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Research Article

Investigating the Influence of Natural and Human Activities on Drinking Water Quality in Waterberg, South Africa

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Abstract

Background and Objective: Ga-Nkidikitlana is a village in the Northern part of the Limpopo Province, South Africa, at Waterberg. The area is renowned for its dry deciduous forest and bushveld ecosystem. The study's objective was to evaluate the influence of natural and human activities on drinking water quality in Ga-Nkidikitlana Village. **Materials and Methods:** In 2023, thirty water samples were collected from three sources: Rivers, boreholes and reservoirs. All samples were transported to the water quality laboratory for analysis, where standard APHA methods were utilized. The water parameters, such as pH, EC, TDS, TH, K, Ca, Mg, Na, Zn and V were measured. Principal Component Analysis (PCA) was used to show the correlation between the factors and locations. **Results:** The study found that the cations and anions in the water followed a trend of $\text{Na}^+ > \text{Mg}^{+2} > \text{Ca}^{+2} > \text{K}^+ > \text{Fe}^{+2}$. The PCA results showed that the river samples differed from the others. However, the water samples from Ga-Nkidikitlana Village were grouped into three components, with the borehole and reservoir samples showing a correlation with sodium, magnesium and calcium. The study also revealed that pH had a negative correlation with the water's total hardness, while electrical conductivity (EC) had a positive correlation with the total hardness of water samples. Total coliform was detected in all water samples, with the highest levels found in boreholes. However, only low levels of *Escherichia coli* were detected in all samples. **Conclusion:** The microbial contamination levels in the water samples are safe for soil irrigation, but they should be monitored for drinking purposes. Also, the salinity levels in the water samples were higher than average, indicating caution should be taken when using the water for any purpose.

Key words: Pollution, salinity, water quality, principal component analysis, multivariate analysis, *E. coli*

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Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

The report published by the World Health Organization (WHO)¹ highlight that South Africa is already grappling with water scarcity issues². The nation receives insufficient and unreliable rainfall, which means that water is a precious resource that is becoming increasingly scarce³. The current situation presents numerous challenges, such as limited access to clean drinking water and decreased agricultural productivity. Climate change's impact worsens the problem, making water scarcity more severe. It is crucial to take immediate action to tackle this issue and guarantee that South Africa's water resources are managed and utilized sustainably and fairly⁴.

Access to clean and safe water is crucial for sustaining life. It's not just about the availability and quantity of water, but also about the quality⁵. Water quality is a critical factor that needs to be addressed to meet the diverse needs of humans and the environment. Poor water quality can have far-reaching consequences on human health, agricultural productivity, aquatic ecosystems and economic development⁶. Therefore, ensuring that water is available and safe for consumption and other uses is essential for the well-being of both humans and the natural world. Water quality also plays a crucial role in determining soil suitability for crop production and the development of population centres⁷. Groundwater, a significant water source for many communities, can be contaminated through human activities, as evidenced by various studies⁸. It is, therefore, imperative to ensure that water sources are protected from pollution to maintain the quality and safety of the water supply. Access to groundwater resources is vital for the survival and prosperity of rural communities in Limpopo, including Ga-Nkidikitlana in Waterberg. Without these resources, these communities would face significant challenges in meeting their basic needs and driving economic growth. Therefore, the study aims to identify the physicochemical linkage with groundwater resources in Waterberg rural areas, Limpopo Province, South Africa.

MATERIALS AND METHODS

Study sites: The water samples were gathered at Ga-Nkidikitlana from the Waterberg Region in the Limpopo Province of South Africa. Thirty samples were chosen at random from boreholes, reservoirs and rivers in Waterberg from March, to December, 2023. The water samples were collected in sterilized glass sampling bottles using autoclaving. These 1 L sample bottles were then transported to the laboratory for analysis.

Physico-chemical analysis: In the laboratory at the University of Limpopo, water samples underwent analysis for pH, electrical conductivity, TDS, metals and anions. Before incubation, each sample was filtered through a sterile membrane (pore size 0.45 µm, diameter 47 mm) using a 100 mL volume. In addition, on-site pH and electrical conductivity measurements were conducted using a handheld multiparameter meter (ProQuatro Multiparameter Meter, USA). Standard APHA¹ methods were used for water analysis, while USEPA PhosVer 3 method was used for metal analysis, yielding results in mg/L⁹.

Water quality analysis: Various water quality ratios were measured, including sodium adsorption ratio (SAR)¹⁰, soluble sodium percentage (SSP)¹¹, magnesium adsorption ratio (MAR)¹² and Kelley's ratio (KR)¹³. The equations for these ratios are given below:

$$SAR = \frac{Na^+}{\sqrt{\frac{Ca^{2+} + Mg^{2+}}{2}}}$$

$$SSP = \frac{Na^+ + K^+}{Na^+ + K^+ + Ca^{2+} + Mg^{2+}} \times 100$$

$$MAR = \frac{Mg^{2+}}{Ca^{2+} + Mg^{2+}} \times 100$$

$$KR = \frac{Na^+}{Ca^{2+} + Mg^{2+}}$$

Bacterial contamination: To test water quality, a 100 mL sample is filtered through a cellulose ester membrane filter that retains bacteria. Different plates are incubated to count the colonies of different bacteria present. Total coliforms are counted by incubating plates at 37°C for 24 hrs. Fecal coliforms are counted by incubating plates at 44.5°C for 24 hrs. Fecal enterococci are counted by incubating plates at 37°C for 48 hrs. *Clostridium perfringens* bacteria are counted by incubating plates in micro-aerophilic conditions at 37°C for 24 hrs. To count *Escherichia coli* bacteria, membranes from the mFC (m-faecal Coliform) agar plates containing fecal coliform bacteria are placed onto Nutrient MUG agar plates and incubated at 37°C for 24 hrs¹⁴.

Statistical analysis: The samples were studied for correlation using Pearson correlation and normalized through XLSTAT (V26.2.2.0) software before Principal Component

Analysis (PCA). The scores were calculated for each variable based on each principal component and a two-dimensional plot (F1 and F2) was created using the scores for the first two components.

The study involved conducting correlation analysis to identify the most significant water quality parameter and its correlation with other parameters. This analysis included variables such as pH (potential of hydrogen), EC (electrical conductivity), TDS (total dissolved solids), K (potassium), Ca (calcium), Mg (magnesium), Na (sodium), Zn (zinc) and V (vanadium) for 30 water samples. The correlations were computed using XLSTAT (V26.2.2.0) software. Correlation analysis is a preliminary descriptive technique used to estimate the degree of association among multiple variables included in the study.

RESULTS

The general characteristics of groundwater in the studied areas of Limpopo Province were outlined in Table 1. The pH of the groundwater is slightly acidic and other indicators suggest that all the samples were of poor quality as they exceeded the control work.

The Pearson correlation (Fig. 1) shows that EC, TDS and total hardness; calcium, magnesium and vanadium; vanadium with magnesium, sodium and calcium had a strong positive correlation. In contrast, pH had a strong negative correlation with EC, TDS and total hardness.

Regarding the water quality indices (Table 2), the highest SAR value of 17.2 was found for boreholes and the lowest value of SAR (14.0) was calculated for river samples. The result indicated that the higher SSP of Waterberg, Limpopo Province, water samples, the higher value was calculated for rivers (90.1) and the lowest value for reservoirs (38.8). Regarding the magnesium adsorption ratio (MAR), the result ranges showed the highest at 50.0 in the river and the lowest in reservoirs at 38.2. Regarding Kelley's ratio (KR) indicates balance among Na^+ , Ca^{+2} and Mg^{+2} ions in water, the result ranges from 29.4 to 124.1, in which the highest value of 124.1 was recorded for reservoirs. In 90% of the water samples, KR value measured over 1.0, indicating an excessive amount of N^+ in the water of the locations studied (Table 1).

The PCA accounted for 100% of the variability in the water quality parameters in Waterberg, Limpopo Province (Fig. 2). The result indicated that 84.4% explained by PC1 and 15.6% explained by PC2, which the water quality parameters had a significant effect on tested water in Waterberg, Limpopo Province. The PCA plot showed that the borehole and reservoirs had the same quality and were placed close to each other. In contrast, River samples were placed separately from the control borehole and reservoir water samples (Fig. 2).

The microbiological quality of the water (Table 3) showed that the highest total coliform bacteria were detected in borehole samples with 176.6 (CFU/100 mL), followed by

Table 1: Average of the physicochemical properties of the water samples from Waterberg

Factors	River	Reservoirs	Borehole	Control
pH	6.5	6.8	6.7	7.6
EC	285.0	301.0	317.0	0.9
TDS	1800.0	1956.5	2060.3	5.85
TH	883.0	915.8	1005.0	0.0
K	1845.7	4.1	4.1	0.15
Ca	26.1	164.4	199.1	0.0
Mg	26.6	122.5	123.1	0.0
Na	71.5	206.4	200.0	0.0
Zn	0.0	0.0	2.7	0.0
V	0.1	0.3	0.3	0.0

TDS: Total dissolved solids, TH: Total hardness pH: Potential of hydrogen, EC: Electrical conductivity, TDS: Total dissolved solids, K: Potassium, Ca: Calcium, Mg: Magnesium, Na: Sodium, Zn: Zinc and V: Vanadium

Table 2: Water quality indices of the water samples of the Waterberg area, Limpopo Province, South Africa

Sites	SAR	SSP	MAR	KR
River	14.0	90.1	50.0	29.4
Borehole	17.2	42.3	42.7	123.8
Reservoirs	15.8	38.8	38.2	124.1

SAR: Sodium adsorption ratio, SSP: Soluble sodium percentage, MAR: Magnesium adsorption ratio and KR: Kelley's ratio

Table 3: Bacterial contamination of the water samples of the Waterberg area, Limpopo Province, South Africa

Factors	River	Reservoirs	Borehole	Control
Total coliforms (CFU/100 mL)	104.2	90.3	176.7	0.0
<i>Escherichia coli</i> (CFU/100 mL)	0.8	0.7	1.0	0.0

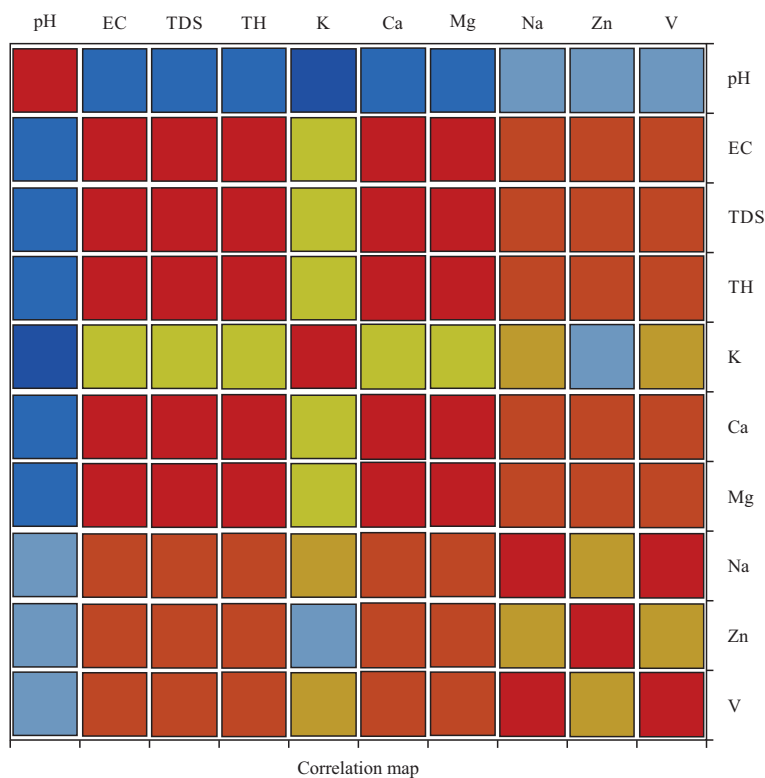


Fig. 1: Correlation of the various water properties of the Waterberg area, Limpopo Province, South Africa
TDS : Total dissolved solids and TH: Total hardness

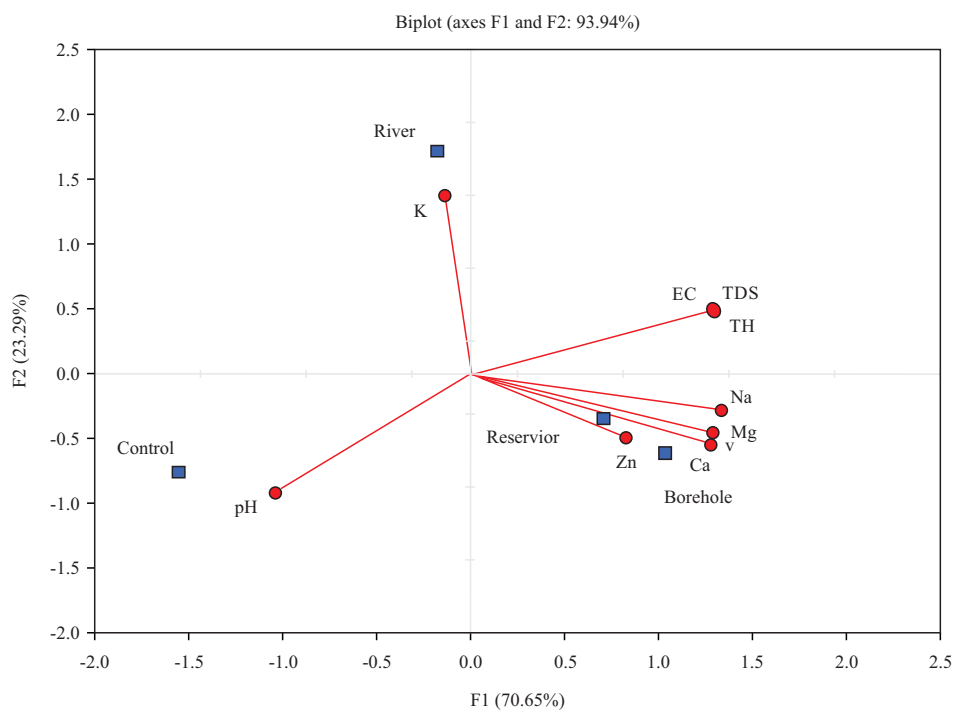


Fig. 2: Principal Component Analysis (PCA) of the water samples of the Waterberg area, Limpopo Province, South Africa
R : River, TDS: Total dissolved solids and TH: Total hardness

river (104.2 CFU/100 mL) and reservoirs (90.3 CFU/100 mL). However, *Escherichia coli* was highest in boreholes (1 CFU/100 mL) and lowest in reservoirs (0.7 CFU/100 mL).

DISCUSSION

Groundwater is a vital resource for human consumption, agricultural irrigation and industrial processes. However, its chemical properties can vary significantly, depending on the geological and environmental conditions of the region where it is extracted⁷. The hydrogeochemical properties of groundwater are determined by its dissolved constituents, such as minerals, gases and organic matter¹⁵. These constituents can affect the taste, color and odor of the water, as well as its physical and chemical properties. By analysing the hydrogeochemical properties of groundwater, experts can determine its suitability for different uses and develop strategies to manage and protect this valuable resource⁶.

The SAR index indicates the level of sodium hazard present in a water sample. Elevated levels of sodium ions in water can negatively impact the soil's permeability and lead to infiltration issues. The SAR values of irrigation water are closely related to the extent to which Na^+ is absorbed into the soil¹⁶. The SAR index categorized water into four classes, as S1 (<10; excellent), S2 (10-18; good), S3(18-26; doubtful) and S4 (>26; unsuitable). The result of the present study indicated that 100% of the Waterberg water samples with SAR values of between 10-18, indicate a good state of the quality. Based on the KR value, which is balancing between Na^+ , Ca^{+2} and Mg^{+2} , KR value over 1, shows the excess amount of Na^+ . However, Waterberg water samples have excellent quality for irrigation purposes. The magnesium adsorption ratio (MAR) causes a harmful effect on the soil when it exceeds 50¹⁷. The result indicated that none of the water samples from Waterberg had MAR value over 50. Therefore, the water samples are good for soil irrigation purposes.

The Principal Component Analysis (PCA) results have revealed that the quality of the groundwater in the studied areas is mainly influenced by three factors: Total dissolved solids (TDS), electrical conductivity (EC) and sodium content. The samples collected from boreholes indicated high water hardness, which is mainly due to the presence of high levels of calcium and magnesium. It is important to note that the maximum permissible limit for the total hardness (TH) of water is 500 mg/L, while the recommended limit is 100 mg/L as per the World Health Organization (WHO) guidelines¹. However, it is worth mentioning that the continuous usage of hard water for irrigation purposes may lead to an increase in soil pH, which can negatively impact plants that require acidic

reassuring to know that the high TH levels in the groundwater do not pose any immediate health risks, as per the findings of Sengupta¹⁸. The quality of water samples collected from various boreholes was evaluated based on the level of microbial contamination. It is believed that the depth at which water was sampled from the boreholes could have influenced the quality of the samples¹⁹. The borehole water samples showed the highest contamination of total coliform bacteria, which could be attributed to the presence of sewage pipes in close proximity to the groundwater sources. This suggests that there is a high risk of contamination from human waste in the groundwater sources²⁰.

Despite the presence of coliform bacteria, the amount of *E. coli* detected in the Waterberg region was low; however, that also can affect health. The bacterium *E. coli* is a type of coliform bacteria commonly found in human and animal feces and its presence in water indicates fecal contamination²¹. This suggests that the water in the region is contaminated by human or animal feces, which is a negative indicator of its quality. The WHO¹ noted no coliform bacteria should be detected per 100 mL of the water sample. Overall, the study found that the borehole water samples showed high levels of total coliform bacteria, which suggests that the water in the region should be monitored for drinking purposes. However, it is important to note that proper sanitation measures must be taken to prevent contamination of the groundwater sources in the future.

CONCLUSION

The Waterberg region in South Africa has high sodium levels in its water. Regular monitoring of water quality is crucial, as borehole samples show high bacterial contamination. Implementing proper hygiene measures is essential to prevent the spread of diseases. Further investigations are recommended to gain a comprehensive understanding of the situation and quality of drinking water in Waterberg.

SIGNIFICANCE STATEMENT

This study investigated the water quality in Waterberg region. This study's findings can potentially benefit for human, plant and animal communities of that region. Therefore, it is crucial to understand the quality of water, which can be effective on the environment of Waterberg region. Furthermore, this study will assist researchers in identifying critical areas for understanding the situation of water quality in Waterberg.

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