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Exposure assessment of potentially toxic trace elements in indigenous goats in the rural communal production systems of the northern region of South Africa

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Abstract

Recent advances in analytical techniques have allowed hydro-geochemical databases to form an essential component of animal and human epidemiological studies. Geographically localised communities and livestock production systems have a higher incidence of risk factors, and therefore baseline concentrations of key health elements are required to assess the quality of the water. Risk assessments conducted for drinking water for indigenous goats in rural communal livestock production systems for three separate communities found several trace elements (As, Br, Cd, F, Pb, Hg, Mo and Se) occurring as localised anomalies in the aquatic environment at concentrations exceeding local and international guidelines (at times by several orders of magnitude). The watering points assessed are capable of contributing significantly to the mineral requirements of the indigenous goats thus exposed. Potential hazards were identified that impact on the norms of health, palatability and product quality for human consumption. Hydro-geochemical correlations were noted that increase both the risk associated with exposure and the likelihood of incomplete diagnosis of mineral related disorders. Recommendations are also made with regard to a programme monitoring water quality and the need to include water chemistry when formulating rations, mineral supplements and diagnosing disorders or diseases across different production environments.

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Introduction

Groundwater is a major water source in rural communities in South Africa, with over 280 towns relying on subterranean water. Research conducted for the Water Research Commission of South Africa (WRC) regarding livestock production systems for rural communities observed the presence of potentially hazardous chemical constituents (PHCC) in groundwater used for livestock and human consumption (Casey *et al*., 1998; Casey & Meyer, 2001). Investigations into PHCC in rural groundwater supplies occurred concurrently with the development of software-driven, risk assessment models for water quality guidelines applicable to multiple livestock species and shared domestic exposures typical within the rural context (Casey & Meyer, 2001).

This paper presents concerns raised by tier 1 generic risk assessments applicable to the norms affecting indigenous goat production in rural communities.

Materials and Methods

Point-of-use samples were collected from groundwater utilized by indigenous goats and domestic users in three separate communities in the northern region of South Africa, namely the Immerpan Resettlement district, Jericho district, and the Rietgat and Hartebeeslaagte district, situated on the eastern periphery, central, and western periphery of the Bushveld Igneous Complex, respectively. Following chemical analyses by ICP-AES techniques using full quantitative and semi-quantitative procedures (ISCW, 2001), generic level risk assessments were conducted using constituent ingestion rate risk assessment software (CIRRA Version 1.03 developed for the WRC) (Casey *et al*., 1998; Casey & Meyer, 2001). Results are presented according to recognized stochastic water quality constituents (WQC) variables where:

Potentially hazardous chemical constituent (PHCC) indicates that exposure to the (WQC) in question is likely to result in adverse effects and exceeds the Department of Water Affairs and Forestry (DWAF, 1996) guideline, or the internationally recommended upper guideline limit (WHO, 1996; USEPA, 1998).

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Constituent of Concern (COC) observed within 10% of the PHCC guideline, and indicates that the WQC in question could conceivably become a PHCC due to concentration variations, such as seasonal fluctuation in the water source or evaporative effects, and should therefore be monitored.

Results and Discussion

Table 1 presents the point prevalence observations for the generic risk assessments for the three districts. Some of the associations of PHCC recorded within a district may be explained to some extent by known geochemical correlations, whilst others are probably influenced to a greater extent by agricultural practices and Eh and pH conditions in the water delivery system. Apart from the Immerpan district where high TDS values resulted in high sodium and chloride concentrations, the majority of the PHCC recorded are associated with trace element geochemistry. This accords with findings of other workers in the field of geochemistry and epidemiology (Mills, 1996). From Table 1, the elements with well-documented toxico-dynamics and toxico-kinetics that are of concern include arsenic, cadmium, fluoride, lead, mercury and selenium. Uncertainty regarding either the toxicity or physiological significance from drinking water exposure exists for antimony, beryllium, bromide, strontium, tellurium, thallium and titanium.

Table 1 Point prevalence of potentially hazardous chemical constituents (PHCC) and constituents of concern (COC) in the drinking water of indigenous goats in three rural communities in the northern region of South Africa

	Potentially Hazardous Chemical Constituents*			Constituents of Concern*		
Water Quality Constituent	Immerpan district (n = 16)	Jericho district (n = 41)	Rietgat & Hartebeeslaagte district (n = 16)	Immerpan district (n = 16)	Jericho district (n = 41)	Rietgat & Hartebeeslaagte district (n = 16)
Antimony	-	M	-	-	-	-
Arsenic	H	I	-	-	-	-
Beryllium	-	H	-	-	-	-
Bromide	H	H	H	-	-	-
Cadmium	-	H	-	-	I	-
Chloride	H	-	-	-	-	-
Chromium	-	I	-	-	I	-
Fluoride	H	I	-		I	-
Lead	-	M	-	-	I	-
Manganese	-	H	-	-	-	-
Mercury	-	M	M	-	-	-
Molybdenum	-	M		H	I	-
Nickel	-	-	I	-	-	I
Nitrate	-	-	-	-	-	I
Selenium	H	H	I			I
Sodium	H	-	-	-	-	-
Strontium	-	-	-	H	H	H
Tellurium	M	M	-	-	-	-
Thallium	H	H	-	-	-	-
Titanium	H	I	-	-	-	-
TDS**	H	I	-	-	I	-
Uranium	-	I	I	-	I	-
Vanadium	-	-	I	-	-	-
Zinc	-	-	-	-	-	H

*Where, n = number of watering points observed, and H = high (PHCC or COC > 66% of n), M = medium (PHCC or COC >33% but <66% of n), I = isolated (PHCC or COC < 33% of n), - = no observed PHCC or COC

** TDS = total dissolved solids (electrical conductivity)

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The observations of anomalously high concentrations of essentially toxic elements may be considered to be congruous with associated geology, and furthermore, may result in adverse effects in indigenous goats for the recognized norms of health, palatability and product quality. Implications of water chemistry for environmental exposure and clinical applications have been demonstrated in beef cattle with regard to selenium and lead in an area to the south of the Immerpan district (Elsenbroek *et al*., 2003).

The high maximum values observed for many of the constituents are depicted in Table 2, and highlight the requirement to progress from PHCC assessments to dose-based estimates of risk. Site-specific risk factors may ameliorate or exacerbate toxicity in indigenous goats following exposure. Concurrent exposure to multiple PHCC in the drinking water may cause additive to infra-additive biological effects that can include potentiation. These influence animal health directly through drinking water, and may also impact human health indirectly via adverse livestock product quality. Water for domestic use (drinking, food preparation and bathing) and agricultural use (animal watering, and irrigation of household crops) constitutes a multiple-exposure pathway with limited dietary dilution. High doses (concentration and environmentally based) coupled with repeated exposure typical of the rural communities studied increase the risk of cellular injury. Many PHCC identified in the communities are stored by binding to fat and negatively charged, sulphur-containing groups of proteins, thereby altering receptor structure and function and causing cellular or tissue dysfunction. Many PHCC are also class A, B, or C carcinogens (IARC, 1987).

Table 2 Main potentially hazardous chemical constituents (PHCC) and constituents of concern (COC) identified from 41 water samples in villages in the Jericho district – northern region of South Africa

WQC	PHCC	COC	Average (mg/L)	s.d. (mg/L)	Median (mg/L)	Guideline (mg/L)	Range (mg/L)	
							Min	Max
As	8	0	0.039	0.074	0	0.01	0	0.288
Br	35	0	0.261	0.176	0.275	0.01	0	2.292
Cd	30	1	0.046	0.045	0.038	0.005	0	0.186
Cr	4	15	0.039	0.072	0.019	0.05	0.003	0.329
F	11	1	1.087	0.747	0.53	1	0.01	7.77
Hg	28	0	0.118	0.116	0.082	0.001	0	0.444
Pb	24	1	0.026	0.024	0.021	0.01	0	0.090
Mn	35	0	0.35	0.61	0.15	0.4	0.01	2.76
Mo	20	5	0.055	0.052	0.049	0.02	0	0.204
Se	30	0	0.752	0.685	0.711	0.02	0	2.292
Ti	12	0	0.433	1.025	0.1	0.1	0.033	4.531
TDS	8	4	294.3	200.5	251	500	63	805
Sr	0	32	0.254	0.268	0.149	0.1	0.034	1.137
U	12	4	0.016	0.016	0.011	0.02	0	0.068

TDS = total dissolved solids (electrical conductivity)

Although PHCC toxicities are described by quantitative structure-activity relationships, allowing for predictable responses from chemical exposure, many expressions of toxicity are generic, with low-dose, long-term exposure characteristic of the rural communities. These are also more relevant, causing subclinical responses to exposure, with adverse effects primarily attributed to chronic, secondary induced deficiencies. A major challenge is to adequately define the criteria for identifying these disturbances and detecting the primary toxicity. Although effects tend to be non-specific, they have significant impacts on health and productivity. An additional concern is that some PHCC have the ability to produce adverse, long-term effects through mobilization after exposure has ceased (e.g. lead). The localised nature of the causative geochemical anomalies poses a challenge to community epidemiologists, animal scientists and veterinarians because of the difficulty in establishing a clinical reference point. The cumulative nature of the observed PHCC highlights the need for water quality monitoring, linked to clinical biochemistry and pathological investigations as a vital means for using retrospective identification of causative factors in proactive risk

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management. The use of animals to monitor biochemical trends is of great value in this regard. It follows that the indigenous goat, due to the shared exposure, economical importance and as a food source for humans may serve as an ideal animal model that can be used to obtain rapid evidence critical to community epidemiology, thereby constituting an integral part of rural public health.

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