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ORIGINAL ARTICLE

# Evaluation of seasonal variation of water quality using multivariate statistical analysis and irrigation parameter indices in Ajakanga area, Ibadan, Nigeria

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## Abstract

The variation of groundwater quality across different regions is of great importance in the study of groundwater so as to ascertain the sources of contaminants to available water sources. Geochemical assessment of groundwater samples from hand-dug wells were done within the vicinity of Ajakanga dumpsite, Ibadan, Southwestern, Nigeria, with the aim of assessing their suitability for domestic and irrigation purposes. Ten groundwater samples were collected both in dry and wet seasons for analysis of physicochemical parameters such as: pH, EC, TDS, $Na^+$, $K^+$, $Ca^{2+}$, $Mg^{2+}$, $HCO_3^-$ $Cl^-$, $SO_4^{2-}$, $NO_3^{2-}$ principal component analysis (PCA) and cluster analysis (CA) were used to determine probable sources of groundwater contamination. The results of the analyses showed the groundwater samples to be within permissible limits of WHO/NSDWQ, while elevated values of concentrations of most analyzed chemical constituents in water samples were noticed in $S_1$ and $S_{10}$ due to their nearness to the dumpsite and agricultural overflow, respectively. Groundwater in the study area is of hard, fresh and alkaline nature. There are very strong associations between EC and TDS, $HCO_3^-$ and $CO_3^{2-}$ in both seasons. PCA identified five and three major factors accounting for 95.7 and 88.7% of total variation in water quality for dry and wet seasons, respectively. PCA also identified factors influencing water quality as those probably related to mineral dissolution, groundwater–rock interaction, weathering process and anthropogenic activities from the dumpsite. Results of CA show groups based on similar water quality characteristics and on the extent of proximity to the dumpsite. Assessment for irrigation purpose showed that most of the water samples were suitable for agricultural purpose except in a few locations.

**Keywords** Physicochemical · Dumpsite · Freshwater · Anthropogenic · PCA · CA

## Introduction

The assessment of groundwater quality is as important as its quantity for various purposes ranging from domestic, industrial and agricultural uses all over the globe (Subramani and Damodarasamy 2005). The quality of groundwater in a particular region is a function of physical, chemical and biological parameters. The variation of groundwater quality in a particular area is a function of physical and chemical parameters that are greatly influenced by geological formations and anthropogenic activities (Subramani and Damodarasamy 2005). Pollution of groundwater is a major threat posed by leachate which is formed by anaerobic decomposition of waste and may infiltrate the aquifer (Tesfaye 2007). Groundwater contamination has become a great problem due to rapid growth rate of population, industrialization and urbanization in the metropolitan city all over the world. The quality of groundwater is normally characterized by different physicochemical parameters level. These parameters change widely due to various types of pollution, seasonal variation and groundwater extraction (Ramakrishnaiah et al. 2009). Siting of open dumpsite near the residential areas can have undesirable effect on nearby water sources if the leachate emanated from decomposed solid waste penetrate and contaminate the water table. The use of polluted groundwater for drinking and consumption purposes can cause major health problem. According to WHO, about 80% of

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all diseases in human beings are caused by water (Ramakrishnaiah et al. 2009). Therefore, a periodic assessment of groundwater quality is necessary in order to ascertain the quality for human consumption purpose as well as to provide an overall scenario about the sources of groundwater contamination, thereby open an avenue for better planning for sustainable management of groundwater.

Hydrochemical study reveals the quality of water suitable for domestic and agricultural purpose. Further, it is possible to understand the change in quality due to rock–water interaction or any type of anthropogenic influence (Wilcox 1948). Several environmental researchers have identified contamination plumes from disposal sites (Matias et al. 1994; Ikem et al. 2002; Tijani et al. 2002) with most of these published studies focusing on defining the spatial extent of groundwater pollution based on geochemical analysis results. The suitability of groundwater resources for irrigation purpose was also studied (Sujatha and Reddy 2003; Sadashivaiah et al. 2008; Ramesh and Bhuvana 2012). Several published research studies have employed the use of multivariate statistical analysis in the interpretation of groundwater quality data obtained from various sources (Sundaray 2010; Singh et al., 2008; Uddamari et al. 2014; Oketola et al. 2013; Molla et al. 2015; Arslan 2013; Zhang et al. 2014; Majolagbe et al. 2016; Markic et al. 2015; Razmkhah et al. 2010). Scientists have also employed the use of principal component analysis (PCA) to study soil physicochemical properties and its geochemical constituents, identification of heavy metals pollutants in soil, analysis of heavy metals presence in dust and evaluation of influence of seasons on air pollution (Adhikari et al. 2003; Ma et al. 2016; Satyanarayanan et al. 2016; Gergen and Harmanescu 2012; Iwara et al. 2014; Lu et al. 2010; Burt et al. 2014; Benhaddya and Hadjel 2014; Abdul Raheem et al. 2008). However, the study of irrigation suitability of groundwater samples within dumpsite and their interpretation using multivariate statistical analysis has not been efficient.

The present study was carried out during dry and wet seasons from close by hand-dug wells neighboring Ajakanga solid waste disposal site for better understanding of spatial and seasonal variability of physicochemical parameters, hydro-geochemical facies of groundwater and identification of contamination sources that may affect the groundwater samples using multivariate statistical approach.

### Site description and geological setting

Ibadan is located approximately within the squares of longitude 3° 35$^1$–4° 10$^1$ east of the Greenwich meridian and latitude 7° 20$^1$–7° 40$^1$ north of the equator. Solid wastes are dumped indiscriminately on open grounds and along road networks in so many places within Ibadan metropolis. There are several collection points from which refuse are cleared by government trucks at regular intervals and deposited at the central dump sites managed by the government. The city generates about 1,618,293 kg of solid waste daily. There are four designated dumpsites in Ibadan namely: Aba-Eku, Ajakanga, Awotan and Lapite. For this study, the area is Ajakanga dumpsite in southwestern part of Ibadan. Ajakanga dumpsite lies between latitude of 3° 50 187–3° 50 696E and longitude 7° 18 021–7° 18 979N. It was opened in 1998 and still in operation till date. The general overview of the dumpsite is shown in Fig. 1. The study area falls within the humid and sub humid tropical climate of southwestern Nigeria with a mean annual rainfall of about 1230 mm and mean maximum temperature of 32 °C. The soil type of the study area belongs to Orthic Luvisol (FAO 2015). The mean value of the water retention capacity of the experimental soil within the dumpsite is 37.25%.

The geology of the area is a basement complex formation of southwestern Nigeria and are mainly the metamorphic rocks of Precambrian age with few intrusions of granites and porphyries of Jurrasic age. The dominant rock types are: quartzite of meta-sedimentary series, banded gneiss, augen gneisses and migmatites which constitute the gneiss–migmatite complex. Other minor rock types include pegmatite, quartz, aplites, amphibolites and xenolith (Adeigbe and Oluwatoke 2009). Banded gneiss constitutes over 75% of the rocks in and around Ibadan while augen gneisses and quartzites share the remaining in about equal percentages (Adeigbe and Oluwatoke 2009). The basement complex rocks in their unchanged form are characterized by low porosity and permeability which determines the hydrogeological properties of the rocks depending on the grain size and mineralogy of the rocks. The topsoil has been disturbed due to dumping activities in the study area and hence, constitutes the waste dump and the leachate derived from its decomposition processing as shown in Fig. 2.

## Materials and methodology

### Collection of groundwater samples

Ten water samples were collected from nearby hand-dug wells within Ajakanga solid waste disposal site during the months of March and August, 2013 using 2-L polyethylene bottles. The distance of the hand-dug wells to the study area as well as the latitude and longitude of each sampling point was taken with the aid of Hand held Garmin Etrex GPS (Azim et al. 2011) is shown in Table 1. The groundwater flow direction of the sampling points is shown in Fig. 3. Groundwater flow divergent zones were around sampling points S6, S7 and S8 while the convergent zones were

**Fig. 1** General overview of Ajakanga dumpsite

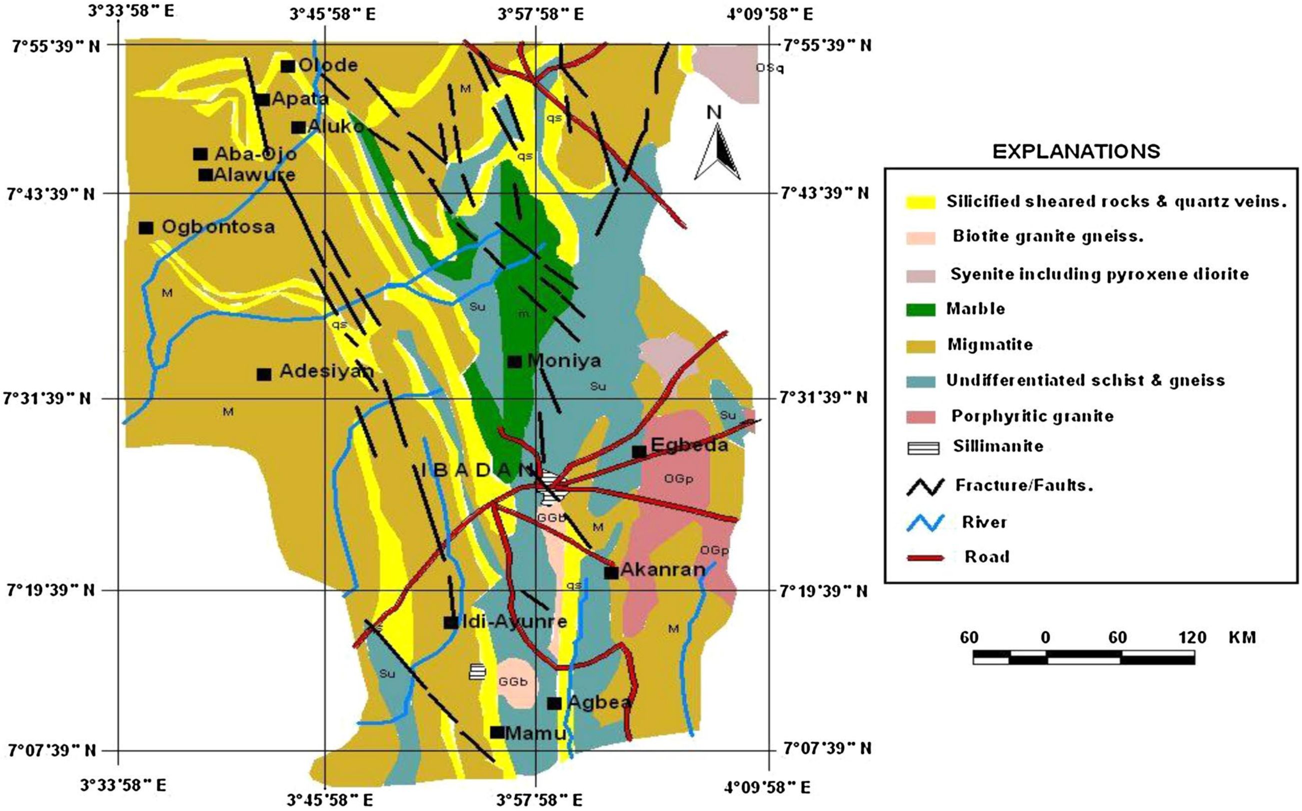

**Fig. 2** Generalized geological map of Ibadan (JPEG)

around sampling points S1, S4 and S10. Samples S1, S2, and S10 were at downside of the dumpsite while samples S7 and S8 were at a distance of more than 250 m from the dumpsite.

Water samples were collected by lowering the bottle at depth of about one foot below the surface, rinsed the bottle three times with the water to be collected before the actual

**Table 1** Water sampling location parameters during dry and wet seasons

| Sample code | Depth to bottom (m) | Dry season depth to water level (m) | Wet season depth to water level (m) | Distance to landfill (m) | Coordinates |
|---|---|---|---|---|---|
| $S_1$ | 9.1 | 3.7 | 2.7 | 90 | 7° 18$^1$ 40.53″N<br>3° 50$^1$ 32.22″E |
| $S_2$ | 2.7 | 2.0 | 2.1 | 110 | 7° 18$^1$ 38.57″N<br>3° 50$^1$ 26.00″E |
| $S_3$ | 3.5 | 3.5 | 3.2 | 100 | 7° 18$^1$ 44.22″N<br>3° 50$^1$ 32.71″E |
| $S_4$ | 6.4 | 5.8 | 2.7 | 200 | 7° 18$^1$ 44.03″N<br>3° 50$^1$ 40.84″E |
| $S_5$ | 5.5 | 5.2 | 2.7 | 220 | 7° 18$^1$ 47.81″N<br>3° 50$^1$ 41.94″E |
| $S_6$ | 5.5 | 4.6 | 4.3 | 200 | 7° 18$^1$ 49.23″N<br>3° 50$^1$ 40.01″E |
| $S_7$ | 5.8 | 5.5 | 3.2 | 270 | 7° 18$^1$ 56.15″N<br>3° 50$^1$ 45.07″E |
| $S_8$ | 8.2 | 7.2 | 6.5 | 520 | 7° 18$^1$ 04.45″N<br>3° 50$^1$ 53.57″E |
| $S_9$ | – | – | – | 120 | 7° 18$^1$ 49.46″N<br>3° 50$^1$ 53.57″E |
| $S_{10}$ | 3.7 | 1.8 | 1.8 | 120 | 7° 18$^1$ 41.10″N<br>3° 50$^1$ 34.89″E |

collection of the samples. After collection, the cap of each sampling bottle was screwed on tightly to avoid leakage (Asef Iqbal and Gupta 2009; Reza and Singh 2010; Odukoya and Abimbola 2010). A 0.45-µm membrane filter was used to remove unwanted materials from collected water samples.

The collected water samples were transferred into 2-L sterilized polyethylene bottles and kept at 4 °C before chemical analyses at the laboratories. Water samples of approximately 125 mL were used for elemental analysis. Some of water sampling bottles for the analysis of cations and heavy metals were acidified with concentrated nitric acid to bring water acid solution to pH below 2 while the other un-acidified water samples were analyzed for anions concentration. Chemical analyses were carried out for major anions, cations and heavy metal concentrations using the standard procedure recommended by APHA (1998). The qualitative chemical analyses were carried out at the analytical laboratory of department of Environmental Management and Toxicology (EMT) and Central Biotechnology laboratory, both of Federal University of Agriculture, Abeokuta (FUNAAB), Ogun State, Nigeria. Total dissolved solids (TDS), electrical conductivity (EC) and pH were measured in situ with the aid of multi-purpose conductivity meter.

The samples were collected in both wet and dry seasons. Preservation of water samples and chemical analyses were carried out as using standard methods of APHA (20th edition, 1998). The groundwater sampling locations and dumpsite are depicted in Fig. 4. The predominant rock type in the study area is migmatite gneiss (as shown in Fig. 4). Sodium and potassium were determined using flame photometric method while calcium and magnesium concentrations were analyzed using absorption mode of atomic absorption spectrometric (AAS) method. Sulphate and nitrate were analyzed by turbidimetric and UV spectrophotometric method, respectively, chloride, carbonate and bicarbonate by titration method while total hardness (TH) was determined by ethylene diamine tetra acetic acid (EDTA) titration method using Eriochrome black-T as an indicator.

## Multivariate statistical analysis

Two different multivariate statistical analyses were used to analyze the groundwater geochemical data. These are principal component analysis (PCA) and cluster analysis (CA). PCA is a multivariate statistical procedure which is used to diminish the dimensionality of the original data set consisting of a large number of interrelated variables while still retaining the inherent dependencies existed in the data set (Jianqin et al. 2010). Cluster analysis (CA) is a statistical technique that classifies water samples quality parameters into cluster whereby samples/variables within a particular cluster are similar to each other, but dissimilar from other clusters (Zhang et al. 2014; Sundaray 2010). CA was performed based on agglomerative schedule using a combination of Ward's linkage method (Ward 1963) and squared Euclidean distances as a measure of similarity between samples and/or parameters (Zhang et al. 2014) while PCA extract factor with eigenvalue > 1 which explained more total variation in the data set. Only component (factor) with eigenvalue > 1 were retained and later subjected to varimax

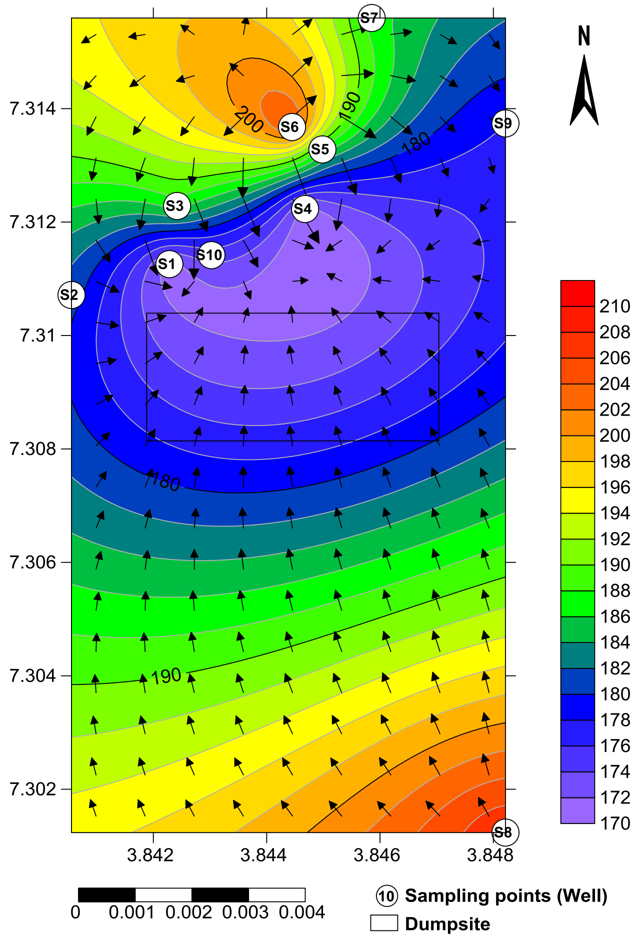

**Fig. 3** Potentiometric map showing the groundwater flow direction with respect to dumpsite location

rotation (Kaiser 1958; Vega et al. 1998; Usman et al. 2014) before being used for interpretation.

## Results and discussion

The results of water quality parameter analyses on collected water samples during dry and wet seasons sampling periods are presented in Table 2. The table shows the variation in the concentration level of analyzed parameters during wet and dry seasons.

### Groundwater quality for drinking purposes

The pH values of groundwater samples during dry and wet seasons ranged from 6.9 to 7.8 and 6.7 to 7.3, respectively. The pH values for the two seasons lie within the permissible limit (Kamble and Saxena 2016; Chavan and Zambare 2014; Ariyo and Enikanoselu 2007). The total dissolved solids (TDS) concentrations during dry and wet seasons varied from 88 to 299 mg/L and 95 to 351 mg/L, respectively. All TDS values lie below 500 mg/L specified by WHO (2007) and NSDWQ (2007) limit. Based on TDS results, all the analyzed water samples can be classified as freshwater since their TDS values is less than 1000 mg/L (Subramani and Damodarasamy 2005; Adebayo et al. 2015). Highest TDS value of 299 mg/L was noticed in $S_1$, 90 m away from the dumpsite during dry season. The result agrees with similar work by Adeolu et al. 2011. Electrical conductivity (EC) values ranged from 176 to 598 µs/cm in dry season and from 191 to 705 µs/cm during wet season. The EC values in both seasons lie within the standard limit of 1000 µs/cm specified by WHO (2007) and NSDWQ (2007). The average concentration of total hardness (TH) varies from 46 to 406 mg/L and 116 to 432 mg/L during dry and wet sampling periods, respectively. Based on Sawyer and McCarthy (1967) classification for total hardness, 20% fall under “soft class”, 40% under “Hard class”, 30% under “moderate hard” class while the remaining 10% falls under “very hard” class during dry season. However, during the wet season, none of the samples falls under “soft” class of hardness, 10% falls under “moderate hard” class, 60% fall under “Hard” class while the remaining 30% fall under “Very Hard” Class. It was observed that in all the sampling locations, TH values were higher in wet than in dry season. The $Cl^-$ concentration of water samples during dry and wet seasons ranged from 16 to 113 mg/L and 10 to 53 mg/L, respectively. The observed values $Cl^-$ in both seasons were within the permissible limit of 250 mg/L.

The $NO_3^-$ concentration in groundwater ranged from 1.5 to 15.9 mg/L during dry season and 0–3.9 mg/L during wet season. The concentration of $NO_3^-$ in groundwater and surface water is normally low (Azim et al. 2011). The $NO_3^-$ values for both seasons were found to be within the limit of 50 mg/L specified by WHO (2007). The low concentrations of $NO_3^-$ in analyzed groundwater samples agree with similar studies by Chavan and Zambare (2014), Ariyo and Enikanoselu (2007) and Subramani and Damodarasamy (2005). The values of $SO_4^{2-}$ in the groundwater samples ranged from 14.4 to 127.7 mg/L and 7.6 to 52.3 mg/L during dry and wet seasons, respectively. However, sulphate values in both seasons lie below 250 mg/L specified by WHO (2007) and NSDWQ (2007). For the anions ($HCO_3^-$ and $CO_3^{2-}$), $CO_3^{2-}$ concentrations in dry and wet seasons ranged from 60 to 288 mg/L and 60 to 300 mg/L; while $HCO_3^-$ values ranged from 122 to 586 mg/L and 122 to 610 mg/L in dry and wet seasons, respectively.

The $Ca^{2+}$, and $Mg^{2+}$ status level in analyzed water samples during dry and wet seasons ranged from 1.3 to 49.2 mg/L and 2.0 to 173.4 mg/L; 1.1 to 14.2 mg/L and 3.3 to 49.3 mg/L, respectively. $Na^+$ concentration value in groundwater samples ranged from 12 to 30 mg/L and 11 to 24 mg/L during dry and wet seasons, respectively.

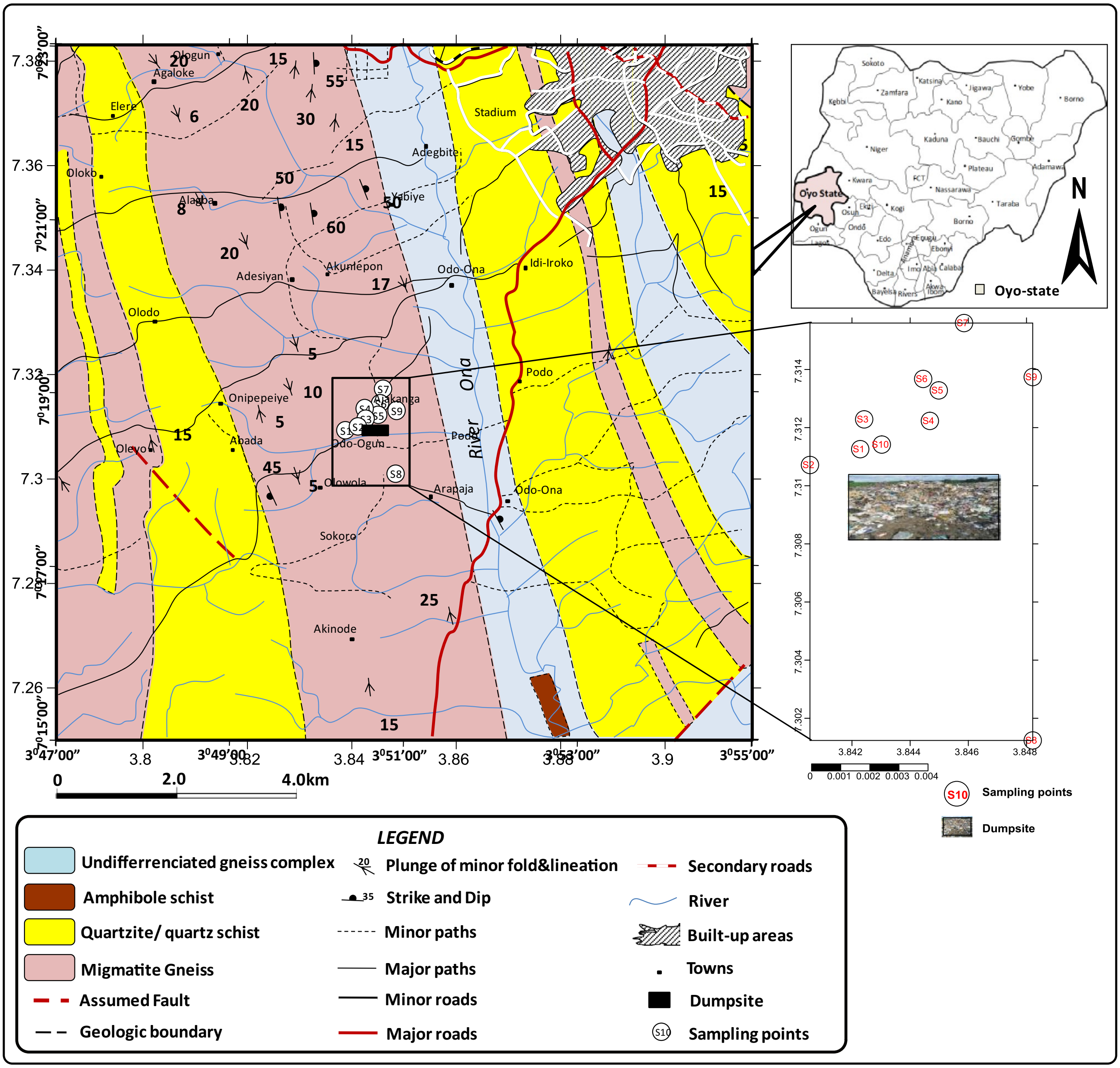

**Fig. 4** Geological map showing the rock type that underlies the sampled area, dumpsite and layout of the sampling points (reproduced with permission from Jones and Hockey 1964)

There is no significant seasonal variations of $K^+$. The values in groundwater samples ranged from 2 to 6 mg/L and 1 to 6 mg/L during dry and wet seasons, respectively (Kamble and Saxena 2016; Udayalaxmi et al. 2010; Odukoya and Abimbola 2010). The lowest and highest concentration of $K^+$ in groundwater may be due to the fact that most potassium-bearing minerals are resistant to decomposition by weathering processes and fairly low concentrations of ionic potassium in groundwater (Scheytt 1997; Sravanthi and Sudarshan 1998). However, higher concentration of some water quality parameters were noticed in Wells 1 and 10 which may be due to effect of leachate migration in the southern part of the dumpsite; nearness to dumpsite; agricultural run-off and fertilizer application on the nearby farm settlement.

## Result of statistical analyses

Table 3 shows the details of the descriptive statistics of the analyzed water quality parameters from ten sampling points within the vicinity of the dumpsite. The degree of a linear association between any two of the analyzed variables

**Table 2** Physicochemical parameters during dry and wet seasons for analyzed water samples

| Sample | pH | | EC (µs/cm) | | TDS (mg/L) | | $Cl^-$ (mg/L) | | $HCO_3^-$ (mg/L) | | $CO_3^{2-}$ (mg/L) | | TH (mg/L) | | $Na^+$ (mg/L) | | $K^+$ (mg/L) | | $SO_4^{2-}$ (mg/L) | | $NO_3^-$ (mg/L) | | $Mg^{2+}$ (mg/L) | | $Ca^{2+}$ (mg/L) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Dry | Wet | Dry | Wet | Dry | Wet | Dry | Wet | Dry | Wet | Dry | Wet | Dry | Wet | Dry | Wet | Dry | Wet | Dry | Wet | Dry | Wet | Dry | Wet | Dry | Wet |
| $S_1$ | 7.1 | 7.0 | 598 | 465 | 299 | 237 | 96 | 52 | 414.8 | 317.2 | 204 | 156 | 180 | 432 | 30 | 22 | 2 | 1 | 26.45 | 25.49 | 1.8 | .1 | 13.88 | 18.02 | 24.01 | 20.76 |
| $S_2$ | 7.1 | 7.3 | 420 | 425 | 210 | 214 | 24 | 33.5 | 195.2 | 366 | 96 | 180 | 276 | 404 | 17 | 18 | 5 | 3 | 14.36 | 16.45 | 2.2 | 0 | 13.61 | 23.32 | 18.26 | 22.63 |
| $S_3$ | 7.4 | 6.9 | 367 | 377 | 184 | 185 | 24 | 13 | 292.8 | 414.8 | 144 | 204 | 178 | 350 | 13 | 17 | 1 | 1 | 19.68 | 7.58 | 1.5 | 0 | 12.69 | 20.07 | 8.12 | 14.27 |
| $S_4$ | 7.8 | 7.3 | 275 | 259 | 138 | 128 | 54 | 10.5 | 585.6 | 268.4 | 288 | 132 | 100 | 234 | 16 | 17 | 4 | 6 | 38.71 | 15.32 | 2.7 | 0 | 10.35 | 5.89 | 5.38 | 23.05 |
| $S_5$ | 7.4 | 7.1 | 176 | 205 | 88 | 101 | 16 | 10 | 219.6 | 219.6 | 108 | 108 | 46 | 180 | 18 | 11 | 2 | 1 | 57.74 | 18.23 | 10.2 | 2.9 | 1.12 | 3.29 | .41 | 9.66 |
| $S_6$ | 7.2 | 6.7 | 530 | 411 | 264 | 205 | 113 | 52.5 | 170.8 | 219.6 | 84 | 108 | 200 | 260 | 18 | 24 | 6 | 1 | 127.74 | 27.74 | 11.9 | 3.2 | 12.97 | 14.69 | 7.28 | 4.51 |
| $S_7$ | 7.2 | 6.9 | 299 | 191 | 150 | 95 | 32 | 16.5 | 366 | 122 | 180 | 60 | 96 | 116 | 16 | 14 | 4 | 1 | 88.07 | 24.68 | 16.0 | 3.0 | 5.03 | 5.32 | 1.32 | 2.01 |
| $S_8$ | 7.6 | 7.0 | 225 | 242 | 112 | 121 | 28 | 15 | 122 | 170.8 | 60 | 84 | 70 | 206 | 15 | 16 | 2 | 1 | 45.81 | 14.20 | 5.1 | .9 | 5.68 | 5.42 | 2.19 | 8.43 |
| $S_9$ | 7.3 | 7.2 | 273 | 251 | 137 | 125 | 26 | 13.5 | 268.4 | 219.6 | 132 | 108 | 118 | 210 | 12 | 15 | 3 | 2 | 21.77 | 14.20 | 5.8 | 3.9 | 11.63 | 9.64 | 9.02 | 10.88 |
| $S_{10}$ | 6.9 | 7.2 | 568 | 705 | 284 | 351 | 39 | 40.5 | 536.8 | 610 | 264 | 300 | 406 | 190 | 19 | 24 | 2 | 2 | 29.19 | 52.26 | 3.4 | 2.6 | 14.23 | 49.34 | 49.18 | 173.42 |

All parameters are in unit of mg/L except pH (no unit) and EC in µs/cm

**Table 3** Descriptive statistics of the analyzed water quality for dry and wet season

| | Dry | | Wet | | Analysis *N* |
|---|---|---|---|---|---|
| | Mean | Std. deviation | Mean | Std. deviation | |
| pH | 7.3000 | .26247 | 7.0600 | .19551 | 10 |
| EC | 373.1000 | 149.56860 | 353.1000 | 158.21255 | 10 |
| TDS | 186.6000 | 74.62082 | 176.2000 | 79.46180 | 10 |
| $Cl^-$ | 45.2000 | 33.13877 | 25.7000 | 17.24529 | 10 |
| $HCO_3^-$ | 317.2000 | 156.02439 | 292.8000 | 142.27523 | 10 |
| $CO_3^{2-}$ | 156.0000 | 76.73330 | 144.0000 | 69.97142 | 10 |
| TH | 167.0000 | 108.71063 | 258.2000 | 103.55653 | 10 |
| $Na^+$ | 17.4000 | 4.94862 | 17.8000 | 4.31535 | 10 |
| $K^+$ | 3.1000 | 1.59513 | 1.9000 | 1.59513 | 10 |
| $SO_4^{2-}$ | 46.9520 | 35.86853 | 21.6150 | 12.40855 | 10 |
| $NO_3^-$ | 6.0600 | 4.98045 | 1.6600 | 1.59457 | 10 |
| $Mg^{2+}$ | 10.1190 | 4.55695 | 15.5000 | 13.80501 | 10 |
| $Ca^{2+}$ | 12.5170 | 14.89881 | 28.9620 | 51.28535 | 10 |

measured by Pearson's correlation coefficients for dry and wet seasons are presented in Tables 4, 5, respectively. There are very strong associations between EC and TDS, $HCO_3^-$ and $CO_3^{2-}$ during both seasons. Highly significant correlation between EC and TDS buttress the fact that EC depends largely on the quality of the dissolved salts present in water sample. There is negative correlation between $Na^+$ and $K^+$, TH and $NO_3^-$ during dry and wet seasons. The negative correlations between TH and $NO_3^-$ and between $Na^+$ and $K^+$ were expected because the effect of nitrogen-fixing bacteria decreases with increasing hardness of water (Fabiyi 2008) while ion is normally less than and $Na^+$ in igneous rock typical of basement complex formation (Scheytt 1997).

Both PCA and CA were performed on the normalized data set of 13 physicochemical parameters during dry and wet seasons. Tables 6, 7 show the factor loading and eigenvalues of extracted components during dry and wet seasons, respectively, while Fig. 5a, b shows the dendrograms of analyzed parameters for dry and wet seasons while Fig. 6a, b depicts dendrograms for groundwater sampling points.

## PCA, CA and ANOVA results during dry season

PC analysis identified five principal components accounting for 95.7% of the total variation in the original water quality data set during dry season.

PCI (Factor 1) accounts for 44.9% of the total variance, showing strong positive loading on EC, TDS, $Ca^{2+}$, $Mg^{2+}$ and TH, moderate loading for $Na^+$ The strong positive loading factor of EC, TDS and TH may be interpreted as the influence of anthropogenic pollution from solid waste on the dumpsite while high loading of $Ca^{2+}$, $Mg^{2+}$ and TH may be

**Table 4** Correlation coefficient of Ajakanga water samples parameters during dry season

| | pH | EC | TDS | $Cl^-$ | $HCO_3^-$ | Hardness | $CO_3^{2-}$ | $SO_4^{2-}$ | $NO_3^-$ | $Na^+$ | $K^+$ | $Mg^{2+}$ | $Ca^{2+}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| pH | 1 | | | | | | | | | | | | |
| EC | − .735$^{a}$ | 1 | | | | | | | | | | | |
| TDS | − .736$^{a}$ | 1.000$^{b}$ | 1 | | | | | | | | | | |
| $Cl^-$ | − .255 | .680$^{a}$ | .678$^{a}$ | 1 | | | | | | | | | |
| $HCO_3^-$ | − .001 | .282 | .286 | .121 | 1 | | | | | | | | |
| Hardness | − .687$^{a}$ | .784$^{b}$ | .784$^{b}$ | .165 | .308 | 1 | | | | | | | |
| $CO_3^{2-}$ | − .001 | .282 | .286 | .121 | 1.000$^{b}$ | .308 | 1 | | | | | | |
| $SO_4^{2-}$ | − .049 | .032 | .029 | .504 | − .256 | − .229 | − .256 | 1 | | | | | |
| $NO_3^-$ | − .106 | − .264 | − .266 | .078 | − .271 | − .381 | − .271 | .837$^{b}$ | 1 | | | | |
| $Na^+$ | − .481 | .640$^{a}$ | .640$^{a}$ | .614 | .270 | .226 | .270 | − .004 | − .162 | 1 | | | |
| $K^+$ | − .124 | .154 | .152 | .422 | − .153 | .079 | − .153 | .569 | .409 | − .076 | 1 | | |
| $Mg^{2+}$ | − .425 | .795$^{b}$ | .796$^{b}$ | .448 | .289 | .746$^{a}$ | .289 | − .302 | − .588 | .230 | .170 | 1 | |
| $Ca^{2+}$ | − .656$^{a}$ | .748$^{a}$ | .749$^{a}$ | .148 | .490 | .907$^{b}$ | .490 | − .376 | − .460 | .421 | − .185 | .642$^{a}$ | 1 |

$^{a}$Correlation is significant at the .05 level (2-tailed)

$^{b}$Correlation is significant at the .01 level (2-tailed)

**Table 5** Correlation coefficient of water samples parameters during wet season

| | pH | EC | TDS | $Cl^-$ | $CO_3^{2-}$ | $HCO_3^-$ | Hardness | $SO_4^{2-}$ | $NO_3^-$ | $Na^+$ | $K^+$ | $Mg^{2+}$ | $Ca^{2+}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| pH | 1 | | | | | | | | | | | | |
| EC | .075 | 1 | | | | | | | | | | | |
| TDS | .077 | 1.000$^{b}$ | 1 | | | | | | | | | | |
| $Cl^-$ | − .321 | .717$^{a}$ | .729$^{a}$ | 1 | | | | | | | | | |
| $CO_3^{2-}$ | .333 | .889$^{b}$ | .882$^{b}$ | .344 | 1 | | | | | | | | |
| $HCO_3^-$ | .333 | .889$^{b}$ | .882$^{b}$ | .344 | 1.000$^{b}$ | 1 | | | | | | | |
| Hardness | .164 | .379 | .391 | .473 | .338 | .338 | 1 | | | | | | |
| $SO_4^{2-}$ | − .104 | .738$^{a}$ | .738$^{a}$ | .595 | .541 | .541 | − .235 | 1 | | | | | |
| $NO_3^-$ | − .376 | − .130 | − .135 | − .020 | − .253 | − .253 | − .704$^{a}$ | .360 | 1 | | | | |
| $Na^+$ | − .361 | .375 | .387 | .775$^{b}$ | .055 | .055 | .626 | .069 | − .296 | 1 | | | |
| $K^+$ | .719$^{a}$ | − .034 | − .037 | − .238 | .131 | .131 | .036 | − .104 | − .367 | − .020 | 1 | | |
| $Mg^{2+}$ | .171 | .961$^{b}$ | .957$^{b}$ | .538 | .934$^{b}$ | .934$^{b}$ | .243 | .730$^{a}$ | − .057 | .155 | − .022 | 1 | |
| $Ca^{2+}$ | .277 | .816$^{b}$ | .809$^{b}$ | .311 | .840$^{b}$ | .840$^{b}$ | − .129 | .836$^{b}$ | .103 | − .145 | .114 | .887$^{b}$ | 1 |

$^{a}$Correlation is significant at the .05 level (2-tailed)

$^{b}$Correlation is significant at the .01 level (2-tailed)

due to calcite and dolomite dissolution, weathering process, groundwater geological interaction and mineral precipitation. This positive loading on $Ca^{2+}$, $Mg^{2+}$ and TH suggest $Ca^{2+}$, $Mg^{2+}$ that probably contribute mostly to hardness of water in the study area.

Negative loading of pH with $Ca^{2+}$ during dry season means a decrease in pH as the $Ca^{2+}$ concentration in water rises (Mohapatra et al. 2011). PC2 accounted for 21.9% of the total variance, showing strong positive loading on $SO_4^{2-}$ and this may be due to anthropogenic/organic wastes, atmospheric deposition, agricultural wastes, fertilizers and bacterial oxidation from dumpsite (Sidle et al. 2000) or atmospheric deposition (Wayland et al. 2003). Moderate positive loading for $K^+$ may be due to weathering of granite and magmatic rock, $Cl^-$ may be due to anthropogenic waste from dumpsite or mineralization of groundwater while moderate loading of $NO_3^{2-}$ may be an indication of livestock and municipal wastes from the dumpsite. PC3 accounts for 12.54% of the total variance while PC4 and PC5 accounted for 8.39 and 7.91% of the total variance.

During dry season, three clusters were identified on the dendrogram of physicochemical parameters. Cluster 1 showed a closed association between $HCO_3{}^-$ and $CO_3{}^{2-}$ and completely agrees with results of correlation coefficient analysis during dry season. Cluster 2 formed

**Table 6** Factor loading and eigenvalues of extracted components during dry season

| | Component | | | | |
|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 |
| TDS | .945 | .288 | − .056 | − .091 | − .027 |
| EC | .943 | .292 | − .058 | − .093 | − .027 |
| $Ca^{2+}$ | .892 | − .235 | − .125 | .246 | − .137 |
| TH | .862 | − .047 | − .302 | .336 | .115 |
| $Mg^{2+}$ | .829 | − .030 | − .183 | − .141 | .466 |
| pH | − .687 | − .271 | .386 | − .363 | .355 |
| $Na^{+}$ | .600 | .202 | .262 | − .432 | − .510 |
| $SO_4^{2-}$ | − .226 | .884 | .259 | .167 | − .030 |
| $K^{+}$ | .018 | .707 | .073 | .184 | .553 |
| $NO_3^{-}$ | − .451 | .688 | .189 | .450 | − .261 |
| $Cl^{-}$ | .497 | .651 | .335 | -.425 | .097 |
| $HCO_3^{-}$ | .495 | − .411 | .723 | .242 | .055 |
| $CO_3^{2-}$ | .495 | − .411 | .723 | .242 | .055 |
| Initial eigenvalue | 5.832 | 2.859 | 1.630 | 1.090 | 1.029 |
| % of variance | 44.858 | 21.991 | 12.538 | 8.386 | 7.912 |
| Cumulative % | 44.858 | 66.849 | 79.388 | 87.773 | 95.685 |

**Table 7** Factor loading and eigenvalues of extracted components during wet season

| | Component | | |
|---|---|---|---|
| | 1 | 2 | 3 |
| EC | .996 | − .048 | − .071 |
| TDS | .994 | − .049 | − .085 |
| $Mg^{2+}$ | .970 | .002 | .119 |
| $CO_3^{2-}$ | .910 | .269 | .108 |
| $HCO_3^{-}$ | .910 | .269 | .108 |
| $Ca^{2+}$ | .857 | .008 | .492 |
| $Na^{+}$ | .817 | − .228 | − .331 |
| $SO_4^{2-}$ | .757 | − .421 | .372 |
| $Cl^{-}$ | .672 | − .398 | − .475 |
| pH | .157 | .772 | .457 |
| $K^{+}$ | .029 | .753 | .245 |
| $NO_3$ | − .136 | − .716 | .553 |
| TH | .337 | .392 | − .815 |
| Initial eigenvalue | 7.162 | 2.366 | 2.006 |
| % of variance | 55.096 | 18.203 | 15.428 |
| Cumulative % | 55.096 | 73.298 | 88.726 |

by $Cl^{-}$, $Na^{+}$, TH, $Ca^{2+}$, $Mg^{2+}$and TDS are completely in accordance with correlation coefficient and PC1. This is an indication of common source. Cluster 3 during dry season comprises $SO_4^{2-}$, $NO_3^{2-}$, $K^{+}$and pH. This is an indication of anthropogenic pollution from nearby dumpsite, agricultural wastes and effect of dumping wastes on pH.

On the basis of dendrogram of sampling points, two clusters were formed during dry season. Cluster 1 consists of samples $S_2$, $S_3$, $S_4$, $S_5$, $S_7$, $S_8$ and $S_9$ while cluster 2 consists of $S_1$, $S_6$ and $S_{10}$. These clusters of sampling points during dry season were grouping based on similar water quality characteristics. One-way ANOVA result shows significant difference at 5% level between the two clusters for EC, TDS, $Cl^{-}$, $Na^{+}$and $Ca^{2+}$. This is an indication that the EC, TDS, $Cl^{-}$, $Na^{+}$and $Ca^{2+}$ are physicochemical variables that differentiate the two identified clusters.

## PCA, CA and ANOVA during wet season

Three principal components were extracted and accounted for 88.7% of the total variation in data set. Factor 1 accounts for 55.1% of the total variance and characterized by strong positive loading for EC, TDS, $Ca^{2+}$, $Mg^{2+}$, $HCO_3^{-}$, $CO_3^{2-}$, $Na^{+}$and $SO_4^{2-}$, moderate loading on $Cl^{-}$ and negative loading on $NO_3^{-}$. The elements in PC1 probably show mineral components of groundwater, dissolution of carbonate minerals, rock–water geochemical reaction, dilution of groundwater, weathering and anthropogenic pollution. Dissolution of gypsum mineral could increase $SO_4^{2-}$ concentration in groundwater (Yidana 2010).

Negative loading on $NO_3^{-}$ may be due to action of denitrifying bacteria, laminar flow direction and diffusion process (Singh et al. 2008). Factor 2 has strong positive loadings for pH and $K^{+}$ and accounts for 18.2% of the total variability in the data set while PC3 accounted for 15.4% of the total variance and has a strong negative loading for TH.

Negative loading of EC, TDS, $Na^{+}$, $SO_4^{2-}$, $Cl^{-}$ and $NO_3^{-}$ in PC 2 reflects their reduction due to dilution process during wet season.

On the basis of cluster analysis on physicochemical parameters, four clusters were identified during wet season. Cluster 1 comprises $HCO_3^{-}$, $CO_3^{2-}$, EC, TDS, $Ca^{2+}$, $Mg^{2+}$and $SO_4^{2-}$ and completely agrees with correlation coefficient analysis and PC1 during wet season. This is a cluster based on rock–water interaction, mineral dissolution and anthropogenic pollution source. Cluster 2 comprises $Cl^{-}$, $Na^{+}$and TH, cluster 3 comprises pH and $K^{+}$ and correlates very well with strong positive loading of pH and $K^{+}$ during wet season while cluster 4 consists of only $NO_3^{-}$ and corresponds with strong negative loading of $NO_3^{-}$ on PC 2. The dendrogram schedule during wet season based on groundwater sampling sites depicts three (3) clusters. Cluster 1 comprises $S_4$, $S_5$, $S_7$, $S_8$ and $S_9$ which were scattered upstream of dumpsite and can be regarded as samples without influence of dumpsite. Cluster 2 comprises $S_1$, $S_2$, $S_3$ and $S_6$ samples on the southern part of the dumpsite. It should be noted that $S_1$, $S_2$, $S_3$ water samples in cluster 2 are within the vicinity of the dumpsite. Cluster 3 contains only sample $S_{10}$ which is an isolated hand-dug well within a

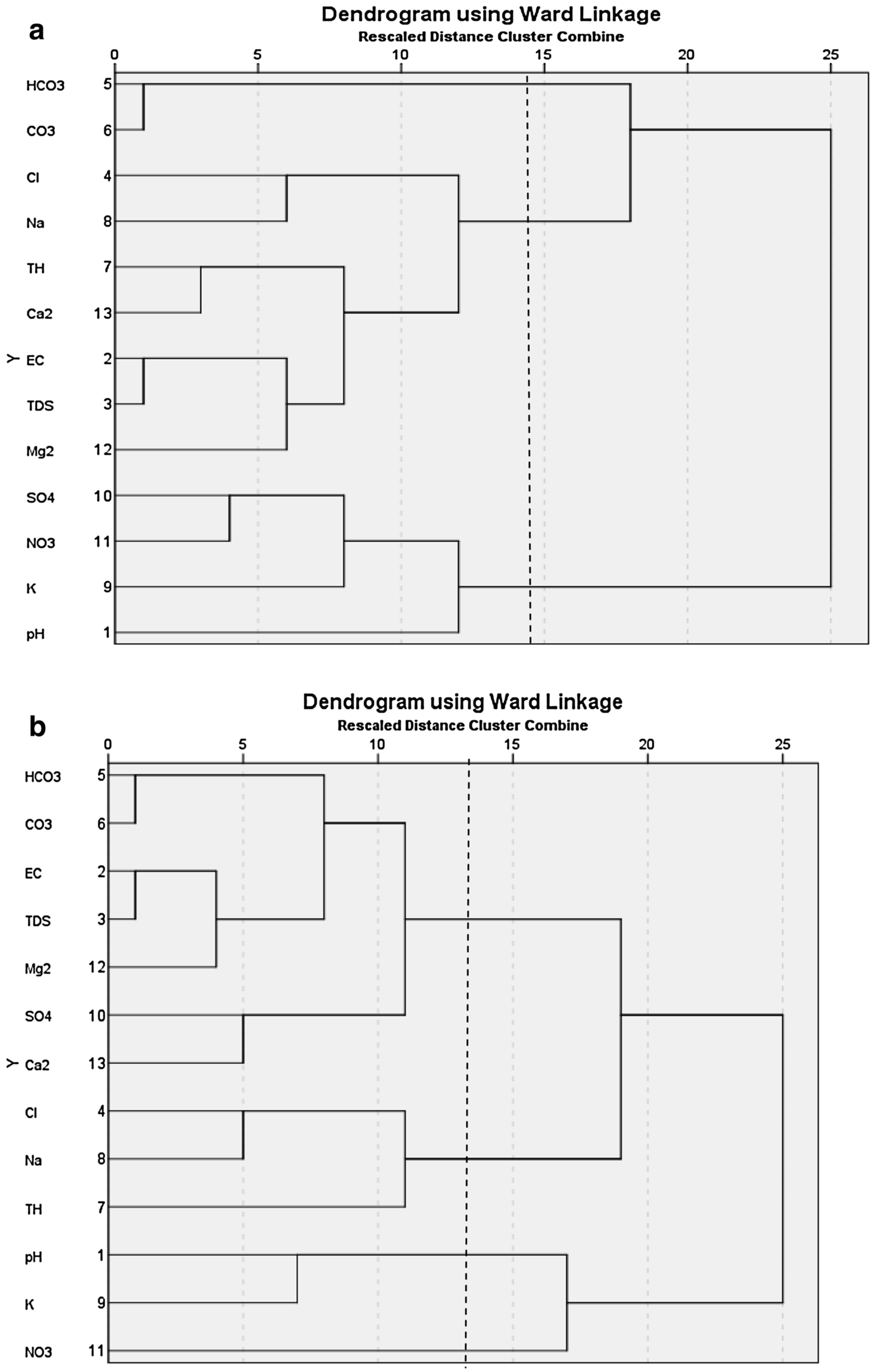

**Fig. 5** **a** Dendrogram of analyzed parameters during dry season. **b** Dendrogram of analyzed parameters during wet season

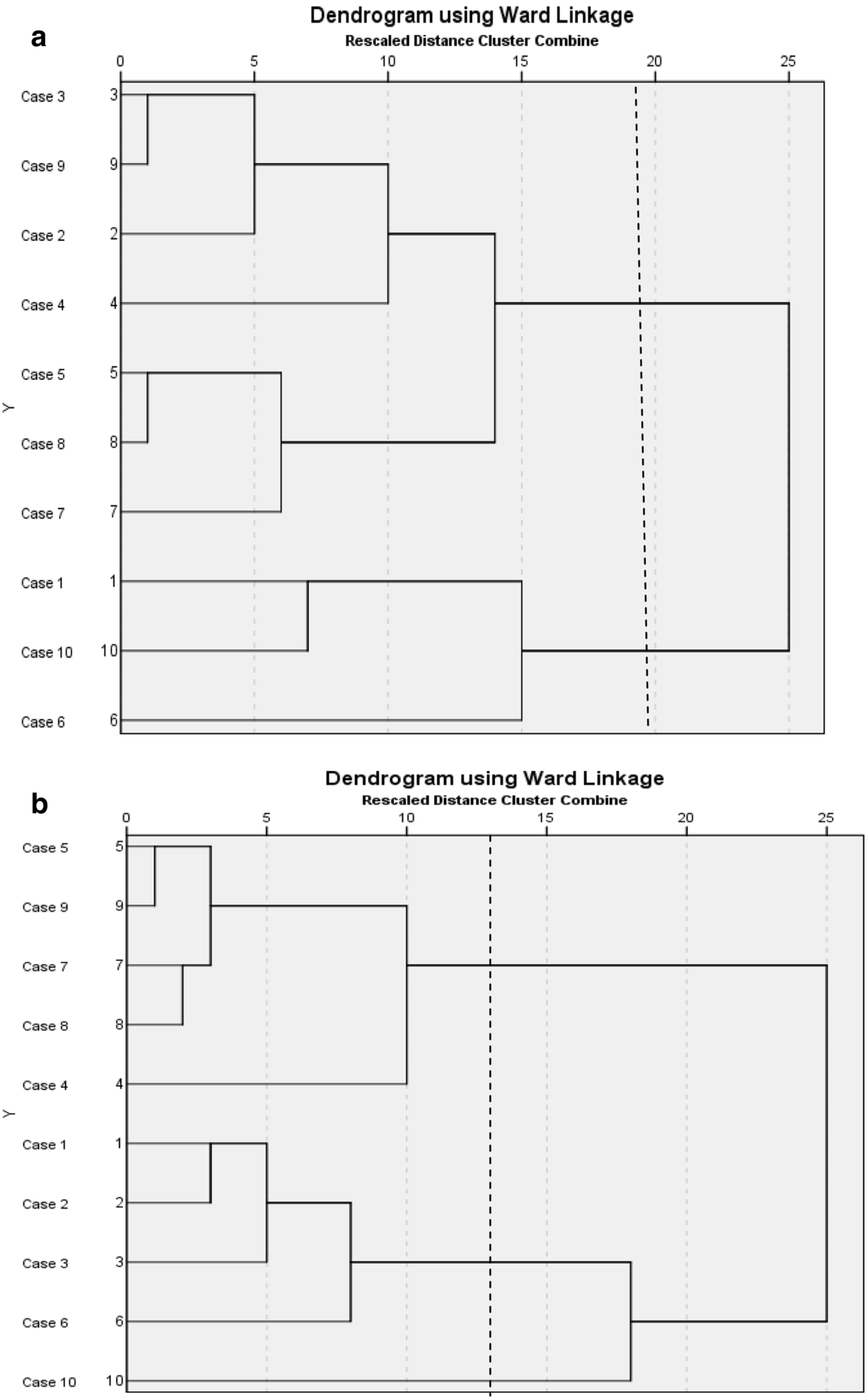

**Fig. 6** **a** Dendrogram of water sampling locations during dry season. **b** Dendrogram of water sampling locations during wet season

**Table 8** Irrigation parameters during dry season

| Sample | SAR | % Na | SSP | RSBC | KR | PI |
|---|---|---|---|---|---|---|
| $S_1$ | 1.201193 | 35.13 | 36.50 | 5.599 | .55 | 106.8 |
| $S_2$ | .730645 | 25.37 | 29.76 | 2.287 | .36 | 90.8 |
| $S_3$ | .660378 | 27.49 | 28.76 | 4.394 | .38 | 135.8 |
| $S_4$ | .923797 | 36.01 | 41.35 | 9.331 | .61 | 207.6 |
| $S_5$ | 3.279626 | 82.59 | 87.97 | 3.579 | 6.86 | 298.8 |
| $S_6$ | .921176 | 32.87 | 39.33 | 2.436 | .54 | 110.2 |
| $S_7$ | 1.411331 | 54.16 | 62.19 | 5.934 | 1.43 | 266.5 |
| $S_8$ | 1.208652 | 50.74 | 54.70 | 1.891 | 1.12 | 167.4 |
| $S_9$ | .6195 | 25.85 | 29.66 | 3.949 | .37 | 134.8 |
| $S_{10}$ | .611852 | 18.26 | 19.39 | 6.341 | .23 | 84.8 |

**Table 9** Irrigation parameters during wet season

| Sample | SAR | %Na | SSP | RSBC | KR | PI |
|---|---|---|---|---|---|---|
| $S_1$ | .84831 | 27.14 | 27.88 | 4.162 | .38 | 92.6 |
| $S_2$ | .63066 | 19.87 | 21.83 | 4.868 | .25 | 83.8 |
| $S_3$ | .67644 | 23.44 | 24.27 | 6.086 | .31 | 107.1 |
| $S_4$ | .81534 | 29.14 | 35.21 | 3.247 | .45 | 119.1 |
| $S_5$ | .77695 | 37.90 | 39.97 | 3.117 | .63 | 192.3 |
| $S_6$ | 1.22494 | 41.40 | 42.44 | 3.375 | .72 | 117.9 |
| $S_7$ | 1.16686 | 51.66 | 53.86 | 1.90 | 1.11 | 175.7 |
| $S_8$ | 1.05194 | 43.60 | 45.23 | 2.379 | .79 | 151.0 |
| $S_9$ | .79447 | 31.80 | 34.29 | 3.056 | .48 | 127.5 |
| $S_{10}$ | .25789 | 4.83 | 5.21 | 1.329 | .05 | 28.4 |

cultivated farmland on the upstream of the dumpsite. It should be noted that clusters of sampling points were based on similar topography setting, characteristics location of the sampling sites and vicinity with respect to the dumpsite.

The one-way ANOVA result shows that all the analyzed parameters except pH, $K^+$, $NO_3^-$ differ significantly at 5% level among the three clusters of groundwater samples. This implies that all the variables in the data set except pH, $K^+$, $NO_3^-$ are factors that discriminate one cluster from the other.

## Groundwater quality for irrigation purpose

The suitability of groundwater for irrigation purpose was evaluated by calculating SAR, %Na, soluble sodium percentage (SSP), Kelly's ratio (KR), permeability index (PI) and residual sodium bicarbonate (RSBC). The results of calculated irrigation parameters are presented in Tables 8, 9 for dry and wet seasons, respectively.

The %Na for the groundwater samples from the study area was estimated using the formula:

$$\%\mathrm{Na} = \frac{(\mathrm{Na}^+) \times 100}{(\mathrm{Ca}^{2+} + \mathrm{Mg}^{2+} + \mathrm{Na}^+ + \mathrm{K}^+)}, \tag{1}$$

where the concentrations are in meq/L.

**Table 10** Quality of groundwater based on %Na values

| %Na | Water class | % during dry season | % during wet season |
|---|---|---|---|
| < 20 | Excellent | 10 | 20 |
| 20–40 | Good | 60 | 50 |
| 40–60 | Permissible | 20 | 30 |
| 60–80 | Doubtful | – | – |
| > 80 | Unsuitable | 10 | – |

The classification of groundwater samples based on %Na values is shown in Table 10.

SAR for the groundwater samples was estimated from the formula (Karanth 1987):

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

The water samples having SAR values less than 10 are considered excellent, 10–18 as good, 18–26 as fair (doubtful) and above 26 as unsuitable for irrigation use (USDA 1954). In the present study, the SAR values for both seasons are less than 10 and can thus be graded as "Excellent" for irrigation use (as shown in Tables 8 and 9).

Kelly's ratio (KR) was calculated by using the numerical formula (Kelly 1963):

$$\mathrm{KR} = \frac{\mathrm{Na}^{+}}{\mathrm{Ca}^{2+} + \mathrm{Mg}^{2+}}, \tag{3}$$

where concentrations are expressed in meq/L.

The Kelly's ratio of 1 or less than 1 is an indication of good quality water for irrigation purpose, whereas above one is suggestive of unsuitable for agricultural purpose due to alkali hazards (Karanth 1987). It is observed from Tables 8 and 9 that, 70% of the samples in the study area have KR values below 1, thus belonging to "Good" class while 30% belongs to "Unsuitable" class during dry season. However, in wet season, 90% belong to "Good" class while 10% of samples belong to "Unsuitable" class for irrigation need.

The residual sodium bicarbonate (RSBC) was determined using the formula (Gupta and Gupta 1987):

$$\left[\left(\mathrm{HCO}_3^{-}\right) - \left(\mathrm{Ca}^{+}\right)\right], \tag{4}$$

where the ion concentrations are in meq/L.

According to USDA (1954), RSBC values exceeding 2.5 meq/L is "Unsuitable for irrigation", if the value of RSBC lies between 1.25 and 2.5 meq/L, it is "marginally suitable" while a value less than 1.25 meq/L indicate safe water quality. Based on this classification, during the dry season, 70% fall under "Unsuitable class and 30% fall under "marginally suitable". However, in wet season, 70% of analyzed samples still fall under "Unsuitable" class while 30% fall under "Marginally suitable" class based on RSBC values (Tables 8 and 9).

Todd (1995) defines soluble sodium percentage (SSP) as:

$$\mathrm{SSP} = \frac{\left(\mathrm{Na}^{+} + \mathrm{K}^{+}\right) \times 100}{\left(\mathrm{Na}^{+} + \mathrm{K}^{+} + \mathrm{Ca}^{2+} + \mathrm{Mg}^{2+}\right)}, \tag{5}$$

where the concentrations are in meq/L.

The classification of groundwater for irrigation purpose based on SSP value is shown in Table 11.

The permeability index is calculated by using the formula (Ragunath 1987):

$$\mathrm{PI} = \frac{\left(\mathrm{Na}^{+} + \sqrt{\mathrm{HCO}_3^{-}}\right)}{\left(\mathrm{Ca}^{2+} + \mathrm{Mg}^{2+} + \mathrm{Na}^{+}\right)} \times 100, \tag{6}$$

where the concentrations are expressed in meq/L.

The PI values > 75 indicate excellent quality water for irrigation. PI values less than 25 reflect "unsuitable" water for irrigation. On the basis of PI values in Tables 8 and 9, all the water samples from the study area during dry season can be classified as "Excellent" class for agricultural use. During wet season, 90% belong to "Excellent" class while only 10% falls under "Doubtful to unsuitable" class.

**Table 11** Quality of groundwater based on SSP values

| SSP values | Water class | % during dry season | % during wet season |
|---|---|---|---|
| < 60 | Excellent | 80 | 100 |
| 60–75 | Good to permissible | 10 | – |
| > 75 | Doubtful to unsuitable | 10 | – |

## Conclusion

The study provides information about the quality of groundwater from hand-dug wells at several locations closed to Ajakanga dumpsite. The major ions in all analyzed groundwater samples were found to lie within the standard limits of WHO (2007) and NSDWQ (2007). However, high concentration of some water quality parameters were noticed in Wells 1 and 10, which may be due to effect of leachate migration towards the southern part of the dumpsite; nearness to dumpsite; agricultural run-off and fertilizer application.

Five principal components with three factors were responsible for 95.7 and 88.7% of the total variance in the data set during dry and wet seasons, respectively. PCA identified parameters influencing water quality were probably related to mineral dissolution, groundwater–rock interaction, weathering process and anthropogenic activities from the dumpsite while cluster analysis based on groundwater samples during dry and wet seasons showed 2 and 3 significant clusters, respectively.

The dendrogram also reflects variation of water quality with climatic season as shown in the differing number of clusters during both seasons. The analyzed physicochemical parameters that explained more than 40% of the total variance in the original data set during both seasons were: EC, TDS, $\mathrm{Ca}^{2+}$, $\mathrm{Mg}^{2+}$ and TH. Calculated irrigation parameters values indicate that, sizeable number of groundwater samples will neither cause salinity hazards nor have adverse effects on soil properties and thus suitable for irrigation needs.

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