Investigating the health impacts of particulates associated with coal mining in the Hunter Valley

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ABSTRACT

There have been many calls for epidemiological investigations into the potential health impacts of coal mining in the Hunter Valley. Epidemiological studies of air pollution and health are subject to potential confounding by other determinants of health outcomes such as temperature, tobacco smoke exposure and socio-economic status. Furthermore, the effect sizes are generally quite small. Therefore, large and well-designed studies, with careful measurement of air pollution exposures, health outcomes and potential confounders are required to establish whether adverse health effects of the pollutant exposure do exist. Studies conducted in smaller populations are very likely to miss small but important impacts. There is a need, therefore, to integrate understanding of dose response (concentration-response) relationships between particulate exposure and health outcomes from large population based studies with local exposure monitoring data to assess potential public health impacts and to evaluate local sources of pollution.

Keywords: Particulates, epidemiology, health impact

BACKGROUND

The Hunter Valley in south-eastern Australia is a major coal producing and power generating centre. There are currently approximately 20 active open cut coal mines across 15 operations in the Hunter Valley that transport coal to Newcastle which exports over 150 mega tonnes of coal per annum, making it the world's largest coal exporting port. Newcastle is the sixth largest city in Australia with a regional population of around 400,000 people and with approximately another 100,000 living in the Hunter Valley where major industries are agriculture and mining. The area with the greatest concentration of large open cut mines in proximity to residential areas is between Singleton (population 23,000) and Muswellbrook (population 16,700).

There has been a significant expansion in open cut coal mining over the last 20 years with further expansion planned and dependent on international coal prices. There are five coal-powered power stations in the region – two in the Upper Hunter about 70km north-west of Newcastle and three others approximately 25 to 50 km to the south of Newcastle.

The history of industrial development and expansion of the coal industry has led to calls for studies of the impact of coal mining and power generation on the health of local communities. In September 2013, a forum attended by international experts on air pollution and health was held with a primary objective to review the current state of knowledge on the effects of air pollution associated with coal mining and transport and with the operation of coal-burning electricity generating stations based on local and international studies. An additional objective was to discuss alternative approaches to further research for defining the relationship between air pollution and health in the setting of the Hunter. The meeting also gave an opportunity for local stakeholders to express their concerns, which mainly related to the effects of particulate matter, arising from coal mining and transport, on health. Therefore the forum and this paper focused primarily on the implications of PM10 and PM2.5 particulates.

Challenges for epidemiological health studies

Early studies of the relationship between particulate pollution and health focused on respiratory health outcomes. However, both epidemiological and toxicological studies of PM2.5 pollution show that exposure to this pollutant is associated with systemic inflammation that, at a population level, has its greatest impact on the cardiovascular system (WHO 2013, Brook et al. 2010). Particulate air pollution is also associated with a wide range of other adverse health outcomes including lung cancer (Kunzli et al. 2010).

The calls for "health studies" are often specifically for epidemiological studies examining associations between health outcomes and either air pollution levels or proximity to sources of air pollution. The lack of a definitive local health study has frustrated many community members.

There are a number of challenges to investigating the relationship between air pollution and health outcomes. One of these is that the difference between the lowest and highest levels of air pollution is often less than three-fold and "unexposed" subjects do not exist. This is different from the situation in tobacco research, for example, where many people are never-smokers and heavy smokers may have 10–20 times higher exposure than occasional smokers. To describe and quantify the effects of relatively small differences in ambient air pollution concentration requires not just good control of confounding factors but, in most cases, very large study populations (Kunzli et al. 2010). For example one of the largest cohort studies reporting air pollution health effects, the American Cancer Society Study, involved 500,000 subjects, followed over 16 years. The range from the lowest to the highest long-term average PM2.5 concentrations observed in the enrolled communities was only three-fold and the risk of death during follow-up varied by 10–15% across this exposure range (*i.e. relative risk*s were 1.10 to 1.15) (Pope et al. 2002). The APHEA-2 mortality studies covered over 43 million people and 29 European cities, which were all studied for more than 5 years in the 1990s (Katsouyanni et al. 2001).

The challenges for conducting such studies are that the main population centres in the affected areas in the Upper Hunter Valley comprise less than 50,000 people and there is a less than 2 fold difference in particulate exposure between the most exposed population centres in the Hunter Valley and levels typically observed elsewhere in Australia. Some of the other challenges associated with such analyses are summarised in Box 1.

While long term cohort studies, in which selected community members are followed over time to investigate health outcomes or variation in health, could be conducted, given the challenges of outlined above there is little chance that these would have sufficient power to demonstrate statistically significant associations between particulate exposures and health outcomes. Furthermore, it would take many years to complete the study, by which time the findings would be less relevant to concerned communities, who require this information now.

Cross sectional studies, in which the relationship between current exposure to air pollutants and current health status is examined, are more feasible but they are generally difficult to interpret because past exposure, not current exposure, is most likely to be the cause of current health states. This problem could potentially be overcome if there was an historical record of air pollution exposure but, unfortunately, the Upper Hunter Air Quality Monitoring Network has been established only recently.

Epidemiological Studies Conducted in the Hunter

Due to recognition of the challenges outlined above there have been few epidemiological studies of the relationship between air pollution and health conducted in the Hunter Valley. However, in this section we summarise the findings of those that have been published.

The NSW Ministry of Health conducted a review of a wide range of health outcomes in communities in proximity to coal mining and power generation areas in 2010 entitled: *Respiratory and cardiovascular diseases and cancer among residents in the Hunter New England Area Health Service May 2010* (NSW Ministry of Health 2010). While some adverse health outcomes were more common in areas adjacent to coal mines and power stations, often the poorest health outcomes were in rural and remote areas of NSW that were not adjacent to power stations or power generation facilities. The report concludes the data do "not establish that these adverse health effects are attributable to air pollution or to any other specific exposure." The report noted a number of limitations in the analysis including that hospitalisation data may represent health service usage rather than actual morbidity, coding of health outcomes may not be uniform across all facilities, and the analysis at the health service administrative cluster level does not directly compare populations exposed and unexposed to coal mining or power generation (NSW Ministry of Health 2010).

An analysis compared general practice consultation data from the Hunter Valley region for 1998–2010 with data from all other rural NSW residents (Merritt et al. 2010). The analysis concluded there was no evidence of a significant excess of adverse health states among residents in the Hunter Valley region of NSW. The finding that respiratory problems remained unchanged in the Hunter, while they had decreased in other rural areas of NSW, was considered worthy of further exploration.

The interpretation of these studies, with their aforementioned challenges, is further complicated by socio-cultural determinants of health that have been associated with poor health indicators in Hunter coal mining areas prior to the 1980's when underground mining predominated in the Valley (Alexander et al. 1986, Higginbotham et al. 1999). This differential in chronic disease risk factors appears to have continued among open cut coal miners – with recent routine and entry medical examinations identifying a higher proportion of newly recruited and current coal miners in Singleton with elevated blood pressure compared to other coal mining areas and the general population (Bofinger and Ham 2003).

Studies near open cut coal mines in other settings

It is noted that attempts to explore the relationship between open cut coal mines and local health outcomes elsewhere have had equivocal and conflicting findings. Some studies find elevated rates of respiratory disease in open cut coal mining communities while others do not (Pless-Mulloli et al 2000, Pless-Mulloli et 2001, Howel et al 2001, Temple and Sykes 1992, Brabin et al. 1994, Jenkins et al. 2013).

A review of studies of cancer risks in populations close to coal mines highlighted the many difficulties associated with interpreting the findings of ecological and cross-sectional study designs used in these studies (Jenkins et al 2013). Ecological study interpretation may be subject to the ecological fallacy and cross-sectional studies cannot provide definitive proof of causation (Sedgwick 2011). A review of chronic health conditions in communities dependent on coal mining, with a focus on central Appalachia in the USA, identified over 60 publications relevant to mining with 38 publications specific to Appalachia and health (Meacham et al. 2012). The reviewers noted that the multiple low quality studies on coal mining and health should be interpreted with caution.

Air Quality Monitoring

Fortunately, it is not necessary to undertake epidemiological studies in which health outcomes are measured in order to draw conclusions about the potential adverse effects of mining and power generation on community health in the Hunter Valley. Much is already known about the association between particulate exposure and health outcomes (see "Air pollution dose and effect: Concentration response functions" section below). What are needed in the Hunter Valley are good measures of variation in exposure to pollutants. It is for this reason that a comprehensive air monitoring program was proposed as a response to community concerns (Dalton 2013). These air monitoring data can be used to predict the health impact of ambient pollution.

The Upper Hunter Air Quality Monitoring Network was deployed between 2010 and 2011 and now has 14 monitors that monitor PM10 and three monitors that monitor PM2.5 levels. Monitors are situated strategically – some in population centres, some close to mines to assist in understanding dissemination of particulates from point sources, and others that monitor air entering the boundary of the air shed with the prevailing winds. The network provides data on PM10 and PM2.5, measured hourly, daily, and annually; because the annual PM2.5 data is most predictive of significant mortality it is therefore the focus of this brief review of the data.

Figure 1 below displays the mean annual PM2.5 and PM10 in the Upper and Lower Hunter Valley. The main population centres of Muswellbrook and Singleton are adjacent to open cut coal mines and coal-fuelled

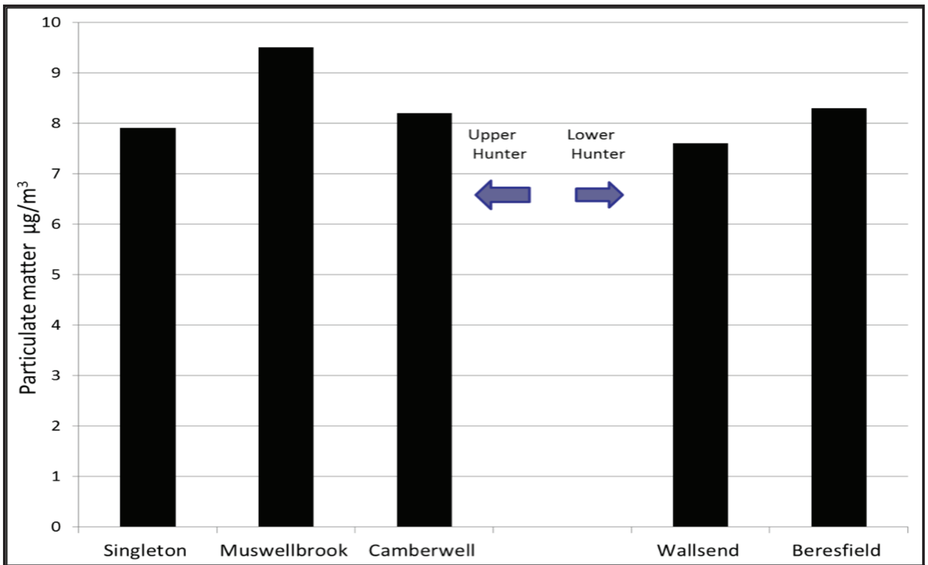
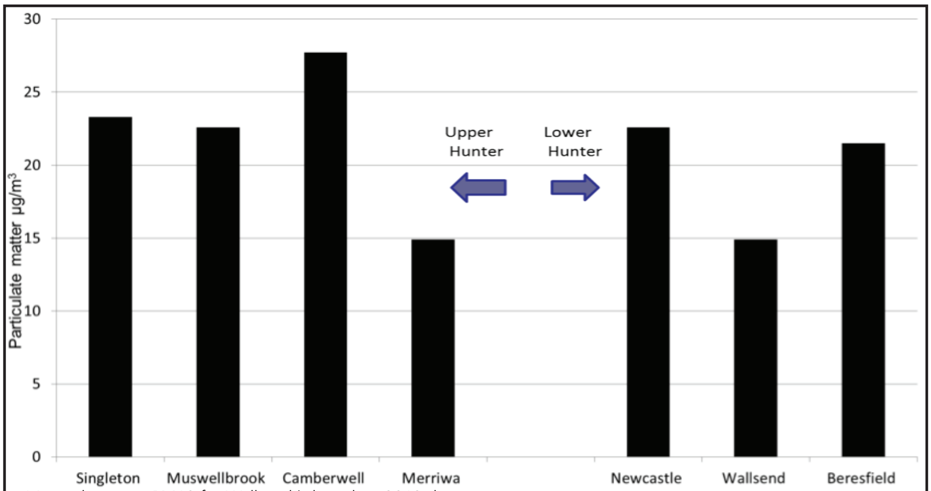


Figure 1. Annual average PM2.5 levels in main population centres, Upper and Lower Hunter, 2013.



*Annual average PM10 for Wallsend is based on 2012 data

Figure 2. Annual average PM10 levels in main population centres, Upper and Lower Hunter, 2013.

power stations. Camberwell, population 180, was selected as a sentinel site as it is almost completely surrounded by open cut coal mines with some less than 1000 metres from the village. Detailed data from the Upper Hunter Air Quality Monitoring Network and other monitors can be downloaded from www.oeh.nsw.gov.au/airqualitysearch.html. Another monitor sited close to industry on Newcastle Harbour that is not part of the official network provides public reports at: http://www.stocktonairqualitymonitoring.com. A site map of the monitoring stations is available at http://www.environment.nsw.gov.au/aqms/uhunteraqmap.htm

Pollution levels in the Hunter Valley compared to other locations.

The mean PM2.5 concentration was 5.6 μg/m^3 for the decade 1998-2008 at Cape Grim in rural Tasmania, a site often used as a global "baseline" reference for unpolluted air entering Australia (ANSTO 2008). At Camden, a residential/semi-rural area approximately 50 km south-west of Sydney, the annual average PM2.5 was 6.5 μg/m^3 in 2013 (OEH 2014). In Europe, approximately 70% and 90% of rural and urban PM2.5 monitors respectively recorded an annual average PM2.5 exceeding 10 μg/m^3 in 2011 (EEA 2013). None of the five PM2.5 monitoring sites in the Lower Hunter or the Upper Hunter Valley recorded an annual average PM2.5 exceeding 10 μg/m^3 in 2013. The National Environment Protection Measure (NEPM) advisory standard and level under the proposed variation to the standard for PM2.5 is an annual average of 8 μg/m^3 (NEPC 2014). This level was exceeded at Muswellbrook and Camberwell.

There is no annual average standard for PM10 under the NEPM, which instead has a goal of no more than 5 exceedances per annum of the 24 hour standard of 50 μg/m^3. The NSW EPA has an annual PM10 goal of 30 μg/m^3 and the WHO PM10 annual guideline is 20 μg/m^3 which is the level proposed for Australia in the consultation for the variation the NEPM standard (WHO 2006, NEPC 2014).

The relatively high number of monitors in the Upper Hunter means that several may "alarm" (that is, report air pollution levels that exceed NEPM standards) simultaneously. This may be misinterpreted as multiple exceedances of the standard. Thus increasing the number of monitors can paradoxically create the impression of a decline in air quality as more monitors signal an exceedance (Kelly M. 2013). Additionally, some monitors are placed directly beside coal mines to assist in tracking dust moving through the air shed rather than monitoring ambient pollution exposures to the community. More work is required to explain to the community how the monitoring network data should be interpreted. While annual data is more predictive of cumulative health impact there continue to be concerns regarding elevations in 24 hour particulate levels. It is probably most relevant to report the number of days on which any of the community-based ambient monitors exceed the 24 hour standards.

Particle characterisation studies in the Upper Hunter

The size, composition, and other characteristics of particles mediate their human health impact. PM2.5 particles, because of their more systemic effects generally have greater health impact than PM10 particles (Brook et al, 2010). Coal dust (produced from mechanical crushing) contributes more to ambient PM10 and larger particle mass concentration than to PM2.5. The major sources of PM2.5 (fine) particles are combustion processes such as motor vehicle exhaust, power generation emissions and wood smoke.

Particle sources in the Upper Hunter are reported in the NSW EPA Emissions Inventory (Morrison and Graham 2014). However, the inventory estimates emissions to air not actual exposure of humans, which may be different due to physical distance from the emissions, wind and transport factors and transformation of pollutants in the atmosphere.

The Upper Hunter Fine Particle Characterisation Study examined the composition of PM2.5 particles in the Upper Hunter Valley towns of Singleton and Muswellbrook (Hibberd et al. 2013). The main sources of PM2.5 particles were identified as secondary sulphates (20%) described as "local and regional sources of SO_2 such as power stations" in Singleton and domestic wood smoke (30%) in Muswellbrook. While open cut coal mines are a significant source of PM2.5 emissions in the immediate vicinity of open cut coal mines in the Hunter Valley, they were not identified as a significant component in ambient monitoring in the towns of Singleton and Muswellbrook. It is possible that a characterisation study of PM10 particles would identify a higher contribution from coal dust.

The particle characterisation study, although based on data from a single 12 month period, highlights the limitations of using emission inventory data as a proxy for human exposure. While the NSW Air Emissions Inventory predicts coal mining emissions to be the predominant source of PM10 and PM2.5 emissions they are clearly not the major source of human exposure to PM2.5 in Muswellbrook and Singleton (Morrison and Graham 2014).

Other studies

Two rail industry and two community sponsored studies have investigated particle emissions in rail corridors because of concerns about coal dust and diesel emissions from trains hauling coal to the port (Katestone 2012, CTAG 2013). While these studies were focused on the Lower Hunter, coal dust emissions in rail corridors feature among concerns raised throughout the valley and in other mining centres. These studies did not use monitors that were calibrated to estimate health impact or allow assessment against NEPM standards and further work is required to address community concern in this area. Additionally, while PM10 and PM2.5 characterisation studies are being conducted in the lower Hunter, a PM10 characterisation study in the Upper Hunter could provide insight into the percentage of PM10 particles in ambient air contributed by coal dust.

Most air monitoring studies have focused on ambient air quality, very little is known about indoor air quality in the Hunter and this is an area that requires further exploration.

Ground water is not a common drinking water source in the open cut mining communities of the Hunter. The drinking water supplies for the towns near extensive open-cut mining and power generation activities are of comparable quality to that of other rural town water supplies (NSW Ministry of Health 2010). Rain water collected from roof tops is common where municipal water is not supplied. Several analyses of water from rain water tanks near open cut coal mines have not implicated coal dust fallout as a source of contaminants of importance to public health (Noller 2009).

Air pollution dose and effect: Concentration response functions

Several international studies have provided data that can be used to estimate the effect of particulate pollution on health outcomes. The multi-city time series analysis APHEA, carried out in 29 (mostly European) study centres, found that, for every 10 μg/m^3 increase in PM10 concentration on one day, compared to another day, there was 0.6% increase in deaths from any cause and a 0.7% increase in deaths attributed to cardiovascular disease. These findings are similar to those of a previous meta-analysis, conducted on behalf of WHO, which found the same effect size for total mortality and a slightly higher effect size for cardiovascular deaths (0.6% and 0.9%, respectively, per 10μg/m^3 increase in PM10 concentration) (Anderson et al. 2004).

PM2.5 particles exert a stronger health impact than PM10 particles. Each 10μg/m^3 increase in PM2.5 particulate air pollution was associated with approximately a 4%, 6%, and 8% increased risk of all-cause, cardiopulmonary, and lung cancer mortality, respectively (Brook et al. 2010).

These concentration-response functions, or dose response relationships, can be used to estimate the impact of changes in air quality at a population level. For example, if the annual average PM2.5 level was to increase by 10μg/m^3 in a town (i.e. this would typically represent a doubling of current average PM2.5 levels), then all-cause mortality would increase by approximately 4% and cardiovascular disease would increase by 6%.

Reviews of concentration-response functions in multiple studies suggest the absence of a PM2.5 threshold below which no one would be affected. In the absence of a threshold, public health benefits will result from any reduction (or prevented increase) of PM 2.5 concentrations whether or not the current levels are above or below a limit value (WHO 2013).

DISCUSSION

In summary, the health protection approach in the Upper Hunter and the new initiatives in the Lower Hunter are based on monitoring the quality and composition of the air that residents are breathing. This provides more timely and relevant information about the potential health impacts of pollution sources than an epidemiological ("health") study could provide in this population setting.

While there has been much community concern about the health effects of pollution arising from coal mining in the Hunter Valley, it is apparent that, apart from small villages in close proximity to mines that are subject to heavy PM10 impacts, the pollution sources that are of greater concern for health are residential wood smoke, industrial and agricultural diesel combustion, and power generation, which contribute substantially to fine particle pollution. The major impact of mining on this source of emissions may be the increasing use of diesel in mining vehicles and in coal transport including trucks, trains, port shipping and associated infrastructure.

While the more health damaging PM2.5 particles are invisible, larger particles of coal dust are visible and this may drive concerns regarding their health impact. However, whereas the International Agency for Research on Cancer has classified diesel exhaust and "air pollution" as carcinogenic, coal dust has not been classified as to its carcinogenicity in humans (IARC 2013a; IARC 2013b; IARC 1997).

Air quality in the most populous areas of the Upper Hunter is good relative to international standards. However, it is important to safeguard the air shed against any deterioration in air quality. There is no clearly established threshold for adverse health impacts within the range of particulate levels encountered in the Upper Hunter. Communities in rural areas value their air quality and rather than planning to allow air pollution levels in pristine environments to rise to some cumulative limit, health protection and environmental justice objectives may be better achieved through applying limits on incremental increases in ambient pollution (NSW DPI 2012).

Box 1 Understanding air pollution and health: the challenges
(Source: Kunzli et al 2010. page 8).

The interaction between air pollution and health is a complex and difficult subject: interpreting the research, and communicating its meaning, is not easy. Some of the main current challenges in air pollution research are listed below.

Air pollution has multiple sources
Numerous emitters contribute to pollution. Mobile and stationary combustion processes play a particularly dominant role.

Air pollution is a mixture of many pollutants
Air pollution comprises hundreds of pollutants, only a few of which may be monitored, investigated and regulated.

Air pollution is a dynamic process
Once emitted, pollutants interact with each other and the environment in complex ways, which may depend on temperature, humidity and other environmental conditions. Thus, pollution changes in concentration, composition and possibly toxicity.

Exposure varies
A range of factors determine whether and to what extent pollution leads to exposure – the contact between pollution and the human body. Proximity to the source, physical barriers between sources and people, time spent in polluted air and level of physical activity all influence the amount of exposure and, ultimately, the dose reaching the target organs.

Low exposure levels are still relevant
In most European and Western countries, air quality is far better than it was in the 1950s. Thus, the health effects of air pollution are expected to be smaller and far less obvious than, for instance, the drastic increase in mortality and morbidity during smog episodes in the 1950s. A simple look at a few health statistics will never reveal the health effects of current air pollution.

Cause and effect are not always clear
While patients may present a range of symptoms and pathological signs resulting in a clinical diagnosis compatible with pollution-induced health problems, the latter are usually "unspecific" to pollution, so their presence does not disclose the underlying cause of the problem. For example, a myocardial infarction caused by air pollution cannot be distinguished from an infarction caused by any other trigger of a thrombosis. There is no "air pollution-specific disease", nor is the treatment of air pollution-related ailments cause specific.

Pollution does not act in isolation
Health is the result of a wide range of exogenous and endogenous factors, interacting in complex ways. Thus, the type and extent of air pollution-related health effects may ultimately depend on the combined set of co-factors.

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