AIR POLLUTION LEVELS MEASURED AT TRAFFIC HOT SPOTS: BRISBANE URBAN CORRIDOR STUDY

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Abstract

Air pollution levels were monitored continuously over a period of 4 weeks at four sampling sites along a busy urban corridor in Brisbane. The selected sites were representative of industrial and residential types of urban environment affected by vehicular traffic emissions. The concentration levels of submicrometer particle number, $PM_{2.5}$, PM_{10}, CO, and NO_x were measured 5-10 meters from the road. Meteorological parameters and traffic flow rates were also monitored. The data were analysed in terms of the relationship between monitored pollutants and existing ambient air quality standards. The results indicate that the concentration levels of all pollutants exceeded the ambient air background levels, in certain cases by up to an order of magnitude. While the 24-hr average concentration levels did not exceed the standard, estimates for the annual averages were close to, or even higher than the annual standard levels.

Keywords: Traffic emissions, aerosol, PM_{10}, $PM_{2.5}$, submicrometer particles, CO, NO_x, Standard, NEPM, US EPA, ambient air

1. Introduction

Air quality in our cities has emerged as a major social and health issue over recent years. There is wide-spread concern that health costs attributed to air pollution may be very high, and are often under-estimated. On a regional basis, air pollution arises from a number of sources. These include industry, transport, power generation, domestic heating and some natural occurrences such as bushfires or dust storms. Road vehicles are the dominant source of many pollutants, because of their large numbers and extensive use throughout the main population centres. Although wind and natural dispersion tend to spread pollutants across the broad urban area, people living close to major traffic routes are inevitably exposed to higher concentrations than areas with lesser traffic. Given that urban transport routes are a fact of life, and it is impractical to completely separate people from the vicinity of road traffic, mitigation strategies must inevitably focus on reducing the levels of pollutants emitted by vehicles, at least in the short to medium term.

Despite the increasing interest in traffic emissions and its contribution to air pollution levels, the amount of currently available information and real-world data is limited, especially in the immediate vicinity to busy roads. This applies especially to particle number concentration in the submicrometer size range, for which the traffic exhaust is the major source. Such information is critical for a qualified assessment of exposure levels, remedial strategies as well as traffic and land management strategies.

The aim of this study was to provide quantification of the particle and gaseous pollutants in ambient air dominated by vehicular traffic exhaust emissions measured under real-world conditions at four different sites in Brisbane. The study has the following specific objectives:

- Quantification of the concentration levels, source identification and assessment of the relationship between monitored pollutants
- Characterisation of the temporary variation in pollutants levels (weekly, hourly)
- Comparison of measured data with available standards and/or ambient background levels.

2. Experimental

2.1. Monitoring Sites

Air monitoring campaign was conducted jointly by the International Laboratory for Air Quality and Health (ILAQH) QUT and EPA QLD at four sites along the Brisbane Urban Corridor (BUC) over 4 weeks during June-July 2002. The monitoring sites

were selected for their proximity to major intersections along the Corridor representing "hot spot" where the concentrations of targeted pollutants were likely to be highest. The sites varied in topographic and demographic surrounding.

The main characteristics of the selected sites were as follows:

- Site 1: Granard and Beaudesert Roads (industrial environment; open flat terrain; stop/start traffic mode; fleet composition: 20% heavy duty vehicles (HDV) 80% Light duty vehicles (LDV); Traffic flow rate ~ 4.1×10^4 vehicles/day (actual).
- Site 2: Kessels and Mains Roads (urban/industrial environment); semi-open terrain, on a hill near in the vicinity of a forest area; stop/start traffic mode; 11% HDV; 89% LDV; Traffic flow rate: 3.5×10^4 vehicles/day (actual).
- Site 3: Kessels and Logan Roads; urban environment (shops, office areas); open area, slight elevation; stop/start traffic mode; 10% HDV; 90% LDV; Traffic flow rate: 3.3×10^4 vehicles/day (estimate).
- Site 4: Mount Gravatt-Capalaba and Newham Roads; closed terrain (at the bottom of a small valley); residential environment; stop/start traffic mode; 12% HDV; 88% LDV; Traffic flow rate: 2.6×10^4 vehicles/day (estimate).

All sites were in 60 km/h traffic speed zone with traffic lights within 50 m from the sampling location.

2.2. Instrumentation and Parameters Measured

The instrumentation used in the study included: Scanning Mobility Particles Sizers (SMPS TSI Model 3071) for determination of particle number size distribution and concentration levels in the submicrometer size range; two Tapered Element Oscillating Microbalance (TEOM) units for monitoring of $PM_{2.5}$ and PM_{10}, one Dustrak unit (TSI Model 8520) for $PM_{2.5}$ measurements; CO and NO_x analysers. The size range of particle numbers measured by the SMPS was 0.017 to 0.7 μm. The time resolution was 5 minutes for SMPS, $PM_{2.5}$ (Dustrak, TEOM) and 30 minutes for the remaining instrumentation. The TEOM is certified by the US EPA as an equivalent to gravimetric techniques for PM_{10} and $PM_{2.5}$ measurements in ambient air.

All instruments were calibrated before the start of measurements at each site using standard calibration procedures. Inter-comparison between Dustrak and TEOM ($PM_{2.5}$) was done by running both instruments side-by-side at the sampling Sites 1 and 4. The results showed a close linear relationship between the two (R^2~0.75, n=230). Since the TEOM unit for monitoring of $PM_{2.5}$ was unavailable during the measurements at Sites 2 and 3, $PM_{2.5}$ TEOM equivalent concentration was determined from the Dustrak data using the experimentally determined relationship:

$$PM_{2.5TEOM} = 0.65\ PM_{2.5Dustrak} + 2.54\ (\mu g/m^3)$$

Instruments were mounted in two air-conditioned enclosures (trailer and a metal cabinet) located 5-10 m away from the kerbside at each test site with a sampled air intake (U-shaped probe facing down) located on the top of both enclosures approximately 2-3 m above the ground.

Meteorological parameters (wind velocity and direction, air temperature) were measured by a meteorological station mounted on the top of the monitoring trailer.

2.2. Data Processing and Analyses

The obtained results were screened for corrupted data and outliers using Boxplot and nonparametric tests. Identified outliers were removed and the remaining data selected for further analyses. All obtained data were aligned according to the time of measurements and averaged into 1-hr and 24-hr mean values. Data were analysed by exploratory, correlation and other statistical methods using SPSS and S-plus packages.

3. Results and Discussion

3.1. Hourly concentartion of pollutants

Hourly averages of CO and NO_2 concentration are presented in Figures 1 and 2.

Mean values for CO levels were between 0.7 ppmv and 1.5 ppmv with the 95% percentiles up to 3.5 ppmv. The density distribution of hourly averages was left skewed with a long tail on the right hand side, indicating the presence of high CO emitters. Maximum values of up to 6 ppmv were measured at Site 3.

The mean values for NO_2 were between 18 and 34 ppbv with a maximum of about 63 ppbv. The results were similar to that for CO. The lowest concentrations were observed at Site 4. This effect could be associated with a relatively lower traffic count compared to other test sites and predominantly upwind sampling conditions, i.e., sampling point located upwind in relation to the road. The mean values (mean±standard error) for NO were between 60±8 ppbv (n=164, Site 4) and 132±7 ppbv (n=183, Site 1) and for NOx between 79±8 ppbv and 162±7 ppbv.

Hourly averages followed a diurnal pattern with the peaks associated with the morning (7.00-8.00 AM) and afternoon (4.00-6.00 PM) traffic peaks. A relatively strong correlation between traffic flow rates and CO and NO_x (R^2~0.6-0.8) indicated that traffic emissions were a dominant emission source.

CO and NO_2 are critical pollutants regulated by the NEPM Standard (NEPC). The ambient air quality goals contained in the Environmental Protection Policy relating to human health and well-being are 9 ppmv for CO (8-hr average) and 120 ppbv for NO_2 (1-hr average). Comparisons of measured data with the standard values indicate that both, CO and NO_2 levels complied with the NEPM standards.

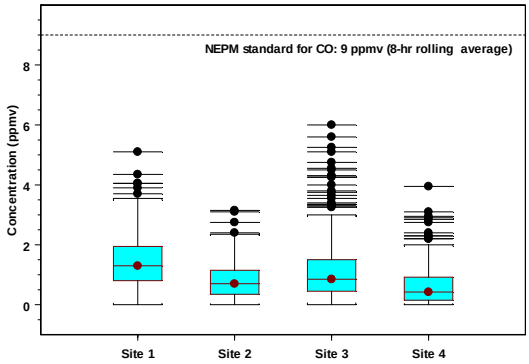


Figure 1 Boxplots of 1-hr averages for carbon monoxide measured at Sites 1-4.

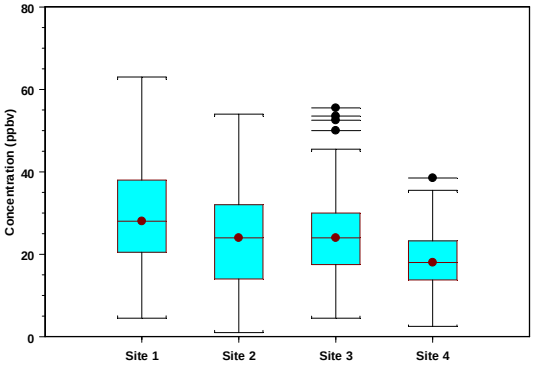


Figure 2 Boxplots of 1-hr averages for Nitrogen dioxide measured at Sites 1-4.

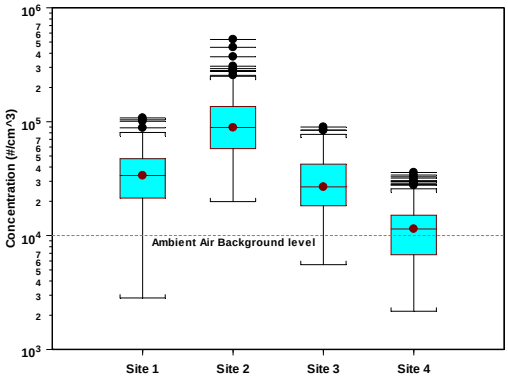


Figure 3 Boxplots of 1-hr averages for particle number concentration $N_{0.014\text{-}0.750}$

Boxplots of particle number and mass concentration (1-hr average) are presented in Figures 3-5. The concentration levels of $PM_{2.5}$ presented in Figure 5 include data based on TEOM readings (Site 1 and 4) and TEOM equivalent estimated from Dustrak data and a known relationship between the responses of both instruments. The PM_{10} data presented are averages of the direct readings obtained from the TEOM.

The means of $N_{0.014\text{-}0.750}$ (1-hr average) varied between $(12.2\pm7.2)\times10^3$ particles/cm^3 (Site 4, n=170) and $(1.1\pm0.8)\times10^5$ particles/cm^3 (Site 2, n=157). The measured range was between 2.2×10^3 particles/cm^3 and 5.3×10^5 particles/cm^3. In general, the lowest concentration was measured at Site 4 (sampling upwind of the road with relatively low traffic count), while consistently higher concentration levels were observed at Site 2. This is possibly associated with a high traffic count, large fraction of HDV in the traffic fleet and predominantly downwind sampling conditions.

Several episodes of rapid bursts in concentration of particles smaller than 0.05 μm were observed at Site 2. This could be attributed to the generation of secondary, nuclei mode particles from the volatile organic materials and/or biogenic emissions of aerosol from the nearby forest. Similar episodes have been reported in the literature, for example by Kulmala et al. (2004). Further elaboration on the effect is however beyond the scope of this paper.

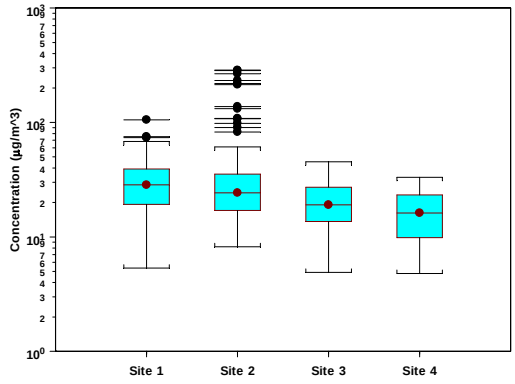


Figure 4 Boxplots of 1-hr average PM_{10} (TEOM Data) measured at Site 1-4.

The means of PM_{10} (1-hr averages) varied between 17.0±7.5 µg/m^3 (Site 4, n=100) and 37.0±46 µg/m^3 (Site 2, n=163), with a range between 5 µg/m^3 (minimum) and 286 µg/m^3 (maximum). The extreme concentration level and large spread in data observed at Site 2 were associated with a dust storm, which occurred during one of the sampling days discussed later. Excluding data affected by this event from the analysed data set results in a mean PM_{10} concentration of 25.0±13.3 µg/m^3 (Site 2, n=139) and a maximum of 90.4 µg/m^3.

Comparing means and spread in data shows that PM_{10} levels at Site 1 were consistently the highest (mean 31.3±15.7 µg/m^3; range 5.4-105.4 µg/m^3), which is associated with high traffic count and large proportion of heavy duty vehicles (HDV) in the traffic fleet.

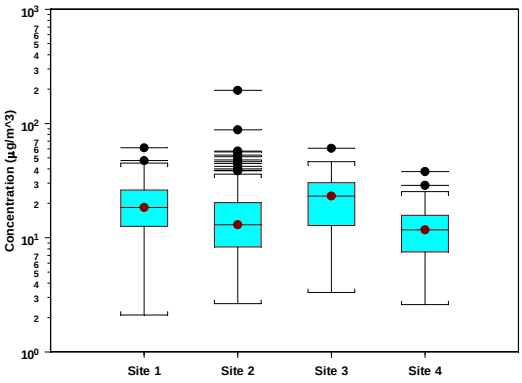


Figure 5 Boxplots of 1-hr average for $PM_{2.5}$ (TEOM Data) measured at Site 1-4.

The means of 1-hr averages for $PM_{2.5}$ measured at Sites 1-4 were between 12.3±5.9 (mean ± Std. Deviation) µg/m^3 (Site 4, n=114) and 20.7±10.6 µg/m^3 (Site 1, n=163) with the maximum value of up to 195 µg/m^3 observed at Site 2 (this was not related to the dust storm observed for PM_{10} data reported above, but rather due to a short episode with increased $PM_{2.5}$ level caused by an unidentified source).

Analyses of time series for size differentiated PM (number and mass) showed a close relationship between the measured concentration levels and traffic count, thus indicating that traffic emissions were the dominant source contributing to the measured levels. In general, concentration values followed diurnal patterns with peaks associated with the morning traffic peak hours, similar to trends observed for CO and NO_x.

Wind velocity was negatively correlated with the concentration levels due to the dispersion effect. Wind direction affected the measured levels, with the lowest reading related to the upwind (in relation to the road) sampling conditions. The effect was most pronounced at Site 4.

3.2. Correlation Analyses

Correlation analyses between gaseous pollutants (CO, NO_x, NO_2, and NO) showed high correlation levels suggesting that the targeted pollutants originated from the same source, i.e., traffic emissions. The determination coefficient (Pearson linear correlation) between CO and NO_x for data measured at Sites 1-4 was in the range 0.84 to 0.95.

Correlation between PM_{10}, $PM_{2.5}$ and $N_{0.014-0.750}$ for the data measured at Sites 1, 3 and 4 was strong (R^2 ~ 0.68-0.91), while the same parameters were correlated weakly for data measured at Site 2 (R^2 ~0.26-0.32). This indicates the presence of sources other than traffic emissions, contributing to, or affecting, the measured parameters differently. For example, several episodes of outbursts of nuclei mode particles (below 0.020 µm) were observed in the $N_{0.014-0.750}$ data set obtained at Site 2. This could be related to biogenic emissions from the nearby forest, and/or creation of secondary nuclei mode aerosols from organic VOC, both of which may cause an increase in concentration of submicrometer particles, without any immediate effect on the PM of larger sizes.

A strong correlation was observed between $N_{0.014-0.750}$ and CO (R^2~0.58-0.82) and $N_{0.014-0.750}$ and NO_x (R^2 ~0.69-0.91) for all sites, while the correlation between CO and NO_x was relatively strong at Sites 1, 3 and 4 (R^2~0.48-0.91) and relatively weak at Site 2 (R^2~0.15-0.26). In general, higher correlation between CO, NO_x and $N_{0.014-0.750}$ concentration levels are attributed to similar dispersion characteristics of gaseous and submicrometer particles, as compared to the dynamics of PM_{10} and $PM_{2.5}$. It may be concluded

that traffic emissions dominated the concentration levels of targeted pollutants at the sampling sites with an unidentified source affecting submicrometer particle levels present at Site 2.

The fraction of $PM_{2.5}$ contributing to PM_{10} was assessed from the available TEOM data (30 min averages). The ratio of $PM_{2.5}/PM_{10}$ was 0.61±0.13 (R^2=0.90, n=232) and 0.66±0.16 (R^2=0.82, n=150) for Site 1 and 4, respectively. The calculated $PM_{2.5}$ fractions are consistent with the results presented by other studies (eg. Harrison et al. 2004). A strong correlation indicates that both $PM_{2.5}$ and PM_{10} originated from the same source (traffic emissions). A small spread and comparable values of $PM_{2.5}/PM_{10}$ ratios observed at two different sites indicates that the $PM_{2.5}$ contribution to PM_{10} of fresh traffic emissions is relatively constant. The findings may have implications for PM monitoring programs near the sources, however to be conclusive, more systematic assessment would be required. An analysis of the relationship between particle number ($N_{0.014-0.750}$) and mass (PM_{10}, $PM_{2.5}$) concentration is beyond the scope of this paper.

3.3. Daily average concentration levels

In general, daily (24-hr average) PM levels varied throughout the week with higher values observed for the week-days (Mo-Fri) compared to the weekend (Sat-Sun). This is associated with the overall lower traffic count together with a smaller faction of HDV vehicles in the traffic fleet (restricted travel of HDV) during the weekends over the week-days.

The daily averages for $N_{0.014-0.750}$, $PM_{2.5}$ and PM_{10} measured at Sites 1-4 are presented in Figure 6-8, respectively.

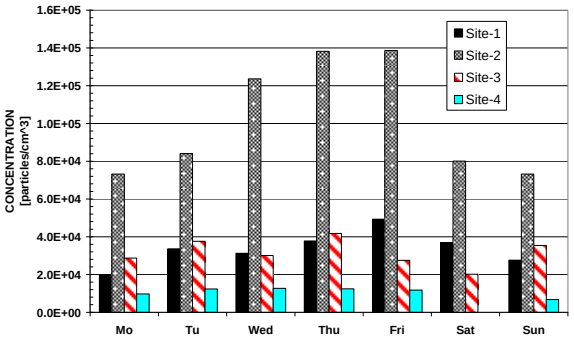
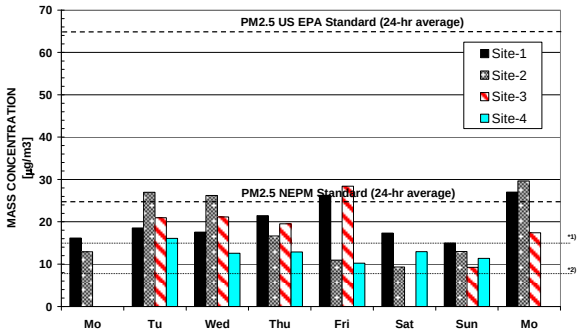


Figure 6 Daily (24-hr) average of $N_{0.014-0.750}$



*1) US EPA PM2.5 Annual Standard (15 µg/m^3)
*2) NEPM Advisory Annual PM2.5 Standard (8 µg/m^3)

Figure 7 Daily (24-hr) average of $PM_{2.5}$

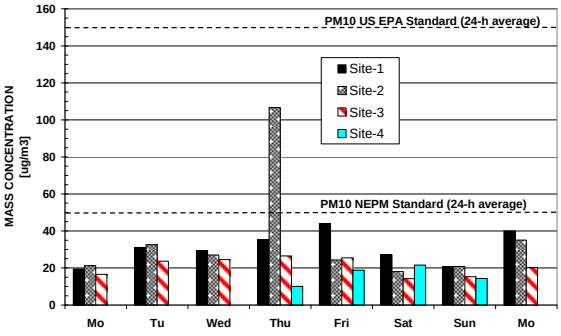


Figure 8 Daily (24-hr) average of PM_{10}

Since there are no existing standards for submicrometer particle number concentration levels, the measured data will be compared to the Brisbane urban ambient air background. Over the last 7 years QUT has conducted continuous monitoring of ambient air parameters for the Brisbane CBD. Based on the analyses of collected data, the background value has been estimated as approximately 1.0×10^4 particles/cm^3 (Morawska et al. 2002). The obtained results for $PM_{2.5}$ and PM_{10} will be compared to the existing standard and guidelines presented in Table 1.

Table 1 Review of standards for $PM_{2.5}$ and PM_{10} mass concentration of ambient air

Country/ Authority	Size Fraction	Standard/Guideline (µg/m^3)	
		Averaging Period 24-hr	Annual
New Zealand	PM_{10}	50	20
Australia *1)	PM_{10}	50	–
	$PM_{2.5}$	25	8
United Kingdom	PM_{10}	50	–
Europe	PM_{10}	50	30
USA *2)	PM_{10}	150	50
	$PM_{2.5}$	65	15
California	PM_{10}	50	30
Japan	PM_{10}	100	–

*1) NEPM Standard Australia ($PM_{2.5}$ – advisory standard only, introduced in Jan 2005); *2) US EPA Standard 1997

3.3.1. $N_{0.014-0.750}$

The 24-hr average $N_{0.014-0.750}$ concentration measured were in the range of: (i) $(2.0\text{-}5.0)\times10^4$ particles/cm^3 at Site 1; (7.3-14)$\times10^4$ at Site 2; (2.0-4.2)$\times10^4$ at Site 3; and (0.7-1.3)$\times10^4$ particles/cm^3 at Site 4. The large range is associated with differences in traffic parameters, topography, meteorological conditions and the presence of sources other than traffic.

Comparison of the measured data with urban ambient background levels (annual average of 1.0×10^4 particles/cm^3) shows that $N_{0.014-0.750}$ levels exceeded the annual background levels typically in the range of 2-5 times, and in some cases by over an order of magnitude (Site 2). Extremely high levels at Site 2 are associated with a combined effect of traffic emissions and some other sources, as explained above. Relatively low 24-hr averages observed at Site 4 are due to upwind sampling conditions as well as an overall reduced traffic count during the monitoring period.

3.3.2. $PM_{2.5}$

The 24-hr average $PM_{2.5}$ concentrations measured were in the range of: (i) 15-27 μg/m^3 at Site 1; (ii) 9 -30 μg/m^3 at Site 2; (iii) 9 -28 μg/m^3 at Site 3; and (iv) 10-16 μg/m^3 at Site 4. The measured daily average concentrations were well below the current US EPA 24-hr $PM_{2.5}$ standard (65 μg/m^3), and in some cases above the NEPM 24-hr $PM_{2.5}$ Advisory Standard (25 μg/m^3). Comparison with the annual $PM_{2.5}$ Standards (US EPA 15 μg/m^3; NEPM Advisory Standard 8 μg/m^3), although only indicative, suggests that the $PM_{2.5}$ levels may not comply with the current US EPA $PM_{2.5}$ Standard, and will exceed the levels suggested by the annual $PM_{2.5}$ NEPM Advisory Standard. The authors acknowledge that the sampling Sites 1-4 are not representative of the locations recommended in the NEPM Standard, which focuses on sites not affected by a strong local source (such as near a busy intersection). However, the question about the air quality (and entitlement of the general public to equality in relation to ambient air quality within an urban frame-work), remains to be addressed. Further monitoring is required to provide more conclusive assessment.

3.3.3. PM_{10}

The 24-hr average PM_{10} concentration measured were in the range of: (i) 21 to 44 μg/m^3 at Site 1; (ii) 18 to 35 μg/m^3 at Site 2; (iii) 14 to 27 μg/m^3 at Site 3; and (iv) 10 to 22 μg/m^3 at Site 4. Extremely high levels observed during one of the measuring days at Site 2 (24-hr average for PM_{10} of 107 μg/m^3) were associated with a "dust storm" event i.e., an increase in PM_{10} levels due to other than traffic emissions related sources, and were excluded from the presented conclusions.

In summary the observed values were in general well below the PM_{10} US EPA 24-hr Standard (150 μg/m^3) and below the current NEPM PM_{10} 24–hr standard of 50 μg/m^3 although at Sites 1 and 2, the observed values were relatively close to the Standard values.

In recent years, such measures as technological advances in engine design, the use of catalytic converters in emissions treatment and the reduction of sulphur content in diesel fuels have led to a reduction in PM_{10} exhaust emission and ambient levels. However, the same has not been true of associated $PM_{2.5}$ levels. Therefore, concerns in relation to $PM_{2.5}$ and submicrometer particle levels, based and driven by the outcomes of current epidemiological and health risk studies in relation to air pollution, still remain. Considering its effect in relation to human health, environment, socio-economical burden and the cost of remedial measures, in order to provide and maintain ambient air pollution at sustainable levels, a more coordinated effort is required by researchers and monitoring and regulatory agencies.

4. Conclusions

The presented study, while limited in scope, quantified the concentration levels of PM and gaseous pollutants attributed to traffic emissions at four urban "hot spots" providing currently unavailable data required for an accurate assessment of the exposure to public near busy roads. Comparison with the existing national and international standards showed that the levels of PM_{10}, $PM_{2.5}$, $N_{0.014-0.750}$ CO, NO_x at selected sampling locations for normal environmental conditions comply with 24-hr average standards, and 8-hr and 1-hr average standards for CO and NO_2, respectively.

The measured $PM_{2.5}$ concentrations were consistently close to, or higher than, the annual standards. Due to a relatively short sampling period, one week at each site, the authors acknowledge that, in relation to the annual data, the presented findings are merely indicative. However, the consistency in the observed pollution levels (24-hr average) and the expected increase in traffic density in the near future, suggest that the annual levels of $PM_{2.5}$ and PM_{10} at the selected sites and other location with comparable conditions may exceed annual $PM_{2.5}$ Standards. More comprehensive monitoring programs over extended time periods are required to provide a more robust assessment.

5. Acknowledgement

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our colleagues from the International Laboratory for Health and Quality for their assistance with the field work.

6. References

NEPC, National Environment Protection (Ambient Air Quality) Measure NEPM 1998, 2003: http://www.ephc.gov.au/nepms/air/air_nepm.html

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