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Uranium contaminated drinking water linked to leukaemia—Revisiting a case study from South Africa taking alternative exposure pathways into account

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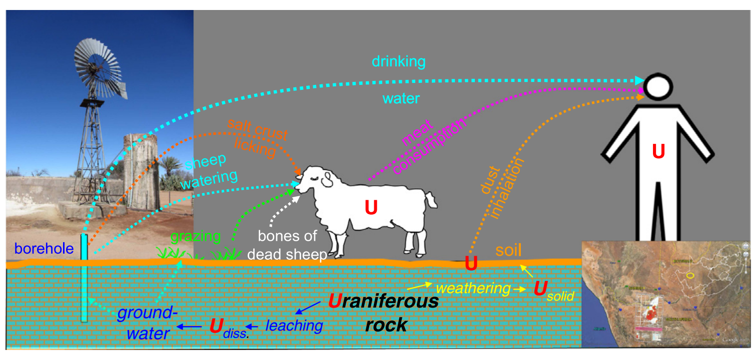
HIGHLIGHTS

- U-levels in tissue of sheep reflect U-levels in sheep drinking water.
- U-deposition rates in wool are much higher than in bones as known U-target.
- Inner organs show 50% higher U-levels than meat, levels increase with age.
- U-intake rates of farm residents well exceed limits of TDI and absorbed dose.
- Similar situations are likely to occur elsewhere in arid South Africa.

GRAPHICAL ABSTRACT



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ABSTRACT

The paper presents results of a follow-up to an earlier study which established a geospatial link between naturally elevated uranium (U) levels in borehole water and haematological abnormalities in local residents serving as a proxy for leukaemia prevalent in the area. While the original study focussed on drinking water only, this paper also explores alternative exposure pathways including the inhalation of dust and the food chain.

U-levels in grass and tissue of sheep generally reflect U-levels in nearby borehole water and exceed background concentrations by 20 to nearly 500 times. U-levels in sheep tissue increase with age of the animal. Wool showed the highest U-concentration followed by other non-consumable tissue such as hooves, teeth and bones. Lower levels occur in edible parts such as meat and inner organs. The U-deposition rate in wool is several orders of magnitudes higher than in bone as a known target organ. Wool is an easy-to-sample non-invasive bioindicator for U-levels in meat. Depending on the original water content, dried samples show up to 5 times higher U-levels than identical fresh material.

Contaminated drinking water is the main exposure pathway for farm residents resulting in U-uptake rates exceeding the WHO's tolerable daily intake (TDI) limit by up to 900%. This is somewhat mitigated by the fact that U-speciation is dominated by a neutral calcium-uranyl-carbonate complex of relatively low toxicity. Commercially available household filters are able to significantly reduce U-levels in well water and are thus recommended as a short-term intervention. Based on average consumption rates sheep meat, as local staple food, accounts for 34% of the TDI for U. Indoor levels of radon should be monitored, too, since it is linked to both, U

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and leukaemia. With elevated U-levels being present in other geological formations across South Africa boreholes in these areas should be surveyed.

1. Introduction

In the early 1990s the Community Health Unit of the Tygerberg Hospital in Cape Town (South Africa) noticed that a disproportionately high number of its leukaemia patients originated from a certain farming area around the rural town of Pofadder in the arid Northern Cape Province. After being alerted to this fact, the Water Research Commission (WRC) of South Africa funded a study to investigate a possible link to the quality of drinking water in the area (Toens, 1997; Toens et al., 1998).

Using two large pre-existing data sets independently generated by the Atomic Energy Corporation of South Africa (AEC) in the early 1980s on U-levels in 126 boreholes in the area and results of blood samples taken during a community health survey in 1993 from 630 local residents, a significant geo-statistical correlation between the spatial distribution of elevated U-level in borehole water and abnormal haematological values in blood samples of residents (abnormal lymphocyte counts were used as proxy for leukaemia) was established (Toens et al., 1998; Toens, 2008). Given the radiotoxicity of U, a link not only to kidney damage (Kurttio et al., 2002; Magdo et al., 2007) but also blood- and other cancers, while not conclusively proven, is not implausible as a range of international studies suggests (Vahrenholz et al., 1997; Auvinen et al., 2002; Hakonson-Hayes et al., 2002;, Kurttio et al., 2006; Prat et al., 2009). This specifically includes leukaemia as bones were identified as a target organ for accumulating U (Nozaki, 1970; Fisenne and Welford, 1986; Kurttio et al., 2005) with the human skeleton accounting for over half of all incorporated U (UBA, 2005). Accumulation of U in bones is problematic as it may interfere with blood production in the red bone marrow especially since it was found that U-deposition is not confined to the outer mineral part, as previously thought, but occurs throughout the entire bone (Arruda-Neto et al., 2004). Emitting energy-rich alpha-particles, assumed to be (at least) 20 times more biologically damaging than beta- or gamma radiation, U deposited in the bone marrow may therefore be able to trigger leukaemia or other heamatological malignancies despite the low penetration depth of alpha radiation. However, apart from direct impacts of ingested U, leukaemia and other cancers may also be caused indirectly by U via inhaling the radioactive daughter product radon (^{222}Rn, a gas) or causing elevated natural background radiation[1].

When Dr. Toens, the leader of the WRC study brought this to the attention of the Department of Water Affairs and Forestry (DWAF) and asked for rapid intervention to limit possible adverse health impacts, the DWAF responded that other potentially toxic materials such as contaminated dust or pesticides had not been investigated and thus declined to commit to any—potentially costly—intervention for improving the water quality (Toens, 1998)[2].

Toens et al. (1998) had confined their explanation of the detected link between U and leukaemia to the direct consumption of untreated polluted borehole water, even though Toens himself in later correspondence on the project proposed to also analyse the sheep meat (Toens, 1998). As all sampled residents live on sheep farms where untreated borehole water is used for watering the animals, consumption of possibly contaminated sheep meat, a staple food in the area, is considered a potential pathway of U-exposure.

In order to address these gaps and arrive at a more comprehensive understanding of the mechanisms and pathways that expose local resident to U, a follow-up study was designed (Winde, 2011) and an associated field sampling campaign conducted in July 2012. The main purpose of this follow-up study was to investigate whether, and if so to what extent, potentially contaminated food and inhaled dust may contribute to the U-exposure of residents possibly explaining the geospatial link between U-levels in borehole water and the frequency of haematological abnormalities in water users. To this end dust, agrochemicals, vegetation (sheep fodder) as well as sheep tissue was sampled and analysed for U. By using biological material as the indicator for U-exposure, this approach follows earlier studies which include the analysis of human tissue (Lucas and Markun, 1970; Igarashi et al., 1987; Karpas et al., 2005a/ b; Muikku et al., 2009).

2. The study area

2.1. Location

The study area of the original WRC-project is located in the Kenhardt municipal district of the Northern Cape Province around the small rural town of Pofadder. For the present study five farms were identified using a specifically designed selection procedure described in the Methodology section. All sampled farms fall within the boundaries of the original study by Toens et al. (1998) (Fig. 1).

2.1.1. Climate, geology and hydrogeology

Situated at the southern fringe of the Kalahari Desert the climate of the study area is arid with an average rainfall of just below 100 mm/a. High inter-annual variability means that several years may pass without any rainfall. Consequently, there are no perennial streams and, generally, groundwater is the sole source of water supply on farms[3].

[1] Řeřicha et al. (2006) linked leukaemia (in particular chronic lymphatic leukaemia, CLL) in a cohort of over 23.000 underground U-miners in Czech Republic not directly to U but to its radioactive daughter product radon. Auvinen et al., 2005 investigated a possible link between Rn inhalation and stomach cancer in a Finish population. Damage of stem cells in fatty red bone marrow by ionizing radiation from inhaled radon have also been proposed by Tong et al. (2012) and an increased risk of childhood leukaemia due to Rn by Richardson et al. (1995). However, Hauri et al. (2013) found no link between elevated Rn exposure of children in Swiss households and childhood leukaemia using a prospective census-based cohort study. Applying the same approach Spycher et al. (2015) established, however, a clear relationship between elevated background radiation (especially in high-altitude mountainous areas of Switzerland) and leukaemia and other cancers in children. Using a record-based case–control study over a 26 year period Kendall et al. (2013) found the same link between elevated background radiation and leukaemia (but not for other cancers) in British children. In their international review of epidemiological studies on U-related cancers Timarche et al. (2004) points to the general challenge of distinguishing between the radiotoxic and chemotoxic effects of U as well as those caused by the radiotoxicity of its progeny rendering the establishment of clear causal relationships difficult. Efforts to evaluate the biological effects of U as an internal emitter by the United Nations Scientific Committee on the Effects of Atomic Radiation are still underway and have not yet been completed (UNSCEAR, 2014). The continued existence of scientific uncertainties regarding U-toxicity is also acknowledged by World Health Organisation in their latest update of drinking water guideline values (WHO, 2012).

[2] Subsequent enquiries to the DWAF by the Northern Cape Regional Office in Upington that was alerted to possibly associated health risks of consuming water with 205 μg U/l (found at the farm Fonteintje) received a downplaying response stating that neither the chemical nor the radiological toxicity of U posed any undue risk (Kempster, 1999). This was despite the fact that this U-level exceeded the applicable (very liberal) guideline value for domestic water use in South Africa (70 μg/l) by nearly 300% - at a time when the WHO guideline value (2 μg/l) was 35-times lower.

[3] An exception is the town of Pofadder where efforts to improve tap water quality eventually led to replacing the local groundwater by water sourced from the nearby Orange River via a pipeline installed several years ago.