Monitoring groundwater quality in a Namibian rural settlement

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Abstract

Drinking water in rural areas is often contaminated due to poor sanitation practices, which cause problems such as diarrhea, polio and cholera. Rural water quality is a critical issue in Namibia because a great deal of the population lives in rural settlements. The aim of this study was to assess the levels of nitrate and some microbial parameters in borehole waters in 8 rural settlements in Hardap, Namibia. The tests were conducted in 2016 and the results compared to tests on the same boreholes in 2011. Parameters were determined using standard procedures. Water infrastructure and sanitation practices were also examined. Water parameters were compared to NamWater safe water drinking guidelines. The results revealed that sanitation practices need to be improved to avoid health risks. High levels of nitrate and coliform bacteria were identified as the most threatening contaminants that were determined. Water quality has deteriorated in these settlements since 2011, when only two of the boreholes yielded water unfit for drinking. In 2016 the number of unfit boreholes had increased to four. Systematic monitoring of groundwater quality, workshops on public health and sanitation practices, and improved sanitation facilities are recommended.

Key words: groundwater, microbial parameters, Namibia, nitrate, rural settlements, sanitation practices

INTRODUCTION

The quality of drinking water determines the level of community health. Good water quality is essential for the survival of mankind and the natural environment. Social welfare and economic development cannot be sustained without reliable and good quality water supplies, and this is particularly true for arid countries such as Namibia, where water resources are extremely limited and highly valued, as a social and economic good (Ministry of Agriculture Water and Rural Development of Namibia 2001).

Namibia, like many other countries, has been unable to supply its entire population with piped water, which is considered the best method of alleviating water-borne illnesses. A large portion of Namibia's population uses water from boreholes. Groundwater is rarely treated and so the cleanliness of water is a major concern.

Water and sanitation go hand in hand, so failure to provide basic sanitation and safe drinking water can have significant consequences for the health status of the population. Drinking water in rural areas is often contaminated due to poor sanitation practices, which cause problems like diarrhea, polio and cholera, especially among young children, the elderly and those with weak immune systems (Black 1993). Because of this, improved sanitation facilities are needed to ensure the good health of the rural population.

Groundwater resources are under threat from pollution arising from the low level of hygiene practiced in developing nations (Akujieze *et al.* 2003). Environmental health involves all the factors,

circumstances and conditions in the environment or surroundings of humans that can influence health and wellbeing. The neglect of rural areas in most developing countries in terms of basic infrastructure like piped water and sanitation facilities, exposes villagers to a variety of health-related problems including water–borne diseases (Punmia & Jain 1998).

According to the National Planning Commission (2007) inadequate water supply and non-functional water infrastructure continue to pose a health hazard, especially to the poor. The real challenge in Namibia lies with the lack of progress on sanitation, with only 34% of the population having access to improved sanitation as indicated in the Namibia Demographic and Health Survey of 2013 (MoHSS & ICF International 2014).

Rural water is particularly at risk of being polluted by either animal and human waste, or waste disposal. Even though permits may be issued and quality control exercised over groundwater pumping in rural areas, the quality of water consumed by the end user may be very poor. On the other hand, providing people with clean water does not mean that health and hygiene standards are immediately raised. Many water points and traditional sources are highly contaminated, and methods of transport and storage in the home can also contribute to water contamination (Du Toit & Sguazzin 1995). In the rural regions of Namibia, farming communities struggle to obtain potable water and it is a challenge to ensure that water is acceptable for human consumption. Poor sanitation practices, lack of education, geographic location and insufficient governmental communication amplify this challenge (Boutin *et al.* 2011). If solutions to the ongoing water quality and sanitation issues in rural areas are not found, other serious problems could arise such as poor public health, land degradation, soil erosion and desertification (Du Toit & Sguazzin 1995). The Namibia Demographic and Health Survey of 2013 (MoHSS & ICF International 2014) indicates that the victims of inadequate sanitation are primarily the poor in rural areas. Today access to clean water and sanitation remains a basic need for development in Namibia. The aim of this study was to evaluate nitrate and microbiological parameters in groundwater, and assess sanitation practices that might lead to groundwater contamination.

The need for groundwater monitoring

Groundwater monitoring is important because it serves as an early warning mechanism if the resource starts depleting and deteriorating, and to evaluate whether the water is suitable for use. Water quality monitoring provides information necessary for the proper management of the resource. The benefits include increased knowledge of potential dangers or risks, trends in groundwater replenishment, and changes in water quality and possible sources of pollution (World Meteorological Organization 2013).

As it is much more difficult to find permanent and suitable solutions for remote, low income and/or individual consumers, than those that can be implemented by/for higher income or bulk consumers, it remains a challenge to find the most economically justifiable solution in each circumstance. Most rural water users base their perceptions of water quality almost entirely on taste and aesthetic appearance, so that if the water tastes bad, smells or does not look good, they are inclined to say that its quality is poor. Although this might give some indication of water quality, more complex tests are needed (Tredoux *et al.* 2001). Tredoux *et al.* (2009) gave a good example of the importance of knowing drinking water status from the Gobabis district in Namibia in the 1970s, when it was reported that 25 babies died of methemoglobinemia through drinking groundwater with extremely high nitrate concentrations which led to nitrate poisoning.

To draw any meaningful management conclusion regarding groundwater quality, data must be collected and evaluated over a period of time. In Namibia, seasons with exceptionally high rainfall – e.g., 1955, 1969, 1974, and 2006 – went hand in hand with recorded cases of very high stock losses caused by nitrate poisoning (Tredoux *et al.* 2001).

In Namibia, water quality is tested and measured in compliance with the Namibian water quality standards, as recommended by its bulk water supplier (NamWater 2009). An internationally

recognized standard that is widely applied is that of the World Health Organization (WHO 2011). The objective of water quality standards is to protect public health.

Overview of 2011 case study of rural settlements in hardap region

This paper expands on data from the 2011 research conducted on the same rural settlements (Boutin *et al.* 2011). In 2011 farmsteads and surrounding communities were targeted on the basis of preliminary work by Simataa (2010) in which farms suspected of having hazardous groundwater contamination were identified. The research was conducted on the so-called Odendaal farms in the Hardap region, close to Mariental.

A major reason for choosing this study area was that the settlements are isolated and the residents relied mainly on groundwater, which made them vulnerable. The fieldwork showed that livestock and community impacts were significant causes of pollution. The aim of the research was to analyze and improve water quality and sanitation on the farms, and through interviews with farmers, meetings with local experts, and water tests, a baseline was established with social and environmental components. Working with the communities, an approach was developed to promote water and sanitation in the area, and pilot a dry sanitation system – the Otji toilet – which was installed at a farm called Nico. A list of recommendations was also developed for preventing further water contamination.

The initial task in the study by Boutin *et al.* (2011) was a baseline assessment of eight Odendaal farms, in Hardap, and the development of solutions for their water quality and sanitation issues. As part of this, infrastructure analyses, water quality tests, and community interviews were performed. The tests showed that the most threatening water quality parameters were elevated levels of nitrate and coliform bacteria, both of which can be by-products of fecal contamination.

Water from each farm was classified by chemical and bacteriological quality. Two farms were found to have acceptable water, four had water that posed a low health risk, and two had water unfit for human consumption. Although a number of parameters were taken into consideration, the poor classifications were primarily attributed to high levels of nitrate and coliform bacteria.

Visual evaluations of the water infrastructure showed that most was functional. All communities were equipped to draw and store water, and leaking pipes were the most prevalent issue, although lack of maintenance was common. Financial constraints were the major contributing factor to the lack of repairs. A more minor problem was the poor condition of reservoirs, which had many holes and needed cleaning, as also seen from previous studies by Boutin *et al.* (2011) and Simataa (2010).

Boutin *et al.* (op cit) noted that the majority in the communities believed that the water was fit for human consumption. No interviewees mentioned changes in water quality over time. Only some communities attributed instances of local sickness to poor water quality. None of the farms has waste management systems, garbage is simply burnt. All of the communities were unaware of the water contamination implications from human and livestock defecation.

Boutin *et al.* (op cit) identified some common problems caused by economic and environmental conditions. The first was high nitrate levels, which were attributed to open defecation by livestock and people over long periods of time. It was considered that environmental conditions tended to intensify this problem – e.g., in most cases, livestock pens were at higher topographic elevations than boreholes, so that nitrate-rich substances could seep into the ground and flow (with the groundwater) to the borehole. Lack of sanitation systems for humans exacerbated this contamination. The local population were very poor so most farmworkers could not afford sanitation systems, and used the bush or bucket system.

One community had a pit latrine system, but this is unsound environmentally because the feces remain in the ground causing potential nitrate contamination. Pit latrines can also lead to bacteriological problems.

Nitrate concentrations and coliform bacteria were identified as the most threatening contaminants, and arose from human/animal defecation. Six farms needed water treatment measures, and steps

were recommended to prevent further water resource contamination at the other two. It was also noted that education and community involvement are essential to improving water quality and sanitation effectively. While the communities were unaware of the causes and implications of groundwater contamination, they were willing to learn and participate in treatment and prevention (op cit).

METHODS

Study area

Hardap is one of the fourteen regions of Namibia, Mariental is its capital. The region is one of the driest in Namibia, and its resources are not only limited but also highly vulnerable to degradation. Average annual rainfall in this semi-arid to arid environment ranges from 75 to 200 mm. Rainfall is often localized and variable, and of low reliability, and occurs in the late summer. The amount of rainfall increases from south to north. Prolonged droughts are common and are considered normal (Mouton 1995).

The region's crop production sub–sector is of marginal importance due to low rainfall, poor soils and the pastoral heritage of the population. Subsidized ploughing services rendered by the government continue to ensure that small areas of maize and beans are cultivated, mainly for communal area subsistence needs. The main agro-economic activity is small scale livestock farming with more emphasis on goats than sheep (MAWF 2005).

The settlements included in this study were selected from previous work and lie along the B1 road (Figure 1).
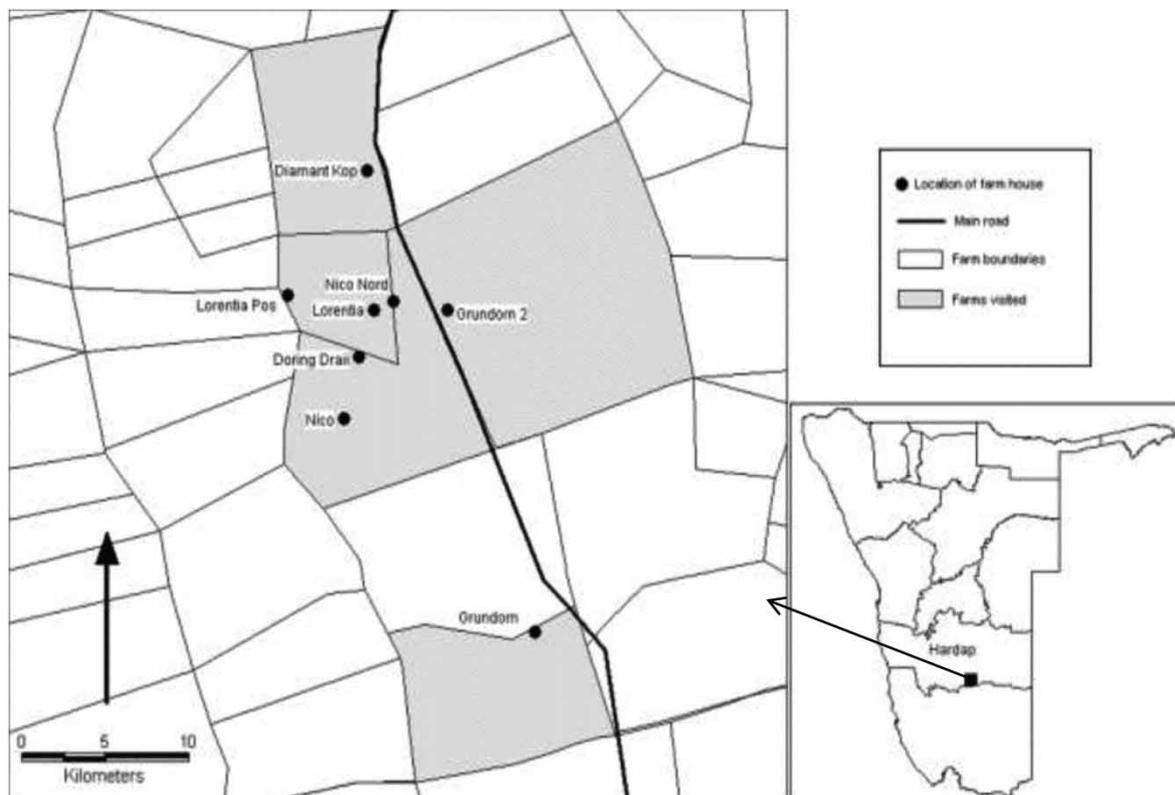

Figure 1 | The farm settlements. Diamant Kop, Lorentia Pos, Lorentia, Nico, Nico Noord, Gründorn 2, Doring Draai, Gründorn (Boutin et al. 2011).

Water analysis

The study's aim was to evaluate water quality in 2016 and compare it to that found in 2011. Water was collected in sterile bottles using the APHA (2005) safe water sampling technique. Water was tested for nitrate, total coliforms, fecal coliform, *E.coli* and Enterococci. The chemical and microbial results were compared to those given in the guidelines for safe drinking water used by Namibia Water Corporation (NamWater, 2009) (Tables 1–3).

Table 1 | Namwater water quality group description

Group	Description
A	Water with excellent quality
B	Water with good quality
C	Water with low health risk
D	Water with high health risk, or water unfit for human consumption

Table 2 | Namwater limits for nitrate in drinking water

Parameter	Unit	A	B	C	D
NO_3-N	mg/L	<10	>10 <20	>20 <40	>40

Table 3 | Limits for microbial parameters in drinking water (NamWater 1998)

Group	Determinants			
	HPC/1 ml	TC /100 ml	FC /100 ml	*E.coli*/100 ml
A	<100	0	0	0
B	>100 <1,000	>0 <10	>0 <5	0
C	>1,000 <10,000	>10 <100	>5 <50	>0 <10
D	>10,000	>100	>50	>10

HPC, Heterotrophic plate count; TC, Total coliforms; FC, Fecal coliforms.

The guideline levels are divided into four groups. The highest group to which any component is assigned determines the water's classification as a whole. Ideally water should be in group A or B. If water is classified as Group C, the situation is not critical, but attention should be given to constituents exceeding their Group B limit. If, however, the water is classified as Group D, immediate attention is required to reduce the problem constituent concentrations to safe levels.

RESULTS

Nitrate

Diamant Kop and Lorentia were the only farms that clearly breached the 40 mg-N/l mark; here it was 69 mg/l and 50 mg/l, respectively (high health risk). The nitrate levels at Grundorn (2), Nico Noord and Nico were 35 mg/l, 33 mg/l and 32 mg/l, respectively, indicating that the water on these farms needs immediate treatment to prevent further contamination. Doring Draai reported 28 mg/l, on the margin of dangerous contamination levels. The water is acceptable for consumption but measures are needed to stop or decrease pollution. Nitrate levels at Grundorn and Lorentia Pos were the lowest at 12 mg/l, indicating that the water was relatively safe to drink (Figure 2).
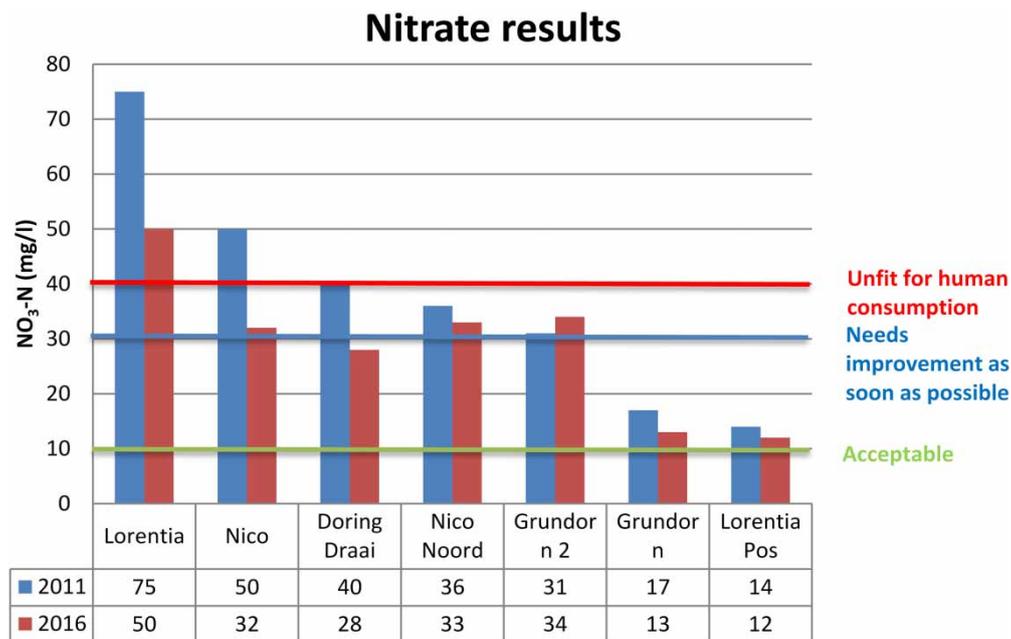
Nitrate results

Figure 2 | Nitrate results for 2011 and 2016.

Nitrate concentrations above the recommended level – 10 mg-N/l – are dangerous to pregnant women and pose a serious health threat to infants less than three to six months old, because they can cause methemoglobinemia or blue-baby syndrome in which blood loses its ability to carry sufficient oxygen (Fecham *et al.* 1986; Burkart & Kolpin 1993).

Most farms have seen a decrease in nitrate levels over the 5 year period – see Figure 2. The greatest such decrease occurred at Lorentia, where it dropped from 75 to 50 mg/l. The difference between the 2011 and 2016 nitrate levels for Diamant Kop have not been included – they are irrelevant because the 2011 results are based on NamWater's bulk water supply, not groundwater from the farm.

Microbial results

Half (4) of the groundwaters tested were unfit for human consumption (Grade D), one needed immediate treatment (C), two were categorized as of low health risk and one was of excellent quality (A) – see Table 4. The water at Diamant Kop was categorized in Group A because no bacterial parameters were found there. Waters from Gründorn and Doring Draai were categorized in Group B, with low total coliform levels. Enterococci were only detected at Gründorn at 34/100 ml, and fecal coliform and *E.coli* were absent from the waters from both farms. Nico was Group C,

Table 4 | Test results for total coliforms, fecal coliform, E.coli and Enterococci, 2016

Location	Total coliforms (count/100 ml)	Fecal coliform (count/100 ml)	*E.coli* (MPN/100 ml)	Enterococci (count/100 ml)	Grade
Diamant Kop	0	0	0	0	A
Gründorn	5	0	0	34	B
Doring Draai	4	0	0	0	B
Nico	25	0	0	4	C
Lorentia Pos	165	0	0	1	D
Lorentia	201	32	32	145	D
Nico Noord	>201	3	3	43	D
Gründorn 2	>201	5	5	>201	D

bacteriologically, because of the high total coliform levels. There were low levels of Enterococci, and neither fecal coliform nor *E.coli* were detected. The other farms – Lorentia Pos, Lorentia, Nico Noord and Gründorn (2) – were all classified Group D. Samples from Lorentia Pos reported no fecal coliform or *E.coli*, and Enterococci levels were very low, but the total coliform count was high (165/100 ml). Samples from Lorentia reported high quantities of all bacterial parameters, apart from Enterococci. Nico Noord had extremely high levels of total coliforms and relatively high levels of Enterococci, with low fecal coliform and *E.coli* counts. Gründorn (2) reported high levels of both total coliform and Enterococci (201/100 ml).

In 2011, there was only 1 Group D classification compared to four Group D classifications in 2016 (Table 5). There has thus been a deterioration of water quality on these farms. This was mainly due to the high amount of total coliforms and Enterococci detected.

Table 5 | Microbial results for 2011 and 2016

Location name	Total coliforms (count/100 ml)		E.coli (MPN/100 ml)		Classification	
	2011	2016	2011	2016	2011	2016
2. Gründorn	2	5	0	0	C	B
3. Doring Draai	0	4	0	0	C	B
4. Nico	23	25	1	0	D	C
5. Lorentia Pos	4	165	4	0	B	D
6. Lorentia	23	201	1	32	B	D
7. Nico Noord	23	201	2	3	B	D
8. Gründorn (2)	0	201	0	5	B	D

DISCUSSION

The results correspond with those from previous studies (Simataa 2010; Boutin *et al.* 2011; Lewis & Claasen 2016). The decrease in nitrate levels could have been caused by the drought over the last 5 years (UNICEF 2014; Aljazeera 2017; The Namibian 2017). Many authors note that high nitrate levels are usually associated with high precipitation (Fraters *et al.* 1998; Boumans *et al.* 2001; Elmi *et al.* 2002; Salo & Turtola 2006).

Diamant Kop

No comparison is possible between the 2011 and 2016 results as the waters came from entirely different sources. The current groundwater is Group D and immediate action is required, although the bacterial parameters show that the water is excellent bacteriologically. The grading rises because the nitrate levels exceed the Group D basal threshold.

Gründorn

Both the nitrate and bacterial concentrations placed the waters in Group B – i.e., water quality is acceptable.

Doring Draai

Water at Doring Draai improved, on the basis of nitrate content, from low health risk (Group C) to acceptable for human consumption (Group B) between 2011 and 2016. The microbial classification remained B.

Nico

The chemical and bacterial classifications for Nico remained in Group C. Nitrate levels fell from 75 to 50 mg/l, perhaps because of the construction of the Otji-toilet in 2011, which decreased the contact between human feces and the environment.

Lorentia Pos

The nitrate classification for this farm remained in Group B from 2011 to 2016. The bacterial classification also remains unchanged in Group D (high health risk).

Lorentia

The water's bacterial quality at Lorentia worsened over the period, from Group C (low health risk) to D (high health risk). The nitrate classification remained in Group D.

Nico Noord

The bacterial and chemical water quality conditions for Nico Noord remained the same (Group C – low health risk) from 2011 to 2016.

Gründorn (2)

From 2011 to 2016 the nitrate classification remained in Group C, but the bacterial classification declined from Group B to D, because of high concentrations of total coliforms and *E.coli*. In other words, water quality went from low to high health risk, which requires immediate attention.

Concluding remarks

This study has revealed that groundwater; the main drinking water source in the informal settlements, is not fit for human consumption in some areas. The poor quality observed arises mainly from high levels of nitrate, Enterococci and total coliforms. It is thought likely that the groundwater contamination can be attributed largely to unhygienic practices at water points and poor management of resources, including the land closely associated with the water infrastructure and infrastructure layout. Many people have developed bad sanitation habits and are unaware of the importance of water conservation, or the causes or implications of groundwater contamination. To overcome this, educational workshops and awareness programs are necessary.

An appropriate water quality monitoring and evaluation program is needed in rural areas. Without an appropriate regional water quality monitoring program, water quality could become a limiting factor for future rural economic development. A plan of action is needed urgently.

Water quality in rural areas is closely linked to sanitation practices, so the provision of water supplies and sanitation facilities and systems should always be considered together. The scarce water resources in Namibia, the poor access to running water in rural areas and the large proportion of the population living in vulnerable conditions in informal settlements, require an effective research and development program for dry sanitation systems and more affordable solutions, to facilitate increased access to sanitation for all and drastically reduce open defecation.

REFERENCES

Akujieze, C. N., Coker, S. J. & Oteze, G. E. 2003 Groundwater in Nigeria – a millennium experience – distribution, practice, problems and solutions. *Hydrogeology Journal* **1**, 259–274. Available at: https://link.springer.com/content/pdf/10.1007/s10040-002-0227-3.pdf.

Aljazeera 2017 Available at: http://www.aljazeera.com/indepth/features/2013/10/namibia-battles-worst-drought-decades-201310851010116562.html (accessed 29 September 2017).

American Public Health Association (APHA) 2005 *Standard Methods for the Examination of Water and Wastewater*, 21st edn. American Public Health Association, Washington, DC, USA. Available at: https://www.mwa.co.th/download/file_upload/SMWW_1000-3000.pdf.

Black, R. E. 1993 Persistent diarrhoea in children of developing countries. *Pediatr. Infect. Dis. J.* **12**(9), 751–761.

Boumans, L. J. M., Fraters, B. & van Drecht, G. 2001 Nitrate in the upper groundwater of 'De Marke' and other farms. *Netherlands Journal of Agricultural Science* **49**, 163–177. Available at: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3482663/.

Boutin, V., Butler, C., Kesseli, S. & McCorry, M. 2011 *Improving Water Quality and Sanitation in Rural Namibian Communities*. Interactive Qualifying Project.

Burkart, M. R. & Kolpin, D. W. 1993 Hydrologic and land – use factors associated with herbicides and nitrate in near-surface aquifers. *J. Environ. Qual.* **22**, 646–656. https://pubs.er.usgs.gov/publication/70169050.

Du Toit, D. & Sguazzin, T. 1995 *Sink or Swim. An Environmental Resource Book for Namibian Teachers*. Enviroteach. Available at: https://www.researchgate.net/publication/280820487_Hydrologic_and_Land_Use_Factors_Associatedwith_Herbicides_and_Nitrate_in_Near_Surface_Aquifers.

Elmi, A. A., Madramootoo, C., Egeh, M., Liu, A. & Hamel, C. 2002 Environmental and agronomic implications of water table and nitrogen fertilization management. *J. Environ. Qual.* **31**(6), 1858–1867. Available at: https://www.ncbi.nlm.nih.gov/pubmed/12469835.

Fecham, R., Mcgarry, M. & Mara, D. 1986 *Water, Wastes and Health in Hot Climates*. Wiley and Sons, New York, p. 82.

Fraters, D., Boumans, L. J. M., van Drecht, G., de Haan, T. & de Hoop, W. D. 1998 Nitrogen monitoring in groundwater in the sandy regions of the Netherlands. *Environmental Pollution* **102**, 479–485. Available at: http://www.sciencedirect.com/science/article/pii/S0269749198800729.

Lewis, E. & Claasen, T. 2016 Monitoring water quality and sanitation practices in semi-arid rural areas in Namibia. *Int. J. of Science & Technology* **4**, 100–105. Available at: http://www.theijst.com/wp-content/uploads/2016/09/16.-ST1607-047.pdf.

Ministry of Agriculture, Water and Forestry (MWAF) 2005 *Infrastructure Upgrade of Rural Water Supply 2*.

Ministry of Agriculture, Water and Rural Development of Namibia 2001 *Groundwater in Namibia an Explanation to the Hydrogeological Map*. Available at: http://www.bgr.bund.de/EN/Themen/Wasser/Projekte/abgeschlossen/TZ/Namibia/groundwater_namibia.pdf?__blob=publicationFile.

Ministry of Health and Social Services of Namibia (MoHSS) and ICF International 2014 Available at: https://dhsprogram.com/pubs/pdf/FR298/FR298.pdf.

Mouton, D. 1995 *Information Folder on the Southern Communal Areas in the Hardap/Karas Region*. Windhoek.

Namibia Water Corporation (NamWater) 1998 Guidelines for the Evaluation of Drinking-Water for Human Consumption with Regard to Chemical, Physical and Bacteriological Quality. Available at: https://www.namwater.com.na/images/data/downloads/guidelines%20drinking%20water.doc.

National Planning Commission 2007 *Regional Poverty Profile: Oshana. Village Level Participatory Poverty Assessments in the Oshana Region, Namibia (January March 2006), Namibia*.

Punmia, B. C. & Jain, A. K. 1998 *Wastewater Engineering*. Laxmi Publications (P) Ltd, New Delhi.

Salo, T. & Turtola, E. 2006 Nitrogen balance as an indicator of nitrogen leaching in Finland. *Agriculture, Ecosystems and Environment* **113**, 98–107. Available at: http://www.sciencedirect.com/science/article/pii/S016788090500438X.

Simataa, F. 2010 *Water and Sanitation: A Preliminary Assessment of Water Supply on Selected Odendaal Farms in Southern Namibia*.

The Namibian 2017 Available at: https://www.namibian.com.na/152587/archive-read/President-declares-drought-an-emergency (Accessed 25 September 2017).

Tredoux, G., Engelbrecht, J. P. & Talma, A. S. 2001 Nitrate in groundwater in southern Africa. In: *New Approaches Characterising Groundwater Flow* (Seiler, K. P. & Wohnlich, S., eds). Swets and Zeitlinger, Lisse, Netherlands.

Tredoux, G., Engelbrecht, J. P. & Israel, S. 2009 *Nitrate in Groundwater: Why is it a Hazard and how to Control it? Report to the Water Research Commission by CSIR, Natural Resources and the Environment, Stellenbosch*. WRC Report No. TT 410/09.

UNICEF Namibia 2014 *Drought Situation Report #5*. Available online: www.unicef.org/appeals/files/UNICEF_Namibia_Sit_Rep5_DroughtCholera_10Feb2014.pdf (accessed 29 Septmeber 2017).

World Health Organization (WHO) 2011 *Water for Health, WHO Guidelines for Drinking-Water Quality*. World Health Organization, Geneva.

World Meteorological Organization 2013 *Planning of Water-Quality Monitoring Systems*. Geneva, Switzerland.