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Environmental health challenges in remote Aboriginal Australian communities: clean air, clean water and safe housing

Clifford H[1*], Pearson G[2], Franklin P[1,2], Walker R[1] and Zosky G[3]

[1]Telethon Kids Institute, University of Western Australia, Perth, Western Australia
[2]School of Paediatrics and Child Health, University of Western Australia, Perth, Western Australia
[3]School of Medicine, University of Tasmania, Hobart, Tasmania
*Corresponding author: Dr Holly D. Clifford, Telethon Kids Institute, 100 Roberts Road Subiaco, Western Australia 6008, ph: 61 8 9489 7787, fax: 61 8 9489 7700, email: holly.clifford@telethonkids.org.au

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Abstract

Objective: A considerable health disparity exists between Aboriginal and non-Aboriginal Australians, including a higher incidence and severity of cardiovascular and respiratory diseases. The burden of these diseases appears to be greatest in communities located in the remote regions of Australia. Unique environmental challenges in these regions may be a contributing factor; however these are yet to be adequately investigated. We aimed to develop a case to improve our understanding of environmental risk factors in remote Aboriginal communities.

Methods: We comprehensively reviewed the literature regarding physical environmental challenges that are likely to be highly prevalent in remote Aboriginal communities, and have been linked with adverse health. We focused on exposure to inhaled geogenic (earth-derived) dust and biomass smoke, bacterial and heavy metal contamination of drinking water and overcrowding.

Results: These environmental factors are anecdotally high in remote Aboriginal communities and have been linked, mostly epidemiologically, to cardiovascular, respiratory and other infectious diseases. These challenges are an under-recognised problem and are likely to have a significant impact on Aboriginal community health; increased research focus in this area would be of great benefit.

Implications: It is crucial to identify and quantify these physical environmental factors, and to determine the mechanisms through which they impact on health, particularly as these factors are modifiable and may be suppressed using relatively simple, cost-effective changes in community infrastructure. Protection against these exposures is likely to reduce their cumulative negative effects on individuals across the life course and result in significantly improved health in remote Aboriginal Australian communities.

Contents

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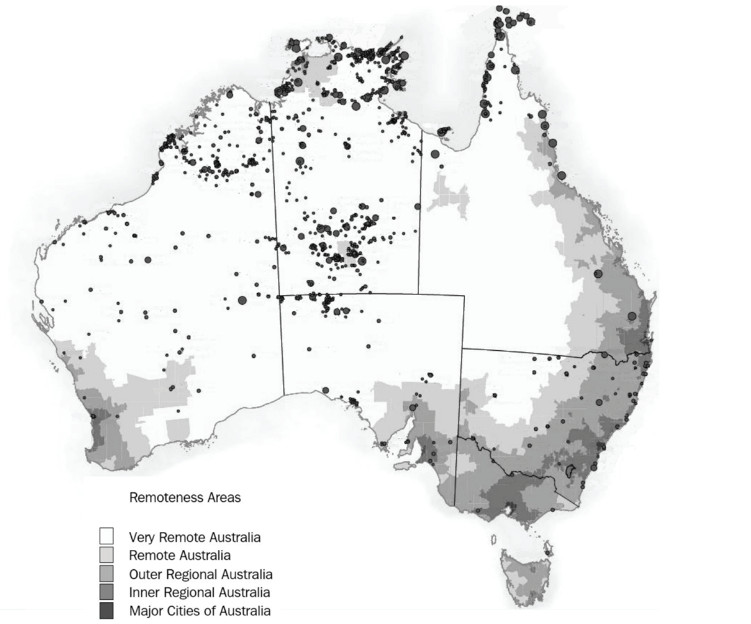
Aboriginal and Torres Strait Islander Australians have a significant health disadvantage compared with other Australians, with a higher incidence and severity of many diseases including cardiovascular disease, respiratory diseases, renal disease and diabetes [1]. Mortality rates for Aboriginal Australians are almost twice as high as for non-Aboriginal individuals [2], and life expectancy is estimated to be up to 11.5 years less [3]. Furthermore, mortality rates of Aboriginal Australians are higher than those of other Indigenous populations elsewhere in the world [4]. There is an increasing impetus to identify the determining factors of this health disparity, with an overall aim of 'closing the gap' [5] and improving the health of Aboriginal Australians.

Previous studies have concentrated on the risk factors associated with poor health outcomes identified in developing countries, such as malnutrition, low birth weight, and tobacco smoke exposure [6]. There has been a particular focus on 'choice-based' lifestyle factors such as smoking and alcohol consumption, which are major causes of various health conditions including lung, cardiovascular and liver diseases [7,8]. Smoking and alcohol use in Aboriginal communities have a complex social aetiology associated with pervasive effects of colonisation on Aboriginal social, cultural and spiritual wellbeing, and represent a significant and ongoing challenge in Aboriginal health.

Outside of smoking and alcohol, many other factors may also account for the disease disparities with non-Aboriginal groups. There are many physical environmental factors that Aboriginal individuals may be uniquely exposed to which may have a significant impact on health. These include; geogenic (earth-derived) dust exposure, biomass smoke exposure, bacterial or heavy metal contamination of drinking water, and overcrowding. These are a selection of the environmental factors likely to be involved, with the scope of this review unable to exhaustively cover all contributing factors; other factors not discussed include house function and sewage and waste management, amongst others. The exposures reviewed herein are particularly relevant to remote Aboriginal communities where service delivery and infrastructure remain well below what is provided in urban and less remote centres, and are inadequate to support essential quality of life elements such as clean air, clean water and safe housing. Little consideration has been given to fully understanding the role some of these factors play in disease aetiology and severity in remote Aboriginal communities.

The Aboriginal population is more widely dispersed across Australia than the broader population [9], with discrete Aboriginal communities amply distributed across the remote areas of the country (Figure 1) [10]. Discrete Aboriginal communities range in size from less than 50 residents to greater than 1000 residents [11]. Approximately one quarter of Aboriginal people live in remote or very remote areas, compared with only 2% of the non-Aboriginal population [12]. Many of the health issues linked to alcohol and smoking in Aboriginal populations occur across urban, rural and remote areas. However, individuals in remote communities are likely to have additional challenges based on the unique geology, weather and environmental exposures found in the isolated areas of Australia.

Figure 1. Discrete Indigenous communities are widely dispersed across the remote and very remote regions of Australia



Note: Circles indicate relative size of community and shading from dark to light represents increasing remoteness
Source: Adapted from ABS 2006 [10]

Remoteness *per se* has been associated with adverse health outcomes within Aboriginal communities. The leading cause of Aboriginal mortality, cardiovascular disease, is more prevalent in Aboriginal communities in remote areas compared with urban areas [13]. Furthermore, children living in remote areas have higher hospitalisation rates for respiratory diseases, up to 3 times higher than those residing in metropolitan areas, even though they have less access to health services [14]. The reasons for these observations are not known but one potential explanation is the impact of the physical environment.

Unique physical environmental exposures in remote Aboriginal Australian communities have not been comprehensively quantified, and the mechanisms through which they cause adverse health effects have not been fully elucidated. As such, there are many unanswered questions in this field. It is not known whether physical environmental factors, and the levels of exposure, are unique to the remote regions of the country. Additionally, what is it about the physical environment that may be causing Aboriginal Australians to have such a high disease burden? This review will discuss a range of physical environmental factors which have been linked with poor health (Table 1), and are likely to be highly prevalent, and display unique characteristics, in remote Aboriginal

Australian communities. This review draws on published studies and government reports to present what is known and also highlight what is not. The purpose of the review is to develop a case to improve our understanding of environmental risk factors that are often easily modifiable through simple investments in infrastructure.

Table 1. Associations between physical environmental challenges, health and disease

Physical environmental factor	Associations with health and disease			
	Inflammatory and disease biomarkers	Disease	Severity/Exacerbations	Mortality
Particulate air pollution	Increase in leukocytes in diabetics [15] Inflammatory mediators such as E-selectin [16] Pro-inflammatory cytokines such as IL-6 [17, 18] Cardiac biomarkers such as CRP and fibrinogen [17, 19-21] Inflammatory cell trafficking, oxidative stress and neuroinflammation [22]	Asthma and respiratory infections [6, 23-26] COPD and pulmonary fibrosis [27] Lung cancer [28] Cardiovascular diseases [29] Brain abnormalities and cognitive deficits [30]	Decreased lung function in cystic fibrosis patients [31] Asthma hospitalisations [32, 33] Cardiac arrest [34] Cardiovascular hospitalisations [35, 36] Stroke [37]	All cause [35, 38-43] Respiratory [40, 44] Cardiovascular [40, 42, 43, 45-47] Acute stroke [37, 48]
Mineral dusts	In vitro IL-6 and IL-8 cytokines [49]	Asbestosis and silicosis [50] Asthma [51] Parkinson's-like neurodegeneration [52]	Asthma exacerbations [33, 53] Cardiovascular hospital admissions [54]	All cause [55] Respiratory [56-58] Lung cancer [57] Cardiovascular [57-59]
Biomass smoke	Pro-inflammatory mediators in vitro [60] Inflammatory cells [61-63] Cytokines such as IL-6, IL-8 [62]	Asthma [64, 65] COPD [66] Chronic bronchitis [67] Lung cancer [68] Congestive heart failure [65]	Respiratory hospital admissions [69-71] Asthma [71, 72] Acute lower respiratory tract infections [73-76] Ischaemic heart disease [77] Anaemia [73] Low birth weight [78-80]	All cause [55, 81, 82] Cardiovascular [55, 81, 82] Respiratory [81, 82] Infant mortality [78, 80]
Contamination of drinking water (bacteria or heavy metals)	Cytokines such as TNF-α [83] Cardiovascular markers such as VCAM-1 [84]	Diarrhoea and bacterial infection sequelae such as myocarditis and diabetes [85] Lower respiratory tract infections and diarrhoea [86] Bronchiectasis and obstructive lung diseases [87, 88] Cardiovascular diseases [89-91]	Impaired lung function [92-94] Anaemia [95] Cognitive decline [96]	All cause [97] Infectious diseases [97] Cancer [97, 98] Cardiovascular [98-101] Cerebrovascular disease, diabetes and kidney diseases [102]
Overcrowding		Acute lower respiratory illness [103] Bacterial carriage [104] Pneumonia [105, 106] Acute rheumatic fever [107] Meningococcal disease [108] Skin infections [109]	Acute hospitalisation rates [110]	Childhood mortality [111, 112]

Note: CRP, C-reactive protein; COPD, chronic obstructive pulmonary disease; TNF, tumour necrosis factor; VCAM-1, vascular cell adhesion molecule 1.

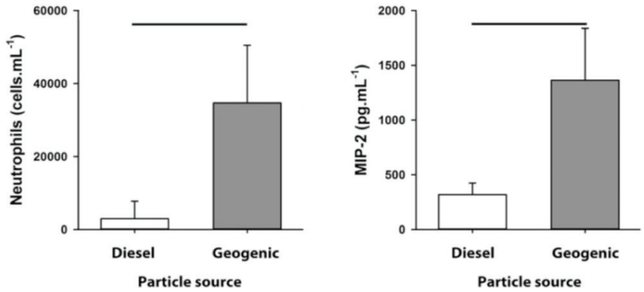
Particulate air pollution

Ambient particulate air pollution in both cities and rural areas contributes to approximately 3.7 million premature deaths annually worldwide [113]. Particulate matter (PM) has been extensively linked epidemiologically to adverse health outcomes (Table 1). PM with a diameter of <10μm (PM_{10}) is known as the inhalable fraction as it is small enough to reach, and hence damage, the lower respiratory tract [114]. Fine particles ($PM_{2.5}$) can reach as far as the terminal alveoli [29] and ultrafine particles ($PM_{0.1}$) can travel from the lung epithelium directly into the systemic circulation [115]. PM exposures have been associated with a wide range of respiratory diseases such as asthma and respiratory infections [6, 23-26], chronic obstructive pulmonary disease (COPD) and pulmonary fibrosis [27], and lung cancer [28] (Table 1). These exposures have also been linked with many cardiovascular diseases including hypertension and myocardial infarction [29], as well as disruption of the blood-brain barrier and brain abnormalities/damage [22, 30, 116]. Hospital admissions and mortality due to respiratory and cardiovascular exacerbations have also been extensively linked with PM [32, 33, 35, 36-40, 42, 43, 45-48] (Table 1). PM specifically from mineral dusts has also been associated with adverse health outcomes such as silicosis and fibrosis [50, 51, 56]. Recently, dust storms have been associated with increased hospital admissions due to COPD [54]. Dust inhalation may prime inflammatory cells in the lung to increase their capacity to release toxic oxygen radicals [117, 118] and initiate an inflammatory response [119-121] and this can lead to lung tissue damage [122] and, following travel into the systemic circulation, may also impact on cardiovascular outcomes [29]. Socio-economic disadvantage, existing chronic cardiovascular and respiratory disease, and diabetes have all been shown to modify the effect of particulate air pollution on health outcomes [123]. Aboriginal Australians have a high prevalence of these health risks and have been recognised as more likely to be at greater risk from poor air quality than other Australians [124].

Remote Aboriginal Australian communities are likely to be exposed to high levels of PM_{10}. The national ambient air quality standard for PM_{10} in Australia is 50μg/m^3 averaged over a 24-hour period, with ≤5 exceedances recommended within a year [125]. These standards are based mostly on international studies of urban particulates. However, in remote communities in arid regions of Australia, these air quality targets are regularly surpassed. For example, PM_{10} levels exceeded 50μg/m^3 12 and 18 times in 2000 in Boodarie and Dampier, respectively [126]. Rather than the air pollution of major cities, which contains a large proportion of PM from vehicle emissions and carbonaceous sources, remote arid regions experience unique challenges. The physico-chemical features of PM10 from geogenic sources differ greatly depending on geographic location [127, 128] and airborne geogenic dusts are highly prevalent in remote areas due to their unique geology, dry climate, exposure to wind erosion and proximity to open cut mining activities [129].

Urban particles have been shown to exacerbate the response to respiratory viral infection [130, 131], however the response to urban particles may be surpassed by the response to geogenic dust particles from remote areas. Geogenic PM_{10} sampled from remote Western Australian towns induced a greater inflammatory response compared with the same dose of diesel exhaust particulates (a major constituent of urban particles) [132] (Figure 2). How this affects the lung during respiratory infection or chronic lung disease is yet to be determined. The unique physico-chemical characteristics of geogenic PM_{10} may contribute to the observed differences with urban particles.

Figure 2. Geogenic particles from remote Western Australia induce a greater inflammatory response than urban diesel particles.



Note: Intranasal exposure to 30μg of geogenic particles from remote towns in Western Australia induced a greater influx of neutrophils and greater production of pro-inflammatory cytokine MIP-2 compared to the same dose of diesel exhaust particles in mice. Lines indicate p< 0.01.

Most studies on dust exposure have been in the occupational health setting, where a known, homogenous exposure (usually silica) is investigated in a selected population [133, 134], however these give a poor estimate of the impact of exposure on disease in the general population [135]. Based on animal data, chronic low level exposure to particles containing biologically active metals may be sufficient to impact on respiratory health at a community level. The properties of PM_{10} can determine the magnitude, duration and characteristics of the inflammatory response in the lung [127, 128, 136, 137]. Toxicological studies have shown that metals influence the toxicity of inhaled particles; metals such as lead and nickel can exert negative health effects from inhalation [128]. The nickel and vanadium content of $PM_{2.5}$ was attributed to more than one-third of cardiovascular hospital admissions in the U.S. [47].

Iron content in geogenic PM_{10} may be particularly important. Carriage rates of several bacterial respiratory pathogens, including S. pneumoniae and H. influenzae, in the upper airway are particularly high in Aboriginal children [138]. Many bacterial species rely on iron acquisition during infection for their survival and virulence [139, 140]. Thus, iron-laden dust particle exposure, which is expected to be high in remote, arid regions, may be perpetuating chronic bacterial infections in Aboriginal children. This is supported by the fact that the rates of bacterial pneumonia in Aboriginal children were twice as high in the central arid regions of the Northern Territory compared to the northern tropical regions [141]. Additionally, a study comparing the lung health of residents in two remote W.A. Aboriginal communities found that residents from the arid community, compared with the tropical community, experienced more frequent respiratory symptoms and had poorer lung function – despite the lower smoking rates in the arid community [142]. The authors speculated that "environmental factors" may be playing a role in respiratory health in remote Aboriginal communities [142]. Furthermore, studies examining 'red dust' (iron ore) in Port Hedland, W.A. [129] and Whyalla, S.A. [143] showed that those exposed to higher levels had higher respiratory hospitalisation rates; specifically, districts living closest to iron ore stockpiles had higher rates of hospitalisation for acute respiratory illness than both the local and state average [129] and children <15 years old in the high dust exposure area were significantly more likely to be admitted to hospital for respiratory infections [143]. It was also recently shown that geogenic dust PM_{10} from remote W.A. towns caused a significant inflammatory response in the lung as well as lung function deficits in vivo in mice [127,144], and iron content in the particles was postulated to be a main driver of the effects seen [144]. How this translates to deficits in lung function and lung disease in human populations, and specifically in Aboriginal communities, is not yet known. The relative proportions of elements such as iron in dust in remote Aboriginal communities have not yet been specifically characterised, nor have the consequences of the inhalation of these metals.

Ongoing dust issues in remote Aboriginal communities are propagated by a lack of adequate infrastructure and dust suppression measures. Despite town planning documents for Aboriginal communities [145-147] that clearly identify dust exposure as an issue and recommend the sealing of roads to aid with dust suppression, the reality is that many remote Aboriginal communities in Australia still do not have the infrastructure in place to act as an appropriate barrier against this environmental exposure. In 2008, two in five remote W.A. Aboriginal communities reported that they usually experience excessive (12%) or high levels (32%) of dust [148]. Furthermore, many communities (63%) had no dust suppression or re-vegetation programs and more than three quarters had unsealed roads [148].

Research needs

Although plausible mechanisms for the impact of geogenic dusts have been established, the specific impact on health in remote Aboriginal communities is still to be determined. Exposure to geogenic dust may be easily modified through provision of well-known dust suppression measures, such as the sealing of roads or increased vegetation. However, a comprehensive evidence base that demonstrates the need for such interventions is required. It is important to have a greater understanding of the environmental risks in Aboriginal communities so that risk assessment can be conducted and the burden of disease associated with these risks better characterised. This necessitates the gathering of quantitative dust monitoring data from remote Aboriginal communities as well as mechanistic data from animal models and human studies. Dust suppression strategies in remote Aboriginal communities may then become more of a priority.

Biomass smoke exposure

Biomass fuel – biological sources of fuel such as wood – are used as the main source of energy in more than half of the global population, and up to 90% of rural households [149]. The burning of biomass fuel and the consequent production of biomass smoke, such as wood smoke from domestic heating and cooking, or bushfire-generated wood smoke, produces a number of chemical compounds, of which >90% are in the inhalable size range [150]. Aboriginal Australian cooking methods originate in and around outdoor fires. Indoor biomass burning may be considered the major problem internationally [151], however, depending on proximity, exposure to outdoor biomass from cooking may still pose a risk to health, particularly when exposed chronically all through life.

Bushfires (or biomass fires) occur fairly regularly in Australia. The particularly arid climate and landscape of remote Aboriginal communities likely potentiates more frequent and severe bushfires. During the above average temperatures and exceptionally dry conditions associated with drought, the greatest areas that are burnt include Australia's rangelands and northern savannas, where extensive bushfires particularly affect pastoralists and Aboriginal communities [152]. Additionally, Aboriginal Australians are involved in traditional burning practices for a number of reasons, including hunting and communication [153].

The pollutant most consistently elevated due to bushfire smoke is PM and during bushfire episodes PM concentrations several times above background urban concentrations can occur, with air quality standards commonly exceeded [154]. Bushfire smoke was found to have a major impact on air quality in regional N.S.W., where during bushfires, the air quality of impacted rural towns was almost twice that of the worst pollution levels in Sydney [155]. During a month-long prescribed burning season in Ovens, Victoria, smoke impacted the town for 12 days, of which 7 exceeded the $PM_{2.5}$ air quality standard [155]. Furthermore, wildfires in this town caused the standard to be exceeded 13 times over 31 days [155].

Wood fire-derived PM is associated with a number of toxic co-pollutants including metals, organic and inorganic compounds [156]. In vitro studies have demonstrated that cellular responses depend on the chemical characteristics of the particles [157, 158]. Reports of the health impacts of wood smoke exposure range from irritation of the respiratory tract, through decreased lung function, to causal links with COPD, asthma and lung cancer, hospital visits and exacerbations, and finally, respiratory and cardiovascular related mortality [68, 151, 156, 159-163] (Table 1). Bushfire-specific

PM_{10} has been associated with respiratory hospitalisations, particularly for COPD and asthma [71]. An increase of 10µg/m^3 of PM_{10} was associated with a 5% increase in respiratory hospital admissions, with effect sizes being larger for Aboriginal people [77, 164]. The effects of PM_{10} from bushfires on respiratory and cardiovascular diseases are greater for Aboriginal compared with non-Aboriginal Australians [77].

Research needs

Bushfires are expected to increase in the future as a result of climate change [165]. The practice of deliberate landscape burning to avert major disasters has also increased but this has become increasingly controversial as the adverse health effects of PM air pollution become more widely known [152]. More research is required regarding the contribution of wood fires and bushfires to air quality in remote Aboriginal communities, as well as more information on the specific health impacts of these biomass particles. Although bushfires would be difficult to control in remote areas, awareness of the health impacts of biomass smoke PM may precipitate the implementation of effective strategies to reduce personal exposure.

Contamination of drinking water

The WHO estimates that about 1.1 billion people around the world are drinking unsafe water [166]. Furthermore, the majority (88%) of diarrhoeal disease in the world is attributable to unsafe water, sanitation and hygiene, as is approximately 3.1% (1.7 million) of all deaths annually [167]. Diarrhoea and related gastrointestinal (GI) illnesses continue to be one of the most important causes of morbidity and mortality, especially amongst young children [168]. A portion of this illness is due to exposure to contaminated water, as a result, for example, of poor water quality, limited access to water or hygiene practices. Examples of major pathogens that are found in contaminated water include Salmonella, Shigella, Campylobacter, E. coli and rotavirus.

Access to good quality drinking water that has acceptable levels of bacteria and heavy metals is an ongoing concern in remote Aboriginal communities. However, as with other environmental exposures discussed in this review, the health impacts of poor quality water in Aboriginal communities has not been fully addressed. Insufficient access to clean drinking water and functioning sewerage systems contributes to skin, eye and diarrhoeal diseases in Aboriginal communities [109, 169]. Gastroenteritis is second only to respiratory infections as the leading cause of hospitalisation for infection in children younger than 2 years, with rates up to 11 times higher in Aboriginal compared with non-Aboriginal children [170-173]. GI hospitalisation rates also vary between geographical locations, higher in remote versus non-remote regions [171-173]. Among Aboriginal children less than 5 years of age in W.A., the highest hospitalisation rates were found in the remote Kimberley and Pilbara-Gascoyne regions, where rates were 3.5 times higher than for Aboriginal children living in metropolitan areas [173].

Although jurisdictional differences do occur and some states have achieved compliance with Australian drinking water guidelines through regular testing and maintenance, for example in the N.T. [174], many areas in Australia still face issues with water quality and system management. In 2006, 978 discrete Aboriginal communities nationwide were not connected to the main town water supply. Of these communities, 17% had their drinking water sent away for testing, and 30% of these failed [11]. A further case in point is W.A., where almost half (49%) of the remote Aboriginal communities have untreated drinking water and 52% are without regular monthly testing of water quality [148].

Heavy metals are one of the most persistent water pollutants [175]. Degradation is difficult and therefore contamination accumulates in the environment. Metals are known to have adverse health impacts, even at low doses. A number of Australian towns have experienced water contamination issues. Shipping of lead (Pb) through Esperance Port in W.A. resulted in contamination and increased blood Pb concentrations in children [176, 177], and testing of rainwater tanks found concentrations of Pb and nickel (Ni) [175] exceeding the Australian drinking water guidelines [178, 179]. Lead is neurotoxic, and no threshold has been identified at which Pb exposure is safe to the developing nervous system [180]. Additionally, Ni has been associated with skin irritation and respiratory diseases such as asthma [181]. There have also been reports of heavy metal contamination of water in Tasmania, where one-third of Tasmania's town water systems exceed the Australian drinking water guidelines for Pb, cadmium and arsenic [182]. The local drinking water source of the town of Royal George, an ex-tin mining town, was found to have arsenic levels 200 times the allowed standard [182]. High levels of arsenic exposure from drinking water have been related to elevated risks of, and mortality due to, cardiovascular diseases [100, 101], diabetes and kidney disease [102] (Table 1). In utero exposure to arsenic via the mother's exposure to contaminated drinking water can impair somatic growth, lung development and lung mechanics [94] and it has therefore been linked to the higher incidence of bronchiectasis and obstructive lung diseases [87, 88].

Concerns have been raised regarding the contamination of groundwater with heavy metals in remote Aboriginal communities, particularly in communities where water is self-supplied and ongoing monitoring of the chemical content of the water is not conducted (more often the smaller communities) [183]. These concerns are also warranted because of the close proximity of many Aboriginal communities to mining activities. The Ranger mine in the N.T., for example, is leaking 100,000L of uranium-contaminated water into the groundwater beneath Kakadu every day [184]. Uranium is mined adjacent to traditional Aboriginal lands and ionising radiation from mining waste accumulates in Australian wildlife, some of which are traditional Aboriginal foods, such as mussels, turtles and fish [185]. There is an urgent requirement for ongoing monitoring of community drinking water sources and the provision of protection and prevention measures for Aboriginal communities living adjacent to mining operations.

Research needs

The degree of water contamination in remote Aboriginal communities must be quantified so as to reiterate the need for the regular screening and treatment of water sources in the remote regions of Australia. The treatment of water sources in remote communities is focussed on microbial contamination and primarily consists of UV and chlorine treatment. However, these are often not effective due to poor maintenance, and bacteria have often been detected in the water supply [145, 146]. Additionally, there is currently no mechanism for heavy metal remediation, even in those communities identified as being at risk due to mining activities [145]. This issue is further complicated by the substantial changes in runoff and underground water flow associated with the seasonal weather extremes experienced in northern Australia. Research on the specific effects of particular metals in contaminated water is also required, to determine the safe limits in order to set appropriate standards.

Overcrowding

A challenge that is highly prevalent in remote Aboriginal communities is based around housing and overcrowded living conditions. Overcrowding and its health implications can arise from the restricted availability of housing, inappropriate housing and community design, and poor housing conditions [186]. Overcrowding is one part of a greater issue of the provision of safe housing in remote Aboriginal communities. Overcrowding, according to the Australian Bureau of Statistics, takes into account household size and composition and is calculated based on the Canadian National Occupancy Standard [187]. When assessing bedroom requirements, households requiring at least one additional bedroom are considered to be overcrowded [187].

The average Aboriginal household is larger than a non-Aboriginal household [4]. Overcrowding is prevalent in Aboriginal Australians, with 26,000 (13%) Aboriginal households and 81,500 (25%) Aboriginal Australian adults living in overcrowded conditions [187]. In 2012-2013, 23% of Aboriginal Australians of all ages were living in overcrowded conditions [11]. Compared with their non-Aboriginal peers, Aboriginal adults were six times more likely to live in houses that required additional bedrooms [187]. This overcrowding is based on a family living in a house too small for their needs, or the cultural norm in which the household includes large numbers of extended family members, some of whom may have special needs (i.e. poor health from chronic conditions, recurrent infections). Furthermore, rates of overcrowding increases with remoteness, with only 17% of Aboriginal people of all ages in major cities experiencing overcrowding, while over half (53%) of Aboriginal people living in very remote areas are affected by overcrowded living conditions [11].

Overcrowding causes extra challenges in caring for children, as well as maintaining good personal and household hygiene [188]. Crowded living conditions and the consequent failure of health hardware due to increased use can lead to poor hygiene and may facilitate the spread of infectious diseases and the exacerbation of chronic conditions. A strong association between overcrowding and health exists even when factors including education, income, ethnicity, poverty and unemployment are taken into account [189]. Overcrowding puts increased stress on health infrastructure, such as water supply and sewage disposal systems, and is closely linked to housing standards and conditions. Overcrowding and poor housing quality has been linked with increased levels of life stressors, harmful alcohol consumption and social problems [190].

Health issues related to inadequate housing and infrastructure in remote regions of Australia include the spread of infectious diseases such as skin infections, respiratory infections, eye and ear infections, diarrhoeal diseases and rheumatic fever [103, 105, 106, 109, 191-193] (Table 1). These diseases are directly related to factors such as overcrowding, and Aboriginal children bear the greatest impact of these diseases [194]. In Aboriginal children, bacterial colonisation of the respiratory tract occurs soon after birth and their bacterial carriage rates are higher than those of non-Aboriginal children [195]. Overcrowding increases this risk of bacterial carriage, with the risk of carriage of S. pneumoniae, M. catarrhalis, and nontypeable H. influenzae increased with each additional household member in an overcrowded house [104].

Research needs

The N.S.W. Department of Health in partnership with the Department of Aboriginal Affairs has been delivering 'Housing for Health' projects in Aboriginal community housing sectors [196], undertaking the repair and maintenance of Aboriginal community housing with the specific intention of improving the safety and health of residents by addressing a variety of factors, including the impacts of overcrowding [196]. These projects have led to positive improvements in community health, including reduced rates of hospitalisations for infectious diseases (including respiratory, skin and intestinal infections, and otitis media), up to 40% lower than the rest of rural N.S.W. without the intervention [196]. Additionally, the Australian Government has committed to the 'National Partnership Agreement on Remote Indigenous Housing' which aims to build new homes and refurbish/rebuild existing homes to address the significant overcrowding and poor housing conditions in remote Aboriginal communities [197]. The establishment of high quality housing and related infrastructure, and the regulation of house crowding in remote Aboriginal communities, is vital to ensure more equitable health outcomes for Aboriginal Australians. Funding in the long term for these types of housing interventions, and the research demonstrating their effectiveness, is required.

Conclusions

It is important to identify the physical environmental challenges and their health implications in remote Aboriginal Australian communities. These factors may be easily modifiable and suppression of these exposures is likely to reduce their cumulative, negative effects on individuals across the life course and result in significant improvements in Aboriginal community health. The impact of environmental modifications needs to be properly assessed. At present, the exposure-disease associations are poorly characterised and difficult to quantify. Quantifying these associations is important for any health risk assessments and/or cost-benefit analyses of potential interventions. Systematic quantification of exposure levels in remote Aboriginal communities is needed, as is mechanistic evidence of how these exposures adversely affect health. Once a comprehensive evidence base is established, communities can lobby for a change in their living conditions that would provide protection from these preventable environmental exposures. Such interventions are strongly aligned with the 'Closing the Gap targets' [5].

Remediation practices should be of high priority in remote Aboriginal communities. These may include the sealing of roads and the establishment of re-vegetation programs in order to suppress exposure to dusts, or the review of ventilation standards for air-conditioning and housing (i.e. designing infrastructure for the environment) to limit geogenic or biomass PM_{10} exposure. This may also include water treatment systems or additional facilities so that there is an adequate water supply, and water quality, in these communities, or more effective housing/community design or housing interventions so as to reduce overcrowded households. These solutions can be expensive to implement, particularly in remote settings, and the efficacy of these solutions needs to be assessed. It is imperative that research in this area is translated into policy and practice so as to address these modifiable factors, and to have positive impacts on the health and wellbeing of Aboriginal Australians.

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Director Professor Neil Drew

Address Australian Indigenous Health*InfoNet*
Edith Cowan University
2 Bradford Street
Mount Lawley, WA 6050

Telephone (08) 9370 6336

Facsimile (08) 9370 6022

Email healthbulletin@ecu.edu.au

Web www.healthbulletin.org.au

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