 doi:10.20944/preprints202306.1257.v1

Groundwater Contamination in rural communities and its potential impact on human health

Funanani Mashau [1,2*]

[1] School of Health Systems and Public Health, Faculty of Health Sciences, University of Pretoria, Pretoria, South Africa

[2]Department of Public Health, Faculty of Health Sciences, University of Fort Hare, South Africa

*** Correspondence:** mashaufunanani@yahoo.com

Abstract: Groundwater use for domestic and agricultural purposes is every day in rural communities. However, groundwater quality in those communities is still being determined due to the lack of water quality monitoring programs. The purpose of this study was to evaluate groundwater quality in rural communities using physiochemical parameters. Eight communities using communal boreholes were selected. Water samples were analysed for temperature, pH, electrical conductivity, total dissolved solids (TDS), ammonia, nitrate, and nitrite as *Nitrogen*. The pH means ranged from 6.6 to 8.1, whereas high TDS levels of 1390 mg/L and 1470 mg/L were observed in two boreholes. Three boreholes had higher electrical conductivity. Two boreholes had elevated nitrate levels of 15 and 21.5 mg/L. The high nitrate level correlates with the pH, EC, and TDS values. Our results suggest that high nitrate levels measured in communities' boreholes pose ill health to the community, especially children, infants, and elders. Prenatal exposure to high nitrate has been found to have acute health effects in infants. Therefore, there is a need for further longitudinal studies on health risks among vulnerable groups in these communities.

Keywords: Groundwater**;** Physicochemical properties**;** Water quality**;** Human Health**;** Rural (domestic) communities

1. Introduction

Groundwater is an essential source of drinking water for most rural communities with no proper water supply infrastructure. In addition, these communities can use other water sources such as rivers, streams, lakes, and springs. The use of groundwater is being perceived as a safe source of drinking water in rural communities. Even though groundwater has good microbiological quality, most boreholes must be better maintained and monitored. For this reason, it may take longer to notice the decline in water quality. Several studies have reported groundwater contamination due to industrial, domestic, and agricultural wastewater being discharged into freshwater bodies (Sojobi et al., 2015; Chakraborti et al., 2016; Indelicato et al., 2017). This includes nitrate contamination due to synthetic and natural fertilisation, leaking septic systems and bacterial production (Fenech et al., 2012). Nitrogen, in some forms of ammonia (NH_4 and NH_3) and Nitrogen oxide (NO_2)), can also be transformed by the biogeochemical process to nitrate (WHO, 2004). Nitrate contamination in drinking water poses significant human health risks, which include carcinogenic effects and blue baby syndrome, also known as methemoglobinemia (Stadler, 2012; Murgulet & Tick, 2009).

A previous study reported a high concentration of fluoride levels in some areas in Limpopo province, South Africa (Ncube & Schutte, 2005), while recently Edokpayi et al. 2018 revealed a high concentration of heavy metals in borehole water in the same province. No data on water quality status is readily available in most rural areas, especially in communities that depend primarily on groundwater for domestic and agricultural purposes. Thus, the study aimed to assess the water quality in the communal boreholes area due to agricultural activities, which can contaminate the water and have human health risks.

2. Materials and Methods

2.1 Study Sites and Design

The study was conducted in one of the districts of Limpopo provinces, South Africa. The district consists of four central municipalities, whereby one of the municipalities was selected for this study as it has more active communal boreholes than the other. The total population in the area is up to 516.031, according to StatsSA, 2011. Unemployment is at 36.7%, and there is a significant dependence on pensions and social grants. Eight communal boreholes (B1-B8) representing eight villages were selected for this study (**Table 1**). The study received ethical approval from the Faculty of Health Sciences, University of Pretoria (reference no. 115/2016). The district's area manager of the Department of Water and Sanitation gave verbal approval.

2.2. Sample collection

2.2.1. Water sampling, handling, and storage

The collection of drinking water samples was done according to the standard sampling prescribed by the Department of Water and Sanitation (previously known as the Department of Water Affairs and Forestry), South Africa (DWAF, 2000). Samples were collected over four months (August (Winter), September (Spring) and October (spring) 2017), and March (Autumn) 2018 to allow the capturing of variability. In brief, water samples were collected at the point of use, using 500mL polypropylene bottles with screw caps as recommended by the participating laboratory. Taps were flushed for 2 minutes before the collection. During collection, bottles were filled to the maximum level to prevent air bubbles upon sealing. Samples collected were delivered to the laboratory within 48 hours in an enclosed insulated carrier with ice packs to maintain a cool temperature. Some samples were collected next to the communal tanks (**Figure 2**). A total of 27 samples were collected.

2.3. Sample analysis

2.3.1. Physical properties

Water temperature, conductivity, pH, and total dissolved solids analyses

Standard methods were applied in measuring temperature (^{O}C), conductivity (EC), total dissolved solids (TDS) and pH using HI 9811-5 portable pH/EC/TDS/^{O}C meters from HANNA instruments. The instrument was calibrated for pH using pH 4, 7 and 9 buffer solutions. EC and TDS calibration were performed using HI 70031 (1413 µS/cm) and HI 70032 (1382 ppm, or mg/L) calibration solutions. The company issued a calibration certificate.

2.3.2. Chemical properties

Free and Saline Ammonium as N (Nitrogen), Nitrate and Nitrite as N analysis

All samples collected were analysed by *WATER LAB* (Pty) Ltd laboratory in Pretoria. The South African National Accreditation System (SANAS) has accredited the laboratory to conduct all mentioned water quality parameters. The Nitrate as *N*, Nitrite as *N* and Free and Saline Ammonium as *N* were analysed using the ultraviolet (UV) spectrophotometer method (APHA, 2012) using a Discrete Analyser (Aquakem 250). The method has been previously described elsewhere (Khan et al. 2013). The standards and blanks were used to maintain the reliability and reproducibility of the analyses.

Inorganic chemicals

Parameters were analysed using inductively coupled plasma optical emission spectrometry (ICP-OES) (Edokpayi et al. 2018). The instrument was standardised with nine standard solutions (multi-point linear fitting) for Copper (Cu), Manganese (Mn), Iron (Fe), Fluoride (F^-), Chloride (Cl^-), Nitrate (NO^{3-}), Sulphate ($SO^{4\ 2-}$), Zinc (Zn) and Lead (Pb). Analytical precision was checked by frequently analysing the standards and the blanks. Multiple working solutions of 1, 5, 10 and 20 units/ppm were prepared and used in calibrating each anion.

2.4. Data analysis

All data were entered into Microsoft excel sheet version 2016. Data were then exported onto Stata/IC 14.1 (Stata Corp, USA) for summary and descriptive analysis.

3. Results

3.1. Description of characteristics of physical properties among the boreholes.

The summary of physio-chemical characteristics of borehole water is shown in **Table 2**. pH values range from slightly acidic to alkaline (6.6 to 8.1), which is within the recommended values, while total dissolved solids range from 205 -1470 mg/L. B3 and B6 have total dissolved solids of 1390 and 1470 mg/L, respectively, which are above the standards of ≤ 1200 set in South Africa (SANS 241, 2015).

3.2. Nitrite, Nitrate and Ammonia as Nitrogen

The mean concentrations of Nitrite were ≤ 0.05 mg/L for all the samples analyzed. Boreholes supplying drinking water to the villages (B7 and B8) had 21.5 and 15 mg/L of nitrate concentrations, respectively, which is above the South African standards of ≤ 11 mg/L (**Table 3**). Other boreholes have lower concentrations, ranging from 0.4 to 10.5 mg/L (**Figure 3)**. The ammonia levels as nitrogen range from < 0.1 to 0.2 mg/L (**Figure 4**).

3.3. Inorganic parameters

Table 4 shows the mean concentrations of heavy metals. Samples were screened once-off in duplicates. Thus, communal boreholes 3, 6 and 8 had the highest chloride concentrations. 460, 396 and 337 mg/L, respectively, above the recommended South African set standard of ≤ 300 mg/L. Other chemicals were within the recommended set standards of South Africa (see **Table 4** for details).

3.4. Correlation analyses

We used classifications for correlation as described by Adebayo et al. 2016 as follows: perfectly correlated (R^2 = 1), very strongly correlated (±0.9 ≤ R^2≤ 1), strongly correlated (±0.7 ≤ R^2 < ±0.9), moderately correlated (±0.5 ≤ R^2 < ±0.9), and poorly correlated (R^2 < ±0.5). Correlation coefficient values for four (pH, EC, TDS, NH_4, NO_3) parameters are shown in **Table 4.** Electrical conductivity (R^2 = 0.67) was strongly correlated with total dissolved solids. The correlation between nitrate with pH, EC and TDS was moderate as R^2 = 0.62, R^2 = 0.51 and R^2 = 0.50, respectively.

4. Discussion

Eight communities in the Northern region of South Africa, Limpopo, with communal boreholes were evaluated for drinking water quality. Physical properties (pH, temperature, electrical conductivity, and total dissolved solids (TDS)) were measured. We also quantified the levels of Nitrate, Nitrite and Ammonia as *Nitrogen*. The levels were also compared with standards set by South Africa for drinking water.

In this study, two communal boreholes located at B8 and B7 had high levels of Nitrate at 15 and 21.5 mg/L, respectively. According to SANS 241-1 of 2015, an amount above 11 mg/L may cause acute or chronic health problems in individuals. The water quality guide for domestic use in South Africa indicates that nitrate levels between 10-20 mg/L may cause infant methaemoglobinaemia, while levels above 20 mg/L cause mucous membrane irritation in adults (DWAF, 1996). The World Health Organization (WHO) reported that high nitrate levels risk human health due to increased methemoglobin levels and carcinogenic compounds (WHO, 2007). Penka et al., 2008 found a relative risk of thyroid disorders for pregnant women exposed to high-nitrate levels with an odds ratio of 5.294 (95% CI: 1.003-27.939; *P*=0.0454). High exposure to nitrate is also associated with methemoglobinemia in infants (Khan et al., 2013; WHO, 1996). Exposure of pregnant women to high levels of nitrate through drinking water has been associated with congenital disabilities (Brender et al. 2013).

Previous studies have suggested that possible causes of NO_3^- and NO_2^- contamination of boreholes include sewage disposal to the location, over-application of fertiliser, manure application, landfill leachate, wastewater leakage and municipality runoff (Aslam et al., 2018; Gu et al. 2017; Chen et al. 2016). Most of these rural communal boreholes are located either close to the downstream or soak away pits or landfills or dumping sites, according to Afangideh et al., 2011. In the other area of the Vhembe district, landfills are one of the significant threats to groundwater contamination (Fatta et al., 1999). The Makhado area is predominately agricultural, which includes ploughing and livestock farming. We suggest that the over-application of fertiliser or manure application may cause contamination. In addition to agricultural activities, animal dung (especially from cattle) may be the source of nitrates.

Parameters such as Chloride, Sulphate, fluoride, Copper, Iron, Lead, Manganese and Zinc were also assessed. The presence of cations, anions, and heavy metals in drinking water has been found to pose risks to human health possibly. A study conducted in the Muledane area of the Vhembe district found that manganese, chromium, and iron were above recommended standard limit sets by DWAF, 1996, for domestic use (Edokpayi et al., 2018). The study complements our findings on groundwater contamination levels in the district, and the presence of chemicals was suggested to pose potential human health risks, especially to adults and children using borehole water for consumption.

The current study found high levels of electrical conductivity in three communal boreholes. The presence of high electrical conductivity indicates the presence of ions in the water. The presence of nitrate correlates with the pH, EC, and TDS in water. Therefore, it is essential to investigate the presence of such parameters in future studies. Besides chemical contamination, groundwater is not free of microorganisms as perceived. In the investigated area, high levels of faecal contamination have been previously found in groundwater sources (Bessong et al., 2009). Thus, posing a possibility of waterborne diseases within the communities.

5. Conclusions and Recommendations

The study presents the status of the communal boreholes in the Makhado area of the Vhembe district. The water quality still worries due to the high levels of nitrate in the groundwater, which poses a potential health risk to infants. Further assessment should be done to assess more possible sources of groundwater contamination in an area. There is a need to implement monitoring programs for all drinking water sources in the Vhembe district of South Africa in order to comply with the South Africa National Standards (SANS) set for drinking water. The installation of the new borehole system should be considered by finding a new place where water can be pumped from the ground because most borehole systems studied were old and poorly maintained. The conducting of health risk assessment is of importance in the study area. This is specifically for vulnerable groups (elders, pregnant women, and children under the age of 5 years) who rely on boreholes as a source of drinking water. This study provides evidence of the temporal trends and the level of groundwater contamination within an aquifer. Additionally, the study provides evidence to the groundwater management and water pollution prevention team in South Africa on the level of groundwater contamination.

Conflict of Interest

The authors declare that the research was conducted without any commercial or financial relationships that could be construed as a potential conflict of interest.

Author Contributions

Conceptualization, F.M., E.J.N., and K.V.; methodology, F.M.; formal analysis, F.M.; writing-original draft preparation, F.M.; writing-review and editing, E.J.N., K.V, funding acquisition, F.M

Funding

This study was funded by the South African National Research Foundation (NRF) Grant (SFH150625121049).

Acknowledgments

The authors would like to thank the Department of Water and Sanitation, Vhembe district, Limpopo, South Africa, for permitting us to conduct the study.

References

Sojobi A.O. 2016 Evaluation of groundwater quality in a rural community in North Central of Nigeria. *Environmental Monitoring Assessment*, 188, 192.

Afangideh A., Njar G., Ewa E., Eli H. & Iwara A. 2011 Assessment of water quality status of the borehole in Calabar South local government area, Cross River State. *International Journal of Bioscience* (IJB), **1** (5), 71–76.

American Public Health Association Standard methods for the examination of water and wastewater, 22nd ed., Washington DC, 2012

Aslam R.A., Shrestha S., & Pandey V.P. 2018 Groundwater vulnerability to climate change: a review of the assessment methodology. *Science Total Environmental*, **612**,853–875.

Bessong P.O., Odiyo J.O., Musekene J.N., & Tessema A. 2009 Spatial distribution of diarrhoea and microbial quality of domestic water during an outbreak of diarrhoea in the Tshikuwi community in Venda, South Africa. *Journal of Health Population Nutrition*, **27** (5), 652.

Brender J.D., Weyer P.J., Romitti P.A., Mohanty B.P., Shinde M.U., Vuong A.M., Sharkey J.R., Dwivedi D., Horel S.A., Kantamneni J., & Huber J.R., J.C. 2013 Prenatal nitrate intake from drinking water and selected birth defects in offspring of participants in the national birth defects prevention study. *Environmental Health Perspectives*, **121,** 1083-1089.

Chakraborti D., Rahman M.M., Ahamed S., Dutta R.N, Pati S., & Mukherjee S.C. 2016 Arsenic contamination of groundwater and its induced health effects in Shahpur block, Bhojpur district, Bihar state, India: a risk evaluation. *Environmental Science Pollution Research*, **23** (10), 9492–9504.

Chen M., Qin X., Zeng G., & Li J. 2016 Impacts of human activity modes and climate on heavy metal "spread" in groundwater are biased. *Chemosphere*, **152**, 439–445.

DWA. 2012 Department of Wate Affairs, South Africa. URL: http://www.dwa.gov.za/Documents/BD2012/Limpopo.pdf (Assessed 20 December 2021).

DWA. 2014 Department of Water Affairs, South Africa. URL: http://www.dwa.gov.za/Documents/Blue%20Drop%20Report%202014.pdf (Assessed 20 December 2021).

DWAF. 2000 Department of Water Affairs and Forestry, South Africa Quality of domestic water supply. Volume 2: sampling guide: 3,4,17.

DWAF DoWAaF. 1996 South African water quality guidelines, vol 1, 2nd edn. Domestic Water Use Department of Water Affairs and Forestry Pretoria, Pretoria.

Edokpayi J.N., Enitan A.M., Mutileni N., & Odiyo J.O. 2018 Evaluation of water quality and human risk assessment due to heavy metals in groundwater around Muledane area of Vhembe District, Limpopo Province, South Africa. *Chemistry Central Journal*, **12,** 2 https://doi.org/10.1186/s13065-017-0369-y.

Fatta D, Papadopoulos A., & Loizidou M. 1999 A study on the landfill leachate and its impact on the groundwater quality of the greater area. *Environmental Geochemistry Health*, **21** (2), 175–190.

Fenech C., Rock L., Nolan K., Tobin J., & Morrissey A. 2012 The potential for a suite of isotope and chemical markers to differentiate sources of nitrate contamination: a review. *Water Research*, **46** (7), 2023–2041. http://dx.doi.org/10.1016/j.watres.2012.01. 044.

Gopina G. 1994 Contamination of groundwater with nitrates. In: Vasilev, K. (Ed.), Manual for Safety Application of Pesticides and Fertilizers Around Water Sources (in Bulgarian). Medicine and Sport, Sofia, pp. 59–70.

Gu X., Xiao Y., Yin S., Pan X., Niu Y., Shao J., Cui Y., Zhang Q., & Hao Q. 2017 Natural and anthropogenic factors affecting the shallow groundwater quality in a typical irrigation area with reclaimed water, North China Plain. *Environmental Monitoring Assessments*, **189** (10), 514

Khan S., Shahnaz M., Jehai N., Rehman S., Shah M.T., & Din S. 2013 Drinking water quality and human health risk in Charsadda district, Pakistan. *Journal of Cleaner Production*,

60, 93–101.

Ncube E.J., & Schutte C.F., 2005 The occurrence of fluoride in South African groundwater: A water quality and health problem. *Water SA*, **31** (1), 35-40.

Murgulet D., & Tick G.R. 2009 Assessing the extent and sources of nitrate contamination in the aquifer system of southern Baldwin County, Alabama. *Environmental Geology*, **58** 1051. http://dx.doi.org/10.1007/s00254-008-1585-5.

SANS 241-1. 2015 South African Bureau of Standards Drinking Water- Part 1: Microbiological, physical, aesthetic and chemical determinants. Pretoria: SABS Standards Division.

Stadler S. 2012 Identification of sources and infiltration regimes of nitrate in the semiarid Kalahari: regional differences and implications for groundwater management. *Water SA*, **2** 213–224.

WORLD HEALTH ORGANIZATION (WHO). 2007 Nitrate and nitrite in drinking-water: Background document for development of WHO guidelines for drinking water quality. URL: http://www.who.int/water_sanitation_health/dwq/chemicals/nitratenitrite2ndadd.pdf. (Assessed 20 December 2021).

WHO. 2011 Guidelines for drinking-water quality: the fourth edition incorporating the first addendum. Geneva: World Health Organization; 2017. Licence: CC BY-NC-SA 3.0 IGO.

WHO. 1996 The world health report 1996: fighting disease, fostering development. Geneva. URL: http://www.who.int/whr/1996/en/ (Assessed 20 December 2021)

WHO. 2004 Guidelines for drinking water quality. Recommendations, third ed. 1. WHO, Geneva, p. 540.

WHO. 2006 Guidelines for Drinking water quality: First Addendum to 3rd Edition. Geneva. URL: http://www.who.int/water_sanitation_ health/dwq/gdwq0506.pdf. (Assessed 20 December 2021).