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Research article

Groundwater quality evaluation for domestic and irrigation purposes for the Nwanedi Agricultural Community, Limpopo Province, South Africa

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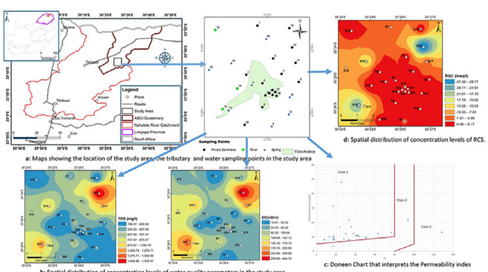
GRAPHICAL ABSTRACT



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ABSTRACT

In addition to quantity of water supply for various water uses, water quality is also of concern. The current state of the water quality is not known; neither is its suitability for domestic and agricultural uses. The current study investigated the suitability of the groundwater resource for domestic and agricultural uses in Nwanedi agricultural community. Water samples were collected from the existing boreholes following procedure for standard water sampling. Physicochemical parameters (pH, TDS, EC), anions (Cl^-, SO_4^{2-}, HCO_3, and NO_3.-N), cations (Mg, Ca, K, and Na), and HCO_3 were analysed successively. The assay results were used to generate the agricultural water quality parameters (Sodium Adsorption Ratio, Magnesium Adsorption Ratio, Permeability Index, Residual Sodium Carbonates, Sodium percentage, Kelly's Ration and Chloride Index). Also, the communality test was conducted to investigate the suitability of the data for factor analysis and the loading of different parameters on the resultant factors. The assay results indicated that the water quality in the area is relatively fresh and adequate for domestic consumption, although there are infrequent excessive levels of nitrates ranging between 0.52–135.54 mg/l. Similarly, the groundwater was found to be ideal for irrigation (SAR 0.07–0.94 meq/l, MAR 26–48 meq/l, PI (92.5%) Class 1, PI 13–111 meq/l, RSC < -1, and CI = Class 1). The communalities which are the index of the measure of efficiency indicated that all the parameters except K were suitable for FA assessment. The hydrochemical composition is controlled by natural and anthropogenic processes such as on-sight sanitation, agricultural leachates, and domestic effluents. Future comparative studies on how groundwater quality is influenced by climate conditions (dry and wet season) should be conducted in this area.

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1. Introduction

Water quality is a fundamental component of the water supply system (Brodie et al., 2019), which must meet requirements for public, commercial, and industrial activities (Nathanson, 2020). The agricultural and the domestic sector require water that is within a predefined spectrum of the hydrochemical constituents (WHO, 2006; Panneerselvam et al., 2021a; Mishra et al., 2022). If the concentration of the key physicochemical constituents is not within the required range for a certain water use, then water is deemed unfit for that particular use (Paul et al., 2009; Pande and Muharir, 2021). The consumption of water with unfit quality has the potential to result in bad effects (WHO, 2006). Hence, it is important to understand the quality of the water resource before use (Fahad et al., 2020; Panneerselvam et al., 2021b). According to Braune and Mutheiwana (2009), out of roughly 200 million people that reside in sub-Saharan Africa, approximately 60–90% of them mainly rely on groundwater for living. Water resources in this region are mainly consumed from the source, without prior treatment. According to Braune and Mutheiwana (2009), most of the groundwater development is not succeeded with water quality assessment. The consumption of untreated water is an unideal practice. In the worst-case scenario, such water resources could be contaminated. Hence, the prolonged consumption of such water resources has the potential to result in a diverse array of health problems to the human (Fahad et al., 2020), livestock (Giri et al., 2020), and crops (Suresh and Nagesh, 2015).

According to Zarei and Pourreza Bilondi (2013), the state of the water quality occurs as a result of natural processes and anthropogenic activities. These aspects variably influence the chemistry of water in both space and time (Guler et al., 2005). Vorosmarty et al. (2010), inferred that water resources throughout the world, are subjected to the risk of contamination. Gajbhiye et al. (2014) discovered that there is an increase in water resource contamination due to the fast increase in the human population, and rapid industrialization. In many parts of the world, anthropogenic activities pollute the water to a point that it is not fit for either domestic use or irrigation (Schwarzenbach et al., 2010). The use of contaminated water for agriculture results in retarded growth of crops or even permanent production loss (Mateo-Sagasta et al., 2017). Despite the potential predicaments posed by poor water quality to the crops, agricultural water quality is often overlooked.

Groundwater provides the main portion of global freshwater supply and will continue to do so over the coming decades (Bhattacharya and Bundschuh, 2015) The agricultural community of Nwanedi is reliant on groundwater resources for their domestic and agricultural needs. Water quality monitoring in this area has lately been infrequent. Nevertheless, there has been intensification on the agricultural participation (game and crop production) at both subsistence and semi-commercial level. Since the last monitoring (2010), there has been an increase in settlements with improper sanitary infrastructures. These activities pose the risk to contaminate the water resources (Ismael et al., 2021). Crops thrive within a confined set of the physicochemical parameters of the water quality (Abbas et al., 2020). If the water does not adhere to such standards, there is potential for permanent detrimental effects on the soil structures and production of sub-standard quality crops (Maphuhla et al., 2021). If this occurs, agricultural production will be significantly reduced in both quality and quantity. After this, there will be destabilization of the local economy and the value chain; through the decline of agricultural production that leads to job losses and lowering of the gross domestic product. On the other hand, poor water quality may result in health hazards such as fluorosis and cholera outbreaks that affect the well-being of the inhabitants. In worst-case scenarios, it may result in fatalities. Hence, for better protection and sustainable management of these critical water resources, it is of paramount importance to understand the quality of water resources for both domestic and agricultural use, and the natural and anthropogenic processes that are controlling the hydrochemical composition.

Molekoa et al. (2019) conducted a groundwater assessment study in Ivaplant Mine found in the Limpopo Province of South Africa, aiming at evaluating water quality status and hydrochemical processes governing it. In their study, hydrogeochemical analysis of groundwater samples was employed to calculate the WQI in the area and the WQI suggested that 80% of water samples fall into the good and excellent categories, meaning that water was suitable for domestic use. Another study was conducted by Malaza (2017) in the Soutpansberg Basin around Tshikondeni, Limpopo Province, South Africa, where the impact of anthropogenic and natural sources of contamination on the groundwater quality were investigated in the unconfined aquifer system of the Soutpansberg Basin. In their study, it was found that groundwater is above the desirable Department of Water and Sanitation (DWS) and World Health Organisation (WHO) limits for domestic and irrigation purposes. They also highlighted that leaching of ions followed by weathering and anthropogenic impact (mainly mining and agricultural activities) control the chemistry of groundwater in the study area.

Many studies (e.g. Barbieri et al., 2019; Ricolfi et al., 2020) have been conducted on assessment of groundwater quality for domestic and agricultural irrigation in both national and local catchment level (large scale catchment). However, no studies have been done on quaternary catchment level (small scale catchment); hence, these areas are mainly hotspots for catchment's groundwater pollution. Therefore, to fill up this research gap, the present study is the first of its kind to aim at appraising groundwater quality status of the Nwanedi Agricultural Community (NAC) (located within the quaternary catchment A80J of the Nzhelele River catchment) with focus on its suitability for domestic and agricultural uses. To achieve these objectives, agricultural water quality parameters (Sodium Adsorption Ratio, Magnesium Adsorption Ratio, Permeability Index, Residual Sodium Carbonates, Sodium percentage, Kelly's Ration and Chloride Index) for this area were generated. NAC is one of the most significant agricultural hubs in the Limpopo Province of South Africa. The area is mainly reliant on groundwater resources for both domestic and agricultural demands. Unfortunately, the suitability of the water resources for these activities is not fully understood. Therefore, there is a need to establish the suitability of the water resources for the aforementioned activities. Although NAC is dominated by smallholder farming, the majority of the inhabitants are reliant on agriculture for livelihood. The royal house claims that the sector provides over 1000 direct employment to locals and about 500 foreign nationals. With the consideration of the entire value chain, the agrarian sector employs over 5000 people. The comprehension of the water quality and its subsequent suitability for agricultural suitability helps to nullify the predicaments that are associated with inadequate water quality. Moreover, it helps the government to save economic resources that are set aside for rescuing the sector. On the other hand, it is equally important to comprehend water quality compliance to the regulatory standard for drinking as that knowledge helps to implement the necessary measures that prevent the outbreaks of various water-borne diseases that are detrimental to human health, and fatalities.

2. Materials and methods

2.1. The study area

Nwanedi Village is located in the Musina Local Municipality in the Vhembe District of the Limpopo Province of the Republic of South Africa. The village is confined to the following geographical position 30.4337° East and 22.5861° South. Nwanedi is located in the semi-arid Limpopo with a population of approximately 3000 people (StatsSA, 2017). Nwanedi community is located within the quaternary catchment A80J (catchment area of 874.3 km^2) of the Nzhelele River catchment (Figure 1), a tributary of the Limpopo River. The land-use cover in the area is widely characterised by agricultural land, human settlements and natural vegetation; dark green colour along stream exiting in the

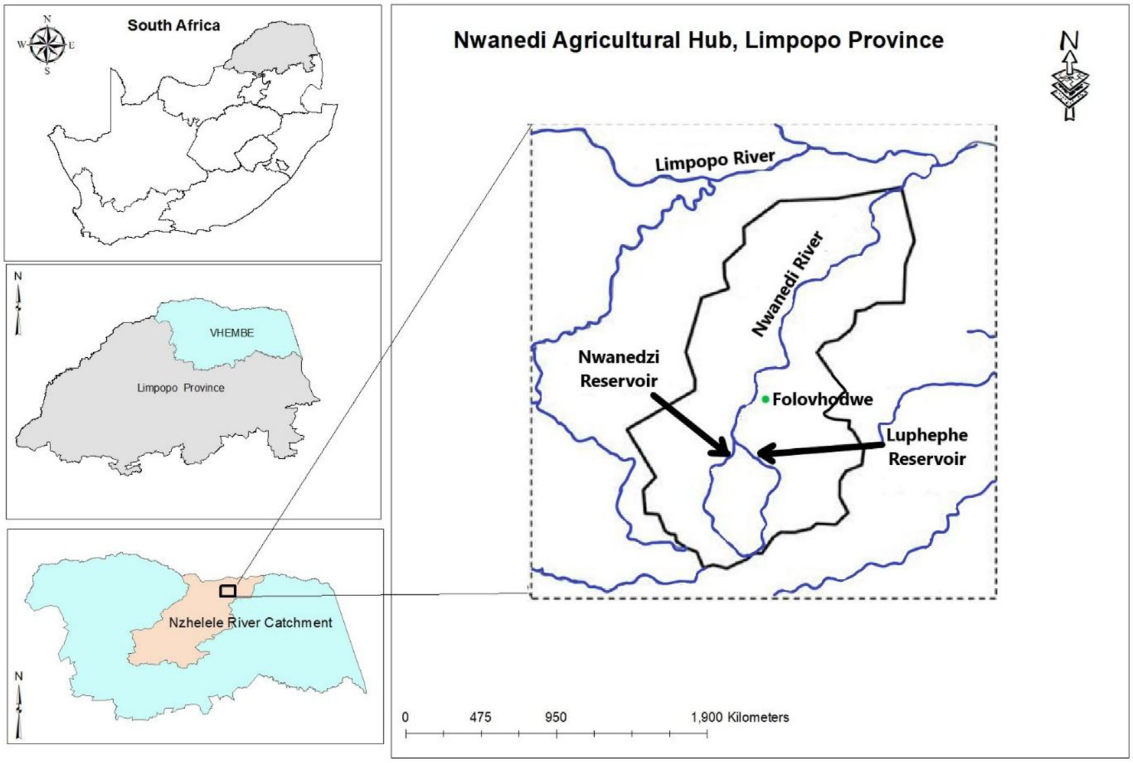


Figure 1. A map showing the location of the study area (Nzhelele River catchment and Quaternary catchment A80J.

southern boundary represents agricultural land, brownish colour is bare land, whitish colour represents mostly built-up and other greenish features are natural vegetation (Figure S1). Local groundwater resources are the main source of water for domestic uses, supplying about 59%, while local surface water supplies 41% of water for domestic uses (Lombaard, 2016). Groundwater supplies 15% of water for irrigation purposes in the area (Lombaard, 2016). The main crop with the largest area under irrigation (16.6%) is the maize, followed by potatoes (12%) and wheat (10.7%). Dryland cultivation with crops such as grain sorghum and cotton are also practised (Lombaard, 2016). The recent establishment of the packhouse attracted more smallholder farmers to the agricultural production scheme and this has added excessive strain on the already strained water supply. This is particularly the case because the Limpopo basin has generally low amounts of precipitation; majority of the catchment basin receives less than 500 mm of rainfall per year, with approximately 95% falling during the wet season of October to April (FAO, 2007). High temperatures during the summer (November–December) occur in the basin; average daily temperatures of about 35 °C and a maximum of about 40 °C in summer months are common (FAO, 2007). The region has experienced severe droughts in the past, resulting in crop failure, livestock mortality, economic losses, and the need for humanitarian aid. There have equally been drought events that compelled the inhabitants to divert to groundwater resources, however in some areas groundwater abstractions were suspended due to excessive salt dissolution, particularly for irrigation.

Different lithological features naturally control the hydrochemical properties of groundwater in many regions due to geological environments (Lee et al., 2019). The quaternary catchment A80J is widely characterised by the Gneiss rock formations which form the secondary aquifers in the area followed by the Sandstones formations (Figure 2). These influence the lithology, which in turn influences the surface water run-off and its contribution to the recharge of the aquifers (underground water storage areas) in the study area. The groundwater quality of the area is controlled by the geochemical influence (interaction of groundwater with rocks) of the Tshipise Fault; significant number of un-rehabilitated mine dumps that are still lying in close proximity to the river, which could be contributing towards this impact (Angliss et al., 2007) when surface water interacts with groundwater; and agricultural fertilizers that leach into groundwater reservoirs during heavy rainfall.

2.2. Water quality assessment

The water quality assessment was carried out based on the primary data obtained from the existing water resources. The data comprises the major physicochemical parameters of water such as EC, TDS, pH, and the major ions of the water, i.e. cations (Na, Mg, Ca, K) and anions ($CaCO_3$, $HCaCO_3$, SO_4, Cl). In addition, the Water Quality Index (WQI) was calculated as per Brown et al. (1972), to determine the suitability of water quality for domestic use and this was calculated using the standards of drinking water quality recommended by SANS241 (2006), using the steps below:

Step 1: Calculate the unit weight (W_n) factors for each parameter using Eq. (1).

$$Wn = \frac{K}{Sn} \tag{1}$$

Where K $= \frac{1}{\frac{1}{S1}+\frac{1}{S2}+\frac{1}{S3}+\ldots+1/Sn} + \frac{1}{\sum\frac{1}{Sn}}$

S_n = Standard desirable value of the nth parameters. On summation of all selected parameters unit weight factors, $W_n = 1$ (unity).

Step 2: calculate the Sub-Index (Q_n) value by using the equation:

$$Qn = \frac{[(Vn - V0)]}{[(Sn - V0)]} * 100 \tag{2}$$

Where: V_n is the mean concentration of the n^{th} parameters

S_n is the standard desirable value of the n^{th} parameters

V_n is the actual values of the parameters in pure water (generally $V_0 - 0$, for most parameters except for pH). Parameter pH is estimated by Eq. (3).

$$QpH = \frac{[(VpH - 7)]}{[(8.5 - 7)]} * 100 \tag{3}$$

Step 3: Combining Step 1 and Step 2, WQI is calculated as follows:

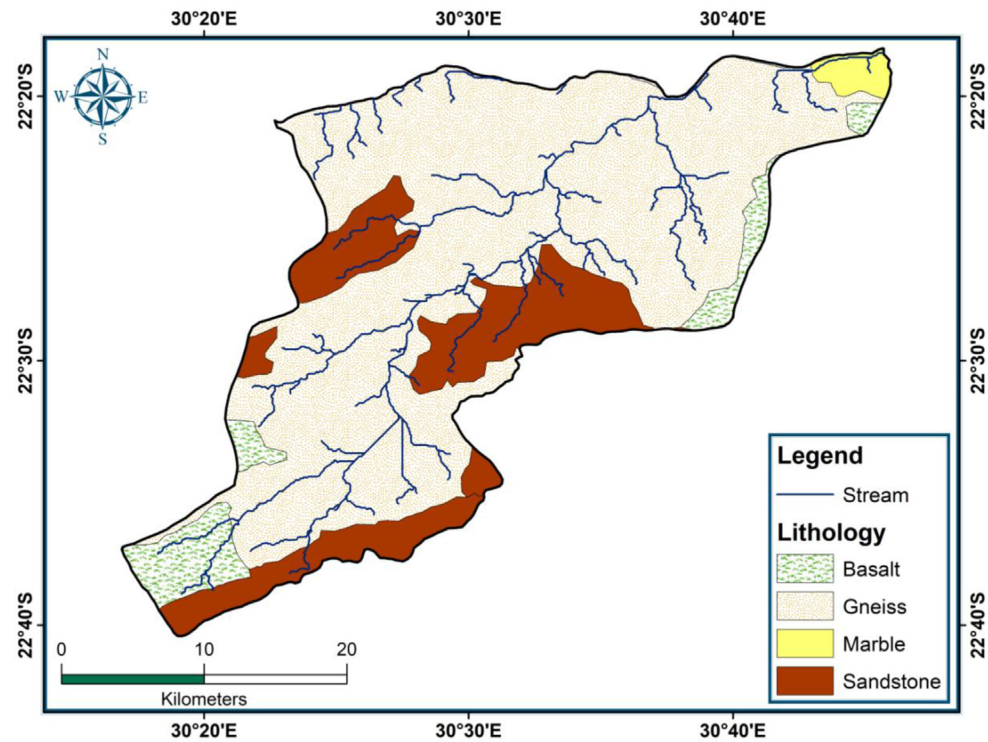


Figure 2. Map showing the hydrogeological setting of the study area.

$$Overall\ \ WQI = \frac{\sum WnQn}{\sum Wn} \tag{4}$$

2.2.1. Water sample collection

The sampling survey was designed after the field reconnaissance work, that led to the identification of the boreholes where groundwater would be collected. Each of the boreholes was visited and the geographical coordinates were recorded. Such locational data was deemed essential for the cartographic activities that were part of the study. The map in Figure S2 shows the layout of the sampling points within the project area. In total, 29 samples were collected during the wet season of the year 2020 from the existing wells. The properly rinsed Teflon bailers were used to collect water samples pumped from the boreholes. Water samples were transferred to properly numbered, well-rinsed airtight clean high-density polyethylene (HDPE) bottles. Two water samples were collected at each point, one for cations and another for anions. The samples for the cations and anions were filtered on-site using a 0.45-micrometer filter and acidified with concentrated nitric acid (HNO_3) to give a pH value of <2 that preserves the metals dissolved and prevents precipitation (Veley, 1891). Immediately after sampling, the bottles were stored in a cooler box (<5 °C) till the samples were delivered to the laboratory.

The physicochemical parameters such as pH, EC, TDS, and alkalinity were measured on-site using an Aquaread GPS Aquameter 200 multi-parameter probes. The measurements of the physical parameters of water are important to carry out on the site because they can easily be subjected to alteration soon after sampling from the aquifer. The equipment was well-calibrated using three known standard solutions before measurement of the physical parameters.

2.2.2. Laboratory analysis

The experiments were performed in a multi-metal system, in the presence of minerals of feeding significance: Mn, Cu, Zn, Cr. Inductively coupled plasma optical emission spectroscopy (instrument Vista-MPX, Varian, Australia) was used in this study. ICP-OES parameters (RF power, nebulizer pressure, auxiliary gas flow rate sample uptake and rinse time) were optimized in order to reach high signal to blank ratios at emission lines of least interference. The water samples were analyzed at the Water Lab using Inductively Coupled Plasma Optical Emission Spectrometry (ICP-OES). The equipment that was used is a Perkin Elmer Optima 2100 DV ICP-OES spectrometer.

2.2.3. Data accuracy checking

The water quality data often contain errors as a result of mishandling and contamination of water samples at any stage of data generation. The post-analysis errors were usually generated during data capturing. Therefore, a data accuracy check was conducted to eradicate such errors and mistakes in two successive phases. The initial phase of data editing comprised visual inspection of the datasets. During this phase, all erratic values that are mostly the results of data capturing were manually excluded from the data set for post-processing. This was succeeded by basic descriptive statistical analysis, which was equally meant for outlining erratic physiochemical values. The second phase of data editing was carried out following the standard requirement for water quality assessment, which was proposed by Freeze and Cherry (1979). The principle behind this approach is that, in a large electrolytic solution, the sum of anions should be equal to the sum of cations. In aligning with this principle, Rockworks software was adopted to aid in Charge Balance Error (CBE). Eq. (1) illustrates how CBE was computed, the threshold of 15% CBE was considered for the assessment of the water quality. Since monitoring was conducted and recorded in mg/l, the monitoring data were converted to meq/L before CBE using Rockworks software.

$$\text{CBE} = \left(\frac{\sum eq_{cations} - \sum eq_{inions}}{\sum eq_{cations} + \sum eq_{inions}}\right) \times 100 \tag{5}$$

Where total cations are in milliequivalents per litre (meq/L) and total anions are in milliequivalents per litre (meq/L). The newly generated data was integrated with the auxiliary data to eradicate the seasonal variability of the water quality since the sampling was limited to one season.

2.2.4. Descriptive statistical analysis

Descriptive statistical analysis of the hydrochemical data comprising the minimum value, the minimum mean, standard deviation, the coefficient of correlation (R) was conducted using John's Macintosh Project (JMP) statistical package. This was carried out to gain a broader spectrum of the distribution of various populations of the chemical data.

2.2.5. Interpolated water quality parameters

The spatial distribution maps of water quality parameters were created using Inverse Distance Weighted (IDW) interpolation technique in the ArcGIS environment (Pande and Mohahir, 2018). The IDW explicitly implements the assumption that things that are close to one another are more alike than those that are farther apart. This technique is versatile, easy to use, and fairly accurate under various conditions and captures the extent of local spatial variation (Muavhi et al., 2021). Consequently, the generated maps were classified using natural breaks method into eight classes. Natural breaks classes are based on natural groupings inherent in the data (Jenks 1967).

2.3. Water quality suitability for irrigation

The water quality assessment was carried out to review the suitability of the water resource for irrigation of the crops. Each crop requires water within a predefined set of physicochemical parameters. The irrigational water parameters were derived from the subsequent water quality results. If water does not conform to the requirement of the crop, there are possible implications, such as poor growth and quality (Moharir et al., 2019).

2.3.1. Sodium Adsorption Ratio

Sodium Adsorption Ratio (SAR) is a measure of the amount of sodium (Na) relative to calcium (Ca) and magnesium (Mg) in the water extract from saturated soil paste. It is the ratio of the Na concentration divided by the square root of one-half of the Ca + Mg concentration (Reeve et al., 1954). The suitability of water resources for irrigation purposes was primarily based on the concentration of Na in relation to the sum of Ca and Mg (Hem, 1985). According to the SAR hazard chat proposed by the Agricultural Council of America, the suitable water resource for irrigation is characterized by the SAR value of <3 meq/L. SAR was computed using Eq. (6),

$$\mathrm{SAR} = \left(\frac{Na^{2+}}{\sqrt{Ca^{2+} + Mg^{2+}}}\right) \tag{6}$$

The result of this processing was a map depicting the spatial variability of the SAR values throughout the study area. The Wilcox diagram was also used to plot the SAR data.

2.3.2. Magnesium Adsorption Ratio

According to Paliwal (1972) and Haritash et al. (2016), Magnesium Adsorption Ratio (MAR) is a critical chemical prerequisite before the adoption of the water resource for irrigation. According to these authors, this phenomenon defines the undesired state of the equilibrium that exists between Ca and Mg. During this state, the soil becomes more alkaline and the soil losses its quality, subsequently, the crop yields will also drop (Haritash et al., 2016). MAR is defined by the following equation, expressed in meq/L

$$\mathrm{MAR} = \left(\frac{Mg^{2+}}{Ca^{2+} + Mg^{2+}}\right) \times 100 \tag{7}$$

MAR defines whether the water resource is ideal for irrigation or not. If the MAR of the water exceeds 50 meq/L then that water is not ideal for irrigation, and if it is less than 50 meq/L, then it is appropriate.

2.3.3. Residual Sodium Carbonate

Residual Sodium Carbonate (RSC) is the essential indicator for the hazardous effects of the carbonate and bicarbonate if the water is adopted for irrigation of crops (Raju, 2007). The suitability of groundwater reserve for irrigation is the function of the sum of the carbonates and the bicarbonates to the sum of the calcium and magnesium. The RSC is determined by the following mathematical equation (Raghunath, 2007):

$$\mathrm{RSC} = (\mathrm{HCO}^{-3} + \mathrm{CO}_2^{-3}) - (\mathrm{Ca}^{2+} + \mathrm{Mg}^{2+}) \tag{8}$$

2.3.4. Permeability index

The Permeability Index is a qualitative classification of estimated rates of vertical movement of water from the ground surface through the unsaturated zone, the zone between the land surface and the water table. Doneen (1962) defines the permeability index as the long-term impacts of irrigation on the permeability of the soil. This phenomenon was calculated based on the following calculation:

$$\mathrm{PI} = \left(\frac{Na^{2+} + \sqrt{HCO_{3-}}}{Ca^{2+} + Mg^{2+}Na^{2+}}\right) \times 100 \tag{9}$$

The Doneen chart for permeability index was incorporated with the spatial 2D map to illustrate the spatial variability of this phenomenon.

2.3.5. Sodium percentage, Kelly's ratio and US Salinity Laboratory

Water quality for irrigation purposes also depends on set of fundamental parameters such as Sodium percentage (Na%), Kelly's Ratio (KR) and US Salinity Laboratory (USSL). These parameters are taken into consideration within research area when determining groundwater suitability for agricultural irrigation purposes. Na% and KR were calculated in meq/l using Eqs. (10) and (11), respectively. Moreover, groundwater suitability for irrigation was fully determined based on the evaluation of the USSL diagram (Figure 5a).

$$Na\% = \frac{(Na + K) \times 100}{(Ca + Mg + Na + K)} \tag{10}$$

$$KR = \frac{Na}{Mg + Na} \tag{11}$$

2.4. Factor analysis

The Factor Analysis was performed to identify the factors that were controlling the hydrochemical composition. What this approach does is to reduce a large data into latent factors that retain most of the variance that was accounted for by the original data (Otitoju, 2013). The Statistical Package for Social Sciences (SPSS) was applied to perform this assessment. The data suitability assessment for Factor Analysis was performed using the Kaiser–Meyer–Olkin (KMO) and the Bartletts Test. The samples that were deemed ideal were then subjected to the second phase suitability assessment, which is the communality assessment. The communality explains how much of the original components were extracted to interpret the factor model. The parameters that offered at least 50% of their original value are ideal for factor analysis.

3. Results and discussion

3.1. Domestic water quality

The groundwater quality and subsequent suitability for domestic and agricultural consumption were established based on the incorporation of the auxiliary data and primary data. This section presents the results and the discussion of the significant physicochemical parameters of the water quality with a specific reference to its suitability for domestic consumption and agrarian production. The suitability of the water for domestic consumption was discussed in terms of the South African National

Standard (SANS241) and World Health Organisation (WHO) standards for drinking water as reflected in Table S1.

One of the most important aspects of water resources is subsequent quality. According to the DWA (1996), the suitability of water for any particular use is based on a set of physiochemical parameters. The usage of water that falls outside the ideal range of the physicochemical constituents may result in undesired consequences. In humans, the consumption of unfit water may yield ill health or mortality. On the other hand, irrigation of the crops using un-ideal water may yield a diverse array of the impacts that incorporate, production loss, retarded growth, destruction of the soil structure, and soil poisoning amongst others. In this study, the domestic water quality is expressed in terms of the SANS241 and WHO standards for drinking water. This standard is a critical constituent of the water quality regulatory guideline in South Africa. The simplified descriptive statistics of the water quality data are shown in Table 1.

Calcium had a relatively narrow range of 147 mg/l, with a min of 30 mg/l, a max of 178 mg/l, a mean, and a standard deviation of 82.01 and 33.11 mg/l respectively. These statistical values outlined that the water quality in this area is of pristine quality and may easily be used for domestic consumption without prior treatment. This is because SANS241 permits the consumption of water for domestic purposes of up to 300 mg/l for calcium. Although these results indicate that the prevalent groundwater resource is ideal for domestic consumption, it is worth noting that the water quality is not a mono- parameter- based assessment. It is rather an assemblage of multiple parameters pointing towards a definitive outcome.

Contrary to the Ca, Mg showed a comparatively wider range of values that start from 11.03 mg/l to 235 mg/l and the mean of 50 mg/l. Only 22% of boreholes conform to class 0 water quality, 7.4% is beyond the maximum allowable limit, according to Razzaque (2018), consumption of water with these levels of Mg have laxative effects to people which critically affects the electrolytes imbalance through excessive water loss. On the other hand, Na had a min value of 9.60 mg/l and a max of 176 mg/l. According to SANS241, all boreholes are suitable for domestic consumption, although 15% of such boreholes conform to class 1. The entirety of the boreholes is classified as class 0 as the parameter had a max of 22.50 mg/l and SANS241 stipulates 30 mg/l as the upper level for class 0. Cl had a relatively low min of 0.5 mg/l and a comparatively high range of 726.50. The parameter had a mean and standard deviation of 95.56 and 153.09 mg/l, respectively. Majority of the boreholes (66.66%) are ideal for domestic consumption, the acceptable and maximum allowable limits comprise 18.51% and 11.11%, respectively. Only a single borehole is unacceptable for domestic consumption. According to Yang et al. (1997), the significant anthropogenic sources of the chloride concentration in groundwater consist of factors such as; infiltration of the irrigational water, sewage effluents, industrial wastewater (processes), and household's wastewater from cleaning agents.

The significant effects associated with excessive Cl concentration exceeding 1200 mg/l include salty taste, nausea, and dehydration (DWA, 1996). Similarly, with the Cl, SO_4 had a min of 2.00 mg/l but with a narrower range of 249.00 mg/l. All but one borehole is classified as class 0. According to SANS241, the ideal pH for drinking water ranges from 5 to 9, on the other hand, the WHO recommends pH range from 6.5 to 8.5. However, the min value of the pH which is < 4 falls outside the required range of the scale. Slightly acidic pH (<4.5) facilitates the dissolution of the heavy metals in water, that are equally not desired in people. According to SANS 241, the ideal levels of EC for drinking water should range from 0 to 170 mS/cm, with the maximum tolerable level of 370 mS/cm, anything beyond that range is excessive. There are occurrences of the max EC values of above 400 mS/m, which surpass the allowable limit. Nevertheless, there are no health implications associated with this parameter (SANS 241, 2006), however, its essence is in the provision of the synoptic view on the prospects of the dissolution of different anions and cations of the water which reflects the status of the TDS.

The TDS has a min and max concentration of 186 mg/l and 1978.80 mg/l. This outlines that the water is ideal for consumption. $N–NO_3$ had a Min, mean, and max of 0,52 mg/l, 21.42 mg/l, and 135.54 mg/l, respectively. This parameter had a standard deviation of 82.06 mg/l, implying that majority of the boreholes exhibited excessive levels of $N–NO_3$ which is unideal for human consumption. The water with $N–NO_3$ can be consumed provided it does not exceed 11 mg/l for an ideal water resource and 20 mg/l, anything beyond that is unacceptable and may result to baby blue syndrome in infants. The max concentration of Fluoride (1.46 mg/l) implied that the parameter conforms to the regulatory standard of SANS241 and WHO, as it stipulates the maximum allowable of <1.5 mg/l.

3.2. Spatial distribution of the selected water quality parameters

The spatial distribution of the selected parameters is reflected in a map Figure 3. The map depicts the spatial variability of EC in 5a, Nitrate in 5b, pH in 5c, TDS in 5d, Fluoride in 5e and WQI in 5f.

3.2.1. pH

The pH is an essential indicator of the water quality status (DWA, 1996). This parameter is defined as the inverse logarithmic concentration of hydrogen ions in the water. Its imperativeness in water quality is due to its ability to appraise the overall water quality situation, for instance, the pH that is ranging from 3.5 to 5, signifies the potential for heavy metal dissolution, which is detrimental to human health (DWA, 1996). Based on SANS241and WHO, majority of the boreholes had a pH that conforms to class one water quality. While these results assert the view that the groundwater is portable for domestic consumption, there are also a few boreholes with pH levels of about 4.18 that fall outside of the consumption levels, as they do not conform to the SANS241 and WHO drinking water standards. These results support the earlier findings of Mpenyana-Monyatsi and Momba (2012), which indicate that the resource is suitable for consumption. Meanwhile, the map in Figure 3c signifies the interpolated spatial distribution of the pH on groundwater resources. The pH has a narrow range of values. The overall chemistry is slightly acidic to neutral. A blue plume on the map presents the acidic part of the water. These values conform to the upstream of the irrigation schemes. The increment in pH values appears to be distributed towards the south of the study area. The low pH plumes also appear to conform to the settlement areas on the eastern part of the study area. This may assert a view that there are anthropogenic activities that acidify the groundwater resource. It is also imperative to apprehend the geological setting of the area.

3.2.2. Electrical conductivity

Groundwater resources always interact with the geological formations, and due to such interactions, the chemistry of the water is spatially

Table 1. The descriptive statistical analysis of water quality parameters.

	Ca	Mg	Na	K	Cl	SO4	HCO	NO3	F	EC	pH	TDS
Min	30.7	11.3	9.6	0.4	0.5	2.0	85.6	0.5	0.0	10.7	4.1	**186.0**
Mea	82.0	51.2	56.2	3.6	95.5	38.9	269.7	21.4	0.3	95.0	6.9	**627.5**
STD	33.1	45.0	47.1	4.1	153.0	56.5	82.0	31.6	0.2	85.5	0.8	**348.0**
Ran	147.3	223.7	166.7	22.0	726.5	249.0	327.8	135.0	1.4	394.0	3.2	**1792.8**
Max	**178.0**	**235.0**	**176.3**	**22.5**	**727.0**	**251.0**	**413.4**	**135.5**	**1.4**	**404.8**	**7.4**	**1978.8**

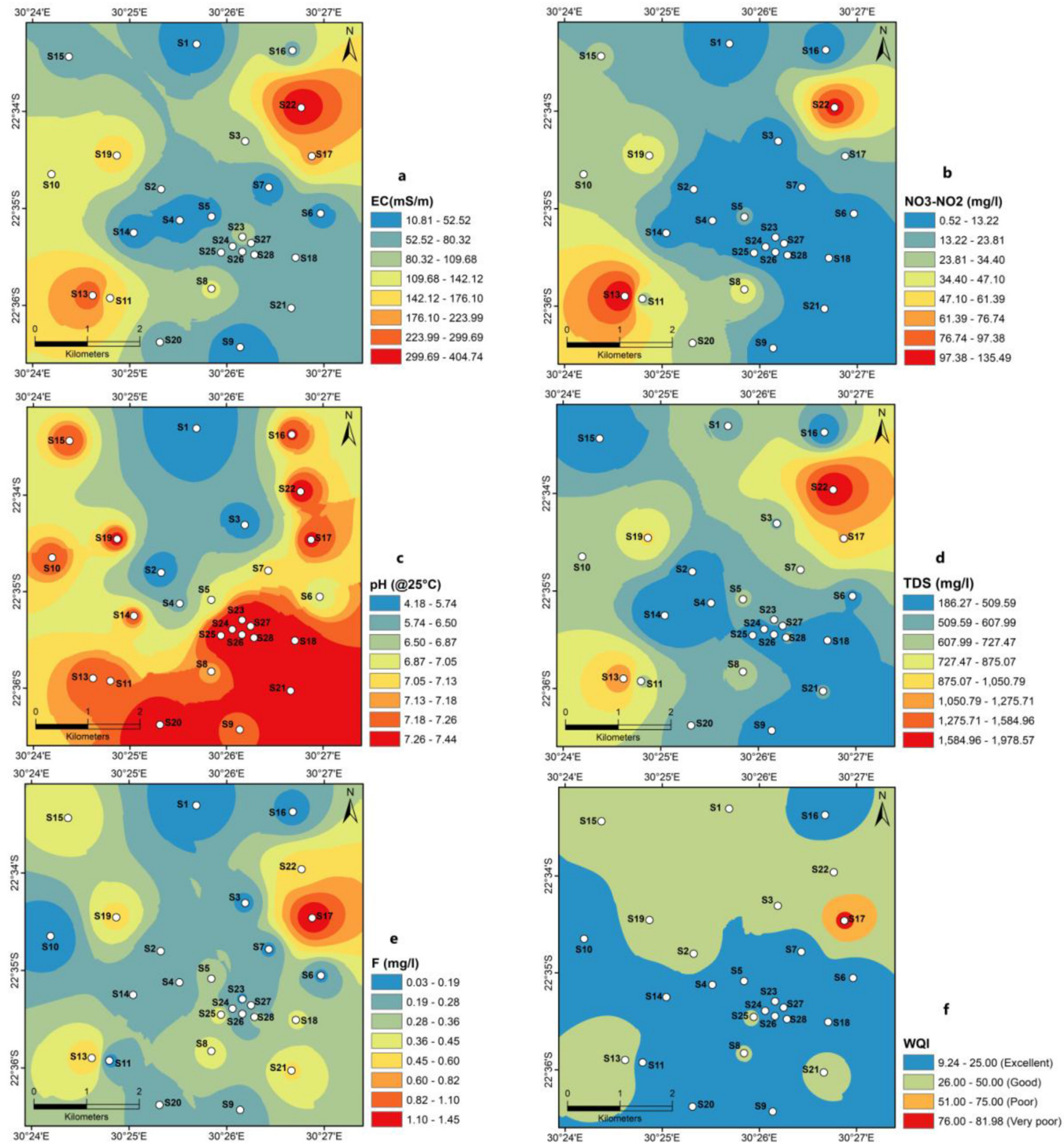


Figure 3. Spatial distribution maps showing water quality parameters for each sampling point in the study area: EC (a), NO_3–NO_2 (b), pH (c), TDS (d), F (e), WQI% (f).

variable. Subsequently, electrical conductivity (EC) defines the ability of water to transmit an electrical charge based on dissolved ions and mineral salts (DWA, 1996). According to the SANS241, class one water quality should have an EC that does not exceed 170 mS/m Table 1 shows that the EC had a min value of 10.78 mS/m and a mean of 95.03 mS/m. These values indicate that the groundwater is generally acceptable for domestic consumption. According to the map in Figure 3a, there is a spatial resemblance between pH and EC. The low pH areas conceal the highly conductive areas. According to the WRC (1998), prolonged consumption of water resources with EC values in excess of 370 mS/m may result in the development of the following health conditions; disturbance of the salt and water balance in children, blood pressure complications in heart patients and renal patients, and laxative effects.

3.2.3. The TDS distribution in groundwater

TDS defines the total amount of solids dissolved (usually mineral salts) in water that remains when the water sample is evaporated to dryness. Table 1 shows that the min, range, and mean of the TDS are

186.00 mg/l, 1792.80 mg/l/, and 627.56 mg/l, respectively. These values signified that the groundwater quality is generally acceptable for domestic consumption. Surprisingly, the map in Figure 3d signifies the spatial conformity between the EC and TDS. These imply that the two parameters are influenced by the same underlying factors.

3.2.4. The nitrate distribution in groundwater

The descriptive statistics report in Table 1 shows that the nitrate has a min, mean, and max of 0.52 mg/l, 21.42 mg/l, and 135.54 mg/l, respectively. These values overlap from the ideal to undesirable water quality. SANS241 and WHO stipulate that the ideal nitrate level for domestic consumption is 6 mg/l and 50 mg/l, respectively. However, very few boreholes conform to this range and majority of the boreholes had nitrates values that are in excess of 20 mg/l. The spatial distribution map of the nitrates in Figure 3b shows that there are two anomaly plumes in the northeast and the southwest of the study area. Surprisingly, these hotspots had excessive values that exceed 50 mg/l which highly surpass the maximum allowable level for this component. Moreover, the anomalous area constitutes the residential area and the lower stream of the irrigation stream. The very same anomalous areas also exhibited a similar trend with the EC and TDS. These results conform to the findings of Mpenyana-Monyatsi and Momba (2012). Tredoux et al. (2000) state that groundwater contamination with nitrates is a common phenomenon in the North West and Limpopo Province. According to the DWA (1996), excessive nitrate levels are derived from the oxidation of vegetable and animal debris and of animal and human excrement. The high nitrate concentrations in the northern part of the study area could be associated with human defecation from improper sanitary infrastructure. According to the SANS241 (2006) and WHO (2017), the water resources that are characterized by nitrates levels that exceed 50 mg/l are not fit for consumption, as this may result in adverse health effects such as Methaemoglobinaemia in infants, and mucous membrane irritation in adults (DWA, 1996). According to Zingoni et al. (2005) the higher nitrate concentrations are often accompanied by microbial contaminants.

3.2.5. Fluoride distribution in groundwater

Figure 3e shows the spatial distribution of the fluoride in groundwater. The parameter does not exhibit any significant spatial trend. However, there are three major hotspots that are scattered throughout the entire area. The first fluoride hotspot occurs in the northwest portion, the eastern portion, and the south. All three hotspots conform to the ideal water quality as stipulated in SANS241and WHO drinking water standards. The results obtained in this study contradict the claims asserted by Ncube (2006) and Abiye et al. (2018), who indicated that there are excessive fluoride levels in Limpopo, Mpumalanga, and North West provinces. The natural sources of fluoride in the area may be associated with volcanic rocks. Fluoride minerals that are associated with volcanic rocks are fluorspar (CaF2) and fluorapatite, and calcium- fluoro-phosphate (DWA, 1996). The fluoride hotspot on the northeast and the south may easily correlate to the excessive use of fertilizers around the irrigation schemes. Since the skeletal deformation and destruction of dental structure occur when the fluoride level exceeds 1.5 mg/l (DWA, 1996), such predicaments are not expected in this area.

3.2.6. WQI

The weighted arithmetic index method was used in the present study for the computation of WQI. The WQI was established through the measurement of various important physicochemical parameters of groundwater. The values of the WQI (Figure 3f) obtained in this study showed that 57% and 39% of groundwater within the vicinity of the study area have an excellent and good water quality, respectively. Meaning that 96% of water is suitable for drinking purposes. However, 4% of groundwater in the area is of very poor water quality, indicating that groundwater within this area is highly polluted and is not suitable for drinking purpose and other important human activities. It was observed that this site is near the old mine tailings found within the study area that could result in the contamination of groundwater water. Al-Omran et al. (2015) found a slight similar range of suitable water from five zones of Riyadh governorate (Nassim, Riyadh main zone, Badiah zones, Ulia and Shifa). WQI results showed that more than 88% of Riyadh main zone, 91% of Ulia, 97% of Nassim, 88% of Shifa, and 100% of Badiah water zones were considered excellent for drinking and the remaining water was considered unsuitable for drinking due to microbial contamination.

3.3. Water quality in agricultural hub for irrigation

3.3.1. Sodium Adsorption Ratio

One of the foremost parameters for reviewing the water quality suitable for irrigation is the SAR. This parameter is attributed as the measure of the concentration of Na in water concerning the sum of the concentration of calcium and magnesium in groundwater (Haritash et al., 2016). The map in Figure 4a shows the interpolated map portraying the concentration of SAR throughout the study area. The Agricultural Council of America recommends that the optimal SAR for crop irrigation should be $<$ 3 meq/l. According to Swanson et al. (2003), the significant SAR level occurs between 5 and 9 meq/l. However, the water resource in the area does not conform to this range. Had there been water sources within this range, ionic substitution could have occurred yielding to sodic enrichment in the soil, which ultimately destroys soil structure, dispersion of clay, reduced permeability, and incapacitated to support plant growth (Swanson et al., 2003). Because of these, the SAR for the study area is ideal for irrigation of a diverse array of crops. Thus, the highest value recorded in this area is 0.94 meq/l, which is a third of the upper limit of the recommended value of 3 meq/l. Despite the value of SAR recommending that the prevalent water is suitable for irrigation, other critical parameters should also be investigated.

3.3.2. Magnesium Adsorption Ratio

An equilibrium exists between the Ca and Mg in groundwater resources, when this state prevails, MAR makes the soil more alkaline, which subsequently reduces the soil quality and crop yield (Haritash et al., 2016). This phenomenon necessitates the classification of groundwater into two classes, namely, the suitable and the unsuitable. The former is denoted with the MAR value that is less than 50 meq/l and the latter with the value that exceeds 50 meq/l. Given this classification, the water resource in the area conforms to the ideal range for irrigation as the area is attributed with the max MAR of 48 meq/l (Figure 4b). These imply that the groundwater resources may be used for irrigation without encountering any form of challenge provided that all management strategies are in place.

3.3.3. Residual Sodium Carbonate

Although carbonates are prominent constituents of the groundwater resource, they should occur within a specific range. If they exceed a specific range, they affect the suitability of the water for irrigation (Das and Nag, 2015). The acceptability of the groundwater is highly affected by the excess concentration of bicarbonates and carbonates over calcium and magnesium (Das and Nag, 2015). The hazardousness of the excess carbonates is on the destructive nature of these compounds to the soil structures (Das and Nag, 2015). The anomaly map in Figure 4d indicates that the RSC value is -1. According to the RSC suitability for irrigation (i.e. suitability is low, medium and high when RSC value is < 1.25, 1.25–2.5 and >2.5, respectively) all the values that are less than 1.25 are ideal for irrigation. These imply that all the water sources in the area are suitable for agricultural watering of the crops.

3.3.4. KR and Na%

The Kelly's Ratio is another significant parameter for rating irrigation water. Na is measured against the Ca and Mg when calculating the KR value. According to Kelly (1940), Ca and Mg preserve their steady state in

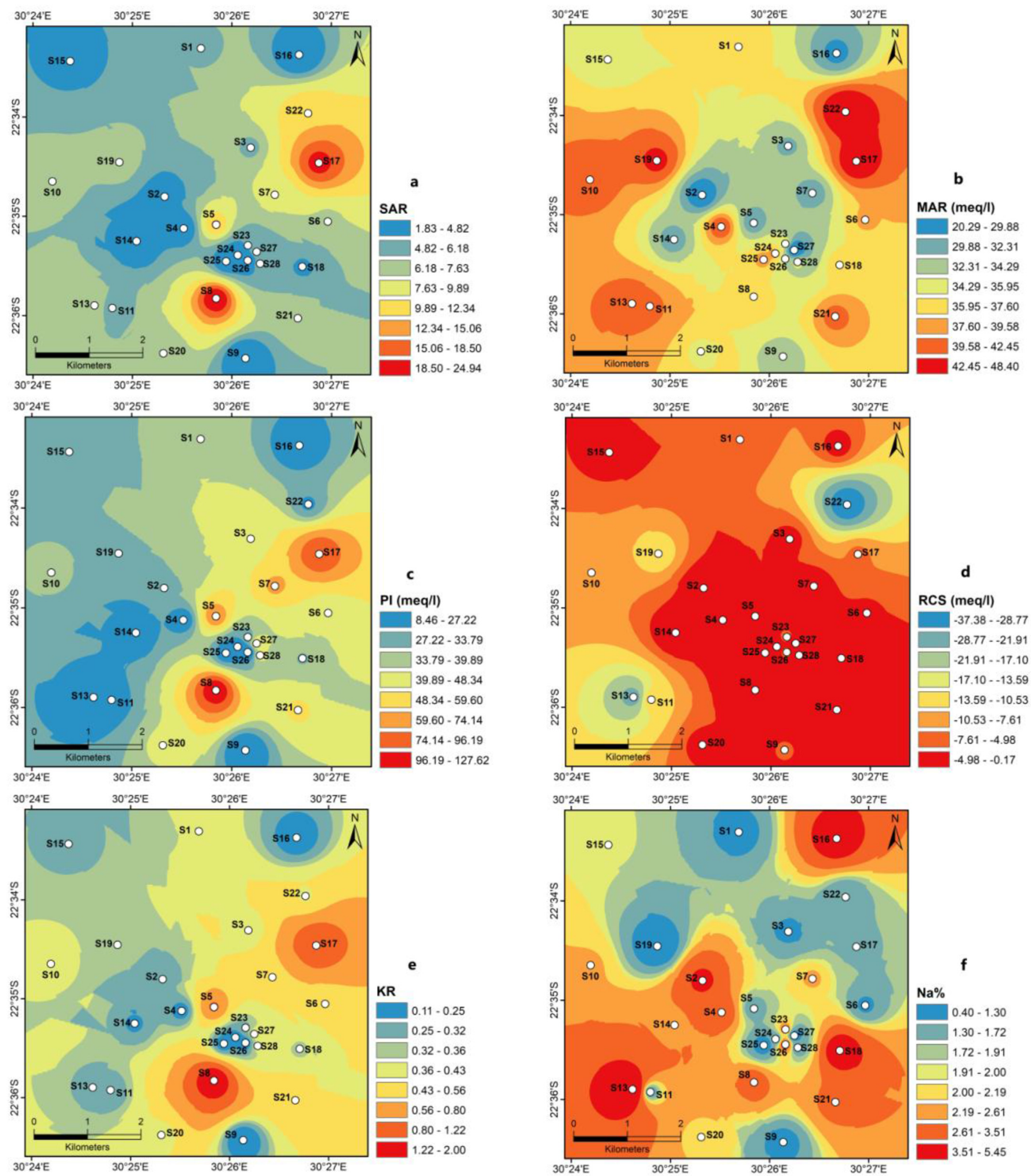


Figure 4. Spatial distribution maps showing water quality parameters for each sampling point in the study area: SAR (a), MAR (b), PI (c), RCS (d), KR (e), Na% (f).

most waters. In the present study, the KR values ranged between 0,23 and 2 (Figure 4e). According to Karakus and Yidiz (2020), the KR values lower than 1 indicates that water is suitable for irrigation and values higher than 1 indicate that water is unsuitable for irrigation purposes. Figure 4e shows that all groundwater samples are suitable for irrigation purposes except for sites 7 and 17. As for Na%, it has also been used as parameter for evaluating the suitability of groundwater for irrigation purposes and can be classified as follows: excellent: <20; good: 20–40; permissible: 40–60; doubtful: 60–80; and unsuitable: >80. Na% values in the present study ranged between 0.41 and 5.2% (Figure 4f), indicating that the water falls within the excellent class; therefore, the water is suitable for irrigation purposes.

3.3.5. Permeability index

Irrigation is a fundamental practice in agriculture, especially in Sub-Saharan Africa that is renowned for semi-arid climatic conditions. In most parts of the country, agricultural production cannot be solely reliant on rain-fed irrigation. This is particularly true as the water resource is insufficient to satisfy the needs of the agrarian sector. Subsequently, it is augmented with groundwater resources. However, the practicing of agricultural irrigation for an extended period leads to the reduction of the permeability of the soil. Fortunately, the major ions of the water such as Na, HCO3-, Ca2 and Mg2 attempt to preserve such reductions (Haritash et al., 2016). Figure S3 shows the Doneen (1962) permeability index chart for the appraisal of the suitability of the groundwater resources for the present study area.

The permeability index chart (Figure S3) and the spatial distribution (Figure 4c) show that the groundwater resource in the area falls within the three possible categories. However, majority (92.59%) of the boreholes coincide with Class one, which comprises the ideal water quality for irrigation of the crops despite the crop family type. Only a single water source falls under classes 2 and 3. This serves to indicate that the groundwater in the area is highly suitable to serve the purpose of irrigation, without limiting the crop type that may be developed.

3.3.6. Chloride index

The chloride index is a fundamental prerequisite before the allocation of water resources for agriculture. The map in Figure S4 depicts the chlorinity index for the study area. Although the index dictates that the water resources can be classified into 5 categories, almost all water sources (92.59%) conform to the first block, which is the water resource that is suitable for irrigation of all crop types (Ramesh et al., 2012). Only three water sources conform to block 2 and 3 which correspond to the water resources that are suitable for low, medium, and high salt-tolerant crops and medium to high salt-tolerant respectively (Ramesh et al., 2012). The water resources in the area may be used for irrigational purposes without any prior treatment or any form of chemical transformation.

3.4. Pearson correlation coefficient analysis

Pearson correlation coefficient analysis (Table 2) was used in the present study to measure aspects of linear relationship between two water parameters or variables. Gummadi et al. (2014) stated that when correlation coefficient values are close to −1 or +1 they indicate a linear correlation between variable x and y. When r value is greater than 0.7 ($r > 0.7$) is indicative of a strong correlation between the parameters; and when r values are between 0.5 and 0.7 they indicate a moderate correlation. The relationship and the effect of RCS, SAR, KR, Na%, PI and MAR on parameter WQI was determined by performing correlation analysis. A moderate positive correlation ($r = 0.516$) was observed between SAR and WQI, whereas low moderate positive correlation was observed between KR and WQI ($r = 0{,}365$); PI and WQI ($r = 0.346$); and MAR and WQI ($r = 0.419$); and therefore, these results were statistically significant. Negative correlation was observed between WQI and RCS ($r = -0.303$) and between WQI and Na% ($r = -0.015$) indicating that these results were not statistically significant.

3.5. Factor analysis

Water resource quality (surface and groundwater) occurs as the result of the interaction between water and the hosting environment. Therefore, the section appraises the processes that control the hydrochemical composition of water in the area. The communality test was conducted to investigate the suitability of the data for factor analysis and the loading of different parameters on the resultant factors. Zarei and Pourreza Bilondi (2013) suggested that the physicochemical state of the groundwater is defined by the interaction of water and its hosting environment through the natural processes and anthropogenic activities (Guler et al., 2005). According to McBride (2005), understanding such underlying processes is fundamental in the proper governance of the groundwater resources.

The processes that define the hydrochemical composition may be easily defined if the parameters have the extraction of at least 50% of the original data in factor analysis. To assess this requirement, the communality test was carried out and the results are in Table S2, and they illustrate the proportion that the extracted components explains against the original data. The communalities which is the index of the measure of efficiency indicated that all the parameters except K were suitable for FA assessment.

3.5.1. Factors loading

The Eigenvectors of the different parameters across the factors are shown in Table S3. The deduction of the factors was evaluated based on the dominant influence. Factor 1 showed the supremacy in the loadings of almost all parameters (EC = 0.97, TDS = 0.97, Ca = 0.94, Mg = 0.95, K = 0.61, Na = 0.73, SO4 = 0.98, Cl = 0.95, N–NO3 = 0.92) with the exception of the few (F = 0.46, pH = 0.23, HCO3 = −0.31). The excessively high loadings of the K, Na, and NO3 signal the effluents from the agricultural practices (DWA, 1996). When these were incorporated with Cl, they signified the contribution of the household in groundwater contamination. Excessive nitrates also serve as an indication that there is improper sanitary infrastructure.

This is rather understandable because of the high on-sight sanitation that takes place in the area, more especially due to the shortage of sanitary infrastructure. On the other hand, the concurrence significant loadings of the Ca, Mg, Na, SO4, and Cl signal the groundwater that is undergoing a particular degree of dissolution (Ishaku et al., 2011). This dissolution is rather at a very early age based on the loadings of the Ca and Mg. The moderately lower loading of the Na to that of Ca and Mg signifies that the dissolution is rather at a very early stage (Ishaku et al., 2011). The high Cl that is incorporated with Na indicates that there is the dissolution of the sodic salts (Jonker, 2014). This is not surprising since this area conforms to the Soutpansberg mountain range that is known for salt deposits (Jonker, 2014).

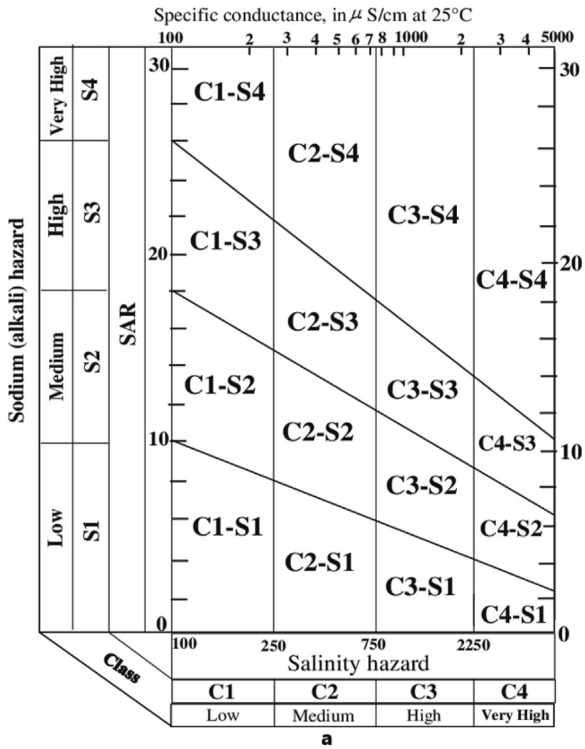
Factor 2 is predominated by the significant loading of $HCO_3 = 0.85$ and F = 0.66. The prominence of the HCO_3 indicates that there is also groundwater recharge that is taking place. On the other hand, fluoride is introduced through the water-rock interaction.

The factor analysis indicated that the groundwater chemistry is controlled by a combination of anthropogenic and natural processes. Anthropogenic activities such as agricultural production, domestic effluents, and on-sight sanitation are responsible for the precipitation of

Table 2. A table showing the Pearson correlation coefficient between WQI and other water quality parameters.

	RCS	SAR	KR	Na%	PI	MAR	WQI
RCS	1						
SAR	−0,148	1					
KR	0,116	0,951**	1				
Na%	−0,002	−0,041	0,018	1			
PI	0,242	0,908**	0,957**	−0,079	1		
MAR	−0,563	0,290	0,137	−0,029	−0,003	1	
WQI	−0,303	0,516**	0,365*	−0,015	0,346*	0,419*	1

**. Correlation is significant at the 0.01 level. *. Correlation is significant at the 0.05 level.



Site	SAR	EC	USSL class
S1	5.85	10.78	C1S1
S2	3.86	63.5	C1S1
S3	5.67	81.6	C1S1
S4	2.52	13.1	C1S1
S5	13.25	41.3	C1S2
S6	7.04	41.5	C1S1
S7	8.88	18.7	C1S1
S8	24.96	122.9	C1S3
S9	1.88	13.5	C1S1
S10	7.29	139.1	C1S1
S11	5.08	137.9	C1S1
S13	7.61	274.8	C1S1
S14	2.09	27.9	C1S1
S15	4.18	75	C1S1
S16	2.33	74.5	C1S1
S17	20.63	186	C1S3
S18	4.37	64	C1S1
S19	7.16	170.1	C1S1
S20	6.19	62.9	C1S1
S21	7.47	72.9	C1S1
S22	12.18	404.8	C2S2
S23	4.98	103.6	C1S1
S24	2.29	72.6	C1S1
S25	2.42	78.5	C1S1
S26	1.78	74	C1S1
S27	6.28	78.3	C1S1
S28	5.82	61.9	C1S1

b

Figure 5. USSL diagram for classification of water used for irrigation purposes (US Salinity Laboratory, 1954).

nitrates, chloride, sodium, and potassium. On the other hand, water-rock interaction, groundwater recharge and salts dissolution are responsible for the rest of the chemical constituents.

3.6. USSL diagram

To provide a clear understanding of the suitability of groundwater for irrigation purposes, both EC and SAR parameters were utilized to prepare the US salinity diagram (Figure 5ab) categorization of irrigation water with respect to SAR for USSL diagram was as follows: S1: Excellent water for all kinds of soil; S2, S3: Water which is good and doubtful for irrigation, respectively, this soil can produce hazardous sodium oxide and requires soil management; S4: Unsuitable water for irrigation purposes. With respect to EC, water for irrigation can be classified as follows: C1: Excellent water for irrigation (can be used for all kinds of soil); C2: good water for irrigation (can be used for all plants provided a medium degree leach forms); C3: Permissible water for irrigation (cannot be used on soils with limited drainage, other plants can tolerate); C4: doubtful water for irrigation. The USSL diagram revealed that groundwater samples for all the sampling sites fall within the C1S1 (low salinity with low sodium) class except for site 8 and 17 that fall within the C1S3 (low salinity with high sodium) and sample 22 falling within the C2S2 (medium salinity with medium sodium). The high levels of Na and EC, where these boreholes are located, could have been derived from ionic leaching, weathering of rocks and anthropogenic activities such as discharge of effluents from agricultural and domestic uses. Generally, the USSL diagram shows that the groundwater in this area is suitable for use as irrigation water; however, groundwater from site 8 and 17 have high Na values; therefore, this water is excellent for irrigation purpose but very doubtful; therefore, the soil where this water is applied can produce hazardous sodium oxide and therefore, requires soil management.

4. Study limitations

The present study did not face any challenge apart from having access to some of the boreholes, which became a challenge during water samples collection. Regardless of that, the present study provides information that can be a useful tool for describing the suitability state of water used for domestic and agricultural activities. Therefore, the tools or methods used in the present study were good enough to achieve the main aim of the study.

5. Conclusion

The aim of the study was to evaluate the water quality suitability for domestic and irrigation uses in Nwanedi Agricultural Community found in Limpopo Province of South Africa. Water quality is a crucial component for consideration before the consumption of this precious resource for both domestic and agricultural sectors. The semi-arid regions of the world do not experience sufficient rainfall for their livelihood. Consequently, they turn to groundwater for water supply. However, the increase in human population, limited access to sanitary infrastructure, and agricultural production pose a risk to contaminate the only source of dependable water supply. The consumption of poor water quality has the potential to affect human health and agricultural production. The present study outlined the major parameters that should be monitored constantly in response to the state of the water quality in the area. The N-NO3 was identified as the major issue of concern for the drinking water quality. This then insinuates that the water should be treated for this parameter prior to consumption to ensure that the water conforms to regulations. Results of the present study indicate that the water quality in the area is relatively fresh and adequate for domestic consumption. However, infrequent excessive levels of nitrates were detected ranging between 0.52 mg/l and 135.54 mg/l. Similarly, the groundwater was found to be suitable for irrigation with SAR ranging between 0.07–0.94 meq/l, MAR 26–48 meq/l, PI (92.5%) Class 1, PI 13–111 meq/l, RSC < -1, and CI $=$ Class 1. The agriculturalists are comforted in ascertaining that the groundwater is suitable to support their operations. According to factor analysis, groundwater chemistry in the study area is controlled by a combination of anthropogenic (agricultural production, domestic effluents, and on-sight sanitation) and natural processes. Anthropogenic activities are responsible for the precipitation of nitrates, chloride, sodium, and potassium. The community of Nwanedi acknowledged that their activities (on-sight sanitation and farming) are affecting the state of the groundwater quality adversely. The state of the groundwater is deteriorating and measures need to be put in place to mitigate such impact. Meanwhile, more research efforts should be directed at uncovering the implementable measures to preserve the state of the groundwater. Also, comparative studies on how groundwater quality is influenced by climate conditions (dry and wet season) should be conducted in this area. It was recommended that: the entire physicochemical parameters be used to determine the domestic water quality of the area; the comprehensive water quality that incorporates the microbial aspects be conducted; the measure for agriculture be put in place to limit the leaching and washing away of the agricultural chemicals to the water resources and there should be a rollout of the sanitary infrastructure to prohibit the outbreaks of water-borne diseases.

Declarations

Author contribution statement

Mulaudzi Mukonazwothe: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Linton Fhatuwani Munyai; Mulalo Isaih Mutoti: Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

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Data availability statement

Data will be made available on request.

Declaration of interests statement

The authors declare no conflict of interest.

Additional information

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