Geologically, the study area lies within the so-called Ilesha Schist Belts Complex of southwest Nigeria, characterized by gneiss-migmatite complex, the metasedimentary assemblages, the amphibolite complex and the granitic rocks units (Elueze 1982). The rock units in Ilesha urban centre include muscovite schist and quartzite schist, while the peri-urban areas are characterized by granite-gneiss, hornblende gneiss and biotite-schist (Fig. 1). Hydrogeologically, the groundwater occurrences are in localized weathered regolith aquifers, which are generally discontinuous and essentially under phreatic unconfined to semi-confined conditions, as in the case of most crystalline bedrock settings in Nigeria (Tijani 1994).

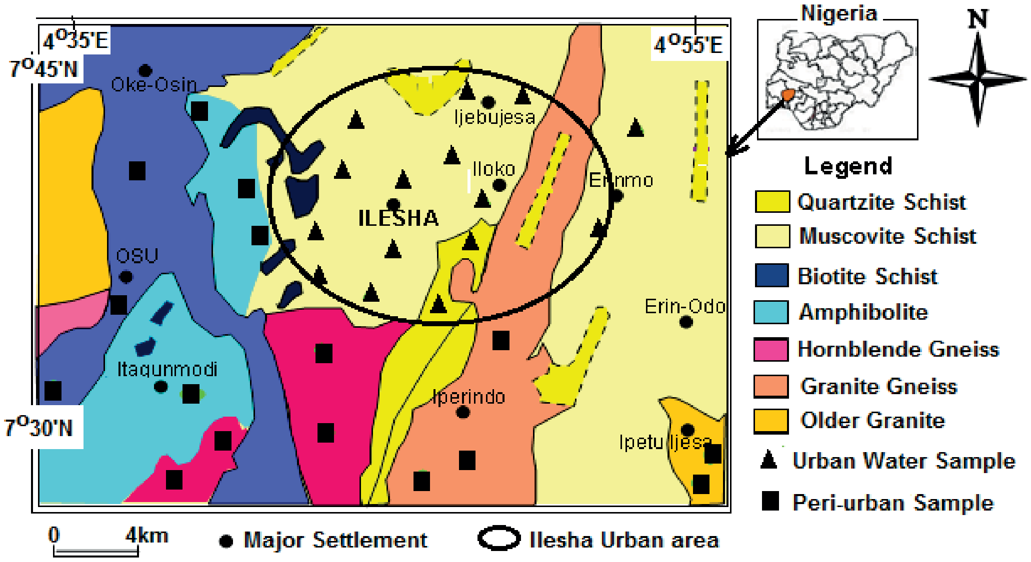

Fig. 1 Geological map of the Ilesha area showing sampling points.

METHODOLOGY

A total of 21 representative water samples were collected from shallow hand-dug wells following standard procedures; including 10 samples from the urban area of Ilesha and 11 samples from the surrounding peri-urban areas. The sampling was done across the different rock types of the study area. In addition to the well inventories (e.g. well depth, water level, etc.), sensitive physico-chemical parameters such as electrical conductivity (EC), pH, temperature and total dissolves solids (TDS) were measured *in situ* in the field.

Laboratory analyses include measurements of cations using inductive couple plasma mass spectrometers (ICP/MS), while anions were measured using titrimetric methods. Subsequent data evaluation involved quality assessment with respect to drinking water standards, as well as statistical evaluation involving correlation and hydrochemical characterization using Piper (1944) trilinear plots and Schoeller (1962) diagrams.

RESULTS AND ANALYSIS

Field measurements and hydrochemical analyses

The inventory of the study shallow-dug wells revealed a depth range of 3.6–13.8 m (average 9.0 m) and water level depth of 1.4–11.3 m characterized by small water columns typical of dug-wells in basement terrain. The field *in situ* measurements revealed EC of 22–825 µs/cm (average 212 µs/cm) and pH 6.4–8.4 (average 7.3) suggesting a neutral to slight alkaline waters for the Ilesha urban areas compared to moderately high EC of 126–1027 µs/cm (average 504 µs/cm) and pH of 7.3–10.5 (average 8.2) for the peri-urban areas suggesting moderately alkaline water.

Major cations concentrations are in the order of Ca>Na>K>Mg with average values of 28.4, 16.7, 8.4 and 5.0 mg/L, respectively, for the urban areas and 82.5, 33.0, 19.3 and 12.4 mg/L,

Table 1 Summary of well inventory and hydrochemical analyses results of water samples from the study area.

Parameters	Ilesha Urban Area (N=10)			Peri-urban Area (N=11)			WHO &SON Standards
	Min.	Max.	Mean	Min.	Max.	Mean	
Well Depth (m)	4.5	11.3	8.4	1.4	11.0	6.6	
DTWL (m)	6.4	11.8	9.6	3.6	13.8	8.4	
Temp. (°C)	26.2	28.7	27.5	26.6	29.9	28.4	Variable
pH	6.4	8.4	7.3	7.3	10.5	8.2	6.5–9.5
EC (μS/cm)	22.0	825.0	212.3	126.0	1027.0	503.5	400–1400
TDS (mg/L)	16.5	618.8	159.2	94.5	770.3	377.7	300–1000
TH (mg/L$CaCO_3$)	3.0	90.2	23.1	11.6	135.8	54.9	<500.0
SAR (meq/L)	0.2	2.1	0.8	0.3	1.7	0.9	
Ca^{2+} (mg/L)	2.7	117.8	28.4	16.9	250.8	82.5	75–200
Mg^{2+} (mg/L)	0.9	17.8	5.0	1.6	21.8	12.4	20–150
Na^{+} (mg/L)	2.4	72.4	16.7	4.4	86.6	33.0	20–200
K^{+} (mg/L)	1.8	32.6	8.4	1.8	49.3	19.3	10–12
HCO_3^{-}(mg/L)	12.2	91.5	33.6	18.7	112.0	60.0	Variable
Cl^{-}(mg/L)	3.1	64.8	18.9	18.0	86.4	39.0	600
NO_3^{-} (mg/L)	0.0	1.2	0.4	0.0	0.7	0.3	50
SO_4^{-2} (mg/L)	0.0	1.7	0.9	0.0	2.9	1.1	400
Cd (μg/L)	0.3	6.1	2.3	0.1	2.5	0.9	3.0
Co (μg/L)	0.1	5.6	1.5	0.0	3.3	0.6	
Cr (μg/L)	0.5	16.4	3.0	0.8	10.8	2.8	50
Cu (μg/L)	1.8	8.6	4.3	0.9	9.3	3.3	200
Ni (μg/L)	2.1	15.0	8.5	1.3	19.0	4.5	20
Pb (μg/L)	1.7	4.8	3.1	0.9	4.4	2.2	10
Zn (μg/L)	26.2	245.4	95.9	12.2	792.8	149.8	300

WHO (1993) – Guidelines for drinking water quality; SON (2007) – Standard Organization of Nigeria; Drinking water quality standards; DTWL = depth to water level; SAR = Sodium adsorption ratio.

respectively, for the peri-urban areas (Table 1). Bicarbonate and chloride are the dominant anions with average concentrations of 33.6 and 18.9 mg/L, respectively, for the urban areas and 60.0 and 39.0 mg/L, respectively, for the peri-urban areas, while other anions like NO_3 and SO_4 are generally less than 2 mg/L in both settings.

The concentrations of trace metals (Cd, Co, Cr, Cu, Ni and Pb) are generally low, with values of less than 10 μg/L in both urban and peri-urban areas. However, with the exception of Zn, the trace metal profiles exhibit slight enrichment with average values of 1.5–8.5 μg/L for the water samples from the urban setting, suggesting anthropogenic impacts, compared to average values of 0.6–4.5 μg/L for the peri-urban areas.

Further evaluation of the results revealed lower concentrations of the cations and anions in the urban areas with corresponding TDS of 16.5–619 mg/L compared to the relatively higher TDS of 94.5–770 mg/L for the peri-urban areas. These can be partly attributed to the slightly alkaline to moderately alkaline pH of groundwater from the peri-urban areas while the lower mineralization of the major ions in the urban areas can be attributed to low mineral dissolution of quartzite and muscovite quartz-schist bedrocks to weathering compared to the weathered granitic, amphibolite and biotite schist units in the peri-urban areas.

Furthermore, a plot of the major ions against the measured electrical conductivity (EC) also confirmed a relatively lower mineralization of the water from the urban areas compared to those of the peri-urban while the linear relationship as shown in Fig. 2 is a clear indication of the contribution of these ions to the overall total dissolved solids of the groundwater system.

Quality and usability assessments

The concentrations of the analysed major ions are within the recommended permissible level of both WHO and SON standards for drinking water. For the trace elements, with the exception of

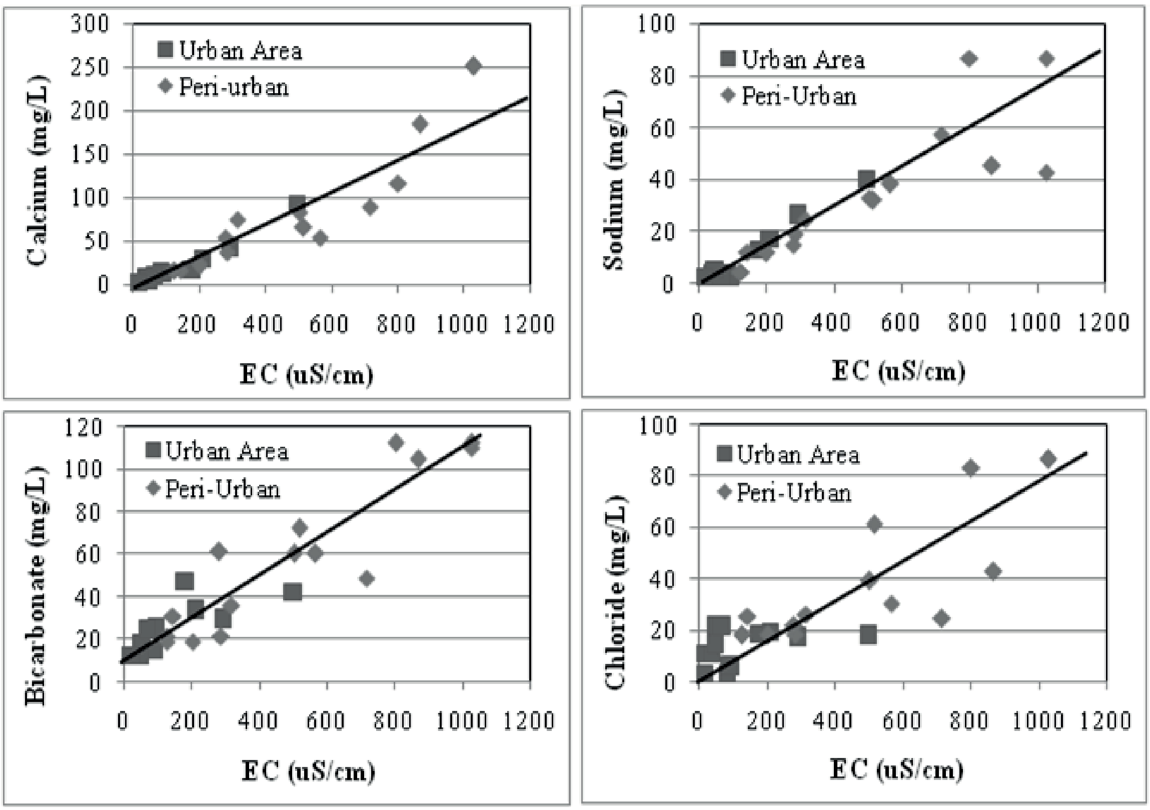

Fig. 2 Cross plots of the major ions against electrical conductivity measurements.

Zn, all the analysed trace metals are within the permissible levels of WHO and SON. The overall implication is that the shallow groundwater system in the study area can be said to be chemically potable and suitable for domestic and household uses. However, the microbiological quality cannot be said to be totally satisfactory, due to the observed proximity of some dug-wells to pit latrines and septic tanks in some households, especially in the urban areas.

In terms of agricultural usage, the estimated sodium absorption ratio (SAR) of 0.31–2.1 meq/L falls within the range of 0–10 meq/L recommended for irrigation on most agricultural soils (USDA 1954, Sawyer and McCarthy 1967). In addition, the salinity hazard as well as the electrical conductivity (EC) and total dissolved solids (TDS) of the analysed groundwater satisfied the criteria for good irrigation water.

Groundwater characterization

The concept of hydrochemical facies was developed in order to understand and identify the hydrochemical evolution of water types using dominant ions in groundwater system (Freeze and Cherry 1979, Domenico and Schwartz 1990). Using Piper and Schoeller plots (Figs 3 and 4) shallow groundwater in the study area revealed two main water types; namely Ca-Mg-(Na)-HCO_3 type mostly in the urban areas and Ca-Na-(K)-SO_4-Cl type with subordinate Na-HCO_3 type in the peri-urban areas.

Ca-Mg-(Na)-HCO_3 water type is a reflection of CO_2-charged infiltrating recharge rainwater characterized by low mineralization due to limited migratory history, while Ca-Na-(K)-SO_4-Cl and Na-HCO_3 water types are products of water–rock interactions and cation-exchange process within the weathered bedrock units of the peri-urban, which are characterized by varied weathered bedrock units. This agrees with other previous studies (Tijani 1994, Tijani and Abimbola 2003, Elueze *et al.* 2004) and it is believed to be common of water types in the basement aquifer of southwestern Nigeria.

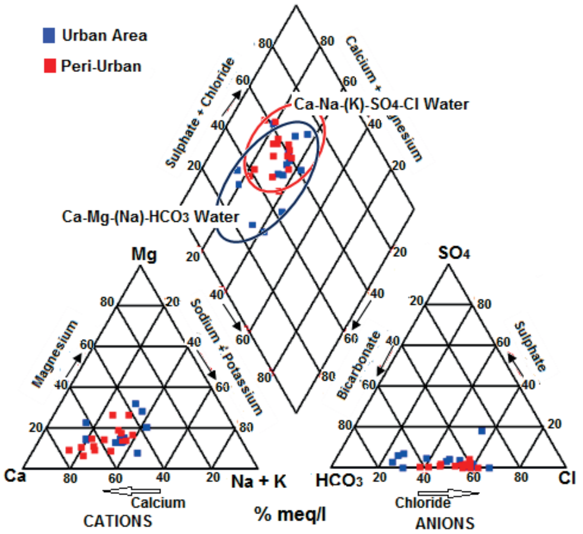

Fig. 3 Piper plots of water samples from the study area.

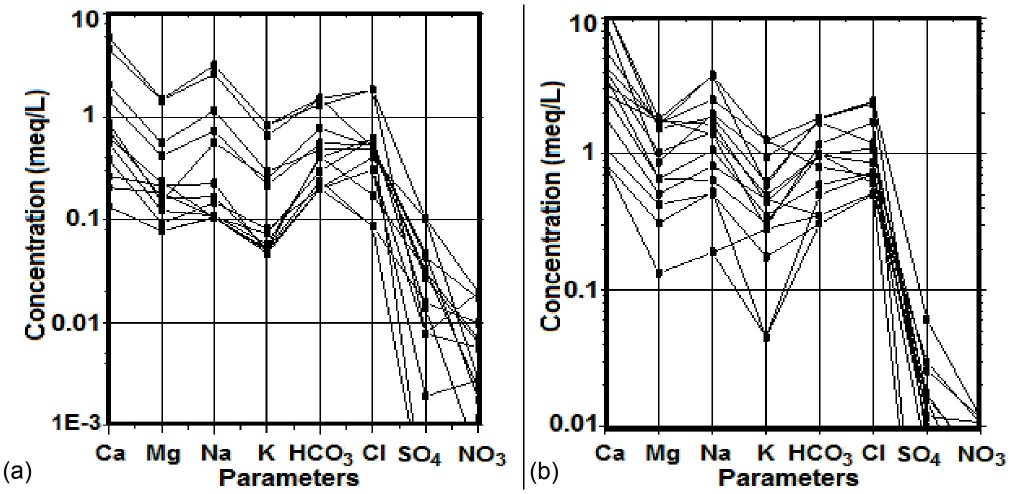

Fig. 4 Schoeller diagram for samples from urban (a) and peri-urban areas (b).

SUMMARY AND CONCLUSIONS

The concentrations of major ions and trace metals in the shallow groundwater system of Ilesha area, southwest Nigeria were evaluated and discussed with respect to anthropogenic and geogenic impacts in a typical weathered crystalline basement terrain. The physico-chemical parameters revealed slight to moderate alkaline waters in the peri-urban area, unlike the neutral to slight alkaline waters of the urban areas. Generally, the EC and TDS in the peri-urban areas are moderately higher compared to the urban areas, a situation attributed to the low weathering potential of the muscovite schist and quartzite schist in the urban areas of Ilesha compared to the relatively weathered biotite schist, amphibolite and granites that characterize the peri-urban areas.

Major cation concentrations are in the order of Ca>Na>K>Mg with average values of 28.4, 16.7, 8.4 and 5.0 mg/L, respectively, for the urban areas and 82.5, 33.0, 19.3 and 12.4 mg/L, respectively, for the peri-urban areas. Bicarbonate and chloride are the dominant anions with average concentrations of 33.6 and 18.9 mg/L, respectively, for the urban areas and 60.0 and 39.0 mg/L, respectively, for the peri-urban areas. Trace metals (Cd, Co, Cr, Cu, Ni and Pb) are generally low, with values of less than 10 µg/L, with the exception of Zn, which can be attributed to zinc-coated roofs. Nonetheless, slight enrichment with average values of 1.5–8.5 µg/L for the water samples from the urban setting is an indication of anthropogenic impacts, compared to average values of 0.6–4.5 µg/L for the peri-urban areas.

In terms of usability, the analysed major ions and trace metals are within the recommended permissible level of both WHO and SON standards for drinking water, suggesting a chemically potable shallow groundwater system suitable for domestic and household uses. In addition, the estimated sodium absorption ratio (SAR) of 0.31–2.1 meq/L falls within the range of 0–10 meq/L recommended for irrigation on most agricultural soils. Nonetheless, a follow-up microbiological analysis is recommended to assess possible contamination of the dug-wells that are in close proximity of pit latrines and septic tanks in some households, as observed during the field sampling operation.

Water characterization revealed geogenic controls on the water chemistry with Ca-Mg-(Na)-HCO_3 water type in urban areas suggesting CO_2-charged infiltrating rain water characterized by low mineralization and Ca-Na-(K)-SO_4-Cl and Na-HCO_3 water types as products of water–rock interactions and cation-exchange process within the weathered bedrock units of the peri-urban, which are characterized by varied weathered bedrock units.

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