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SPATIAL AND TEMPORAL VARIATIONS OF GROUNDWATER QUALITY IN ABEOKUTA CITY, NIGERIA

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ABSTRACT

The quest for safe drinking-water is very high in the ongoing period of environmental pollution. Generally, anthropogenic activities resulting from increasing population and urbanization are major sources of pollution to groundwater. This paper assesses the variation in groundwater distribution in Abeokuta city, Ogun State, Nigeria to determine the water quality status. Secondary groundwater quality data across a period of fifteen years (2001 – 2015) were retrieved from the database of the Department of Water Resources Management and Agro-meteorology, Federal University of Agriculture, Abeokuta, Nigeria to establish the status and examine the spatial and temporal variation. The data was subjected to statistical and geo-statistical analysis. Results showed that temperature, pH and electrical conductivity have a dominant range of 28.0 – 29.9 ºC, 7.01 – 7.50 and 201 – 600 µS/cm, respectively. The major cations Ca^{2+}, Mg^{2+}, Na^{+} and K^{+} have respective dominant concentration range from below detection limit (bdl) – 80mg/L, bdl – 30mg/L, 11 – 20 mg/L and bdl – 10 mg/L, while the major anions Cl^{-}, HCO_3^{-}, NO_3^{-} and SO_4^{2-} have respective dominant concentration range of 11 – 30, 101 – 200, 1.60 – 4.00 and bdl – 10 mg/L. High (> 1000 µS/cm) conductivity values are detected in parts of the city, which may be due to high concentrations of magnesium, calcium, potassium, chloride and bicarbonate. Only few parts (5.7%) of the city have poor water quality status, while groundwater quality in about 45.7% and 48.6 % of the city may be classified as good and excellent water quality, respectively. The spatial trend showed that groundwater in the core townships of Abeokuta such as Itoku and the environs should not be encouraged for direct consumption without prior treatment. But generally, the groundwater in most part of Abeokuta metropolis is safe for domestic use, though requires some form of household treatment before drinking.

Keywords: Abeokuta city, Drinking-water, Groundwater, Spatial and temporal trend, Water quality.

INTRODUCTION

The quantity of water delivered and used in households is an important aspect of domestic water supply as it influences hygiene and sanitation and therefore, public health. Without water, life cannot be sustained beyond a few days and the lack of access to adequate water leads to the spread of many infections such as the diarrheal diseases (WHO, 2003). One of the ways through which most communities and households have tried to provide solutions to drinking water challenges is by tapping groundwater through the construction of shallow hand-dug wells, which are commonly prone to contaminations due to the mode of construction and hygiene practices.

Groundwater, as one of earth's most vital renewable and widely distributed resources, is an important source of water supply throughout the world. The quality of groundwater, including its quantity, is a vital concern for mankind since it is directly linked with human welfare (Balakrishnan *et al.,* 2011). In comparison with surface water, groundwater is believed to be relatively clean and free from pollution owing to the fact that groundwater contamination can be traced to the processes involved in groundwater occurrence and recharge. Nevertheless, groundwater can be contaminated naturally or by numerous types of human activities; domestic, commercial, industrial, and agricultural activities all of which can affect the water quality (USEPA, 1993; Rivers *et al.*,1996; Pacheco and Cabrera, 1997; Goulding, 2000; Kim *et al.*, 2004; Jalali, 2005; Srinivasamoorthy *et al.*,2009; Balakrishnan *et al.,* 2011). Contamination of groundwater can result in poor drinking water quality, loss of water supply, high clean-up costs, high costs for alternative water supplies, and potential health problems.

The yearly increase in Abeokuta's human population and urbanization encourages consequent rise in the construction of onsite sanitary facilities in close proximities to water wells. Untreated household and industrial wastes are often discharged into drainage channels and water courses. Water wells are eventually recharged by polluted surface water bodies and contaminated through seepage from sanitary facilities.

In recent times, the use of Geographical Information Systems (GIS) technology has simplified the assessment of the environment and natural resources. In groundwater studies, GIS is commonly used for site suitability analyses, managing site inventory data, estimation of groundwater vulnerability to contamination, groundwater flow modeling, modeling of solute transport and leaching, and integrating groundwater quality assessment models with spatial data to create spatial decision support systems (Engel and Navulur, 1999). Babiker *et al.* (2007) proposed a GIS-based groundwater quality index method known as geo-statistics, which synthesizes different available water quality data such as Cl, Na and Ca by indexing them numerically relative to the WHO standards.

This study assessed groundwater quality status of Abeokuta city, Ogun State, Nigeria and environs over a fifteen year period (2001 – 2015), using statistical and geo-statistical methods to determine the spatial and temporal trend in the study area.

Study Area

The study area is Abeokuta metropolis, the capital city of Ogun State. The city is located in the Sub-Humid Tropical Region of Southwestern Nigeria, with a boundary covering the entire Abeokuta South and parts of Abeokuta North, Obafemi Owode and Odeda Local Government Areas of Ogun State (Figure 1). It lies between Latitudes 7º 5' N to 7º 20' N and Longitudes 3º 17' E to 3º 27' E (Figure 1). Abeokuta covers a geographical land area of 879 square kilometers and has human population of about 451,607 with an annual growth rate of 3.03% as at 2006 census (NPC, 2010). The population is project-

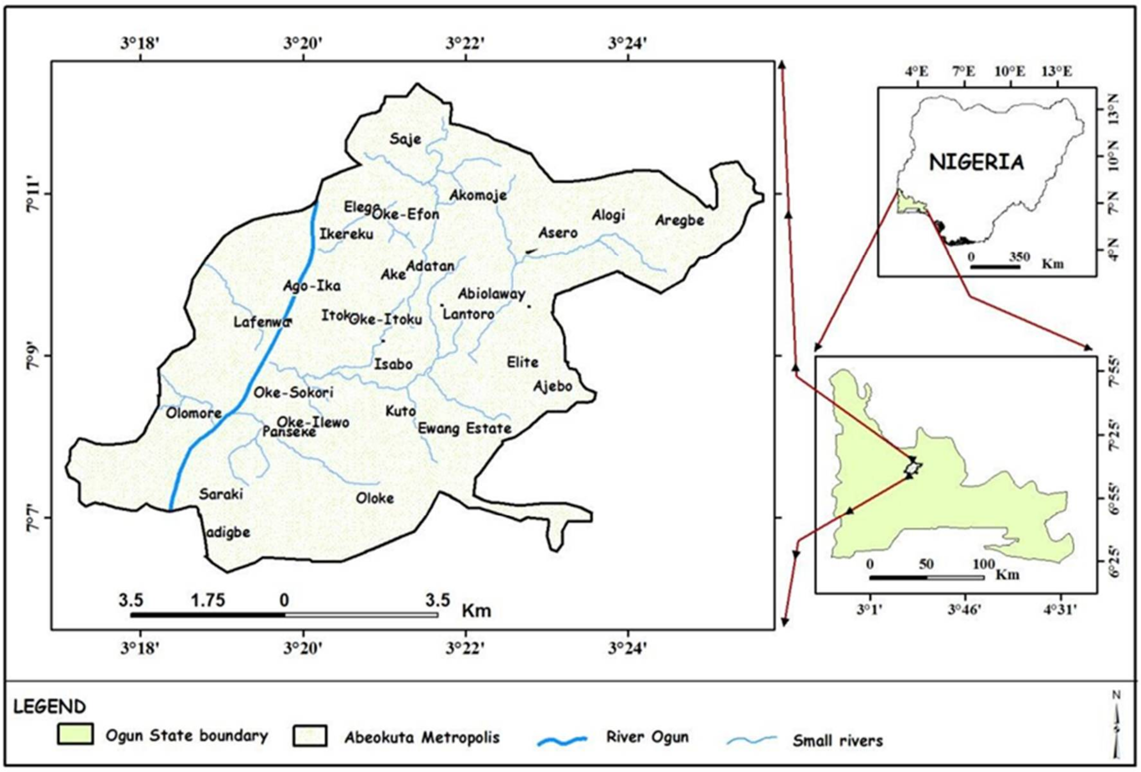

Figure 1: Map of Ogun State, Nigeria showing Abeokuta city

As shown in Figure 1, the Abeokuta environment has one major river (River Ogun), which passes through and divides the city into two parts to form a dendritic drainage pattern. On the outskirts upstream of the river is another major river, which discharges its flow into the River Ogun at Oyan and takes its name from this point. Streams and rivulets and annual and perennial streams in the neighborhood of this river empty their water or flow into this river both upstream and downstream with eroded materials. River Ogun acts as collecting basin for all the rivulets and streams in Abeokuta. The rivulets and streams are distributed on both sides of Ogun River, takes their source from flow areas of high altitude and flow through to discharge their flow into Ogun River. The rivulets and streams takes their names from flow path such as Sokori, Arakanga, Olomore, Imala, Magbon, Adigbe and Asero streams, among others (Orebiyi *et al.*, 2010).

Abeokuta is composed of granite and associated metamorphic rocks of the basement complex. The city is characterized by an undulating topography with elevation ranging from 100 to 400m above mean sea level. The topography is rugged with distinctly pronounced domed and boulder strewn hills. These hills are developed over the basement complex with summits ranging between 300m to 600m above mean sea level. Popularly known among these hills is "Olumo" rock (Orebiyi, 2009). Olumo rock is a major tourist attraction in the city.

Abeokuta experiences two major types of climatic seasons, the hot and dry season

(November to March, with harmattan in December to January) and warm and wet season (April to October).

The rainfall is bimodal with peaks in July and September. The onset of the rain varies from late March to April. The length of dry period is about 130 days, while the wet season is about 200 days in length finishing around late October. The rain is orographic and can sometimes be with heavy showers. The rain of the second modal is small showers and frontal (Orebiyi, 2009). The annual rainfall is approximately 1408 mm (Akinyemi *et al.*, 2011). Eighty percent of the annual rainfall (1160 mm) falls during the South West monsoon (April - October) and the remaining twenty percent (250 mm) falls during the North East monsoon (November-March). The air is very humid throughout the year, with monthly average temperatures ranging from 28°C in July/ August to 32°C in February/March (Orebiyi, 2009). The estimated mean annual potential evaporation is 1100 mm (Moroof and Gabriel, 2014).

Large part of Abeokuta has been deforested to give way to various human activities such as schools, banks, public institutions and agencies. Only small pockets of the ancient forests exist, mainly scattered forest reserves and those found along river valleys. The forests consist of tall trees, middle layer trees and lower trees as well as sparse layer of undergrowth made up of herbs (Orebiyi, 2009).

MATERIALS AND METHODS

Data collection and simplification

The research involved the use of secondary data extracted from archive. The available annual groundwater quality data in Abeokuta over a period of fifteen years (2001 - 2015) were retrieved. The data was sourced from the database of the Department of Water Resources Management and Agricultural Meteorology in the Federal University of Agriculture, Abeokuta (FUNAAB). The Department was established in 1988 and had since been the repository of research-driven and water-related data, particularly, for the study area. Sensitivity test was conducted on the secondary data to check for consistency. The data was later subjected to statistical analysis such as descriptive statistics. Other forms of analysis include Water Quality Indexing (WQI) and spatial distribution analysis, including piper's plot, which was used to determine the major ions contributing to dissolved contents in the groundwater.

For data simplification, the delineated map of the study area was divided into grids (cells) of 1000m by 1000m (Figure 2). The gridded map was then overlaid on Google Earth and the areas that fall within each of the cells were identified and documented. The average of the values for each of the selected water quality parameters in the areas that fall in each of the cells was computed and used as the mean annual concentration values for each of the cells. The mean annual concentration values were also used to plot a piper diagram and compute WQI scores for each of the cells. The WQI scores and the respective co-ordinates (latitude and longitude) were incorporated into the interphase of ArcMap 10.1 to generate the groundwater quality status map. The outcome of this process is a map showing the spatial spread of the degree of groundwater contamination in Abeokuta metropolis. Groundwater suitability for, particularly, domestic uses in the study area was deduced from the spatial map.

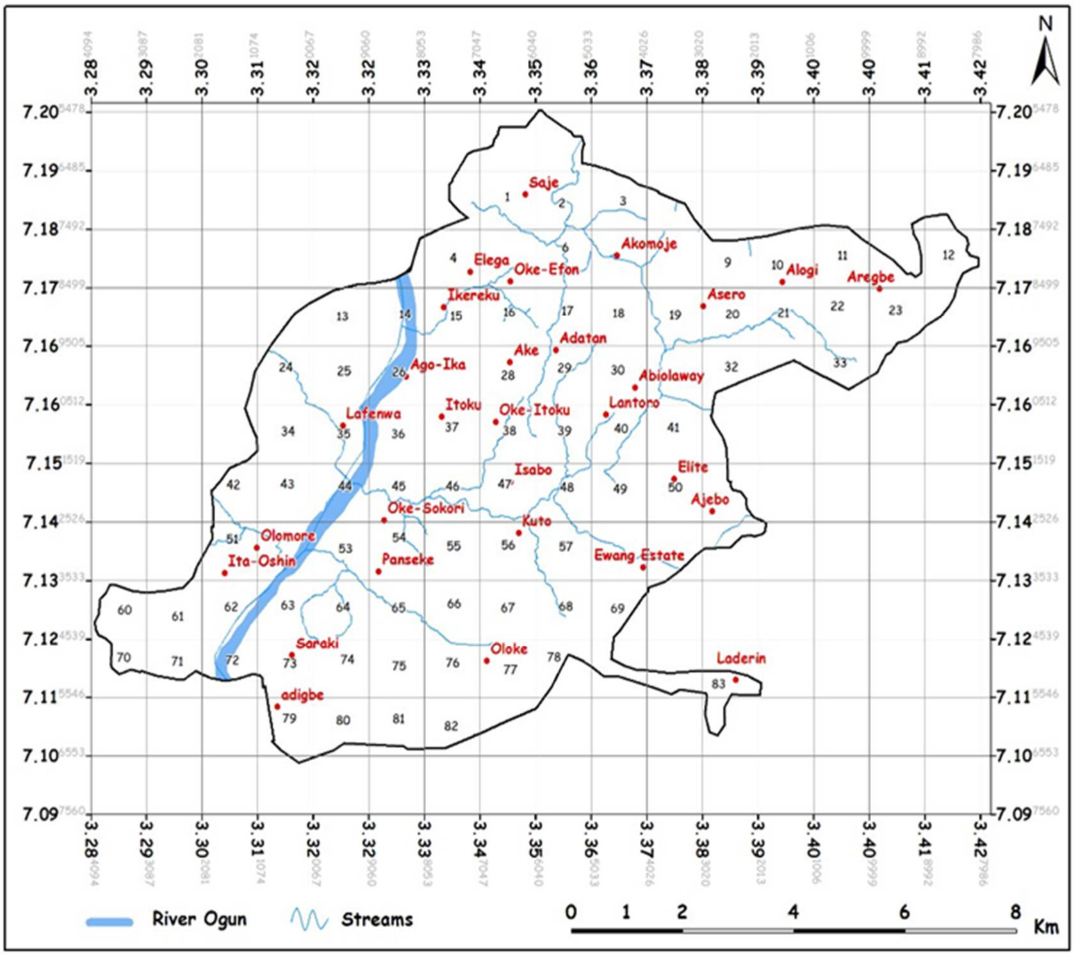

Figure 2: Gridded map of Abeokuta city, Nigeria

Water Quality Index (WQI) Analysis

WQI analysis was used to determine the groundwater quality status. The WQI as described by Allaa *et al.* (2012) was calculated using the standards of drinking-water quality recommended by the World Health Organization (WHO, 2011; 2017).

The weighted arithmetic index method (equation 1), which required aggregating the quality rating (q_n) and unit weight (W_n) as shown in equations 2 and 3 respectively, was used to compute the WQI scores for each of the selected cells.

$$WQI = \frac{\sum q_n W_n}{\sum W_n} \quad (1)$$

The quality rating (q_n) is given as:

$$q_n = \frac{(V_n - V_{io})}{(S_n - V_n)} \times 100 \qquad (2)$$

Where, q_n = Quality rating for the n^{th} water quality parameter.
V_n = Estimated value of the n^{th} parameter at a given sampling point.
S_n = Standard permissible value of the n^{th} parameter.
V_{io} = Ideal value of n^{th} parameter in pure water (*i.e.* 0 for all other parameters except the parameter pH and Dissolve Oxygen (7.0 and 14.6 mg/L respectively).

The unit weight (W_n) is given as:

$$W_n = \frac{K}{S_n} \qquad (3)$$

Where, W_n = unit weight for the n^{th} parameters.
S_n = standard value for the n^{th} parameters.
K = constant for proportionality.
The water samples were then classified using the criteria in Table 1.

Table 1: Water quality index categories (Source: Allaa *et al.*, 2012)

WQI	0 – 25	26 - 50	51 – 75	76 - 100	>100
Water Quality	Excellent	Good	Poor	Very poor	Unsuitable

Ionic composition of groundwater

To classify the groundwater into types based on ionic composition and to determine the predominant ions, the cations - sodium (Na^+), potassium (K^+), magnesium (Mg^{2+}) and calcium (Ca^{2+}) and anions; sulphate (SO_4^{2-}), chloride (Cl^-), bicarbonate (HCO_3^-) and/carbonate (CO_3^{2-}) concentrations were plotted with the aid of Geochemist's Workbench 11.0 on a tri-plot or Piper Diagram. Piper Diagram is a triangular graphical representation that helps to classify water samples to types.

RESULTS AND DISCUSSION

A total of 825 number units of data with 18 usable water quality parameters were extracted from archive across the 15 years of 2001 - 2015. The parameters with their respective available number of data and description were shown in Table 2. To further explore the temporal variation of the water quality parameters, the fifteen years data was subdivided into five years interval of 2001 – 2005, 2006 – 2010 and 2011 – 2015 (Table 3).

Table 2: Descriptive statistics of selected groundwater quality parameters across 2001 - 2015 in Abeokuta, Nigeria

Parameters	N	Arithmetic Mean	Std. Deviation	Minimum	Maximum	WHO(2011; 2017) (permissible limit)
Temperature (ºC)	584	28.8	2.38	15.50	36.70	-
pH	753	7.07	0.65	4.60	9.50	6.5-8.5
EC (µS/cm) @ 25 ºC	752	608.13	387.36	25.00	2846.48	1000
TDS (mg/L)	754	329.49	237.69	12	1743	500
Ca^{2+} (mg/L)	372	54.91	55.97	0.24	354.00	200
Mg^{2+} (mg/L)	345	28.78	33.41	bdl	173.00	150
Na^{+}(mg/L)	310	47.79	85.63	0.50	552.00	200
K^{+} (mg/L)	274	17.16	18.38	bdl	140.40	<20
HCO_3^{-} (mg/L)	160	121.91	127.24	19.10	829.60	200
SO_4^{2-} (mg/L)	279	37.57	38.62	bdl	137.00	250
Cl^{-} (mg/L)	440	86.69	106.71	bdl	970.00	250
NO_3^{2-} (mg/L)	373	4.39	4.40	bdl	28.70	10
Zn^{2+} (mg/L)	216	0.1474	0.179	bdl	0.5600	1.50
Pb^{2+} (mg/L)	226	0.0645	0.08	bdl	0.3300	0.015
Cd^{2+} (mg/L)	149	0.0511	0.05	bdl	0.1460	0.002
Fe^{2+} (mg/L)	88	0.1607	0.52	bdl	3.4124	0.003
Cu^{2+} (mg/L)	191	0.0713	0.18	bdl	1.5000	1.30

NB: bdl = below detection limit; - = no maximum limit; N = number of available data unit

Table 3: Arithmetic mean of selected groundwater quality parameters within 2001 – 2005, 2006 – 2010 and 2011 - 2015 in Abeokuta, Nigeria

Parameters	Arithmetic Mean			WHO (2011; 2017) (permissible limit)
	2001-2005	2006-2010	2011-2015	
Temperature (ºC)	32.0	27.7	30.6	-
pH	6.78	7.26	6.96	6.6-8.5
EC (µS/cm) @ 25 ºC	441.72	594.25	701.59	1000
TDS (mg/L)	132.12	295.11	401.27	500
Ca^{2+} (mg/L)	24.24	44.91	88.30	200
Mg^{2+} (mg/L)	7.22	39.37	35.98	150
Na^{+}(mg/L)	92.40	79.67	22.82	200
K^{+} (mg/L)	21.34	23.34	17.55	<20
HCO_3^{-} (mg/L)	120.58	129.94	119.10	200
Cl^{-} (mg/L)	37.05	95.65	106.06	250
NO_3^{2-} (mg/L)	10.04	8.42	12.11	10
SO_4^{2-} (mg/L)	13.33	25.70	83.42	250
Zn^{2+} (mg/L)	0.1385	0.2331	0.0216	1.50
Pb^{2+} (mg/L)	-	0.0895	0.0352	0.015
Cd^{2+} (mg/L)	-	0.0770	0.0337	0.002
Fe^{2+} (mg/L)	0.0209	-	0.2141	0.003
Cu^{2+} (mg/L)	0.2984	0.0513	0.0284	1.30
E. coli (CFU/100ml)	74.21	108.90	29.26	0

NB: - = No available data

Trend and dominant range of groundwater quality parameters in Abeokuta city

Table 2 showed the mean temperature of groundwater in Abeokuta city, a value of 28.8 ºC. The value is within the optimal growth range (20°C to 45°C) for mesophilic bacteria including human pathogens (Prescott *et al.,* 1999), which implied that bacteria have the tendency to grow in the groundwater sources if not adequately monitored and maintained. The overall pH value of groundwater in the study area ranged from 4.60 – 9.50 with a mean value of 7.07 (Table 2). The computed mean pH values of 6.79, 7.26 and 6.96 for 2001 – 2005, 2006 – 2010 and 2011 – 2015, respectively (Table 3) were within the WHO (2011) recommended range of 6.5 – 8.5 for drinking water. To allow for comparison, the extracted EC values were converted to values related to temperature at 25 ºC as suggested by Oluwasanya

(2009). Result showed that the EC of groundwater in Abeokuta ranges from 25 – 2,846.48 µS/cm (Table 2). Although a mean EC value of 608.13 µS/cm was computed for the city across the fifteen years, findings showed that some places in the city have very high EC values, which may be due to the high rate of subsurface flow of foreign materials such as the intrusion of textile tie and dye chemicals into the groundwater systems (for instance, Itoku). Textile tie and dye cottage industry is one of the predominant livelihood activities in Abeokuta, Nigeria. The computed mean EC values for the period 2001 – 2005, 2006 – 2010 and 2011 – 2015 were 441.72 µS/cm, 594.25 µS/cm and 701.59 µS/cm, respectively (Table 3). The mean values are within the permissible limit of 1000 µS/cm recommended for drinking-water (WHO, 2011; 2017)

The overall concentration of calcium ion ranged from 0.24 – 354 mg/L with a mean value of 54.91 mg/L, while that of magnesium was from a value below detection limit (bdl) to 173 mg/L with a mean value of 28.78 mg/L (Table 2). The computed mean concentration of calcium ion within 2001 – 2005, 2006 – 2010 and 2011 – 2015 were 24.24 mg/L, 44.91 mg/L and 88.30 mg/L respectively, while that of magnesium were 7.22 mg/L, 39.37 mg/L and 35.98 mg/L respectively (Tables 3). The concentration of calcium and magnesium in water make up the total hardness. The mean concentration of calcium (54.91 mg/L) and magnesium (28.78 mg/L) found in the groundwater system over the fifteen years, however, indicated that groundwater in Abeokuta was moderately hard.

Sodium and potassium ions were found to have overall concentration ranges of 0.50 – 552 mg/L and bdl – 140.40 mg/L, with respective mean values of 47.79 and 17.16mg/L (Table 2) in the study area. The computed mean concentrations of the two parameters within 2001 – 2005, 2006 – 2010 and 2011 – 2015 were 92.40 mg/L, 79.67 mg/L and 22.82 mg/L, respectively for sodium, and 21.34 mg/L, 23.34 mg/L and 17.55 mg/L, respectively for potassium (Table 3). Although the overall mean concentration of sodium and potassium in the study area was within the prescribed drinking-water limit of 200 and 20 mg/L, respectively, some of the data have concentrations of the parameters above these values.

The bi-carbonate content in the groundwater was from 19.10 – 829.60 mg/L with a mean value of 121.91 mg/L (Table 2). The computed mean concentrations within 2001 – 2005, 2006 – 2010 and 2011 – 2015 were 120.58 mg/L, 129.94 mg/L and 119.10 mg/L, respectively (Table 3), all of which was within the acceptable limit of 200 mg/L prescribed for drinking water (WHO, 2011). However, a total of 26 data units had values above the stipulated limit. Result further showed that the dominant bi-carbonate range in the city was 101 – 200 mg/L.

The overall chloride and nitrate-NO_3 concentrations were from bdl – 970 mg/L with a mean value of 86.69 mg/L and bdl – 28.70 mg/L and a mean value of 4.39 mg/L, respectively (Table 2). The computed mean concentrations within 2001 – 2005, 2006 – 2010 and 2011 – 2015 were 37.05, 95.65 and 106.06 mg/L, for chloride and 10.04 mg/L, 8.42 mg/L and 12.11 mg/L for nitrate-NO_3, respectively (Table 3). Result showed that the mean concentration of chloride in groundwater in a lot of places across the city, though within the permissible limit, were mostly higher than 100 mg/L. A high number of data units with chloride concentration within 101 – 150 mg/L were found in places around Itoku, Elega, Saje, Ikereku, Ake, Adatan and Lantoro Townships, generally the downtown areas (major commercial areas). High chloride content is an indication that the water resource is prone to chloride contamination sources such as weathering of rocks, sewage and runoff. The highlighted locations were particularly plagued with either or combination of sewage, solid waste dumps or cottage industrial effluents. As noted earlier, the predominant textile tie and dye production in Abeokuta is the leading occupational trade in Itoku Township and its environs. Also, the high mean concentrations of nitrate-NO_3, which were above the recommended limit of 10 mg/L for drinking-water (WHO, 2011; 2017) computed for year 2001 – 2005 and 2010 – 2015 are indications of nitrate-NO_3 contaminations in most parts of the city. Therefore, it is suggested that some level of water treatment should be provided with groundwater-based supplies in Abeokuta city to control nitrate-NO_3 and chloride concentrations before consumption.

Sulphate content in the study area was within bdl – 137 mg/L with a mean value of 37.57 mg/L (Table 2). The computed mean concentrations within 2001 – 2005, 2006 - 2010 and 2011 – 2015 were 13.33 mg/L, 25.70 mg/L and 83.42 mg/L, respectively (Tables 3). The mean concentration of sulphate found in the groundwater in the city was within the permissible limit of 250 mg/L and as such poses no problems. However, places around Isabo, Kuto, Oke-Sokori and Panseke have high sulphate values, which confirmed the findings of similar studies conducted by Oyawale (2001) and Orebiyi *et al.* (2009). The two studies showed sulphate as the anion with highest concentration in the groundwater resource of Abeokuta. Thus, there is the need to carefully monitor the groundwater systems in the highlighted locations to curb and manage the increasing trend.

Furthermore, findings showed that concentration of heavy metals with values above permissible limits in the groundwater resource of the study area is in the order of cadmium > lead > iron> copper > zinc. The mean concentrations of iron, zinc and copper found in the city, though high, were mostly within the permissible limits. However, cadmium, lead and iron (in few cells) were above the allowable limits. The cells (22, 27, 29, 34, 37, 38, 39, 40, 46, 47, 48, 56, 58, 64, 76, 77 and 81) where cadmium, lead and iron were dominant require necessary treatments to reduce the concentration of the highlighted trace metals before considerations for drinking purposes, since the metals are detrimental to human health. According to Oke and Tijani (2012), the enrichment of Fe^{2+} can be attributed to the chemical weathering of mafic minerals such as biotite pyroxene, hornblende and amphibole dominating the mineralogical composition of the bedrock that serve as aquifers for shallow groundwater systems in Abeokuta city. Other factors included the tropical climatic situation with rainfall above 1,200 mm, and abundant sunshine leading to oxidation and ferruginization of Fe-bearing minerals. Other sources of Fe^{2+} according to Elueze and Bolarinwa (2004) may be derived from solid phase rock minerals, that is, acidic groundwater attack on iron enriched rocks such as goethite and hematite found to be common in rocks within southwestern Nigeria.

In addition, Figure 3 showed that the dominant ranges for temperature, pH and EC (at 25 ºC) were 28.0 - 29.9 ºC, 7.01 – 7.50 and 201 – 600 µS/cm, respectively. Calcium, magnesium, sodium and potassium have respective dominant ranges of bdl – 80, bdl – 30, 11 – 20 and bdl – 10 mg/, whereas bi-carbonate, chloride, nitrate-NO_3 and sul-phate in the groundwater resource of the study area are in the range of 101 – 200 mg/L, 11 – 30 mg/L, 1.60 – 4.00 and bdl – 10 mg/L respectively (Figure 3).

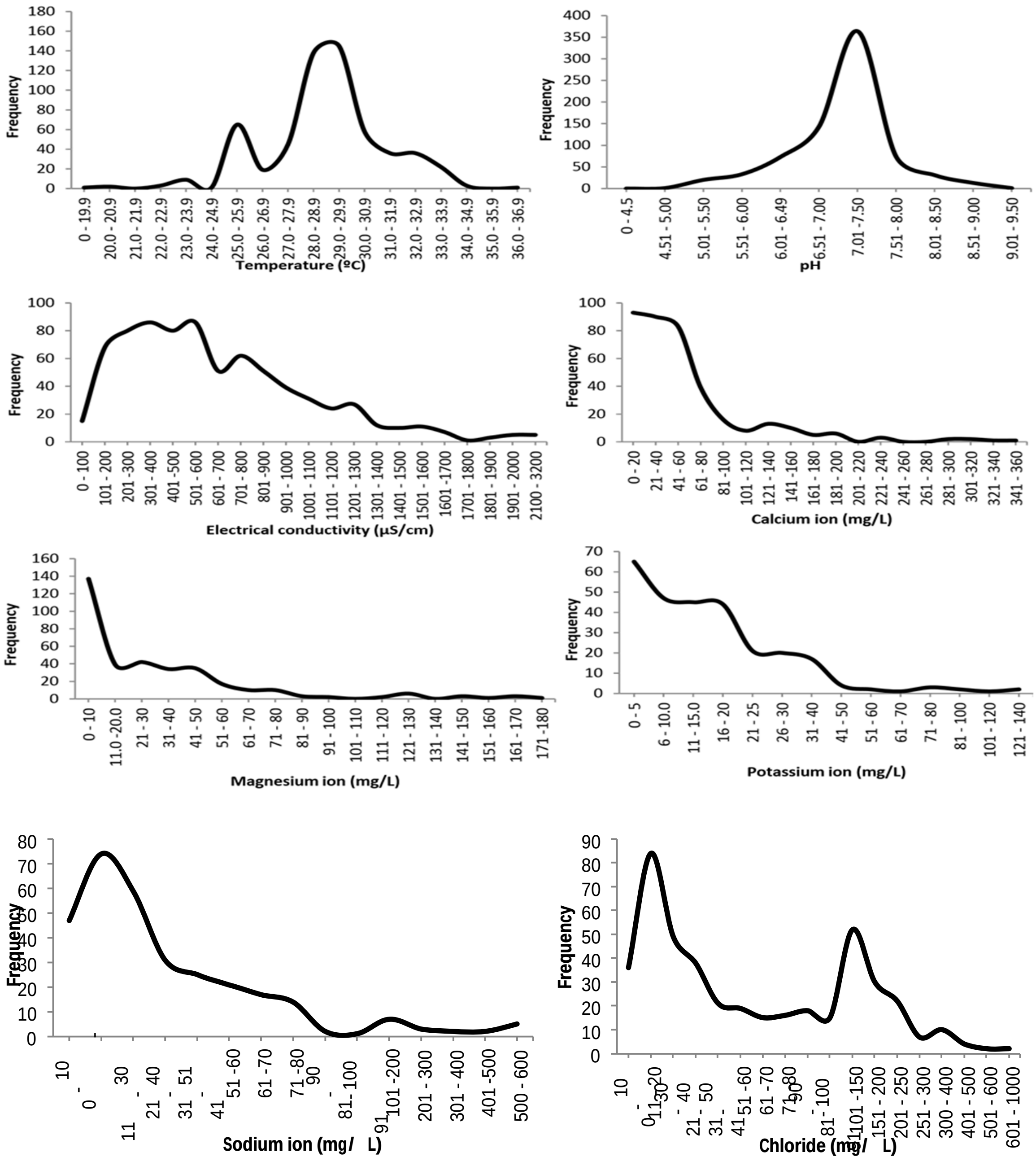

Figure 3: Frequency and variations of selected groundwater quality parameters in Abeokuta metropolis, Nigeria

Major Ionic contents in groundwater sources in Abeokuta city

Table 2 highlighted the presence of high (> 1000µS/cm) conductivity values with an upper band of as much as 2,846µS/cm in the study area. However, the piper diagram (Figure 4) showed that the dominant cations contributing to the high conductivity values are $Mg^{2+} > Na^{+} / K^{+} > Ca^{2+}$ and $Cl^{-} > HCO_3^{-}$ as the dominant anions (Figure 4). Hence, it is necessary to consider the reduction of magnesium and chloride content in groundwater when treating dug-wells found with high conductivity values. The source of magnesium in groundwater is mainly natural through weathering of underlying rocks and as such will be difficult to control. However, attention should be given to processes causing high chloride content such as runoff and sewage intrusion into the groundwater resource. Proactive vigilance would prevent increase in the conductivity value of groundwater in the city and mitigate future build-up of the identified parameters beyond levels that can be detrimental to public health.

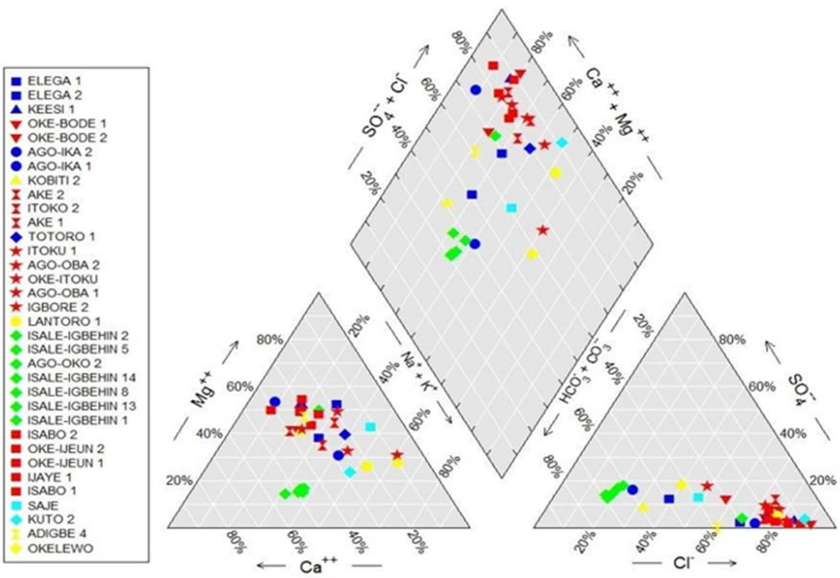

Figure 4: Major ionic contents resulting in high EC (> 1000 µS/cm) values in groundwater of Abeokuta Metropolis, Nigeria

Extent of groundwater contamination in Abeokuta city

The WQI analysis identified the overall water quality status of the groundwater resource of individual cells in the gridded map of Abeokuta city. The WQI results showed an index range of 2.34 – 68.5, indicating that the quality status of groundwater in Abeokuta city is within poor and excellent quality. However, only few (5.71 %) of the cells have poor water quality status, while about 46 % and 49 % of the cells have good and excellent water quality status respectively (Figure 5). The excellent water quality status identified in cells 4, 15, 16, 21, 26, 27, 29, 38, 40, 45, 46, 56, 55, 57, 64 and 65 indicates that the groundwater sources in the highlighted cells is generally free from contamination and may have no health implication if ingested directly without any form of treatment prior to consumption. However, household level water treatment is still advised for the sources in the excellent and good WQI categories.

Cells 36 and 37 on the other hand are found to have poor water quality status. By implication, the towns in the two cells, which include Olowu, Totoro, Gbagura, Adekunle -Fajuyi, Bode-Olude, Igbore, Itoku, Ikija, Oke-Ijemo, Idi-Ape, Kemta-Oloko and Sapon are prone to groundwater contamination. Same townships were already identified and noted to have inappropriate well construction methods and poor hygiene practices (Oluwasanya *et al.,* 2016). The recurrent poor water quality status of the groundwater sources in these two identified cells further implies that priority action in water safety planning is required to forestall likely public health concerns.

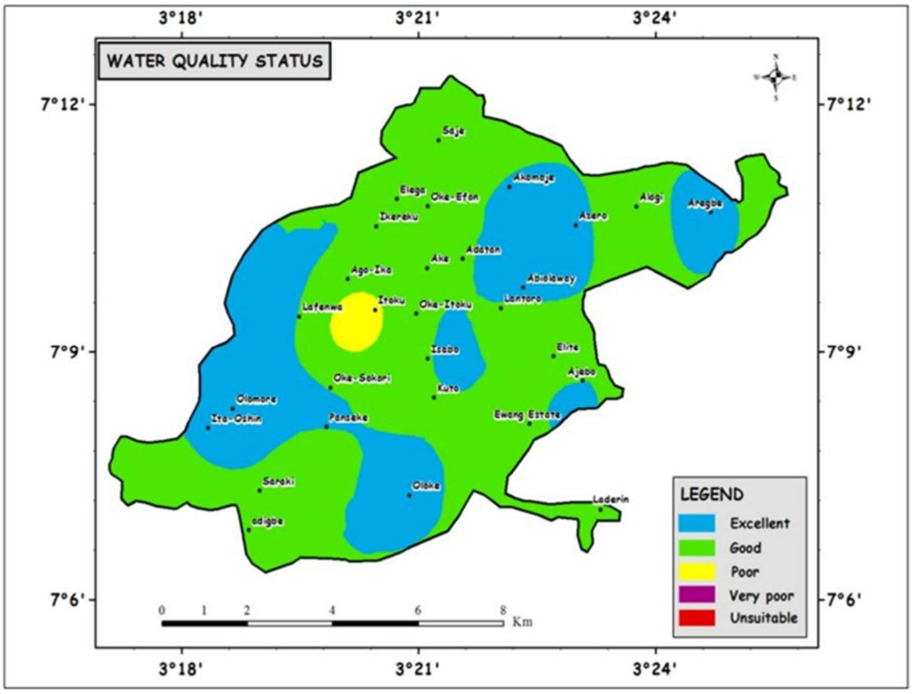

Figure 5: Groundwater quality status (2001 – 2015) of Abeokuta city, Nigeria

'Big Data' Analysis: Implications for Water Quality Management

This research investigated groundwater quality in Abeokuta city using fifteen years (2001 - 2015) data to highlight the temporal and spatial trend and generate a groundwater quality status map to better understand the dynamics, if any, in the water quality profile for the study area. The work identified locations of interest such as places with unacceptably high (>1000 µS/cm) EC values and detrimental concentration levels of heavy metals. Similarly, the study identified areas within Abeokuta city where priority action is needed for household water treatment programs and water safety planning. Therefore, synthesis of secondary data is becoming increasingly useful in water quality management to isolate water quality parameter of interest or specific location condition of note to improve understanding and enhance relevant informed decision processes.

CONCLUSION

This paper investigated groundwater quality in Abeokuta, Nigeria and presented a water quality status map. The map indicated that, generally, water from groundwater sources in the study area is fit for human consumption. Places with poor water quality are also indicated. Household water treatment solutions and water safety planning of drinking water sources are recommended. The water treatment approach should consider the reduction or removal of groundwater constituents such as EC, pH, K^+, Ca^{2+}, HCO_3^-, NO_3^-, Cd, Fe and Pb, the values of which were found to be relatively higher than stipulated drinking-water limits. This paper promotes the synthesis of secondary data in water quality profiling and highlights the need to encourage 'Big data' analysis to enhance water quality management. It is important to note that the dynamics of water scarcity is intensified through rising demand by consumers and, essentially, by declining water quantity and quality. Consequently, water security is impaired, in part, by deteriorating water quality. Therefore, this paper advocates proactive and constant monitoring of water quality as sustainable development will not be achieved without a water secured world.

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APPENDIX

Appendix I: Extracted locations in cells of the gridded map of Abeokuta metropolis, Nigeria

SN	Sample Locations	Coordinates	
		Latitude (o N)	Latitude (o E)
4	Kugba, Elega	7.18335	3.34269
5	Kugba Road,	7.18358	3.35271
7	Oba-Ademola Road	7.18409	3.37105
8	Ajikunta Street, Alani-Kayode, Sowemimo Way,	7.18442	3.37820
15	Adedotun, Ikija Road, Mokola, Balogun, Para-	7.17525	3.34330
16	Oke-Bode, Sokori Street	7.17502	3.35182
17	Afolabi-Soyinka, Gbesele	7.17526	3.36128
18	Bola Ajibola Street, Alabata Street, Car Wash	7.17482	3.36953
19	Asero, Orita Aare, Ransom Kuti	7.17462	3.37872
20	Alamu Kayode Street, Fajol Hotel, Muda Lawal	7.17537	3.38794
21	Ebenezer, Alogi, Obantoko	7.17496	3.39617
22	Shomorin	7.17597	3.40493
23	Aregbe	7.17534	3.41438
24	Premier Akindele, Oke Sabo, Adebowale Street	7.16653	3.31572
25	Agbo Eran, Omideyi, Iwajowa	7.16593	3.32508

26	Ago-Ika	7.16577	3.33400
27	Sodeke, Kobiti	7.16600	3.34295
28	Ake, Iporo Ake, Itoko, Isabo Road (Itesi Street), Oju-Agemo	7.16531	3.35161
29	Isale Ake, Adatan, Isale Abetu, Kugba	7.16642	3.36076
30	Ilupeju Street, Abiola Way, Oke Abete	7.16607	3.36934
31	Oke-Ibukun	7.16572	3.37838
34	Elemere Street, Ladipo Street, Sokori, Owode	7.15673	3.31599
35	Lafenwa, Ilupeju Street, Omideyi	7.15716	3.32506
36	Olowu Road, Totoro, Gbagura, Adekunle Fajuyi, Bode-Olude	7.15738	3.33386
37	Igbore, Itoku, Ikija, Oke-Ijemo, Idi-Ape, Kemta,Oloko, Sapon	7.15734	3.34255
38	Ijemo, Shokenu, Ijemo-Agbadu	7.15768	3.35185
39	Erinoso, Skido, Igara, Abule-Oloni, Oke-Ejigbo, Akiode	7.15737	3.36074
40	Oke-Yidi, Abiola Way, Lantoro, Olorunsogo, Oke-Lantoro	7.15709	3.36994
41	Salamu-Kaula, Oke-Ayo, Ajayi, Akinosho, Abeni-Adeleye Avenue, Williams Crescent	7.15730	3.37838
42	Mosebolatan Street, Sekoni, Oyetola	7.14847	3.30683
43	Federal Housing Estate, Irepodun Close, Omolade-Odunbaku Close	7.14860	3.31599
44	Akin Olugbade	7.14830	3.32525
45	Totoro, Ogbe, Ita-Eko	7.14765	3.33392
47	Isabo, Ijaye, Shokenu, NUD	7.14857	3.35180
48	Oke-Ejigbo, Olorunsogo, Ijeun-Titun, MKO Abiola Way, Iyana- Mortuary	7.14808	3.36120
49	Iyana Tekobo, Mayegun Avenue, Oluga Street, Adeboye Street, Elite	7.14787	3.36976
50	FMC, Sobola Street	7.14824	3.37869
51	Ita-Oshin	7.13919	3.30704
52	Surulere Street, Oriyanrin Street, Olomore	7.13915	3.31615
53	Akin Olugbade, Quarry, Bella Street	7.13871	3.32537

54	Ita-Iyalode, Ijeja, Omida, Ita-Eko, Ibara, Post Office	7.13893	3.33400
55	Continental Suites, Presidential, Ibara Road, Ibara Baptist Church, Saje	7.13914	3.34289
56	Kuto	7.13925	3.35167
57	Leme, Sam Ewang-Estate, Idi-Aba	7.13901	3.36100
58	Olokuta Street, Ogunsanya Street,Abeo	7.13851	3.36950
61	Coker Street	7.12831	3.29819
62	Upright Hotel, Kuforiji Olubi Street	7.12978	3.30686
63	Upright Hotel, Kuforiji Olubi Street	7.13004	3.31601
64	Onikoko, Adigbe, Lipede	7.12968	3.32498
65	Onikolobo, Ibara Housing Estate	7.12963	3.33392
66	Blue Mango Hotel, Okelowo Bus-Stop	7.13023	3.34293
67	Gateway Hotel, Wenby's Suits, Kuto	7.12961	3.35164
68	Abule Olukosi Road, Ijeun-Lukosi Stadium	7.12984	3.36105
70	Idi-Ori, Bola Folaji Street	7.12200	3.29001
71	Surulere Street, Ogunyemi Street, Alaapa Road	7.12188	3.28941
72	Bode-Oriyomi Street, Sanyaolu Street	7.12135	3.29814
73	Saraki, Isokan, Obada, Road	7.12154	3.30700
74	Adigbe, Iyana-Cele, Araromi Street, Re-deemed Church Of God, DG Hotel	7.12109	3.31637
75	Anewennu Estate, Diocese Of Egba Bish-op's Court, Fawobi Street	7.12157	3.32536
76	Oloke Street, Segun-Anjorin Street, Abule Ojere, Duro Street	7.12066	3.33399
77	Obada Road, Isokan Street	7.12109	3.34268
78	Oke-mosan	7.12200	3.36000
79	Adigbe, Mango, Abule Ojere	7.11262	3.31628
83	Laderin	7.11822	3.38842

Note: Excluded cells were due to lack of information from Google earth

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