Changes in Air Quality due to Closure of a Major Industry

Seyed Ali Sajjadi[1]*, Howard A. Bridgman[2], Nasrin Sadeghi[3]

[1] Dept. of Environmental Health Engineering, Gonabad University of Medical Sciences, Gonabad, IR Iran.
[2] School of Environmental and Life Sciences, University of Newcastle, NSW 2308, Australia
[3] Dept. of Occupational Health, Gonabad University of Medical Sciences, Gonabad, IR Iran
* Corresponding Author: Faculty of Health, Gonabad University of Medical Sciences, Gonabad, IR Iran. Email: sa_1344@hotmail.com, Tel: +98-533-7225027, Fax: +98-533-7223814

ABSTRACT

Introduction: This paper describes the impacts of the closure of a major industry on air quality in the Lower Hunter Region. BHP Rod and Bar was recognized as the most important source of particulate matter (PM_{10}, bsp), nitrogen dioxide (NO_2), and sulphur dioxide (SO_2) in Newcastle before it closed in October 1999.

Objective: This study investigated the impacts of the closure of a major industry, a steel works in Newcastle, on air quality in the Lower Hunter Region, New South Wales.

Method: A combined three-station data set for these pollutants for 3.5 years before and after closure allowed a comparison of daily and data set averages, using both the measured data, and a Mixed Model to calculate significant changes in the time series by month.

Result: PM_{10} increased after BHP closure by 13.2%, an unexpected result, but the post closure data set was influenced by summer bushfires. bsp decreased by 10.2%, reflecting the reduction is emissions due to industrial burning processes. This result was verified by a separate $PM_{2.5}$ data set which showed significant reductions in elemental carbon and soil source components. SO_2 concentrations dropped by 40.2% after closure, a change which verified the importance of BHP as a source. Despite the industry being a major source of NO_2, there was no significant change of this pollutant after closure, suggesting dominance of other sources.

Conclusion: Air pollution in the region is caused by different sources. Further research into the role of meteorology and quantifying changes in the range of sources is recommended.

Keywords: Industry, particulate matter, NOx, SO_2, Lower Hunter, BHP

Introduction

The impacts of dominant industries from small industrial complexes on air quality of the surrounding area can be considerable.[1,2] For example, Bhopal and colleagues[3] described the impacts of emissions from a coking works in northern England on the health of residents nearby. Another study[4] made a similar assessment around a wallpaper factory.

Despite Australia having relatively clean air, air pollution from industrial sources is still one of the main concerns of the Australian nation[5]. Air quality problems have occurred in locations such as Newcastle, Wollongong, and Mount Isa due to the operation of a variety of local heavy industries. For example, until the late 20th century, the Lower Hunter Region and Newcastle were known for air pollution caused by the local major chemical, steel making industries, harbour activities and mining located adjacent to the centre of the city[6,7].

Industry in Lower Hunter was also thought to endanger local public health by emitting pollutants in the air, although there was no clear evidence[8]. Due largely to public and local council pressure over the recent decades, important efforts were made to reduce air quality problems in the region. As a result, air quality appeared to have improved considerably by the mid-1990s[6]. Therefore, Newcastle and the Lower Hunter area, like most of Australian cities, now have a relatively low level of pollution in the air. Most of the time, the levels of pollutants monitored are within the accepted levels of standards.

Although daily and monthly air pollution has been monitored since 1957 in the Newcastle Council area (see Figure 1), there was no regular air quality monitoring system over shorter time periods in the Lower Hunter Region until mid-1990s. According to the available information, since the mid-1990s, the concentrations of primary air pollutants such as SO_2, NO_2 and particulate matter have been within the national and international standards and guidelines[8], with only occasional exceedences.

Figure 1 goes here

In October 1999, economic considerations led to the closure of the largest local steel works industry in the Newcastle area, and dominant industrial pollution source, Broken Hill Proprietary Rod and Bar (BHP). The purpose of the current study is to assess the impact of the closure of BHP Rod & Bar on atmospheric pollution levels in the Newcastle and Lower Hunter Region, NSW.

Study location, pollution sources and climate

The Lower Hunter Region is situated on the southeast coast of Australia in New South Wales (NSW), about 150 kilometres north of Sydney. The region is defined as the part of Hunter River valley that opens out to a coastal plain. It is surrounded by the coast to the east, and the remainder is bounded by higher terrain enclosing the end of the valley. It is separated from the rest of Hunter River valley by the rise in the valley floor northwest of Maitland[9]. As Figure 1 shows, the coastal strip extends from Nelson Bay in Port Stephens to the south to include the northern part of Central Coast Region. The study area extends from 151º 15' to 152º 10' longitude east and from 32º 40' to 33º 05' latitude south. Within the Lower Hunter Region are the

Local Government Areas (LGA) of Newcastle, Lake Macquarie, Port Stephens, Maitland and Cessnock. These LGAs are roughly contained within 45 kilometres radius of Newcastle CBD, where the major industry BHP Rod and Bar was operating. Newcastle, as the biggest city of Lower Hunter, is the seventh most populated city in Australia and the second largest city of New South Wales.

The region has fully integrated industries, steel works, mining, rail and harbour activities[10]. BHP started constructing the country's first integrated steel works at Newcastle in 1913. From this period, the city was not only a coal mining town but grew quickly as an industrial and commercial city. The opening of BHP in 1915 led to a rapid increase of industrial employment, and consequently considerable growth of population in the following decades. By 1983, there were over 11,000 employees working in the BHP industry[11]. To the people of Newcastle, their city was initially a powerful industrial centre, a constant source of employment, of which they were proud[12]. They accepted as necessary the side effects of industry, pollution, as "black smoke belching forth over the city meant employment"[13] although not without complaint. But to outsiders, despite the industrial modernization, Newcastle was a dirty and polluted city. Many visitors had a very negative view of the city, so that the city was being identified as "brown town" [12].

Bridgman and colleagues[6] reported public concerns and regular complaints about poor air quality over the Newcastle area which was mainly linked to manufacturing activities and the industries, particularly those located on south of Kooragang Island (Figure 1). The BHP Rod and Bar steel making industry was identified as the principal source of sulphur dioxide (SO_2), nitrogen dioxide (NO_2) and particulate matter [7,8]. In the early 1990s, BHP was the source of around 30% of total particulate matter, 80% of total NOx emissions and more than 90% of total SO_2 pollution in the industrial zone of inner Newcastle.

A later study[14] completed by Victoria Environment Protection Authority claimed that BHP was the biggest polluter in the Region, and was responsible for almost 60% of all air pollutants released in the study area. The study revealed that in 1994 approximately 188,318 tonnes of 24 different toxic pollutants were released in the Newcastle study area. This equated to 1.3 tonnes of air pollutants per person living in the study region. The study also reported that industry emissions in Newcastle were 26 times higher than results from a trial project carried out elsewhere. Industry contributed a massive 82% of overall air pollution in Newcastle, the bulk of which was released from BHP steel works.

Therefore, this study focuses on the pollutants SO_2, NO_2, particulate matter less than 10 μm diameter (PM_{10}), and bsp representing fine particulates through light scattering, which were of most concern during BHP operation.

The climate of the region is best described as mainly being under sub-tropical influence[15], with mid-latitude impacts in winter. The temperature along the coastal area is strongly influenced by the ocean. In such locations, average maximum ranges from around 27 to 28°C in summer and from 17 to 18°C in winter. Further inland, it is rather warmer in summer and cooler in winter. Wind speed and direction are affected by the topography of Hunter Valley and the ocean. In winter, prevailing winds are north-westerly and can reach 25 kmh^{-1}. The prevailing winds in

summer are east to south-easterly, associated with onshore flow[6,15]. Low level overnight inversions under clear skies are common.

Material and Method

Monitoring Data

As Figure 1 shows, there is several air quality monitoring stations in the Lower Hunter area. However, only the EPA stations record hourly values of the study variables. These stations, Newcastle, Wallsend and Beresfield, were established in 1996 and are maintained by New South Wales Department of Environment and Climate Change (NSWDECC). They were established to provide representative regional air quality measurements. The combination of data from these stations was utilized to represent a regional pollution trends and variations, as well as covering the possible missing data in some stations.

Air pollution data from these stations were obtained from NSWDECC as hourly averages. Missing data from individual stations were assumed to be equal to the mean of the same day at other sites. Initially, regional hourly concentrations for each pollutant were calculated by averaging across the stations. Then mean daily levels were computed by averaging these hourly values for each day. Daily data were considered as a missing if the number of hourly values was less than 12 in a given day (more than 50% of measurements were missing). After creating mean daily levels, the number of days with missing value was less than 1%, with the exception of SO_2 before BHP closure. During this period, SO_2 concentrations were not recorded for about 19% of the study period, mostly for the first six months of the pre-closure study period. This caused potential limitations in the data set and the results, but SO_2 was included because BHP was the major source of this important pollutant.

As Table 1 shows, inter-site correlations between pollutants measurements at the three monitoring stations, especially after closing BHP, were significant. Therefore, for purposes of this analysis, and in the absence of any other choice, the daily average measurements of pollutants from the three stations can be assumed to represent the air quality of the study area.

Table 1 goes here

A second data set, measurements of fine particulate matter, was obtained from the Newcastle City Council for the study period. These measurements occurred at Mayfield (Figure 1) and were daily average concentrations of $PM_{2.5}$ for Wednesday and Sunday. The site was part of the Aerosol Sampling Program (ASP) operated by the Australian Nuclear Science and Technology Organisation[16]. The filters were analysed chemically at ANSTO and the relative importance of main sources identified. These included industry, soil, sea salt and ammonium sulphate, plus the elements iron, lead, potassium and zinc. ANSTO reports these data to the Newcastle City Council as monthly averages.

Study Period

The time periods selected for investigation were for when the most complete data set was available. Considering data availability, 3.5 years before BHP closure, from 1/1/1996 to 30/06/1999, and 3.5 years after closing BHP, from 1/1/2001 to 30/06/2004, as study period were selected. To compare seasonal changes for both periods, the same beginning and ending time of year were chosen. Since BHP Rod and Bar steel works was closed in October 1999, the period between 30/06/1999 and 1/1/2001 was considered as the industrial phase out period, and therefore not included in the analysis.

Statistical Analysis

The NSWDECC data were first assessed descriptively to determine average concentrations and ranges, through tables and graphs, and to describe basic before and after differences. These results are presented as daily average time series, and data set averages including standard deviations, maximums and minimums. The latter statistics are presented by winter and summer season.

The statistical approach used to examine in more detail the difference in monthly average air pollution variables before and after the closure of BHP was the Mixed Model in the Statistical Analysis System programme[17]. The Mixed Model is generally used in controlled experimental studies in which the measures of outcome are investigated before and after series of trials[18]. This study did not find an example which employed this model in urban air pollution study. In other words, this approach is used for the first time to investigate the impacts of an industry on ambient air pollution. BHP was the central point in the trial, and the model allowed direct comparison of outcomes (pollution concentrations) before and after closure.

The Mixed Model used is a generalisation of the standard linear model that examines statistical inferences along the data set time series. The model allows the data to exhibit correlations with non-constant variability. It also provides the flexibility of modelling the means of the data and their variances and covariances. The primary assumptions of underlying the analysis are that the data are normally distributed; the means of the data are linear in terms of parameters; and the variances and covariances of the data are different in terms of different sets of parameters[17], but show a matching structure[18]. In longitudinal studies such as the current one, to increase the frequency of covariance parameters, repeated measures are taken on the same unit over time; and these repeated measurements are correlated or reveal variability that may change[17]. In other words, repeated-measures data analysis examines and compares response trends over time.

For this study, the benefits of the Mixed Model are its ability to directly compare and correlate pre- and post-BHP concentrations. It analyses the data in its original form, and handles between and within parameter effects similarly. The model allows a wide range of statistical assessments if needed (covariance structures, random coefficients, and restricted maximum likelihood for example). While being computationally intensive, it was reasonably easy to use, and based on comparisons with other models, such as Poisson Regression and General Linear Model (GLM), produced a better fit to the data set.

To apply the model optimally, the unit of repeated measurements was created as data must be similarly ordered for each subject. For this study the unit of repeated time was one month. As a result, each study period consisted of 42 units or months. For the pollutants, only measurement

unit, BHP and season were classified and included in the model. Inspection of the data showed they were Guassian in distribution; consequently, their likelihood was maximised to estimate the model parameters. Therefore, Residual/ Restricted Maximum Likelihood (REML) was selected as estimation method for the covariance parameters. Compound Symmetry (CS) was preferred for covariance structure after comparing to the other structures including autoregressive (AR) and unstructured (UN) covariance. The comparison involved goodness of fit criteria including REML log likelihood and Akaike Information Criteria (AIC) in which compound symmetry was found to provide the best fit. (The smaller value, the better fit).[17]

In addition, the standard errors are adjusted for covariance parameters in the model. The type of test is t-test for pair wise comparison adjustments with the P value = 0.05 and 95% confidence interval. Slice effect which uses an F-test, univariate ANOVA, and shows statistical difference month by month, was also included in the model.

The ANSTO $PM_{2.5}$ data sets were graphed, and the results used in support comparison with the NSWDECC results for bsp, which represents fine particles.

Results

Descriptive Statistics

The descriptive statistics for the pollutants in the NSWDECC data set (averaged across the three monitoring stations) are shown in Table 2, and Figures 2 and 3.

PM_{10}: The averaged PM_{10} concentrations (Table 2) increased by about 13% after BHP was closed. The same increasing trends were observed for both cool and warm seasons. A considerable difference was seen for maximum daily levels after the closure of BHP. The unusual PM_{10} concentration of 161.8μg/m3 was due to a bushfire incidence, which can occur in extremely hot days in summers. (The day in which this value was recorded, December 5, 2002, the daily average temperature was 26.3∘C peaking at 31.2∘C).

Table 2 goes here

As Figure 2 (top) reveals, PM_{10} did not show a clear pattern of seasonal variations; however, by peaking in summer time, particularly when BHP was operating, it reflected some positive relationship with temperature. Before the closure of BHP, the levels of PM_{10} rarely exceeded 40μg/m3, and the same was observed for period of 2001-04, with the exception of short time between November and February in 2002. In other words, PM_{10} levels rarely exceeded the levels recommended by standards, which is 50μg/m3 for 24 hours.

Figure 2 goes here

The averages in Table 2 show an overall increase in PM_{10} after BHP closed, but as Figure 2 shows, this change is strongly influenced by the summer period 2002, which was a bushfire period.

Fine particles: bsp, which represents fine size fraction of particulate matter, unlike PM_{10}, decreased after BHP closure (Table 2). The decrease of mean daily concentrations was similar in both cool and warm seasons. On the other hand, the occasional increase of peak daily levels (Figure 2 bottom) after BHP closure, especially in summer seasons, indicates complications in the trend of pollutant emissions. An increase in maximum daily level of fine particles was noticeable, which might occur because of some occasional pollution sources other than usual sources. Bushfire periods in January 2002 and summer 2002-2003 dominated the peaks in the record.

The levels of fine particles peaked slightly in warm season, though there was no clear pattern of seasonal variations. Most of the time bsp levels remained below 1 bsp, which was within recommended guidelines (2.1 bsp).

NO_2: Daily mean NO_2 concentrations decreased slightly after the closure of BHP (Table 2). The decrease was greater in warm season where as in winter, NO_2 levels remained unchanged. Maximum daily and highest mean daily levels were measured in the cool season before and after BHP closure.

The NO_2 time series in Figure 3 (top) presents very distinct seasonal variations, with NO_2 levels peaking during the cool season. Figure 3 also shows that, with the exception of two days before and three days after BHP closure, NO_2 levels did not exceed 2 pphm over the study period. This means the NO_2 concentrations were most of the time below the recommended standards, which range between 3 (annual) and 12 (hourly) pphm.

Figure 3 goes here

SO_2: In the 2001-04 period, after BHP closure, both mean and maximum daily concentration of SO_2 dropped dramatically (Table 2). There were similar decreases in both the cool and warm seasons. On some days, the SO_2 concentrations were too low to be detectable by the equipment. Over the study period, the highest level of SO_2 was recorded in warm seasons. Despite 19% of SO_2 measurements missing in period 1996-99, the standard deviation (SD) of records gives a good estimation of pollutant distribution. As seen in Table 2, the high value of standard deviation, which was almost equal to the mean daily SO_2, indicated a relatively broad rage of measurements in the period 1996-99. In addition, the decrease of SO_2 was significant in both the cool and warm seasons.

Figure 3 (bottom) shows peaks in SO_2 levels in June 1996, April 1997, and between June and August 1997, while it remained in a relatively steady state over the rest of study period, particularly after the closure of BHP. These high values explain the high standard deviation and broad range of SO_2 measurements in the period 1996-99. SO_2 appeared to have a small seasonal trend which peaked in the cool seasons. The trend was more noticeable after the closure of BHP.

Apart from the high values mentioned above, in 1996-99, SO_2 levels rarely reached 1 pphm, and most of the time remained below 0.5 pphm after the closure of BHP. In other words, the majority of SO_2 levels were within national and international standards, which range from 3 to 8 pphm.

Analytical statistics

PM_{10}: The results of the Mixed Model showed that PM_{10} concentrations significantly changed after the closure of BHP (Figure 4a). The estimation of PM_{10} in period 2001-04 recorded an increase of 13.2%, compared to period 1996-99. The results also established the differentiations between the same season before and after BHP closure that were significant. The mean PM_{10} concentration over a given month before the closure of BHP was not statistically similar to the PM_{10} levels in the same month after BHP closure. The results also support the lack of seasonal variations for PM_{10} concentrations, described in the previous section. As Figure 4a shows, model estimations of PM_{10} levels were higher over the whole of 2001-04, with the exception of two short periods. The highest difference was observed at the end of 2002 and, as described earlier, was caused, at least in part, by bushfires. Overall estimations of PM_{10} concentrations for about 12 months at the end of the 2001-04 period were clearly higher then the PM_{10} levels in the similar period before BHP closure.

Figure 4 goes here

Model calculations showed that PM_{10} estimations were significantly different in 15 months out of the 42 months of record. Those differences led to an overall statistically significant difference for PM_{10} levels after compared to before the closure of BHP.

Fine particles: Even with the small decrease, the Mixed Model (Figure 4b) revealed a significant difference for fine particles (bsp) before and after BHP closure. Despite the considerable correlation between PM10 and bsp, unlike PM_{10}, fine particle concentrations appeared to be lower in 2001-04. The model estimation of fine particles in period 2001-04 was 10.2% lower than the average in 1996-99. As Figure 4b shows, the estimations of bsp were roughly at the same levels at the beginning as well as the ending of both periods. The most noticeable difference was observed in the middle of 2003.

The difference between bsp estimations before and after the closure of BHP was statistically significant for 30% of time (14 months). About 40% of months with the significant difference were in common with PM_{10}.

Assuming bsp is an indicator of $PM_{2.5}$, the results shown in Figure 4b can be further justified by the monthly ANSTO $PM_{2.5}$ data measured at Mayfield (Figure 1). This site is located close to the western side of the BHP industrial complex. Figure 5 provides some representative results for the two study periods. In Figure 5, the 2001-2005 data are in light grey and labelled 0104. The elemental carbon data is also representative of potassium and zinc; soil is representative of lead and iron; and organics are indicative of sea salt and ammonium sulphate.

Figure 5a shows that there is a reduction in PM weight (or mass) after the closure of BHP, but on a month by month comparison, some months show increases after closure. Overall $PM_{2.5}$ weight after closure averaged $8.2 \mu gm^{-3}$ compared to $10.6 \mu gm^{-3}$ before closure, a difference of $2.4 \mu gm^{-3}$. Elemental carbon, representing burning sources, shows a major reduction by $1270 \mu gm^{-3}$ (51%) which is highly significant (Figure 5b). The average concentration of soil elements is also reduced significantly by $0.92 \mu gm^{-3}$ (58%) after closure. Reduction occurred in all months except

five (Figure 5c). Organics (Figure 5d) representing more natural sources do not show a significant change between the two time periods, indicating no impact from BHP operations.

Figure 5 goes here

NO$_2$: Figure 4c shows the monthly estimations of NO$_2$ before and after BHP closure. As previously indicated, there was no a major difference for the pollutant before and after the closure of BHP. Corresponding to very small changes (overall 3.3% decrease), the results of statistical analysis did not reveal a significant difference. Moreover, the non-significant seasonal difference indicated similarity between the same seasons in periods 1996-99 and 2001-04, which is consistent with the descriptive results.

According to Figure 4c, the maximum difference between estimations of NO$_2$ levels was observed in the middle 2002. However, the overall difference of NO$_2$ estimations was slight, particularly for the end of study periods. Over the whole study period, NO$_2$ estimations were significantly different in only 3 months.

SO$_2$: The Mixed Model revealed that overall SO$_2$ levels dramatically changed after the closure of BHP (Figure 4d), and the change was statistically significant. As Figure 4d shows, SO$_2$ estimations were more consistent in the period after BHP closure. On the other hand, the trend of SO$_2$ between middle 1996 and middle 1997 fluctuated notably, so that the maximum levels and consequently the highest differences were observed in the beginning of study period.

In contrast, while SO$_2$ concentrations were generally higher before BHP closed in the second half of the study periods, the difference was considerably less. The last few months of period 2001-04 were the only occasion that SO$_2$ estimations were higher than the estimations of period 1996-99, while for the rest of study period these remained consistently in lower. The model results also indicated a weak seasonal variation for SO$_2$ emissions. SO$_2$ estimations were significantly different in about 60% of the time on a monthly basis, which was the highest difference amongst the pollutants considered in the study.

Table 3 shows the summary of pollutant changes before and after the closure of BHP. Of the pollutants considered in the study, only PM10 increased after the closure of BHP, while the rest of pollutants decreased. The most significant decrease was found for SO$_2$ concentrations, and NO$_2$ showed the least difference before and after BHP closure.

Table 3 goes here.

Discussion

This study found significant changes on overall concentrations and measurements of several air pollutants in the Lower Hunter Region, NSW after the closure of major industry, BHP Rod and Bar, in October 1999. Descriptive analysis of changes in pollution concentrations was supported by a comparative time series significance assessment using a Mixed Model, for the periods 01/01/96-30/06/99 and 01/01/01-30/06/04. Although there were some assumptions which were

required to apply the model, the findings were logically consistent with the descriptive results, and were thought to present statistically reliable comparisons for the state of study variables before and after closure.

The study found an overall 15% increase of averaged mean daily PM_{10} levels after BHP closure. The statistical analysis also found the increase significant. Since BHP was claimed to be the main source of particulate matter in the area, the increase of PM_{10} concentrations was an unexpected result. There are two possible reasons for the increase. First is that a few extremely high records of the pollutant contributed to the increase. Reported in the summer time, these were due to bushfire events. Second, after BHP closure, other sources of the pollutants in the study area increased, especially motor vehicles. As the statistical model showed in Figure 4, the difference in measurements was more noticeable from 2003, three years after the closure of BHP.

Fine particles, represented by bsp, decreased significantly after BHP closure. It is difficult to separate the contribution of fine particles to PM_{10}, but the opposite result for bsp implies a complicated trend of particle emissions. It is possible that the particles emitted from industry were dominated in numbers by fine particles, mainly due to the burning processes. However, the contribution of the other sources to the trends of fine particles pollution must be acknowledged. The bsp results were supported by $PM_{2.5}$ source categories measurements from a Newcastle City Council site at Mayfield, which showed major reduction in burning processes, heavy metals and soil after BHP closure.

Although BHP was identified as the major source of NO_2 in the early 1990s, after the closure of BHP, overall NO_2 levels decreased only slightly in the study area. The small decrease of NO_2 was found insignificant in the statistical analysis. Again, emissions from other sources, particularly from a growing number of motor vehicles, may have influenced the trend of NO_2 emissions after the closure of industry.

The study found a significant decrease of mean 24-hour SO_2 levels after the closure of BHP. The 37% decrease of averaged SO_2 levels in the period 2001-04, may also have been affected by improved fuel quality (utilizing low sulphur containing fuel) from other sources[19]. Newcastle City Council claimed that, even before BHP closed, because of the closure of several other local emission sources, the SO_2 pollution was no longer a considerable problem in the Lower Hunter Region[8].

It is important to acknowledge the limitations to this study, which are areas requiring further research. Lack of precise information on air quality at a local scale was the first limitation. The assumption that a combination of pollution data, which were collected from three monitoring stations, represented the air quality of the Lower Hunter, was necessary but my have lacked accuracy.

Employing the Mixed Model for investigating the impacts of BHP closure was a new experiment that was applied for the first time in this study. Despite the reasonable outputs, applying the Mixed Model in such studies should be further evaluated in future studies. Inconsistencies may arise if different statistical approaches are applied in the study data set.

Conclusion

Air pollution in the Lower Hunter region is caused by different sources. For example, aside from major industry, motor vehicles are a considerable source of pollution, and bushfires dominate when they occur. Although this study identified some of these other sources, it could not differentiate quantitatively between sources. Such details, and the role of meteorology, are left to future data analysis and interpretation.

Conflict of Interest: The authors declare that there is no conflict of interests.

References

1. Wordley, J.; Walters, S.; Ayres, J.G. (1997) Short Term Variations in Hospital Admissions and Mortality and Particulate Air Pollution. Occupational and Environmental Medicine, 54, 108-116.
2. Atkinson, R.W.; Anderson, H.R.; Sunyer, J; Ayers, J.; Baccini, M.; Vonk, J.M.; Boumghar, A.; Forastiere, F.; Forsberg, B.; Toulumi, G.; Schwartz, J.; Katsouyanni, K., 2001: Acute Effects of Particulate Air Pollution on respiratory Admissions. American Journal of Respiratory and Critical Care Medicine, 164(10), 1860-1866.
3. Bhopal, R., Phillimore, P., Moffatt, S., and Foy, C., 1994: Is living near a coking works harmful to health? A Study of Industrial Air Pollution. Journal of Epidemiology and Community Health, 48, 237-247.
4. Acquilla, S., Kingham, S., Dunn, C., Halpin, J., Fou, C., Bhopal, R., Pless-Mulloli, T., and Blain, P., 1996: Health in the vicinity of a wallpaper factory, Epidemiology, 7, 4(suppl) S101.
5. Australian Bureau of Statistics (ABS) (2004) http://www.abs.gov.au.
6. Bridgman, H.A. and McManus, P. (2000) "Weather, climate and air quality: The Hunter's atmosphere" in Journeys, The making of the Hunter Region, eds.: McManus, P.; O'Neil, P.; Loughran, R.; Lescure, O. R., Allen & Unwin, Sydney, Australia, pp. 42-66.
7. Bridgman, H.A.; Manins, P.; Whitelock, B. *An assessment of the cumulative emissions of air pollution from Kooragang Island and the inner suburbs of Newcastle*. The University of Newcastle, Report to NSW Dept. of State Development, Sydney: Australia; 1992
8. Newcastle City Council (NCC) (1998) Air Quality Summary Paper: Newcastle Airshed Management Plan, Newcastle, NSW.
9. New South Wales Department of Environment and Conservation (NSWDEC)(2005) "The Lower Hunter Region" http://www.environment.nsw.gov.au/air/nepm/3.02hunter.htm

10. Lewis, P.R.; Hensley, M.J.; Wlodarczyk, J.; Toneguzzi, R.C.; Westley-Wise, V.J.; Dunn, T.; Calvert, D., 1998: Outdoor air pollution and children's respiratory symptoms in the steel cities of New South Wales. Medical Journal of Australia, 169, 459-463.

11. O'Neill P. and Green, R., 2000: Global economy, local jobs in Journeys, The making of the Hunter Region. eds.: McManus, P.; O'Neil, P.; Loughran, R.; Lescure, O. R., Allen & Unwin, Sydney, Australia, pp. 108-34.

12. Winchester, H., McGuirk, P, Dunn, K.. 2000, Material and symbolic identities of Newcastle: Continuity and change in Journeys, The making of the Hunter Region. eds.: McManus, P.; O'Neil, P.; Loughran, R.; Lescure, O. R., Allen & Unwin, Sydney, Australia, pp. 207-26

13. Rutherford, A., 1999, Editorial, Kunapipi, 12(3), vi.

14. Environmental Protection Authority of Victoria (EPAVIC), 1996, The National Pollutant Inventory (NPI); The Newcastle trial. Melbourne, Australia.

15. Bridgman, H.A., 1984: Climate atlas of the Hunter Region, Board of Environmental Studies Research Paper No. 9, The University of Newcastle, Australia.

16. Huo, X.X., Crisp, P.T., and Cohen, D.D., 1998: Elemental composition of fine aerosol particles around Sydney during 1992 and 1993. Clean Air and Environmental Quality, 32, 28-37.

17. SAS Institute Inc., 2004, SAS/STAT Software: Changes and Enhancements through Release 9.1.3. SAS Institute INC., Carey, NC.

18. Littlle, R.C., Henry, P.R., Ammerman, C.B., 1998: Statistical analysis of repeated measures data using SAS procedures. Journal of Animal Science, 76, 1216-1231.

19. Department of the Environment and Heritage of Australia (DEH), 2004, Ambient Air Quality Standard. www.deh.gov.au/atmosphere/airquality/standard.html.

Table 1: Inter-site correlation coefficients of pollution before and after BHP closure*

Variable		Before BHP closure		After BHP closure	
		Wallsend	Beresfield	Wallsend	Beresfield
PM_{10}	Wallsend		0.72		0.83
bsp	Newcastle	0.56	0.58	0.78	0.83
	Wallsend		0.55		0.74
NO_2	Newcastle	0.60	0.54	0.75	0.69
	Wallsend		0.73		0.83
SO_2	Wallsend		0.40		0.59

*$P < 0.001$

Table 2: Daily average concentrations of pollutants before and after BHP closure

PM_{10} ($\mu g/\ m^3$)

HP	Cool Season a				Warm Season b				Whole Study Period			
	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max
Operating	15.8	6.8	2.2	43.3	20.6	9.2	5.8	85.8	18.2	8.4	2.2	85.8
Closed	18.0	6.8	5.0	51.1	23.5	13.3	5.8	161.8	20.9	11.2	5.0	161.8

bsp ($10^{-4}\ m^{-1}$)

BHP	Cool Season a				Warm Season b				Whole Study Period			
	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max
Operating	**0.27**	0.18	0.02	1.11	**0.28**	0.15	0.05	1.47	**0.28**	0.17	0.02	1.47
Closed	**0.24**	0.16	0.01	1.14	**0.26**	0.20	0.03	*2.21*	**0.25**	0.19	0.01	*2.21*

NO_2 (pphm)

BHP	Cool Season [a]				Warm Season [b]				Whole Study Period			
	Mean	**SD**	**Min**	**Max**	**Mean**	**SD**	**Min**	**Max**	**Mean**	**SD**	**Min**	**Max**
Operating	**1.10**	0.37	0.08	*2.53*	**0.75**	0.33	0.20	2.42	**0.92**	0.39	0.08	*2.53*
Closed	**1.11**	0.37	0.22	2.22	**0.72**	0.32	0.13	1.92	**0.90**	0.39	0.13	2.22

SO_2 (pphm)

BHP	Cool Season [a]				Warm Season [b]				Whole Study Period			
	Mean	**SD**	**Min**	**Max**	**Mean**	**SD**	**Min**	**Max**	**Mean**	**SD**	**Min**	**Max**
Operating	**0.34**	0.30	0.00	2.16	**0.23**	0.18	0.00	*2.25*	**0.29**	0.26	0.00	*2.25*
Closed	**0.23**	0.15	0.00	0.93	**0.13**	0.11	0.00	1.13	**0.18**	0.14	0.00	1.13

[a] Temperature <18 ºC > 90% matched with April – September

[b] Temperature≥ 18 ºC; > 90% matched with October - March

Table 3: Difference of pollutants estimation in Lower Hunter, before and after BHP closure

	1996-99	2001-04	Difference	P value
PM_{10}	18.206	20.608	+13.2%	0.0210
bsp	0.274	0.246	-10.2%	<0.0001
NO_2	0.923	0.892	-3.3%	NS [a]
SO_2	0.299	0. 178	-40.5%	<0.0001

[a] Not Significant
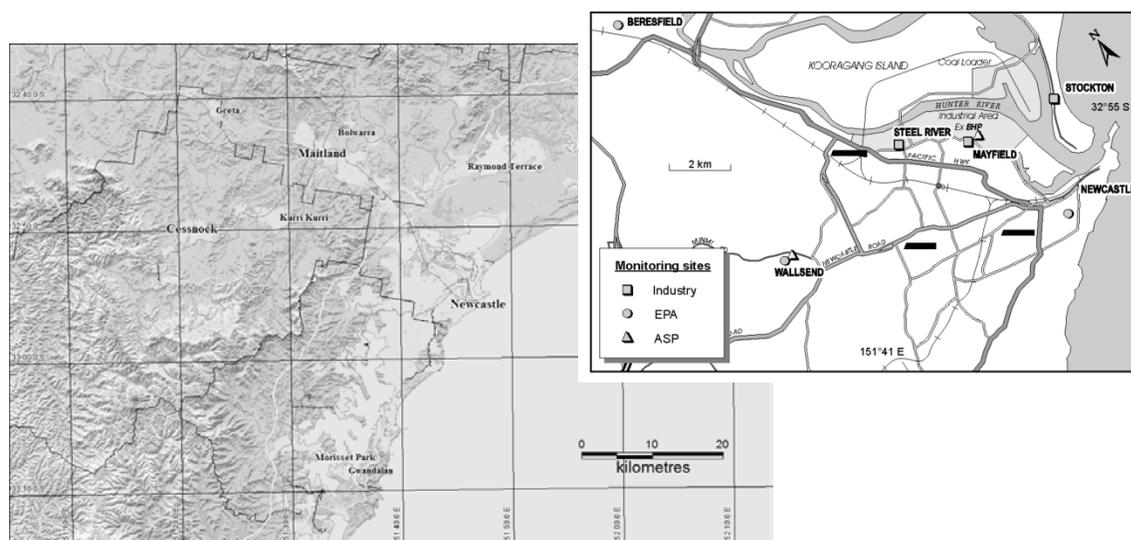
Figure 1: The Lower Hunter Region (left), and the Newcastle area (right) including air pollution monitoring stations
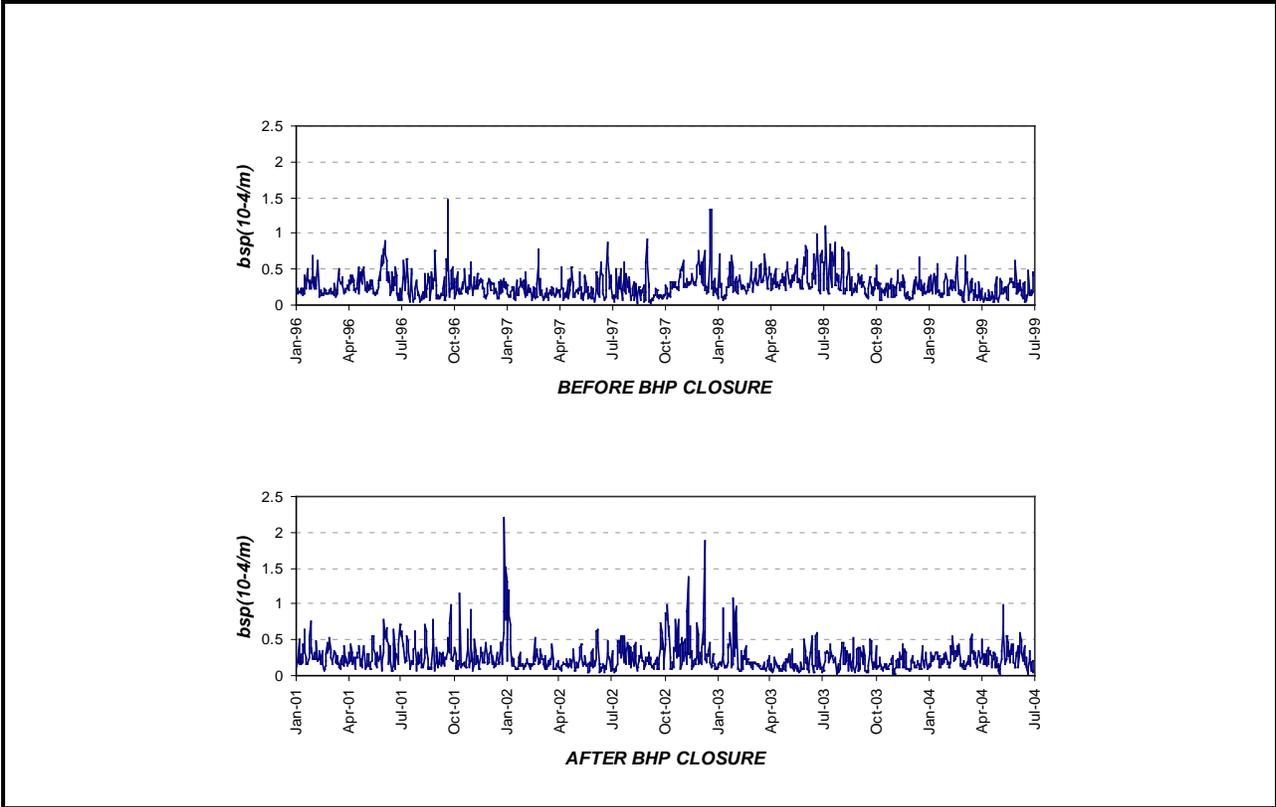
Figure 2: Daily PM$_{10}$ and bsp time series, before and after BHP closure
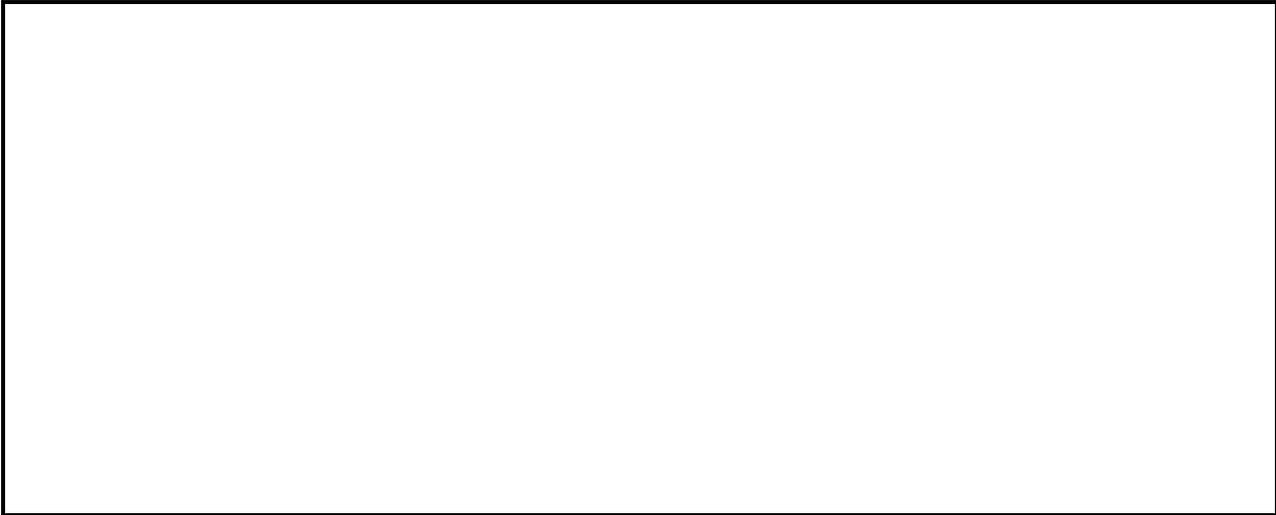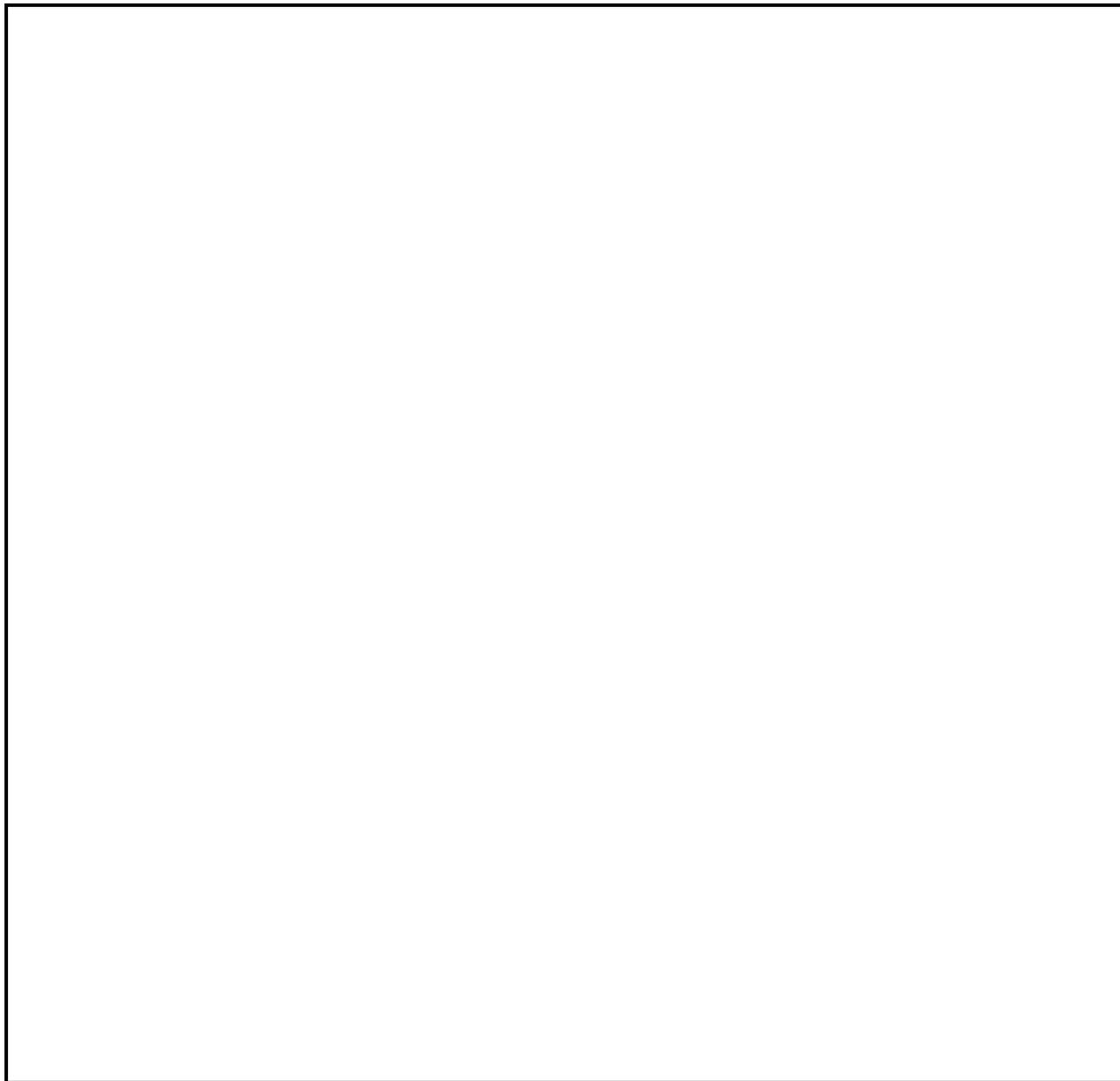
Figure 3: Daily NO₂ and SO₂ time series, before and after BHP closure
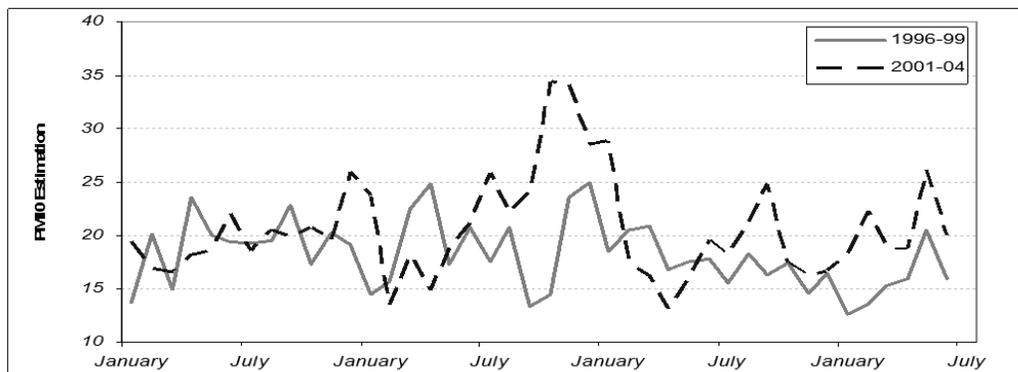
a. PM$_{10}$
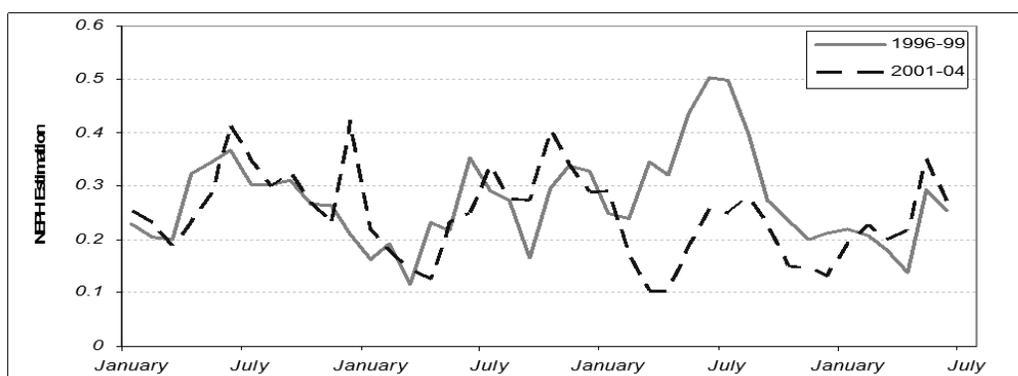
b. bsp
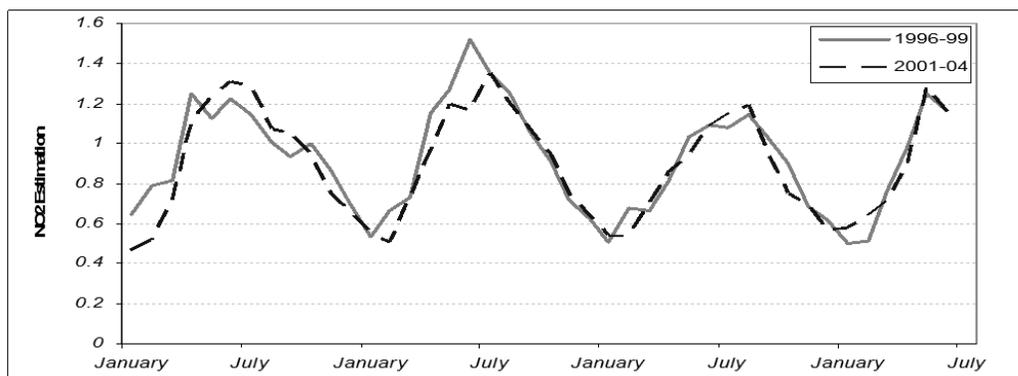
c. NO$_2$
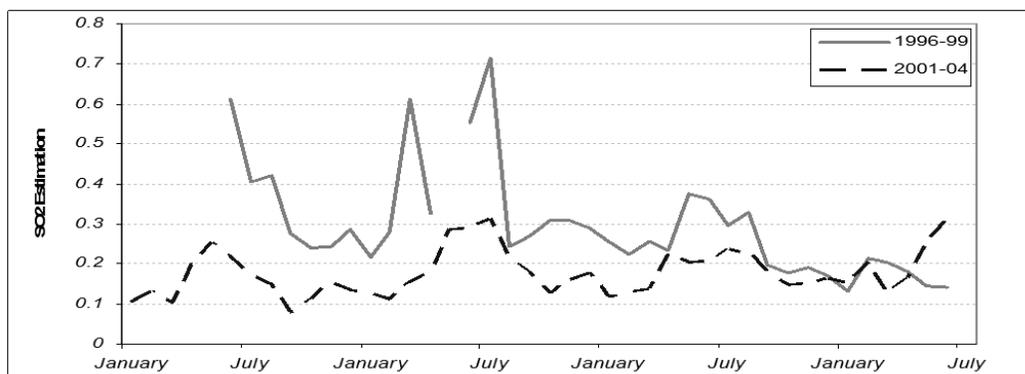
d. SO$_2$

Figure 4: Mixed Model results for the four study pollutants.
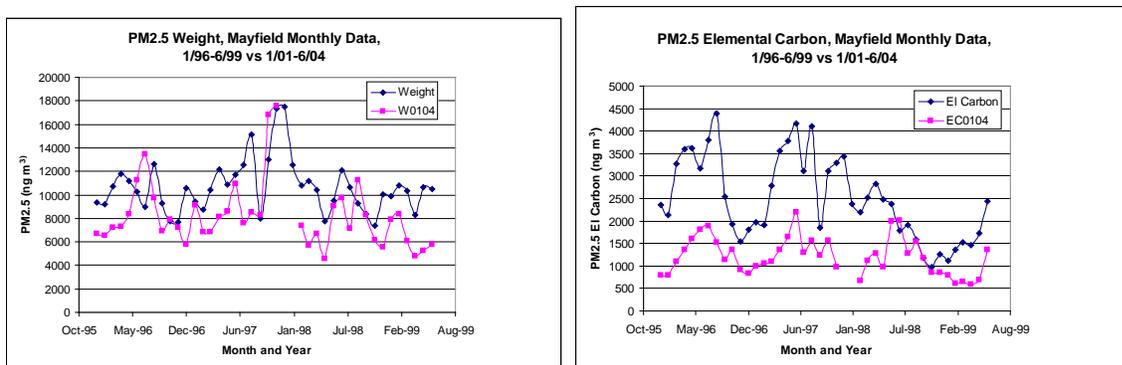
a.

b.
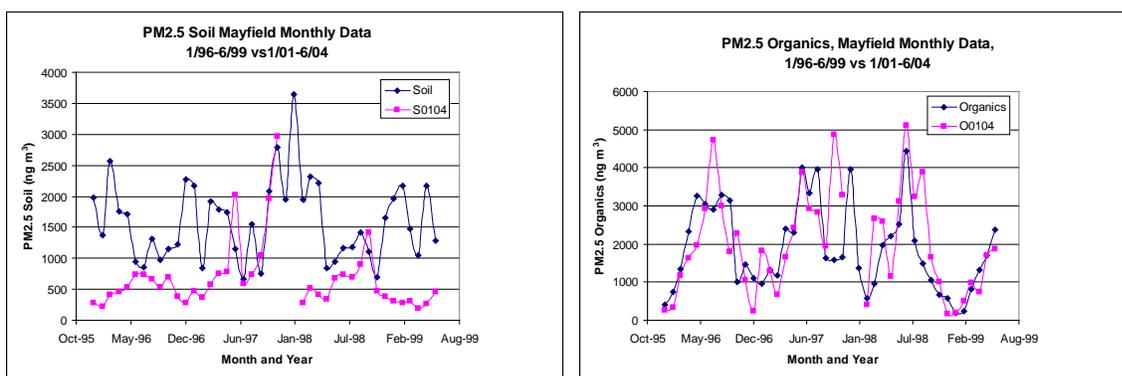
c.

d.

Figure 5: Mayfield Monthly PM$_{2.5}$ in ng/ m^3, from the ANSTO ASP location (Figure 1). The data for 2001-2004 (light grey) are plotted on top of the data for 1996-1999 by equivalent month for comparison. The four representative source categories are: a. Total weight; b. Elemental Carbon; c. Soil; d. Organics. The data for Dec 2002 and Jan 2003 are missing.