Geographical Research

# Unsafe drinking water quality in remote Western Australian Aboriginal communities

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*Received 23 April 2018 • Revised 22 July 2018 • Accepted 31 July 2018*

## Abstract

Chronic kidney disease (CKD) is important in the fields of public health and health geography because of its heavy burden on the health system and high cost of treatment in its advanced stages. The causes of CKD are associated with diabetes and hypertension, but in some parts of the world, the disease occurs in the absence of these factors. Researchers identify this condition as CKD of "unknown" causes (CKDu). CKDu is a multi-factored health problem and one suspected causal factor is contaminated drinking water. The disease occurs globally but is found in particularly high concentrations among people of certain ethnic and disadvantaged social groups living in very different locations around the world. CKD has become endemic in Western Australia where hospital admissions for Aboriginal people requiring renal dialysis or treatment for diabetes are much higher than for the general population. The possible proportions of CKDu cases among the CKD patients are unknown. This study examines the drinking water quality among communities such as these. Water chemistry analysis in these areas indicates that the nitrate and uranium content greatly exceed officially recommended levels. Most of these communities rely on raw groundwater to supply their domestic needs, and it is very likely that the people are unwittingly ingesting high levels of nitrates and uranium, probably including uranyl nitrates. Very few such remote communities have access to treated drinking water, and cost-effective water treatment systems are required to provide potable water at the local scale.

**Keywords** *health geography; chronic kidney disease; remote Aboriginal communities; drinking water quality; heavy metals; Western Australia*

## Introduction

Chronic kidney disease (CKD) is a global problem that is of particular importance because of the suffering it causes, and also because of the heavy financial burden it imposes on public health systems, which arises from the high cost of treatment in the advanced stages of the disease. In Australia, an estimated 10 per cent of the adult population have biomedical signs of CKD, the disease being particularly prevalent among Aboriginal people (AIWH, 2017). CKD has long been linked with diabetes and hypertension, but in some parts of the world, notably Sri Lanka, El Salvador, Nicaragua, Costa Rica, and other Central American countries, the disease has been found

doi:10.1111/1745-5871.12308

to occur in the absence of these factors. Researchers studying this problem use the term CKD of unknown aetiology (CKDu) to identify the condition. Several hypotheses have been offered to explain the occurrence of CKDu, among them dehydration associated with heat stress, strenuous labour, exposure to agrochemicals that are nephrotoxic (harmful to kidneys), and contaminated drinking water (PAHO, 2017; WHO Country Office Sri Lanka, 2016). The proportion of CKDu cases among Australian Aboriginal CKD sufferers is unknown, but it may be significant at least in some environments. Contaminated drinking water is a problem in remote Western Australian Aboriginal communities where the incidence of CKD is high. It is likely that the cause of CKDu is multifactorial.

In this paper, we apply a geographical perspective to research undertaken as part of a collaborative project involving medical, public health, environmental engineering, and geographical professionals. The geographical component relates to spatial patterns of distribution, both geological and anthropological, in a specific region of Western Australia. The paper includes discussions relating to geological topics such as the mineral content of rocks and to matters of particular interest to human geographers, notably dispersed patterns of human settlement and the provision of services to remote communities. We also speculate about the possible relationship of a serious health problem and to the environment of the people who inhabit it.

For health geographers, this study provides a practical example of the application of their discipline to the search for solutions to problems that require detailed research in many other fields. The subject under discussion is one that should concern geographers and others because it addresses a question of social disadvantage in a country that enjoys one of the highest standards of living in the world.

In the following discussion, we investigate water contaminants present mostly in groundwater in remote communities and consider their possible role as nephrotoxic agents contributing to CKD. Our study focuses on nitrate and uranium compounds because it is well known that many of the towns and communities in the study area are at risk from water contamination with naturally occurring nitrates, and there is a considerable overlap between the region's considerable uranium deposits and the aquifers from which bore water is drawn (Jeffries-Stokes, 2017).

### *Method and data sources*

In what follows, we examine the hypothesis that contaminated drinking water may be one of the factors that causes CKDu, focusing particularly on the possible role of groundwater containing uranium and nitrates. Both of these compounds are believed to be nephrotoxic (Jayatilake *et al.*, 2013; Jeffries-Stokes, 2017; Nolan & Weber, 2015; Soderland *et al.*, 2010). Additionally, the reaction between dissolved uranium species in solution with nitrate can form a compound called uranyl nitrate, which is highly nephrotoxic (Blantz *et al.*, 1985). We consider this question as it relates to remote Western Australian Aboriginal communities. Our discussion is based on data obtained from publications listed in the PubMed, Medline, Scopus, Science Direct, SciFinder, and Western Australian Government databases for the years 1962 to 2017. Water quality test results were obtained from projects assessed and declared by the Western Australian Government Department of the office of the Environmental Protection Authority and the Office of the Auditor General Western Australia. The groundwater quality data at Wiluna were collected from January 2010 to August 2014 by the consultants, RPS Group, on behalf of Toro Energy Limited for an environmental impact assessment by the Environmental Protection Authority (EPA). A public environmental review (PER) of the 'Extension to the Wiluna uranium project' was completed in February 2016 and approval for the project was granted to Toro Energy Limited in July 2017 by the Australian Government's Department of the Environment and Energy. The RPS Group report is available through a link at the Western Australian Government website. Other information was obtained from Western Australian Government publications as listed under references. This study uses the Australian Drinking Water Guidelines (ADWG) as the primary reference base. Where appropriate, the World Health Organization (WHO) and United States Drinking Water Guidelines (USEPA) are consulted (Commonwealth of Australia, 2016; WHO, 2011, 2012); these are listed in Table 1. While drinking water guidelines are being applied, it is not yet known if they are relevant to the formation and nephrotoxic effects of uranyl nitrate.

Starting with a brief consideration of CKD in Western Australia, we examine the possible role of uranium and nitrate compounds as contributory factors in the occurrence of CKDu before discussing the findings as they relate to Western Australia. We follow this work with brief case

Table 1 Combined Drinking Water Guidelines

| Element | WA Govt (Water Corporation, 2013) (mg $L^{-1}$) | ADWG (Commonwealth of Australia, 2016) (mg $L^{-1}$) | WHO (WHO, 2011) (mg $L^{-1}$) | US EPA (USEPA, 2009) (mg $L^{-1}$) |
|---|---|---|---|---|
| Nitrate | | 50 (as NO3) child<br>100 (as NO3) adult | 50 (as NO3) | 45 |
| Nitrate-N | 11.3 | | 11 | 10 |
| Nitrite | | 3 | 3 | 1 |
| Uranium | | 0.017 | 0.02 | 0.03 |

studies of some remote Aboriginal communities. Based on our conclusions from this study, we make recommendations intended to contribute to better health in Aboriginal Australian communities and reduce the financial burden of public health care in that state.

## Chronic kidney disease in Western Australia

Chronic kidney disease is endemic in Australia. In 2014 alone, 2,610 people commenced kidney replacement therapy and 22,234 people remain on dialysis or are living with a transplant (The Australian Kidney Foundation – Kidney Health Australia, 2016). In 2014, the number of people who died from CKD was estimated at 22,218; that is, one person every 25 minutes (The Australian Kidney Foundation – Kidney Health Australia, 2016).

Most of these people will not know they have CKD as there are no symptoms in the early stages of the disease. It is estimated that one in 10 Australian adults is currently living with biomedical markers of CKD, expressed as reduced glomerular filtration rates or presence of protein in the urine. Unfortunately, one in five Indigenous Australians has these markers (The Australian Kidney Foundation – Kidney Health Australia, 2016).

### *Chronic kidney disease in Western Australia's Indigenous population*

Indigenous adults living in remote areas are more than twice as likely to have markers of CKD (The Australian Kidney Foundation – Kidney Health Australia, 2016). In Western Australia, 10.1 per cent of the population or 176,900 people live with markers of CKD. This number increases for Indigenous Western Australians at 22.8 per cent of the population or 10,200 people. This bias is reflected in higher hospital admission rates for Indigenous people when compared with that of the general population. In 2007, admissions for Indigenous people was 12 times higher for renal dialysis and eight times higher for diabetes (Government of Western Australia, 2013a).

For at least the past two decades, excessive rates of kidney disease have been recognised among Aboriginal people living in remote areas of Australia. The age-standardised incidence rate of renal replacement therapy (RPT) for Aboriginal people in the Kalgoorlie region from 1993 to 1998 was about 27 times that of the general Australian population, which was, along with Tennant Creek in the Northern Territory, the highest in the nation (Cass *et al*., 2001). Similar patterns were found by other researchers with expanded numbers of Indigenous people starting renal replacement therapy over the period from 1993 to 2001(Preston-Thomas *et al*., 2007). Kidney Health Australia's regionalising data from the Indigenous component of the Australian Health Survey, conducted in 2012, showed a high frequency of markers of kidney disease in WA's Indigenous people (The Australian Kidney Foundation – Kidney Health Australia, 2016).

## Can uranium and nitrate compounds act as facilitators of CKD?

Environmental toxins implicated in kidney damage include heavy metals, such as uranium, cadmium, lead, aluminium, and arsenic. Other implicated toxins include nitrate, fluoride in conjunction with water hardness, pesticides, herbal medicines, and air pollutants, such as tobacco smoke. Although these factors are known to play a role in the causation of kidney disease, defining their exact role in the aetiology is a challenge (Jayatilake *et al*., 2013; Jeffries-Stokes, 2017). In this paper, we will discuss two environmental toxins, namely, uranium and nitrate present in very high concentrations in water sources in remote Western Australia.

### *Uranium*

Uranium is found in minute quantities in most rocks, soils, and water bodies. However, it accumulates in the environment due to leaching from soils, rocks, and natural deposits, release of mill tailings, and combustion of coal and other fuels, including the use of phosphate and other fertilisers containing uranium. Western Australia has approximately 211,000 tonnes of known uranium deposits (Government of Western Australia, 2013) with uranium levels recorded in remote parts of the state as generally naturally occurring (Commonwealth of Australia, 2016). The term "naturally occurring uranium (U)" refers to U compounds with a series of radioisotopes: 234U, 235U, and 238U with 238U providing the majority of the isotopes (Government of Western Australia, 2013). Uranium is responsible for both radiological and chemical toxicity; nevertheless, the low level of radioactivity of natural uranium poses no danger of cancer risk. However, researchers consider that the chemical toxicity is responsible for kidney injury (Závodská *et al.*, 2008). Contamination of aquifers with uranium is known to impair kidney function and damage bones (Nolan & Weber, 2015). Nephrotoxicity of uranium in mammals has been extensively reported, but limited data are available for humans (Agency for Toxic Substances and Disease Registry (ATSDR), 2013; Vicente-Vicente *et al.*, 2010; WHO, 2012).

Uranium enters drinking water when groundwater dissolves minerals containing uranium in surrounding bedrocks. Numerous factors regulate mobility of U in water, most importantly pH, formation of complexes with coexisting dissolved ions and oxidation–reduction reactions. Oxidised uranium is relatively soluble and leaches from rocks to migrate in the environment. Most commonly, inorganic soluble uranium salts are uranyl nitrate, uranyl fluoride, uranium tetrachloride, uranyl acetate, and sulphate. Uranium dissolves readily in hydrochloric acid and nitric acid but slowly in sulphuric acid (Katz, 2014). Combustion of fossil fuels may result in formation of NOx and SOx gases, which dissolve in rain drops and form nitric and sulphuric acid. Ammonia evaporation from the farming industry may also lead to the formation of nitric acid.

Uranium needs to be in its hexavalent (VI) state to become mobile in solution; this occurs via the process of nitrate reduction to the oxidation of organic matter, and can generate alkalinity, mobilising uranium in its hexavalent state—U (VI), activating its solubility. The generation of alkalinity alone cannot produce soluble uranium if the uranium originated in its tetravalent state—U (IV), which is insoluble and immobile. In strong reducing environments, precipitation of soluble uranium will occur. Generally, in aqueous solutions, this change only occurs in the oxidised hexavalent form U (VI), at low pH due to the soluble $UO2^{2+}$ uranyl cations. The uranyl ion is very pH dependent due to hydrolysis and the formation of carbonate species where atmospheric CO2 or carbonate minerals are present. Under reducing/anoxic conditions, U is reduced to its tetravalent U (IV) state and its concentration in water decreases due to poor solubility of uraninite (UO2). The uranium oxidation–reduction reactions that occur in the environment and in microbial reactions may also result in the formation of complexes with organic matter. Uranium (VI) forms stable complexes with dissolved organic carbon. Therefore, uranium mobility can be significantly enhanced in organic-rich waters (Smedley *et al.*, 2006). Recent studies indicate that oxidation of uranium (IV) minerals (uraninite) by dissolved oxygen (aerobically) or nitrates (anoxically) from agricultural run-off into uranium (VI) may form chemical complexes with carbonate and calcium ions in groundwater, mobilising the uranium through the soil column and contaminating the groundwater (Burow *et al.*, 2017; Nolan & Weber, 2015). In the presence of iron, certain bacteria (*Thiobacillus* and *Ferrobacillus*) can oxidise any dissolved iron from the ferrous to the ferric state. Consequently, ferric iron can convert insoluble uranium dioxide, UO2 ($U^{4+}$) to soluble $UO2^{+2}$ ions ($U^{6+}$) thus mobilising the uranium (Scharer & Ibbotson, 1982). Evidently, the groundwater biogeochemistry of uranium is quite complex, making the treatment of contaminated groundwater difficult (Stewart *et al.*, 2006).

Uranium toxicity depends on absorption, which increases with increasing solubility. Once ingested, uranium initially appears in the bloodstream where it forms a bond with the membrane of the red blood cells. Clearance from the bloodstream is rapid as uranium accumulates in the kidneys and the skeleton with less depositing in the liver (WHO, 2012).

Uranium exposure is "weakly associated" with altered proximal tubular functions, suggesting that low levels of ingestion cause renal damage (Chandrajith *et al.*, 2010; Kurttio *et al.*, 2002). Consumption primarily leads to nephritis (inflammation of the kidneys) in people (WHO, 2012). The ADWG list the safe upper limit of uranium ingestion in drinking water as 0.017 mg/L$^{-1}$ (Commonwealth of Australia, 2016).

### *Nitrate*

In a simple nitrogen cycle, the nitrogen (N2) transfers to ammonium (NH4) and then via nitrification converts to nitrite (NO2) and nitrate (NO3), where it moves into the groundwater (Powlson, 1993). At higher levels (Table 1), nitrogen becomes a listed contaminant in drinking water (Commonwealth of Australia, 2016; Flamenbaum *et al*., 1974; Office of the Auditor General Western Australia, 2015; WHO, 2011).

The toxicity of nitrate to humans is due to the reduction of ingested nitrite which then transforms into nitrosamines, which are carcinogenic (Tiso & Schechter, 2015). A major health effect of nitrates in humans is the oxidation of normal haemoglobin to methaemoglobin, which inhibits the transport of oxygen to tissues. This condition is called methaemoglobinaemia (blue baby syndrome), with infants under the age of six months at the greatest risk (Commonwealth of Australia, 2016). High levels of nitrates in adults have been linked to stomach, colon, bladder, and prostate cancer (Morales-Suarez-Varela *et al*., 1995). A 2011 study conducted in Taiwan found childhood brain tumours associated with high levels of nitrates in the drinking water (Weng *et al*., 2011). Ingestion of nitrates through the actions of nitrosamines in the gut could lead to increased risk of diabetes, hypertension, and cardiovascular disease, which could contribute to the risk of renal disease (Jeffries-Stokes, 2017).

A study led by Australia's CSIRO (1992) recorded high nitrate concentrations in groundwater in arid zones of Australia (Barnes *et al*., 1992). The researchers found that high levels of nitrate originated near the surface, caused by biological fixation from the cyanobacteria present in the soil crust combining with bacteria in termite mounds. Nitrate-NO3 samples taken from the groundwater recorded levels in exceedance, up to 80 mg/L$^{-1}$ (Barnes *et al*., 1992).

A groundwater chemical analysis by the WA Rivers and Water Commission (completed in 1999) sampled 35 bores and wells, with the highest nitrate-NO3 level (130 mg/L$^{-1}$) sampled in alluvium (Johnson *et al*., 1999).

### *Uranyl nitrate*

It has been suggested that for uranyl nitrate to form in solution, nitrates bind to uranyl ions in solution (Ye *et al*., 2010). There is evidence that uranium oxide, when exposed to excess nitric acid, dissolved to form uranyl nitrate (Gelatar *et al*., 2015). Furthermore, uranyl nitrate depends on acid concentration, and the production of uranyl nitrate increases with nitric acid concentration (Ye *et al*., 2010). Uranyl nitrate in solution is a weak acid due to the hydrolysis of uranyl ions (Tomazic *et al*., 1962).

Uranyl nitrate is the most widely used uranyl salt of commerce. Because of high solubility in water, uranyl nitrate is absorbed by the gastrointestinal tract to a much greater degree than low soluble uranium compounds, therefore, associated with high toxicity of the soluble forms of uranium. Uranyl nitrate received much attention from investigators of animal toxicological research, although all soluble uranium compounds have renal toxicity (Agency for Toxic Substances and Disease Registry (ATSDR), 2013). World Health Organization Guidelines for drinking water quality on uranium have detailed studies of uranium nephrotoxicity on humans and animals, and the effect of uranyl nitrate on animals has been extensively discussed (WHO, 2012).

## Uranium and nitrates in drinking water sources in Western Australia

Most residents in remote Western Australia use groundwater as their primary drinking water source. Water quality data from these remote areas have been reviewed and compared with ADWG (Commonwealth of Australia, 2016) to determine the presence of soluble uranium and nitrates; known nephrotoxic agents (Flamenbaum *et al*., 1974; WHO, 2012).

Uranium ingestion causes nephritis, or inflammation of the kidneys (WHO, 2012). Uranyl nitrate is another known nephrotoxic agent (Flamenbaum *et al*., 1974). Water quality data (pH, CaCO3, nitrates, and uranium) have been analysed for three remote regions in Western Australia, with a focus on the groundwater at Wiluna. The desert towns of Leonora and Laverton (South) to Wiluna (North), including the town of Leinster, lies within the region (Figure 1). Groundwater is used throughout Leonora, Laverton, and Wiluna for town water supplies, pastoral purposes, for irrigated horticulture, and citrus cultivation at Wiluna (Johnson *et al*., 1999).

The Northern and Eastern Goldfields are major nickel and gold producing regions. There are over

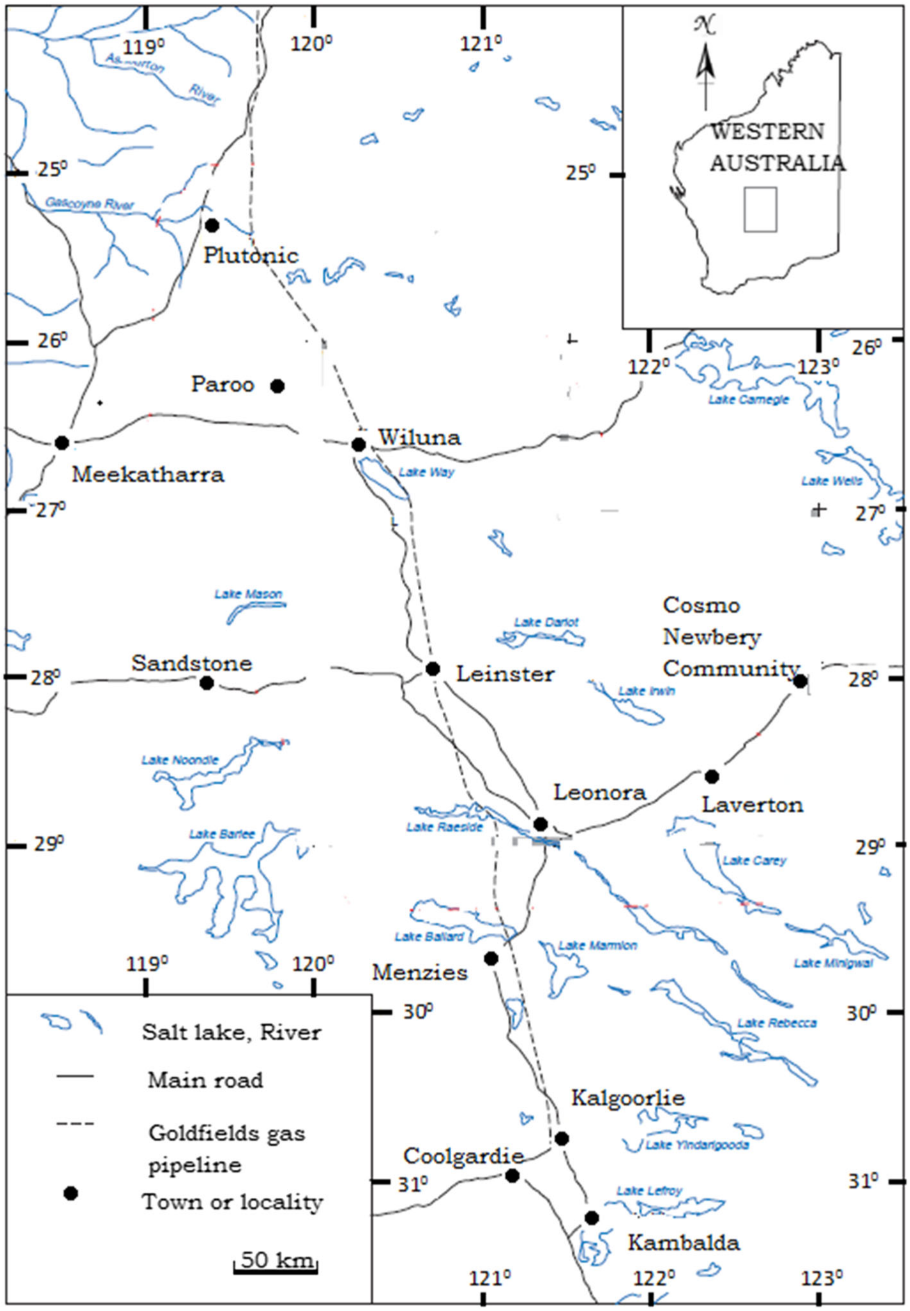


Figure 1 Location map for study settlements
Source: Johnson *et al.*, 1999

20 operating mines and numerous prospects for uranium, rare earths, and base metals, all dependent on groundwater for ore processing (Johnson *et al.*, 1999). A review of regional groundwater resources shows that the Leinster's groundwater source contains salinity ranging from 1,000 up to 200,000 mg/L$^{-1}$, where the average rainfall is about 250 mm per year for the region (Rajapakse *et al.*, 2013).

The water supply for Laverton is obtained from the Beasley Creek bore and the Wedge Pit bore field, which are located about 12 kilometres north-west of the town. Nitrate in all the town water supplies exceeds the 50 mg/L$^{-1}$ (nitrate as

NO3) standard for drinking water and is generally greater than 30 mg/L$^{-1}$, with a maximum concentration of 130 mg/L$^{-1}$.

Most of the remote communities rely on untreated groundwater systems to provide domestic water, although many different water treatment systems are available (USEPA, 2009; WHO, 2012). Their suitability for remote community applications at affordable cost needs further research.

According to the Water Corporation (2013) in 1996, the Western Australian Department of Heath exempted the following remote towns from meeting the water quality guidelines regarding excessive nitrate levels in drinking water: Cue, Meekatharra, Mount Magnet, Nabawa, New Norcia, Sandstone, Wiluna, Yalgoo, Laverton, Leonora, and Menzies. These exemptions are still current. Community health nurses are instructed to provide bottled water free to nursing mothers, at no cost.

Yalgoo recently reported that no bottled water has been supplied, nor were they aware of the requirement. The Shire Council of Yalgoo suspects this to be the case in four other communities (ABC News, 2016).

The 2015 Western Australian Auditor General's report reviewed the Remote Area Essential Services Program, which delivers power, water, wastewater repair, and maintenance services to a few remote communities. This program is managed by the Western Australian Department of Housing. Figure 2 identifies the 14 communities where nitrate-NO3 exceeds the ADWG for children (50 mg/L$^{-1}$), two communities who exceed the ADWG for adults (100 mg/L$^{-1}$), and another community where the nitrate level is in the upper limits of exceedance (Office of the Auditor General Western Australia, 2015). These levels have been recorded for 84 communities in 2014 (Office of the Auditor General Western Australia, 2015).

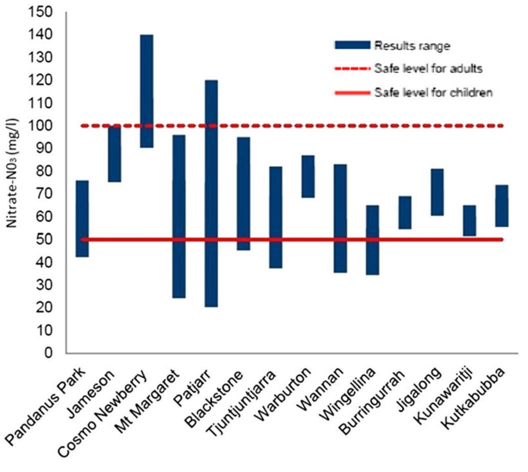


Figure 2 Nitrate-NO3 levels in remote WA drinking water. Source: Office of the Auditor General Western Australia, 2015

The Auditor General's report notes that there are three communities where safe drinking water levels were exceeded for uranium (0.017 mg/L$^{-1}$) (Office of the Auditor General Western Australia, 2015). Of particular concern is the remote community of Tjuntjuntjarra, where drinking water failed safe levels for both nitrates and uranium. Tjuntjuntjarra, one of five communities being monitored, has failed 18 out of 22 water quality tests for uranium. These levels are reported to be up to double the safe guideline values. The other four communities have not been named (Office of the Auditor General Western Australia, 2015).

The following four examples illustrate the nature of the problem. The remote community of Cosmo Newberry exceeded nitrate levels in drinking water, recording 140 mg/L$^{-1}$. The Auditor General's report found nitrates in the community of Mt Margret in exceedance of the ADGW at 25–95 mg/L$^{-1}$ in 2013–14 (Office of the Auditor General Western Australia, 2015).

In the Northern Goldfields, the community of Kutkabubba recorded nitrate exceedances in water up to 75 mg/L$^{-1}$ (Office of the Auditor General Western Australia, 2015). The uranium in this region is generally found at surface level to a depth of five metres underground (Scott, 2015). Drinking water in Kutkabubba is sourced directly from two bores and is delivered via a gravity system, as raw untreated water (Western Australian Planning Commission, 2012).

Most groundwater in Wiluna (30 kilometres south of Kutkabubba) can be found at an approximate depth of two to 10 metres, and uranium is found in contact with the groundwater (Scott, 2015). Groundwater chemical analysis at Wiluna was undertaken from January 2010 to August 2014 (RPS Group, 2015). According to that report, more than 200 samples for all major and minor ions were recorded over a period of four years. Results for nitrate-N and uranium are shown in Figure 3. Of these, nitrate-N was sampled only 48 times, ranging from 6.2 to 107 mg/L$^{-1}$ (RPS Group, 2015). Nitrate-N levels exceeded WA guidelines of 11.3 mg/L$^{-1}$, 83 per cent of the time (RPS Group, 2015).

Uranium levels in the groundwater were tested 212 times ranging from 0.0001 to 1.46 mg/L$^{-1}$, exceeding guidelines 79 per cent of the time (RPS Group, 2015).

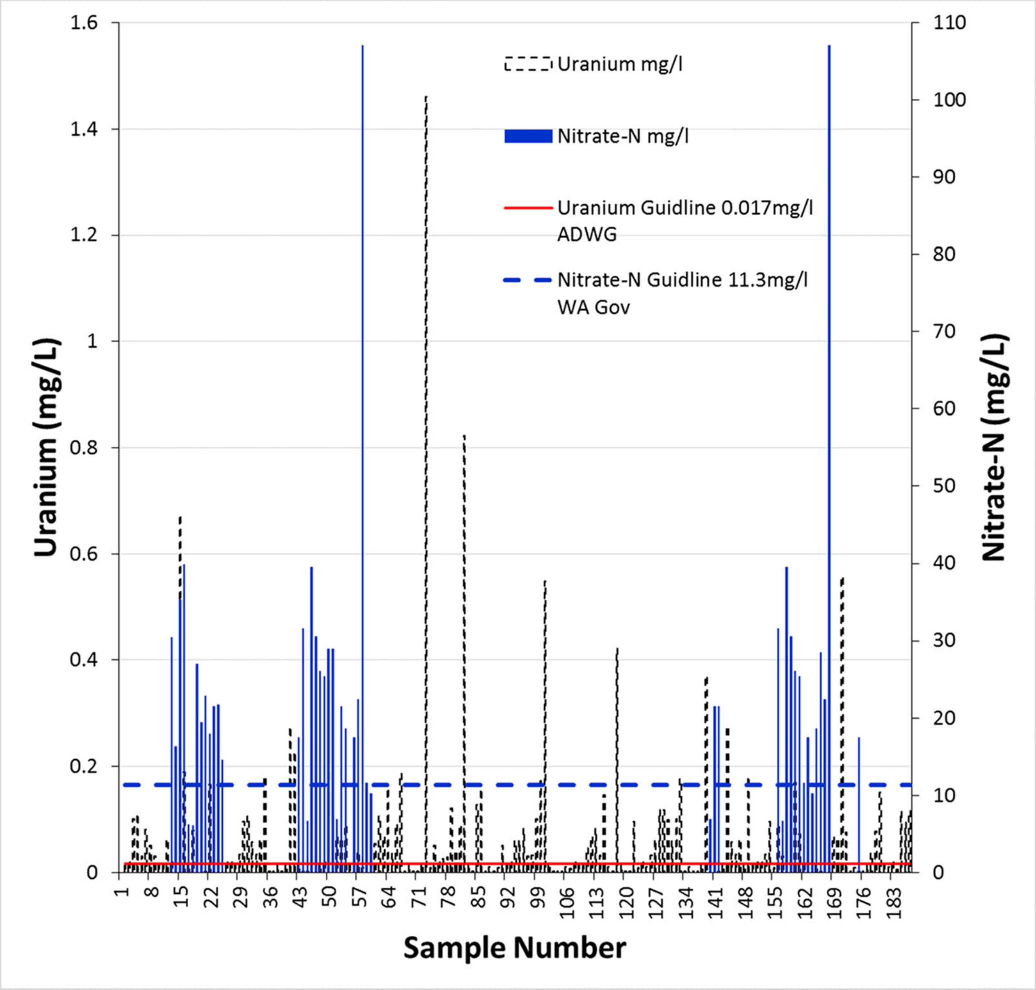


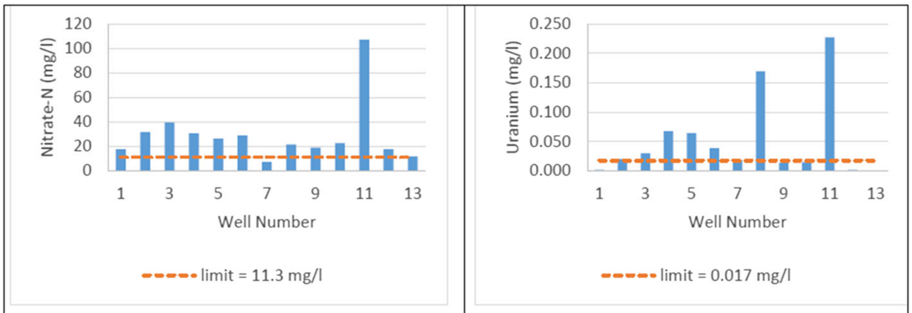
Figure 3 Nitrate-N and Uranium levels in WA Wiluna groundwater 2010–14

### *Uranium contamination in aquifers could be linked to nitrates*

Figures 4a and 4b show uranium and nitrate levels respectively in 13 groundwater wells sampled during March 2014 at South Wiluna in Western Australia. Both graphs clearly indicate that uranium and nitrate levels exceed the guideline values in most of the samples. It has been suggested that uranium contamination in aquifers could be directly linked with nitrates because nitrates can mobilise uranium (Nolan & Weber, 2015; Pasquale, 2016). Figure 4c clearly demonstrates this relationship where the nitrate-N levels follow a similar trend to uranium levels. The United States study found that, although nitrate was the primary agent in the mobilisation of uranium, it did so in conjunction with alkalinity and carbonates (Nolan & Weber, 2015). The actual amount of nitrate required in solution to mobilise the U is still unknown.

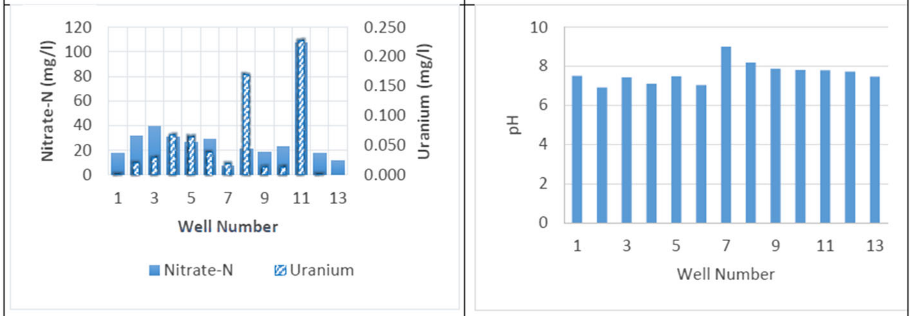
The relationship between mobilising uranium (IV) in the presence of high alkalinities, expressed as CaCO3, has been historically established (Parkhurst *et al*., 1996). Where high levels of uranium in solution are detected in conjunction with pH ranges seven to eight, the carbonate–ion activity enhances uranium mobilisation (Nolan & Weber, 2015).

As can be seen in Figure 4d, the pH range of the groundwater is within this range and alkalinity was present between 50 and 300 mg/L$^{-1}$ as CaCO3, supporting the earlier favourable conditions for uranium mobilisation. Although the pH range in the March 2014 samples varied between 6.9 and 9.0, the 2010 and 2014 samples show that there are wells with pH as low as 5.9,



(a) Nitrate levels

(b) Uranium levels



(c) Uranium-Nitrate Relationship

(d) pH

Figure 4 South Wiluna (WA) Groundwater quality, March 2014

suggesting favourable conditions for uranyl nitrate formation.

The area of Yeelirrie has tested positive for uranium in both surface and groundwater. Uranium has been detected in exceedance, recording 0.439 mg/L$^{-1}$ in surface water (URS Australia Pty Ltd, 2015) where the health based limit is 0.017 mg/L$^{-1}$; that is, 25 times higher, whereas in the groundwater levels as high as 2.4 mg/L$^{-1}$ (140 times higher) were reported (URS Australia Pty Ltd, 2011). Nitrates were present but levels were within guideline values. The surface water sources reported here were ephemeral and not considered suitable for drinking water supply, stock watering, or irrigation. Many of the groundwater bores in the Yeelirrie catchment are pastoral wells, monitoring wells, and production wells. Most pastoral wells have fallen into disuse in recent times, but at least one well in the area continued to be used as a water supply source.

These observations are at least compatible with the hypothesis that high levels of uranium and nitrate contamination in drinking water can cause renal injury. We have also demonstrated that, in all the communities examined as case studies, uranium and nitrate concentrations greatly exceed officially recommended levels. Thus, uranium and nitrate levels above health guideline values in drinking water supplies may be additional causal factors in the occurrence of CKD in remote Western Australian Aboriginal communities.

## Conclusion

Western Australia is one of many areas around the globe where CKD has become a serious public health problem. Considering the alarming CKDu cases reported in different geographic areas globally, the likelihood of a high proportion of CKDu cases among these CKD patients is a cause for concern. The multifactorial nature of CKDu warrants novel risk factors to be investigated. Focusing on remote Aboriginal communities, this study examined a possible causal relationship between the occurrence of the disease and the presence of contaminants in drinking water, particularly uranium and nitrates found in the local groundwater.

Both uranium and nitrates can cause renal injury; they are nephrotoxic agents in their own right. Chemical analysis of groundwater used for drinking has shown that both uranium and nitrates are present in solution, in remote Western Australia. The recorded data are in exceedance of the safe drinking water guidelines. While the role of CaCO3 (as expressed as alkalinity) has been historically documented in its ability to mobilise uranium, recent research indicates that the role of nitrates as critical in mobilising uranium in solution. Most remote communities rely on raw groundwater to supply domestic water, often without treatment. In these cases, it is extremely likely that the communities are unwittingly ingesting high levels of nitrates and uranium including a probability of the presence of uranyl nitrates. Very few remote communities in Western Australia have access to treated drinking water, and cost-effective water treatment systems are required to provide potable water at the local scale.

Uranium is generally not analysed routinely in groundwater monitoring and should be included in water-quality investigations. The relationship between soluble uranium and nitrates creating uranyl nitrate in drinking water, as an additional environmental water contaminant, remains to be investigated. The implementation of measures to supply safe drinking water to Western Australia's remote Aboriginal communities is urgently needed, and further research is required on the public health implications of chemically contaminated water supplies. Sound public health policies to ensure access to safe drinking water to remote communities are a priority.

Research is needed to determine what proportion of Aboriginal CKD patients also suffer from the normal causal conditions, and how many do not, thus indicating possible signs of CKDu. More broadly, the research should be expanded to examine aspects of water supply that relate to alternative sources available and the means of distribution to highly dispersed remote settlements. Qualitative research is needed to ascertain the special requirements of Aboriginal communities. It is important to ensure that the improvement of the health and wellbeing of Australia's Indigenous population is achieved in a manner that meets the needs and aspirations of the country's Aboriginal people. As researchers and policymakers, we need to listen to their voice. Only by undertaking studies that draw on a wide range of knowledge and expertise can health policies for spatial and social planning be successfully prepared and applied.

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