

The public health impacts of mining in Australia

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Mining activities have long been linked to health loss among occupationally exposed populations, leading to significant strengthening of workplace health and safety regulations. However, non-occupational research is revealing increasingly robust evidence of both direct and indirect health risks, which are consistent with known emissions of toxic chemicals into the air, water and land during extraction, transportation and processing of mined materials. Epidemiological studies have identified a higher risk of cancer, circulatory and respiratory diseases, congenital anomalies and perinatal disorders in mining regions, globally.¹ Most research has been conducted in the United States, China and Europe, with studies emerging from Africa, South America, South-East Asia and India. Although Australia is one of the most important exporters of mined minerals and precious metals, research has focused mostly on environmental contamination and human health risk assessment of heavy metal byproducts such as lead and mercury.²⁻⁵ Limited epidemiological research in communities in mining areas in Australia hinders a comprehensive understanding of the public health impacts of mining, especially because of the magnitude and extent of mining activities in almost every Australian state and territory.

There were about 719 mines extracting solid materials in Australia in 2023;⁶ the majority in Western Australia, New South Wales and Queensland (Box 1). Gold, coal and iron ore mines account for 57% of total mining operations (30%, 17.5% and 9.8% respectively) with the remaining 43% mines extracting other minerals, including copper, mineral sands, silver, zinc, nickel, lead, bauxite, lithium, cobalt, asbestos and uranium.⁷ Although oil extraction is limited and onshore conventional gas reserves are dwindling, Australia's gas production and coal seam (unconventional) gas extraction is rapidly growing, with substantial gas resources and reserves in other states and the Northern Territory.

Mining, often identified as the most important industry in economic terms, has an EBIDTA ("earnings before interest, taxes, depreciation, and amortisation", which is a measure of profitability to net income) of \$274676 million (the next two sectors are rental and real estate and construction, with EBIDTAs of \$69508 million and \$58801 million, respectively).⁸ However, the environmental, climate and health costs of mining are substantial. Globally, it has been estimated that, if environmental costs are deducted from mining-generated income, the net economic gain is reduced by about 70%,⁹ whereas the value of statistical life costs exceeds the benefits of mining in coal mining areas in the United States.¹⁰ The environmental disruption of mining activities is associated with impacts from soil, air and water contamination. Higher concentrations of metals such as aluminium, iron, manganese, nickel and zinc, which exceeded the limits of Australia standards, have been measured in water from coal mine and gas extraction activities within, or discharging into, high conservation environments in several states.¹¹⁻¹³ Nevertheless, a complete cost-benefit assessment of mining must include both occupational and public health impacts.

Summary

- Australia is rich in minerals of commercial interest along with oil and gas, and mining activities are carried out in almost all states and territories. The public health impacts of mining on the Australian general population need to be addressed to enable a comprehensive cost-benefit assessment of these activities balanced against their broader impacts.
- This systematic search and thematic review of the literature evidenced that exposure to agents released during mining operations, such as cadmium, iron, manganese, zinc, arsenic and lead, is associated with neoplastic and non-neoplastic diseases in adults and children.
- Mining of lead is specifically associated with negative fertility effects in men and with intellectual disability and impaired immune function in children. Asbestos mining is associated with higher morbidity and mortality due to respiratory and non-respiratory cancers, and recent analyses have identified a higher risk of severe respiratory and circulatory diseases in communities in proximity to coal mining.
- Although unconventional gas extraction is more newly introduced in Australia, research has found a higher risk of hospitalisation by all-causes and for circulatory, respiratory and blood and immune diseases, especially in children.
- These findings are consistent with extensive research globally, but human studies in this field are scarce in Australia. Multisectoral approaches are required to address these impacts, including committed involvement of the mining industry, the academic sector and, especially, the different levels of government.

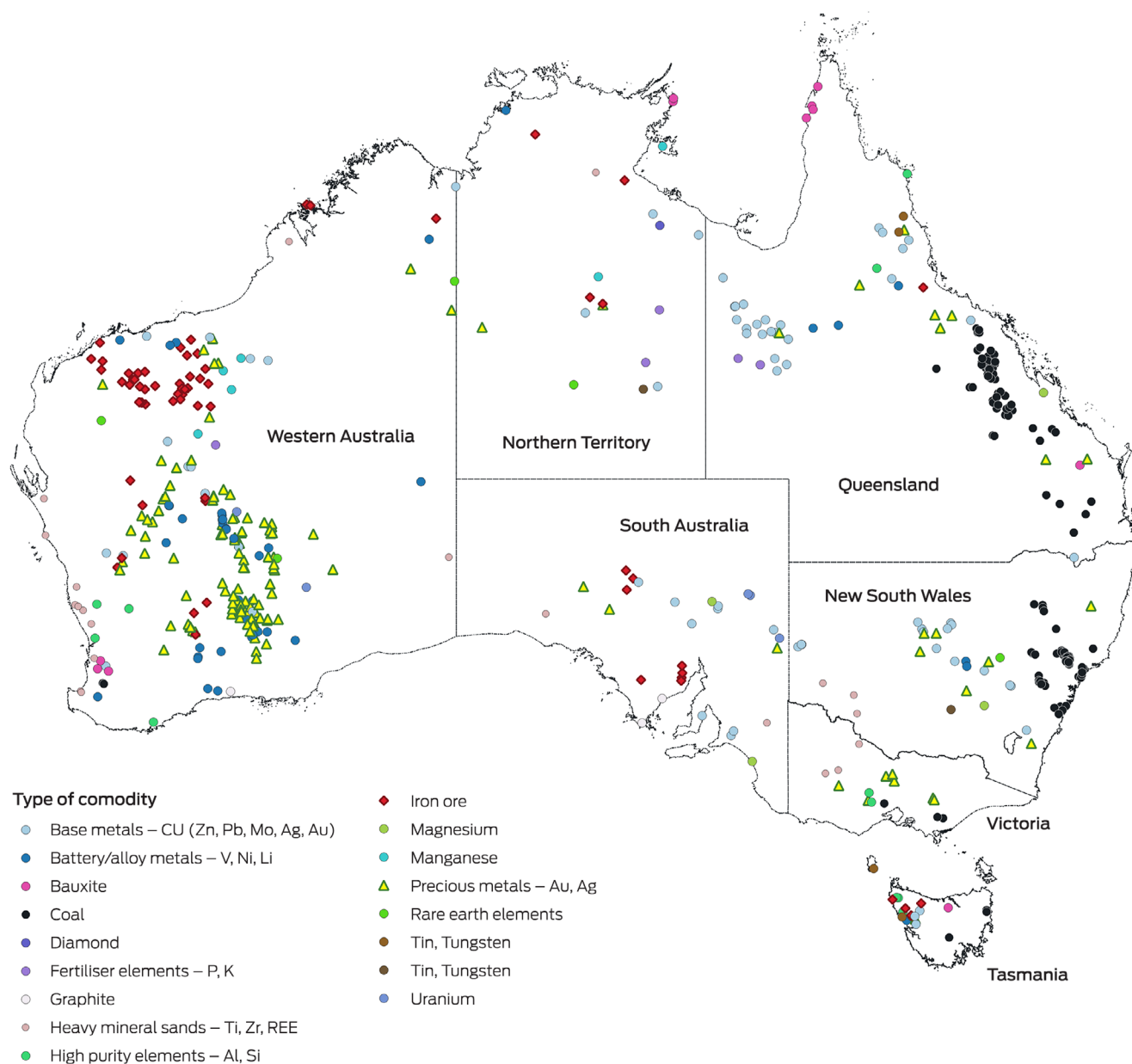
Since most research in Australia has focused on the health impacts of mining on workers, in this review we assess the evidence on the health impacts of mining in the general population, which encompasses the broader community. We implemented a systematic search of studies on the health impacts of mining and coal seam gas production in Australia, using three databases: Scopus, EMBASE and PubMed. We used a combination of title and abstract searches, keywords and MeSH terms to identify 29 and four studies on mining and gas production, respectively (Box 2). We then reviewed the systematic search findings in context with the scientific literature globally using a narrative review approach (the search strategy and selection process are provided in the [Supporting Information](#)). In the following sections, we address the health impacts of mining identified in the selected studies, discuss their findings with studies in other mining regions, and comment on the limitations, challenges and future directions for this research field (Box 3).

Epidemiological research on the human impacts of mining

Globally, epidemiological studies have assessed the health impacts associated with mining waste and emissions. Tailings from gold and silver mining are associated with high levels of heavy metals in soil and water near the mining activities, which can have a carcinogenic effect if ingested or inhaled. Multiple studies have estimated increased carcinogenic and

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1 Location of mine activities by type of mineral in Australia, 2023



Ag = silver; Al = aluminium; Au = gold; Cu = copper; K = potassium; Li = lithium; Mo = molybdenum; Ni = nickel; P = phosphorus; Pb = lead; REE = rare earth elements; Si = silicon; Ti = titanium; V = vanadium; Zn = zinc; Zr = zirconium. Source: Map designed with data from the Australian Operating mines 2023 dataset, Geoscience Australia.

non-carcinogenic risk in both children and adults^{40,41} and in women of reproductive age who live in communities in proximity to gold mining.⁴²

Mining of base, heavy and precious metals

In Australia, several studies have identified high concentration levels of cadmium, copper, iron, manganese, zinc, arsenic and lead in risk assessment analyses that evaluated bioavailability and risk reference dose models, or comparisons with international guidelines to estimate health risks.^{22,24,43} Consistently, analyses of human samples have identified high toenail arsenic concentrations in children in gold mining areas in Victoria, correlated with soil arsenic levels,^{23,25} supporting research on the potential pathways for systemic absorption of arsenic.⁴⁴ A

higher risk of all cancers and higher risk for melanoma, leukemia and prostate cancer in males and melanoma and colon cancer in females was associated with higher arsenic concentration in populations in proximity to gold mining areas in Victoria.²⁶

In contrast to gold, which is mined mostly in Western Australia (60%), silver is mined as a byproduct of copper, zinc and lead, with the majority of mining operations located in Queensland.⁴⁵ There are multiple studies assessing the health impacts associated with zinc–lead–silver mining in Australia, although most relate to lead-linked impacts and in a few locations where severe contamination has prompted a social and public health response. Broken Hill in New South Wales has the world's largest zinc–lead–silver ore deposit, with subsequent lead contamination affecting local communities.¹⁵ Research

2 Studies selected in the review by type of mining, health outcomes and methodological approach

Author (year)	State (city/town)	Type of mining	Agent	Health outcome or risk identified	Analysis
Abraham et al (2018) ¹²	Victoria	Legacy mines	Heavy metals	Concentration exceeded safe standard	Health risk assessment
Fazle Bari et al (2021) ¹⁴	NSW	Legacy mines	Arsenic	Higer bioaccessibility in contaminated soil	Health risk assessment
Dong et al (2019) ¹⁵	NSW (Broken Hill)	Lead, silver, zinc	Lead	Concentration exceeded safe standard	Health risk assessment
Gillings et al (2022) ¹⁶	NSW (Broken Hill)	Lead, silver, zinc	Lead	Concentration exceeded safe standard	Health risk assessment
Gulson (1996) ¹⁷	NSW (Broken Hill)	Lead, silver, zinc	Lead	Higher concentrations in incisal and cervical sections of deciduous teeth (compared with controls)	Health risk assessment
Gulson et al (1994) ¹⁸	NSW (Broken Hill)	Lead, silver, zinc	Lead	Elevated blood lead levels	Health risk assessment
Gulson et al (2004) ¹⁹	NSW (Broken Hill)	Lead, silver, zinc	Lead	Elevated blood lead levels	Health risk assessment
Mackay et al (2013) ²⁰	Queensland (Mt Isa)	Lead, silver, zinc	Lead	Concentration exceeded safe standard	Health risk assessment
Taylor et al (2014) ²	NSW (Broken Hill)	Lead, silver, zinc	Arsenic, cadmium, lead	Higher concentration in places accessible to children	Health risk assessment
Yang and Cattle (2015) ⁴	NSW (Broken Hill)	Lead, silver, zinc	Lead	Concentration exceeded safe standard	Health risk assessment
Hinwood et al (2004) ²¹	Victoria	Gold	Arsenic	Higher urinary inorganic concentrations	Health risk assessment
Martin et al (2018) ²²	Victoria	Gold	Arsenic	Rapid lung bioaccessibility of arsenic in contaminated dust	Health risk assessment
Martin et al (2013) ²³	Victoria	Gold		Positive association of toenail Arsenic concentrations with concentration in soil	Health risk assessment
Noble et al (2010) ²⁴	Victoria (Stawell)	Gold	Arsenic	Concentration exceeded safe standard	Health risk assessment
Pearce et al (2010) ²⁵	Victoria	Gold	Arsenic	Concentration exceeded safe standard	Health risk assessment
Pearce et al (2012) ²⁶	Victoria	Gold	Arsenic	Higher risk of all cancer and melanoma	Epidemiological study
McCarron (2018) ²⁷	Queensland (Darling Downs)	Unconventional gas		Increased acute circulatory admissions, compared with unconventional gas emissions in the same period	Epidemiological study
Werner et al (2017) ²⁸	Queensland	Unconventional gas		All-cause hospital admissions	Epidemiological study
Werner et al (2018) ²⁹	Queensland	Unconventional gas		All-cause and respiratory hospital admissions	Epidemiological study
Werner et al (2016) ³⁰	Queensland	Unconventional gas		Neoplasm and blood/immune diseases hospitalisations	Epidemiological study
Ali et al (2018) ³¹	NSW	Coal		Concentration exceeded safe standard	Health risk assessment
Cortes-Ramirez et al (2024) ³²	Queensland	Coal		Chronic circulatory and respiratory hospitalisations	Epidemiological study
Cortes-Ramirez et al (2022) ³³	Queensland	Coal		Chronic circulatory and respiratory hospitalisations	Epidemiological study
Merritt et al (2013) ³⁴	NSW (Hunter Region)	Coal		General practice consultations and prescriptions (no significant differences with rural areas were found)	Epidemiological study
Franklin et al (2011) ³⁵	WA (Wittenoom)	Asbestos		Respiratory and non-respiratory system cancers and reduced lung function	Epidemiological study
Reid et al (2007) ³⁶	WA (Wittenoom)	Asbestos		Higher rate of mesothelioma	Epidemiological study
Reid et al (2009) ³⁷	WA (Wittenoom)	Asbestos		Higher mortality rate due to mesothelioma	Epidemiological study
Reid et al (2013) ³⁸	WA (Wittenoom)	Asbestos		Increased “all cause” and “all cancer” mortality in females and males	Epidemiological study
Reid et al (2008) ³⁹	WA (Wittenoom)	Asbestos		Excess cancer mortality, including mesothelioma in females	Epidemiological study

NSW = New South Wales; WA = Western Australia. ♦

has identified high lead concentrations in children's teeth and serum,^{17,18} supporting previous analyses that estimated an increased risk posed by the high concentration of lead and

other metals including manganese, zinc, arsenic, lead^{2,16} and the implementation of a comprehensive plan for abatement of lead hazards in children's homes.

3 Key points on the health impacts of mining

- Mining byproducts are associated with health impacts in the general population in Australia and globally.
- Research in Australia consistently evidences multiple morbidity and mortality outcomes in the general population living in mining areas.
- Proximity to mining and exposure to toxic chemicals are associated with cancer and diseases of the respiratory, cardiovascular, immune and reproductive systems.
- Children and women in mining regions are especially vulnerable, with higher risk of perinatal conditions, and respiratory and blood and immune diseases.
- A multisectoral approach and stronger multilevel government coordination are required to address these public health impacts.

Although much debate on legacy sources (closed mines) being the dominant source of contamination hindered effective public health interventions in the early 1990s, recent research has found that contemporary mining activities are influencing the human exposure to lead within the Broken Hill general population.¹⁵ Studies of the human health impacts of lead in Australia are scarce. Nevertheless, epidemiological research has identified high concentration of lead in blood, urine and semen, which has been associated with impairment of semen quality and declining fertility in men,⁴⁶ and intellectual disability (lower IQ scores) and impaired immune function of T lymphocytes and erythrocytes in children in lead mining areas.^{3,5} The studies in Broken Hill are consistent with research in other zinc–lead–silver mining regions in Australia, including the identification of high blood lead concentration in children in North Lake Macquarie in New South Wales and Mount Isa in Queensland.^{19,47}

Coal mining

Despite Australia being the second largest coal exporter globally, with coal being mined for more than a century, the health impacts of coal mining on the general population have been barely investigated. Some studies have identified mental health and socially determined health conditions in communities in coal mining areas in Queensland, but these analyses did not use health data or bioindicators in a risk assessment context.^{48,49} Analyses in the Hunter Valley in New South Wales identified a higher rate of respiratory diseases compared with other non-coal mining areas, but these differences were not statistically significant.³⁴

More recent research has estimated an increased risk of hospitalisation due to circulatory and respiratory diseases in the Queensland general population using a Bayesian spatial and spatiotemporal framework to account for spatial dependency after adjusting for sociodemographic and environmental factors.^{32,33} These findings support previous studies that suggested that higher particulate matter concentrations in coal mining regions in Australia increase the risk of respiratory and circulatory diseases in communities in the vicinity of mining activities.⁵⁰ This is consistent with the results from multiple studies in the United States and Europe which estimate a higher morbidity and mortality risk in communities in coal mining regions compared with non-coal mining regions.¹

Asbestos

A number of epidemiological studies on the impacts of asbestos mining have identified increased morbidity and mortality in communities close to these activities; however, most of these studies were done in Wittenoom, Western Australia.³⁷⁻³⁹ The

higher exposure of these populations is associated with a higher risk of multiple respiratory and non-respiratory cancers, especially in women and children, with early asbestos exposure in childhood also being associated with subclinical restrictive lung function.^{35,36,39} Despite the above studies evidencing significant human health impacts, the health effects of exposures to other mining wastes and emissions have not been estimated using human or clinical data and need to be assessed indirectly, mostly from risk assessment analyses.

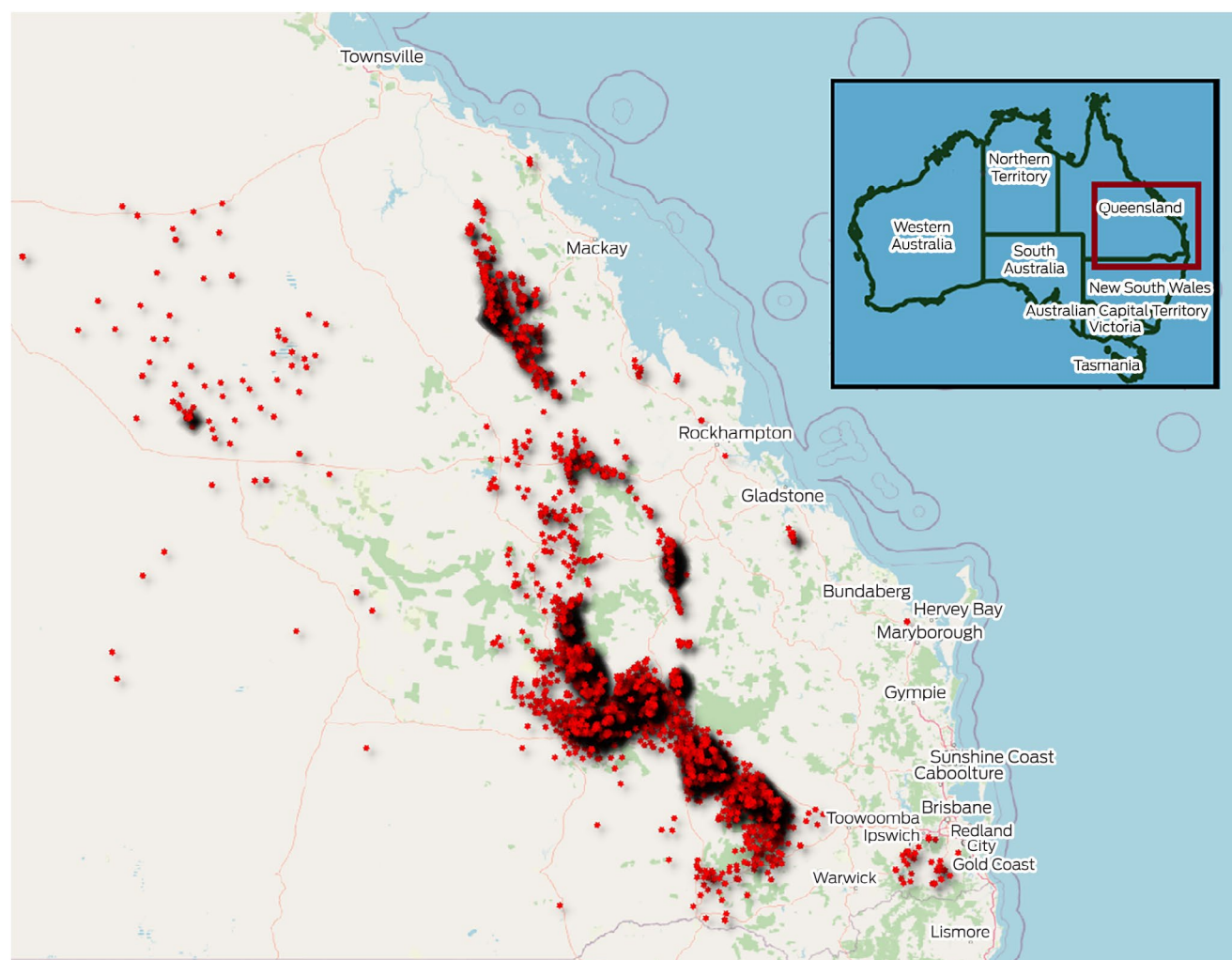
Evidence from non-human exposed studies

The assessment of the environmental properties associated with mining byproducts within close proximity to population centres, crops and potable water sources is an alternative way to assess the human health risks of mining activities. Risk assessment analyses of gold–copper mine tailings in central-western New South Wales have identified levels of aluminium, copper and iron above recommended agricultural guidelines that affected *Trifolium subterraneum* and *Phalaris aquatica* growth, suggesting a biotoxic effect.⁵¹ This is consistent with risk assessments of other abandoned gold mine sites in New South Wales, which measured high concentrations of fine arsenic particle size arsenic (<53 µm fraction).¹⁴ These particles have a high bioaccessibility and can be transferred easily through water and wind erosion, with concerns for potential inhalation and dermal contact via contaminated soils.²¹ Gold mining in other states is also associated with heavy metals pollution, such as contaminated soils in legacy gold mines in Maldon, Victoria, where arsenic and mercury concentrations exceeding safety environmental thresholds are considered a risk to the health of both humans and aquatic ecosystems.¹²

Lead exposure is prevalent in areas adjacent to local mining operations, especially in Broken Hill and Mount Isa, where soils have been chronically contaminated. Although the levels of lead in the air in Broken Hill appear to be declining, mine-related emissions remain a cause of concern, with air lead concentrations being about 200 times greater than in other lead mining areas in New South Wales.^{4,15,16} In Mount Isa, lead concentrations in soil, dust and aerosols from areas adjacent to the copper and lead mines and smelters are derived from the Mount Isa lead–zinc ore bodies — an accumulation of solid and continuous mass of ore adhered to rocks.²⁰ Multiple analyses of the lead isotopic composition indicate that atmospheric deposition of mine and smelter-derived dusts are determinants of environmental contamination and form a significant pathway for lead exposures to the Mount Isa population.^{20,52,53}

Analyses of coal mining areas, coal deposits and coal-fired power stations in New South Wales have identified significant metal deposition of multiple potentially toxic agents such as copper, cobalt, zinc, arsenic, selenium, lead and aluminium, along with spheroidal carbonaceous particles¹³ and air emissions including particulate matter, sulphur dioxide and nitrogen oxides.⁵⁰ Other risk assessment studies in the state have assessed the contamination of water from coal mining discharging into conservation environments. A study in the outer region of Sydney found sediment of arsenic, nickel and zinc in downstream coal mining discharge locations that exceeded the national guidelines.³¹ These analyses highlight the need to assess the management of coalmine run-off and to regularly monitor sensitive receptors, such as natural water bodies, in combination with stronger regulatory measures to ensure safe and sustainable environmental and public health outcomes.

4 Distribution of coal seam gas wells (unconventional gas) in the Queensland Maranoa-Balonne-Condamine subregion, 2024*



* Dark areas represent a high density of wells. Source: Map designed with data from the Queensland Spatial Catalogue — bore hole series, Department of Natural Resources and Mines, Manufacturing, and Regional and Rural Development (<https://qldspatial.information.qld.gov.au/catalogue/custom/search.page?q=borehole>).

Health impacts of unconventional gas extraction

Australia's unconventional gas industry is the newest and least mature mining sector, commencing with new technological developments, notably horizontal drilling and hydraulic fracturing in the 1990s. Gas production in Queensland has surged since exports commenced in 2015. Profitable application of these technologies requires a vast land and water footprint containing thousands of wells and ancillary infrastructure close to homes and schools in densely populated areas (Box 4).⁵⁴

The presence of this infrastructure has substantially increased emissions of nitrogen oxides, carbon monoxide, particulate matter, volatile organic compounds and formaldehyde in populated, high agricultural value areas of Darling Downs, Queensland, with a coincident increase in hospital admissions for severe circulatory, respiratory and cardiopulmonary conditions.²⁷ Air quality testing in surrounding residential areas reveals exposures to toxic chemicals, including known carcinogens such as lead and cadmium.⁵⁵ A community survey revealed higher than expected frequencies of symptoms known to be associated with these exposures, with 58% of surveyed residents indicating that their health had been negatively affected.⁵⁴ Frequently reported symptoms included paraesthesia,

headache, severe nose bleeding along with fatigue, weakness, attention deficit, eye and skin irritation, cough, rashes, joint pains, muscle pains and spasms, nausea and vomiting across all cohorts of the community, including children.⁵⁴ Further studies found a higher risk of respiratory diseases in areas with unconventional gas operations compared with other rural areas with agricultural activities or other forms of mining.²⁹ Beyond this evidence of acute effects, there are concerns about the long term public health impacts of chronic exposures that are currently not monitored.²⁷ This is particularly relevant considering these analyses found up to a 467% increase in blood and immune diseases in children living in unconventional gas areas compared with rural areas.²⁹

Despite the undisclosed large volume of chemical mixtures deployed in hydraulic fracturing affecting water aquifers and the air pollution associated with these activities, very few epidemiological studies have investigated the health impacts in exposed Australian communities.⁵⁶ In contrast, there is an extensive body of research mostly in the United States, that establishes that people living in proximity to unconventional gas operations are at higher risk of multiple health consequences, including respiratory and circulatory diseases, mental health conditions, negative birth outcomes and congenital anomalies.⁵⁷

These include higher frequencies of asthma exacerbations and hospitalisations in children in unconventional gas production areas in Pennsylvania and Texas⁵⁸⁻⁶⁰ and increased deaths and reduced life expectancy from cardiovascular, respiratory diseases and some cancers in Oklahoma and other states.^{61,62}

Other studies also found higher hospitalisation rates for heart disease, respiratory and neurological disorders, and childhood cancers and immune deficiency disorders.^{27,28,58,63} Some of the most significant health risks are associated with pre-birth exposure, which have a transgenerational impact. These risks include low birth weight and small for gestational age,⁶⁴⁻⁶⁹ pre-term delivery and spontaneous abortion,^{65,70-75} birth defects, such as congenital heart valve defects, anencephaly, spina bifida and gastroschisis,^{64,76-80} and blood cancers, especially acute lymphoblastic leukaemia.^{81,82} This evidence provides a strong ground to consider that similar trends may be emerging in Australia, as populations increase their exposure to chemicals linked to oil and gas operations.

The list of impacts includes other health issues with profound effects and high public health costs, especially mental health conditions, more frequent traffic and pedestrian injuries and fatalities in unconventional gas production regions, increased incidence of sexually transmitted infections, and elevated risk of domestic and sexual violence associated with an influx of mobile workers into socially vulnerable areas.⁵⁷ It is concerning that there are no peer-reviewed human health impact assessments, accessible environmental baseline assessments or real-time monitoring of environmental exposures, with no requirements for the industry to rectify these data gaps.^{83,84} As data for further analysis are inaccessible and the risks and severity of impacts remain incompletely defined, a comprehensive and effective application of the precautionary principle should be put in place until there is knowledge that these operations can be safely implemented in areas with potentially exposed populations.⁸⁵

Future directions and conclusions

The findings of epidemiological and risk assessment studies in Australia coincide with global research in that mining is associated with a higher risk of morbidity and mortality in the general population in the vicinity of these industrial activities. The analyses of human tissues and samples indicate that neoplastic and non-neoplastic diseases in exposed populations are mediated by a higher concentration of toxic mining byproducts such as cadmium, arsenic, mercury, lead and particulate matter among others.

We have highlighted some specific health conditions, but mining is also a determinant of social and economic issues that can have complex and deeper links with health impacts in communities in proximity to mining activities. Analyses of social and economic stress in mining communities have identified demographic imbalances, reflected in increasing antisocial behaviour, erosion of social capital, insecurity and crime, which are all associated with a higher risk of physical, mental and social health conditions.^{48,49} Aboriginal people are often at high risk of those conditions as well as deep cultural and spiritual losses from damage to their country land.⁵⁷ The contrasting benefits derived from mining, mostly economic, versus its public health and other impacts support the concept of the so-called "resource curse" (a paradox where a resource-rich country underperforms economically), which should be extended to incorporate differences in health and social detrimental effects.⁸⁶ This has

been demonstrated in Australia, where long term analyses identify that resource booms tend to exacerbate inequality,⁸⁷ and should be more relevant when considering the potential severe effects on vulnerable populations, especially children, and on reproductive health.⁸⁸

A striking issue when assessing which health conditions are associated with mining in Australia is the scarcity of research studies, especially the analysis of human exposures using high quality health data. Although Australia is in a selected group of top research countries globally, the number and scope of studies in this area are limited to mostly non-experimental associational analyses in a few mining regions, restricting timely and effective decision making to address these problems. This scarcity of research might relate to diverse factors, including deficiencies in public health and environmental legal frameworks, inefficient coordination between local and state government,⁴⁷ outdated standards and exposure regulations,⁸⁹ excess of political conflicting interest and incongruent environmental protection in the context of climate change,⁹⁰ and the mining industry's role in pro-industry lobbying.⁹¹ The academic sector, on the other hand, might tend to prioritise research in fields with higher returns in global rankings rather than environmental health problems.⁹² Another missing aspect is the association of mining with morbidity and/or mortality in Aboriginal and Torres Strait Islander people, which have not been investigated in epidemiological research except for social impact assessment analyses and government and academic reports. All mining in Australia is carried out on the Traditional Lands and Seas of Aboriginal peoples; often without their free, prior and informed consent. There is a small but growing grey literature that describes the severe social, emotional and spiritual impacts of mining on the Traditional Custodians of the impacted lands, who are often also the most affected by physical harms due to proximity and underlying conditions.⁵⁷ Traditional Custodians feel a profound depth of social, emotional, cultural and spiritual loss as they witness the integrity of their Lands and Sea country broken and lose access and ability to fulfill their custodial responsibility to care for important sacred sites. They also suffer greatly when they lose their right to hand down the knowledge and stories about their Lands to their children, which threatens the survival of their cultural ways; however, these issues are rarely incorporated in epidemiological analyses of the health impacts of mining.^{33,48} All these factors severely affect the capacity of Australia to address the detrimental effects of mining in fair alignment with its economic benefits.

To overcome the multidimensionality of these limitations, it is critical to involve the mining industry, the community, the academic sector and the different levels of government. Analyses of the legal and economic challenges of fossil-fuel resource developments in Australia have identified the need for an interdisciplinary approach, combining foreign investment, human rights, environmental law and land access regimes to balance the direct economic benefits with environmental and public health concerns.^{93,94} The coordinated participation of local and state governments is identified as a key factor to set governance arrangements to ensure the commitment of mining companies and other stakeholders to address mining-specific impacts.⁹⁵ These initiatives should be supported by strengthening current regulations, such as adherence to the health impacts assessment in all policies approach,⁹⁶ and incorporation of epidemiological studies in well regulated processes, including environmental impact assessment.⁹⁷

The academic and health sectors need to fill the knowledge gap of the health consequences of mining operations in the population in mining communities across the country. Although epidemiological research of diseases associated with environmentally widespread exposures such as soil and water contamination and air emissions are challenging, recent methodological approaches have been used to address research limitations and identify specific conditions associated with mining, such as cardiovascular and respiratory diseases in coal and unconventional gas mining areas in Queensland.^{29,30,32,33} Robust methodologies such as these spatial epidemiological analyses, Bayesian modelling to assess human health risks from multiple exposure pathways⁹⁸ and target trial emulation⁹⁹ can be used to develop a progressive understanding of the causal links between mining and morbidity and mortality in exposed populations. Further, both the public health and university sectors need to take responsibility for exercising and reinforcing the critical relevance of the precautionary principle and its use, given the high level of scientific uncertainty about the health

risks of industrial activities such as mining and unconventional gas production.

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Supporting Information

Additional Supporting Information is included with the online version of this article.