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Assessment of quality of water provided for wildlife in the Central Kalahari Game Reserve, Botswana

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A R T I C L E I N F O

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A B S T R A C T

Arid and semi-arid environments have low and unpredictable rainfall patterns resulting in limited availability of surface water for wildlife. In the Central Kalahari Game Reserve (CKGR) wildlife populations have lost access to natural surface water through cordon fences, livestock and human encroachment along the access routes. Artificial waterholes have been developed in the reserve to compensate for this loss. However, there have not been any assessments of the quality of water provided for wildlife and how that may be contributing to populations declines in the CKGR. We assessed water quality from 12 artificial waterholes against both Botswana and international livestock standards for drinking. Overall the quality of water provided is poor and poses a health risk to both animals and humans. Eight out of twelve boreholes tested exceeded the maximum acceptable Total Dissolved Solids (TDS) limits while three and four boreholes have toxic levels of lead and arsenic, respectively. Thus, pumping ground water could have more negative than positive impacts on wildlife thus defeating the intended management purpose. Failure to provide water of acceptable quality is a major concern for wildlife management in the CKGR and it may underlie some wildlife declines in the reserve. These findings confirm that restriction of populations from natural water sources create complex management challenges, especially where safe and sustainable alternative sources are scarce. Restriction of access of the population to natural water sources by fences and provision of poor quality water could compromise the overall fitness of wildlife populations and contribute to their decline.

1. Introduction

Arid and semi-arid environments have low rainfall and prolonged hot and dry periods. Wildlife populations in these environments are limited by access to water within commutable distance from food resources (Rosenstock et al., 1999). Similarly, natural surface water in the Central Kalahari Game Reserve (CKGR) is very limited and only available in pans for a short time with no natural surface water available in the reserve for most of the dry season, as is typical of the Kalahari ecosystem. Habitat loss and fragmentation have deprived wildlife populations' access to key water resources outside the reserve, which has resulted in drastic declines of herbivore populations, especially during drought periods (Williamson et al., 1988). Wildebeest in the Kalahari depended on the Boteti river system during drought, but this resource was cut from the population by veterinary cordon fences since the late 70s (Owens and Owens, 1984). Artificial waterholes were developed since 1984 (Bonifica, 1992) in the reserve to increase the viability of wildlife populations by compensating for lost access to permanent water sources outside the reserve.

Worldwide, development of artificial water for wildlife has become a major management intervention to address effects of habitat loss, especially in arid and semi-arid environments (Dolan, 2006). However, this has not been without controversy and criticism, particularly on its effects on distribution and movement of wildlife (Smit et al., 2007), decline of some rare species (Harrington et al., 1999), as well as carnivore hunting strategies (Harrington et al., 1999; Rosenstock et al., 2004). Nonetheless, it possible that some ecosystems could collapse without artificial provision of water, especially where natural water has been lost or access prevented by human induced development (Williamson et al., 1988).

Both availability and quality of water have effects on population dynamics. Poor water quality has been observed to reduce reproductive rates and survival rates of animal populations, resulting in potential population declines (Pokras and Kneeland, 2009). Surprisingly, specific research on water quality and its possible effects on wildlife populations has been limited (Rosenstock et al., 1999; Wolanski and Gerata, 2001),

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therefore neglecting the potential negative effects of artificial water provision for wildlife on animal health and production (Simpson et al., 2011). Other than a limited study on total dissolved solids (TDS) of the water from the developed waterholes (Bonifica, 1992), after decades of provision of water to wildlife in the CKGR there has never been a comprehensive study conducted to investigate the quality of water at artificial water points and its impact on the ecosystem. Other water quality characteristics, such as presence of toxic heavy metals were not tested. Toxic levels of heavy metal can compromise the ability of prey to respond to potential predation (McPherson et al., 2004), thereby increasing vulnerability of prey.

Water from the boreholes is usually pumped into ponds for animals to drink. This exposes the water to seasonal atmospheric environmental variability such as wind and temperature (Vega et al., 1998), leading to evaporation into the air as well as and filtration of salts and solids as water sinks into the soil, potentially resulting in increase in the concentration of salts and other impurities that cannot evaporate or filtered into the soil. The increase in the concentration of salts may worsen the quality of the water available to animals.

There are records of elevated blood lead levels in vultures in and around the CKGR (Kenny et al., 2015). Sources of the lead have not been established. There is a strong suspicion that lead ammunitions are the source but underground water is also a possible source. Arsenic effects on humans have been well documented and it is regarded as a carcinogen (Vainio and Wilbourn, 1992; Ng et al., 2003). Effects of long term ingestion of arsenic include damages of internal organs such as kidney, liver, bladder and lungs (IARC, 2004). These effects have been reported in animals as well (Biswas et al., 2000; Ng et al., 2003). Consumption of arsenic is generally caused through drinking water (Ng et al., 2003).

Considering the potential risks of poor water quality for wildlife and its consequences for conservation, the general objective of this study was to test water quality from the artificial waterholes within the CKGR and Khutse Game Reserve (KGR) to determine whether water quality fell within recommended safety standards. The specific objectives of this study were to (1) to determine seasonal variations in water quality in the study area, (2) to compare water quality of the waterholes between the waterhole outlet and the pond, and (3) to compare water quality of the waterholes against Botswana (and international) water standards for livestock. The quality of the water from the ponds were expected to be poorer than that from the boreholes due to water evaporation and filtration of salts and other impurities. The water quality was expected to worsen in the dry season due to lack of recharge from rainfall to counteract inputs of solutes from mineralisation processes in the geosphere.

2. Study area

The Central Kalahari Game Reserve (52,145 km^2) and the Khutse Game Reserve (2550 km^2) formed the study area. The area falls within 21°00' – 23°00′ S and 22°47.5' – 25°25′ E. The study area temperatures range from −6 °C in winter to 43 °C summer, with mean annual rainfall ranging from 350 to 400 mm (DHV, 1980, unpublished). There is no permanent surface water in the reserves, but 13 artificial waterholes have been developed for wildlife (Fig. 1). The wildlife population in the area includes large ungulates such as giraffe (*Giraffa camelopardalis*), eland (*Taurotragus oryx*), blue wildebeest (*Connochaetes taurinus*), gemsbok (*Oryx gazella*), kudu (*Tragelaphus strepsiceros*) and springbok (*Antidorcus marsupialis*), and large carnivores such as lion, leopard (*Panthera pardus*), cheetah, wild dog and brown hyaena.

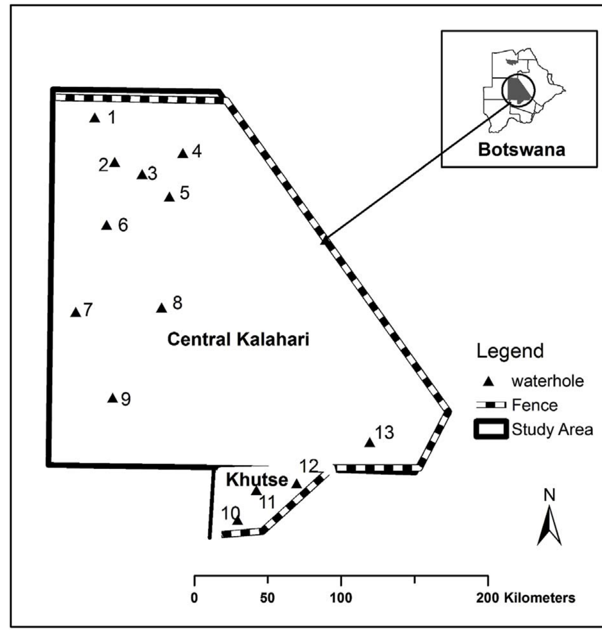

Fig. 1. Showing study area and locations of waterholes in the Central Kalahari and Khutse Game Reserves. 1 = Motlopi, 2 = Passarge, 3 = Tau, 4 = Sunday, 5 = Letiahau, 6 = Piper, 7 = Xade, 8 = Xaka, 9 = Quee, 10 = Moreswe, 11 = Molose, 12 = Khutse, 13 = New waterhole.

3. Methods

Water samples were collected from 12 of the 13 waterholes in September 2013, January 2014 and June 2014 and tested for quality. January represented the wet season, whereas June and September represented the dry season. Data collected in June was only used for Passarge waterhole because the waterhole was dry in September sampling. The 13th waterhole (labelled 13 in Fig. 1), was new (and not currently used by wildlife) and could not be reached due to logistical reasons. Three of the waterholes were within KGR and the rest in the CKGR. The quality of the water was tested by collecting samples from the ponds and outlet that releases water into the ponds. Samples were tested for pH, Electrical Conductivity and Total Dissolved Solids (TDS) using standard procedures (Rice et al., 2012) at the Okavango Research Institute environmental laboratory in Maun. Analysis for calcium, magnesium, lead and zinc were conducted using Atomic Absorption Spectrometry (AAS). A Flame Photometer was used to analyse for sodium, and Inductively Coupled Plasma Optical Emission Spectrometry (ICS-OES) was used to test for arsenic concentration. Due to lack of standards for wildlife, the water quality was compared to the Botswana Standards for livestock and poultry specification (BOBS, 2010) and international guidelines summarised by Rosenstock et al. (2004). Concentrations of TDS were compared between seasons and between water outlets and ponds of each waterhole using paired *t*-test. Lead and arsenic concentrations were not normally distributed; therefore, Wilcoxon paired test was used to compare concentration of lead and arsenic between seasons, and between outlets and ponds.

4. Results

All the artificial waterholes recorded levels of calcium, magnesium, potassium and zinc that were lower than the maximum acceptable levels (Table 1). Six of the waterholes recorded levels of sodium that are higher than the maximum limit, in at least one season. All artificial waterholes, except Letiahau, Khutse and Motlopi had pH values above the Botswana recommended range of 5.5–8.3 for livestock.

Eight out of 12 waterholes recorded levels of TDS higher than the conservative recommended limit of 3000 mg/L (Rosenstock et al., 2004), while six are above the highest recommended range (Rosenstock et al., 2004; BOBS, 2010). Only Quee, Xaka, Xade and Piper were below the TDS conservative limit (3000 mg/L). Xaka and Quee had less than 1000 mg/L TDS, whereas Khutse, Letiahau and Moreswe had over 10,000 mg/L (Fig. 2). Seasonal comparison of TDS did not show

Table 1
Showing seasonal pH, calcium, magnesium, sodium and zinc levels for water in the Central Kalahari Game Reserve. Values in bold were above maximum acceptable limits. Values in parentheses represent maximum acceptable limits.

	EC		pH		Ca		Mg		Na		Zn	
	(7800 μS/cm)		(5.5–8.3)		(700–2000 mg/L)		(400 mg/L)		(2000 mg/L)		(20–50 mg/L)	
	Wet	Dry	Wet	Dry	*Wet*	*Dry*	Wet	Dry	*Wet*	*Dry*	*Wet*	*Dry*
Sunday	x	**17,750**	x	**8.39**	x	3.72	x	11.39	x	**3059.01**	x	0.01
Passarge	**13,130**	**13,280**[a]	**8.87**	**8.62**[a]	7.31	7.43[a]	3.267	2.89[a]	**3163.36**	**2927.29**[a]	0.01	0.01
Tau	**5840**	**6240**	**9.11**	**9.28**	3.52	1.42	1.051	0.38	1227.57	1220	0.01	0.06
Letiahau	**22,700**	**23,800**	8.00	7.45	386.65	314.64	91.9	86.54	**4721.44**	**3848.43**	0.02	0.08
Piper	3640	3810	8.26	**8.82**	3.67	2.78	3.678	5.10	736.54	819.03	0.00	0.05
Xade	2500	2600	**9.00**	**9.29**	1.30	1.03	0.241	0.27	585.46	562.46	0.00	0.05
Xaka	1067	1120	8.30	**8.96**	1.24	0.60	0.374	0.39	264.40	215.03	0.00	0.00
Khutse	**21,900**	**23,000**	8.15	7.67	386.90	279.25	178.15	179.89	**4627.01**	**4835.21**	0.03	0.12
Molose	**7010**	**7260**	**8.39**	**8.04**	14.84	11.64	3.466	4.01	1558.07	1539.37	0.00	0.08
Moreswe	**18,470**	**25,300**	**9.08**	**9.26**	2.07	1.62	1.183	0.83	**4202.08**	**4835.21**	0.02	0.08
Motlopi	**11,880**	12,440	8.09	7.91	105.72	81.21	104.76	113.34	**2407.93**	1776.20	0.02	0.07
Quee	1050	1093	8.06	**8.35**	9.48	8.25	6.775	6.67	221.91	226.96	0.00	0.06

X there was no water coming out of the waterhole.
[a] Sampled in a June 2014 because the waterhole was dry in the September sampling.

significant difference between wet and dry season ($t = -1.64$, $df = 10$, $p\text{-value} = 0.1322$). However, the TDS concentration was higher in the ponds than in the waterhole outlet ($t = -2.3472$, $df = 9$, $p\text{-value} < 0.05$).

Sunday, Khutse, Letiahau and Moreswe waterholes had higher levels of lead than the maximum limits (Fig. 3). Lead concentrations were not different between the wet and dry season ($t = -0.44042$, $df = 10$, $p\text{-value} = 0.669$). The dry season levels for Khutse, Letiahau and Moreswe were more than twice recommended limit. Concentrations of lead between ponds and waterhole outlets were not different ($V = 21$, $p\text{-value} = 0.5382$).

Arsenic levels for all the waterholes were above the most conservative guidelines of 0.02 mg/L (Rosenstock et al., 2004). Piper, Tau and Moreswe waterholes were above Botswana's recommended limits (0.2 mg/L). None of the waterholes were above highest recorded maximum acceptable limit of 0.5 mg/L (Fig. 4). There was no difference between the wet and dry season concentration of arsenic in the water ($t = 0.55902$, $df = 10$, $p\text{-value} = 0.5884$). Arsenic concentrations were not different between ponds and waterholes outlets ($V = 19$, $p\text{-value} = 0.4316$).

5. Discussion

Most of the boreholes in the study area exceeded the conservative TDS and pH limits. TDS and pH are commonly used as easily measurable indicators and monitoring parameters of water quality (www.safewater.org). TDS is regarded as a measure of ions in water and these can be contributed by calcium, magnesium, sodium, and potassium cations and carbonate, hydrogen carbonate, chloride, sulphate, and nitrate anions. Elevated TDS may not necessarily mean a health hazard. Water taste deteriorates with increasing TDS and water with high TDS is less preferred by both humans and wildlife. Furthermore, very high concentration of salts in water will not be helpful for quenching thirst (Sengupta, 2013). Our results show that the salinity of the water was high in the ponds compared to the outlets. This is probably due to accumulation of salts because of evaporation of water, and in some cases, poor filtration due cemented bases of some waterholes.

Some of the waterholes have high levels of heavy metals (lead and arsenic) thus exposing animals to toxins. Lead is known for health risks such as neurological impairment and malfunctioning of the central nervous, digestive and circulatory system (Ekong et al., 2006; Pokras and Kneeland, 2009). Unfortunately, most of these studies were on

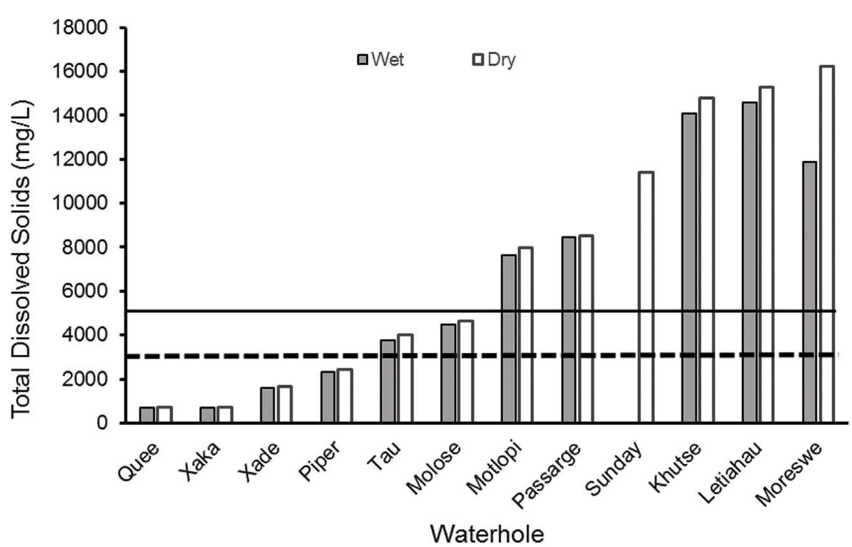

Fig. 2. Seasonal values for Total Dissolved Solids for the Central Kalahari/Khutse Game Reserve. Dotted and solid horizontal lines show recorded ranges of maximum acceptable limits, respectively (3000 and 5000 mg/L).

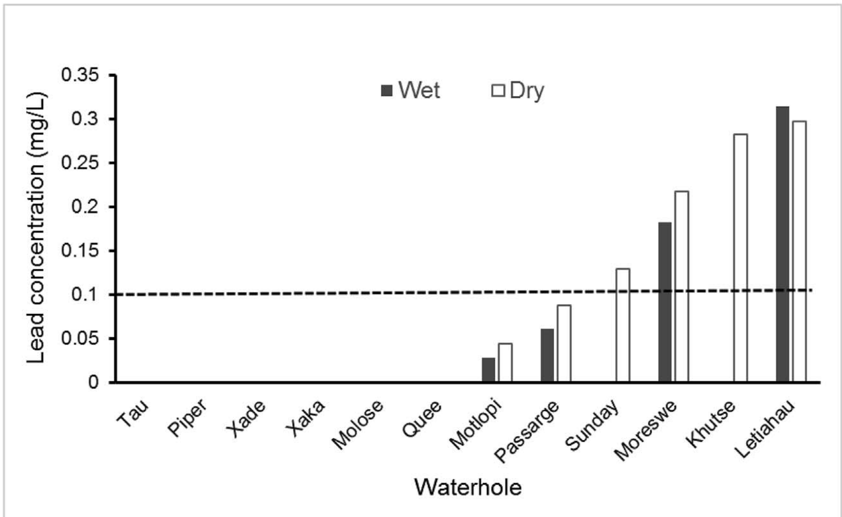

Fig. 3. Dry season values for lead for the Central Kalahari/Khutse Game Reserve. Dotted horizontal lines show maximum acceptable limits (0.1 mg/L).

human health. Nevertheless, Pokras and Kneeland (2009) rightfully highlighted that our understanding of effects of lead on humans can help us to protect non-human species. We therefore assume that the effects on humans may as well be presented on animals, though, not at the same magnitudes. In their review, Pokras and Kneeland (2009) revealed that exposure to lead can interfere with mental processes and behaviour that are critical to reproductive success of animals. Furthermore, birds that ingest lead are known to suffer negative effects such as an impaired digestive system (de Francisco et al., 2003). Vultures in Botswana have elevated blood lead concentration in 30% of vultures tested (Kenny et al., 2015), and it is currently unclear what has caused these elevated levels. Coincidentally, most of the waterholes that had high levels of lead (Letiahau, Khutse and Moreswe), had very high levels of salinity (TDS). The high salinity of the water my discourage animals from drinking the water, therefore reducing their chances of exposure to lead. Unfortunately, limited options of water sources may force the animal to drink the saline water, exposing the animals to lead poisoning. Some waterholes Arsenic content is high, even compared underground water in the Okavango that recorded a maximum of 0.0116 mg/L (Huntsman-Mapila et al., 2006). Arsenic is classified as a carcinogen and has effects such as increased prevalence of cancer; vascular, cardio- and cerebro-vascular diseases; injury to the nervous systems (Biswas et al., 2000; Thomas et al., 2000; Ng et al., 2003). Thus exposure to this heavy metal may pose health threat to wildlife populations.

Overall the water provided in the CKGR for wildlife has poor quality and may pose a health risk to both animals and humans. It is key to note that water in artificial water points is pumped from deep ground water, which would not be accessible to wildlife under natural conditions; hence the argument that wild animals would be better adapted to saline water than livestock or humans does not hold. Among the Kalahari ungulates, the blue wildebeest is the least adapted to drylands (van Hoven, 1983), and provision of artificial waterholes in the reserve was primarily meant to compensate for the lost access to water outside the reserve. Studies show that wildebeest have become dependent on waterholes (Mills and Retief, 1984, Selebatso et al., 2017), especially Piper and Tau pans waterholes (Moses Selebatso, per obs), and spent most of the time around these sources. This implies that these wildebeest herds and many other wild populations such as gemsbok, giraffes, vultures, etc, are exposed to this heavy metal and may have compromised survival and reproductive rates (Biswas et al., 2000; Thomas et al., 2000; Ng et al., 2003). Hayward and Hayward (2012) also highlighted the importance of water provision in the conservation of African herbivore populations in dry savanna landscapes. A study in the Kalahari

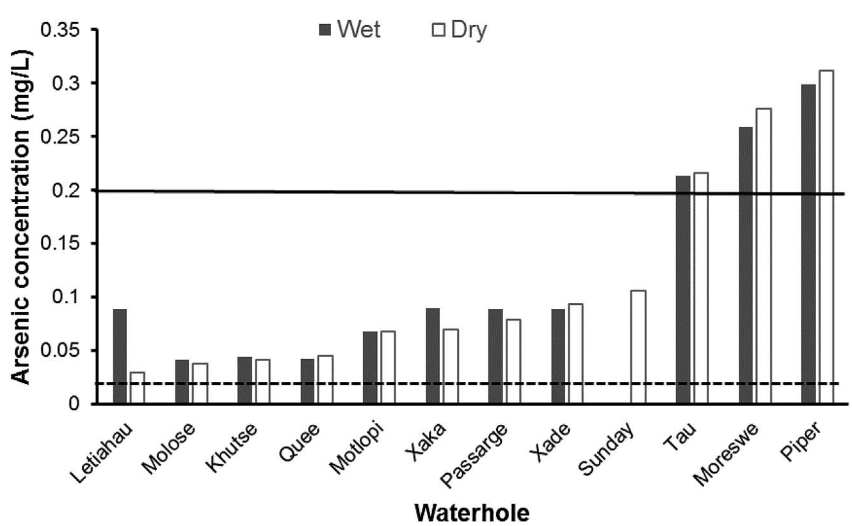

Fig. 4. Seasonal values for arsenic for the Central Kalahari/Khutse Game Reserve. Dotted and solid horizontal lines show recorded ranges of maximum acceptable limits, respectively (0.02 mg/L and 0.2 mg/L).

Gemsbok National Park (KGNP), the current South African side of the KTP, showed that animals preferred to use waterholes with better water quality than those with lower quality (Child et al., 1971), and that mortalities of wildebeest was correlated with poor water quality (Knight, 1995). Thus these findings support our concerns that wildlife is not likely to be resilient to poor water quality.

Khutse, Moreswe and Letiahau waterholes failed for most parameters measured (especially Moreswe), whilst Piper and Tau had excessive levels of arsenic, a health hazard. Thus it is clear that these waterholes need to be dealt with. Treatment of the water to improve its quality can be a very expensive. Therefore, exploration and equipping of alternative boreholes, particularly to replace Khutse, Moreswe, Letiahau and Piper would be cheaper in the long-term. Otherwise, Motlopi and Passarge water may be improved by desalination only because all other quality determinants are not as bad.

6. Conclusions

The quality of some water provided for wildlife in the CKGR is below acceptable standards and poses a health risk. The current failure to provide water of acceptable quality is a major concern for wildlife management in the CKGR and may underlie some wildlife declines in the CKGR. These findings have important implications for water provision in conservation areas, especially in semi-arid and arid regions, and calls for further research to quantify effects of water quality on wildlife and development of specific standards for wildlife. The findings also emphasize the need for water quality analysis and regular monitoring of artificial water for wildlife in semi-arid and arid environments where ground water may be saline and have toxic levels of heavy metals. These call for management intervention that involves desalination of water, seek alternative water sources and closure of those sources (particularly Letiahau, Moreswe, Sunday and Khutse) that have extreme excess of impurities. Where possible samples from animals should be tested for both lead and arsenic levels. These findings confirm that restriction of populations from natural water sources create complex management challenges, especially where safe and sustainable alternative sources are scarce. Restriction of access of the population to natural water sources by fences and provision of poor quality water could compromise the overall fitness of wildlife populations and contribute to their decline.

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