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Research paper

Groundwater quality assessment in the Breede area, Western Cape, South Africa

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Groundwater is an essential part of food and water security. This critical resource must be managed appropriately and used sustainably. This study aimed to assess groundwater quality, suitability for domestic and irrigation purposes, and factors contributing to the groundwater chemistry, in the Breede Water Management Area (WMA), Western Cape, South Africa. Groundwater samples were collected and analysed for major ions such as K^+, Mg^{2+}, Na^+, Ca^{2+}, Cl^-, HCO_3^-, NO_3^-, F^-, SO_4^{2-} and physical variables like pH, electrical conductivity (EC), total dissolved solids (TDS), and temperature. Water quality index (WQI), total hardness (TH), South African Water Quality Guidelines (SAWQG) and World Health Organisation (WHO) drinking water quality guidelines were used to assess suitability for drinking purposes. Permeability index (PI), magnesium hardness (MH), sodium adsorption ratio (SAR), sodium percentage (Na%) and graphical representations such as Wilcox and United States Salinity Laboratory (USSL) diagram were used to assess suitability for irrigation purposes. Multivariate statistical analysis and the Piper diagram were used to determine the geochemical processes influencing the groundwater quality. TH and WQI revealed that, overall, groundwater in Breede WMA is soft and suitable for drinking. The irrigation suitability indices showed that groundwater is suitable for irrigation, with the exception of a few sites that are doubtful. The dominating water type in the area is Na-Cl, followed by mixed Ca-Mg-Cl. Multivariate statistical methods revealed that the groundwater is affected by the dissolution of rock salts, calcite dissolution, cation exchange and agricultural activities. The overall groundwater in the Breede Water Management Area is suitable for domestic purposes. Water in the boreholes along the coastal area and Borehole W1 must be treated before domestic and irrigation use. There must be consistent groundwater quality monitoring in Breede to identify changes in groundwater quality.

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INTRODUCTION

Water is an essential need of life and critical for socio-economic development. It can be found in surface and underground sources. South Africa is a water-scarce country; water use efficiency and sustainability are, therefore, essential.

The agricultural industry in the Western Cape Province puts significant pressure on the water resources, with current utilisation at about 40% (DEADP, 2011). The Breede Water Management Area (WMA) is one of the areas in the province with intensive agricultural activities. Good quality water is essential in agriculture for crop yield. Sources of groundwater pollution include return flows from irrigation, agrochemicals (BGCMA, 2017), industrial, mining activities and geogenic sources such as dissolution of rock salts, calcite dissolution and cation exchange (Molekoa et al., 2019).

Cullis et al. (2018) highlighted that there is a direct link between economic growth and water quality. As the economy grows, more water is required for many of the economic activities. Water quality is as important as water availability because every water use requires the water to be of a certain quality for it to be suitable for use. Most industries generate a considerable amount of wastewater that cannot be re-used and need to be discharged. Inappropriate discharge of effluent into the environment causes environmental pollution. The Breede WMA has been experiencing significant urban and peri-urban growth, which has led to economic growth and a decline in water quality (Cullis et al., 2018).

The estimated groundwater usage in the Breede WMA is 107 million m^3/a, where 103 million m^3/a is utilised solely for irrigation, with the remaining 4 million m^3/a used for domestic and stock-watering purposes (DEADP, 2011). Studies conducted in the Breede WMA identified the following water quality problems in the Breede River and its tributaries: salinity, nutrient enrichment, microbial contamination, agrochemicals from irrigation return flows, turbidity, low levels of dissolved oxygen, impacts of sand mining and the dairy industry (DEADP, 2011; BGCMA, 2017). There is, therefore, a possibility of groundwater contamination through surface and groundwater interaction and recharge from runoff.

Dissolved salts and minerals in water serve as nutrients but are only required in small quantities (WHO, 2005). A higher concentration of chemical nutrients than required compromises the water quality, thus rendering it toxic to plants and humans (Molekoa et al., 2019). To gain a better understanding of the suitability of water for different purposes, the chemical parameters must be analysed, focusing on the combined chemistry of all ions, not on individual ions (Belkhiri and Mouni, 2012).

This study aimed to assess the groundwater quality, suitability for irrigation and domestic purposes, and potential polluting factors in the Breede WMA. Groundwater samples were collected from the monitoring boreholes in the area and analysed for selected parameters. The results were compared to international and local drinking water quality standards such as WHO (2017) and DWAF (1996a) to determine the suitability of the water for drinking purposes. Statistical analysis, geochemical assessment, and graphical methods were used to determine the suitability of the groundwater for drinking and irrigation purposes and to determine potential polluting processes and factors.

STUDY AREA

The Breede WMA is situated in the Western Cape Province, South Africa, and covers an area of 19 668 km^2 (DWAF, 2002). It is bounded in the west by the Berg WMA, the Olifants/Doorn and Gouritz WMAs in the north and east, respectively, and the Indian Ocean in the south (DWAF, 2002). Breede WMA consists of several municipalities, namely, Breede Valley, Theewaterskloof, Langeberg, Overstrand and Witzenberg (BOCMA, 2015). The Breede River is the main river in the area and the largest dam is Theewaterskloof (Cullis et al., 2018).

The Breede WMA experiences winter rainfall. April to September is the wet winter season and the dry hot season is from October to March. Rainfall is higher in the mountainous areas. The highest rainfall experienced in the mountains is 2 300 mm per annum, while the low-lying areas experience about 400 mm per annum. During the summer months, the weather is dry and hot, with significant evaporation. Temperatures vary between −1°C in winter and 30°C in the summer months (DWAF, 2008).

According to DWAF (2002), the dominating geology in the Breede WMA is the strata of the Cape Supergroup, with the mountain ranges comprising mainly Table Mountain sandstone. The Supergroup constitutes the largely arenaceous Table Mountain Group which unconformably overlies the Malmesbury and Cape Granite rocks and underlies the Bokkeveld Group (Fig. 1). The coastline consists of extensive limestones (DWAF, 2002).

METHODS

Groundwater samples were collected from 12 monitoring boreholes in the area (Fig. 2), 2 boreholes from every sub-area (W boreholes are at Worcester, K in Koo valley, S in Stanford, CI in Cape Infanta, C in Ceres and G in Grabouw).

Sampling method and on-site physical parameter analysis

The samples were collected using the low-flow method. The method allows for the collection of a good representative sample without purging the borehole. It collects samples at a specific depth where the screen is inserted (Sundaram et al., 2009). According to Newell et al. (2000), this method is more suitable than the purging method because it eliminates variability being introduced by purging. The advantage is that it leaves the stagnant water within the borehole undisturbed and collects the sample directly from the aquifer.

Temperature, electrical conductivity (EC) and pH were measured on site using the Extech digital multiparameter Model DO700. The instrument was calibrated for all three parameters prior to the site visit. The samples were collected in 1.0 L high-density polyethylene bottles. To prevent contamination of the samples, the bottles were washed and rinsed with a solution of 1:1 nitric acid, followed by deionised water. At the site, they were rinsed 3 times with water from the borehole before taking the actual sample (Sundaram et al., 2009). Cation samples were acidified with concentrated nitric acid to a pH < 2 to preserve the samples and minimise precipitation and adsorption to the container wall during transportation (Molekoa et al., 2019). Anion samples were kept in a portable ice chest with ice to keep them cool during transportation to the laboratory in order to avoid any chemical changes (Weaver et al., 2007).

Sample analysis

The borehole samples were analysed using spectroscopic, spectrophotometric and titrimetric methods for the cations (Na^+, K^+, Ca^{2+} and Mg^{2+}), anions (NO_3^-, F^-, Cl^- and SO_4^{2-}) and physical parameters (EC, total dissolved solids (TDS) and hardness), respectively.

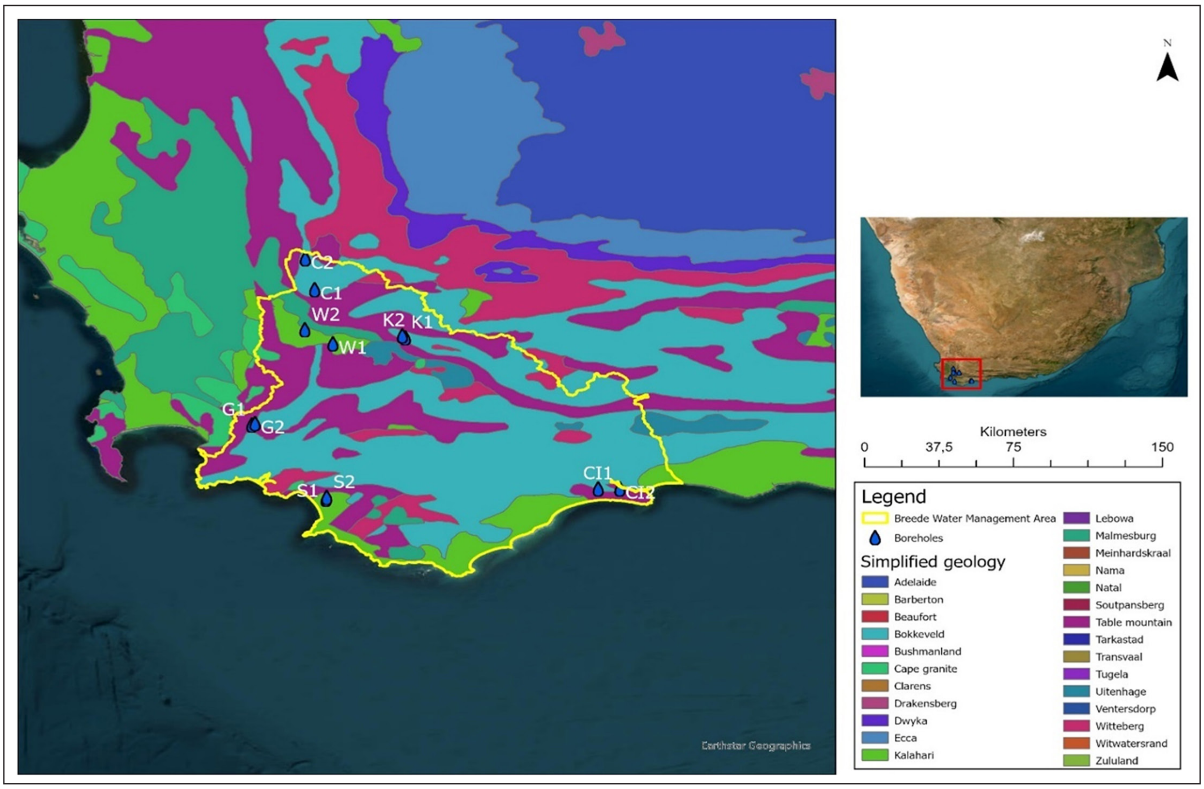

Figure 1. Geological map of Breede Water Management Area

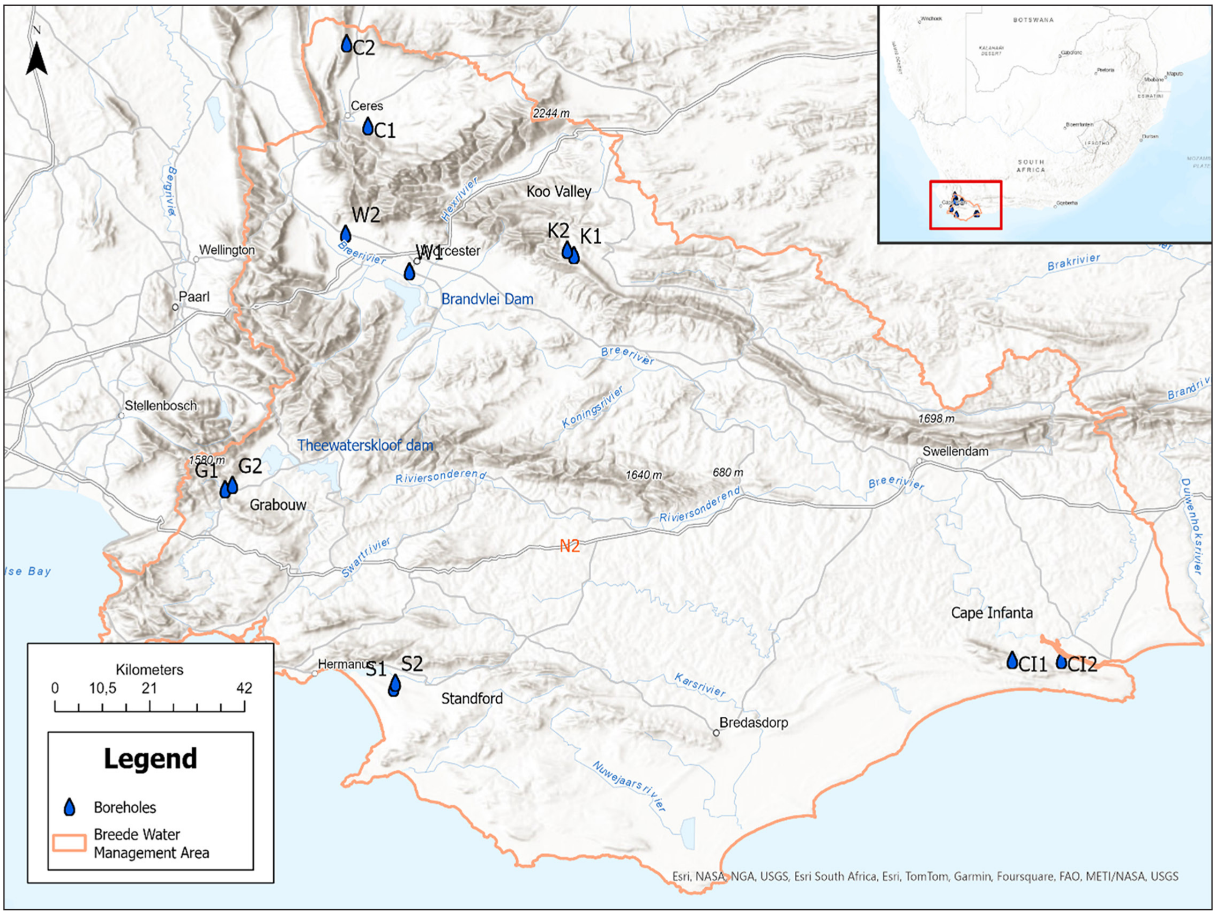

Figure 2. Breede Water Management Area map and selected boreholes

Cation analysis

The cations were analysed by inductively coupled plasma–optical emission spectrometry (ICP–OES) using a Prodigy6 (Teledyne Leeman Labs) spectrometer. The instrument uses the C-type concentric nebuliser which takes 2 mL of the sample per minute, and a cyclonic spray chamber. The torch in the instrument was configured at a dual view. The instrument was calibrated using the linear method before analysing the samples.

The samples were filtered using 0.45 µm filter paper prior to analysis to remove any suspended solids. Each sample was pipetted into a 100 mL volumetric flask and preserved with 1 mL of 65% nitric acid. Sodium was analysed at a wavelength of 589.592 nm, calcium at 315.887 nm, magnesium at 285.213 nm and potassium at a wavelength of 285.213 nm.

Anion analysis

Sulphate, chloride, fluoride, and nitrate were analysed using the Gallery Plus discrete analyser (Thermo Fischer Scientific). Samples were filtered through a 0.45 µm filter to obtain a clear sample. 2 mL of the sample was used for the analysis and determined at the anion-specific wavelengths. Sulphate was quantified at a wavelength of 420 nm, chloride at 480 nm, fluoride at 620 nm and nitrate at 540 nm.

The Gallery Plus discrete analyser was operated under the following temperature conditions: incubator 37°C, reagent disk 3.7°C and inside analyser 20.1°C.

Physical parameter analysis

The total dissolved solids and water alkalinity (via bicarbonate) were determined using a Titralab AT1000 Series (Hach) auto titrator. For the bicarbonate, a HACH-PHC805 electrode was used. 50 mL of the sample was used and titrated with 0.1 N sulphuric acid. TDS was calculated from the value of EC as analysed using the Titralab, employing an EC HACH-CDC401 electrode.

Data analysis

Suitability for domestic use

The suitability of the water for domestic purposes was assessed by comparing the major ion results with South African Water Quality Guidelines (SAWQG) and World Health Organisation (WHO) drinking water quality guidelines. Suitability was also assessed using a water quality index (WQI) and total hardness (TH).

Water quality index

A water quality index is an arithmetic-weighted method used in groundwater quality studies to determine the fitness of water for different uses (Loh et al., 2020). It is reliable, efficient, and useful because it summarises a large dataset into a value that describes the overall quality of the water. In this study, a WQI was used to determine suitability for drinking purposes.

The relative weight of each parameter was computed using Eq. 1:

$$RW_i = \frac{AW_i}{\Sigma_i^n AW_i} \tag{1}$$

RW_i is the relative weight of each parameter, AW_i defines the assigned weight of each parameter, and n is the total number of parameters. Water quality parameters are selected that are of concern or have the potential to be pollutants based on economic activities in the area and assigned a weight from 1–5 based on their impact. F^-, SO_4^{2-} , and NO_3^-, were assigned a weight of 5.

TDS, pH, EC, Na^+ and Cl^- were assigned a weight of 4. K^+, Mg^{2+} Ca^{2+}, were assigned a weight of 2. The weight was assigned based on the importance of the parameter in drinking water quality assessment. A high weight was assigned to parameters with high concentrations owing to their major contribution to the water quality of the area and to their health implications. A lower weight was assigned to parameters with lesser concentrations and the least impact on drinking quality (Hassen et al., 2016; Salem et al., 2019).

The quality rating of each parameter was calculated using Eq. 2:

$$Q_i = \frac{C_i}{S_i} \text{ x } 100 \tag{2}$$

Q_i represents the quality rating of each parameter in the sample, C_i is the concentration of each parameter calculated in mg/L, and S_i is the permissible standard derived from the South African water quality guideline for drinking water.

The subindex of each parameter was calculated using Eq. 3:

$$SI_i = Q_i \text{ x } RW_i \tag{3}$$

SI_i represents the subindex for each parameter, Q_i represents the quality rating of the parameter based on the concentration of the parameter and RW_i defines the relative weight of each parameter.

The WQI of the water sample was computed using Eq. 4:

$$WQI = \sum SI_i \tag{4}$$

Total hardness

Total hardness (TH) was used to determine the suitability of water for human consumption. Water hardness can cause kidney failure in human beings (Dhanasekarapandian et al., 2016). Water with a TH < 75% is classified as soft, TH of 75–150% is moderately hard, TH of 150–300% is classified as hard, and TH > 300% is classified as very hard (Subramani et al., 2005). Total hardness was computed using Eq. 5 (ionic concentrations in mg/L).

$$TH = 2.497 \text{ Ca} + 4.115 \text{ Mg} \tag{5}$$

Irrigation suitability

The suitability of the groundwater for irrigation purposes was assessed using the following indicators: permeability index (PI), sodium adsorption ratio (SAR), magnesium hazard (MH), sodium percentage (Na%). All indicators were calculated using Eqs 6–9 below. Before calculating the indicators, the ion concentrations were converted to milliequivalent per litre (meq/L).

Sodium adsorption ratio:

$$SAR = \frac{Na^+}{\sqrt{\frac{Ca^{2+} + Mg^{2+}}{2}}} \tag{6}$$

Magnesium hazard:

$$MH = \frac{Mg^{2+}}{Ca^{2+} + Mg^{2+}} \text{ x } 100 \tag{7}$$

Permeability index:

$$PI = \frac{Na^+ + \sqrt{HCO_3^-}}{Ca^{2+} + Mg^{2+} + Na^+} \tag{8}$$

Sodium percentage:

$$Na\% = \frac{Na^+ + K^+}{Ca^{2+} + Mg^{2+} + Na^+ + K^+} \text{ x } 100 \tag{9}$$

United States Salinity Laboratory and Wilcox diagrams

The United States Salinity Laboratory (USSL) and Wilcox diagrams are graphical representation data analysis methods that use graphs and charts to analyse and interpret numerical data and functions, indicating suitability for irrigation. USSL is a plot of SAR versus EC. Wilcox is plotted using sodium percentage (Na%) versus salinity hazard (EC). Both diagrams were generated using Diagrammer v6.76 software (Simler, 2022).

Geochemical assessment of groundwater

A geochemical assessment was used to identify processes that influence the concentrations of the major ions, and thus indicate sources of pollution. Several methods can be adopted for geochemical assessment (Mallick et al., 2018). For this study, only multivariate statistical analysis and the Piper diagram were used.

Piper diagram

A Piper diagram was used to determine the possible sources of groundwater pollution in the area, and, furthermore, to classify groundwater into hydrochemical facies, also known as water types. The water types give information about the common composition and origin of the ions (Mokoena et al., 2021). The diagram was plotted using Diagrammer v6.76 software (Simler, 2022).

Multivariate statistical analysis

Principal component analysis (PCA) and Pearson correlation were computed using *R* v1.1 (R Core Team, 2019). The multivariate statistical methods were used to understand the relationship between the measured variables which will reveal the origin of the major ions. The correlation matrix was computed between all measured constituents from all the groundwater samples in the Breede WMA.

The results showed 13 principal components, of which only the first 4 had eigenvalues > 1, as indicated in Table 1. The proportion of variation is explained for each eigenvalue in the second column of Table 1. The cumulative percentage in the third column was computed by adding successive proportions of variation explained to obtain the running total. The selected principal components were those with corresponding eigenvalues > 1. The first 4 principal components (PCs) explain over 77% of the variance. Given the relatively high percentage of explained variance, only the first 4 principle components were retained for analysis and are assumed to adequately represent the overall variance. The variables were plotted on the PC1–PC2 plane to discriminate between several groups of water samples. The PC1–PC2 plane allowed us to differentiate between relatively highly mineralised water and alkaline water.

RESULTS

Univariate statistical analysis

Water used for drinking should be free of toxic substances, have a low TDS value and be soft (Salem et al., 2019). The South African

Table 1. Eigenvalues and percentage variance of PCs

Principal component	Eigenvalue	Variance %	Cumulative variance %
PC 1	5.8	44.8	44.8
PC 2	2.0	15.7	60.5
PC 3	1.1	8.7	69.3
PC 4	1.0	7.8	77.0

Table 2. Descriptive statistics for Breede WMA groundwater chemistry

Variables	Min	Max	Std dev	Median	Mean	SAWQG DWAF (1996)	No, of samples exceeding SAWQG target	WHO (2017) Guidelines	No. of samples exceeding WHO guidelines target
pH	4.3	8.3	1.4	5.8	6.1	6.0–9.0	16	–	–
Temp (°C)	15.8	25.5	2.1	19.7	19.6	–	–	–	–
EC (mS/m)	5.5	194.6	60.3	65.8	78.6	70	16	–	–
TDS (mg/L)	39.1	1 383.1	390.0	170.9	373.5	450	12	600	9
Na^+ (mg/L)	7.0	280.0	81.1	24.0	68.9	100	9	200	3
Mg^{2+} (mg/L)	1.0	41.0	1.1	5.5	9.1	30	3	100	0
Ca^{2+} (mg/L)	0.4	92.0	21.6	8.5	17.5	32	6	200	0
K^+ (mg/L)	0.7	11.0	2.8	3.5	4.1	50	0	15	0
HCO_3^- (mg/L)	1.0	262.2	72.2	18.7	51.1	–	–	–	–
F^- (mg/L)	0.2	2.3	0.4	0.2	0.3	1	2	1.5	0
SO_4^{2-} (mg/L)	4.6	53.7	14.3	9.7	17.1	200	0	250	0
NO_3^- (mg/L)	0.5	4.0	0.7	1.0	1.1	6	0	50	0
Cl^- (mg/L)	10.7	599.2	151.3	44.5	121.2	100	15	250	6

– no standard value available; max = maximum; min = minimum; std dev = standard deviation

Table 3. Water quality index values for groundwater in the Breede WMA

Borehole No.	WQI value	Description
G1	40.3	Excellent
G2	22.7	Excellent
C1	24.9	Excellent
C2	21.4	Excellent
K1	42.6	Excellent
K2	47.0	Excellent
W1	111.4	Poor
W2	40.5	Excellent
S1	100.1	Poor
S2	78.9	Good
Cl1	198.8	Poor
Cl2	117.5	Poor
Overall WQI	64.5	Good

Table 4. Total hardness of groundwater in Breede WMA

Borehole No.	Total hardness (mg/L)	Classification
G1	18.2	Soft
G2	11.6	Soft
C1	13.8	Soft
C2	6.6	Soft
K1	21.6	Soft
K2	56.4	Soft
W1	84.8	Moderately hard
W2	49.7	Soft
S1	244.1	Hard
S2	140.0	Moderately hard
Cl1	209.9	Hard
Cl2	114.8	Moderately hard

Water Quality Guidelines (DWAF, 1996) and World Health Organisation guidelines for drinking water quality (WHO, 2017) were used as the reference to evaluate suitability for domestic purposes. A descriptive statistical summary of the water quality data is presented in Table 2. The average concentration of most of the major ions and parameters complied with WHO guidelines and SAWQG, except for EC and chloride.

Water quality index

WQI values range from 0–300, in which 0–50 is interpreted as 'excellent', 50–100 as 'good', 100–200 as 'poor', 200–300 as 'very poor', and values above 300 as 'unsuitable' (Molekoa et al., 2019). The WQI values in the study area ranged from 21.4 to 198.8, with an average of 70.5, as shown in Table 3. The WQI measure for the overall Breede WMA was 64.5, i.e. 'good', implying that most of the groundwater in the area is suitable for drinking without any treatment. There are a few areas which show poor water quality for drinking purposes.

Total hardness

TH ranged from 6.6 mg/L to 244.1 mg/L, averaging 81 mg/L. Water in 58.3% of the boreholes was classified as soft, 25% as moderately hard and 16.7% as hard. Magnesium and calcium contribute to water hardness (El-Aziz, 2018). Table 4 presents the TH results for the study area.

Sodium adsorption ratio

Sodium adsorption ratio, also known as sodicity, indicates whether water will induce sodic soil conditions (DWAF, 1996b). It is influenced by sodium, magnesium and calcium (Sridharan and Senthil Nathan, 2017). SAR values of 0–10 are classified as 'excellent' for irrigation, values of 10–18 are 'good', 18–26 are 'doubtful' and values above 26 are 'unsuitable'. SAR results (Table 5) indicated that water from all of the boreholes sampled in the Breede WMA was classified as excellent for irrigation purposes.

Table 5. Sodium adsorption ratio of groundwater in the Breede WMA

Sodium adsorption ratio	Description	No. of boreholes
0–10	Excellent	12
10–18	Good	0
18–26	Doubtful	0
> 26	Unsuitable	0
Total		12

Sodium percentage

High sodium concentration destroys the soil's physical structure and impacts drainage. When Na^+ combines with CO_3^{2-}, the soil structure becomes alkaline and, subsequently, saline when combined with Cl^-. These two conditions result in reduced crop yield (Dhanasekarapandian et al., 2016). The sodium percentage (Na%) results in Table 6 show a minimum of 35.8% and a maximum of 77.9%, with an average of 64.6%. Water from 8.3% of boreholes in the area fall in the 'good' class for irrigation, while 16.67% fall within the 'permissible' class and 75% are in the 'doubtful' class.

Permeability index

Poor soil permeability results from irrigating crops with water that has poor quality. The salts in the water accumulate in the soil and prevent water from penetrating to reach the roots of the plants (Srivastava, 2019). According to El-Aziz (2018), a permeability index (PI) value <25% is 'safe' for irrigation, values from 25–75% are moderately safe and values >75% are unsuitable. PI in the study area ranged from 12.1–60.1%, with an average of 28.5%. Water from 41.7% of the boreholes was safe for irrigation, and from 58.3% was moderate, with no unsafe sources. Table 7 indicates the permeability index results for the study area.

Magnesium hazard

Magnesium damages the soil structure and makes the soil alkaline. This results in reduced crop yield (Ismail and El-Rawy, 2018). When water has a magnesium hazard (MH) > 50%, it is considered unsuitable for irrigation, whereas MH < 50% indicates suitability (Ismail and El-Rawy, 2018). Table 8 shows that groundwater MH in the Breede WMA ranges from 12.4–73.8%, with an average of 52.9%. Water from 41.7% of the boreholes was suitable for irrigation and from 58.3% was unsuitable.

Wilcox diagram

The Wilcox diagram, which is a plot of Na% with respect to EC, is shown in Fig. 3. The diagram indicates that water from 75% of the boreholes fall in the 'excellent to good' category, while 25% fall in the 'good to doubtful' category.

USSL diagram

Figure 4 shows the USSL diagram for the study area. Water from 41.7% of boreholes was categorised as having low salinity and low sodium content. Water in this category is very good for irrigation. It can be used on all types of soil and all types of plants. Water from 33.3% of the boreholes fell in the medium salinity and low sodium hazard category. Water from 8.3% of boreholes fell in the high salinity and low sodium content category, indicating that it is partially suitable for irrigation. Water from 16.67% of boreholes fell in the high salinity and medium sodium content category, meaning that it is not recommended for irrigation and should not be used on soils with poor permeability (Alavi et al., 2010).

Piper diagram

The Piper diagram for the Breede WMA revealed that Na-Cl is the dominant water type, followed by mixed Ca-Mg-Cl. The plot in Fig. 5 also reveals that the alkali metals (Na^+ and K^+) exceed alkaline-earth metals (Ca^{2+} and Mg^{2+}), and strong acids (Cl^- and SO_4^{2-}) exceed weak acids (HCO_3^- and CO_3^{2-}) (Marghade et al., 2015).

The Na-Cl water type can be attributed to rock salt dissolution and ion exchange Mokoena et al., 2021). The mixed Ca-Mg-Cl type shows that the water comes from mixed sources (Solomon, 2013). This water type is dominant in the Stanford area, a coastal area where the soil is rich with lime. The mixed Ca-Mg-Cl can be attributed to seawater intrusion and calcite dissolution.

Table 6. Sodium percentage of groundwater in the Breede WMA

Sodium percentage (Na%)	Class	No. of boreholes	Percentage (%)	Boreholes
0–20	Excellent	0	0	–
20–40	Good	1	8.3	S1
40–60	Permissible	2	16.7	S2, W2
60–80	Doubtful	9	75	G1, G2, C1, C2, K1, K2, W1, Cl1 and Cl2
> 80	Unsuitable	–	–	–
Total		12	100	

Table 7. Permeability index of groundwater in the Breede WMA

Permeability index percentage	Description	No. of boreholes	Percentage (%)	Boreholes
< 25	Safe	5	41.7	G1, C1, K2, Cl1, Cl2
25–75	Moderate	7	58.3	G2, C2, K1, W1, W2, S1, S2
> 75	Unsafe	0	0	–
Total		12	100	

Table 8. Magnesium hardness of groundwater in the Breede WMA

Magnesium hazard (%)	Description	No. of boreholes	Percentage (%)	Boreholes
< 50	Suitable	5	41.7	G2, K1, W2, S1, S2
> 50	Unsuitable	7	58.3	G1, C1, C2, K2, W1, Cl1, Cl2
Total		12	100	

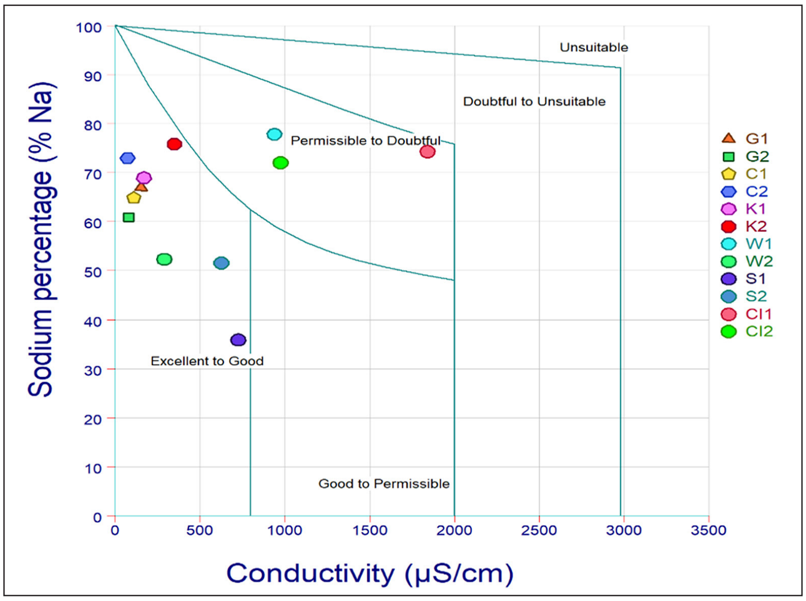

Figure 3. Wilcox diagram for groundwater in the Breede Water Management Area

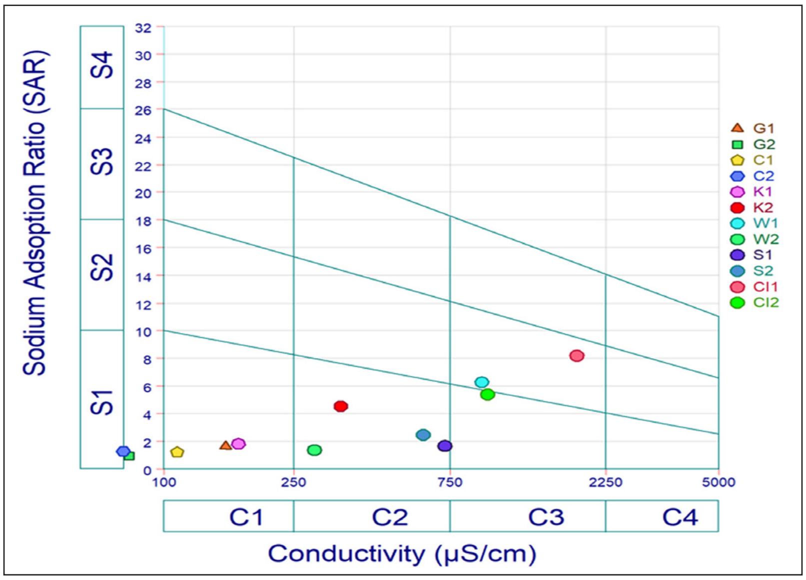

Figure 4. United States Salinity Laboratory diagram for the Breede WMA

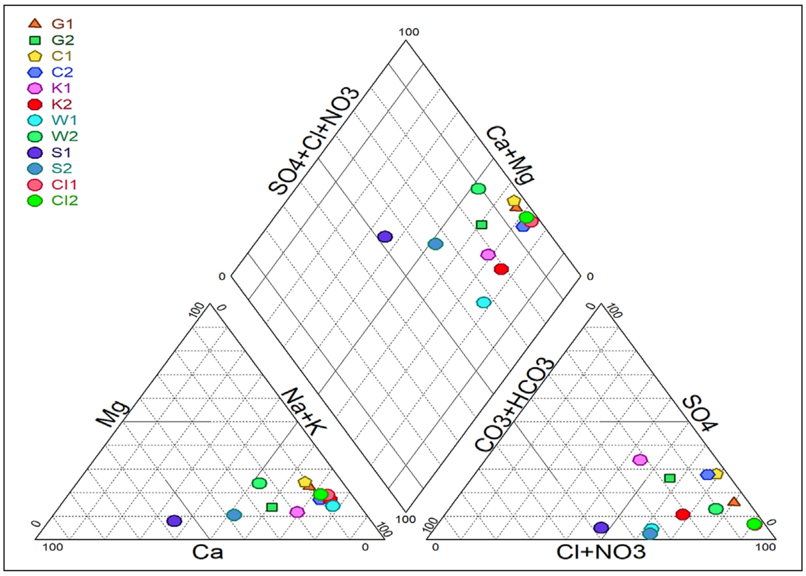

Figure 5. Piper diagram for Breede WMA groundwater

Multivariate statistical analysis

The Pearson correlation matrix was used to determine the relationship between the major ions and physical variables, as shown in Table 9. The results show that TDS strongly correlates with Cl^-, Mg^{2+}, Na^+, Ca^{2+}, HCO_3^-, K^+ and SO_4^{2-}. This suggests that these ions are the main constituents contributing to groundwater salinity in the study area. Their relationship with salinity is directly proportional. Processes such as evaporation and seawater intrusion are known to contribute to the salinisation of groundwater (World Water Quality Alliance, 2021). Strong correlations between cations and anions exist, for example, Cl^- and Na^+, Cl^- and Mg^{2+}, Cl^- and Ca^{2+}. The Na^+ and Cl^- relationship may be attributed to the dissolution of rock salt and or seawater intrusion. The strong relationships between Cl^- and Mg^{2+}, as well as Cl^- and Ca^{2+}, indicate that cation exchange greatly influenced groundwater composition.

PCA was conducted to identify the relationship and origin of the ions. Four PCs with eigenvalues > 1 were selected. The first and second principal components, PC1 and PC2, account for 44.9% and 15.7% of the variance, respectively. PC1 was shown to associate with Mg^{2+}, SO_4^{2-}, Na^+, K^+, Cl^-, and TDS. This suggests that the sources of these major ions are mineralisation. The loadings of these constituents are relatively high compared to the other constituents. The correlation of Cl^- and SO_4^{2-} with cations may also indicate the salinisation of the water due to agricultural activities (WHO, 2017). The contribution of SO_4^{2-} may be due to fertilisers (Marghade et al., 2015). It follows that PC1 describes more highly mineralised water samples than PC2. PC2 accounts for only 15.7% of the variance and is mainly associated with Ca^{2+}, HCO_3^-, NO_3^-, temperature and pH. PC2 is related to alkaline waters characterised by a relatively high concentration of bicarbonates compared to the concentration of other constituents. Figure 6 presents the PCA biplot for groundwater analysis in Breede WMA.

Table 9. Pearson correlation matrix for groundwater chemistry in Breede WMA

	Na	Ca	Mg	K	NO_3	Cl	SO_4	F	HCO_3	TDS	T	EC	pH
Na	1												
Ca	0.81#	1											
Mg	0.94*	0.76"	1										
K	0.74"	0.42	0.64	1									
NO_3	−0.09	0.12	−0.04	−0.17	1								
Cl	0.93*	0.79"	0.94*	0.65	−0.07	1							
SO_4	0.56	0.45	0.52	0.49	0.06	0.56	1						
F	0.19	0.05	0.16	0.07	−0.13	0.17	0.42	1					
HCO_3	0.68	0.79"	0.58	0.46	0.08	0.64	0.29	−0.04	1				
TDS	0.93*	0.83#	0.93*	0.68	−0.01	0.98*	0.63	0.19	0.69	1			
T	0.29	0.44	0.33	0.15	0.25	0.35	-0.08	−0.43	0.65	0.35	1		
EC	0.57	0.41	0.57	0.47	−0.13	0.61	0.32	−0.22	0.4	0.59	0.31	1	
pH	0.12	0.29	0.04	0.20	−0.01	0.19	0.12	−0.31	0.34	0.20	0.23	0.19	1

*significant correlation (>90%), #significant correlation (>80%), "significant correlation (>70%)

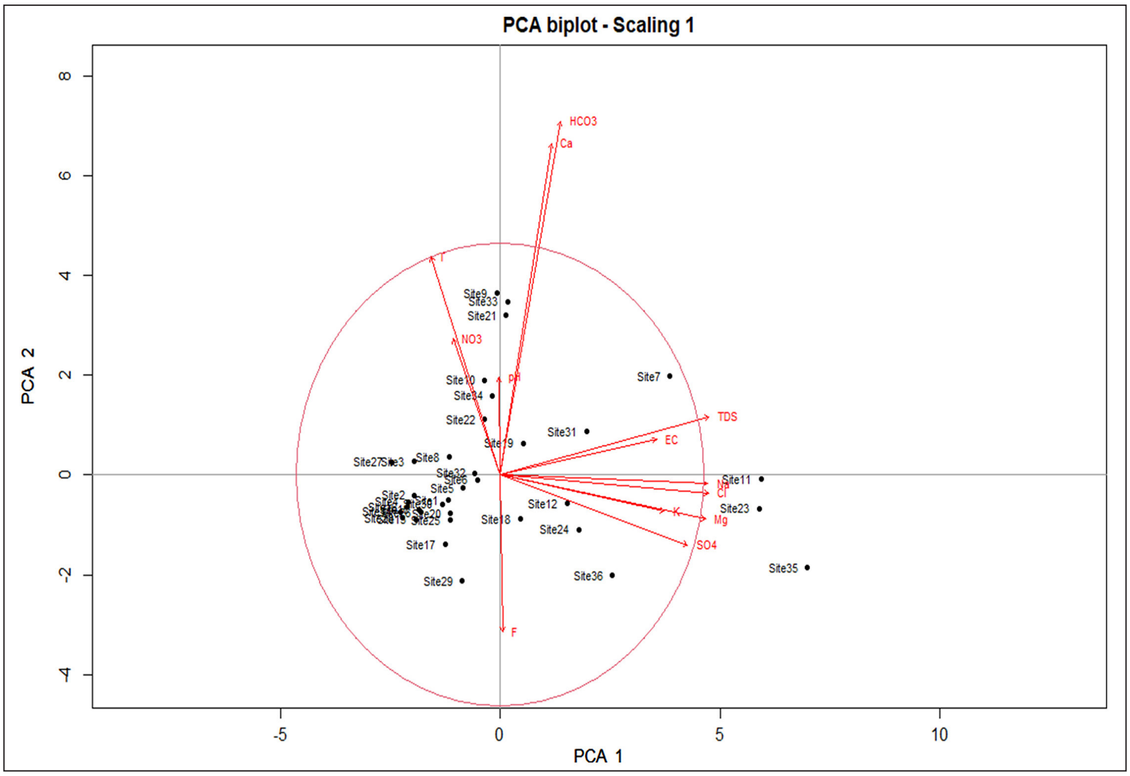

Figure 6. Principal component analysis biplot for groundwater analysis in Breede WMA

DISCUSSION

Water used for drinking purposes should be free of toxic substances, have a low TDS value, and must be soft. The effects of poor water quality can include health problems for human beings using the water for domestic purposes, productivity or yield problems for crops being irrigated, the cost of treating the water and negative impacts on the biodiversity of the aquatic ecosystem (DWAF, 1996a; DWAF, 1996b).

The concentrations of most parameters in Breede WMA groundwater complied with the requirements of the SAWQG and the WHO water quality guidelines. The WQI and TH were used to determine the water's suitability for domestic use. WQI results revealed that Boreholes W1, S1, CI1 and CI2 were in the 'poor' category for drinking water. Borehole S2 fell in the 'good' category and the rest of the boreholes in the area fall in the 'excellent category'. The results for the overall Breede WMA were in the 'good' category. Total hardness results revealed that Boreholes G1, G2, C1, C2, K1, K2, and W2 fell in the 'soft' category. Water from Boreholes W1, S2 and CI2 is moderately hard and S1 and CI1 fall in the hard category.

Assessment of suitability of the groundwater for irrigation was carried out using irrigation indexes such as PI, SAR, MH, Na% and graphical representation methods such as USSL and the Wilcox diagram.

SAR results indicated that 100% of the boreholes were suitable for irrigation. Na% shows that 8.3% of boreholes in the area fall in the 'good' class for irrigation, while 16.67% fall within the 'permissible' class and 75% are in the 'doubtful' class. MH revealed that 41.7% of the boreholes were suitable for irrigation and 58.3% were unsuitable for irrigation. 58.33% of the boreholes in the area showed moderate PI and 41.67% of the boreholes are safe for irrigation in terms of the impact on soil permeability.

The results from the USSL diagram reveal that water in Borehole W1 in Worcester and Boreholes CI1 and CI2 in Cape Infanta must only be used on crops that have high salt tolerance and on soils with high permeability. The Wilcox diagram results showed that Boreholes W1, CI1 and CI2 are in the 'good to doubtful' category while the other boreholes were in the 'excellent to good' category for irrigation purposes.

Multivariate statistical analysis and a Piper diagram were applied to determine the geochemical processes that influence the groundwater quality in the Breede area. The Piper diagram shows that the dominant water type in the Breede WMA is Na-Cl, followed by mixed Ca-Mg-Cl. Na-Cl could be attributed to rock salt dissolution and ion exchange processes. Mixed Ca-Mg-Cl could be attributed to seawater intrusion and calcite dissolution. Pearson correlation results revealed that processes that influence the chemistry in the area may be attributed to the dissolution of rock salt and/or seawater intrusion. The strong relationships between Cl^- and Mg^{2+}, as well as Cl^- and Ca^{2+}, indicate that cation exchange may have a large influence on groundwater composition. PCA results revealed that mineralisation of the groundwater and alkaline waters have an influence on the groundwater chemistry of the area.

There is similarity between WQI and TH results – both revealed that all boreholes showed suitability for domestic use except for Boreholes W1, S1, S2, CI1 and CI2. Wilcox and USSL showed similar results: Boreholes CI1, CI2 and W1 were not suitable for irrigation while all the other boreholes were suitable. The Piper diagram revealed that the dominant water type in the area is Na-Cl while the Pearson correlation also revealed that there is strong correlation between sodium and chloride. Both these measures indicate that rock salt dissolution and ion exchange contribute to the chemistry of the groundwater.

CONCLUSION

The study aimed to determine the status of groundwater quality, determine factors that influence the quality of groundwater and evaluate its suitability for irrigation and domestic purposes. Most of the measured variables complied with SAWQG and WHO drinking water quality guidelines, indicating that groundwater quality in Breede WMA is suitable for domestic use. These results correspond with the WQI results which revealed that the overall groundwater quality in the Breede WMA is suitable for domestic use. TH results showed that water from most boreholes was 'soft', with a few yielding water that was 'moderately hard' and 'hard'.

The suitability of the groundwater for irrigation was assessed using various parameters and indices, such as PI, SAR, MH, Na%, in combination with USSL and Wilcox diagrams. The irrigation indices revealed that most of the groundwater in the Breede WMA is suitable for irrigation. SAR results indicated that 100% of the boreholes are in the 'excellent' category for irrigation. PI results revealed that there is no borehole with unsafe water. Na% results also revealed there are no boreholes that were indicated to be unsuitable. MH results indicated that 41.7% of the boreholes were suitable for irrigation and 58.3% were unsuitable for irrigation.

The results from the USSL and the Wilcox diagram corresponded. Both techniques showed that all the boreholes were suitable for irrigation except for Boreholes W1, CI1 and CI2. In terms of the Wilcox diagram, Boreholes W1, CI1 and CI2 fall in the permissible to doubtful category, while in terms of USSL, these three boreholes fall in the high salinity and medium sodium content category.

The Piper diagram showed that the dominant water in Breede is Na-Cl, followed by mixed Ca-Mg-Cl. Pearson correlation and PCA results show that processes influencing the chemistry of groundwater in the area could arise from a combination of rock salt dissolution, seawater intrusion, mineralisation of the groundwater and alkaline waters.

RECOMMENDATIONS

This study recommends that water in the boreholes along the coastal area and Borehole W1 in Worcester be treated before being used for domestic and irrigation purposes. There needs to be consistent groundwater quality monitoring in the Breede Water Management Area to identify changes in groundwater quality. Future studies on groundwater quality must include heavy metals, microbial parameters, and pesticides. The effects of pesticides from agricultural run-off, microbial contamination from domestic waste and heavy metals from industrial waste must be monitored to properly manage the groundwater resources. Municipal authorities should develop initiatives to educate the surrounding communities, especially farmers, on water quality, its potential impact on their practices, and possible treatment methods to improve water quality.

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AUTHOR CONTRIBUTIONS

MP Makonko: sample collection and wrote the paper; F Wewers: supervision of student and oversight of study.

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