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ORIGINAL ARTICLE

# Assessment of the quality of groundwaters proximal to dumpsites in Awka and Nnewi metropolises: a comparative approach

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**Abstract**

Using integrated geoscientific approach, this paper assessed the quality of groundwaters around open dumpsites in Awka and Nnewi metropolises, Nigeria. Ten water samples for each of the metropolises were subjected to hydrogeochemical analysis. Seventeen parameters were subjected to correlation, factor, cluster, pollution index, and quality analyses. The interrelationships between parameters were obtained. The order of cation and anion dominance in Awka is Ca > Mg > Na > K and $Cl > HCO_3 > SO_4 > NO_3 > PO_4$, respectively. In Nnewi, the order is Na > Ca > K>Mg and $Cl > SO_4 > HCO_3 > PO_4 > NO_3$, respectively. Heavy metals occurred in the order Pb > Fe > Cu > Cd in Awka and Fe > Cu > Pb > Cd in Nnewi. Five water types and three water facies dominate Awka metropolis, whereas eight water types and four water facies dominate Nnewi metropolis. The physicochemical parameters for both metropolises are well within quality standards. However, pH of most of the samples is off standard limits, classing the waters as neutral to slightly acidic. Also, the groundwaters are generally contaminated with heavy metals. Pollution index of Awka metropolis (ranging 0.542–73.083) is higher than that of Nnewi metropolis (ranging 0.069–6.617). Further, Pb has the highest contamination factor in Awka metropolis, whereas Cd has the highest in Nnewi metropolis. Based on the gross characteristics observed in both metropolises, the waters are considered unfit for drinking purposes, but could be used for other domestic and industrial purposes which do not require them being used for food processing.

**Keywords** Awka · Groundwater quality · Nnewi · Pollution index · Open dumpsites · Water chemistry

## Introduction

Groundwater is a major source of water supply in urbanized areas, such as Awka and Nnewi metropolises. Residents in these areas depend on it for drinking, domestic, and industrial purposes. The quality of this resource is much dependent on its natural physical and chemical statuses, as well as any alterations that may have occurred as a consequence of human activities (Fetter 1990). In the study area, adequate waste disposal methods have not been well adopted. Gullies and pits are often used as dumpsites (landfills). Various inorganic and organic wastes are indiscriminately disposed in these open dumpsites. Maiti et al. (2016) reported that the electronic products, paint waste, automobile batteries, etc., that are usually dumped with other municipal solid wastes, without proper segregation, increase the volume of heavy metals in dumpsites and hence elevate consequent toxic environmental effects. Occasionally, the dumpsites are set ablaze in an attempt to reduce the volume of wastes and to create accommodation spaces for more wastes. Although this practice seems to solve immediate waste management problems, it usually has more far-reaching impacts on water resources and public health. Ziraba et al. (2016) observed that the implications of poorly managed waste systems on public health are many and depend on the nature of the waste, individuals exposed, duration of exposure, etc.

Groundwater becomes polluted or contaminated if anthropogenic activities, like poor waste management, alter its natural quality making it unfit for use for which it had previously been suited (Fetter 1990). Because the dumpsites (landfills) in the study area are ill-managed, they have become sources of vermin and air pollution to inhabitants in the area. Leachates from poorly managed landfills, such as those in the study area, have the potentials to cause an

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outbreak of groundwater pollution. In such cases, the availability of quality water for drinking, domestic, and industrial purposes is adversely impacted upon. The public health is also threatened.

Many researchers (Mor et al. 2006; Srivastava and Ramanathan 2008; Singh et al. 2008; Odukoya and Abimbola 2010; Maiti et al. 2016) from different parts of the world have reported different cases of groundwater pollution due to dumpsite leachates. But, there is a paucity of literatures reporting on the influence of poorly managed waste disposal sites in Awka and Nnewi metropolises. Only few studies (known to the current author) had attempted to report on the water quality of the two metropolises. However, Ezeabasili et al. (2014), Okoro et al. (2014), and Okoye et al. (2016) assessed the general quality of water supply in parts of Awka metropolis, whereas Agu et al. (2014) reported the influence of some solid waste dumpsites in parts of Awka metropolis. On the other hand, Momoh et al. (2013) reported the physicochemical effect of leachates on groundwater within a dumpsite in a part of Nnewi, whereas Ilechukwu and Okonkwo (2012) and Onunkwo et al. (2014) studied the heavy metal contamination in the groundwater systems in some parts of the Nnewi metropolis.

Regular groundwater pollution monitoring and assessment, as well as good waste management programs, are essential steps toward ensuring that the water quality and public health are sustained. Adequate system is necessary to keep track of potential groundwater pollution outbreak in areas proximal to landfills. Usually, several scientific techniques are integrated in an attempt to monitor or assess water systems. Studies including physicochemical analysis, hydrogeochemistry, statistical analysis, and quality indices evaluation can regularly be carried out to ascertain the quality status of water resources around dumpsites (Nishida et al. 1982; Chon et al. 1991; Kim et al. 1998; Emoyan et al. 2005; Singh et al. 2008; Odukoya and Abimbola 2010; Tiwari et al. 2017).

The previous studies on water quality (mostly concentrated on the physicochemical properties) of the two metropolises did not employ hydrogeochemical and statistical analyses. Therefore, in this paper, the impact of poor waste disposal systems (dumpsite leachates) on the quality of groundwater resources in Awka and Nnewi metropolises, Nigeria is assessed using integrated physicochemical, hydrogeochemical, and multivariate statistical methods. The research objectives were to: (1) identify the physicochemical and hydrogeochemical characteristics of water samples from the two metropolises; (2) identify the statistical interrelationships between analyzed physicochemical and hydrogeochemical parameters; (3) identify other possible factors (other than dumpsite sources) influencing the groundwater chemistry; and (4) determine the pollution index of the samples from the two metropolises. The quality of the groundwaters for drinking, domestic, and industrial purposes was ascertained in the end. Moreover, this paper provides comparisons between the groundwaters within the vicinity of the Awka and Nnewi open dumpsites. The information provided in this paper is important for groundwater monitoring and sustainability programs/projects in the duo cities.

## The study area

### Location and physiography

Awka and Nnewi are amongst the major cities in Anambra State, southeastern Nigeria. The two cities are located within latitudes 5°58′N–6°12′N and longitudes 6°53′E–7°07′E, but are few tens of kilometers away from each other (Fig. 1). Awka is an administrative, commercial, recreational, and educational city that has high population. Nnewi, on the other hand, is majorly an industrial (particularly for automobiles and their parts), commercial, and administrative populous city. Both cities are characterized by uneven topographies and majorly drained by several existing tributaries to Niger River. Average elevation above the sea level in the Nnewi area is about 60 m while that of Awka is about 70 m (Nfor et al. 2007). The cities are part of the rainforest zone of Nigeria, experiencing wet and dry seasons annually. Due to urbanization, the vegetation covers are not in their natural luxuriant status. Also, cover crop cultivation and other cultivation activities are not extensively practiced in the two areas. This exposes many parts of the areas to direct rainfall and infiltration. The average annual rainfall of the two areas is about the range 2000–3000 mm; the daily temperature range in the metropolises is about 22–32 °C, whereas the average relative humidity is about 68–79% (Onyido et al. 2014).

### Geology and hydrogeology

Awka metropolis is mainly underlain by Imo Formation, consisting more of mudrocks and few fairly consolidated sand members, whereas Nnewi metropolis is majorly underlain by Nanka Formation, consisting of loose, friable sands (Fig. 1). The Imo Formation is Paleocene in age while the Nanka Formation is Eocene. Generally, both lithologies, mudrocks and sandstones, are porous. However, mudrocks are known to inhibit the migration of leachates into groundwater systems, because of their low permeability. On the other hand, sandstones, because of their high permeability potentials, do not hamper the infiltration of leachates into aquiferous systems. Because mudrocks and sandstones characterize the study area, it was suspected that parts of the area which are underlain by mudrocks would have low risk of leachate contamination than those underlain by sandstones. A

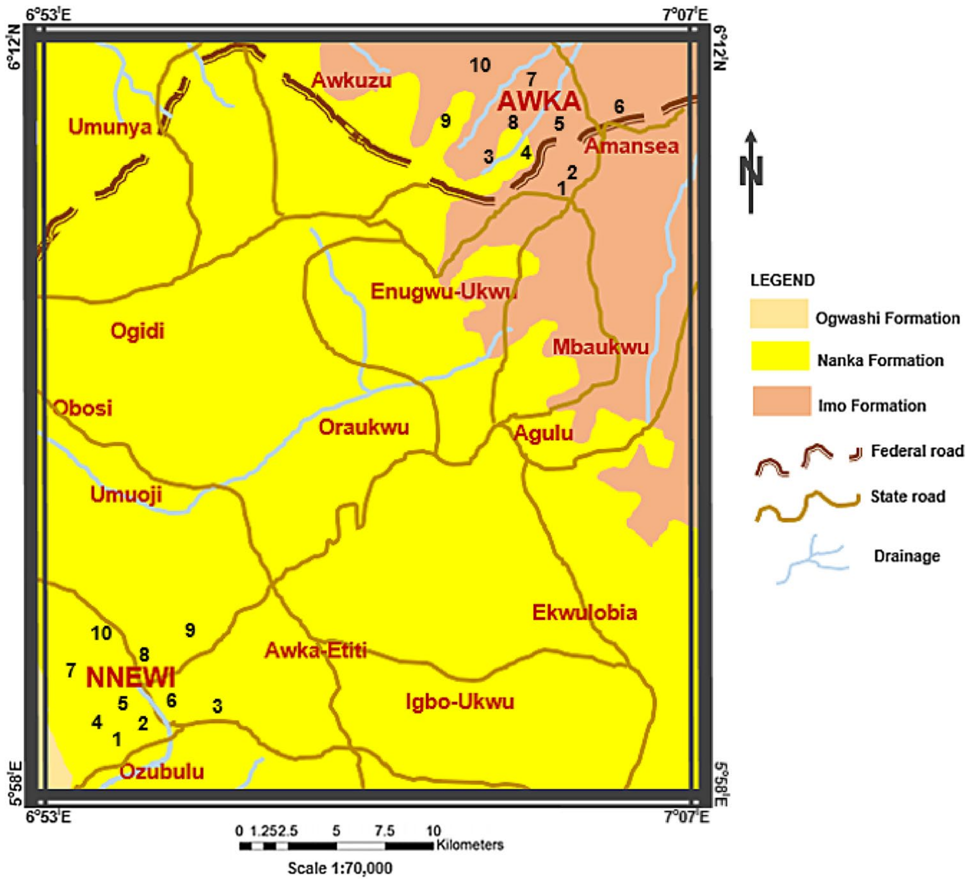


**Fig. 1** Map showing the sample locations, geology, accessibility, and drainage of the study area

previous hydrogeological study carried out in the two cities by Nfor et al. (2007) revealed that the average depth to water table in the Nnewi metropolis is about 110 m and average static water level of 120 m. The authors also reported that the Awka metropolis has its average depth to water table at about 16–35 m and average static water level of about 40 m. Their research showed that although Awka area has shallower water table, the transmissivity at such depths was very low, because of the underlying lithology. Therefore, drilling of boreholes for water supply in the area could be at much deeper depths.

## Materials and methods

This study employed integrated physicochemical, hydrogeochemical, graphical, statistical, and comparative approach, to achieve its objectives. Twenty water samples were randomly collected from boreholes (water taps) in residential and public apartments proximal (between 50 and 200 m) to several open waste dumpsites in the study area; ten samples for each of the metropolises. The sampling exercise was carried out in March 2018. The coordinates of the boreholes were taken by GARMIN GPSMAP 78S series handheld Geographical Positioning System (GPS) (Fig. 1). The samples were collected using polythene containers which were thoroughly washed to avoid contamination. They were legibly labeled; Awka groundwater samples have prefix ABH, whereas those from Nnewi have NBH prefix. Samples were refrigerated prior to laboratory analysis to prevent any reactivity.

Physical parameters including pH, temperature, electrical conductivity (EC), and total dissolved solids (TDS) were measured at various sample sites using handheld analyzing kits (conductivity/TDS/temperature meter; HM Digital COM-100). Heavy metals and cation concentrations in the samples were analyzed using atomic absorption spectrophotometric (AAS) technique (Bulk Scientific 210 VGP), while the anions were analyzed using iron chromatographic method. However, for $SO_4$ and $HCO_3$, titrimetric method was used. Standard analytical reagents (Merck Grade) were used to analyze the chemical quality of the water samples. The analytical procedures followed the recommendations by American Public Health Association (APHA 2005).

Piper trilinear diagrams, Durov diagrams, Giggenbach and Wilcox diagrams are essential tools used in the study of hydrogeochemistry of water samples. These diagrams were plotted using AquaChem geochemical software (version 2014, Schlumberger Water Services, Canada). Pearson's correlation analysis, principal component analysis, and cluster analysis of the measured parameters were determined using

SPSS statistical software (version 22, IBM Inc. 2013). Pollution index for each of the samples was calculated using the obtained concentrations of heavy metals and later summed to obtain the total pollution index for each sample. Microsoft Excel (version 2016) was used in creating heavy metals' comparison charts. The quality and suitability of the groundwaters for domestic, drinking, and industrial purposes were determined by comparing obtained physicochemical values with standards of the World Health Organization (WHO 2011) and those of the Nigerian Industrial Standard (NIS 2007).

## Results and discussion

### Geochemistry of groundwaters

Hydrogeochemical analysis helps to understand and distinguish between the rock–water interactions and anthropogenic influences. The results of the measured physicochemical and hydrogeochemical parameters are presented in Table 1, whereas the order of dominance of cations, anions, and heavy metals, for the two metropolises, are presented in Table 2. The water types and facies identified in the two metropolises are summarized in Table 3. Five water types were identified in the Awka metropolis against eight identified in the Nnewi metropolis. The different water types fall within different facies: three facies in the Awka metropolis and four facies in the Nnewi metropolis (Table 3).

**Table 2** Order of dominance of ions and heavy metals in the two metropolises

| Metropolis | Cations and anions | Heavy metals |
|---|---|---|
| Awka | Cations: Ca > Mg > Na > K<br>Anions: Cl > $HCO_3$ > $SO_4$ > $NO_3$ > $PO_4$ | Pb > Fe > Cu > Cd |
| Nnewi | Cations: Na > Ca > K>Mg<br>Anions: Cl > $SO_4$ > $HCO_3$ > $PO_4$ > $NO_3$ | Fe > Cu > Pb > Cd |

Figures 2 and 3 show that the water samples from Awka metropolis have more alkaline earth metals than alkalis and more strong acids (chlorides) than weak ones (bicarbonates). However, the duo figures show that the Nnewi samples are more enriched with alkalis than alkaline earths and more strong acids (Cl + $SO_4$) than weak ones ($HCO_3$). The positions of Awka water samples on the trilinear diagram (Fig. 2a) suggest that majority of the alkalis have secondary salinity and non-carbonate hardness, whereas the positions of Nnewi samples (Fig. 2b) suggest that majority of the alkalis are of non-carbonate origin and have primary salinity (Piper 1944; Tiwari et al. 2017). Durov diagram is also important in depicting the hydrogeochemical processes or trends dominating aquifer systems. Figure 3a also shows

**Table 1** Physicochemical and hydrogeochemical parameters analyzed in the groundwater samples

| S/no | Sample ID | Temp (°C) | pH | EC (µS/cm) | Expressed in mg/L | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | TDS | $NO_3$ | $PO_4$ | Cl | $SO_4$ | $HCO_3$ | Ca | Mg | Na | K | Fe | Cu | Pb | Cd |
| 1 | ABH01 | 26 | 4.8 | 412 | 110 | 1.1 | 0.9 | 63 | 6 | 25 | 63 | 25 | 8 | 3 | 0.07 | 0.02 | 0 | 0.007 |
| 2 | ABH02 | 27 | 5.5 | 120 | 54 | 0.8 | 0.4 | 34 | 7 | 70 | 14 | 15 | 8 | 2.8 | 0.2 | 0.09 | 1.2 | 0.009 |
| 3 | ABH03 | 24 | 5.6 | 240 | 87 | 2.3 | 0.8 | 55 | 12 | 40 | 28 | 17 | 5 | 3.2 | 0.02 | 0.03 | 0.8 | 0.007 |
| 4 | ABH04 | 26 | 6 | 180 | 92 | 4.2 | 1.2 | 76 | 11 | 39 | 58 | 24 | 17 | 2.6 | 0.01 | 0.15 | 1.09 | 0.002 |
| 5 | ABH05 | 24 | 5.9 | 17 | 24 | 0.8 | 0 | 80 | 13 | 52 | 48 | 18 | 10 | 1.2 | 1 | 0.17 | 0.9 | 0.001 |
| 6 | ABH06 | 25 | 5.8 | 12 | 36 | 0.9 | 0 | 94 | 8 | 30 | 83 | 19 | 23 | 2 | 0.07 | 0 | 2.9 | 0 |
| 7 | ABH07 | 23 | 6.1 | 41.5 | 40 | 0.5 | 0.7 | 149 | 8 | 32 | 53 | 25 | 4 | 3 | 0.02 | 0.08 | 1 | 0.003 |
| 8 | ABH08 | 27 | 6 | 43 | 20 | 1.2 | 0 | 67 | 9 | 25 | 47 | 45 | 8 | 1.4 | 0.01 | 0.05 | 1 | 0.004 |
| 9 | ABH09 | 27 | 5.8 | 60 | 12 | 0.6 | 0 | 82 | 10 | 180 | 60 | 51 | 12 | 1 | 0.05 | 0.1 | 0 | 0 |
| 10 | ABH10 | 26 | 5.5 | 33 | 25 | 0.4 | 0 | 60 | 4 | 184 | 45 | 56 | 14 | 0.8 | 0.03 | 0 | 0 | 0.006 |
| 11 | NBH01 | 26 | 7.5 | 108.4 | 82.3 | 0.18 | 0.06 | 70.5 | 4.2 | 6 | 6.2 | 4.4 | 12 | 5 | 0.08 | 0 | 0 | 0 |
| 12 | NBH02 | 27 | 4.5 | 92.5 | 17.9 | 0.17 | 0.08 | 68.2 | 14.5 | 7 | 4.78 | 2.8 | 8 | 2 | 1.2 | 0.1 | 0.06 | 0 |
| 13 | NBH03 | 25 | 6.2 | 35.2 | 15.6 | 1.2 | 0.8 | 39 | 2.83 | 3 | 4.2 | 0.83 | 12 | 3 | 0.28 | 0.09 | 0.03 | 0 |
| 14 | NBH04 | 26 | 5.1 | 87.5 | 11.75 | 2.1 | 1.2 | 38 | 5.4 | 2 | 9.63 | 1.7 | 24 | 7 | 0.12 | 0.12 | 0.07 | 0.05 |
| 15 | NBH05 | 28 | 7.3 | 30.5 | 62.8 | 1 | 1.3 | 42 | 4.27 | 4 | 1.72 | 0.73 | 6 | 5 | 0.13 | 0.08 | 0.06 | 0 |
| 16 | NBH06 | 28 | 6.3 | 89.3 | 65 | 0.15 | 1.1 | 48 | 2.8 | 2 | 10.31 | 5.8 | 23 | 1 | 0.02 | 0.04 | 0 | 0.03 |
| 17 | NBH07 | 25 | 4.7 | 64.1 | 21.78 | 0.04 | 0.2 | 18.3 | 23 | 1 | 11.91 | 1.3 | 5.2 | 2 | 0.24 | 0.09 | 0 | 0 |
| 18 | NBH08 | 28 | 4.2 | 50 | 10.5 | 0.08 | 0.8 | 28 | 13 | 2 | 8 | 0.83 | 0.46 | 3 | 0.19 | 0.03 | 0.04 | 0 |
| 19 | NBH09 | 27 | 7.3 | 66 | 10.2 | 0.03 | 0.03 | 20.15 | 10 | 5 | 17 | 0.72 | 12 | 0.93 | 0.32 | 0.06 | 0.03 | 0.02 |
| 20 | NBH10 | 26 | 6.9 | 38 | 28.8 | 0.04 | 0.08 | 25.73 | 35 | 2 | 4 | 1.1 | 1.4 | 0.62 | 0.1 | 0.1 | 0.06 | 0.03 |

**Table 3** Hydrogeochemical classifications of the groundwater samples

| Metropolis | Groundwater type | Sample in water type | | | Characteristic groundwater facies dominating metropolis |
|---|---|---|---|---|---|
| | | Number of samples | Sample identity | Percentage (%) | |
| Awka | 1. Ca–Mg–Cl | 4 | ABH01, ABH04, ABH06, ABH07 | 40 | 1. Alkaline earth-chloride/sulfate[a] (50%) |
| | 2. Mg–Ca–$HCO_3$ | 3 | ABH02, ABH09, ABH10 | 30 | 2. Alkaline earth-bicarbonate (30%) |
| | 3. Mg–Ca–Cl–$HCO_3$ | 1 | ABH03 | 10 | 3. Alkaline earth-chloride/sulfate[a]-bicarbonate (20%) |
| | 4. Ca–Mg–Cl–$HCO_3$ | 1 | ABH05 | 10 | |
| | 5. Mg–Ca–Cl | 1 | ABH07 | 10 | |
| Nnewi | 1. Na–Mg–Cl | 1 | NBH01 | 10 | 1. Alkali-alkaline earth-chloride/sulfate[a] (30%) |
| | 2. Na–Cl | 3 | NBH02, NBH03, NBH05 | 30 | 2. Alkali-chloride/sulfate[a] (30%) |
| | 3. Na–Ca–Cl | 1 | NBH04 | 10 | 3. Alkaline earth-alkali-chloride/sulfate[a] (20%) |
| | 4. Na–Ca–Mg–Cl | 1 | NBH06 | 10 | 4. Alkaline earth-chloride/sulfate[a] (20%) |
| | 5. Ca–Na–Cl–$SO_4$ | 1 | NBH07 | 10 | |
| | 6. Ca–Cl–$SO_4$ | 1 | NBH08 | 10 | |
| | 7. Ca–Na–Cl | 1 | NBH09 | 10 | |
| | 8. Ca–$SO_4$–Cl | 1 | NBH10 | 10 | |

[a]"Chloride/sulfate" as used in the table represents the anion class "strong acids, (Cl + $SO_4$)"

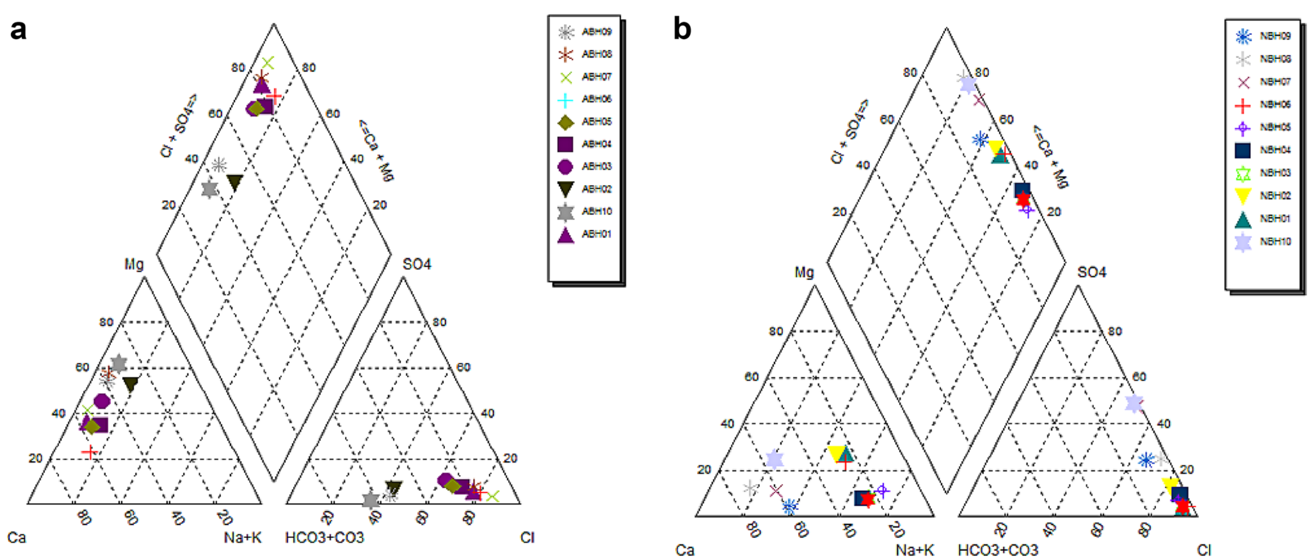


**Fig. 2** Piper trilinear diagrams for: **a** Awka metropolis. **b** Nnewi metropolis

that the Awka samples concentrated in the field marked by simple dissolution or mixing (Lloyd and Heathcote 1985; Onwuka et al. 2018). On the other hand, Nnewi samples plotted in two fields: simple dissolution or mixing field and revised ion-exchange field (Fig. 3b) (Lloyd and Heathcote 1985; Onwuka et al. 2018).

Sodium absorption ratio (SAR) and salinity of water are usually functions of its chemistry. These also determine water quality, and can easily be assessed by plotting a Wilcox diagram. This diagram (Fig. 4) was used in assessing the sodium and salinity hazards of the water samples. The results (Fig. 4a, b) show that sodium and salinity hazards of all the water from the two metropolises are low. It was observed that most of the samples did not appear on the diagram. This could mean that SAR of the samples was very insignificant, and hence could not appear.

Moreover, to ascertain the rock–water equilibrium of the groundwaters, it was necessary to plot the ionic values of the samples in Giggenbach triangles. The triangles modeled for the two metropolises show that all the samples plotted at the base of the triangles, suggesting that they are immature groundwaters (Fig. 5). This implies that the waters had not

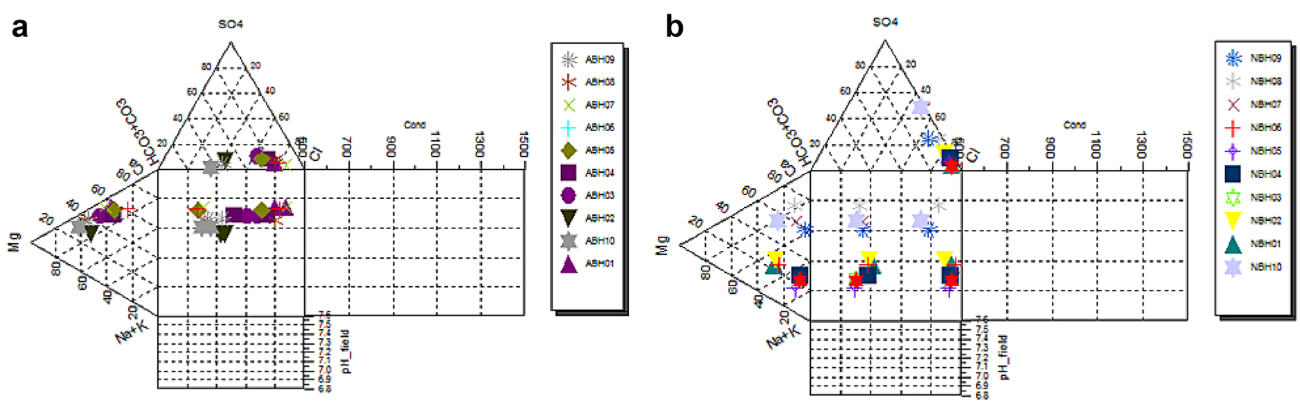


**Fig. 3** Durov diagrams showing hydrogeochemical processes/trends for: **a** Awka metropolis. **b** Nnewi metropolis

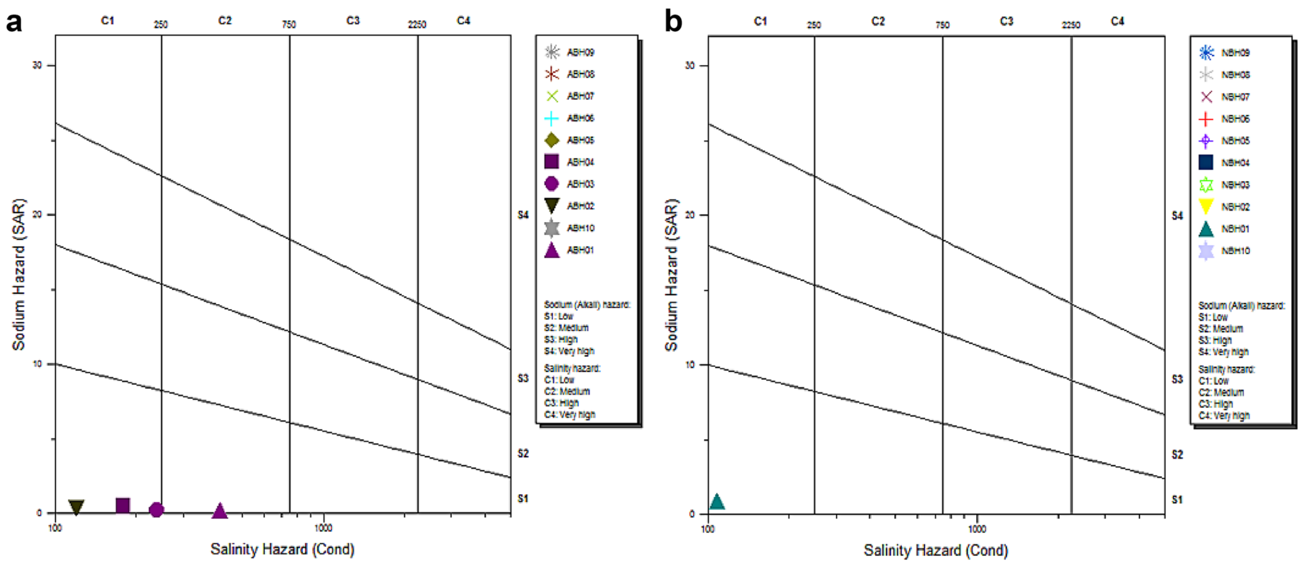


**Fig. 4** Wilcox diagrams showing sodium and salinity hazard statuses: **a** Awka metropolis. **b** Nnewi metropolis

had long time interaction with their respective aquifers (having short residence time) when the samples were collected. This also correlates well with the physicochemical values obtained.

It was also necessary to examine the water–environment interactions that give the waters their characteristic chemistry and quality. Gibbs (1970) diagram helps to establish the relationship between water chemistry and various hydrologic processes and lithology of an aquifer. Figure 6 presents Gibbs diagrams for Awka metropolis while Fig. 7 presents Gibbs diagrams for Nnewi metropolis. Dominance due to evaporation, rock–water interaction (or weathering), and precipitation are the three distinct fields of the Gibbs diagrams. The results show that the hydrogeochemical arrangement of the groundwaters in Awka metropolis is majorly controlled by weathering (which involves leaching) and precipitation, whereas that of Nnewi metropolis is majorly controlled by precipitation.

Figure 8 presents the heavy metal distributions in the two metropolises. In the Awka metropolis, it was observed that the dominating heavy metal is lead (Pb) while iron (Fe) is the dominant heavy metal in the Nnewi metropolis. The presence of Pb, Cu, and Cd in the samples could be attributed to industrial wastes such as automobiles, batteries, and paints, etc. Iron in water can be linked to oxidation of metal wastes in the dumpsites or oxidation of ferromagnesian minerals contained in the underlying lithologies. Moreover, the relatively high concentrations of these heavy metals in some samples are in line with similar reports of Srivastava and Ramanathan (2008), Singh et al. (2008), Momoh et al. (2013), Agu et al. (2014), and Onunkwo et al. (2014).

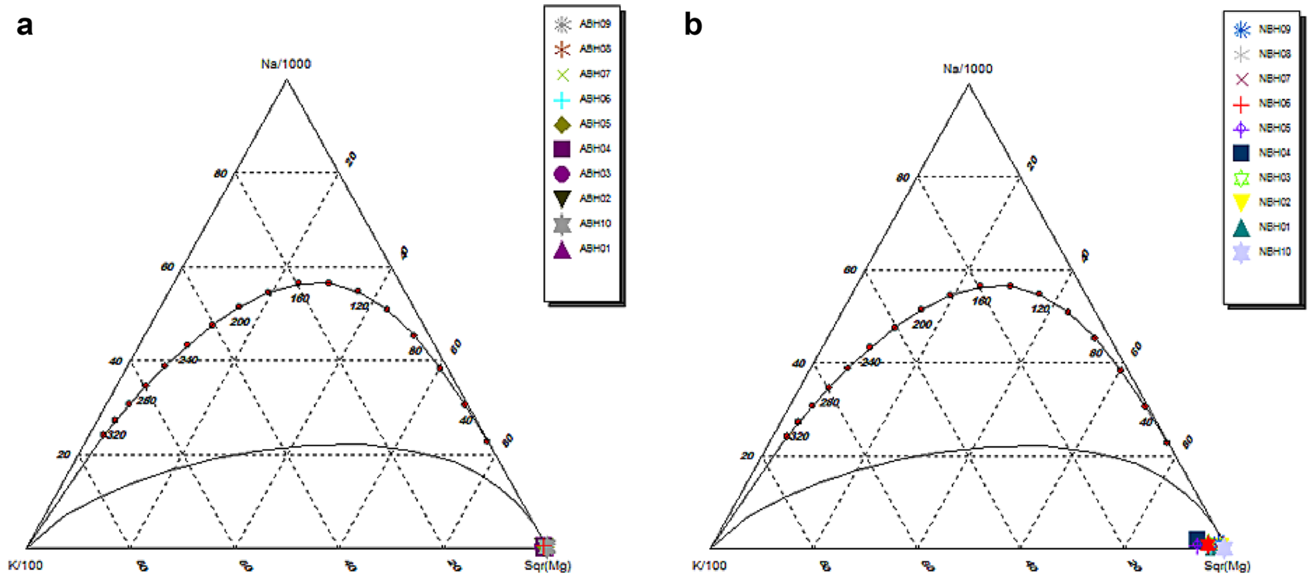


**Fig. 5** Giggenbach triangles showing rock–water equilibrium of samples: **a** Awka metropolis. **b** Nnewi metropolis

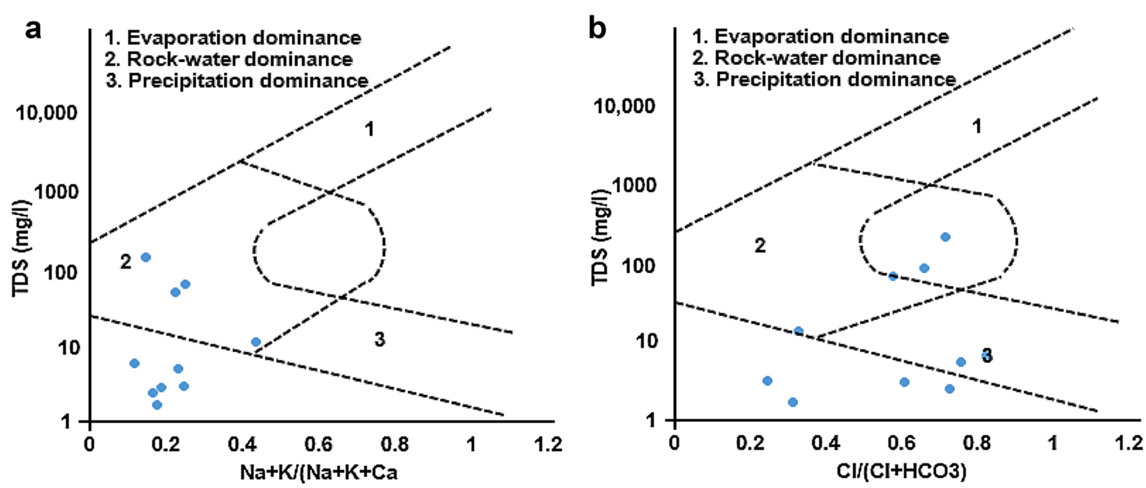


**Fig. 6** Gibbs weight ratios plotted against TDS, Awka: **a** cations vs TDS. **b** Anions vs TDS

## Pearson's correlation analysis

The strength of the relationships between all the parameters for Awka and Nnewi metropolises is shown in Tables 4 and 5, respectively. Significant positive associations exist between the following pairs in the Awka metropolis: pH/Cl, pH/$SO_4$, TDS/EC, EC/$PO_4$, EC/K, EC/Cd, TDS/$NO_3$, TDS/$PO_4$, TDS/K, $NO_3$/$PO_4$, $PO_4$/K, Cl/Ca, $SO_4$/Cu, $HCO_3$/Mg, Ca/Na, Na/Pb, and Fe/Cu (Table 4). From the analysis, TDS appears to greatly influence the EC of the waters. $NO_3$, $PO_4$, and K seem to be the main contributors of the groundwater TDS. This also indicates that the three ions have high mobility (Mor et al. 2006). The strong acids ($Cl + SO_4$) influence the pH of the groundwaters. For the Nnewi metropolis, no significant positive relationship exists between sulfate, calcium, and other parameters (Table 5). However, significant positive correlations exist between the following pairs: pH/TDS, EC/Cl, EC/Mg, EC/Na, TDS/Cl, TDS/Mg, $NO_3$/$PO_4$, $NO_3$/Na, $NO_3$/K, $NO_3$/Cu, $PO_4$/K, Cl/$HCO_3$, Cl/Mg, $HCO_3$/Fe, Mg/Na, Na/Cd, and Cu/Pb. The pH seems to be influenced by TDS, which is, in turn, influenced by Cl and Mg. In this metropolis, Cl and Mg seem to have the highest mobility (Mor et al. 2006). $NO_3$ showed significant correlation with Cu, indicating some anthropogenic source. The EC appears to be influenced more by Cl, Mg, and Na. No significant correlation was recorded between TDS and EC.

Generally, the significant positive correlations ($\geq 0.5$) occurring between some cations, anions, and heavy metals

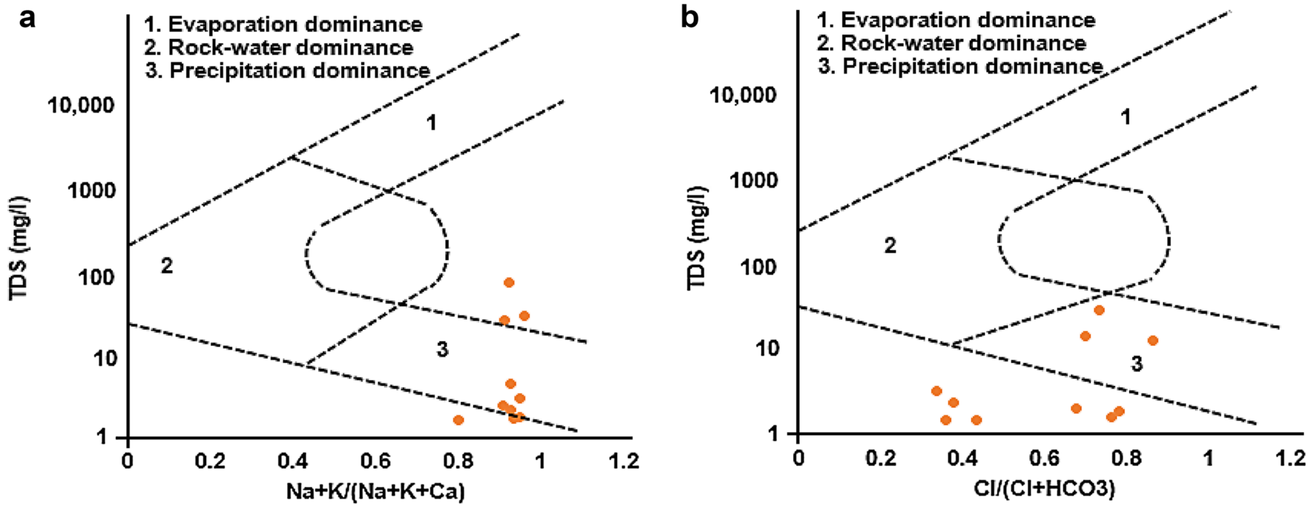


**Fig. 7** Gibbs weight ratios plotted against TDS, Nnewi: **a** cations vs TDS. **b** Anions vs TDS

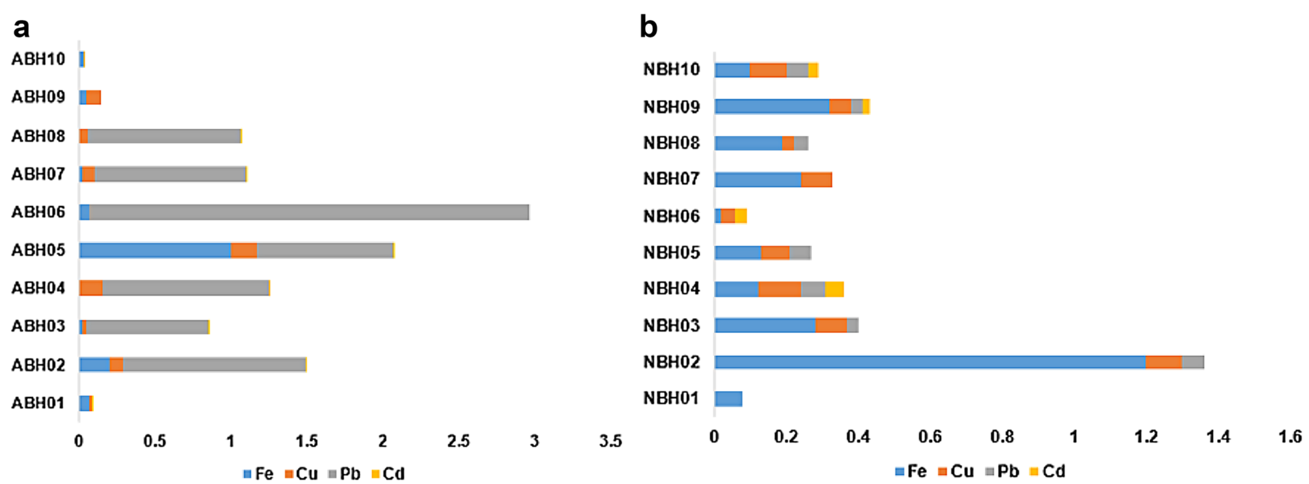


**Fig. 8** Heavy metal distribution in: **a** Awka metropolis. **b** Nnewi metropolis

suggest that they were leached into the groundwaters from same source. Weak correlations ($\leq 0.5$) between some variables might be linked to variations in their sources of origin and or geochemical behavior of parameters. For the two metropolises, no significant positive correlation exists between temperature and other parameters. This suggests that temperature has no significant influence on the occurrence of all other parameters measured. It was observed that the pairing patterns are not the same for the two metropolises. However, similar patterns exist between $NO_3/PO_4$, and $PO_4/K$ in the two metropolises.

## Principal component analysis

In addition to the Pearson correlation analysis, principal component factor analysis (PCA) was used to identify the most significant hydrogeochemical parameters (components), their interrelationships, and the variability existing between them (Singh et al. 2008; Tiwari et al. 2017). This analysis is very important in groundwater quality management as it helps to relate the distribution of various parameters to different possible sources, which have different chemical signatures. In this study, 17 variables (parameters), for each of the ten groundwater samples representing each metropolis, were used for the PCA. Their communalities were extracted at initial of 1.00 and six principal components were extracted for both metropolises (Table 6). The six components signify six possible different factor loadings indicating that six different contributions seem to be involved in determining the chemical composition of groundwater in the vicinity of the landfills in Awka and Nnewi (Singh et al. 2008). The total sample component variances for the Awka

**Table 4** Pearson correlation coefficient matrix of analyzed quality parameters for Awka metropolis

| | Temp | pH | EC | TDS | $NO_3$ | $PO_4$ | Cl | $SO_4$ | $HCO_3$ | Ca | Mg | Na | K | Fe | Cu | Pb | Cd |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Temp | 1.000 | | | | | | | | | | | | | | | | |
| pH | −0.265 | 1.000 | | | | | | | | | | | | | | | |
| EC | 0.092 | −0.754 | 1.000 | | | | | | | | | | | | | | |
| TDS | −0.094 | −0.545 | **0.909** | 1.000 | | | | | | | | | | | | | |
| $NO_3$ | 0.027 | 0.169 | 0.389 | **0.623** | 1.000 | | | | | | | | | | | | |
| $PO_4$ | −0.217 | −0.208 | **0.731** | **0.893** | **0.707** | 1.000 | | | | | | | | | | | |
| Cl | −0.629 | **0.527** | −0.358 | −0.250 | −0.169 | 0.045 | 1.000 | | | | | | | | | | |
| $SO_4$ | −0.334 | **0.505** | −0.079 | 0.016 | 0.461 | 0.120 | 0.093 | 1.000 | | | | | | | | | |
| $HCO_3$ | 0.381 | −0.066 | −0.316 | −0.490 | −0.359 | −0.462 | −0.183 | −0.308 | 1.000 | | | | | | | | |
| Ca | −0.096 | 0.082 | −0.086 | −0.076 | −0.001 | −0.103 | **0.531** | −0.055 | −0.086 | 1.000 | | | | | | | |
| Mg | 0.481 | 0.056 | −0.299 | −0.524 | −0.298 | −0.465 | −0.016 | −0.389 | **0.737** | 0.151 | 1.000 | | | | | | |
| Na | 0.234 | 0.126 | −0.294 | −0.143 | 0.193 | −0.248 | −0.014 | −0.098 | 0.161 | **0.635** | 0.089 | 1.000 | | | | | |
| K | −0.342 | −0.252 | **0.642** | **0.796** | 0.392 | **0.824** | 0.065 | 0.052 | −0.659 | −0.220 | −0.725 | −0.369 | 1.000 | | | | |
| Fe | −0.298 | 0.110 | −0.252 | −0.254 | −0.202 | −0.320 | −0.039 | 0.469 | −0.081 | −0.112 | −0.331 | −0.057 | −0.298 | 1.000 | | | |
| Cu | −0.071 | 0.475 | −0.179 | −0.084 | 0.331 | 0.152 | 0.122 | **0.661** | −0.067 | −0.159 | −0.243 | −0.103 | −0.074 | **0.589** | 1.000 | | |
| Pb | −0.241 | 0.402 | −0.367 | −0.090 | 0.115 | −0.120 | 0.223 | 0.171 | −0.531 | 0.292 | −0.539 | **0.513** | 0.191 | 0.036 | −0.076 | 1.000 | |
| Cd | 0.181 | −0.619 | **0.538** | 0.475 | −0.030 | 0.328 | −0.594 | −0.438 | −0.070 | −0.732 | −0.147 | −0.537 | 0.465 | −0.232 | −0.360 | −0.331 | 1.000 |

Correlation is significant at 0.05 level (two-two-tailed); Significant positive values (≥ 0.5000) are in bold

**Table 5** Pearson correlation coefficient matrix of analyzed quality parameters for Nnewi metropolis

| | Temp | pH | EC | TDS | $NO_3$ | $PO_4$ | Cl | $SO_4$ | $HCO_3$ | Ca | Mg | Na | K | Fe | Cu | Pb | Cd |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Temp | 1.000 | | | | | | | | | | | | | | | | |
| pH | 0.037 | 1.000 | | | | | | | | | | | | | | | |
| EC | 0.007 | −0.111 | 1.000 | | | | | | | | | | | | | | |
| TDS | 0.251 | **0.593** | 0.295 | 1.000 | | | | | | | | | | | | | |
| $NO_3$ | −0.212 | −0.051 | −0.086 | −0.153 | 1.000 | | | | | | | | | | | | |
| $PO_4$ | 0.382 | −0.086 | −0.239 | 0.133 | **0.669** | 1.000 | | | | | | | | | | | |
| Cl | 0.147 | 0.101 | **0.616** | **0.561** | 0.053 | −0.025 | 1.000 | | | | | | | | | | |
| $SO_4$ | −0.272 | −0.184 | −0.287 | −0.333 | −0.468 | −0.566 | −0.448 | 1.000 | | | | | | | | | |
| $HCO_3$ | 0.169 | 0.282 | 0.403 | 0.229 | −0.170 | −0.418 | **0.698** | −0.281 | 1.000 | | | | | | | | |
| Ca | −0.019 | −0.087 | 0.331 | −0.322 | −0.227 | −0.235 | −0.461 | −0.025 | −0.163 | 1.000 | | | | | | | |
| Mg | 0.213 | 0.122 | **0.759** | **0.663** | −0.220 | 0.016 | **0.662** | −0.335 | 0.201 | 0.044 | 1.000 | | | | | | |
| Na | −0.008 | 0.117 | **0.563** | 0.182 | **0.520** | 0.419 | 0.282 | −0.634 | −0.020 | 0.326 | **0.552** | 1.000 | | | | | |
| K | −0.081 | −0.026 | 0.183 | 0.182 | **0.774** | **0.506** | 0.316 | −0.520 | 0.063 | −0.279 | −0.055 | 0.323 | 1.000 | | | | |
| Fe | 0.020 | −0.437 | 0.218 | −0.375 | −0.167 | −0.395 | 0.383 | 0.114 | **0.621** | −0.116 | −0.045 | −0.184 | −0.211 | 1.000 | | | |
| Cu | −0.368 | −0.295 | −0.325 | −0.572 | **0.507** | 0.128 | −0.293 | 0.339 | −0.227 | −0.147 | −0.486 | 0.042 | 0.056 | 0.322 | 1.000 | | |
| Pb | 0.172 | −0.152 | −0.343 | −0.427 | 0.487 | 0.236 | −0.047 | 0.186 | 0.100 | −0.407 | −0.525 | −0.150 | 0.288 | 0.307 | **0.649** | 1.000 | |
| Cd | 0.010 | 0.081 | 0.203 | −0.145 | 0.401 | 0.261 | −0.218 | 0.063 | −0.369 | 0.320 | 0.150 | **0.618** | 0.095 | −0.336 | 0.351 | 0.297 | 1.000 |

Correlation is significant at 0.05 level (two-tailed); Significant positive values (≥ 0.5000) are in bold

**Table 6** Communalities and principal components' loadings affecting the quality of the groundwaters in Awka and Nnewi metropolises

| Quality parameter | Communality extraction (initial at 1.000) | | Components for Awka (initial eigenvalue = 1) | | | | | | Components for Nnewi (initial eigenvalue = 1) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Awka | Nnewi | 1 | 2 | 3 | 4 | 5 | 6 | 1 | 2 | 3 | 4 | 5 | 6 |
| Temp | 0.810 | 0.975 | −0.119 | *−0.624* | 0.050 | *0.572* | −0.212 | −0.178 | 0.285 | 0.005 | 0.052 | −0.272 | *−0.819* | 0.382 |
| pH | 0.995 | 0.808 | *−0.520* | *0.642* | −0.122 | 0.064 | 0.200 | *−0.504* | 0.357 | −0.034 | −0.202 | −0.461 | 0.463 | 0.460 |
| EC | 0.974 | 0.921 | *0.876* | −0.238 | 0.094 | 0.157 | 0.107 | 0.324 | *0.708* | −0.070 | 0.036 | *0.640* | 0.043 | −0.029 |
| TDS | 0.992 | 0.906 | *0.947* | 0.041 | 0.182 | 0.185 | 0.038 | 0.156 | *0.784* | −0.057 | −0.088 | −0.469 | 0.190 | 0.158 |
| $NO_3$ | 0.948 | 0.991 | *0.506* | 0.389 | 0.094 | *0.682* | 0.113 | −0.233 | −0.068 | *0.945* | 0.208 | 0.042 | 0.185 | −0.124 |
| $PO_4$ | 0.963 | 0.953 | *0.863* | 0.226 | 0.102 | 0.175 | 0.350 | −0.051 | 0.094 | *0.821* | −0.078 | −0.319 | −0.395 | −0.079 |
| Cl | 0.972 | 0.954 | −0.286 | *0.558* | 0.289 | −0.433 | *0.552* | 0.053 | *0.765* | −0.022 | *0.596* | 0.062 | 0.088 | 0.034 |
| $SO_4$ | 0.816 | 0.809 | 0.013 | *0.718* | −0.441 | 0.320 | 0.033 | 0.039 | *−0.655* | −0.486 | −0.087 | 0.077 | 0.206 | 0.298 |
| $HCO_3$ | 0.778 | 0.819 | *−0.545* | *−0.601* | −0.142 | 0.210 | 0.232 | 0.037 | 0.462 | −0.331 | *0.673* | 0.102 | 0.083 | 0.161 |
| Ca | 0.978 | 0.781 | −0.326 | 0.284 | *0.746* | 0.118 | 0.162 | 0.441 | −0.011 | −0.137 | *−0.625* | *0.574* | −0.182 | −0.089 |
| Mg | 0.957 | 0.838 | *−0.584* | *−0.612* | 0.086 | 0.193 | 0.434 | −0.087 | *0.855* | −0.093 | −0.149 | 0.235 | −0.046 | 0.135 |
| Na | 0.923 | 0.943 | −0.392 | 0.144 | *0.627* | 0.464 | −0.362 | 0.096 | *0.535* | *0.607* | −0.236 | 0.473 | 0.043 | 0.083 |
| K | 0.956 | 0.799 | *0.887* | 0.260 | 0.124 | −0.247 | 0.035 | −0.157 | 0.244 | *0.713* | 0.297 | −0.122 | 0.176 | −0.311 |
| Fe | 0.968 | 0.954 | −0.241 | 0.368 | *−0.615* | −0.042 | −0.345 | *0.525* | −0.103 | −0.343 | *0.758* | 0.466 | −0.185 | 0.001 |
| Cu | 0.859 | 0.860 | −0.087 | *0.540* | *−0.606* | 0.406 | 0.144 | 0.084 | *−0.663* | 0.407 | 0.288 | 0.315 | 0.196 | 0.187 |
| Pb | 0.996 | 0.955 | −0.103 | *0.607* | 0.429 | −0.141 | *−0.579* | −0.280 | −0.491 | 0.433 | *0.573* | −0.016 | −0.108 | 0.433 |
| Cd | 0.975 | 0.966 | *0.654* | *−0.585* | −0.251 | −0.243 | −0.189 | −0.220 | −0.055 | *0.557* | −0.396 | 0.426 | 0.065 | *0.557* |
| | Total | | 5.219 | 3.933 | 2.341 | 1.793 | 1.450 | 1.123 | 4.337 | *3.608* | 2.617 | 2.161 | 1.327 | 1.183 |
| | % Variance | | 30.701 | 23.135 | 13.769 | 10.531 | 8.531 | 6.603 | 25.511 | 21.223 | 15.392 | 12.713 | 7.808 | *6.958* |
| | Cumulative % | | 30.701 | 53.836 | 67.605 | 78.151 | 86.682 | 93.286 | 25.511 | 46.733 | 62.125 | 74.839 | 82.647 | 89.605 |

Significant component loadings are in italics and Nnewi metropolises were, respectively, explained at 93.286% and 89.605%. The number of significant principal components for interpretation was selected with minimum eigenvalue of > 1 (Table 6). Component (factor) loadings of < ± 0.5 show poor loadings, ± 0.5 signifies moderate loadings, and > ± 0.5 indicates high loadings. It is also pertinent to note that some parameters have more than one factor class. This could be indicating that they came from more than one source.

For the Awka metropolis, the first component (factor class) explains 30.701% of the total variance and has significant loadings for pH, EC, TDS, $NO_3$, $PO_4$, $HCO_3$, Mg, K, and Cd (Table 6), signifying that these parameters were possibly introduced into the groundwaters from leaching of domestic–commercial wastes (e.g., food and vegetable materials). The second component accounts for 23.135% of the total variability with significant loadings for temperature, pH, Cl, $SO_4$, $HCO_3$, Mg, Cu, Pb, and Cd. This group indicates sources from heavy chemical wastes, such as car batteries and paints, impacting on the groundwater quality. The chemical constituent $HCO_3$ and Mg are commonly originated from natural oxidation and weathering. The third component explains 13.769% of the total variance and has loadings for Ca, Na, Fe, and Cu, which are thought to occur as a result of geogenic processes (silicate rock weathering), except for the Cu which is attributed to landfill source (Singh et al. 2008). The fourth component's loading for temperature and $NO_3$, with 10.531% variability, is indicative of leaching from organic wastes in the municipal landfills. The fifth component (8.531%) has significant loadings for Cl and Pb, indicating industrial waste origin. The loading for pH and Fe on the sixth component (having 6.603% of the total variance) shows that the groundwater chemistry in this area is significantly controlled by the pH variation in aquifer systems (Srivastava and Ramanathan 2008).

For the Nnewi metropolis, the first component explains 25.511% of the total variability and has significant loadings for EC, TDS, Cl, $SO_4$, Mg, Na, and Cu (Table 6), indicating a mixed source/origin. Cu is diagnostic of dumpsite source. $SO_4$ could be due to the oxidation of sulfide in soils. On the other hand, Cl, Mg, and Na are linked to geogenic processes, and they in turn influence the EC and TDS (as shown in the correlation matrix). With 21.223% of the total variance, second component has significant loadings for $NO_3$, $PO_4$, Na, K, and Cd indicating sources linked to anthropogenic and geogenic sources. The third component explains 15.392% of the total variance and has loadings for Cl, $HCO_3$, Ca, Fe, and Pb. This assemblage is also indicative of mixed source. While Pb is linkable to dumpsite source, Cl, $HCO_3$, Ca, and Fe are more characteristic of geogenic origin (Onwuka et al. 2018). The fourth, fifth, and sixth components, respectively, explain 12.713, 7.808, and 6.958% of the total variability. They have significant loadings for EC and Ca, temperature, and Cd, respectively (Table 6), signifying mixed sources.

## Hierarchical cluster analysis

Cluster analysis (CA) is a statistical classification method used for discovering whether quality parameters of a sample population fall into same or different groups by making quantitative comparisons of multiple characteristics. In this study, the CA was used to cluster the hydrogeochemical variables (parameters) according to their similarities using Ward's method and squared Euclidean distance. One cluster with two sub-clusters was identified for Awka and Nnewi metropolises (Fig. 9). For the Awka metropolis, the two

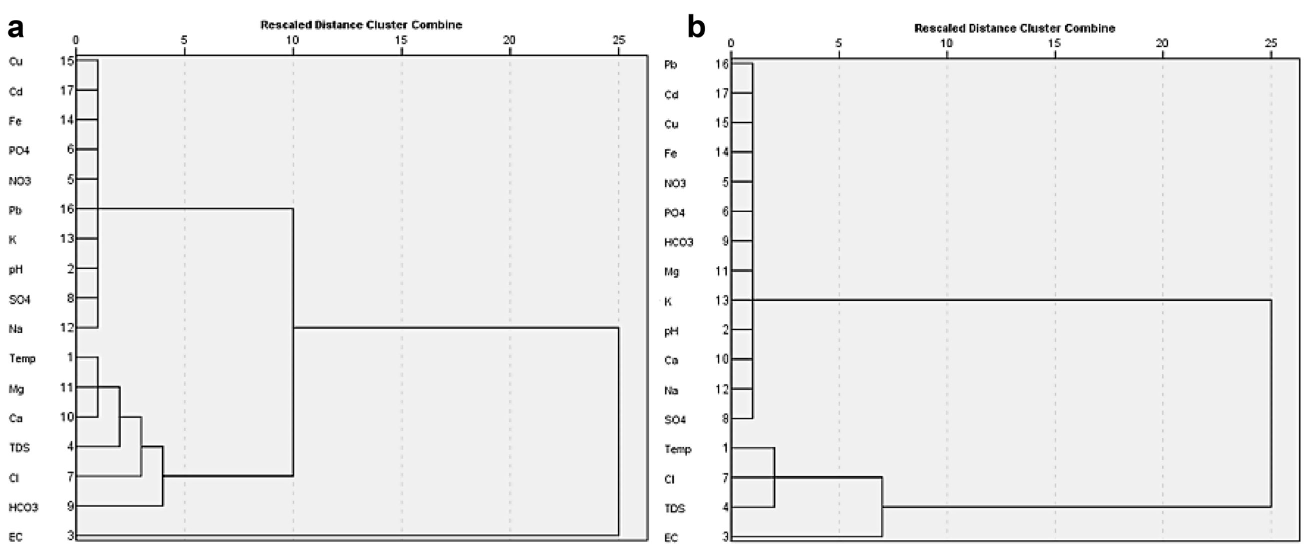


**Fig. 9** Dendrogram for cluster analysis (using Ward's linkage method; squared Euclidean): **a** Awka metropolis. **b** Nnewi metropolis

sub-clusters are Cu–Cd–Fe–$PO_4$–$NO_3$–Pb–K-pH-$SO_4$–Na and Temp-Mg–Ca-TDS-Cl–$HCO_3$-EC (Fig. 9a). The first cluster indicates a group of parameters (contaminants) indicating origin from combined landfill processes and anthropogenic activities (i.e., from heavy chemical and organic waste sources). However, the second sub-cluster indicates a group of contaminants characteristic of geogenic processes. On the other hand, the two sub-clusters identified for Nnewi metropolis are: Pb–Cd–Cu–Fe–$NO_3$–$PO_4$–$HCO_3$–Mg–K-pH-Ca–Na–$SO_4$ and Temp-Cl-TDS-EC (Fig. 9b). Similar to the first sub-cluster in Awka, the first sub-cluster linkage in Nnewi depicts a group of parameters sourced from heavy chemicals and organic wastes disposed into the dumpsites; while the second sub-cluster picturizes a group of parameters common to geogenic processes (mineral dissolution or weathering). As cited earlier, $SO_4$ has no significant Pearson correlation with other parameters in Nnewi metropolis. However, the PCA and CA successfully showed its association with other parameters, pointing out its possible source.

## Pollution index

Excess concentrations of heavy metals in water make it unfit for various purposes, especially for human consumption. Pollution index (PI) is, therefore, useful in the evaluation of the degree of trace metal contamination in water. In this study, the PIs of the groundwaters were calculated using the formula below:

**Table 7** Pollution index (PI) calculated for the water samples based on heavy metal concentrations

| Sample ID | Fe | Cu | Pb | Cd | Total PI |
|---|---|---|---|---|---|
| Awka metropolis | | | | | |
| ABH01 | 0.058 | 0.10 | 0.00 | 0.583 | 0.741 |
| ABH02 | 0.167 | 0.45 | 30.00 | 0.750 | 31.367 |
| ABH03 | 0.017 | 0.15 | 20.00 | 0.583 | 21.050 |
| ABH04 | 0.008 | 0.75 | 27.75 | 0.167 | 28.675 |
| ABH05 | 0.833 | 0.85 | 22.50 | 0.008 | 24.191 |
| ABH06 | 0.058 | 0.00 | 72.50 | 0.000 | 73.083 |
| ABH07 | 0.017 | 0.40 | 25.00 | 0.250 | 25.667 |
| ABH08 | 0.008 | 0.25 | 25.00 | 0.333 | 25.591 |
| ABH09 | 0.042 | 0.50 | 0.00 | 0.000 | 0.542 |
| ABH10 | 0.025 | 0.00 | 0.00 | 0.500 | 1.067 |
| Nnewi metropolis | | | | | |
| NBH01 | 0.069 | 0.00 | 0.00 | 0.000 | 0.069 |
| NBH02 | 1.000 | 0.50 | 1.50 | 0.000 | 3.000 |
| NBH03 | 0.233 | 0.45 | 0.75 | 0.000 | 1.433 |
| NBH04 | 0.100 | 0.60 | 1.75 | 4.167 | 6.617 |
| NBH05 | 0.108 | 0.40 | 1.50 | 0.000 | 2.008 |
| NBH06 | 0.017 | 0.20 | 0.00 | 2.500 | 2.717 |
| NBH07 | 0.200 | 0.45 | 0.00 | 0.000 | 0.650 |
| NBH08 | 0.158 | 0.15 | 1.00 | 0.000 | 1.308 |
| NBH09 | 0.267 | 0.30 | 0.75 | 1.667 | 2.984 |
| NBH10 | 0.083 | 0.50 | 1.50 | 2.500 | 4.583 |

$$PI = \text{heavy metal concentration in water} / \text{allowable limit} / \text{number of heavy metals} \quad (1)$$

In calculating the PIs, the WHO (2011) standards were used as allowable (tolerable) level for the waters (Odukoya and Abimbola 2010). Most of the samples in both metropolises have low concentrations of Fe. PIs of the individual heavy metals were first calculated for all the samples and then summed up to get total PI of each trace metal. Results (Table 7; Fig. 10) show that the Awka metropolis has higher PIs (ranging from 0.542 to 73.083) than the Nnewi metropolis (having PI range 0.069–6.617). In the Awka metropolis, Pb has the highest contamination factor; whereas in the Nnewi metropolis, Cd has the highest. High Pb concentration suggests that the wastes are mainly of municipal origin containing refuse batteries, paint products, metallic items, etc. (Kale et al. 2010; Maiti et al. 2016).

However, it is suspected that the higher PI values recorded in Awka, than in Nnewi, could be due to the following reasons (factors):

1. Volume of accumulated wastes is higher in Awka because it has higher population than Nnewi. Regions with higher population are more likely to have higher waste generation rate per capita. The higher the volume of waste, the higher the possible impact of its leachates on groundwater.
2. Wastes highly rich in Pb concentrations are more common in Awka, thereby raising its pollution index.
3. Depth to water table around dumpsites in Awka is shallower. When this is the case, the distance between pollution source, as well as travel time of contaminants, and groundwater is shortened.
4. Dumpsites in Awka being underlain by sand members with high transmissivity (a case common to Nnewi lithology) instead of mudrock members with low transmissivity, against the report of Nfor et al. (2007). It therefore means that lithologic permeability, which is often proportionate to transmissivity and enhances mobility of contaminants, is also high in Awka.
5. Dumpsites in Awka being older than those in Nnewi, since the former became urbanized before the latter. The older and active a dumpsite is, the higher is its potential to release high concentrations of leachates into aquifers.

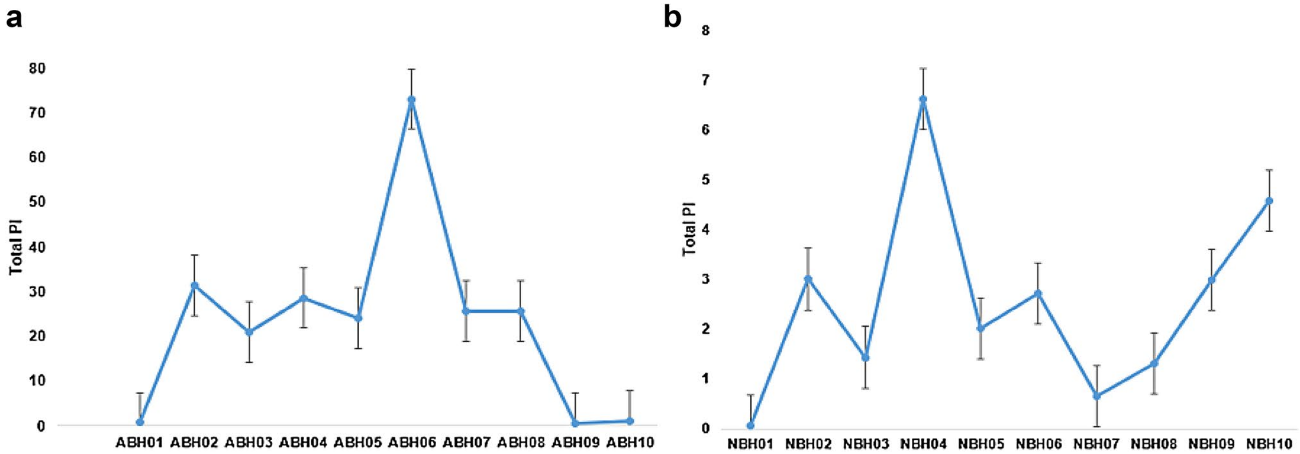


**Fig. 10** Pollution index (PI) for **a** Awka metropolis. **b** Nnewi metropolis

## Quality of the groundwaters for drinking, domestic, and industrial purposes

Quality water is very essential for the sustainability of life, public health, and environment. The usefulness of water for any particular purpose is determined by its quality (Fetter 1990). The physical and chemical characters of any water determine its quality. Table 8 shows the statistical summary of all analyzed hydrogeochemical parameters and their comparisons with water quality standards. It was observed that apart from pH values, which most are off the allowable limits of 6.5–8.5 (indicating the waters are neutral to slightly acidic), the physicochemical parameters are generally well below the maximum allowable limits of NIS (2007) and WHO (2011) (Table 8). This indicates that the waters are good for use, based on the physical properties and chemical ionic concentrations. All the water samples in the two metropolises are classified as "desirable for drinking" based on the TDS concentration (Carrol 1962; Davis and De Wiest 1966). Likewise, on the basis of EC, 90% of the samples in Awka are excellent for drinking while 10% classed as "good" for drinking. In Nnewi, 100% of the samples are "excellent" for drinking and domestic purposes, based on EC (Langenegger 1990). However,

**Table 8** Statistical summary of analyzed parameters and their comparisons with water quality standards

| Parameter measured | Awka | | | Nnewi | | | Quality standards | |
|---|---|---|---|---|---|---|---|---|
| | Range | Mean | Std. dev. | Range | Mean | Std. dev. | NIS (2007) | WHO (2011) |
| Temp (°C) | 23–27 | 25.5 | 1.4337 | 25–28 | 26.6 | 1.1738 | Ambient | – |
| pH | 4.8–6.1 | 5.7 | 0.3801 | 4.2–7.5 | 6 | 1.2719 | 6.5–8.5 | 6.5–8.5 |
| EC (µS/cm) | 12–412 | 115.8 | 128.5064 | 30.5–108.4 | 66.15 | 27.4012 | 1000 | 500 |
| TDS (mg/L) | 12–110 | 50 | 34.4642 | 10.2–82.3 | 32.66 | 26.8604 | 1000 | 600 |
| $NO_3$ (mg/L) | 0.4–4.2 | 1.28 | 1.1573 | 0.03–2.1 | 0.5 | 0.7035 | 50 | 45–50 |
| $PO_4$ (mg/L) | 0–1.2 | 0.4 | 0.4543 | 0.03–1.3 | 0.57 | 0.5254 | – | 10 |
| Cl (mg/L) | 34–149 | 76 | 30.5796 | 18.3–70.5 | 39.79 | 18.2896 | 250 | 200–250 |
| $SO_4$ (mg/L) | 4–13 | 8.8 | 2.7809 | 2.8–35 | 11.5 | 10.4967 | 100 | 200–250 |
| $HCO_3$ (mg/L) | 25–184 | 67.7 | 61.7541 | 1–7 | 3.4 | 2.0110 | – | 250 |
| Ca (mg/L) | 14–83 | 49.9 | 18.9997 | 1.72–17 | 7.76 | 4.5615 | – | 75 |
| Mg (mg/L) | 15–56 | 29.5 | 15.2188 | 0.72–5.8 | 2.02 | 1.7706 | – | 50 |
| Na (mg/L) | 4–23 | 10.9 | 5.8013 | 0.46–24 | 10.41 | 8.0510 | 200 | 200 |
| K (mg/L) | 0.8–3.2 | 2.1 | 0.9298 | 0.62–7 | 3 | 2.1063 | – | 12 |
| Fe (mg/L) | 0.01–1 | 0.148 | 0.3046 | 0.02–1.2 | 0.268 | 0.3406 | 0.3 | 0.3 |
| Cu (mg/L) | 0–0.17 | 0.069 | 0.0597 | 0–0.12 | 0.071 | 0.0376 | 0.1 | 0.05 |
| Pb (mg/L) | 0–2.9 | 0.889 | 0.8554 | 0–0.07 | 0.035 | 0.0276 | 0.01 | 0.01 |
| Cd (mg/L) | 0–0.09 | 0.004 | 0.0032 | 0–0.05 | 0.013 | 0.0183 | 0.003 | 0.003 |

on the basis of heavy metal concentrations, most of the groundwater samples are contaminated and hence unfit for drinking purposes. Several health problems (hazards) have been associated with heavy metal contaminated water. The hazards span from gastrointestinal disorder, kidney damage, cancer, nervous system problems, metabolism disorders, mental retardation, etc. (NIS 2007; WHO 2011).

Few samples (ABH05, NBH02, and NBH09) exceeded the 0.3 mg/L limit of iron in drinking water (Table 8). Fe is essential for the formation of hemoglobin in the red blood cells. However, excess of it in drinking water may lead to a disease called hemochromatosis while its deficiency causes anemia (Saba and Umar 2016). Likewise, few samples recorded Cu concentrations above the 0.05–01 mg/L limits. Though Cu is not entirely bad for health, its excessive occurrence in water may lead to copper poisoning. However, majority of the samples in the two metropolises have Pb concentrations exceeding the 0.01 mg/L limit of NIS and WHO. The excess occurrence of Pb can lead to lead poisoning and other associated ailments. Cd is a hazardous trace element which often leads to kidney failure and cancer, when consumed in excess. In this study, Cd concentrations in most of the samples exceeded the set limit (Table 8), thus, indicating that the consumers of these waters are predisposed to the health impacts associated to excess intake of Cd.

## Conclusions

This study has examined the quality of groundwaters within and around open dumpsites in Awka and Nnewi metropolises, southeastern Nigeria. The results from the two metropolises were compared. The results reveal that the quality of many of the groundwater samples has been impacted. Some of the groundwater samples in the two metropolises were contaminated with heavy metals, possibly leached from toxic wastes in the dumpsites. However, Awka metropolis has higher pollution index than Nnewi metropolis. Based on the findings presented in this paper, the groundwaters are considered unfit for drinking purposes, but could be used for other domestic and industrial purposes which do not require them being used for food processing. Nevertheless, further studies (including biological analysis) are encouraged, as this study only presents a preliminary effort to assess the impact of the poorly managed dumpsites on the quality of groundwater supply in the study area. Also, mitigation measures should be adopted, to avert the possible pollution outbreak due to poor waste disposal/management in the duo metropolises.

## Compliance with ethical standards

**Conflict of interest** The author declares there is no conflict of interest regarding this paper.

## References

Agu, K. C., Orji, M. U., Onuorah, S. C., Egurefa, S. O., Anaukwu, C. G., Okafor, U. C., et al. (2014). Influence of solid waste dumps leachate on bacteriological and heavy metals contamination of ground water in Awka. *American Journal of Life Science Research, 2*(4), 450–457.

APHA. (2005). *Standard methods for the examination of water and waste water* (21st ed.). Washington DC: American Public Health Association.

Carrol, D. (1962). Rainwater as a chemical agent of geologic processes—a review. US Geological Survey, Washington, DC. Water supply paper 1535-G, 18.

Chon, H. T., Ahn, J. S., & Jung, M. C. (1991). *Environmental contamination of toxic heavy metals in the vicinity of some Au–Ag mines in Korea* (p. 891). Truku: Proc. of the 4th Biennial SGA Meeting.

Davis, S. N., & De Wiest, R. J. M. (1966). *Hydrogeology* (Vol. 463). New York: Wiley.

Emoyan, O. O., Ogban, F. E., & Akarah, E. (2005). Evaluation of heavy metals loading of River Ijana, Nigeria. *Journal of Applied Sciences and Environmental Management, 10*(2), 121–127.

Ezeabasili, A. C. C., Okoro, B. U., & Okonkwo, A. U. (2014). Assessment of water supply quality in Awka, Anambra state, Nigeria. *STECH, 3*(3), 81–93.

Fetter, C. W. (1990). *Applied hydrogeology*. USA: Mirril Publ. Co.

Gibbs, R. J. (1970). Mechanisms controlling world water chemistry. *Science, 170,* 795–840.

Ilechukwu, I., & Okonkwo, C. (2012). Heavy metal levels and physicochemical parameters of potable water in Nnewi, Anambra state, Nigeria. *Archives of Applied Science Research, 4*(5), 2094–2097.

Kale, S. S., Kadam, A. K., Kumar, S., & Pawar, N. J. (2010). Evaluating pollution potential of leachate from landfill site, from the Pune metropolitan city and its impact on shallow basaltic aquifers. *Environmental Monitoring and Assessment, 162,* 327–346.

Kim, K. W., Lee, H. K., & Yoo, B. C. (1998). The environmental impact of gold mines in the Yugu-Kwangcheon Au–Ag metallogenic province, Republic of Korea. *Environmental Technology, 19,* 291.

Langenegger, O. (1990). Groundwater quality in rural areas of western Africa, UNDP project INT/81/026:10.

Lloyd, J. A., & Heathcote, J. A. (1985). *Natural inorganic hydrochemistry in relation to groundwater: An introduction* (p. 296). New York: Oxford University Press.

Maiti, S. K., De, S., Hazra, T., Debsarkar, A., & Dutta, A. (2016). Characterization of leachate and its impact on surface and groundwater quality of a closed dumpsite—a case study of Dhapa, Kolkata, India. *Procedia Environmental Sciences, 35,* 391–399.

Momoh, S. O., Mgbemena, C. O., Agbadua, S. A., & Matthew, D. O. (2013). The physicochemical effect of leachates on ground water within Okpuno-Egbu Umudim Dumpsite Nnewi, Anambra state Nigeria. *DIU Journal of Science and Technology, 8*(2), 25–32.

Mor, S., Ravindra, K., Dahiya, R. P., & Chandra, A. (2006). Leachate characterization and assessment of groundwater pollution near municipal solid waste landfill site. *Environmental Monitoring and Assessment, 118,* 435–456.

Nfor, B. N., Olobaniyi, S. B., & Ogala, J. E. (2007). Extent and distribution of groundwater resources in parts of Anambra state, Southeastern Nigeria. *Journal of Applied Sciences and Environmental Management, 11*(2), 215–221.

NIS. (2007). Nigerian standard for drinking water quality. *Nigerian Industrial Standard, 554,* 13–14.

Nishida, H., Miyai, M., Tada, F., & Suzuki, S. (1982). Computation of the index of pollution caused by heavy metals in river sediment. *Environmental Pollution (Series B), 4,* 241.

Odukoya, A. M., & Abimbola, A. F. (2010). Contamination assessment of surface and groundwater within and around two dumpsites. *International Journal of Environmental Science and Technology, 7*(2), 367–376.

Okoro, B. U., Ezeabasili, A. C. C., & Dominic, C. M. U. (2014). Quality assessment of traditional hand dug wells in Awka, Anambra state, Nigeria. *GJEDT, 3*(3), 34–38.

Okoye, N. M., Orakwe, L. C., & Nwachukwu, P. C. (2016). Groundwater quality mapping using GIS: A case study of Awka, Anambra state, Nigeria. *IJEMR, 6*(2), 579–584.

Onunkwo, A. A., Nwagbara, J. O., & Ahiarakwem, C. A. (2014). Assessment of heavy metals in Nnewi under ground water. *International Journal of Engineering Research and Development, 10*(11), 1–5.

Onwuka, O.S., Ezugwu, C.K., & Ifediegwu, S.I. (2018). Assessment of the impact of onsite sanitary sewage system and agricultural wastes on groundwater quality in Ikem and its environs, southeastern Nigeria. Geology Ecology and Landscapes. https://doi.org/10.1080/24749508.2018.1493635.

Onyido, A. E., Nwangwu, U. C., Aribodor, D. N., Umeanaeto, P. U., Ugha, C. N., Ugwu, F. M., et al. (2014). Bacterial pathogens associated with wild-caught houseflies in Awka metropolis of Anambra state, Southeastern Nigeria. *New York Science Journal, 7*(12), 1–8.

Piper, A. M. (1944). A graphical procedure in the geochemical interpretation of water analysis. *Eos Transactions American Geophysical Union, 25,* 914–928.

Saba, N., & Umar, R. (2016). Hydrogeochemical assessment of Moradabad city, an important industrial town of Uttar Pradesh, India. *Sustainable Water Resources Management, 2,* 217–236.

Singh, U. K., Kumar, M., Chauhan, R., Jha, P. K., Ramanathan, A. L., & Subramanian, V. (2008). Assessment of the impact of landfill on groundwater quality: A case study of the Pirana site in western India. *Environmental Monitoring and Assessment, 141,* 309–321.

Srivastava, S. K., & Ramanathan, A. L. (2008). Geochemical assessment of groundwater quality in vicinity of Bhalswa landfill, Delhi, India, using graphical and multivariate statistical methods. *Environmental Geology, 53,* 1509–1528.

Tiwari, A. K., Singh, A. K., Singh, A. K., & Singh, M. P. (2017). Hydrogeochemical analysis and evaluation of surface water quality of Pratapgarh district, Uttar Pradesh, India. *Applied Water Science, 7,* 1609–1623.

WHO. (2011). *Guidelines for drinking water quality* (3rd ed.). Geneva: World Health Organization.

Ziraba, A. K., Haregu, T. N., & Mberu, B. (2016). A review and framework for understanding the potential impact of poor solid waste management on health in developing countries. *Archives of Public Health, 74,* 55. https://doi.org/10.1186/s13690-016-0166-4.