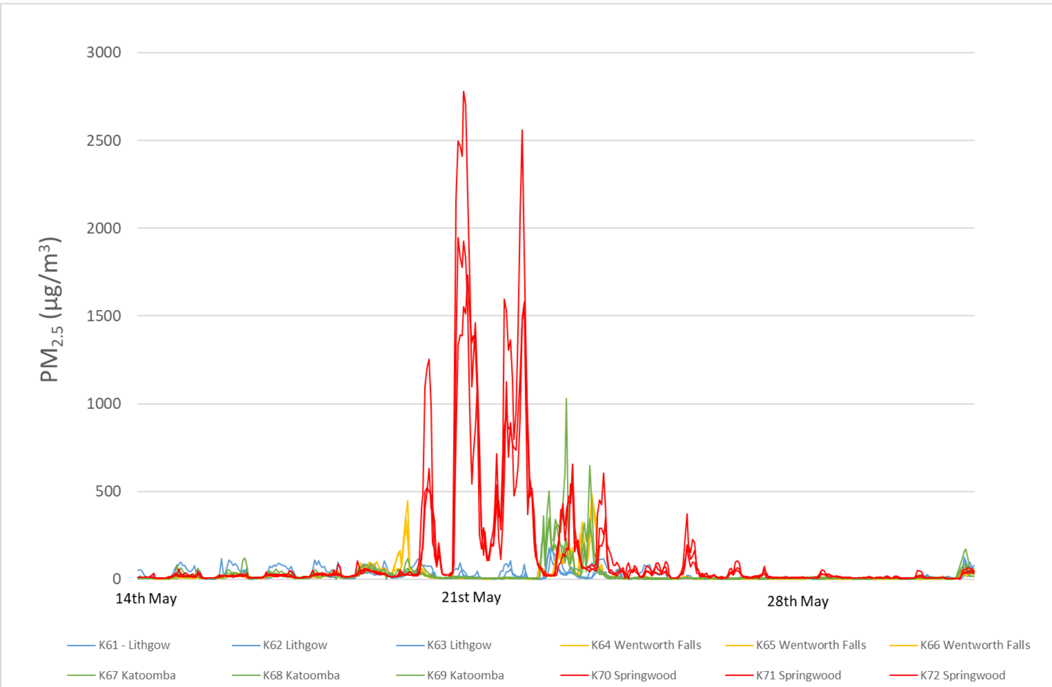


Figure D2: Comparison of Particulate Concentrations by Township, 14th to 31st May 2019.



Note concentrations above 500 µg/m³ are beyond the upper limit of the KOALA sensors and are considered out of range.

Figure D3: KOALAs Hourly $PM_{2.5}$ Averages By Township, 14th to 31st May 2019

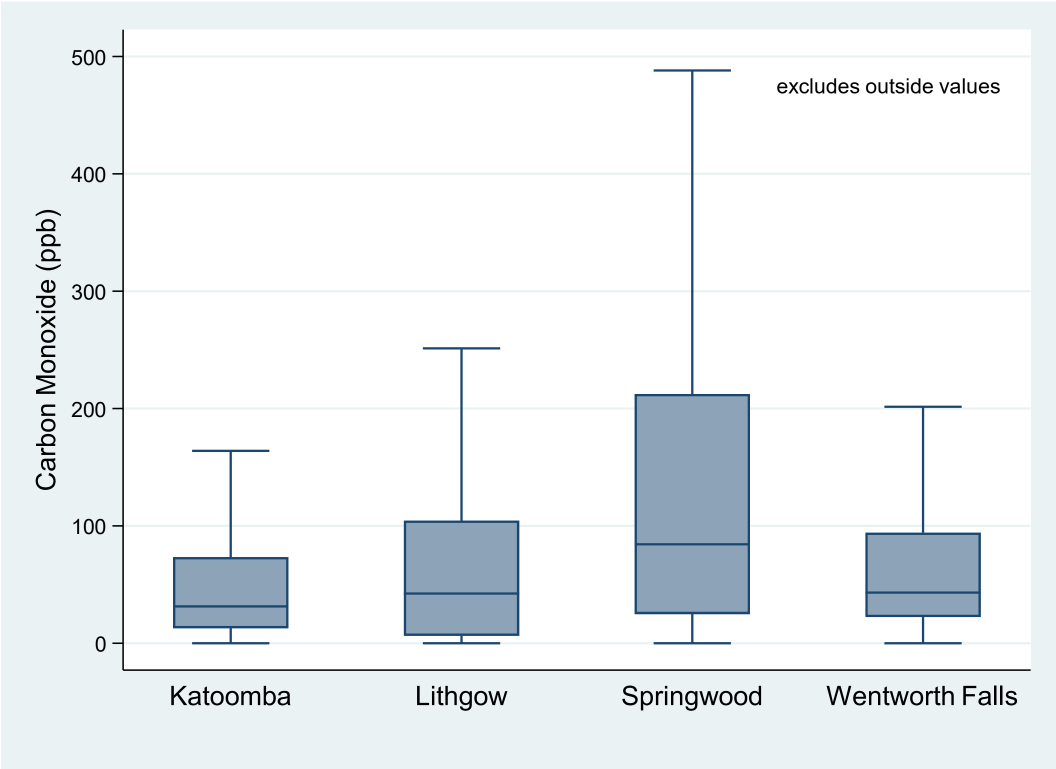


Figure D4: Comparison of Carbon monoxide Concentrations by Township, 14th to 31st May 2019

Appendix E: KOALAs maintenance and error log

Instrument Reference	Project Location	Hourly $PM_{2.5}$ ($\mu g/m^3$)	
		Date	**Issue**
K2	Katoomba Monitoring Station	29/08/2019	Sensor replaced - age
		1/03/2020	Data missing - no communications
K3	Katoomba Monitoring Station	29/08/2019	Sensor replaced - age
		3/10/2019	Sensor replaced - faulty particle sensor
K62	Lithgow	5/01/2020	Sensor replaced - faulty particle sensor
		4/12/2020	Data missing - no communications
		17/02/2020	Data missing - no communications
K63	Lithgow	7/09/2019	Data missing - no communications
		6/02/2020	Sensor replaced - faulty particle sensor
		02/06/2020	Sensor replaced - faulty particle sensor
K64	W. Falls	7/05/2019	Sensor replaced - faulty particle sensor
		6/12/2019	Sensor replaced - faulty particle sensor
		1/03/2020	Sensor replaced - mainboard failure
K98	W. Falls	18/03/2020	Data missing – faulty CO sensor
		02/06/2020	Sensor replaced - faulty particle sensor
K65	W. Falls	7/05/2019	Sensor replaced - faulty particle sensor
K66	W. Falls	7/05/2019	Data missing - no communications
		1/03/2020	Sensor replaced - faulty particle sensor
K68	Katoomba	10/03/2020	Data missing - no communications
K69	Katoomba	20/11/2019	Data missing - no communications
K70	Springwood	02/06/2020	Data missing - faulty particle sensor