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Radon, Salinity and Elemental Concentrations of Water Sources within the Kuiseb and Cuvelai-Etosha Basin, Namibia

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ABSTRACT

The absence of baseline information on radon measurements and concerns about possible consequences of long term exposure to high radon (Rn^{-222}) concentrations and its progenies necessitated for the evaluation of radon concentrations in boreholes and households. This study thus investigated the levels of Radon gas (Rn^{-222}), salinity and elemental composition of different water sources (tap-water, boreholes and surface water) within the Kuiseb and Cuvelai-Etosha basin, in order to address the lack of scientific correlational studies on radon levels and toxic trace elements in drinking water. Radon concentrations were measured using an AlphaGRAUD PQ2000 PRO system, and the elemental composition was determined using a NexION 350D Inductively Coupled Plasma Mass Spectrometer. The findings of this study showed high (2.71 Bq/m^3) Rn^{-222} concentrations in the Kuiseb (possibly caused by natural uranium ore deposits in the Erongo Region) compared to the 0.43 Bq/m^3 average in the Cuvelai-Etosha Basin. The study also measured high salinity (63 $^{0}/_{00}$) concentrations (linked to high Total Dissolved Solids of 25.46 g/L) in the Cuvelai waters compared to the (37 $^{0}/_{00}$) salinity (with low TDS of 3.8 g/L) in the Kuiseb, thus pointing to the geological and meteorological make up of Cuvelai i.e. Kalahari sedimentary rocks, runoff sediments, high temperature and evaporation rates, as well as alternating floods and drought (rainfall variations). The elements observed in significantly high concentrations include Ba, K, Sb, As, Cd, Cr, Cu, Mo, Ni, V, Zn and Bi in the Kuiseb, and Ca, Cl, Mg, Na, Al, Be, Br, Ce, Cs, Fe, Pb, Mn, Se, Ti in the Cuvelai-Etosha Basin. Further, the Cuvelai-Etosha proved to have more anthropogenic activities (including burning of vegetation) influencing the elemental composition, and causing deterioration of the water quality.

1. Introduction

The occurrence of surface water is often seasonal, mainly available during the rainy seasons, equally a small part of the rainfall permeates into groundwater reserves. Furthermore, groundwater may portray high rates of salinity such that the end-water is too saline for consumption (Shanyengana, 2002). The same can be said for the Kuiseb and Cuvelai-Etosha Basins.

The northern part of the Kuiseb basin is dominated by schist rock which can be reflected in the hydrology and hydrochemistry as there is a low yield and a lower groundwater quality due to high salinity contents in the water (Falke & CIM-Consultant, 2008). The quality of groundwater in the Kuiseb is highly depended on recharge and geological conditions. Similarly, the Cuvelai-Etosha basin is devoid of water bodies and groundwater is often saline. In some places the salt content of the groundwater is even three times higher than seawater. During dry seasons, the water becomes saltier due to evaporation and hydraulic links to the saline ground water (Kluge & Krug, n.d).

Another aspect worth noting is elemental composition which is likely to have an impact on water quality. Concentration levels of trace elements have been known to pose potential health risks to man (Alexander, 2013).

Studies show that more trace elements occurred at greater concentrations in wells in drier regions (Ayotte, Gronberg, & Apodaca, 2011). Furthermore the depreciation of water quality is not only affected by climatic conditions, salinity or trace elements, but there are other factors such as radionuclides. For example the presence of uranium and radon in groundwater at high concentrations can affect human health.

Namibia has a large number of uranium occurrences and deposits in several geological environments, ranging from the most prominent geological type of these is the unique, granite rock related uranium occurrence in the central part of Namib Desert, to calcrete and permo-triassic age karoo sandstone (Palfi, n.d). However, the impacts of geogenic and anthropogenic activities may include, land destruction, change in air quality and water contamination.

In nature, absolute closed systems rarely exist, and predictions regarding radionuclide concentrations in water bodies invariably include considerable uncertainties. Generally, radionuclides and their decay products are found in groundwater in element-specific concentrations, dependent on complex hydro-geological processes and conditions, including dissolution rates, transport and ion-exchange processes, among others (VO Consulting, 2010).

Radon is a radioactive gas which is formed during the decay of uranium-238 and on decaying, it produces solid heavy metal radioactive particles of polonium, lead and bismuth which can exist as respirable sized particles and sometimes ingested through drinking water (Southern African Institute for Environmental Assessment, 2010). It is found ubiquitously as a part of our environment; hence no area on earth can be completely safe from radon gas. Moreover, radon concentration intensities rest strongly on geological and geophysical conditions, as well as on atmospheric factors such as rainfall and temperature (Ur-Rahman, 2010).

Radon can enter homes via the drinking water supply (Environmental Services, 2014). Groundwater dissolves radon from uranium-containing rock, resulting in generally higher concentrations of radon in well water compared with drinking water derived from surface waters (National Research Council, 1999).

The study therefore was aimed at addressing the limited level of knowledge and limited scientific studies on radon concentrations. In addition, heavy metals are amongst the most persistent pollutants in aquatic ecosystems because of their resistance to disintegration in natural conditions (Khan, 2011). Hence it is vital to assess presence of these elements in drinking water (Kuiseb and Cuvelai-Etosha Basins). The findings of the study may play a role in informing policy decisions planning of water augmentation programmes.

2. Materials and Methods

2.1 Description of Study Sites

There are 11 recorded river basins in Namibia of which only two basins were considered for the study; namely the Kuiseb and Cuvelai-Etosha Basins. The two regions in question where purposively selected for the study. The Kuiseb basin, is considered as a "Uranium Province". On a contrary, the Cuvelai-Etosha, there are no Uranium mining. Both basins highly depended on groundwater.

The Kuiseb River is one of the four rivers in Erongo region and forms part of the Khomas region (IWRM Joint Venture Consultants, n.d). The basin is divided into three zones; the upper part consists mainly of the highlands and commercial farms, the middle part has the Namib-Naukluft Park and small scale farmers (predominantly Topnaar communities), and the lower part entails Walvis Bay and surrounding areas. The water in the basin is a result of rainfall and runoff activities (Heyns & van Vuuren, 2009). Kuiseb River houses two aquifers which are located in the lower basin area at Swartbank and Rooibank. Table 1 shows the sampling points for this study.

Cuvelai-Etosha Basin is located in the north-central part of Namibia extending across four regions, namely Ohangwena, Omusati, Oshana and Oshikoto. The basin is further divided into four sub-basins, namely, Olushandja, Iishana, Nipele and Tsumeb (IWRM Joint Venture Consultants, n.d). Groundwater in the basin is mainly abstracted from the Ohangwena Kalahari Aquifer and the Discontinuous Perched Aquifer (where fresh water is only found in certain parts of the aquifer) by means of boreholes. Wells are used to supply water, especially to isolated villages in the basin (IWRM Joint Venture Consultants, n.d). Generally, the quality of groundwater is poor (saline water) except the Tsumeb Karst has good groundwater quality.

2.2 Sampling and Analyses

A total of 56 sampling points were considered of which 25 sampling points were from the Cuvelai-Etosha and 31 were from the Kuiseb basin in 2015. Physical parameters (temperature, Total Dissolved Solids (TDS), salinity and conductivity) were measured onsite using a portable HQ40d Dual Input Multi-parameter instrument.

Elemental concentrations were determined using Inductively Coupled Plasma Mass Spectrophotometer (ICP-MS), following EPA Method 200.8 (model NexION 300D/350D) in Standard, Collision and Reaction Modes as described by Pruszkowski & Bosnak (2014).

Radon measurements were done onsite using an ALPHAGRAUD instrument and the radon data were downloaded using DATAEXPERT software.

The radon concentration in water samples is based on the radon concentration indicated on the radon monitor. The measured value in sample at this stage is not yet the actual radon concentration in the measured samples. This is because the radon driven out is diluted by the air within the measurement set-up and a small part of the radon remains diluted in the watery phase. To quantify the dilution effect, the exact interior volume in the measurement set-up (V_{system}) is necessary. The quantity of radon remaining in the sample can be determined by the introduction of the distributing coefficient which describes the temperature dependent quantity of the sample which remains chemically dissolved. Hence the general approach as presented in Equation (AquaKI, n.d).

$$C_{water} = \frac{C_{air} \times \left(\frac{V_{system} - V_{sample}}{V_{sample}} + k\right) - C_0}{1000}$$

where, C_{Water} is Rn concentration in water sample (Bq/L), C_{Air} is the Rn concentration (Bq/m³) in the measuring set-up after expelling the radon, C_0 is Rn-concentration in the measuring set-up before sampling (zero level) (Bq/m³), V_{system} is interior volume of the measurement set-up (mL), V_{Sample} is volume of the water sample (mL) and k (0.26) is the Radon distribution coefficient.

Rn is an abbreviation which is used to denote radon.

3. Results

3.1 Radon Concentration

Radon measurements were taken from 13 sampling points (n = 13) in the Kuiseb and 17 points (n = 17) in the Cuvelai. The average Radon concentrations where higher (2.71 Bq/m³) in the Kuiseb (Figure 1) than the Cuvelai (Figure 2) which recorded 0.43 Bq/m³.

Figure 1: Radon concentrations of groundwater (except MSIG, which is a tap water source) in the Kuiseb Basin.

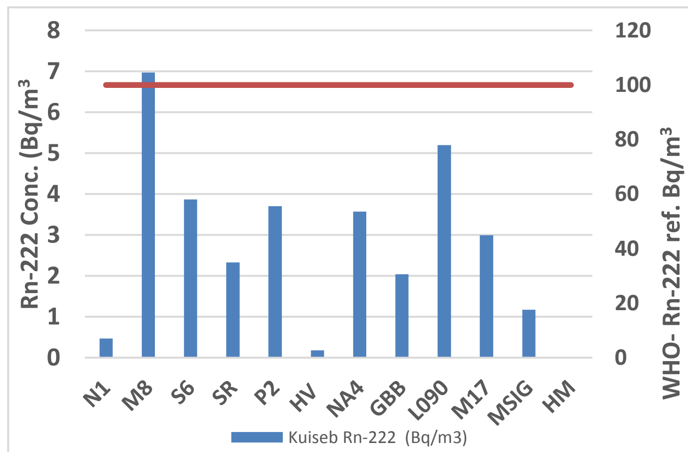
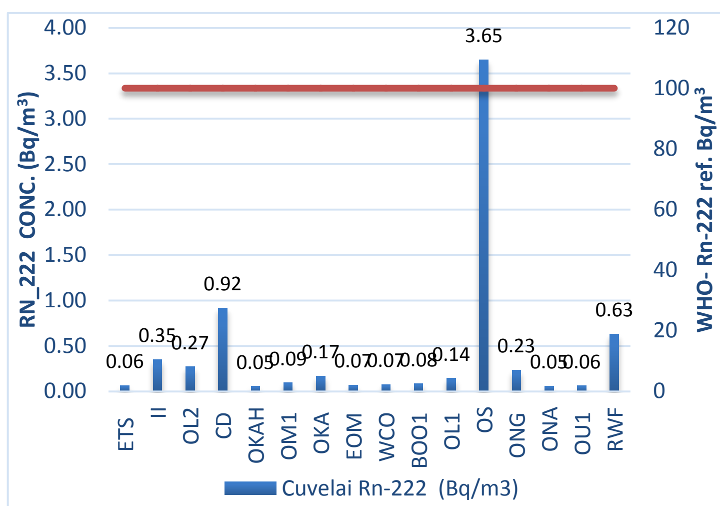


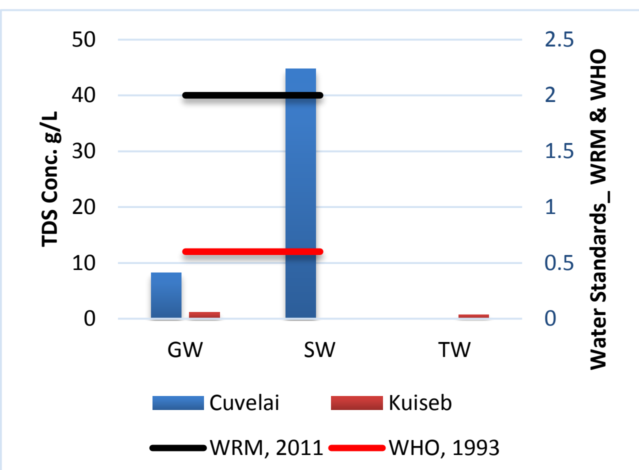
Figure 2: Radon concentrations in groundwater (OS, BOO1, OM1), tap water (OL2, OKAH, OL1, ONG) and surface water in the Cuvelai Basin.



It is worth noting that the geological setting (granitic rocks) could be the cause of high Radon concentrations in the Kuiseb; the Cuvelai-Etosha on the other hand, is dominated by Kalahari sedimentary rocks (Roesener & Schreuder, n.d). Also, the different water sources in each basin (i.e. closed water points in different households (groundwater) in the Kuiseb and surface water in the Cuvelai) could be responsible for the high concentrations in the Kuiseb (Ur Rahman, 2010).

A correlation analysis of four uranium decay chain elements and radon gas in water was performed to determine the correlation. There is no significant relationship between the elements in the uranium decay chain and radon gas [Pb-Rn r (10) = -0.35, P = 0.26; Bi-Rn r (10) = -0.26, P = 0.42; Th r (10) = -0.26, P = 0.41; and U-Rn r (10) = -0.21, P= 0.52] Although the correlation matrix did not show any significant relationship between radon gas and uranium decay elements, a negative relation is observed. The negative relation is expected in the decay chain, as elements disintegrate, there would be a decrease and increase of elements down the decay chain.

Figure 3: Salinity levels of the Cuvelai study sites



3.2 Salinity Levels

The salinity concentrations for the sampling points within the basins is shown in Figure 3 and 4. In general, the Cuvelai-Etosha basin has a 63 $^{0}/_{00}$ salt content, which is higher than the Kuiseb (37 $^{0}/_{00}$) as percentage difference between the two basins salinity across each basin was summed to get an aggregate percentage per basin.

Figure 4 Salinity levels of the Kuiseb study sites.

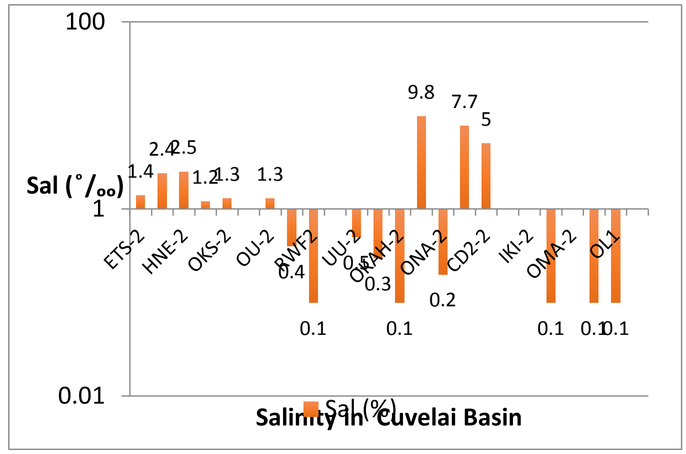
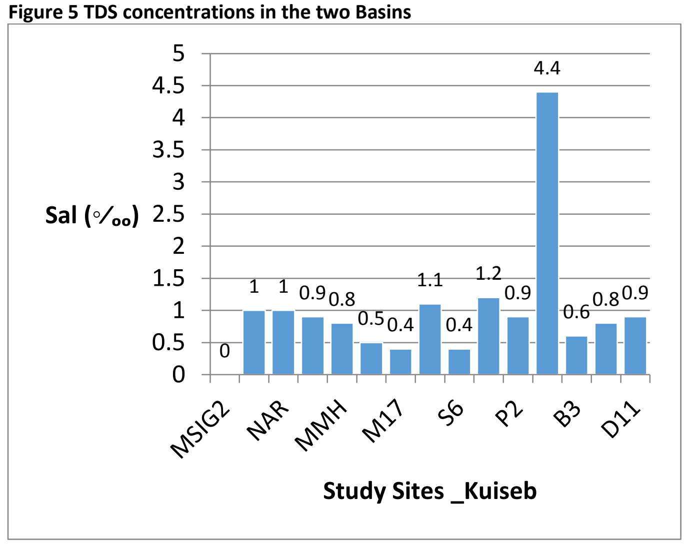


Figure 5 TDS concentrations in the two Basins



The high salinity levels in the dams and boreholes can be linked to the total dissolved solids (Figure 5) in the water as well as the geological makeup of the area. This is because salinity is associated with the amount of dissolved ions.

Pearson correlation of the different parameters in the Cuvelai-Etosha Basin yielded r = 0.77, P = 0.00 for salinity and electrical conductivity. The Kuiseb samples showed correlation between some variables like conductivity, TDS and salinity, using Pearson correlation matrix. The Cuvelai-Etosha basin has higher concentration levels of TDS than that of the Kuiseb basin. The Cuvelai-Etosha mean TDS concentration is 25.46 g/L and it is approximately 6 times greater than the concentration of 3.87 g/L recorded in the Kuiseb basin. The Cuvelai is mainly made up of limestone, dolomite and Kalahari sediments (unconsolidated to semi-consolidated sand, gravel and silt and calcrete) (Mendelson, Jarvis, & Robertson, 2013). On the other hand, the Kuiseb basin ('Uranium Province') made up of metamorphic sedimentary rocks with granite intrusions (Mendelsohn, 2000). is situated in the western part, much of the region is however occupied by the Namib Desert that stretches parallel to the coast about 120-150 km inland.

The Cuvelai Basin had a high average conductivity level of 0.025 mS/m compared to the Kuiseb Basin (0.018 mS/m). Conductivity is affected by inorganic substances dissolved in the water. Moreover, the EC of water can primarily be affected by the geology of the area through which water flows. Areas with granite bedrock tend to exhibit lower conductivity because granite composition is made up of inert materials that do not dissolve into components once washed into water. Environments with clay such as the Cuvelai constitute higher conductivity levels. Hence, the significance of measuring conductivity to determine the suitability of water for its intended use (Sarda & Sadgir, 2015).

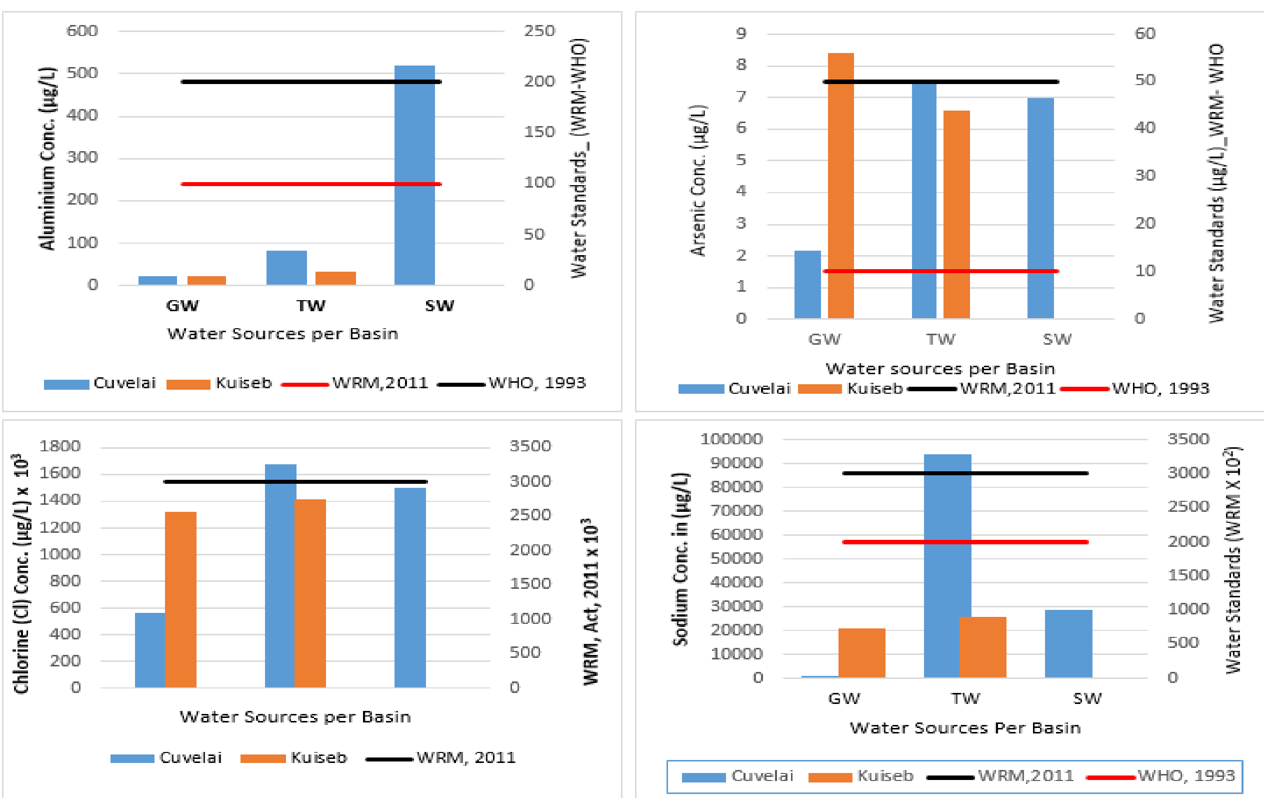
3.3 Elemental Composition

The average elemental concentrations for Ba, K, Sb, As, Cd, Cr, Cu, Mo, Ni, V, Zn and Bi were higher in the Kuiseb, while the Cuvelai-Etosha measured higher concentrations for Ca, Cl, Mg, Na, Al, Be, Br, Ce, Cs, Fe, Pb, Mn, Se, Ti and U. Figure 6 shows a comparison of selected elements to the standards.

The results show that the following sites in the Cuvelai-Etosha basin exceeded the aluminum standards: Ondihaluka (2 946.25 µg/L); Onghenga (702.36 µg/L); Okankolo (116.55 µg/L); Okalongo (742.46 µg/L); Onankali (1 975.76 µg/L) and Iikokola (444.44 µg/L)).

The different sites for the Cuvelai-Etosha did not exceed the arsenic (As) limit of not more 50 µg/L (As) set in the WRM Act, 2011. However, Outapi (31.97 µg/L), Onguma (19.17 µg/L), Crow's Dam (15.72 µg/L), Okankolo (12.74 µg/L), Oluno (12.56 µg/L) and Etope (10.24) exceeded the WHO guideline 10 µg/L (As). The presence of arsenic in drinking water is a concern as it has been documented by the International Agency for Research on Cancer (IARC) as a carcinogen in humans (International Agency for Research on Cancer, 1988). Humans may be exposed to arsenic in water from wells drilled into arsenic-rich ground strata or in water contaminated by industrial or agrochemical waste.

Figure 6 Elemental Concentrations exceeding the set standards



The results show high concentrations of chloride (Cl^-) recorded in 11 out of 19 boreholes exceeded the standards. Chloride in water at a concentration of about 250 mg/L leads to water being unpotable due to the salty taste and may become aesthetically undesirable for consumption (WHO, 1993).

4. Discussion

The varied geological setting of the two basins, i.e. granitic rocks for the Kuiseb and Kalahari sedimentary rocks in the Cuvelai could account for the higher levels of Rn in Kuiseb than the Cuvelai-Etosha (Roesener & Schreuder, n.d). Furthermore, water sources sampled from in the Cuvelai are surface water (open sources) and Rn is likely to aerate out into the atmosphere; while the Kuiseb water points were mainly groundwater, thus accounting for high Rn concentrations because water is enclosed, and so is the radon gas (Ur Rahman, 2010).

The high salinity in Cuvelai-Etosha may be due to the abundant limestone, dolomite and calcrete (unconsolidated to semi-consolidated sand, gravel and silt) (Shuuya, 2008). Also, Harbeck (1995) indicated that there is a relationship between evaporation and salinity; hence high evaporation rates affect the salinity contents in a water body. Moreover, water flow in the Cuvelai is seasonal. Hence, Cuvelai water harbours much mud and sediments which in turn is deposited as clay and the clay limits filtration leading to more evaporation (Mendelson, Jarvis, & Robertson, 2013). This process leads to increase in salinity concentration in water bodies and the likelihood of lessened quality for human consumption in the basin.

The total dissolved solids (TDS) can be related to the geology of the area in which the water sources are found. Geologically, the Cuvelai is made up of sand, sandstone and calcrete. Calcrete contains salt compounds such as calcium carbonates, sulphates and phosphates that may be dissolved in the water making it saline. Most of the standards were met, however, results show that arsenic, and chlorine and boron concentrations were elevated in some households and hence did not comply with the standards. Arsenic, which is highly toxic to humans, is widely strewn in the earth crust and commercially used for various purposes. The arsenic can be introduced into the water bodies or distribution systems through minerals and ore dissolution, atmospheric deposition and industrial effluent (Smedley and Kinniburh, 2002). There are other factors that aid the release of arsenic on a large scale in groundwater. In areas where groundwater flow is sluggish, arsenic is released from sediments flowing from burial and has been able to accumulate in groundwater. Also pH conditions > 8.5 in semi-arid/ arid environments as a result of collective effects of high evaporation rates, mineral weathering and strong reducing conditions at near neutral pH values leads to desorption of arsenic (As) mineral oxides (Jack et al, 2003).

5. Conclusion

The study recorded high Radon concentrations (2.71 Bq/m^3) while the Cuvelai concentrations recorded 0.43 Bq/m^3.The Cuvelai-Etosha basin has higher salt concentrations in the water of 63 $^0/_{00}$ than the Kuiseb (37 $^0/_{00}$). The elemental concentration standards were also exceeded in the Cuvelai study sites. The Cuvelai-Etosha waters are more saline than that of the Kuiseb, mainly due to its geological characteristics and climatic conditions such as high evaporation rates and low rainfall returns in the region. Although average radon levels are relatively low in both Water Basins (Cuvelai-Etosha & Kuiseb), which is a positive finding, it is imperative that further studies are conducted on the subject of radon in Namibia to close the gap of lack of scientific data and information. Since a large portion of the population is highly dependent on groundwater, it is vital that these sources are well managed for protection against any form of contamination. Cuvelai waters harbours a lot of mud and sediments which in turn are deposited as clay which limits filtration .This process however leads to increase in the salinity concentration in water bodies and the likelihood of lessened quality for human consumption in a basin.

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ADDITIONAL MATERIALS

Table 1A: Sampling points used for the study

	Kuiseb Basin		**Cuvelai-Etosha Basin**	
	Code	**Location**	**Code**	**Location**
1	SW	Seawater	ON1	Ondihaluka (surface water)
2	GBB	Gobabeb (borehole)	HNE	Helao Nafidi (surface water)
3	HM	Homeb Mine (Spring)	OHE	Onghenga Etale surface
4	HV	Homeb Village (borehole)	OKS	Okalongo (surface water)
5	N1	Natab 1 Village (borehole)	EOM	Etaka (Onesi) (surface water)
6	N2	Natab 2 (borehole)	RWF	Raucana Waterfalls (surface water)
7	SR	SoutRiver (borehole)	WCO	Canal (downstream) (surface water)
8	KN	Klipneus (borehole)	ETS	(Etope) (surface water)
9	SB	Swart Bank (borehole)	BOO	Outapi (groundwater)
10	U	Utusib Clinic(household)	UU	Uuyoka/Onlondo (surface water)
11	UR	Ururas Village (borehole)	OKA	Okankolo (surface water)
12	IK	! Khaodanab (household)	OKAH	Okankolo (household)
13	RB	Rooi Bank (household)	ONA	Onankali (surface water)
14	GBBH	Gobabeb (household)	OS	Oniipa Spring
15	MSIG	Meersig (household)	II	Dam iipanya
16	NHE	Kuisebmund (household)	IKI	Iikokola (household)
17	ERF 5504	Ndamona (household)	ONG	Onguma (household)
18	MMH	Mola Mola (household)	OMA	Omapalala (household)
19	ERF 6226	Opposite W/bay School	HOC	Near Oniipa church (household)
20	NAR	Narraville (household)	OL1	Oluno1 (household)
21	M8	Swart Bank (borehole)	OL2	Oluno2 (household)
22	M17	Swart Bank (borehole)	ETS	Etope, Ohangwena (surface water)
23	S6	Swart Bank (borehole)	OU	Outapi (Surface water)
24	NA4	Swart Bank (borehole)	OM1	Omutele (groundwater)
25	LO90	Swart Bank (borehole)	CD	Crow's Dam (surface)
26	P2	Rooi Bank (borehole)		
27	A2	Rooi Bank (borehole)		
28	B3	Rooi Bank (borehole)		
29	B5	Rooi Bank (borehole)		
30	D11	Rooi Bank Dorop (borehole)		
31	A5	Rooi Bank (borehole)		

Table 2A: Salinity levels for the two basins

	Cuvelai-Etosha			Kuiseb		
Water source	SW	GW	TW	SW	GW	TW
Minimum (Salinity $°/_{00}$)	0.1	7.7	0	-	0.4	0
Maximum (Salinity $°/_{00}$)	5	9.8	0.1	-	4.4	1
Average	1.12	8.75	0.05	-	1.12	0.74

The salinity levels per type of water (groundwater (GW), households tap water (TW) and surface water (SW) is given in Table 2.