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Exploring the determinants of health and wellbeing in communities living in proximity to coal seam gas developments in regional Queensland

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Abstract

Background: There is some concern that coal seam gas mining may affect health and wellbeing through changes in social determinants such as living and working conditions, local economy and the environment. The onward impact of these conditions on health and wellbeing is often not monitored to the same degree as direct environmental health impacts in the mining context, but merits attention. This study reports on the findings from a recurrent theme that emerged from analysis of the qualitative component of a comprehensive Health Needs Assessment (HNA) conducted in regional Queensland: that health and wellbeing of communities was reportedly affected by nearby coal seam gas (CSG) development beyond direct environmental impacts.

Methods: Qualitative analysis was initially completed using the Framework Method to explore key themes from 11 focus group discussions, 19 in-depth interviews, and 45 key informant interviews with health and wellbeing service providers and community members. A key theme emerged from the analysis that forms the basis of this paper. This study is part of a larger comprehensive HNA involving qualitative and quantitative data collection to explore the health and wellbeing needs of three communities living in proximity to CSG development in regional Queensland, Australia.

Results: Communities faced social, economic and environmental impacts from the rapid growth of CSG development, which were perceived to have direct and indirect effects on individual lifestyle factors such as alcohol and drug abuse, family relationships, social capital and mental health; and community-level factors including social connectedness, civic engagement and trust.

Conclusions: Outer regional communities discussed the effects of mining activity on the fabric of their town and community, whereas the inner regional community that had a longer history of industrial activity discussed the impacts on families and individual health and wellbeing. The findings from this study may inform future health service planning in regions affected by CSG in the development /construction phase and provide the mining sector in regional areas with evidence from which to develop social responsibility programs that encompass health, social, economic and environmental assessments that more accurately reflect the needs of the affected communities.

Keywords: Health needs assessment, Wellbeing, Rural health, Social determinants of health

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Background

Regional Queensland has been a focus of Australia's coal seam gas (CSG) development over the past decade. CSG is a natural gas that is extracted via wells drilled in to coal seams, and involves exploration of land for CSG deposits, production, transportation and distribution. Significant CSG deposits are found in Canada, China, USA, and Australia, and were first explored in regional Queensland in the late 1970's, which led to commercial production from 2006. CSG is utilised domestically, but a proportion is converted in to liquefied natural gas (LNG) and exported internationally off the Queensland coast [1]. Growth of the CSG industry and the relatively large geographic span of exploration and extraction means that 'mining activity' often co-exists with primary production of some of Queensland's most diverse agricultural land, with positive and negative implications [1]. There is anecdotal concern that the environmental, economical and social change in the community brought about by the labour intensive development stage of CSG mining can have implications for health and wellbeing [2].

CSG development and public health

There is rich evidence of potential public health implications of extracting conventional resources like coal, diamond and oil internationally [3–5]. However, with the recent emergence of CSG development, there is less known of the potential health impacts in communities as they undergo changes in their environment [6–9]. Broader social determinants of health, like changes in working conditions, community networks or access to services could have serious implications for health and wellbeing in mining or resource settings, and are less understood [2, 10]. There is anecdotal concern that CSG development may have indirect and long-term impacts on the health of communities in which they operate but the scientific evidence is lacking [10].

Growth of CSG development has been rapid, in that approximately 1634 wells have been drilled between 2013 and 2014 alone, and reserves were being discovered at an unprecedented rate. Regional Queensland represents more than 90% of the total gas produced in the state [11]. CSG extraction often occurs on active farms and grazing properties, involving direct interaction with farmers and local community members, and there is some evidence that CSG development can bring about stress and anxiety [1]. There is also a huge demand for labour in the early stages of CSG development; these roles cannot be completely filled locally and thus large workforces often temporarily reside in 'host communities'. Population influx and influence on community structure can impact social capital through reduced social bonds and networks and there is concern for increased risky lifestyle behaviours like drug use and alcoholism that spill over to the communities from the mine workforce [12, 13].

The following paper forms part of a larger Health Needs Assessment (HNA) research project conducted in regions were CSG development was occurring. The purpose of the larger project was not to specifically identify the direct impacts of mining activity, but rather to assess broader population-level health and wellbeing issues in the communities and explore trends and possible determinants. Health is defined as 'a state of complete physical, mental and social wellbeing and not merely the absence of disease or infirmity' [14]. In conjunction, wellbeing is used to describe elements of life that impact on its quality, determining an individual's level of personal satisfaction, happiness and psychological health. Wellbeing may also include community-level factors, such as satisfaction with one's environment, and the level of social connectedness and belonging. This study reports on the findings from a recurring theme that emerged from the qualitative component of the analysis: that health and wellbeing needs were associated with the development stage of nearby CSG mining.

The cyclical nature of mining and the unpredictability of its activity lifespan can have serious implications for surrounding communities and presents governments with the challenge of responding efficiently and effectively to evolving needs. A deeper understanding of the health and wellbeing context in mining communities is pertinent to enable community and health services to prepare for the impacts of social, environmental and economic fluctuations that might come with a mining boom or bust.

Methods

Theoretical framework: Health needs assessment

This study utilised an HNA model to investigate the communities of interest. HNAs are a systematic tool to explore and identify inequalities and health priorities and are useful in identifying health gaps and trends [15]. An HNA starts with a *population* rather than a project and underpinning the HNA approach is the social determinants of health framework, which describes the complex, multi-layered influencing factors, which can impact the health of an individual [15]. These factors include individual lifestyle factors, social and community networks, and the broader socio-economic, cultural and environmental conditions within which one lives. Inclusion of wellbeing indicators at an individual and community level give an indication of quality of life and satisfaction with one's living environment [16].

Study setting

The study was conducted in three local government areas (LGAs): A, B and C in regional Queensland, Australia during June and December 2014. The major township of LGA A, which is furthest from Queensland's capital city of Brisbane, de-identified as Region 1, is classified as outer regional. LGA B's two major townships, Region 2 and 3 are defined as inner and outer; and LGA C's major township, Region 4, is defined as inner regional, according to the Accessibility/Remoteness Index of Australia (ARIA) (Table 1) [17]. ARIA criteria determines remoteness by measuring road distance to service centres, and is compared to 'unrestricted' accessibility in major cities. Geographical areas are categorised as major cities, inner regional, outer regional, remote or very remote. [18] ARIA is deemed an appropriate index for this research given it explores implications of the rural context and social determinants of health.

Mining activity in all of the LGAs was in the development phase during data collection in 2014, which brought a high demand for labour, mostly in the form of non-resident workers, or fly-in-fly-out (FIFO) and drive-in-drive-out (DIDO) employees who resided in the communities whilst on shift. LGA B experienced an increase in non-resident population by 9100 during 2015, compared with 5120 in LGA A. The number of businesses increased from 495 in Region 2 in 2012 to 1255 in 2013, and to 1166 in 2014. In Region 1 a similar pattern was seen but on a smaller scale (435, 790 and 755). At the time of publication, however, mining construction has drawn to a close, leading to an operational phase and a marked decrease in housing and rental prices following the out flux of FIFO and DIDO workforce.

Study design

Qualitative research methodology was utilised to explore the health and wellbeing needs of the communities of interest. This method was part of a larger mixed-method cross-sectional study based on the five principles of HNAs as defined by the National Institute for Health and Care Excellence (Fig. 1) [15]. The research team is preparing a further manuscript that presents quantitative results from the HNA and aims to compare and contrast with qualitative findings.

Data collection tools

Qualitative methods included In-Depth Interviews (IDIs), Focus Group Discussions (FGDs), and workshops with community members. Key informant interviews (KII) were also held with service providers. Development and implementation of the overall HNA was overseen by a steering committee of representatives from academia, government and the mining sector. A community champion provided local-level knowledge and support during participant recruitment and implementation. The qualitative findings for this paper are from the first two steps of the HNA framework. For the full HNA report with comprehensive methodology, refer to: http://www.wesleyresearch.org.au/wellbeing/.

Theme content for the qualitative research tools was originally developed by the qualitative research team following review of the literature and discussion with both the steering committee and local community contacts. Theme lists were developed and included perceptions of health and wellbeing at a community (IDI, FGD, KII) and service level (KII); multi-sectoral interaction and support (KII); barriers and facilitators to achieving good health (all); influences on good health (all) and perceptions of how to engage the community in health and wellbeing activities (all). FGD theme lists were further developed from preliminary findings from the quantitative survey and KIIs; for example, few survey respondents answered the open-ended questions about health and wellbeing priorities and so the FGD questions were adapted to include an emphasis on exploring the prioritisation of needs.

For the workshops, participants were asked to list and rank key health and wellbeing needs and discuss a chosen photo that represented health or wellbeing in the community. Questions were open-ended and participants were encouraged to talk about topics in their own

Table 1 Demographic and economic summaries of four study sites in regional Queensland, 2014

	Region 1	Region 2 & 3	Region 4
Demographics			
ARIA classification	Outer regional[a]	Inner and outer regional	Inner regional[b]
LGA Land Area	58,800 km^2	38,000 km^2	10,500 km^2
Population	14,000	34,000	66,000
% aged <55 years	76%	74.5%[c]	80%
Economic environment			
Main industries	Mining and agriculture	Agriculture, mining and manufacturing	Mining and manufacturing
Median family income	$1444/week	$1294/week	$1941/week

[a]Significantly restricted accessibility to goods, services and opportunities for social interaction
[b]Some restricted accessibility to goods, services and opportunities for social interaction
[c]On average, population slightly older than the total Queensland population [37]

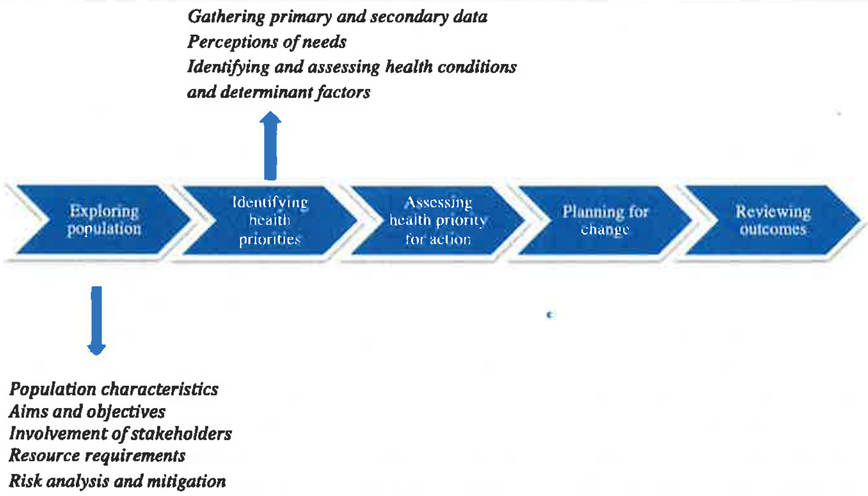

Fig. 1 A simplified HNA process describing the first two stages used in this study. *Adapted from Cavanagh and Chadwick* [14]

terms. Continual reflection and debriefing occurred within the research team following each interview. Field notes assisted with reflexivity of the experiences.

Recruitment of study participants

1. ***Stakeholder analysis and consultation with service providers and community leaders***
   A detailed mapping process identified service providers, health authorities, local governments and key community leaders in the health and community sector. Stakeholders were informed about the research project and invited to participate in a KII. Additional informants were recruited via snowball sampling and through attendance at local interagency meetings. Only the resident population was contacted for research in this study.
2. ***Community consultation with the general population***
   An expression of interest form was attached to the surveys sent out to a random sample of adults (>18 years of age) in each LGA (total = 6000) as part of the larger mixed method study. Those interested in further participation were invited to attend a FGD in their local community or an IDI over the phone. When there was clear indication of specific non-responding groups (e.g. young adults) to the survey or expression of interest, targeted stratified purposive sampling was utilised. Key informants assisted with promotion of research through email mail-outs and distribution of flyers. Middle- to older-aged community members were more likely to participate in the community FGDs and overall, females were more likely to be involved compared to males (Table 2).

Analysis

Qualitative analysis was initially completed using the Framework Method to explore key themes from the FGD, IDI, KII and workshop transcriptions. The Framework Method provides an initial structure whereby the researcher can systematically reduce the data in order to analyse it. This Framework Method was guided by the social determinants of health and social capital frameworks (Fig. 2). In the first instance the first and second author analysed the data for the comprehensive HNA. The first author then coded the data again based on the emerging theme of public health and mining activity, which was then independently verified by the second author. NVivo Qualitative Software was used to analyse the data. Findings from the KIIs, IDIs and FGDs were triangulated against each other to confirm and verify findings.

Ethical considerations

This study was granted ethics approval by the Wesley Hospital Human Research Ethics Committee, (reference number 1410). All participants were given verbal introduction to the study and provided with an information sheet to read. Participants were asked to sign a consent form if they wanted to proceed with the interviews and FGDs. Pseudonyms have been used and all other identifiable information removed for data storage and reporting.

Results

Communities in regional Queensland faced social, economic and environmental impacts during the development phase of the CSG mine cycle. These factors were perceived to have direct and indirect effects on individual lifestyle factors such as alcohol and drug abuse,

Table 2 Qualitative primary research involved 45 key informant interviews with health and community service providers; and 11 focus group discussions and 19 individual in-depth interviews with community members across the four study sites

Region	Key informant interviews (KII) *Organisations (n)*	Focus group discussions (FGD) *Community members (n)*	Individual interviews (IDI) *Community members (n)*
Region 1	Primary care and community services (5)	Male group (3)	Male (1)
	Hospitals (4)	Female group (10)	Females (4)
	Specialised health and community services (3)	Mixed group (4; 1 male, 3 females)	
	Public health services (2)		
Regions 2&3	Specialised health and community services (11)	Male group (6)	Male (1)
	Primary care and community health services (4)	Female group (6)	Females (2)
		Mixed group (6; 1 male, 5 females)	
		Mixed group (9; 2 males, 7 females)	
Region 4	Specialised health and community services (10)	Male group (4)	Males (5)
	Primary care and community health services (3)	Female group (3)	Females (6)
	Hospitals (2)	Female group (4)	
	Government (1)	Mixed group (4; 1 male, 3 females)	
TOTAL	45	59	19

family relationships, social capital and mental health; and community-level factors including social connectedness and trust. Participants highlighted concern for sustained impacts on health and wellbeing, including how the community would cope in the 'bust' period; whether the community would regain its identity; how children would grow up following family-related stress during the current mining 'boom'; and how young ex-mine employees would respond to reduced salaries outside of the mining sector.

Socio-economic and environmental conditions

During the study period, participants in regions 1 and 4 were concerned with increasing cost of services in the

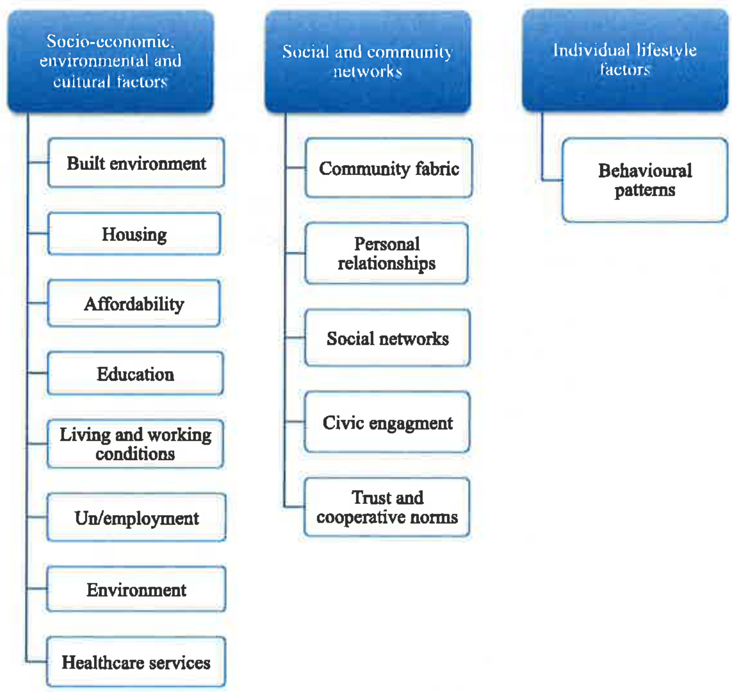

Fig. 2 The Framework Method was developed with reference to the social determinants of health model and provided the authors with an initial structure to systematically reduce and analyse the data

community and subsequent stress and outmigration, and the perceived burgeoning division between those who benefited economically from the CSG development, and those who didn't.

Residents in all regions commented on development of built infrastructure - most noticeably the increased availability of food outlets, liquor stores and takeaway restaurants. Availability of these options was perceived to cater for the increase in shift workers and temporary residents. Participants were concerned about the increased availability of these services in the community, and thought that young families and time-poor adults might also take advantage of convenience foods, which are often less healthy than home-cooked meals. Air travel was also an issue due to the high costs of airfares during periods when FIFO employment was at its busiest. There was concern for affordability of airfares for both leisure and to attend health and emergency medical appointments in major cities. Participants also commented on the increased number of sporting groups and clubs, but felt they were underutilised due to time constraints of shift workers. Several participants commented on the looming mining downturn and the effects this would have on demand for social and community services that had opened during the 'boom' to meet population growth.

Some young men with higher disposable salaries, both community members who were employed in the CSG industry and those who lived temporarily in the host communities, were often associated with antisocial conduct including alcohol-related behaviour and spending less time with family. This was pertinent in region 4. One participant was concerned for the lifestyle of some shift workers:

> *"They come home, they spend an hour, have a shower and then they go to sleep because they start again the day after. And again, at the same time, link that to a low level of education and a low level of understanding, and self-awareness... drinking, constantly being with men, and having a lot of disposable income."* Service provider, specialised community services, region 4

Participants were concerned for spill over effects in the community and what impact the short-term contracts and uncertainty in employment would have on those who had moved to the community with their families, particularly in regions 1–3. A lack of employment opportunities following the mine downturn was predicted and there was concern for the community's ability to cope in this situation. One participant commented on the influx of people who sought work in the mining sector and remained in the community despite being unsuccessful:

> *"It normally peaks, it happens in these times. We have a lot of family breakdowns. It's normally because you know... A lot of people are saying we are an industrial city look what is happening. So we get these families who arrive thinking they will be getting these marvellous jobs on a $100,000 a year they get there with their family and realise they can't afford the rent and there is no work for them. The family breaks down... the husband starts drinking... Drugs as well."* Service provider, community service, region 4

CSG exploration and drilling occurred on private land and there was concern related to the disruption caused by flares, and the effects of CSG on water bores. There were issues raised relating to the environmental effects on fresh water sources in regions 2–4, which deterred participants from fishing for both recreation and consumption. CSG infrastructure also caused increased noise pollution and traffic, which affected community satisfaction with their environment and perceptions of safety.

High rental prices and poor housing availability was linked to the labour-intensive development stages and subsequent population growth, and forced many community members to move elsewhere, as summarised by this participant:

> *"Community member (CM): There has been a shift in the community in the last few years around [region 1]... there's been a lot around wellbeing and affordability too. I think there has been a lot of pressure on that just with the CSG industry in [region 1]; it's probably put a bit of pressure on some people's wellbeing, affordability wise... Probably not us specifically, but I have seen a lot of change around that in the community."*
>
> *Interviewer (I): OK and how has that impacted on people's wellbeing would you say?*
>
> *CM: I would say, stress.*
>
> *I: OK. And what are people doing?*
>
> *CM: "They are moving. They are leaving."* Community member, region 1

Housing issues related to both the mining 'boom and bust' were regularly commented on across all regions. Participants commented on the surge of houses and hotels built to meet the demand during the mining boom. However, increased cost of living and housing prices strained the ability of social services to meet housing demand. Participants felt that prices had started to 'return to normal' leading in to the operational phase of CSG. Conversely, there was then great concern for the surplus of housing and the lack of planning by council, as described by this community member during the downturn:

> *'The councils - they're to blame - they're building it up all the time - how it's going to be the greatest thing to happen to [region 3] and then they... Look at it now they've all left town, it was only going to be short term anyhow until they built everything and it's all been built. There are suburbs out here with houses and houses and there's no one in them but the fact is they're still building them on the flood zones.'* Community member, region 3

Service providers and community members discussed the effects of living and working conditions associated with the mining sector in all regions. There was concern for the impact of shift work on families and social behaviour of mine employees in the community. Service providers commented on a marked increase in family disconnection, unbalanced lifestyles, stress and a lack of social networks for newcomers to the communities. These issues were particularly pertinent for the inner regional area 4:

> *"Mental health is an increasing issue for all regional communities and I think here in particular we have problems with isolation because families move here for work and they aren't supported; or families move here and the husbands are out, or they go out for a week or two weeks at a time, and leave what is essentially a single family, a single parent family."* Service provider, community service, region 4

Community members and service providers commented on relationships between male mining employees and their children and felt that a lack of time spent together due to long working hours could have detrimental effects on child development. Long hours and shift work also placed pressure on mothers to carry out dual responsibilities. These issues were traded off against higher wages afforded to shift workers and the benefits of having financial security.

> *"Shift work. I think that there is some comorbidities that develop amongst the communities that is very much related to long hours, separation from family, unnatural working hours... Even though people who do continual shift work begin to see that as normal, in actual fact it deters that negative impact on us as you know, people. I think you see stress, depression, obesity, diabetes, and dysfunctional relationships."* Service provider, tertiary services, region 4

Individual lifestyle factors

Linked to an increase in a male-dominated environment and higher disposable incomes, participants perceived an excessive use of illicit drugs and alcohol in the community. References to drugs and alcohol were particularly salient in region 4, with concerns for the increased availability of drugs in regional communities:

> *"I: What would be the most pressing health need for the community or for people in your area?"*
>
> *CM: Probably the drinking would be a big thing.*
>
> *I: The drinking - ok - and any other things?*
>
> *CM: Ah in some particular mining camps the drugs are getting in there now.*
>
> *I: And is that having much sort of spill out into the community?*
>
> *CM: "From time to time there is and there has been an increase in the drug raids happening in and around town due to mining people getting hold, of bringing in drugs and then selling them."* Community member, region 4

All communities were concerned for the effects of excessive drug and alcohol consumption among young mine employees. Service providers in region 4 linked the sudden demand for domestic violence support services to the behaviours of partners' who worked in the mine industry. Participants in region 4 mentioned anti-social behaviour in the town centre and insecurity felt by female residents alone in the town at night. It was perceived that these behaviours in the community were unwelcoming to other newcomers outside of the mine workforce.

> *"The other thing some of the local ones, I won't say all of them because I know they all don't do it but some of the local ones who have scored jobs in the industry have been on outrageous wages and what are they doing with those wages, I only have to go I won't tell you where I have to go to buy cocaine and methamphetamine and whatever, but it is so easy to get and these people have a disposable income and they're young they've got no common sense that they're not old enough to have that yet."* Community member, region 2

Residents in region 4 cited the influx of the mine workforce in pubs and high purchasing rates of alcohol in the community, particularly during poor weather when employees were unable to work. It was felt that workers had little else to do in the community. Participants in regions 2 and 4 felt that the traditional, family-oriented pub culture of the community had dissipated because of expensive prices and over-crowding by the mine workforce. In region 4, participants commented on the cultural changes and the lack of social nightlife in the main town:

> *"I think probably there are just a number of groups and they interact at different times out of need. I think that springs back to the basic social lifestyle, which is around shift work. Like you know, this town it's really busy, you can go in at 9'o clock on a Friday and everyone is just about disappeared apart from the nightclubs. You know, it's just an unspoken rule because people are up travelling at about 3.30 am/ 4am. So, because of that, it doesn't evoke community as much. People aren't sitting around until late at night, just enjoying themselves down town because people have gone."* Service provider, tertiary services, region 4

Social capital and community networks

Communities in each region experienced rapid population growth during the study period. Several references were made to the transient nature of the population – interstate, multi-state and overseas migration led to an impact on community culture, particularly because of the impermanent nature of newcomers and contrast with more traditional and regional community values. One participant recalls the traditional clothing often worn by country Australians, which was associated with farming and agricultural lifestyles, and how this is less prevalent in the community now.

> *"There is a change in the values. And there is a lower density of Akubra hats and moleskin [trousers] as you go down the street; it's more reflective gear and every second vehicle has a flag on it. And that's a whole different culture to what was here."* Community member, region 1

Participants discussed the impact of population growth and CSG related infrastructure on social isolation in regions 1–3. Residents withdrew from services in town because of the changing nature, and this was a particular concern given that many residents lived on rural farms with few socialising opportunities outside of their visits to town.

> *"I think too, with the influx of the gas, you know we call them 'glow worms' - with the big bright shirts, they are everywhere you go in the coffee shops, in the restaurants, everywhere you go. You walk down the street and the vehicles with their little flags. You think 'ohhh gosh', just from a visual point of view, that just impacts. And the traffic got a lot more. I mean there are positive and there are negatives, but from a community point of view the ones that have been here longer term have probably withdrawn from the services, they don't feel so connected. Like people can say oh it's not the same place I moved to."* Service provider, specialised services, region 1

Long-term residents felt that newcomers did not want to contribute to the community. Conversely, newcomers felt isolated and some felt they weren't welcomed in the 'cliquey' town. One participant commented on feeling unwelcome in the community due to temporary residence on a street with other FIFO employees.

> *"Being isolated as a worker like I'm a – they call workers like myself a townie. A townie is somebody who works in town, they're here for 3-5 years usually or shorter and I'm actually not part of the community, so some community events some church events they don't always make workers like myself feel particularly welcome because they know they're only here for a short period of time. So that's difficult - a bit of a cliquey town. There's lots of wealthy land owners as well as workers in town... that probably comes back to isolation and not having sort of a connection to this community because they don't have family."* Community member, region 1

Newcomers were often described as transient people who were 'coming for the economy with no intention to stay'. Community members in region 4 mentioned the under-utilised cemetery as an example of the few people who stayed permanently to retire and live the rest of their life in the region.

Participants in region 1 linked poor community well-being to inadequate engagement and communication with the mining sector; Participants were also concerned for the level of community reliance on the mining sector. They felt that the relationship between community members and the sector could be improved, as described by these participants:

> *"CM 1: You know so we're a corporate town, we've been 'corporatised' and now I think people are getting it in their head that they're de-culturising and that if the town wants something, well the resource company will fork out the money and we'll just leave it up to*

them and I think a lot of the young people are seeing that. They're seeing that the school - you don't have to work for it. Yeah that's right the money will just come from them. You're not seeing, like I was very offended to see those signs on the school on every side of the school there's a [mining company] sign and I was thinking now hang on when the brothel comes to town, are they going to be allowed to sponsor the school and put their signs up and what about the hundreds and hundreds of parents over the years that have contributed to that school so where's their name around the oval."

I: I'm just trying to make sure we add it to this, what's the wellbeing need there?

CM 1: "To keep more community engagement."
Community members, region 2

Discussion

The findings in this study support anecdotal evidence of broader health concerns arising from nearby CSG development beyond direct physical health impacts. Communities in this study perceived there to be both direct and indirect impacts of CSG development at both an individual and community level. Outer regional communities (regions 1–3) discussed the effects of mining activity on the fabric of their town and community, whereas the inner regional community (region 4) that had a longer history of industrial activity discussed the impacts on families and individual health and wellbeing. Region 1 is much larger than regions 2–4 but with a much smaller population, which could explain the prominence of community-level health and wellbeing impacts of mining. Region 4 had a greater transient and a younger population, which could explain the focus on individual-level health wellbeing needs [19]. Regions 1–3 were predominantly agricultural regions, which could explain why community members were concerned for the stages following construction, when the population would decrease as quickly as it increased, along with employment opportunities and demand for services. Region 1–3 may be more sensitive to the impacts of CSG development because they are smaller and less developed than region 4. The density and geographical size of the community and its previous experience with mining or other industries is predicted to influence the magnitude of impacts felt [20].

Socio-economic and environmental conditions

The Queensland Government described CSG and LNG development as a 'once in a generation opportunity providing jobs, energy security and prosperity for citizens' [21]. This study demonstrated how the stage of mining activity and subsequent local economic fluctuations affected the social and environmental fabric, which in turn had consequences for health and wellbeing needs at individual and community levels. The 'rapid' nature of CSG development is perhaps a reflection of the labour-intensive development stages, and the short-term impacts this had on the community. It would be valuable to study the effects on health and wellbeing during the consequent stages of mining, to ascertain if the results from this study are unique to the development/pre-construction phase.

A key source of economy for regional Queensland is farming and agriculture. CSG activity commonly occurs on active farms and grazing properties which provides increased opportunity for human interaction and conflict [1]. In the study sites and in the wider literature, CSG development was perceived to disproportionately affect farmers [22]. CSG development involves large water supply usage, environmental disruption and overlap with existing farmland. These conditions could contribute to financial and environmental concerns and influence stress and anxiety levels in an already vulnerable population [23]. Apprehension related to the increased cost of living and uncertainty was thought to force residents out of the communities in search for more affordable living. Economic insecurity can negatively affect mental health [24]. Local mental health services in mining-affected communities need to be aware of the potential triggers during 'boom' periods in order to effectively target services, and monitor and respond to needs.

During the study period, mining communities in regional Queensland experienced significant changes to the built environment and natural landscape, including rapid growth of takeaway and fast food outlets to meet population demands. The public health implications relating to the marked increase in these services is a concern, considering the higher rates of overweight and obesity in rural areas compared to major cities [19]. Increased availability of fast food and takeaway outlets is linked to increased prevalence of obesity in young Australian adults [25]. CSG development utilises a large amount of land due to the multitude of dispersed gas wells, difficult road access, pipelines, and processing plants and dams [1]. In concentrated community centres, this has led to concerns around traffic, volume of activity and destruction to the natural environment, impacting on community wellbeing. Local government is responsible for planning and managing such changes, but unforeseen impacts of the fast-growing and new industry may have contributed to negative community perceptions. Ex-gas mining communities in the US have been branded as 'ghost towns' and 'contaminated communities', reflecting the exodus of people following the mine downturn and little incentive to stay in such altered environments [26]. Evidence-informed planning and communication between local government, mining companies and the public is integral to ensure that long-term effects in the community are mitigated.

Living and working conditions

Social conflict, substance abuse and domestic violence has been linked to the social 'costs' of CSG development and are often considered tertiary socio-economic impacts [12]. These issues were key concerns in the study regions, particularly the social impacts of shift work on families and partners. A lack of understanding of the duration of mine activity led to some tension between longer-term community members and the temporary residents who arrived to work for the mining companies. Some temporary residents felt isolated and unwelcome, feelings of which can lead to poor health and wellbeing and a lack of community cohesion [23].

Individual lifestyle factors

The communities were concerned that working conditions, particularly for young males, led to anti-social behaviour in the community and excessive drug and alcohol abuse. These risky lifestyle behaviours can have significant impacts on mental health and long-term chronic diseases like lung cancer and liver disease. The working conditions of mine employees and potential for risky lifestyle beahviours is often referred to as a socio-economic product of the 'boom town effect' [12, 27]. There has been little research on the implications of CSG development on women but communities in this study were concerned for the impact of working conditions on families and the effects of social isolation on women. There was an identified need for improved social services to support women in these situations.

Social capital and community networks

Social capital represents social connections and the benefits they generate. Social capital can be sourced at an individual (e.g. family support) or wider collective level (e.g. volunteering) [28]. The framework used in the analysis demonstrated the link between CSG development and community fabric, neighbourhood interactions, community satisfaction, trust and cooperative norms.

It was important to community members to understand what was happening in their communities. As CSG is a relatively new industry there was significant uncertainty and anxiety around the unknown effects. Brashier [2011] stated that community reaction to mining development spans four stages: enthusiasm in the initial stages; followed by uncertainty; then panic and finally, adaptation [29]. The term 'solastalgia' has been coined to describe the melancholy felt following the unwelcome change in one's community and is often used in the CSG development context [30]. At a community level, there is a responsibility of local government to provide evidence, transparency and awareness around the CSG mining process to mitigate negative reactions. It is possible that perceived impacts of CSG development on health and wellbeing may reflect an unavailability of reliable sources, inadequate community consultation and a possible reliance on media for information.

'Community resilience' is a term often used in the context of mining and regional communities, and it is even quoted as a local government objective [31]. Resilience can be defined as responding to changes in one's community with a view to reinstate, maintain and enhance community wellbeing [31]. A key focus of research in this context is being able to provide evidence that supports communities in preparing for the local effects of CSG development rather that experiencing uncertainty and disruption.

Public health and policy implications

Extraction of CSG can occur alongside communities for over a decade. There is obvious concern that a lack of assessment of ongoing and cumulative health impacts leads to mining projects being carried out without a thorough understanding of the consequences for host communities [8]. In Australia, this is evidenced by submissions of concern by leading public health organisations to the NSW independent enquiry and commentaries from prominent academics in the field on NSW CSG development in 2013 [7, 8, 32, 33]. There is currently a lack of cohesion in identifying what health and wellbeing outcomes should be considered when examining population-level impacts of mining, and which stakeholders should be held accountable. Research demonstrates that impacts of CSG development stages relate to social, economic and environmental factors that can affect an individual beyond the state of physical health [12, 34]. Furthermore, evidence points to community—level health and wellbeing impacts that, although harder to measure due to the myriad of possible causes, merit attention (Table 3).

There is still much debate and uncertainty around the best tools to measure health and wellbeing impacts in CSG development regions. In the health sector, proxies to determine health impacts include assessing hospitalisation rates and access to health services [6]. Historically, the potential impacts of mining was assessed through health, environmental and/or social impact assessments. According to the International Finance Corporation guidelines, a Health Impact Assessment (HIA) involves the collection and evaluation of baseline data and subsequent risk assessment, and the outcome should include an action plan that addresses the risks

Table 3 Summary of key findings and recommendations

Key Findings	Context	Recommendation
CSG mining during development stage has implications for the social determinants of health (SDoH) and health and wellbeing outcomes	Direct and indirect impacts both at individual and community level	Potential impacts of CSG mining could incorporate standardised assessment of SDoH at individual and community level, with acknowledgment that setting (e.g. level of remoteness can affect magnitude of outcomes; avoid 'one size fits all' approach
Density and remoteness affects magnitude and type of impacts felt	Inner regional experienced more individual level impacts vs outer regional which experienced more community level impacts	
Effects on health and wellbeing may vary with the stages of CSG mining	Lack of assessment of ongoing and cumulative health impacts through the stages	Monitor health and wellbeing over time to enable evidence-informed planning and response to fluctuating demands
Lack of community understanding of CSG timeline and local impacts	Insecurity, lack of trust and concern for the future following completion of CSG mining could exacerbate negative perceptions	Communication of short and long term impacts is imperative alongside effective mitigation and planning
Population level studies are effective to highlight opportunities for targeted research	Groups that might be disproportionately affected by CSG included farmers, young families and women	Targeted research to determine what services are in place or required to meet temporary or longer term needs
Measuring and responding to the impacts of a mining project is not the responsibility of the mining company alone	Assessments should focus on the population, not the project, in order to uncover health and wellbeing outcomes that may not have otherwise been captured	A partnership approach involving local government, communities, research institutes, mining companies and social and health organisations is imperative

previously identified and a monitoring and evaluation strategy [35]. HIAs should incorporate tools to capture broader health and wellbeing outcomes under the social determinants of health framework, and outcomes should be monitored at several points throughout the mining lifecycle.

This study highlights the importance of gaining community views to understand broader health implications of CSG development – the study revealed interesting associations between mining activity and both individual and community level wellbeing. The findings demonstrate the importance of engaging with communities to identify issues throughout the mine cycle, and to use primary qualitative research to gain a deeper understanding of some of the drivers of poor health and wellbeing.

The prevalence of sex work was not mentioned by participants in any of the regions. Sex work in mine settings is a relatively well known occurrence and there are legalised brothels in Queensland, potentially making it a 'non-issue' in these communities [36]. It is also possible that with the discretion around sex work, its occurrence may not have been obvious to participants, or they simply did not consider it as a health or wellbeing need in this region.

This exploratory study highlighted potentially vulnerable groups that may be affected differentially by CSG development, including women and farmers. It is also important to consider whether effects on health and wellbeing differ between migrant populations and permanent residents. Further research could involve assessing health and wellbeing needs of specific groups using the HNA approach. What used to be an 'iron triangle' of government, industry and science needs to incorporate civil society, media and broader stakeholders to enable monitoring, prediction and management of cumulative impacts at a local community-level, and at all stages of mine activity [10].

CSG mining is often referred to as 'rapid' due to the growth of the industry over a short time, labour intensive yet relatively short development phase, and lack of understanding of the possible implications in the local community. It is imperative to understand the context within which CSG mining occurs to predict and control health and wellbeing impacts. More populated communities with existing mining and industry may be less likely to 'feel' impacts of development stages. As our understanding improves of the implications of CSG mining and communities are better prepared for the development stage, effects may become less damaging.

Individually regulating impacts on health and wellbeing is virtually impossible because multiple companies often work in one region and impacts cannot be solely attributed to a particular mining activity [1]. There is also variation in the institutional frameworks that define what health and social assessments must be conducted as part of a mining company's corporate social responsibility, and the findings are often not available in the public domain. HNAs focus on the population rather than a project, and therefore encompass broader health and wellbeing needs and, because of this, HNAs take the responsibility of implementation away from being solely that of the mining sector towards a joint obligation with communities, local government, research institutes and social and health organisations. HNAs are implemented with a partnership approach and significant community involvement, and the outcomes are useful for policy to inform regional and local strategic planning.

Limitations

It is important to note that the HNA process would not have enabled the possible *positive* health implications of mining activity to be revealed, because the aim of the assessment was to determine *needs*. Older women were more likely to take part in the qualitative research and there is a risk of bias and misrepresentation in perceptions because of this. Furthermore, it was known to the research team that the study sites had experienced significant consultation fatigue due to other social, economic and health-related research in the area, which may have contributed to the small population sampled. This corroborates the need for a unified approach to measure, manage and respond to health and wellbeing impacts of CSG development. It is also preferable to gain perceptions from a heterogeneous cross-section of the population with a broader age range than that of this study.

Conclusion

There is evidence of indirect and long-term health and wellbeing implications of living in proximity to CSG development. How communities respond to the boom, post-boom transition and 'bust' of CSG development is important for government, the mining sector and the scientific community. The findings from this study may inform health service planning in regions affected by CSG development and provide the mining sector in regional Queensland with evidence from which to develop social responsibility programs that encompass health, social, economic and environmental assessments that more accurately reflect the needs of the community.

HNAs are a valuable tool for determining cumulative outcomes and needs and operate at population-level rather than project-level. Measuring wellbeing in addition to health provides a more realistic profile of the community. It is recommended that further research is conducted at all stages of the CSG mine cycle to determine trends in health and wellbeing and appropriate responses.

Abbreviations

ARIA: Accessibility/ Remoteness Index of Australia; CM: Community member; CSG: Coal seam gas; DIDO: Drive-in-drive-out; FGD: Focus group discussion; FIFO: Fly-in-fly-out; HIA: Health impact assessment; HNA: Health needs assessment; I: Interviewer; IDI: In-depth interview; KII: Key informant interviews; LGA: Local government area; LNG: Liquefied natural gas; SDoH: Social determinants of health

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Availability of data and materials

To maintain the privacy of research participants who reside in small, rural communities, we have not included qualitative data for public review.

Authors' contributions

CG conceived and designed the Health Needs Assessment study. FM analysed and interpreted the data, which was validated by LM, and wrote the first draft of the manuscript. AT led the research team in the field and AT, LM and CG provided significant input on the structure of the paper and discussion components. All authors read and approved the final manuscript.

Ethics approval and consent to participate

This study was granted ethics approval by the Uniting Care Human Research Ethics Committee, (reference number 1410). All participants were given verbal introduction to the study and provided with an information sheet to read. Participants were asked to sign a consent form if they wanted to proceed with the interviews and focus groups. Pseudonyms have been used and all other identifiable information removed for data storage and reporting.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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For debate

Harms unknown: health uncertainties cast doubt on the role of unconventional gas in Australia's energy future

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Summary

- There is a push to increase production of unconventional gas in Australia, which would intensify the use of the controversial technique of hydraulic fracturing.
- The uncertainties surrounding the health implications of unconventional gas, when considered together with doubts surrounding its greenhouse gas profile and cost, weigh heavily against proceeding with proposed future developments.
- The health and environmental impacts of hydraulic fracturing have been the source of widespread public concern. A review of available literature shows a considerable degree of uncertainty, but an emerging consensus about the main risks.
- Gas is often claimed to be a less climate-damaging alternative to coal; however, this is called into question by the fugitive emissions produced by unconventional gas extraction and the consequences of its export.
- While the health effects associated with fracturing chemicals have attracted considerable public attention, risks posed by wastewater, community disruption and the interaction between exposures are also of concern.
- The health burdens of unconventional gas are likely to fall disproportionately on rural communities, the young and the elderly.
- While the health and environmental risks and benefits must be compared with other energy choices, coal provides a poor benchmark.

Australia has significant reserves of unconventional gas, with combined estimated reserves of coal seam, shale and tight gas amounting to over three and a half times those of conventional gas.[1] The industry is undergoing rapid growth as a result of advances in gas extraction techniques — most notably the widespread adoption of hydraulic fracturing (commonly known as fracking), which involves injecting large quantities of water, chemicals and proppants (materials like sand intended to keep fractures open) into gas reservoirs to open fractures and allow the gas to flow more readily. While coal seam gas (CSG) has been the focus of much public debate in Australia, it is the nascent shale gas industry that is likely to be responsible for the biggest expansion of hydraulic fracturing in the coming decades.

The promise of reliable and affordable energy, the potential windfall from exports, and claims that it is less damaging to the climate than coal have become major selling points of unconventional gas for its proponents. However, the industry has been beset by controversy over its potential negative health, social and environmental impacts.

Fears over the potential health implications of hydraulic fracturing led over 100 medical practitioners to request the Obama administration to halt the construction of new liquefied natural gas (LNG) terminals on the basis that "[t]here is a growing body of evidence that unconventional natural gas extraction from shale ... may be associated with adverse health risks through exposure to polluted air, water, and soil".[2] There are also environmental, social and psychological factors that have more indirect effects on health, and important social justice implications arising from the distribution of health burdens.

While there is a dearth of conclusive evidence about the health and environmental effects of fracturing, there is an emerging body of evidence on the areas of greatest potential risk and uncertainty in regards to water, air and social pathways. When taken into consideration along with concerns about the level of fugitive emissions and the potential effect on the development of renewable energy, these health concerns make unconventional gas a doubtful saviour for Australia's energy needs.

Wastewater is a greater hazard than fracturing fluids

The risk of fracturing chemicals directly contaminating water used for drinking or irrigation has been one of the main sources of public concern. While the risk of well casing failure, spills and other accidents cannot be dismissed,[3,4] these can be mitigated (though not removed entirely) by proper regulation and the move towards "safer" fracturing fluids. However, although any exposure would likely be to heavily diluted chemicals, the toxicological effects of some chemicals in their dilute form are not well understood.[5,6] In particular, chemicals affecting the endocrine system — such as ethoxylated 4-nonylphenol, which has been used in Australian operations[6] — can affect humans at extremely low quantities.[7]

The fate of stranded fracturing fluids (those remaining underground) has also not been well established, and there is a significant failure rate for abandoned wells in the United States, leading to materials leaking into the surrounding areas.[8] Additionally, while the minor seismic activity caused by fracturing is unlikely to result in earthquakes of a magnitude that can be felt, it introduces a further risk of damage to well casings.

However it is wastewater, which contains naturally occurring contaminants that are difficult and costly to remove (as well as fracturing and drilling fluids), that poses a greater human and environmental health risk.[4,8] There are many documented and anecdotal cases of spills, failures of holding dams, and the accidental and planned release of contaminated wastewater in Australia and the US.[9-11] Natural contaminants present in wastewater can include heavy metals and radioactive materials, which have serious and well known health effects.[8] Uranium and heavy metals have been shown to be mobilised by fracturing and drilling chemicals.[12]

Unconventional gas developments create air pollution

One of the clearest health benefits of gas over coal is the fact that it is responsible for significantly less damaging particulate matter (PM) than coal.[13] However, unconventional gas extraction is responsible for air pollution from diesel fumes from infrastructure development and stationary equipment, gas processing, venting and flaring. Fugitive methane emissions can catalyse development of ground level ozone and combine with PM to form smog, both of which contribute to respiratory disease, among other health effects, and damage to crops — gas-field haze is a well known effect in the US, with such pollution capable of travelling substantial distances.[14] Shale gas extraction can also involve the flaring or venting of "associated" gases, which can become hazardous air pollutants.[15]

The cumulative risks from these sources are difficult to estimate, however one study calculated the cumulative cancer risks for residents of Battlement Mesa, Colorado, to be "6 in a million for residents > 1/2 mile from wells and 10 in a million for residents ⩽ 1/2 mile from wells", also noting other symptoms reported by residents "consistent with known health effects of many of the hydrocarbons evaluated".[16]

It is likely that the distance of most Australian operations from densely populated areas at present makes the health impacts of air pollution less pronounced than in the US, although this may change as the industry fights against current setback restrictions. Although not conclusive, findings from an investigation of "downwinder's syndrome" in Queensland suggested no direct link to air pollution,[17] and pollution can also be reduced by improvements to equipment. However it is becoming apparent that *any* level of such air pollutants can have health implications at a population level.[13] Further, given the opportunity to move to far less polluting alternatives such as renewable energy, the reduction of PM compared with coal is not enough to recommend further gas developments.

Moreover, air pollution remains a potentially serious health issue for workers. Although the nature of risks to workers is unclear, potential exposures include toxic materials and chemicals, airborne silica from sand used as a proppant, and radon. A significant number of air samples collected in the US exceeded the recommended exposure limits for airborne silica, with one report claiming the potential of developing silicosis to be a significant known health hazard to workers involved in hydraulic fracturing.[18]

Social impacts exacerbate other health effects

Gas developments can have numerous and considerable social and psychological effects, which may exacerbate more direct health risks. Although there are potential benefits to communities, and effects are likely to be mixed,[14] a study of the impacts of mining and CSG operations on the mental health of landholders in Queensland concluded that these operations placed rural communities "under sustained stress", with study participants perceiving that these operations "significantly impacted or exacerbated issues such as the health, social fabric and economy of the community", and the authors noting that local health services faced "unsustainable pressure".[19]

Unconventional gas developments in Australia also make use of fly-in, fly-out and drive-in, drive-out workforces. While these arrangements have some benefits, they have come under scrutiny for their negative influence on community cohesion, increasing the cost of living, and their association with high levels of alcohol and drug use, mental health issues and violence (although these latter are also more generally associated with the demographic of young men who make up most of these workers).[20]

Social justice implications require more attention

Inequity can be an indirect cause of ill health, and the development of unconventional gas resources threatens to distribute health burdens in an unfair way. Most of the potential health hazards are likely to be felt by groups such as the elderly, children and the poor because of their vulnerability to the hazards involved, those living in rural, agricultural and Indigenous communities because of the location of operations, and future generations — the same groups liable to bear significant costs of climate change — while the financial benefits will accrue to the predominantly foreign owners of the resources.

Australia must also take responsibility for the moral implications of our role as one of the world's largest exporters of gas, with exports expected to reach nearly 70% of gas production by 2035. The emissions from the combustion of exported gas are not included in our national inventory; however it is plausible that countries have a prima facie responsibility for at least part of the harms caused by their exported emissions. According to the International Energy Agency, "Only one third of the carbon contained in proven reserves of fossil fuels can be released into the atmosphere by 2050 if the world is to achieve its under 2°C goal".[21]

It is clear that, insofar as we need to extract and use fossil fuel resources, this needs to occur in a controlled and fair way, but there are currently no such constraints on our development of new sources of gas.

The question of fugitive emissions

A further health issue raised by any proposed energy source is its contribution to climate change, which has the potential to reverse gains in global health, for example by exacerbating illnesses and causing deaths through undernutrition, extreme weather conditions and disease.[22] The combustion of gas produces about 40% of the greenhouse gas (GHG) emissions of coal, which has been offered as a reason to support the industry's expansion, either as a "stepping stone" towards renewables or as an end point in itself. However, this proposed benefit is called into serious question by the level of fugitive emissions (emissions that are not captured for use) produced by its extraction and transport. There is considerable disagreement about the extent of these emissions, with estimates ranging from 0.1% to 9% of gas produced (with current US Environmental Protection Agency estimations at about 2.4%).[23-26] Notably, there are as yet no reliable figures for Australian operations,[27] and regardless of how it compares to coal, unconventional gas is responsible for large quantities of GHG emissions in absolute terms.

Unconventional gas is predominantly methane, which is estimated to have a global warming potential 25 times greater than carbon dioxide over a 100-year period, and 72 times greater over a 20-year period.[28] The nature of climate change and the possibility of "tipping points" in the short term make it important to consider this perspective, with several reports estimating fugitive emissions from unconventional gas to be of a level (between 2% and 3.2% of production) that would likely undermine its climate benefits compared with coal in this time frame.[29,30] The effects of climate change, such as increased floods and drought, can be expected to exacerbate many risks, and are also likely to disproportionately affect vulnerable groups. This highlights the importance of considering the short-term global warming potential of methane and the social justice implications of energy choices.

Increased gas production may also displace emerging renewables markets in export countries and impair the growth of the renewables sector in Australia. In addition, the technology used for generating energy from exported LNG cannot be assumed to be of comparable efficiency to that deployed in Australia.[31]

Implications of the health impacts of unconventional gas

The current evidence does not provide a clear picture of the health implications accompanying the proposed expansion of Australia's unconventional gas industry. In some cases, this is because of gaps in our knowledge that could be rectified, while other risks are inherently uncertain because they involve complex systems and interacting health pathways.

It is important to note that the absence of concrete evidence of harm does not equate to evidence of its absence. The uncertainty over the health implications of unconventional gas is greater than that surrounding any other energy choice, and suggests that adopting an attitude of precaution — such as that employed with the introduction of a new drug — is justified on the basis of health risks alone.

However, as with decision making in a clinical setting, appeals to precaution need to take place in a broader assessment of risks and benefits. In the case of unconventional gas, this includes its implications for climate change, which — as argued above — also indicate its unsuitability. Further, while it is commonplace to compare gas with coal, coal is known to inflict serious damage on human and environmental health,[32] making it a poor benchmark and obscuring unfavourable comparisons with renewable energy choices.

It is clear that Australia must quickly move beyond its reliance on coal for health and environmental reasons. However, when taking into consideration the uncertainties over health risks, the unfavourable comparisons with other energy options, the climate risks associated with fugitive emissions, the moral obligations Australia faces as a gas exporter, the potential displacement of renewables and doubts raised over the claim that gas will prove to be a cheap energy option,[33] the scale is firmly tipped against the further development of unconventional gas.

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Santos is a polluting company with a poor track record

Santos' claims of not having any incidences in their gasfields operations at Moomba or elsewhere are false.

For example, Cooper Basin:

In 2012, Santos reported 17 flow line failures (pinhole leaks) on their 5000 km steel flow line network in the Cooper Basin. Such failures are defined as serious incidents under the currently gazetted Cooper Basin Processing and Production SEO. The failure mechanisms related to internal and external corrosion, with the primary root cause being inadequate monitoring and maintenance.

In September 2011, Santos reported a leak adjacent to crude oil storage Tank 1000 on a separate buried crude line to that which failed in November 2009.

December 2011 Santos reported a failure detected on its 10" buried crude run down line from the crude stabilization plant to Tank 3000. These incidents were attributed to the absence of cathodic protection on the buried sections of these lines and defects in the corrosion protective polyethylene wrap at the locations where the pipes failed.

On 12 January 2011 Santos reported hydrocarbon on groundwater at ~22 m below ground level. Dissolved hydrocarbons in the groundwater had been detected beneath a decommissioned burn pit adjacent to the Toolachee gas processing facility within Petroleum Production Licence 14 in the Cooper Basin.

The oily sludge pit at the Moomba plant is lined but leaked during operation. This allowed for vertical migration of contaminants through the soil profile and hence seepage into the underlying shallow aquifer.

On 12 September 2011 Santos reported a second buried line leak adjacent to crude oil storage Tank 1000 on a separate crude line to that which failed in November 2009. As a result of this line failure, on 17 October Santos reported that 1.2 m of phase-separated hydrocarbon was detected on groundwater in the vicinity beneath the location of this leak. On 28 November 2012 Santos was issued with a formal notice of noncompliance for undertaking an activity, the partial replacement of 2 km of the Moomba to Port Bonython liquids pipeline, without distributing formal notice of entry letters to relevant landowners, thereby breaching section 61 of the Act.

Going further back, Santos in the Cooper Basin:

2001

In June 2001, a pump exploded at the liquids pumping station killing Process Operator Colin Jeremy Sutton. Another worker received burns to the neck and hand. In the South Australian State Industrial Relations Court, Santos pleaded guilty to three counts that it had "failed in its most basic responsibility as an employer" by not ensuring its employees were safe from injury and risk to health. The company was fined $105,000. The magistrate said Santos had failed to supervise Sutton or train him in the use of an emergency shutdown device.

2004

On January 1, 2004, an explosion occurred at Santos' Moomba processing facility. The blast was traced to the Liquids Recovery Plant (LRP), where an inlet manifold and a related flange weld both failed after corrosion by mercury. Mercury was released along with a cloud of flammable gases including methane, ethane, propane and butane. Workers saw the cloud and raised the alarm, shutting down the plant and evacuating to designated safety points. Some workers allegedly did not hear the emergency alarms. The gas cloud ignited on contact with a heating unit 150 metres away, and an explosion followed. The plant was seriously damaged.

Moomba workers who sought to remain anonymous told *The Australian* newspaper on January 5 that the company was running a "cowboy" operation, and that it was luck, not management that had prevented any loss of life.

In 2011, the South Australian industrial relations court ruled that 13 employees had been placed at risk due to critical safety shortcomings. These included an inadequate risk assessment, which failed to identify the likelihood of plant failing due to liquid metal rendering it brittle. The company pleaded guilty to breaching the *Occupational Health Safety and Welfare Act* after a SafeWork prosecution and was fined $84,000. (see: http://www.heraldsun.com.au/news/breaking-news/santos-fined-over-moomba-explosion/story-e6frf7jx-1226119760264)

Pollution Incidents

- Gladstone Harbour, QLD Great Barrier Reef

Santos has been fined a total of $20,000 for five instances of permit breaches around pollution incidents at Gladstone Harbour. Santos failed to report one incident for 8 months, despite a requirement for reporting within 5 business days.

- Channel Country, Western QLD

An oil spill in June 2013 is one of the first major pollution incidents in the Lake Eyre Basin. A published report is available from the Queensland Department of Environment and Heritage Protection.

The oil spill has been described as Queensland's third largest, releasing about 250,000 litres to the Cooper Creek floodplain.

An FOI investigation was launched into this spill. A July 2014 department briefing note obtained by the ABC has revealed an investigation into the spill "determined that there was sufficient evidence to lay charges for breaches of the Environmental Protection Act 1994".

The document noted Santos has "historically had both major and minor spills ... which can be attributed to aging infrastructure and/or poor maintenance and management".

But Santos was not prosecuted.

In fact, Santos does a broad brush overview of their incidents and spills each year.

Incidents and spills

		2010	2011	2012	2013	2014	2015
Uncontained hydrocarbon volume	m^3	18.7	65.9	66.7	385.5	20.0	382.4
Total number of hydrocarbon spills	> 10L	73	85	161	30	42	39
Uncontained non-hydrocarbon volume	m^3	-	-	873	1,426	2,957	2,279
Total number of non-hydrocarbon spills	> 10L	-	-	46	47	52	36
Number of fines for non-compliance with environmental regulations		3	6	14	17	12	3
Value of fines for non-compliance with environmental regulations	$	6,000	12,000	35,000	34,800	72,000*	34,155

Notes: This includes $52,500 imposed by the New South Wales Land and Environment Court for incidents that occurred at the Bibblewindi Water Treatment facility in 2011 while the site was under previous ownership and management.

The above table is from the 2015 Santos Sustainability Report, available online: https://www.santos.com/media/3312/2015_sustainability_report.pdf

Incidents and spills

		2010	2011	2012	2013	2014	2015
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What Onshore Gas in the Territory will provide the Greater Industry

Hon Martin Ferguson AM, Group Executive-Natural Resources, SGH Energy, & Former Federal Minister for Resources

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PANEL | The Case for Onshore Gas Development in Northern Australia

- What is the potential for onshore gas development in Northern Australia?
- What infrastructure investment would be required to be built to develop the industry?
- What might the investment might look like?
- Implications for the broader economy and the East Coast

Panel Chair
Ashley Manicaros, Business Editor, Northern Territory News

Panelists
Richard Cottee, Managing Director, Central Petroleum
Sunil Salhotra, CEO, Pangaea Resources
John Ellice-Flint, Executive Chairman, Blue Energy

Day 2 includes
Daniel Kalinin, Technical Manager – Stimulation, Schlumberger
Malcolm Roberts, CEO, APPEA
David Close, Unconventional Exploration Manager & Chief Geologist, Origin Energy

Full SEAOCC agenda: http://www.ntresourcesweek.com.au/seaaoc/agenda/

Why are these players not fronting the fracking inquiry? They don't like the limelight when it comes to intelligent scientists asking them questions. They just want to sidle up to the NT Government and the media and tell their stories unopposed and unquestioned.

It is blatantly clear what communities are up against.

Santos sent the Fracking Inquiry their B team in Darwin and Origin are more focused on flying media crews to their Amungee site. Other operators like Central Petroleum, APPEA and Pangea didn't even bother to face the inquiry again, yet will be talking up the onshore gas fracking industry next week with the NT Government.

Incidents and spills	Units	
Volume hydrocarbon released	m3	131.5
Number hydrocarbon spills		43*
Volume produced water released	m3	1,499.8
Number produced water spills		43*
Regulator instruments received		1
Fines received from regulators	A$	8,835

Santos

* 17 of the hydrocarbon and produced water spills released both produced water and hydrocarbon i.e. there were 26 spills that released just hydrocarbon, 26 spills that released just produced water and 17 that released both
Definition: Regulator instruments – notices from environmental regulators that require action to address an identified non-compliance (e.g. penalty infringement notice, environment protection order)

From 2016 Santos Sustainability performance data, available online:
https://www.santos.com/media/3604/santos-sustainability-performance-data-2016.pdf

FRACKING INQUIRY BEING SIDELINED BY NT GOVERNMENT AND INDUSTRY:

The Northern Territory Government is failing to appear before this Inquiry and share information and to participate fully in this process. Yet the NT Government is hosting pro onshore gas fracking conference for NT Resources Week, in just a few days.

For example, here is the SEAOCC conference agenda:

Wednesday 16 August:

Northern Territory Ministerial Address

The Hon. Michael Gunner MLA, Chief Minister, Northern Territory

SEAAOC MAIN SESSION COMMENCES

11.20

The Case for Onshore Gas in the Territory

Session Chair

Ashley Manicaros, Business Editor, Northern Territory News

Santos

- The future role of gas
- Innovation in action
- The case for onshore gas – producer perspective
- Regional projects' update

Kevin Gallagher, CEO, Santos

PLOS | ONE
TENTH ANNIVERSARY

Toward an Understanding of the Environmental and Public Health Impacts of Unconventional Natural Gas Development: A Categorical Assessment of the Peer-Reviewed Scientific Literature, 2009-2015

Jake Hays , Seth B. C. Shonkoff

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Abstract

The body of science evaluating the potential impacts of unconventional natural gas development (UNGD) has grown significantly in recent years, although many data gaps remain. Still, a broad empirical understanding of the impacts is beginning to emerge amidst a swell of research. The present categorical assessment provides an overview of the peer-reviewed scientific literature from 2009–2015 as it relates to the potential impacts of UNGD on public health, water quality, and air quality. We have categorized all available original research during this time period in an attempt to understand the weight and direction of the scientific literature. Our results indicate that at least 685 papers have been published in peer-reviewed scientific journals that are relevant to assessing the impacts of UNGD. 84% of public health studies contain findings that indicate public health hazards, elevated risks, or adverse health outcomes; 69% of water quality studies contain findings that indicate potential, positive association, or actual incidence of water contamination; and 87% of air quality studies contain findings that indicate elevated air pollutant emissions and/or atmospheric concentrations. This paper demonstrates that the weight of the findings in the scientific literature indicates hazards and elevated risks to human health as well as possible adverse health outcomes associated with UNGD. There are limitations to this type of assessment and it is only intended to provide a snapshot of the scientific knowledge based on the available literature. However, this work can be used to identify themes that lie in or across studies, to prioritize future research, and to provide an empirical foundation for policy decisions.

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Competing interests: The authors are employees of PSE Healthy Energy, a multidisciplinary scientific research institute that supports the adoption of evidence-based energy policies. This does not alter our adherence to PLOS ONE policies on sharing data and materials.

Introduction

Shale and tight gas development (known to nontechnical stakeholders as "fracking" and referred to herein as unconventional natural gas development, UNGD) continues to be the focus of controversy. Amidst economic and geopolitical considerations, the potential environmental and public health impacts of UNGD have received substantial attention in policy, media, and public debates. Claims of ground water contamination and adverse health outcomes have been widely cited and disputed, but what does the science actually show?

While research continues to lag behind the rapid scaling of UNGD, there has been a surge of peer-reviewed scientific papers published in the past several years (Fig 1). By the end of 2015, over 80% of the peer reviewed scientific literature on shale and tight gas development has been published since January 1, 2013 and over 60% since January 1, 2014. This suggests an emerging understanding of the environmental and public health implications of UNGD in the scientific community. Yet, although numerous hazards and risks have been identified in studies to date, many data gaps remain. Notably, while there is now a far more substantive body of science than there was several years ago, there is still only a limited amount of epidemiology that explores associations between risk factors and health outcomes in human populations [1].

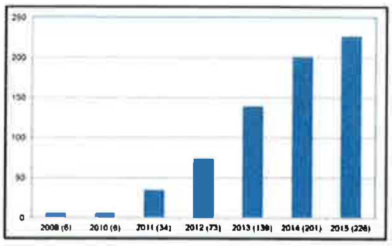

Fig 1. Number of publications that assess the impacts of UNGD per year, 2009–2015.
At least 685 papers have been published in peer-reviewed scientific journals that are relevant to assessing the impacts of UNGD. The number of papers published per year has continually risen and at least 226 were published in 2015 alone.
http://dx.doi.org/10.1371/journal.pone.0154164.g001

In this assessment we provide an overview, a current snapshot, of the scientific knowledge on potential environmental public health hazards, elevated risks, and outcomes associated with the development of shale and tight gas. We include only published, peer-reviewed literature available on the subject. More nuanced and systematic peer-reviewed public health review articles that provide greater levels of appraisal and analysis with in-depth narrative are available [2–4]. This particular assessment is intended to provide a broad understanding of the scientific literature in order to support the following goals:

- To understand the weight and direction of the scientific literature
- To provide comprehensive lists of studies in a field
- To identify themes that lie in or across individual studies
- To map and categorize existing literature for further review
- To prioritize future research and investigations

As activities continue to expand, counties, states, and nations are in a unique position to learn from experiences and scientific assessments conducted where UNGD is already underway [5,6]. While responsible energy policies require more than empirical data inputs [7,8], legislative and regulatory activities will benefit from the emerging body of science on the environmental and public health implications of UNGD. This assessment can be viewed as a summary of the peer-reviewed literature in order to help facilitate research efforts and inform policy discussions at the federal, state, and local levels.

Methods

Database assemblage and review

This assessment was conducted using the PSE Database on Shale and Tight Gas Development (available at: http://psehealthyenergy.org/site/view/1180 and referred to herein as the PSE Database). This near exhaustive collection of peer-reviewed scientific literature on the impacts of UNGD is divided into 12 topics: air quality, climate, community, ecology, economics, general, health, regulation, seismicity, waste/fluids, water quality, and water usage. We assembled this database over three years using a number of search strategies, including the following:

- Systematic searches in scientific databases across multiple disciplines:
    - PubMed (http://www.ncbi.nlm.nih.gov/pubmed/)
    - Web of Science (http://www.webofknowledge.com)
    - ScienceDirect (http://www.sciencedirect.com)
- Searches in existing collections of scientific literature on unconventional natural gas development, such as the Marcellus Shale Initiative Publications Database at Bucknell University (http://www.bucknell.edu/script/environmentalcenter/marcellus), complemented by Google (http://www.google.com) and Google Scholar (http://scholar.google.com)
- Manual searches (hand-searches) of references included in peer-reviewed studies and government reports that directly pertain to unconventional natural gas development.

For scientific literature search engines we used a combination of Medical Subject Headings (MeSH)-based and keyword strategies, which included the following terms as well as relevant combinations thereof:

> shale gas, shale, hydraulic fracturing, fracking, drilling, natural gas, air pollution, methane, water pollution, health, public health, water contamination, fugitive emissions, air quality, climate, seismicity, waste, fluids, economics, ecology, water usage, regulation, community, epidemiology, Marcellus, Barnett, Fayetteville, Haynesville, Denver-Julesberg Basin, unconventional gas development, and environmental pathways.

Our database and this assessment excluded technical papers on UNGD not applicable to determining its potential impacts. Examples of literature that we excluded are engineering papers on optimal drilling strategies, petroleum reservoir evaluations, estimation algorithms of absorption capacity, patent efficacy assessments, and fracture models designed to inform stimulation techniques. Because our assessment is limited to papers subjected to external peer-review, it did not include government reports, environmental impact statements, policy briefs, white papers, law review articles, or other grey literature. Our assessment also excluded studies on some forms of UNGD, such as coalbed methane/coal seam gas as well as other forms of fossil fuel extraction that specifically exclude shale and/or tight gas development (e.g., tarsands, oil shale, etc.). While we are sure that we include the vast majority and certainly the most seminal studies on the environmental public health dimensions of UNGD in leading scientific journals, it is possible that a small number of publications are missing. As such, we refer to the literature database as *near* exhaustive.

The PSE Database has been used and reviewed by academics, experts, and government officials throughout the United States and internationally and has been subjected to public and professional scrutiny before and after this assessment. It represents the most comprehensive public collection of peer-reviewed scientific literature on shale and tight gas development available. Again, many of the publications in this database are discussed in greater detail in published review articles [2–4] and government reports [9,10].

Scope of assessment

Definitions

There has been significant confusion about the environmental dimensions of UNGD (often termed "fracking") because of the lack of uniform, well-defined terminology and boundaries of analysis [11]. The public and the media often use the term "fracking" as an umbrella term to refer to the entirety of UNGD (and often other forms of oil and gas development), including processes such as land clearing, well stimulation, hydrocarbon production, storage and transportation, and waste disposal. On the other hand, the oil and gas industry and many in the scientific community generally use the term as shorthand for one particular type of well stimulation method used to enhance the production of oil and natural gas: hydraulic fracturing.

The PSE Database and this assessment are focused on UNGD in its entirety, and not only the method of well stimulation. Environmental and public health assessments that include only the latter should have a limited role in policy discussions. In order to understand the environmental and public health dimensions of UNGD any reasonable approach must engage beyond a narrow view of only the well stimulation process of hydraulic fracturing, especially when the scientific literature indicates that other UNGD processes warrant greater concern. As such, the boundaries of our assessment include scientific literature on hydraulic fracturing *and* the associated operations and ancillary infrastructure required to develop and distribute unconventional natural gas. Although we use the term UNGD to refer to shale and tight gas development, some of the studies included in this report may either include data from, or be applicable to, other forms of UNGD enabled by hydraulic fracturing. Again, those focused solely on coal seam gas are beyond the scope of this assessment.

Inclusion and exclusion criteria.

The temporal focus of this assessment was between 1 January 2009 and 31 December 2015 in order to capture what we believe to be the entirety of the published peer reviewed science on environmental public health dimensions of UNGD for this time period. We did not include papers released in 2015 ahead of print that will be published in 2016. We included original studies that evaluate environmental and public health hazards, risks, and impacts of UNGD, narrowly defined as shale or tight gas development (Table 1).

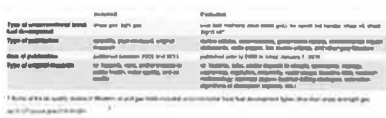

Table 1. Inclusion and Exclusion Criteria.
http://dx.doi.org/10.1371/journal.pone.0154164.t001

The majority of publications in the PSE Database are not considered in this assessment and we excluded the following topics: climate, community, ecology, economics, regulation, seismicity, waste/fluids, and water usage. Although many of these topics also have public health implications (e.g., climate change, economics, water usage, etc.), we have focused this assessment on original research that directly pertains to 1) public health, 2) water quality, and 3) air quality. We excluded some studies that may be located in the three topics used in this assessment, such as those that only provide baseline data or address research methods but fail to assess hazards, risks, or associated impacts.

As previously mentioned, we restricted the studies included in this assessment to those published from 1 January 2009 through 31 December 2015. There are studies on conventional forms of oil and natural gas development that are relevant to the public health dimensions of UNGD, but to maintain greater consistency we excluded those prior to 2009 from the assessment. For example, we did not include a study published in *The Lancet* that examined the association between testicular cancer and employment in agriculture and oil and gas development published in 1984 [12].

Relatedly, the scope of some of the studies we included in this assessment may go beyond shale and tight gas and could potentially include other forms of both conventional and unconventional oil and gas development. For instance, some of the top-down, field-based air pollution studies that gauge leakage rates and emission factors in Western oil and gas fields [13,14]. We included studies not exclusively related to UNGD only when the focus of the studies is relevant and they were published within our specified timeframe. For instance, studies that measured VOC emissions in a region with shale gas development as well as other forms of conventional and unconventional oil and gas development were included in this assessment.

Lastly, we only included original research in our assessment. We considered research original if it measured potential or actual health outcomes or complaints and air quality and water quality assessments related to UNGD. We excluded literature that attempted to determine public opinion or that considered methods for future research agendas.

Categorical framework

We have created binary categories for each topic in an attempt to identify and group studies in an intuitive way that focuses on the indication of what might be considered to be a relevant or significant impact. Some of the studies categorized belong in more than one topic. For instance, studies that contain data that are relevant to both air quality and public health are included in both of these topics [15–17].

As with any scientific analysis there is also a qualitative component in our operational definitions and methods of categorization (Table 2). It is possible that some may disagree as to what constitute findings that indicate a public health hazard or elevated risk. To address this concern we have listed specific criteria of what would qualify a study for inclusion in a particular category within each relevant section below. Examples include statistically significant positive associations between UNGD or a particular health outcome or measurements documented above recommended air quality standards. In some cases, the relative significance of an impact related to UNGD is based on the interpretation of the evidence by the authors of the study. Readers may also refer to the tables included in the appendix for citations and categorization of the studies, which are listed alphabetically by author in each topic (S1 Appendix).

Topics	Categories	
	A	B
Public Health	Findings that indicate public health hazards, elevated risks, or adverse health outcomes	Findings that indicate no significant public health hazards, elevated risks, or adverse health outcomes
Water Quality	Findings that indicate potential, positive association, or actual incidence of water contamination	Findings that indicate minimal potential, no association, or rare incidence of water contamination
Air Quality	Findings that indicate elevated air pollutant emissions and/or atmospheric concentrations	Findings that indicate no significantly elevated air pollutant emissions and/or atmospheric concentrations

doi:10.1371/journal.pone.0154164.t002

Table 2. Categorical Framework.
http://dx.doi.org/10.1371/journal.pone.0154164.t002

Our approach often does not account for various nuances in the results of particular studies. For instance, some studies may contain findings of both positive associations and no associations between UNGD and particular health outcomes. In our assessment we chose to include a study with any positive finding or indication of a particular impact in Category A. As such, a study that found an association between UNGD and health endpoint X, but no association with health endpoints Y and Z, would still be included in Category A.

Public Health.

Studies that assess public health risks and endpoints, including epidemiologic investigations, continue to be particularly limited compared to studies of public health hazards. To date, most of the peer-reviewed health oriented publications are commentaries and literature reviews. In this topic we included original research that considers the question of public health in the context of UNGD. Of course, empirical findings in other categories such as air quality and water quality are relevant to public health. However, in this topic we only include those studies that directly consider the health of human populations and individuals as well as studies that examine animal health as they can provide sentinel information for human health risks.

In this topic we consider research "original" if it measures potential or actual health outcomes or complaints (i.e., not health research that only attempts to determine public opinion or consider methods for future research agendas). In addition to epidemiology, we included studies in this topic that focus primarily on environmental monitoring, but which also contain significant discussion about public health risks or outcomes [15,18,19]. In some of these cases, we have cross-listed the study within the water or air quality topic.

For the public health topic, we placed a study in category A or B based on whether or not it provided evidence, documentation, or acknowledgment of any of the following that are attributed to UNGD:

- A positive association with at least one adverse health outcome (e.g., birth defects, hospitalization)
- A positive association with a known human health risk (e.g., elevated benzene concentrations)
- Increased health risks from exposure to pollutant emissions
- A positive association with reported health symptoms in randomized survey proximity analysis
- Self-reported health symptoms or complaints in humans or animals;
- Toxicological concerns in the context of protective limitations (e.g, monitoring impediments)
- Explicit health concerns based on documented environmental contamination (e.g., endocrine disruption chemicals, high PAH levels in ambient air, etc.)

Water Quality.

The allocation of water quality studies to binary categories is more complex than those focused on human health in that some rely on empirical field measurements, while others explore mechanisms for contamination or use modeled data to assess or predict water quality risks. Some of these studies explored only one aspect of UNGD, such as waste disposal or the well stimulation process enabled by hydraulic fracturing. These studies did not always indicate whether or not UNGD as a whole is associated with water contamination and are therefore limited in their utility for gauging water quality impacts. Nonetheless, we included all original research, including modeling studies as well as those that consider contamination mechanisms and/or exposure pathways. We excluded studies that explored only evaluative methodology or baseline assessments prior to UNGD as well as papers that only comment on or review previous studies. Here we were only concerned with actual findings in the field or modeling studies that specifically address the risk or potential occurrence of water contamination.

For this topic, we placed a study in category A or B based on whether or not it provided evidence, documentation, or acknowledgment of any of the following that are attributed to UNGD:

- A positive association with water contamination (e.g., proximity analysis showing increased concentrations of methane, heavy metals, salinity, etc.)
- Elevated surface or groundwater pollutant concentrations resulting from fluid releases or wastewater treatment/disposal
- Plausible contamination pathways and potential for water quality impacts from risk assessment/analysis of failure mechanism (e.g., casing and cement impairment)
- Plausible contamination pathways and potential for water quality impacts from modeling or geochemical evidence
- Water quality impacts based on analysis of microbial communities
- A significant quantity of reported incidents of water contamination relative to development activity

Air Quality.

The papers included in the air quality assessment are those that specifically address air pollutant emissions and atmospheric concentrations from UNGD at either a local or regional scales. These papers primarily include measurements of local and regional emissions and atmospheric concentrations of non-methane volatile organic compounds, hazardous air pollutants, and tropospheric ozone attributable to upstream natural gas, and sometimes oil, activities since atmospheric measurements usually account for both.

Although methane is a precursor to global background tropospheric ozone concentrations we excluded studies that focus exclusively on methane emissions from this topic. We do, however, include studies that measure emissions of methane *and* non-methane volatile organic compounds (VOC), given the known health-damaging dimensions of a number of VOCs (i.e., benzene, toluene, ethylbenzene, xylene, 1,3 butadiene, acetaldehyde, etc.) and the role of light alkane VOCs in the production of the respiratory irritant, tropospheric (ground-level) ozone. We included a few studies that explore the public health risks associated with air pollutant emissions in both the air and the public health categories.

For this topic, we placed a study in category A or B based on whether or not it provided evidence, documentation, or acknowledgment of any of the following that are attributed to UNGD:

- Measurement(s) or estimation(s) of emissions or atmospheric concentration in excess of recommended air quality standards (e.g., NAAQS, federal ozone standards, etc.)
- Emission estimates that are significantly elevated above state emission inventory estimates
- Public health risks due to toxic air emissions or ambient air concentrations
- Measurement of emissions and/or atmospheric concentrations highly elevated over regional background

Results

Public Health

Based on our criteria, we included 31 original research studies relevant to UNGD and public health hazards, risks, and health outcomes. Of these 31 studies, 26 (84%) contain findings that indicate public health hazards, elevated risks, or adverse public health outcomes and 5 (16%) contain findings that indicate no significant public health hazards, elevated risks, or adverse health outcomes associated with UNGD (Fig 2). The vast majority of all papers on this topic indicate the need for additional study, particularly large-scale, quantitative epidemiologic research.

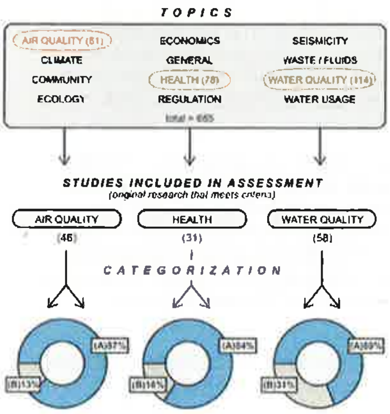

Fig 2. Selection Process and Results.

This assessment draws from the peer-reviewed literature for three topics in the PSE Database: Air Quality, Health, and Water Quality. Of the 61 publications in air quality, 46 met our criteria; of the 78 publications in health, 31 met our criteria; and of the 114 publications in water quality, 58 met our criteria. From here we placed the original research that met our criteria into one of two categories (see Table 2). Our results indicate that 84% of public health studies contain findings that that indicate public health hazards, elevated risks, or adverse health outcomes, 69% of water quality studies contain findings that indicate potential, positive association, or actual incidence of water contamination, and 87% of air quality studies contain findings that indicate elevated air pollutant emissions and/or atmospheric concentrations.

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Water Quality

Based on our criteria, we included 58 original research studies relevant to shale gas development and water quality. Of these 58 studies, 40 (69%) have findings that indicate potential, positive association, or actual incidence of water contamination associated with UNGD, while 18 (31%) have findings that indicate minimal potential, no association, or rare incidence of water contamination (Fig 2).

Air Quality

Based on our criteria, we included 46 original research studies relevant to questions involving associations between UNGD and air pollutant emissions and atmospheric air pollutant concentrations. Of these 46 studies, 40 (87%) have findings that indicate that UNGD increased air pollutant emissions and/or atmospheric concentrations, while 6 (12%) of the studies contain findings that provide no indication of significantly elevated air pollutant emissions and/or atmospheric concentrations (Fig 2).

Discussion

In this assessment, we reviewed the findings of original peer-reviewed research that evaluates associations between UNGD and air quality, water quality, and public health to determine the direction of the scientific literature. For each topic we found that the majority of original research indicate hazards, elevated risks, or potential impacts from UNGD on the outcome of interest. These results suggest that UNGD may contribute to an environmental public health burden, which is consistent with numerous scientific review articles and government reports.

A review of the research included in this assessment can help identify themes that emerge in study design, methodology, hypotheses, scope, findings, and recommendations. With regard to the latter, one one theme that continually emerged was a recommendation for additional empirical investigations to better understand the risks to water, air, and public health presented by UNGD. Other themes included the recognized need among researchers for baseline studies to allow for before and after comparative assessments and longitudinal data to determine potential short- and long-term impacts.

Numerous data gaps on the environmental and public health impacts of UNGD exist, many of which have already been recognized in the scientific literature. Several notable data gaps are worth mentioning, however, and the following remain largely unknown: the extent to which the presence of stray-gas in aquifers indicates the potential for chemical contamination from hydraulic fracturing fluids; changes in well integrity failure rates over time; the legacy effects and relative contribution of air pollutants emissions from aging and abandoned wells; exposure data to characterize the frequency, duration, and degree of exposure to various stressors; community health risks from physical hazards (e.g., light and noise); and the overall magnitude of human-health risks.

The need for quantitative epidemiological research on this subject is widely recognized in the scientific community, but it is difficult to conduct until exposure parameters are better determined and reported cases of health outcomes are analyzed. Many epidemiological studies are expensive, time consuming, and often rely on data that are difficult to obtain. The fact that potential exposures would have taken place before background data could be collected only complicates the issue. Although there is quite a bit of evidence of hazards and elevated risks, drawing conclusions about the magnitude of health burdens attributable to UNGD remains difficult from an epidemiological perspective.

Limitations

There are limitations to this assessment that relate to both its methods and the interpretation of its findings. As previously mentioned, the type of binary categorization we used may not account for the nuances of findings in many of these studies. Relatedly, this type of categorization effectively ranks the quality of the studies included in this article equally, despite clear differences in the weight and merit that should be ascribed to each study, based on either its design or interpretation of the evidence. Our work, however, was not intended to provide commentary on the quality of each study since here we are primarily concerned with the overall weight of the evidence. The quality and subsequent weight that should be given to a particular study are influenced by a number of factors, such as its design, methodology, and execution. We have only broadly surveyed original research across three different topics, including, but not limited to, qualitative epidemiology, risk analysis, in situ measurements, and modeling studies. There are strengths and weaknesses with each empirical method and it was not our aim to consider these attributes on an individual basis. Ultimately, this assessment relied on the peer-reviewed process itself in its consideration of the quality of the work. While not all peer-reviewed studies are of equal merit, this appeared to be the most simple, useful, and appropriate standard for quality control and consideration given our purposes.

Our selection criteria influence the categorization process and certain data inputs are gained or lost by our decisions to include or exclude particular type of studies. By only including original research on air quality, water quality, and public health, we are not accounting for all of the studies that may be pertinent to each topic (e.g., the existence or absence of elevated public health hazards, etc.). For instance, climate change, water usage, and economic gains may all influence environmental and public health outcomes. We have excluded these topics from our analysis and have chosen to focus only on the three that have consistently received the most attention among environmental public health researchers. Additionally, by not including government reports that do not appear in peer-reviewed journals we may be missing useful data and analysis that can inform UNGD public health implications as well as air and water quality concerns.

The majority of studies included in this assessment were conducted to determine whether or not adverse effects from UNGD exist. These types of investigations may, by their very nature, produce reporting or design bias. This is an inherent limitation of the scientific discipline; scientists are not immune from value judgments that shape research and scientific reasoning, including hypotheses to be tested, boundaries of analysis, and interpretation of evidence. Biases are difficult to account for in this context and we have chosen to rely on the peer-review process in this determination.

Furthermore, while the PSE Database is–to our best knowledge–exhaustive, our literature search may not have captured every relevant peer-reviewed scientific paper. Some journal articles are not always available in electronic databases or may be captured at a later time. As UNGD continues to gain the attention of the scientific community in other parts of the world, more and more research on the subject has been published in relatively obscure journals that may not be readily available. While we are confident that our MeSH-terms account for nearly all of the research on this topic, there is a possibility that some studies that use different or less traditional terminology may have been missed. We did our best to account for what may not have been initially discovered in an online database with manual searches of the scientific literature over a several year period.

Differences in geography, geology, petroleum reservoir type, and regulatory regime may also render some studies less relevant when interpreted across geographic space. Our assessment is only concerned with current empirical evidence in the peer-reviewed literature and we do not consider different regulatory regimes that could potentially influence environmental and public health outcomes in positive or negative ways. For instance, technological improvements such as universal deployment of reduced emission completions may mitigate some existing air pollutant emission issues.

Despite its limitations, our assessment provides a general understanding of the weight of the scientific evidence of possible impacts arising from UNGD that are relevant to environmental public health. It demonstrates that the weight of the scientific literature indicates that there are hazards and elevated risks to human health as well as possible adverse health outcomes.

Finally, it must be understood that all forms of energy production and industrial processing have environmental impacts. Our assessment is only focused on assessing the available science on the environmental and public health dimensions of the development of natural gas from shale and tight formations. We make no claims about the level of impact that should be tolerated by society–these are ultimately value judgments that incorporate more than empirical findings.

Supporting Information

S1 Appendix. List of studies included and excluded in assessment by topic.

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(DOCX)

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Author Contributions

Conceived and designed the experiments: JH. Performed the experiments: JH SBCS. Analyzed the data: JH SBCS. Contributed reagents/materials/analysis tools: JH SBCS. Wrote the paper: JH SBCS.

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