Approaches to baseline studies of human health in relation to industries with potential environmental impact

Contribution to the independent review of coal seam gas activities in NSW

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Summary

A number of health concerns have been raised in relation to coal seam gas (CSG) mining in Australia. Very few studies have been conducted to investigate the potential health risks related to CSG industry internationally and in Australia. Health risks may be associated with all stages of CSG extraction (exploration, production and post-production), with possible exposures via water, soil and air pollution. The adverse health outcomes may include respiratory, cardiovascular, genitourinary and digestive diseases, skin problems, some types of cancer, injuries, hormonal disruption, fertility and reproductive effects. Concerns about poorer mental health associated with environmental, economic and social changes in the mining communities have also been raised. We discuss the potential health risks of the various types of exposures during each stage of CSG production. We then review epidemiological study designs aimed at identifying associations between environmental exposures (such as those that may occur during coal seam gas mining activity) and health outcomes, and we discuss the strengths and limitations of each study type. We identify four possible designs – and their key data sources – that could be used to examine potential health risks related to the mining of coal seam gas in New South Wales.

Introduction

Epidemiology is the study of the distribution and cause of disease and illness at a population level and the application of this study to control of health problems. It applies the scientific method to the study of the distribution of health and disease, frequently in pursuit of determining the causes of disease and ill-health.

Coal seam gas (CSG) is a natural gas consisting primarily of methane, which is adsorbed into coal [1]. CSG is a potential source of energy and has been extracted in the United States, Canada, China and some European countries [2]. Australia has large supplies of CSG resources, especially in parts of Queensland and New South Wales (NSW). CSG fields are currently operating mainly in Queensland with a few activities in NSW. CSG is a relatively new source of energy and very little is known – internationally or nationally – about its potential impact on human health. In NSW, some CSG deposits are located in close proximity to large metropolitan areas and in water catchments (Figure 1); therefore the study of the potential adverse effects of exposure to CSG mining is a high priority.

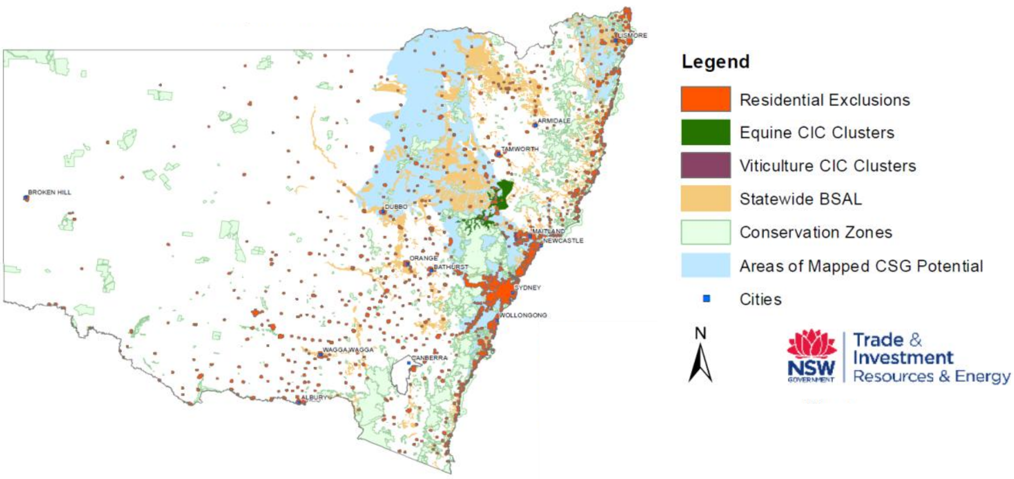

Figure 1. Areas of CSG potential sites in NSW, and areas where exploration is presently prohibited. Downloaded from NSW **Department of Trade and Investment, Regional Infrastructure and Services on 10/08/2014 (http://www.resourcesandenergy.nsw.gov.au/landholders-and-community/coal-seam-gas/facts-maps-links/map-of-csg-potential-and-restricted-areas).**

A number of concerns have been raised regarding the potential health impacts from CSG extraction. Symptoms such as headaches, nausea, dizziness, nose bleeds, skin rashes, and sore, itchy eyes have been reported among people living in communities in close proximity to CSG mining sites [3]. Mental health problems associated with changes in the physical environment and social characteristics of the communities facing potential CSG development have also been reported [4]. Despite growing public concern about potential CSG-related health risks, very few peer-reviewed studies have been conducted either in Australia or overseas (Table 1).

The sources of health risk in relation to CSG can occur at different stages of production; the health impacts from these may be more or less direct, and they may be immediate or cumulative over a longer period of time.

Potential direct health risks of CSG mining

The health risks that may be directly associated with each stage of CSG mining are reviewed below.

Exploration activities

During the exploration stage, a core hole (approximately 20 cm in diameter) is drilled in the ground to obtain a sample of material below the surface, which provides information on the geology and the gas content of the site [5]. Drilling fluids used are usually a mixture of water, clays and additives, such as bentonite, cellulose, polymer, barite and guar gum that could pose a potential hazard to human health [6]. At the end of the exploration stage, the hole is cemented and plugged and the site is expected to be fully rehabilitated [5] . The quality of the rehabilitated land may contribute to health issues as it may take some time before the ground recovers (grasses, trees, and shrubs) to minimise erosion and dust. If a site is not restored to a satisfactory state, this could result in stress for the landowner and for the extended community. The size and density of exploration sites and their distance from population dwellings could be harmful due to increased levels of dust from the clearing of drilling sites, drilling and traffic-related activities.

Production pilot testing is an exploration activity that is used to assess the gas production rates. A cluster of up to five wells is operated for a period of time to estimate the likely production performance. As these wells are likely to be removed from existing production infrastructure, it has been suggested that the gas is used to power production equipment or, alternatively, is flared or vented [7].

During this stage, potential health risks arise from flaring and increased traffic, both associated with emissions (such as ozone and particulates) (cardiovascular and respiratory) [8,9,10,11]; dust (respiratory), noise from machinery (cardiovascular), traffic-related injuries and changes to the physical environment (mental) [12].

Potential health risk summary - Exploration: Health problems that could be associated to the CSG exploration include those related to respiratory and cardiovascular diseases from increased air pollution and noise, traffic-related injuries from increased traffic and mental health/anxiety problems due to changes to the environment and with potential future CSG development in the area. Mental *health problems can be associated with an increased feeling of powerlessness and loss of amenity.*

Production activities

The production stage includes extraction of CSG through wells drilled into coal seams (Figure 2). The wells are typically 300-1000m deep. In order to reduce the water pressure and release gas from the coal, water is extracted from the coal seams. Water and gas are brought to the surface separately: the water upwells through pipes helped by water pumps, while the gas flows up the casing of the well (Figure 2). The overall amount of water extracted from a well varies by location due to different geological structures. For example, while all the wells in the Camden area, NSW, were allowed to extract together a maximum of 30 megalitres per year during the production stage, and extracted less than 3 megalitres in all wells combined in 2010 and 2011 [13], a single well in Surat basin, Queensland extracted around 7-300 gigalitres per year (the amount of water extracted can vary greatly from year to year) [14]. The extracted solution consists mainly of water with high concentrations of salt. It is likely to be brackish (3000 to 7000 milligrams of salt per litre), but also contains some heavy metals and minerals introduced during the drilling process or occurring naturally within coal-seams. It is still not clear how the underground aquifers are impacted; contamination of groundwater could have serious health consequences. The storage and treatment process of the extracted water can also be a hazard to human health. Evaporation ponds for the storage of water produced from newly constructed wells have been prohibited in NSW. Such wells have been found to constitute ideal breeding grounds for mosquitoes [15].

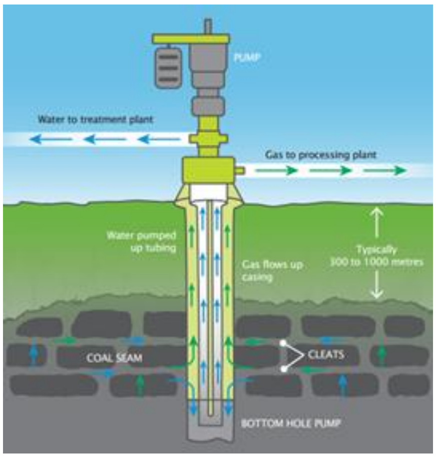

Figure 2. Schematic diagram of coal seam gas extraction process . Downloaded from CSIRO on 10/08/2014 (http://www.csiro.au/Outcomes/Energy/Energy-from-oil-and-gas/UnconventionalGas/Learn-more/What-is-coal-seam-gas.aspx)

Hydraulic fracturing (fracking) is used to increase the production of gas in a well. Fracking is the process of pumping large amounts of water with sand and chemicals into a well. It is claimed to occur only in 5-10% of wells [14]. The majority of the wells around Camden, NSW, have been fracked at some time during the wells' lifetime [16]. The NSW Government banned BTEX (benzene, toluene, ethylbenzene, and xylenes) chemicals in fracking fluids, but these chemicals can still occur naturally around coal and gas deposits, and in areas of heavy motor vehicle traffic [17]. Other chemicals may be used that pose potential health risks and have been associated with digestive, genitourinary, endocrine and skin medical conditions [18].

Flaring is a burning of the excess methane and potential source of air pollution. Fugitive methane emissions can enhance the development of ground level ozone and contribute to respiratory diseases [19].

Mental stress can arise due to conflicts in the communities where mining takes place, and feelings of loss of control (arising from loss of land, land value or livelihood), disruptions to the community's social and physical (aesthetic) status, loss of indigenous cultural heritage and sacred sites, and concerns about health effects may also contribute to poorer mental health [20]. Other triggers may be community severance, loss of privacy, increased cost of living, and shortage of services due to a rapid increase in population numbers from the arrival of a non-resident workforce [4,21]. The farming community may also experience mental distress associated with water shortage and land loss [12].

The production stage can threaten water quantity and quality of surface and/or underground supplies. Water contamination can arise due to naturally occurring radioactive materials, trace elements (e.g., salt, mercury, lead, and arsenic) or methane and other hydrocarbons that are released during fracking [12,22,23]. Contaminated surface or ground water may be associated with neurological and/or respiratory effects and with cancer due to exposure to the minerals and chemicals mentioned above or to other not-identified toxins or factors [24]. Air pollution (e.g., volatile organic compounds like NO_x, CO, and SO_2), noise or seismic activity can also be associated with the fracking process [12,25,26].

Although traffic, noise, dust and air-pollution will intensify with any building project, the sometimes dense distribution of CSG sites over a large area (Figure 3) contribute to the concern that impacts may be greater for this than for other industries.

Potential health risk summary - Production: Health problems potentially associated with the production stage include respiratory, cardiovascular, genitourinary, endocrine, mental and digestive diseases, skin problems, cancer and injuries related to traffic.

Post-production activities

Post-production activities involve sealing of a well to stop the leakage of gas or water [27]. Potential sources of risk include the leakage of gas from any pipes left behind or left over fracking liquids [12].

Figure 3 A section of coal seam gas well cluster and other associated infrastructure between Tara and Chinchilla townships, Queensland. Google Earth, Image Landsat, Imagery date 08/09/2013.

If the production sites are not fully restored, particularly in areas of high agricultural, natural or cultural value, this may lead to mental distress in the local community [12].

Potential health risk summary – Post-production: Health problems potentially associated with the post-production stage included respiratory, cardiovascular, digestive, liver disease, skin problems, cancer and mental health problems.

Potential indirect health risks of CSG mining

There is potential for local farming and agricultural products to become contaminated due to exposure to CSG-related chemical and toxins, air pollution from CSG-related activities and treated produced water with high salt content. It is plausible that these may enter the food chain through consumption of contaminated products such as milk, meat, fruits, vegetables and wildlife (e.g., waterfowl or fish).

Extreme weather or climate events, predicted to become more intensive and frequent in the future, in combination with CSG production, can have additional indirect adverse impacts on human health. An extreme weather event can affect the mining infrastructure or the amount of pollution produced. According to the Department of Natural Resources and Mines, "risk assessments by authorities and industry have clarified the safety of well heads, if a CSG well head is hit by fire it does not pose an increased threat" [27]. However, the spontaneous leakage of methane have been recorded around CSG wells [7] and its high flammability may result in an increased risk to humans from bushfires especially in water-limited regions.

The CSG-related mining activity may have an adverse impact on other resources, such as food supply, due to a potential rise in surface salinity [28], or the spread of weeds [29] and other changes to ecosystems.

Long-term and cumulative health effects of CSG mining

The lifespan of a CSG well maybe over a decade. It is assumed that some health effects may not be evident immediately but rather over some period of time. It is not known how all the stages of CSG production may affect health of those exposed over time, including cumulative effects of long-term exposure.

Overall findings

While there are a number of potential threats to health associated with the CSG mining activity, the epidemiological studies needed to test these claims are yet to be conducted. Importantly, the absence of such studies cannot be used as evidence that CSG poses no threat to public health.

- Very limited peer-reviewed literature related to specific CSG activities exists internationally or nationally. Most information about the impact of CSG activities originates from non-peer reviewed literature, such as reports.
- There exists some literature on natural gas and shale gas mining impact on human health. Although some aspects of these mining activities are similar to CSG, conclusions about their impact on human health cannot be simply adopted as measures of CSG risks.
- CSG mining is a complex process and is location specific; therefore to adopt regulations from other locations regarding human health may not be suitable.
- Fracking fluids, although less frequently used in CSG mining, remain a potentially high threat to human health. The chemicals contained in the fluid vary depending on the source; therefore it is not clear which of the chemicals are used and which could be harmful to human health. It needs to be established whether not only the immediate, but also the long-term and cumulative effects of these chemicals could be harmful.
- Evaporation ponds are banned in NSW and alternative options for treating produced water (and fracking waste water) have been suggested. These solutions may vary within the lifetime of the well and will be location–specific due to geological characteristics, the distance of the well from the

beneficial use and the quality of the produced water. As this is not clearly stated, it is difficult to estimate the potential health threat from water used in CSG mining.

- It is not clearly stated how much leftover brine will be produced and how it will be stored, and the methods applied to utilise the large amounts of salt produced. Since this process it not explained, it is not clear how each solution could affect human health.

Existing studies of the potential health effects of CSG mining

To date, very few published studies assess the impact of CSG on human health; therefore the effect of CSG on human health is largely unknown.

Given that any effects of CSG mining on population health are likely to be geographically widespread (e.g., over a water catchment), diffuse (indirect, operating through multiple pathways) and non-specific (many potential sources of exposure each with several potential health outcomes), determining these effects presents a challenge. As large numbers of people could be exposed, however, even a very small effect can be significant in terms of public health.

We could not find any specific peer-reviewed literature about the effect of CSG-related mining on health. The impact of other types of mining in peer-reviewed literature is documented, but it is uncertain how directly this translates to potential health risks of CSG mining. Environmental studies of other mining activities, including CSG, suggested that they alter the quality of air, water and soil that subsequently affects human health. Mining of natural gas, which involved fracking, was found to adversely affect the quality of air [30]. Cumulative cancer risk among residents living less or equal to half mile (800m) from wells was found to be increased by more than 50% over 30 years compared to those residents living more than half mile from wells [30]. If groundwater aquifers, rivers, ponds or other waterways are contaminated during the CSG mining process (especially if fracking is used), the threat to health could be significant. There is still a lack of information on exposure to natural and added chemicals and their ecotoxicity in both the discharged produced and flow-back waters. Naturally-occurring contaminants mobilised from the coal seams during fracking may add to the mixture of chemicals with the potential to affect both ground and surface water quality and therefore the health of end-users. CSG-produced water is highly saline and contains both naturally occurring heavy metals and drilling (and fracking) chemicals that could affect the nervous, endocrine, cardiovascular and immune system; kidney disease, cancer and other mutations are also reported [24].

The health impact of such water is unknown. Various ways to dispose the water have been proposed. Untreated water disposal includes reinjection into an aquifer or other 'untreated use where detrimental impact unlikely' [31]. Approved methods for disposal of treated water produced during CSG mining may include 'beneficial reuse' such as dust suppression, release to surface waters, irrigation or livestock watering [31]. It is not clear whether spraying roads to lower the immediate level of dust may eventually increase the levels of pollutants by adding dust particles from the produced water, and thus eventually increase the air pollution levels. The potential health consequences must be considered if such spraying were to take place.

Mental health problems have been found in residents experiencing environmental change due to mining activities, including CSG. The changes to social and economic activities in communities affected by the coal mining industry in the Upper Hunter Valley have been found to challenge people's sense of place and identity, as well as the physical and mental wellbeing of the local residents, associated with a sense of injustice and powerlessness [32]. Mining in the region (primarily comprising of coal and CSG) was identified as a major issue, which affected the health, social fabric, and economy of the community [4].

In addition to the peer-reviewed studies, there have been a number of reports that described health complaints of people living close to the CSG exploration sites, such as headache, nausea and vomiting, nosebleeds, irritation of nose, throat and eyes, skin rashes and sores, asthma and pins and needles in hands and feet [21]. An investigation was undertaken by the Darling Downs Public Health Unit to assess the health complaints of residents of Wieambilla, Queensland. The residents reported headache, sore itchy eyes and nose bleeds and an exposure to noise (day and night), odours (rotten egg smell) and dust (from an increase of traffic on unsealed roads). The method of investigation consisted of medical reporting from the local health providers and follow-up of those who with reported symptoms, residents self-reporting to 24-hour health telephone assistance centre, mapping of the households reporting symptoms and their locations to the CSG wells, and a contact made with mining companies asking whether there has been similar health complaints reported to the company's health providers. The report could not determine direct causal link between health complaints and CSG activities in the area [33,34]

Mental health concerns associated with CSG mining activities have also been reported. A survey-based study combined with semi-structured interviews investigated the potential sense of loss of place that may occur as a result of mining, including CSG in Gloucester, NSW, Australia. The participants acknowledged the potential economic benefit from CSG development, but also reported significant loss of sense of place and concerns about the lack of community input into local decisions [35].

Epidemiological studies

To determine whether or not CSG is associated with adverse human health outcomes, there are a number of types of epidemiological study that could be conducted. These depend on the question being asked, the data that is already available or that could be collected, the required time frame and the costs.

Epidemiology makes use of a number of different study designs to investigate whether there is an association between exposure and health outcome. Each study type has its own inherent strengths and limitations, including cost, timeliness, data availability, bias, and the capacity for causality to be inferred from the findings. Key characteristics of the main study designs are summarised in Table 2.

Sources of data

Ideally, studies where data is specifically collected to test hypotheses about the health effects of CSG would be conducted. This would enable good collection of exposure and outcome data, based on *a priori* hypotheses. Although they would yield the best 'fit for purpose' data, such studies are relatively expensive and time-consuming. In NSW, there are a number of existing data sources that may be used to conduct studies into the potential health impacts of CSG. These are summarised in Table 2. These data sets may not, however, contain the necessary exposure or health outcome data. For example, a person's geographic location may be used as a proxy for exposure, but it will only be approximate (such as within a postcode or SLA) and the data sets do not include symptoms such as headaches, fatigue, or stomach upsets – complaints that are low level and do not tend to send people to the hospital.

Table 1. Peer-reviewed studies that assessed the impact of various mining activities, including CSG, on human health.

Study location	Health risks	Method	Findings	Limitations	Author
Garfield County, Colorado, USA	Cancer	US EPA guidance to estimate chronic and sub-chronic non-cancer hazard indices and cancer risks from exposure to hydrocarbons.	Cumulative cancer risk for residents living =< ½ mile (800m) from wells was 10 in a million over 30 years vs 6 in a million for residents living > ½ mile from wells. Benzene was the main contributor to the risk.	Not CSG-specific. Data available for the analysis lacked spatially and temporally; therefore there is uncertainty associated with the results. Some sources of pollution from wells were not measured. The threshold of 800 m was selected based on the complaints of residents. The appropriate data were not available for apportionment to specific sources within the natural gas development. Possible under- and over-estimations of risk due to various needed assumptions in the study.	McKenzie et al. 2012

Study location	Health risks	Method	Findings	Limitations	Author
Upper Hunter, NSW, Australia	Mental health problems	Interviews with over 60 residents to document perceived threats to wellbeing and actual life experience of environmental change due to coal mining related activities.	The transformation of the regional landscape challenged the sense of place, identity, physical and mental wellbeing of the local residents. It was associated with a sense of injustice and powerlessness.	Not CSG-specific.	Albrecht et al. 2007

Study location	Health risks	Method	Findings	Limitations	Author
Southwest QLD, Australia.	Mental health problems	Twelve workshops were conducted in locations throughout southwest Queensland to explore the issues that contributed to uncertainty and stress in the region, and the measures that may be undertaken to address the issues. There were a total of 239 workshop participants comprising landholders, agribusiness and community service providers. Issue-based themes were identified and the identifications for each workshop were recorded.	Mining in the region (primarily coal and CSG) was identified as a major issue which affected community health, social fabric, and economy. Identified social themes that were specific to mining, but not necessarily the type of mining, included the fly-in, fly-out nature of the workforce, relationship breakdowns as mining stressors increased, a cultural shift from a rural culture to one of mining, losing staff to mining, and tension between coal seam gas workers and the local and/or long-established residents. A measure mentioned in eight of 12 communities to minimise mining impacts was the implementation of mental health first aid training to mining-affected communities. A range of other issues were identified such as a lack of primary health care services, support services, and professional support, changing community structure, high cost of living, high rental costs, and inflated costs. However, the relationship between mining and the aforementioned issues cannot be confirmed based on the study methods and findings.	Findings are of perceived concerns of workshop participants only. Additionally, the relative importance of the identified issues and the proportion of participants within a community that identify with an issue cannot be determined from the methods used, resulting in a document of non-specified level of concern within a community. Potential selection and response bias.	Hossain et al. 2013

Study location	Health risks	Method	Findings	Limitations	Author
Powder River Basin, Wyoming, USA.	To assess the likely changes in larval habitat availability for the mosquito *Culex tarsalis*, vector of the West Nile virus. The new habitat is focussed on the produced water ponds from CSG development.	Remote imagery was examined to identify likely areas of larval habitat. Accuracy assessments were carried out using field data and aerial photography.	The study estimated that there was a 75% increase in mosquito larval habitat between 1999 and 2004. This increase was primarily due to the installation of more detention ponds for produced waters of CSG wells.	The method can identify habitat related to ponds with size larger than 0.8 hectares with 72.1% accuracy. It cannot detect habitat below 0.4 hectares.	Zou et al. 2006

Table 2. Key characteristics of major types of epidemiological studies

Study type	Types of analysis	Health data used	Strengths	Limitations
Time series [36]	A time series is a collection of observations that are obtained through repeated measurements over time.	Routinely collected health data such as general practitioner (GP) visits, ambulance calls, emergency department attendances, hospital and death records.	Data readily available. Allows large-scale comparisons. Useful when an outcome of interest or disease is rare. Low cost.	Not performed at individual level (area-level study). Potential for ecological fallacy and aggregation bias. Confidentiality may require aggregation of data either to protect the potential identification of the study subjects or because the disease is rare. Causality is difficult to establish from ecological associations. May not be able to answer specific questions. Prone to bias and confounding. Differences in disease coding and classification, diagnosis and completeness of reporting over time.

Study type	Types of analysis	Health data used	Strengths	Limitations
Case-control [37,38]	Case-control studies compare groups retrospectively. People with the outcome of interest are matched with a control group. They are often used to generate hypotheses that can then be studied via prospective cohort or other studies.	Routinely collected health data such as general practitioner (GP) visits, ambulance calls, emergency department attendances, hospital and death records or collected *de novo* through questionnaires / surveys.	Can be used in the study of rare diseases. Case-control studies are simple to organise. Useful for hypothesis generation.	Bias is a major problem: potential for recall or sampling bias. Care must be taken in the selection of both cases and controls. Not population based, therefore it is impossible to calculate incidence of disease. Can only look at one outcome. Cost will depend upon the number of cases and controls and could range from low to high.

Study type	Types of analysis	Health data used	Strengths	Limitations
Longitudinal or cohort study [38,39,40]	A longitudinal study follows subjects over time with continuous or repeated monitoring of risk factors or health outcomes, or both. These studies are used to study incidence, causes and prognosis. The studies may be prospective or retrospective and sometimes two cohorts are compared.	Routinely collected health data. Questionnaires/survey. Linked health data. Longitudinal studies may be retrospective (routinely collected health data looking back in time) or prospective (self-collected data with follow-up).	Powerful study of causal association between exposure and outcome. Includes a temporal element and is not subject to potential recall bias. If data are routinely collected, this study can be quick and low cost.	Time-consuming and potentially expensive with *de novo* data collection over time. Some participants may be lost to follow-up.

Study type	Types of analysis	Health data used	Strengths	Limitations
Cross-sectional [38,41]	Cross-sectional study gives a snapshot of the outcome of interest in a population at any given time. Cross sectional studies are used to determine prevalence.	Routinely collected data. Questionnaires/survey.	They are relatively quick and easy. Low cost (already collected data may be used). Can encompass a broad scale of information. No loss to follow-up.	May not answer specific question. Not suitable for study of rare diseases. Prone to confounding. Questionnaires or surveys tend to be expensive and logistically intensive. Do not permit distinction between cause and effect. Difficult to make causal inference (they are carried out at one time point and give no indication of the sequence of events - whether exposure occurred before, after or during the onset of the disease outcome). Prevalence-incidence bias (also called Neyman bias).

Study type	Types of analysis	Health data used	Strengths	Limitations
Spatial/Spatio-temporal [42]	Spatial analysis is a set of techniques for analysing spatial data. This includes for example, cluster analysis (temporal, spatial or spatio-temporal) or spatial regression.	Mainly routinely collected health data (point or area-based). Self-collected data may also be used.	Visualisation of health risk and outcome (e.g., locations of CSG wells, unsealed roads, pipes and water treatment facilities in relation to population's residences). Useful for health surveillance and monitoring. Low cost if already collected data are used.	Geo-coded point or small-area health data are usually subject to restriction due to confidentiality. Suffers from ecological fallacy and modifiable areal unit problem.
Multi-level modelling [43]	Multilevel models are a set of statistical techniques for analysing quantitative data measured at two or more levels of analysis (e.g., at the individual, family, or neighbourhood level).	Routinely collected data and/or self-collected data (surveys/questionnaires). Linkage of multiple health datasets.	Can handle clustered, grouped or repeated measures data.	Complexity involved with the modelling process.

Table 3. NSW administrative data sources

Name	Source
Mortality/Cause of Death	NSW Registry of Birth, Death and Marriages Australian Bureau of Statistics
NSW Admitted Patient Data Collection	NSW Ministry of Health
NSW Emergency Department Data Collection	NSW Ministry of Health
NSW Perinatal Data Collection	NSW Ministry of Health
NSW Register of Congenital Conditions	NSW Ministry of Health
NSW Central Cancer Registry	NSW Ministry of Health
Mental Health Ambulatory Data Collection	NSW Ministry of Health
NSW Cancer, Lifestyle and Evaluation of Risk (CLEAR) study	NSW Ministry of Health Cancer Council NSW http://clearstudy.org.au/
Neonatal Intensive Care Units' Data Collection	NSW Ministry of Health Pregnancy and Newborn Services Network http://www.psn.org.au/nicus
Pharmaceutical Drugs of Addiction System	NSW Ministry of Health
Australian Longitudinal Study on Women's Health	Women's Health Australia http://www.alswh.org.au
NSW Pap Test Register	Cancer Institute NSW
Pharmaceutical Benefits Scheme	Medicare Australia
Medicare data	Medicare Australia
Linkage of multiple health datasets/Master Linkage Key	Centre for Health Record Linkage (CHeReL): NSW Ministry of Health http://www.cherel.org.au/
National Health Survey (NHS)	Australian Bureau of Statistics
NSW 45 and Up Study	Sax Institute https://www.saxinstitute.org.au/

Potential studies to assess health impacts of coal seam gas in NSW

Below are descriptions of different types of epidemiological studies that could be carried out to investigate potential health impacts from coal seam gas mining in NSW.

Ecological time-series study

Time-series analysis can uncover potential associations between various environmental variables and their impact on the health of the local population. Routinely collected data of people residing or working within the CSG-affected community, such as that from general practitioners visits, emergency department attendances or hospitalisations, may be used. Health outcomes data on respiratory (including asthma), cardiovascular, mental, digestive, and genitourinary diseases, skin allergies, eye and nose infections, headaches, cancer and falls (potentially associated with dizziness) and others would be investigated. The environmental and weather data, such as wind, rainfall, humidity, temperature and various air pollutants, including ozone and particulates would be used. The statistical analysis would apply Generalised Additive Models, treating daily health variables (potentially subdivided by age and gender, depending on the size of the population) as a dependent variable and with various independent variables, such as time, seasonal and population trends, weather and environmental variables. Values of variables before and during the CSG extraction period could also be included. This type of analysis allows lagging the effect of environmental variables to health outcomes and can account for other potentially modifying variables (such as socio-economic status or bushfires). Such analyses are relatively easy and quick to produce; however, health data may suffer from small daily numbers for specific disease categories, hence limiting statistical power. The increase in statistical power can be achieved by increasing the size of study location or a large specific medical condition (asthma vs all respiratory diseases) to increase the daily number of health data of interest, or the length of the study period [44].

A study in Pennsylvania, USA, evaluated associations between childhood cancer incidence and hydraulic fracturing sites of shale gas. The authors used the Pennsylvania's cancer registry data for a 20-year period during which numerous wells were drilled. The results were deemed inconclusive due to the exposure misclassification and disregard for the extended latency periods of many childhood cancers [45].

The time series analysis of CSG activity (e.g., fracturing) in the Camden area, NSW, using the NSW Register of Congenital Conditions, NSW Central Cancer Registry, NSW Perinatal Data Collection or NSW Admitted Patient Data Collection could evaluate various health outcomes, such as cancers, congenital conditions, birth outcomes, and respiratory or cardiovascular conditions that could be associated with the CSG mining activity. For example, the first CSG wells in Camden area, NSW, were drilled in 1999, which would allow up to 15 years of data, an appropriate length for time series analysis. The population of Camden, Narellan and Campbelltown (townships close by to CSG wells) may be aggregated to allow for sufficient statistical power. In a Spanish study investigating various air pollutants and mortality in 3 cities, the smallest city had a population of 200,000 (approximately the size of Camden, Narellan and Campbelltown combined) with approx. 5 deaths/day on average and a time series of only 2 years. This study had sufficient statistical power to detect an association between air pollution and increased mortality [46].

Such a study would only be able to show with certainty an association and does not provide high level evidence for causality. It would, however, be a useful first stage analysis that could be conducted fairly quickly with routinely collected data that could point to potential outcomes of interest that could then be followed up using other study designs.

Spatial study

Spatial analyses allow for the incorporation of geospatial information where in general time-series possibilities are lacking. Spatial analysis may, for example, be used to analyse the effect of proximity to a well, roads (sealed/unsealed), rivers/ponds, health services, farming activities, vegetation and other land use on the health of the population. The analysis can also include area-aggregated variables accessible on the Australian Bureau of Statistics, such as socio-demographic variables (socio-economic status or prevalence of elderly people). Residential address (if available) or other location information can be geocoded and analysed in relation to health data in that area (general practitioners visits, emergency department attendances, hospital admissions etc.). Spatial analysis may therefore be used, for example, to analyse the effect of noise on population health by measuring the distance between roads and wells from residences and GP visits (especially useful in night-time measure of noise).

Cluster analysis for various health outcomes (at any stage of CSG production) could uncover significant clusters that would serve as an exploratory basis to design more fine-tuned analyses. If continuous measurements of a variable (e.g., air pollution or water quality) is available with sufficient and appropriate spatial distribution, then temporal and/or spatio-temporal clusters of health outcomes within the population under a study could be performed.

McKenzie et al. (2014) estimated associations between maternal exposure to natural gas development (measured by maternal residential proximity to natural gas development) and a number of birth outcomes. No positive association was found between density and proximity of wells within a 10-mile radius of maternal residence and prevalence of oral clefts, preterm birth, or term low birth weight. However, a positive association was observed between density and proximity of pregnant mothers to natural gas development and the prevalence of congenital heart defects and possibly neural tube defects in their newborns [47].

Proximity of CSG wells and its association with various health outcomes could be investigated in regions with CSG extraction activities in NSW. Various routinely collected health data stated in Table 3 could be used. Self-collected data using randomly distributed surveys could be used, and their result analysed in comparison to the distance to e.g., wells or roads. A sufficient statistical power of such analysis may need to be insured by spatial and/or temporal aggregation of the investigated health outcomes. In the case of rare health outcomes, aggregation over several years or over a larger geographical area may be necessary. In a study of the distribution of heat-related mortality (rare event, both spatially and temporally) within Sydney metropolitan area with respect to population density, socio-economic status, vegetation and other variables, was aggregated over numerous days of several years to allow sufficient number of events to occur. This type of analysis doesn't allow for daily reaction to hazard (such as with a time series analysis), but it can show overall incidence of heath outcome in a longer period of time in space [48]. A Sydney-based study of *daily* heat-related emergency hospital admissions aggregated the admissions to five larger geographical regions for Sydney and its surround to achieve enough statistical power for daily admissions count and to investigate the spatial variation within the Sydney region [49].

Multi-level modelling using multiple linked health data

This analytical approach is based on linkage of multiple health datasets, such as the NSW Emergency Department Data Collection, NSW Admitted Patient Data Collection Pharmaceutical Benefits Scheme, NSW Central Cancer Registry and other health-related administrative or self-collected datasets. This approach enables researchers to follow the health status of an individual over a period of time through multiple datasets (potentially tracing a health treatment of fly in/fly out workers if treatment is sought in a location other than within the study area). It is comprehensive and a cost-effective way to perform a longitudinal study. Longitudinally linked data may be used to investigate the potential impact of the CSG industry on population health. It would allow for more detailed health studies of the population's health in the affected region before, during and after CSG production. Multilevel modelling could investigate and measure potential developmental and reproductive health effects of CSG-related activities on the population across multiple spatial scales It is comprehensive; it can follow an individual's health status over time and provide a sequence of events. And additional data can be added to the already linked data on an ongoing basis (this is an advantage since continuously new data is being created).

Linked data allow distinguishing between one individual being admitted repeatedly, rather than being counted as admissions from multiple people, which would be the case with a time series or spatial analysis (prevalence vs incidence). It also allows the calculation of the length of stay for each patient or of whether a certain subgroup (those living closer to CSG wells) is more likely to readmitted to a hospital. Multilevel modelling can also examine the influence of different spatial levels (i.e., neighbourhoods or Statistical Local Area).

Case-control study

This type of study would be of use if there were concerns that illnesses or symptoms within a community might be caused by exposure to some aspect of CSG mining activity. 'Cases' would be those people experiencing symptoms and 'controls' would be a comparable group of people selected from the same population who were not experiencing symptoms. Ideally, detailed measures of potential exposures and outcomes would be available for all participants. This information could be collected *de novo*, such as though questionnaire and even blood sampling, or may be available through routinely collected health data (such as those listed in Table 3). It has the advantage of being useful when the outcome of interest is rare. This type of study cannot estimate the incidence of a health problem in the broader population but it seeks to determine whether or not there are differences in exposure to a risk between cases and controls.

In summary, identifying health impacts associated with industries that affect the environment can be complex. The health effects may be difficult to detect: they may be mild, 'merely' cause a nuisance and not be severe enough to prompt the seeking of medical attention (and would therefore not be detectable in the data, for example, if records from hospital admissions or general practice are analysed); the same exposure may produce diverse symptoms, for example from skin problems to digestive problems, so that these are not readily linked; the geographic area affected may extend well beyond the immediate well surrounds and not make intuitive sense or may be difficult to link to other cases, such as the potential for indirect health risks to arise from contaminated food (which may not be readily traceable to source). Constant monitoring of sources of exposure, such as potential contamination of air, water and soil, and data collected specifically for this purpose may therefore be required. Large sample sizes may be required to detect adverse associations as there may be small numbers of cases falling under specific disease categories.

References

1. CSIRO (2014) What is coal seam gas? Available at http://www.csiro.au/Outcomes/Energy/Energy-from-oil-and-gas/What-is-coal-seam-gas.aspx Accessed on 10/08/2014.

2. Hamawand I, Yusaf T, Hamawand SG (2013) Coal seam gas and associated water: A review paper. Renewable and Sustainable Energy Reviews 22: 550–560.

3. State of Queensland, (Queensland Health) (2013) Coal seam gas in the Tara Region: summary risk assessment of health complaints and environmental monitoring data. Available at www.health.qld.gov.au/publications/csg/ Last accessed on 25/07/2013.

4. Hossain D, Gorman D, Chapelle B, Mann W, Saal R, et al. (2013) Impact of the mining industry on the mental health of landholders and rural communities in southwest Queensland. Australasian Psychiatry 21: 32-37.

5. State of NSW Department of Trade and Investment, Division of Resources and Energy (2013) Coal Seam Gas, Fact sheet 2. Exploration & Production. Available at http://www.resourcesandenergy.nsw.gov.au/__data/assets/pdf_file/0019/516142/Exploration-and-Production-CSG-Fact-Sheet-2.pdf. Accessed on 10/08/2014. .

6. Department of Primary Industries, Office of Water (2013) Water and coal seam gas, Fact sheet 2. How coal seam gas is extracted in NSW. Available at http://www.water.nsw.gov.au/Water-management/Groundwater/Water-and-coal-seam-gas/How-coal-seam-gas-is-extracted-in-NSW/default.aspx Accessed on 10/08/2014.

7. Day S, Connell L, Etheridge D, Norgate T, Sherwood N (2012) Fugitive Greenhouse Gas Emissions from Coal Seam Gas Production in Australia. CSIRO, Australia.Available at http://www.csiro.au/Outcomes/Energy/Fugitive-emissions-from-coal-seam-gas.aspx Accessed on 10/08/2014.

8. Adar SD, Sheppard L, Vedal S, Polak JF, Sampson PD, et al. (2013) Fine Particulate Air Pollution and the Progression of Carotid Intima-Medial Thickness: A Prospective Cohort Study from the Multi-Ethnic Study of Atherosclerosis and Air Pollution. PLoS Medicine 10: e1001430.

9. Brook RD, Rajagopalan S, Pope CA, Brook JR, Bhatnagar A, et al. (2010) Particulate Matter Air Pollution and Cardiovascular Disease: An Update to the Scientific Statement From the American Heart Association. Circulation 121: 2331-2378.

10. Devlin RB, Duncan KE, Jardim M, Schmitt MT, Rappold AG, et al. (2012) Controlled Exposure of Healthy Young Volunteers to Ozone Causes Cardiovascular Effects. Circulation 126: 104-111.

11. Ji M, Cohan DS, Bell ML (2011) Meta-analysis of the association between short-term exposure to ambient ozone and respiratory hospital admissions. Environmental Research Letters 6: 024006.

12. Broomfield M (2012) Support to the identification of potential risks for the environment and human health arising from hydrocarbons operations involving hydraulic fracturing in Europe. European Commission DG Environment. Prepared by AEA Technology plc under contract to the European Commission DG Environment ref 07.0307/ENV.C.1/2011/604781/ENV.F1. Available at http://ec.europa.eu/environment/integration/energy/pdf/fracking%20study.pdf. Accessed on 10/08/2014.

13. NSW Government Sydney Catchment Authority (2012) Sydney Catchment Authority. Literature Review. Coal Seam Gas impacts on water resources. December 2012. Draft Revision 4. Available at http://www.sca.nsw.gov.au/__data/assets/pdf_file/0019/39223/CSG-Impacts-on-Water-Resources-Draft-Revision-4.pdf Accessed on 28/08/2014.

14. Department of Primary Industries, Office of Water (2014) Water and coal seam gas. Fact sheet 4. Managing coal seam gas produced water. Available at http://www.water.nsw.gov.au/Water-management/Groundwater/Water-and-coal-seam-gas/Managing-coal-seam-gas-produced-water. Accessed on 10/08/2014.

15. Zou L, Miller SN, Schmidtmann ET (2006) Mosquito Larval Habitat Mapping Using Remote Sensing and GIS: Implications of Coalbed Methane Development and West Nile Virus. Journal of Medical Entomology 43: 1034-1041.

16. New South Wales Trade & Investment (2014) Coal seam gas. Coal seam gas locations map. Available at http://www.resourcesandenergy.nsw.gov.au/landholders-and-com. Accessed on 10/08/2014.

17. Queensland Government, Department of Environment and Heritage Protection (2014) Fraccing, BTEX chemicals. Available at http://www.ehp.qld.gov.au/management/non-mining/btex-chemicals.html. Accessed on 10/08/2014.

18. Lloyd-Smith M, Senjen R (2011) Hydraulic fracturing in coal seam gas mining. The risks to our health, communities, environment and climate. National Toxic Network. Available at:http://ntn.org.au/wp/wp-content/uploads/2012/04/NTN-CSG-Report-Sep-2011.pdf. Accessed on 28/08/2014.

19. Coram A, Moss J, Blashki G (2014) Harms unknown: health uncertainties cast doubt on the role of unconventional gas in Australia's energy future. The Medical Journal of Australia 200: 210-213.

20. Lloyd DJ, Luke H, Boyd WE (2013) Community perspectives of natural resource extraction: coal-seam gas mining and social identity in Eastern Australia. Coolabah 10: 144-164.

21. Adam K (2013) Health Effects of Coal Seam Gas - Tara. Queensland Health. Medibank Health Solutions Pty Ltd. Available at: http://www.health.qld.gov.au/publications/csg/documents/appx2.pdf. Accessed on 10/08/2014.

22. Tollefson J (2012) Is fracking behind contamination in Wyoming groundwater? Nature doi:101038/nature201211543.

23. Tollefson J (2013) Gas drilling taints groundwater. Nature 498: 415-416.

24. Colborn T, Kwiatkowski C, Schultz K, Bachran M (2011) Natural Gas Operations from a Public Health Perspective. Human and Ecological Risk Assessment: An International Journal 17: 1039-1056.

25. Thompson H (2012) Fracking boom spurs environmental audit. Nature 485: 556-557.

26. Parliament of Victoria (2014) Unconventional Gas: Coal Seam Gas, Shale Gas and Tight Gas. Available at: http://www.parliament.vic.gov.au/publications/research-papers/8927-unconventional-gas-coal-seam-gas-shale-gas-and-tight-gas#_ftn94. Accessed on 27/08/2014.

27. Department of Natural Resources and Mines (2013) Methane gas. Queensland Government. Available at http://mines.industry.qld.gov.au/mining/methane-gas.htm. Accessed on 10/08/2014.

28. Biggs AJW, Witheyman SL, Williams KM, Cupples N, de Voil CA, et al. (2012) Assessing the salinity impacts of coal seam gas water on landscapes and surface streams. Final report of Activity 3 of the Healthy HeadWaters Coal Seam Gas Water Feasibility Study. Department of Natural Resources and Mines, Toowoomba. Available at:http://www.nrm.qld.gov.au/water/health/healthy-headwaters/feasibility-study/pdf/csg-irrigation-salinity-risk-assessment.pdf. Accessed on 10/08/2014.

29. Aerial Agricultural Association of Australia (2011) Coal Seam Gas Policy. Aerial Agricultural Association of Australia. Avalaible at http://www.aerialag.com.au/Portals/0/Users/005/05/5/2011%20AAAA%20CSG%20Policy%2027%209%202011.pdf. Accessed on 10/08/2014.

30. McKenzie LM, Witter RZ, Newman LS, Adgate JL (2012) Human health risk assessment of air emissions from development of unconventional natural gas resources. Science of the Total Environment 424: 79-87.

31. Department of Environment and Resource Management Queensland Government (2010) Coal seam gas water management policy. Available at http://sixdegrees.org.au/sites/sixdegrees.org.au/files/water-management-policy-1.pdf. Accessed on 10/08/2014.

32. Albrecht G, Sartore G-M, Connor L, Higginbotham N, Freeman S, et al. (2007) Solastalgia: the distress caused by environmental change. Australasian Psychiatry 15: S95-S98.

33. DSITIA (2013) Wieambilla estates odor investigation results, July-December 2012. Department of Science, Information Technology, Innovation and the Arts, Brisbane, Queensland, Australia.Available at http://www.health.qld.gov.au/publications/csg/documents/appx4.pdf Accessed on 10/08/2014.

34. Hutchinson P (2013) The Darling Downs Public Health Unit Investigation into the health complaints relating to Coal Seam Gas Activity from residents residing within the Wieambilla Estates, Tara, Queensland. July to November 2012. Final report, January 2013. Available at http://www.health.qld.gov.au/publications/csg/documents/appx1.pdf Accessed on 10/08/2014

35. Jordan W (2010) Our Place, or Mine? Sense of place, social impact assessment and coal mining in Gloucester, NSW (Honours). University of Tasmania.

36. Brockwell PJ, Davis RA (2002) Introduction to Time Series and Forecasting. 2nd ed. Springer-Verlag. New York.

37. Levin KA (2006) Study design V. Case-control studies. Evidence-Based Dentistry 7: 83-84.

38. Mann CJ (2003) Observational research methods. Research design II: cohort, cross sectional, and case-control studies. Emergency Medicine Journal 20: 54-60.

39. Levin KA (2006) Study design IV. Cohort studies. Evidence-Based Dentistry 7: 51-52.

40. Coggon D, Rose G, Barker DJP (2013) Epidemiology for the uninitiated. British Medical Journal Available at: http://wwwbmjcom/about-bmj/resources-readers/publications/epidemiology-uninitiated Accessed on 10/08/2014.

41. Levin KA (2006) Study design III: Cross-sectional studies. Evidence-Based Dentistry 7: 24-25.

42. Openshaw S (1991) Developing appropriate spatial analysis methods for GIS. In: Geographical information systems: principles, techniques, management and applications. 2nd ed.(Longley, PA, Goodchild, MF, Maguire, DJ, and Rhind, DW, eds).

43. Snijders TAB, Bosker RJ (1999) Multilevel Analysis: an Introduction to Basic and Advanced Multilevel Modeling. 2 ed. London. SAGE.

44. Winquist A, Klein M, Tolbert P, Sarnat SE (2012) Power estimation using simulations for air pollution time-series studies. Environmental Health 11: 68.

45. Fryzek J, Pastula S, Jiang X, Garabrant DH (2013) Childhood Cancer Incidence in Pennsylvania Counties in Relation to Living in Counties With Hydraulic Fracturing Sites. Journal of Occupational and Environmental Medicine 55: 796-801.

46. Saez M, Figueiras A, Ballester F, Perez-Hoyos S, Ocana R, et al. (2001) Comparing meta-analysis and ecological-longitudinal analysis in time-series studies. A case study of the effects of air pollution on mortality in three Spanish cities. Journal of Epidemiology and Community Health 55: 423-432.

47. McKenzie LM, Guo R, Witter RZ, Savitz DA, Newman LS, et al. (2014) Birth Outcomes and Maternal Residential Proximity to Natural Gas Development in Rural Colorado. Environmental Health Perspectives, DOI:101289/ehp1306722.

48. Vaneckova P, Beggs PJ, Jacobson CR (2010) Spatial analysis of heat-related mortality among the elderly between 1993 and 2004 in Sydney, Australia. Social Science & Medicine 70: 293-304.

49. Khalaj B, Lloyd G, Sheppeard V, Dear K (2010) The health impacts of heat waves in five regions of New South Wales, Australia: a case-only analysis. International Archives of Occupational and Environmental Health 83: 833-842.

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Dr Pavla Vaneckova is an environmental epidemiologist and GIS analyst. She is experienced in the design and conduct of studies to investigate potential health effects of environmental variables, including time-series and spatial analysis.

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Conflicts of interest statement

Hilary Bambrick is a member of The Climate Institute's Strategic Council and sits on The Australia Institute's Research Committee. She has at times been a member of the Australian Greens. Pavla Vaneckova has no potential conflicts of interest to declare.

Glossary

Bias is the lack of internal validity or incorrect assessment of the association between an exposure and an effect in the target population.

Confounding is a situation in which the association between an exposure and outcome is due to the presence of another variable that is independently related to both the exposure and the outcome.

Ecological fallacy (also known as aggregation bias) is a bias produced when analyses realised in an ecological (group level) analysis are used to make inferences at the individual level.

Exposure is the condition of being exposed to something.

Hazard is a source of danger.

Modifiable areal unit problem occurs during the spatial analysis of aggregated data in which the results differ when the same analysis is applied to the same data, but different aggregation schemes are used.

Neyman's bias occurs if the exposure is related to prognostic factors, or the exposure itself is a prognostic determinant, the sample of cases offers a distorted frequency of the exposure. It arises when a risk factor influences mortality from the disease being studied.

Recall bias if the presence of disease influences the perception of its causes (rumination bias) or the search for exposure to the putative cause (exposure suspicion bias), or in a trial if the patient knows what they receive may influence their answers (participant expectation bias). This bias is more common in case-control studies, in which participants know their diseases, although it can occur in cohort studies (for example, workers who known their exposure to hazardous substances may show a trend to report more the effects related to them), and trials without participants' blinding.

Risk is the probability that an event will occur, e.g. that an individual will become ill or die within a stated period of time or age.