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Biogeochemical Assessment and Health Implications of Borehole Groundwater System using Principal Component Analysis in Itori Community South-West Nigeria

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Abstract

The significance of quality water consumption for the overall health and wellness of any population cannot be overemphasized. The water quality status of boreholes and hand-dug wells in Itori community of Ewekoro Local Government Area, South-West Nigeria was examined in this study. Inhabitants of this region depend solely on these water sources for consumption and other comforting purposes. Water samples were collected from 25 boreholes at various sampled points across the study area. Standard analytical water quality methods using Inductively Coupled Optical Emission Spectrometry (ICP-OES) were employed in the laboratory (Geochemical and bacteriological analyses) for 25 borehole water samples collected in the study area and the corresponding results were compared with both National and International water quality standards. Most quality determinants in the sampled water are within WHO guidelines except BOD, ALK, Cl^-, NH_4^+, HCO_3^{2-}, $MgCO_3^-$, Zn^{2+} and Fe^{3+}. The overall ionic dominance pattern follow the same trend $K^+ > Na^{2+} > Fe^{3+} > Mn^{2+}$ and $Cl^- > NO_3^- > NO_2^-$. The hygienic status of the water sources is found to be poor. High BOD_5, Coliform Count and $BOD_5:NO_3^-$ ratios of groundwater samples are indicative of organic pollution due to faecal contamination with the lowest measured depth of 35m and highest measured depth of 85m. Multivariate statistical approach namely Correlation, Principal Component Analysis and Bubble Plot was used to identify interrelationships among the analyzed physicochemical parameters and the pollution sources. PCA reveals maximum 6 PCs; with the sources of pollution emanating either from natural hydrogeochemical or anthropogenic processes, or a combination of both. The results therefore imply that boreholes in Itori are polluted and pose potential risk to biomedical safety and overall human health. Intervention measures from Government and Non-governmental Organization including public awareness campaigns in Itori and entire Ewekoro local Government Area is necessary to safeguard the inhabitants from water-related diseases and their consequences.

Keywords: Borehole; Hand-dug wells; Groundwater; Water quality; Organic pollution index; Multivariate analysis

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INTRODUCTION

Water is the most important and unavoidable natural resource on earth. It is essential for all known forms of life, and is approximated to cover 70.9% of the earth surface (Pasquini and Alexander, 2004; Verplanck *et al.,* 2006). Despite its abundance, the quality and accessibility of potable water remains a global challenge; moreso, in rural and semi-rural communities in the developing countries (Faremi and Oloyede, 2010; Lashkaripour, 2003). Today, contaminated water has been reported to kill more people than cancer, AIDS, war or even accident (WHO, 2011a). Diarrhoea diseases alone account for an estimated 4.1% of total daily global burden of disease and are responsible for the deaths of 1.8 million people every year; 88% of this burden is attributable to unsafe water supply, poor sanitation and hygiene (WHO, 2004). Microbial contamination of drinking water supplies especially from human faeces is a major contributor to diarrhoeal diseases that kill millions of children every year (Foppen, 2002; Horward *et al.,* 2006; Verplanck *et al.,* 2006; UNEP *et al.,* 2008). It is therefore important that drinking water is free from disease causing germs and toxic chemicals that endanger public health. In Nigeria, only 58% of inhabitants of the urban and semi-urban areas and 39% of the rural areas have access to potable water supply; the rest of the population depend on ground (well and borehole) and surface water (stream and river) for their domestic water supply (FGN, 2012). Chemical and biological contamination are expected to increase because of a daily increase in human and biological population, urbanisation, pollution, atmospheric input from fossil fuel burning and environmental degradation thereby causing series of threats on available water. Research findings indeed reveal deteriorating surface and ground water quality in Nigeria, Uganda and India due to chemical and biological pollution and seasonal changes among others (APHA, 1998; Kumar and Pal, 2010; Oluseyi *et al.,* 2011; Sha'Ato *et al.,* 2010). As challenges confronting water quality status become more serious and widespread, there is an urgent necessity for water quality inspection and monitoring as this would be a very important component of health promotion strategy in developing countries. Over the past two decades, multivariate statistical analysis (PCA and CA) has been successfully applied in hydro-geochemical and biological studies (Amadi *et al.,* 2012). With this technique, large geological, hydrological and biological data are simplified, organised and classified to produce useful information (Kaiser, 1958; Wu *et al.,* 2005). Available technical information on the quality of subsurface water sources of most rural communities in Nigeria is quite inadequate and somewhat misleading; the focus has been drifted more toward the urban and sub-urban settlements. Therefore, this study is principally conducted to assess the quality of subsurface water sources with specific interest boreholes within Itori communities of Ewekoro Local Government Area of Ogun State.

MATERIALS AND METHODS

Study Area

Itori is located on a latitude of 6°56'22.44"N and a longitude of 3°13'14.38"E with an elevation of 27.25 Meters (89.42 Feet). Historically, the people of Itoriland, like other settlers in Ewekoro Local Government Area of Ogun State, migrated from Egbaland. Today, Itori has over thirty thousand population with a highly organized communal system and well behaved youths unlike past few years when the population was less than five hundred and serves as the headquarter of the entire Ewekoro Local Government Area of Ogun State (Ishola, 2019).

Local Geology of the Study Area

The Ewekoro formation is the local geology in the study area which is generally consistent with the regional geology of the eastern part of the Dahomey Basin; predominantly comprises the non-crystalline and highly non-fossiliferous and fossiliferous limestone and thinly laminated fissile and probably non-fossiliferous shale (Kogbe, 1976; Ushie *et al.,* 2014). It is the sedimentary terrain of southwestern Nigeria. Ewekoro formation consists of intercalations of argillaceous sediment. The rock is generally soft and friable but in some places, it is often plastered by materials that are siliceous and ferrigeneous types. The three informal formational units of Abeokuta group are Ise, Afowo and Araromi formations. The strata previously referred to as the Nkporo shale were renamed Araromi formation by Okosun (1998). The Abeokuta formation on surface outcrops comprises mainly sand with sandstone, siltstone, silt, clay, mudstone and shale interbeds. It usually has a basal conglomerate which may measure about 1m in thickness and usually consists of poorly rounded quartz pebbles with silicified and ferruginized sandstone matrix or a softly gritty white clay matrix. In outcrops where there is no conglomerate, a coarse, poorly sorted pebbly sandstone with abundant white clay constitutes the basal bed. The overlying sands are coarse grained clayey, micaceous and poorly sorted and indicative of short distances of transportation or short duration of weathering and possible derivation from the granitic rocks located to the north while the subsurface data of the Abeokuta formation were provided by Ise-2, Afowo-1, Orimedu-1, Bodashe, Ileppawi, Ojo-1 and Itori boreholes (Okosun, 1998). The formation thickness values of 849m, 898m, 624m, 54.4m and 888m were respectively acquired for Ise-2, Afowo-1, Ileppawi, Itori and Ojo-1 boreholes. Notably in the Ise-2 borehole, the formation is essentially constituents of arenaceous sequence between 1261.5m and 2142.1m which in turn consists of sands, grits, sandstone, siltstone, clay and shaly materials. Very coarse loose sands with sporadic thin intercalations of multicoloured shale and limestone were found within the interval of 1076m to 1907m that represent the formation in Ojo–1 borehole. The upper portion of the formation strata from 44m to 98.4m in the Itori borehole consists of coarse-fine and medium-grained sand, silt and sandy clay horizons. Basal conglomerates are also penetrated Ise-2 borehole (Ishola *et al*., 2019). The inset map showing political divisions of the study area within the Nigerian continental environment is shown in Fig.1 while Fig. 2 shows the Geological Map of the Selected Locations of the Study Area within the Nigerian Part of Dahomey Embayment, and the maps of the investigated locations in the study area are shown in Fig. 3.

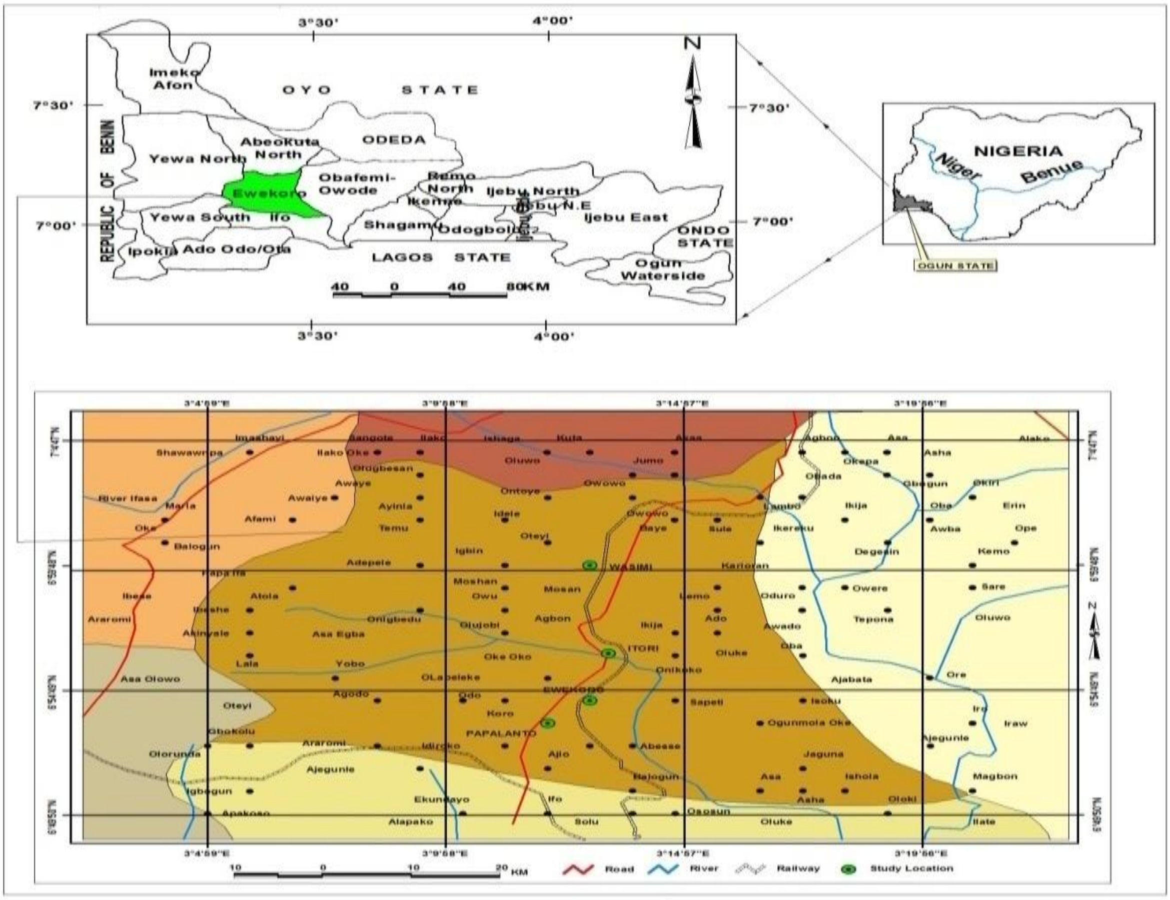

Fig.1: Inset Map showing the Study Areas in Ogun State within Nigeria Continental Domain (Arcview GIS 3.2A Environment, Ishola., 2019**)**

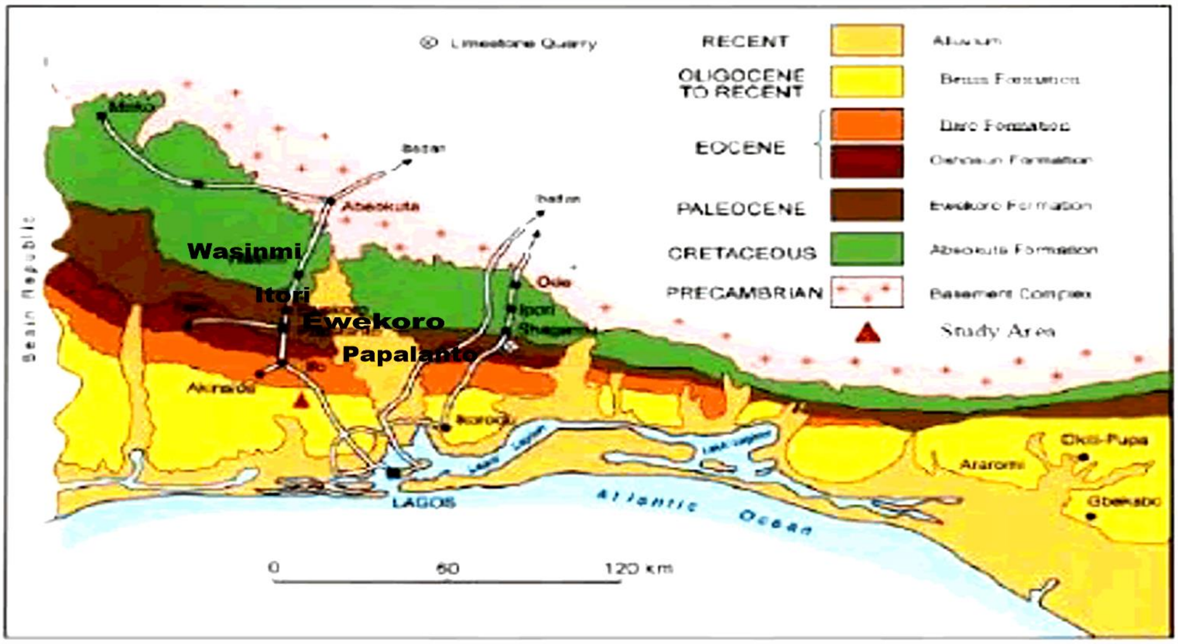

Fig. 2: Geological Map Showing the Selected Locations of the Study Area within the Nigerian Part of Dahomey Embayment (Billman, 1992; Modified by Ishola, 2019**)**

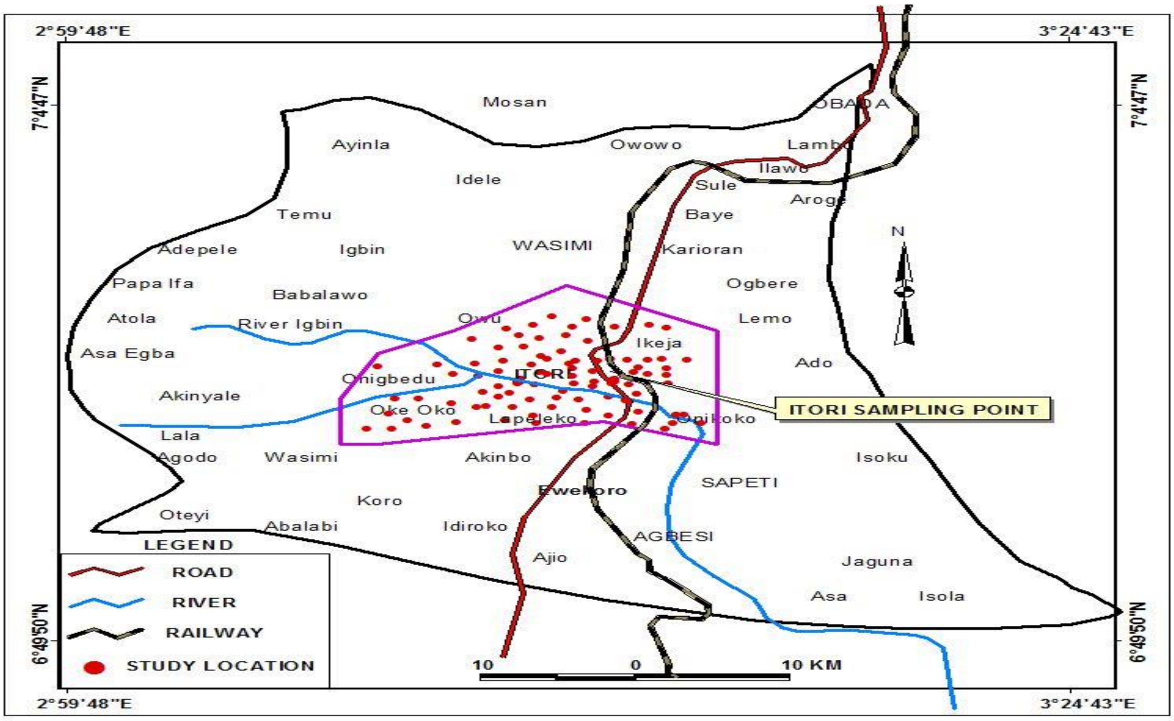

Fig. 3: Data Acquisition Map showing the Investigated Locations in Itori Study Area in Ewekoro LGA, Southwest Nigeria (Ishola, 2019).

Collection and Analyses of Subsurface Water Samples

Water samples were collected from existing and functional 25 boreholes at different and strategic sampling points within Itori communities. Most of the borehole water samples were obtained from private boreholes which serve as a source of household water supply, and also serves as a good source of livelihood to the family through sales to village buyers; few others were a public borehole situated at a market place in the study area. Physico-chemical analyses were carried out on the water samples principally to identify and quantify the physical properties and chemical constituents of water. This includes pH, cations, anions, trace elements e.t.c. Determination of the water quality status is often realizable by extensive utilization of the water chemistry analysis due to the possible interaction it has with its environment which is predominantly the groundwork of studies of water quality, pollution, hydrology and geothermal waters.

Samples collected were immediately stored in clean air tight-proof plastic bottles and labelled appropriately while 1 ml concentrated HNO_3 per litre of the sample was used for the preservation of the samples for metals. All water samples were consequently stored in an insulated cooler containing ice (maintained at 4 °C) and transported to the laboratory. Physico-chemical properties namely Electrical Conductivity (EC), Total Dissolved Solids (TDS), Temperature, Dissolved Oxygen (DO) and pH were determined in-situ using Hannah Combo TDS/pH/EC/Temperature meter series multi-parameters (model HI991300), whereas Hannah (model HI9147) equipment was used for daily measurement of DO for the purpose of ensuring that they are not subjected to physical alteration such as temperature while JYD-IA DO meter was later used for the BOD5 calculation after the expiration of five days incubation. Other physicochemical parameters, bacteriological evaluation and metals levels were measured in the laboratory using standard procedures (APHA, 1992; APHA, 1998).

A sanitized container was used for the sample collection with the sensor on the meter dipped into it while the metre displayed the values it measured on a digital screen. The same procedures were repeated for other water samples. These measured parameters were compared with WHO and other specification. The geographical coordinates of sample points were also taken with GPS mete and their location is indicated on the data acquisition map. Samples specifically meant for anion determination were collected in 500 ml bottles, unfiltered and unpreserved, and later stored below 8 ^{0}C prior to analysis while the third sampling bottles were used for the determination of microbial loads. Ion Chromatography (IC) was used to determine the anions concentrations' while those of Nitrates, Phosphates, Bicarbonates, Chlorides and Sulphates were measured after chromatography separation utilizing conductivity detectors. Inductively Coupled Mass Spectrometer (ICP-MS) and Inductively Coupled Optical Emission Spectrometry (ICP-OES) were used for heavy metals and trace metals detection. Water samples were filtered to less than 0.45 µm using a Pall Corporation GN-6 metricell sterilised membrane for the purpose of improving accuracy and also to prevent cloudiness of the water while ensuring that the minute particles of clay sizes were removed before analysis. When lower levels of contamination are present, ICP-MS provide lower detection limits for measurement while ICP-OES is useful for higher concentrations, such as cases of high levels of contamination (Udousoro and Umoren, 2014). Furthermore, cell-based ICP-MS serves as a very veritable integration tool for the removal of possible interferences that might prevent the detection of a contamination at its emergence. The samples were further examined for microbial analyses under the microscope. The Hetetrophic total bacterial count was determined by pour plate technique using standard methods (APHA, 1998; Pepper *et al.,* 2004). Total Coliform Count was determined by The Most probable number (MPN) index method using 3-3-3 regimen for coliform and total coliform (Pepper *et al.,* 2004). Faecal coliform count was determined using Eosin Methylene Blue medium employing the pour plate technique (APHA, 1992; Burnett and Beuchat, 2001). They were then compared to standards as stipulated by the World Health Organisation (WHO, 2011) and the National Agency for Food and Drug Administration and Control (NAFDAC, 2004). Analyses were in accordance to the Nigerian and WHO standards. The accuracy of the methods for all determinants is better than ±10%, the bias is within ±3%, and the repeatability at the 95% confidence interval is better than at 5%. The analyses were repeated to make certain results correct. These analyses were ultimately carried out in order to study how the concentration of elements in water samples has been affected by the activities in the study area. The depth measurements of the investigated boreholes were determined using Heroin Water level meter.

All the laboratory sample analyses were carried out in the Central Laboratory, Institute of Agricultural Research and Training (IART), Obafemi Awolowo University, Moor Plantation Ibadan Campus.

Analyses of Water Sample Data

Multivariate analyses (Correlation Analysis, Principal Component Analysis and Cluster Analysis) were performed on a series of water quality data. CA was determined using the statistical software- Statgraphic® Centurion XV was used for while SPSS Statistics 20.00 was used for Pearson's correlation coefficients analysis and PCA. Principal component analysis was applied to a matrix of 25 experimental data in ground water (boreholes) standardized through set Varimax rotation with Kaiser Normalization in order to eliminate the influence of drifting units of measurement and to render the data dimensionless,. The adherence to the analytical quality control was ensured through procedural blank measurements, duplicate analyses of water samples and standardization of analytical laboratory devices.

Theoretical Background

The dataset forms an n× m matrix if only we have n objects and measure m characteristics. Next, some measure of similarity should be computed between every pair of available objects. Several coefficients of resemblance have been used, including the correlation coefficient r_{ij} and a standardized m-space Euclidean distance, d_{ij} the distance coefficient is computed by

$$d_{ij} = \sqrt{\frac{\sum_{k=1}^{m}(X_{ik} - X_{jk})^2}{m}} \qquad 2.0$$

where X_{ik} is accompanied by the corresponding K_{th} variable measured on object i and X_{jk} is the K_{th} variable measured on object *j with* m variables a measured on each object, and d_{ij} is the distance between object i and object j (Ishola, 2019). A low distance indicates that the two objects are similar or "close together "whereas a large distance indicates dismiliarity as often expected. Commonly, the n×m raw data matrix is a standardized data prior to computing distance measurements. This ensures that each variable is weighted equally (Davis *et al.,* 1970; Gangopadhay *et al.,* 2001)

Groundwater sample data are collected from ***b*** boreholes, these data are often correlated. This correlation reflects the complexity of the aquifer hydrogeology and indicates that some of the information (elemental concentrations and physicochemical compositions in this case) collected from one borehole is also contained in the remaining ***b-1*** boreholes. Thus, the objective of principal component analysis is to evaluate its concentrations to save on the number of independent variables that describe the elemental concentration physicochemical variations in the aquifer. This reduces the number of variables needed to be measured or observed. A review of the particular aspects of principal component analysis technique important for the present application has been outlined in this section.

Let ***X*** be the observation matrix of deviations from the mean of the order $n \times p$, where n serves as the number of observations on b variables. Here n is the number for which elemental concentration measurement of water samples have been considered for ***b*** boreholes. The mean concentration of the borehole is assumed to be the average of the ***n*** number of observation values for the boreholes. So in $\underline{\underline{X}}$ elemental concentrations for a borehole represent the deviation from their respective mean concentration. It is also considered that this original ***b*** variable set of observations in $\underline{\underline{X}}$ contains a correlation. This correlation can be analyzed using principal components to identify the relative importance of any borehole in representing variations of elemental concentrations among the b wells. This is done by characterizing the variance of $\underline{\underline{X}}$ with q $(q<b)$ principal or orthogonal components and evaluating the correlation between the ith original variable and **jth** principal component. The **jth** principal component, $\underline{\underline{z_j}}$ $(n \times 1)$ column vector), is the linear function such that

$$\underline{\underline{z_j}} = Xa_j \qquad 2.1$$

where a_j is a $p \times 1$ linear transformation coefficient vector corresponding to z_j.

From the theory of Principal Component Analysis (Gangopadhyah *et al.,* 2001), It can be shown that a_j is the characteristic vector associated with the characteristic roots λj (roots of the scalarλ) which are obtained by solving the equation defined by

$$\left| \boldsymbol{S} - \boldsymbol{\lambda I} \right| = 0 \qquad 2.2$$

Where $\underline{\underline{I}}$ and $\underline{\underline{0}}$ are the $\mathbf{p\times 1}$ unit and zero vectors respectively;
S (order **b**) is the estimate of the variance-covariance matrix of $\underline{\underline{\mathbf{X}}}$; it is given by

$$\underline{\underline{S}} = \frac{X^T X}{(n-1)} \qquad 2.3$$

where the superscript $\boldsymbol{T}$ denotes the matrix-transpose operator.
The solution of equation (2.7) is subject to
Normalizing Constraints: $\boldsymbol{a_j}^{\boldsymbol{T}}\boldsymbol{a_i} = \mathbf{1}$; and
Orthogonality constraints: $\boldsymbol{a_i}^{\boldsymbol{T}}\boldsymbol{a_j} = \boldsymbol{a_j}^{\boldsymbol{T}}\boldsymbol{a_i} = \mathbf{0}$
These constraints ensure a unique solution and uncorrelated principal components (Gangopadhyah *et al.,* 2001; Ishola, 2019).
Thus, corresponding to$\boldsymbol{\lambda_1, \lambda_2, \lambda_3}$ ***to*** $\boldsymbol{\lambda_b}$, we have the $\boldsymbol{n\times 1}$ column vectors $\boldsymbol{a_1, a_2, a_3}$, ***to*** $\boldsymbol{a_b}$ respectively. Then, the above equations can be extended to
$\underline{\boldsymbol{a_i}^{\boldsymbol{T}}\mathbf{.}}$ Where $\mathbf{Z} = \underline{\underline{\mathbf{X}}}$ 2.4

$\underline{\underline{\mathbf{Z}}}$ = $(\boldsymbol{z_1, z_2, z_3}$ ***to*** $\boldsymbol{z_b})$ is the transformed n×p matrix of n values for each of the b components, and **A**= $(\boldsymbol{a_1, a_2, a_3}$, **to** $\boldsymbol{a_b})$ is the $\boldsymbol{b\times b}$ linear transformation coefficient matrix (Gangopadhyah *et al.,* 2001; Ishola, 2019). In $\underline{\underline{\mathbf{Z}}}$, the first q components explain most of the variation contained in $\boldsymbol{X}$, and the remaining $\boldsymbol{p\text{-}q}$ provides only a small contribution to the total variation and they may be neglected. The advantage now is working with $\underline{\underline{\mathbf{Z}}}$ in that these new variables (principal components) are mutually uncorrelated and the dimensionality of the original problem is reduced (Davis *et al.,* 1970; Gangopadhay *et al.,* 2001; Ishola, 2019). In this analysis however, the objective is to use the correlation between $\underline{\underline{\boldsymbol{X_i}}}$ and $\underline{\underline{\boldsymbol{Z_j}}}$ to determine the importance of any sampled borehole $\boldsymbol{b_i}$ in representing the elemental concentration variation among the group of b boreholes in the same hydrogeological environment. Therefore, the correlation between the $\boldsymbol{i_{th}}$ standardized observed variable and the $\boldsymbol{j_{th}}$ computed component can be expressed as

$$\cos\boldsymbol{\theta} = (x_i, z_j) = \boldsymbol{\lambda}\mathrm{j}^{1/2}\boldsymbol{a_{ij}} \qquad 2.5$$

where $\boldsymbol{a_{ij}}$ (***i*** **= rows,** ***j*** **= columns)** are the elements of the coefficients matrix $\underline{\underline{\mathbf{A}}}$.
Equation 1.0 can thus be used to calculate the elements of the correlation matrix that depict the degree of correlation between the original observed variable and the derived principal component. This correlation matrix is commonly referred to as the factor loading matrix, and the elements given by equation 2.0 are called factor loadings.

The varimax criterion involves maximization of the variance of the loadings on the factors. We may define the variance $S^2{}_k$ of the loadings on the K_{th} factors as

$$\mathbf{S^2{}_k} = \frac{\mathbf{p}\sum_{j=1}^{m}(l^2jp/h^2j)^2 - \left(\sum_{j=1}^{m}(l^2jp/h^2j)^2\right.}{p^2} \qquad 2.6$$

To aid in the interpretation of the factor loading matrix, an orthogonal transformation such as varimax rotation is often performed (Gangopadhyay *et al.,* 2001) as diagrammatically exemplified in Fig. 5. Setting a cut-off value for factor loading (a measure of significant correlation), boreholes that have loadings below the significance levels for all the extracted components may not be observed. In otherwords, only $\boldsymbol{q}$ $\boldsymbol{(q<b)}$ boreholes that have a significant correlation with extracted component can adequately explain the significant

contribution of the elemental concentration variation in the group of b wells or boreholes as the cosine theta coefficient is defined as:

$$\cos\theta_{ij} = \frac{\sum_{k=1}^{n} x_{ik} z_{JK}}{\sqrt{\sum_{k=1}^{n} X^2{}_{ik} \sum_{k=1}^{n} Z^2{}_{jk}}} \qquad 2.7$$

where X_{ik} is the k^{th} variable of the i^{th} observation and n equation 2.7 serves *as* the number of variables. If we regard our two samples, i and j as defining points in n-dimensional variable space, this measure gives the cosine of the angle between vectors to those two points. In one sense, cosine theta is a measure of the ''great circle'' distance between samples i and j lying on the surface of the hypersphere (Ishola, 2019).

Comparison of equation 2.6 with that obtained for the correlation will show a close similarity between the two, if n variables are used to compute cosine theta were standardized to have zero mean and variance of 1.00, the two measures would be identical, because the cosine of zero degrees is 1.00. Decreasing similarity is indicated by lower values of coefficient, and vice-versa just as in the correlation (Davis *et al.,* 1970; Yeung, 1999).

Fig 2.1 shows the geometrical expression of the process in two dimensions. The mean values of the variables (μ_{x1}, μ_{x2}) and the covariance matrix which is an $n \times p$ *(2×2)* matrix were found in this case using all the data points. If we calculate the eigenvectors of the covariance matrix we get the direction vectors indicated by $\phi_1 and\ \phi_2$ while placing appropriately the two eigenvectors as columns in the matrix $\Phi = [\phi_1, \phi_2]$; we can create a transformation matrix which consequently transfer our data points from the previous $[x_1, x_2]$ axis system to the axis $[\phi_1, \phi_2]$ system with the equation:

$$p_\phi = (p_x - \mu_x).\ \Phi \qquad 2.8$$

where $p_x$is any point in the $[x_1, x_2]$ axis system, $\mu_x = (\mu_{x1}, \mu_{x2})$ is the data mean, and p_ϕ is the coordinate of the point in the $[\phi_1, \phi_2]$ axis system (Harman *et al.,* 1967; Ishola, 2019).

PCA in the Hydrogeochemical Characterization of Aquifers

Owing to the simplicity of its algebra and its straight forward interpretation; PCA is the most widely used method of multivariate data analysis. A linear transformation can be simply defined as that which transforms a set of variables from the state of correlated factors into uncorrelated factors. These transformed orthogonal factors can in turn extract successively a maximal part of the local variance of the variables. The basic problem solved by the principal component analysis is to transform a set of correlated variables into uncorrelated quantities which could be interpreted in a ideal, multi-Gaussian context as independent factors underlying the phenomenon (Wackernagel, 1995; Ishola, 2019).

If **Z** be the n × N matrix of the data from which the means of the variables have already been earlier extracted. Then the corresponding N×N variance-covariance matrix **V** is therefore given as:

$$V = [\sigma_{ij}] = \frac{1}{n} Z^T Z \qquad \text{(Yeung, 1999)} \qquad 2.9$$

Let Y be an n × N matrix containing in its rows the *n* samples of the factors Y_p (*p* =1, ------------, N) which are uncorrelated and of zero mean (Yeung, 1999; Ishola, 2019).

Owing to the fact that the covariances between the factors are nil by definition, the variance-covariance matrix of the factors is diagonal, hence

$D = \frac{1}{n}\boldsymbol{Y^TY} = \begin{bmatrix} \boldsymbol{d_{11}} & \boldsymbol{0} & \boldsymbol{0} \\ \boldsymbol{0} & \ddots & \boldsymbol{0} \\ \boldsymbol{0} & \boldsymbol{0} & \boldsymbol{d_{NN}} \end{bmatrix}$ (Yeung, 1999; Ishola, 2019). 2.10

and the diagonal elements d_{pp} are the variances of the factors.
An N×N orthogonal matrix A which linearly transforms the measured variables into synthetic factors is given by
$\boldsymbol{Y = ZA}$ with $\boldsymbol{A^TA = 1}$ (Yeung, 1999; Ishola, 2019) 2.11
Finding the product of equation from the left with $\frac{1}{n}$ and $\boldsymbol{Y^T}$ with replacement of $\boldsymbol{Y}$ by $\boldsymbol{ZA}$, the following is obtained
:

$\frac{1}{n}\boldsymbol{Y^TY} = \frac{1}{n}\boldsymbol{Y^TZA} = \frac{1}{n}(\boldsymbol{ZA})^T(\boldsymbol{ZA}) = \frac{1}{n}\boldsymbol{A^TZ^TZA} = \boldsymbol{A^T}\frac{1}{n}(\boldsymbol{Z^TZ})\boldsymbol{A}$ 2.12

Finally
$\mathbf{D} = \boldsymbol{A^TVA} \Rightarrow \boldsymbol{VA = AD}$ (Yeung, 1999; Ishola, 2019) 2.13
Rendering the Principal component as nothing other than a statistical interpretation of the eigenvalue problem as shown in equation 2.13 and 2.15:

$\boldsymbol{VQ = QA}$ with$\boldsymbol{Q^TQ = 1}$ (Wackernagel, 1995) 2.15

This can be inferred immediately that the matrix $\boldsymbol{Q}$ orthonormal of eigenvectors of $\boldsymbol{V}$ offers a solution to the problem and the eigenvalues $\boldsymbol{\lambda_p}$ are then simply the variances of the factors $\boldsymbol{Y_p}$. Defining the factors as:
$\boldsymbol{Y = ZQ}$ 2.14

Principal component analysis is also very useful for defining a sequence of orthogonal factors which successively adopt a maximum amount of variance of the data (Gangopadhyah *et al.*, 2001; Ishola, 2019). For instance, take a vector $\boldsymbol{y_1}$corresponding to the first factor obtained by transforming the centred data matrix $\mathbf{Z}$ with a vector $\boldsymbol{a_1}$calculated to a unit length:
$\boldsymbol{y_1} = \mathrm{Z}\boldsymbol{a_1}$with $\boldsymbol{a_1}^T\boldsymbol{a_1} = 1$ (Gangopadhyah *et al.*, 2001). 2.15

The variance of $\boldsymbol{y_1}$ is
$Var(\boldsymbol{y_1}) = \frac{1}{n}\boldsymbol{y_1}^T\boldsymbol{y_1} = \frac{1}{n}\boldsymbol{a_1}^T\boldsymbol{Z}^T\boldsymbol{Z}_{a_1} = \boldsymbol{a_1}^T\boldsymbol{V}\boldsymbol{a_1}$(Gangopadhyah *et al.*, 2001). 2.16

If we are to appropriate a maximal part of the acquired variance of the data to$\boldsymbol{y_1}$, an objective function Φ_1 with a defined Lagrange parameter $\boldsymbol{\lambda_1}$, which multiplies the constraints that the transformation vector $\boldsymbol{a_1}$should be of unit norm.
$\Phi_1 = \boldsymbol{a_1}^T\boldsymbol{V}\boldsymbol{a_1} - \lambda_1(\boldsymbol{a_1}^T\boldsymbol{a_1} - 1)$ (Wackernagel, 1995) 2.17
When the derivative with respect to $\boldsymbol{a_1}$ is set zero:

$\frac{\delta\Phi_1}{\delta a_1} = 0 \Rightarrow 2\mathrm{V}\boldsymbol{a_1} - 2\lambda_1\boldsymbol{a_1} = 0$ (Wackernagel, 1995) 2.18
λ_1 is an eigenvalue of the variance-covariance matrix and the $\boldsymbol{a_1}$is equal to the eigenvector $\boldsymbol{q_1}$ associated with these eigenvalue:
$\mathrm{V}\boldsymbol{q_1} = \lambda_1\boldsymbol{q_1}$ (Gangopadhyah *et al.*, 2001). 2.19
Equation 2.20 shows a second vector $\boldsymbol{y_2}$ orthogonal to the first:
$Cov\,(\boldsymbol{y_2}, \boldsymbol{y_1}) = Cov\,(Za_2, Za_1) = \boldsymbol{a_2}^T\boldsymbol{V}\boldsymbol{a_1} = \boldsymbol{a_2}^T\boldsymbol{\lambda_1}\,a_1 = 0$ 2.20
The function Φ_2 maximize and incorporates two constraints: the fact that $\boldsymbol{a_2}$ should be unit norm and the orthogonally between $\boldsymbol{a_2}$ and a_1. These constraints bring up two new langrange multipliers λ_2 and μ:

$$\Phi_2 = a_2^T V a_2 - \lambda_2 (a_2^T a_2 - 1) + \mu a_2^T a_1 = 0 \qquad 2.21$$

Setting the derivative with respect to a_2:

$$\frac{\delta \Phi_2}{\delta a_2} = 0 \Rightarrow 2Va_2 - 2\lambda_2 a_2 + \mu a_1 = 0 \qquad 2.22$$

$$\underbrace{2a_1^T V a_2}_{0} = 2\lambda_2 \underbrace{a_1^T a_2}_{0} + \mu \underbrace{a_1^T a_1}_{1} = 0 \qquad \text{(Ishola, 2019).} \qquad 2.23$$

It can be seen that μ is nill (the constraint is not active). Therefore,

$Va_2 = \lambda_2 a_2$ (Gangopadhyah *et al.,* 2001; Ishola, 2019). 2.24

Again λ_2 is later turned out to be an eigenvalue of the variance-covariance matrix and a_2 in the corresponding eigenvectors q_2 continuing in the same way. One can find the rest of the N eigenvalues and eigenvectors of V as a solution to the maximization problem (Francisco *et al.,* 2001). The components are subsequently rotated orthogonally (Fig. 4) using the varimax method to obtain a more significant distribution of the weights of the different variables on the components (Davis, 1986). These multivariate techniques are very useful tools for the hydrogeochemical characterization of aquifers Francisco *et al.,* 2001 and for studies of contamination of groundwater (Davis *et al.,* 1970; Wackernagel, 1995; Francisco *et al.,* 2001; Mahannada et al., 2010; Gangopadhyah *et al.,* 2001; Ishola, 2019).

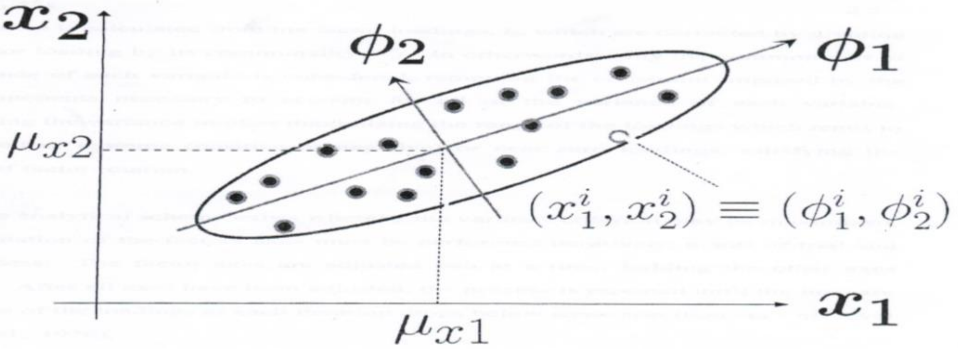

Fig 4: PCA Orthogonal Transformation (Ishola, 2019)

RESULTS

Physicochemical Quality Characteristics

38 parameters (13 Physicochemicals and 25 Elementals) and microbiological analyses of the different groundwater sources in the study area were investigated. The results obtained are well presented in Tables 1 to Tables 2.

The pH levels of the water sources range from 6.40 to 6.86. The temperatures of the water bodies range from 25°C to 30°C. The colour values (in Hazen unit) of water samples range from 3 to 10 while the turbidity of water from the study area ranges from 0.10 NTU to 1.11 NTU. Electrical conductivity is a good measure of dissolved solids; it is an important criterion in determining the suitability of a body of water for irrigation (Kumar and Pal, 2012). The values for Electrical Conductivity of the water sources range from 550 µs/cm to 710 µs/cm across the study area. Similarly, the total dissolved solids (TDS) range from 0.48 mg/L to 10.40 mg/L. Total suspended solids (TSS) range from 0.15 to 0.61 mg/L for boreholes and 0.22 to 0.67 mg/L. The levels of DO recorded are relatively high. A DO range of 6.82 mg/L to 7.84 mg/L is obtained for boreholes. BOD5 levels in the water bodies range from 16.70 mg/L to

20.96 mg/L while Total hardness for water samples ranges from 12.50 mg/L to 25.94 mg/L. The alkalinity levels of boreholes in the study area are very high and range from 141.40 to 1446.10 mg/L while the levels of COD obtained from borehole water sources range from 24.10 mg/L to 36.20 mg/L. Ammonium levels in samples from the study area range from 0.44 mg/L to 1.74 mg/L in the boreholes (Table 1 and Table 2).

Anion and Metal Contents

The anions levels in the different borehole sources are given as follows: Chloride ranges from 34.91 mg/L to 360.50 mg/L while Nitrate ranges from 0.04 mg/L to 0.13 mg/L and nitrite is in the range 0.01 mg/L to 0.03 mg/L. Manganese levels range from 0.00 mg/L to 0.03 mg/L while Potassium, the range is 31.80 mg/L to 42.10 mg/L. Sodium values are in the range of 24.10 mg/L to 42.10 while the range for Iron is 0.04 mg/L to 1.74 mg/L in the borehole (Table 1)

Total Bacterial Count

The water sources in all boreholes have considerable elevated levels of coliform count. THBC ranges from 0 to 2.83×10^2 cfu/ml while the Total TCC ranges from 0 to 18 MPN/100mL in boreholes and the FCC ranges from 0 to 1.3×10^2 cfu/ml in boreholes (Table 2). The BOD_5:NO_3- ratio ranges from 162.55 in borehole and as serves as a very significant index for measuring organic pollution of water bodies from Itori with the lowest measured depth of 35m in ITOBH6 and highest measured depth of 85m in ITOBH15. (Table 1 and Table 2).

Table 1: Descriptive Statistics showing the Concentration Values of Physico-Chemical and Elemental Parameters of Itori Boreholes (N=25)

Parameters	Min	Max	Range	Mean±SD	WHO (mg/L)	NESREA (mg/L)	NSDWQ (mg/L)	USEPA (mg/L)	NAFDAC (mg/L)
PH	6.40	6.86	0.46	6.66±0.16	6.5 – 9.5	7.00-8.50	6.50-8.50	6.50-8.50	6.50-8.50
TEMP (^0C)	26.00	28.00	2.00	26.52±0.77	27	NA	NA	27	27
EC(μScm^{-1})	550.00	710.00	160.00	614.32±56.93	1200	NA	900	1200	1000
DO (mg/L)	6.82	7.84	7.77	**3.56±155.30**	7.5	NA	7.5	NA	NA
BOD (mg/L)	16.70	20.96	4.26	**17.88±1.13**	10	NA	10	NA	NA
COD (mg/L)	24.10	36.20	12.10	**28.75±3.17**	NA	NA	NA	NA	NA
TDS (mg/L)	0.48	10.90	10.43	7.59±2.28	100	1500	500	500	500
TSS (mg/L)	0.15	0.61	0.46	0.34±0.10	< 10	<10	NA	NA	NA
TS (mg/L)	0.28	1.21	0.94	0.60±0.29	1500	NA	NA	NA	NA
TURB (NTU)	0.10	1.11	1.01	0.28±0.28	< 4	5.0	5.0	5.0	5.0
ALK (mg/L)	141.40	1446.10	1304.70	**489.02±507.57**	200	500	100	100	100
TH (mg/L)	12.50	25.94	13.44	17.46±3.77	< 200	100-300	500	NA	100
THC(mg/L)	0.00	0.41	0.41	0.07±0.12	NA	NA	NA	NA	NA
Na^{2+} (mg/L)	24.10	42.10	18.00	30.48±5.10	< 200	NA	200	NA	200
K^+ (mg/L)	31.80	56.91	25.11	38.69±8.72	250	200	NA	200	10
Ca^{2+} (mg/L)	9.40	22.90	13.50	12.96±3.84	100	75	NA	75	75
Mg^{3+} (mg/L)	1.70	5.83	4.13	4.20±1.08	20	15	NA	20	20
Cl^- (mg/L)	34.91	360.50	325.59	**122.04±118.17**	250	200	250	100	100
NO_3^- (mg/L)	0.04	0.13	0.09	0.11±0.02	50	45	NA	10	10
NO_2^- (mg/L)	0.01	0.03	0.02	0.02±0.008	< 3.0	NA	NA	NA	NA
SO_4^{2-} (mg/L)	5.11	12.74	7.63	7.80±2.72	400	500	200	250	100
NH_4^+ (mg/L)	0.44	1.74	1.30	0.95±0.36	1.50	NA	NA	NA	NA
PO_4^{3-} (mg/L)	7.20	10.72	3.52	8.35±1.08	NA	NA	NA	NA	NA
HCO_3^- (mg/L)	72.35	743.50	671.15	**334.65±289.19**	100	NA	NA	NA	NA
$MgCO_3$ (mg/L)	7.60	13.94	6.34	10.43±2.04	10	NA	NA	NA	NA

Cu^{2+} (mg/L)	0.00	0.05	0.05	0.02±0.01	2.0	NA	1.0	1.3	1.0
Pb^{2+} (mg/L)	0.00	0.0004	0.0004	0.0004±0.0005	0.01	0.01	0.01	0.01	0.01
Cd^{2+} (mg/L)	0.00	0.0002	0.0002	0.0002±0.0004	0.003	0.003	0.001	0.005	0.005
Mn^{2+} (mg/L)	0.00	0.03	0.03	0.01±0.009	0.1	0.2	0.5	0.4	2.0
Zn^{2+} (mg/L)	0.40	1.74	1.34	**1.008±0.37**	0.01	NA	NA	NA	NA
Fe^{3+} (mg/L)	0.04	1.20	1.16	**0.44±0.34**	0.3	0.3	0.3	0.3	0.3
Cr (mg/L)	0.00	0.0001	0.0001	**0.0001±0.0003**	0.05	0.05	0.05	0.05	0.05
Co (mg/L)	0.00	0.0001	0.0001	**0.0001±0.0003**	0.05	0.05	0.05	0.05	0.05
Ni (mg/L)	0.00	0.0003	0.0003	0.0003±0.0005	0.02	0.05	NA	NA	0.05
S (mg/L)	0.15	2.81	2.66	1.08±0.67	250	NA	NA	NA	NA
Al^{3+} (mg/L)	0.00	0.00	0.0004	0.0004±0.0005	0.2	NA	NA	0.2	0.5
I (mg/L)	0.02	0.07	0.05	0.03±0.01	NA	NA	NA	NA	NA
Si (mg/L)	0.00	0.02	0.02	0.002±0.006	NA	NA	NA	NA	NA

KEY

NA	–	**NOT AVAILABLE IN THE NATIONAL GUIDELINES AND STANDARDS DRINKING WATER QUALITY**
WHO	–	**WORLD HEALTH ORGANISATION**
NESREA	–	**NATIONAL ENVIRONMENTAL STANDARD REGULATION AGENCY**
USEPA	–	**UNITED STATE ENVIRONMENTAL PROTECTION AGENCY**
NSDWQ	–	**NATIONAL STANDARDS FOR DRINKING WATER QUALITY**
NAFDAC	–	**NATIONAL FOOD AND DRUG ADMINISTRATION AND CONTROL**

Table 2: Bacteriological Counts of Borehole Water Sample in Itori, Southwest Nigeria

SAMPLE CODE	DEPTH (m)	DO (mg/L)	BOD (mg/L)	COLOUR (TCU)	THBC (×10^2cfu/ml)	TCC (MPN/100ml)	FCC (×10^2 cfu/ml)
ITOBH1	**48**	7.50	18.00	5	2.6	18	0
ITOBH2	**36**	7.46	18.40	5	2.02	17	0
ITOBH3	**42**	8.00	18.80	10	2.8	18	0
ITOBH4	**40**	8.04	18.60	5	1.6	17	0
ITOBH5	**44**	7.84	18.60	10	2.8	18	0
ITOBH6	**35**	7.70	18.10	5	2.8	18	0
ITOBH7	**38**	7.40	16.75	5	2.6	5	0
ITOBH8	**40**	7.35	16.84	5	0	0	0
ITOBH9	**42**	7.40	18.90	5	1.7	16	0
ITOBH10	**35**	7.30	18.20	6	1.9	16	0
ITOBH11	**40**	6.92	20.96	5	2.7	18	0
ITOBH12	**45**	6.89	20.16	5	1.8	15	0
ITOBH13	**80**	7.84	18.60	6	2.5	18	0
ITOBH14	**82**	7.82	18.60	6	1.8	16	1.2
ITOBH15	**85**	7.60	16.70	4	0	0	0
ITOBH16	**45**	7.62	16.70	5	1.6	18	0
ITOBH17	**70**	7.60	16.92	5	2.8	18	0
ITOBH18	**60**	7.60	16.90	5	1.6	18	0
ITOBH19	**50**	7.64	16.90	5	2.8	15	0
ITOBH20	**50**	7.62	16.90	5	1.6	18	1.3
ITOBH21	**60**	7.40	16.96	5	1.6	18	0
ITOBH22	**45**	7.62	16.94	4	0.9	7	0
ITOBH23	**45**	7.64	16.92	3	0	0	0
ITOBH24	**40**	7.20	18.10	5	2.6	18	0
ITOBH25	**65**	6.82	17.60	5	1.43	17	0
				WHO (1996) USEPA (2002) Guidelines	**1.0 ×10^2cfu/ml**	**0.00 MPN/100 ml**	**0 ×10^2 cfu/ml**

Key:
ITOBH = Itori Borehole Water
DO = Dissolved Oxygen

BOD= Biological Oxygen Demand
THBC = Total Heterotrophic Bacteria Counts
TCC = Total Coliform Counts
FCC = Total Faecal Coliform Counts

Principal Component Analysis (PCA) of Itori Groundwater

The PCA output obtained from principal components (PCs) is sometimes not readily interpreted as varimax rotation with Kaiser normalization is executed for the purpose of reducing the dimensionality of the data, thereby extracting the most significant variables and prescribed the processes that control water chemistry (Saima *et al.,* 2009). Varimax factor loading coefficient (Rail, 2000; Liu *et al.,* 2003) with a correlation of >0.75 are explained as strong significant factor loading (FL); 0.75-0.50 are considered as moderate FL; and 0.50-0.30 are considered as weak FL. Only FL > 0.75 is ascribed as being positive or negative were later used in this study to explaining the sources of contamination of the investigated boreholes. The rotated component matrix statistics revealed the extracted components for both Physico-chemical and Elemental parameters which have eigenvalues >1. The results of the principal component Analysis (PCA) for Elemental Parameter and Physico-chemical using the principal component analysis method of extraction for rotation sums of squared loadings were presented in Table 5 to Table 6. To determine the number of components to retain in the results, the value of variance after rotation was examined and only components with Eigenvalue ≥ 1 after rotation were considered significant. The rotation converged in 7 iterations with 6 components extracted which accounted for the 886.88% of the total variance observed. The first components accounted for 35.51% of the total variance observed which was significantly contributed by Na^{2+}, K^{+}, Ca^{2+}, SO_4^{2-}, NH_4^{+}, PO_4^{3-}, HCO_3^{-}, Cu^{2+}, Pb^{2+}, Cd^{2+} and Si and weakly by NO_3^{-}. The second components reveal 35.51% of the total variance observed displaying a moderate to high correlation for $MgCO_3^{-}$ and Al^{3+} a moderate one to SO_4^{2-}. The third components represent 11.62% of the total variance which was contributed by Cl^{-}, Zn^{2+}, Fe^{3+}, S and Si. The fourth component represents 9.53% of the total variance observed in the formation which was strongly and positively contributed by NO_3^{-} and Mg^{3+}. The fifth component accounted for 8.73% of the total variance observed and was significantly contributed by Cr, Co and Ni. The sixth components accounted for 5.89% of the total variance observed with high factor loadings for Mn^{2+}, S and I and moderate ones for Zn^{2+}.

The relatively high weights for SO_4^{2-} on C1 and C2, and moderate loadings of Zn^{2+} and S on C3 and C6 lead one to believe that SO_4^{2-}, Zn^{2+} and S have two different origins given that their weights on C4, and C5 are very small. The result is supported by the principal component scores of box data plotted on their respective positions on the components in rotated spaces in Fig 6; this is supported by the dominance of HCO_3^{-} among the water quality determinants displayed in the bubble plot (Fig. 7).

In Physico-chemical Parameters of Itori boreholes, the rotation converged in 10 iterations and 5 components were extracted which accounted for 86.15% of the total variance observed. The first component accounted for 22.40% of the total variance observed with high factor loadings for BOD, COD and ALK and a moderate one for EC and TH. The second component accounted for 21.30% of the total variance observed which was significantly contributed by TEMP, EC, ALK and THC. The third component accounted for 16.85% and significantly contributed by a very high factor loading for TDS. The fourth component accounted for 16.04% of the total variance and was significantly contributed by PH and TSS While the fifth component accounted for 9.56% and was significantly and strongly contributed sorely by DO.

The continuous emergence of EC and ALK in C1 and C2 depicts the strong contributive influence of the duo in the present hydrogeochemical conditions of the subsurface environment of the study area. The degree of relationship of the tested Physico-chemical Parameters is shown by the principal component scores of box data plotted on their respective positions on their components in rotated space in Fig. 6.

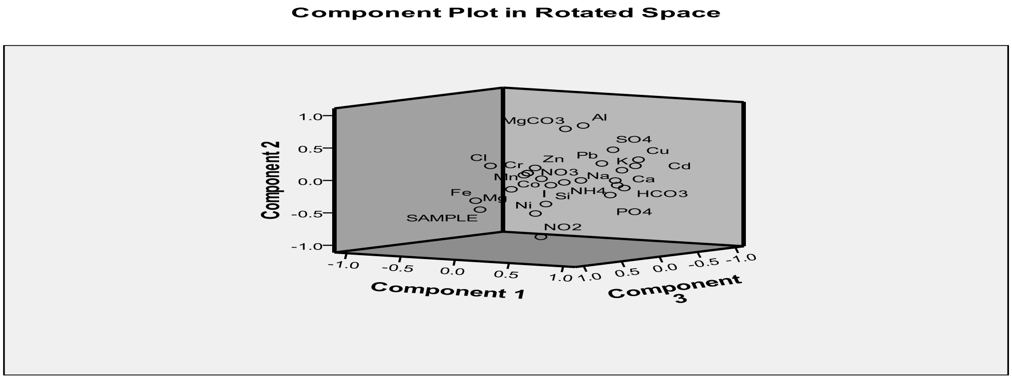

Fig. 5: Plot of Extracted Components 1, 2 and 3 of Elemental Parameters of Itori Boreholes in Rotated Space

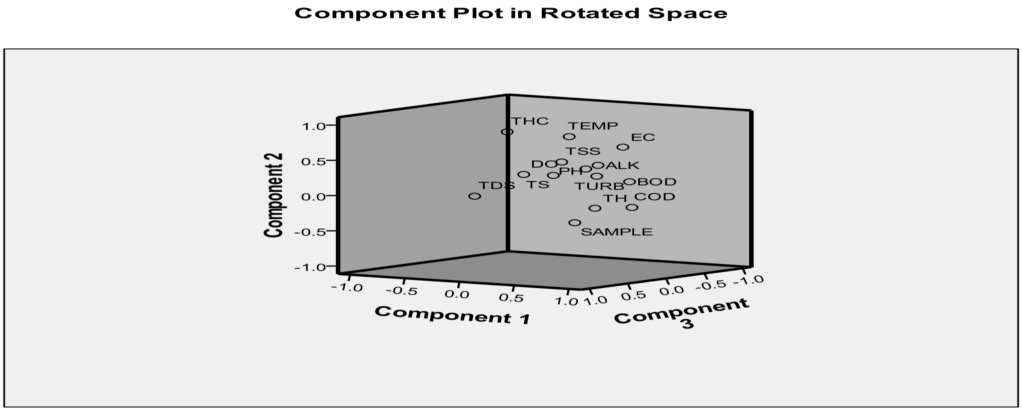

Fig. 6: Plot of Extracted Components 1, 2 and 3 of Physico-Chemical Parameters of Itori Boreholes in Rotated Space

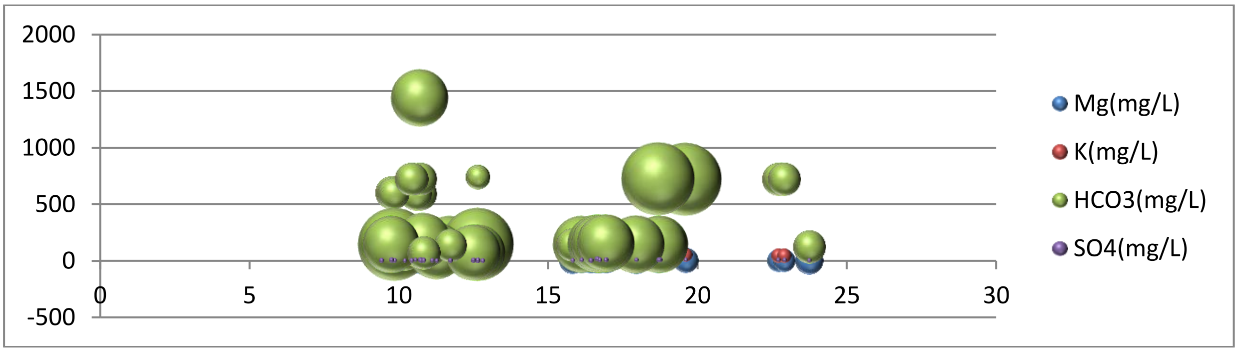

Fig. 7: Bubble Plot of Itori quality determinants showing the predominance of HCO_3^{2-}

DISCUSSION

Ultimate benefit can be derived from water usage when it is within acceptable quality standards; however, where there are certain alterations in the physiochemical parameters, it is quite imperative that it passes through different processes of treatment and management practices in order to improve quality prior to such usage, especially for consumption and other domestic usage. The pH of boreholes and well water from all the sampled locations in Itori is within the permissible standards, the Nigerian standard for Drinking Water Quality (NSDWQ, 2007; Udousoro and Umoren, 2014) inclusive with a safety range (6.5-8.5) and the WHO (2011a) limit (Table 1 and Table 2). The pattern of the overall ionic dominance for Itori follow the trend Cl^- >K^+ >Na^{2+} > Fe^{3+} > NO_3^- >NO_2^- >Mn^{2+}. The borehole and well water samples contain more Fe^{3+} than Mn^{2+} (Table 1 and Table 2) which is in agreement with (USEPA, 2002) report while the elevated values of HCO_3^- and $MgCO_3^-$ are suggestive of possible subsurface dilution of the weathering of the carbonate rocks of the study area being a typical limestone formation; this is supported by the predominance of HCO_3^- among the water quality determinants displayed in the bubble plot (Fig. 14) The results obtained for microbial analyses are shown in Table 3 and Table 4. The highest Total Coliform Count of 241 x 10^2 MPN/100 ml is found in well water while the highest (THBC) and (FCC) are also found in well water samples; 5.2x10^2 cfu/ml and 6.5 x 10^2 cfu/ml respectively. The high coliform count obtained from the analyzed groundwater samples of the investigated study area implies poor sanitary conditions of the water body, and is also an indication of pollution by organic materials (AGWT, 2013; APHA, 1992; Mahananda *et al.,* 2010; Sha'Ato *et al.,* 2010; WHO, 2011a).

CONCLUSION

The Elemental, Physicochemical and Microbial analyses of potable water sources in Itori communities of Ewekoro Local Government of Ogun State, South-West Nigeria reveals that the boreholes are Alkaline. The BOD, ALK, Cl^-, NH_4^+, HCO_3^{2-}, $MgCO_3^-$, Zn^{2+} and Fe^{3+} and Total Coliform levels were found to be higher than the recommended limits of the set standards including WHO and NESREA with the quality determinants revealing the predominance of HCO_3^{2-}. The BOD5:NO_3^- ratio-an index of organic pollution implies that the investigated boreholes were heavily polluted with materials of possible organic origin. Pollution sources may include among others, wastes from domestic and agricultural activities, leachates from waste dumpsites and sewer tanks. These boreholes are invariably grossly unfit for human consumption and detrimental to biological population. There is therefore need for the institution of a statutory unit saddled with the ultimate responsibility for continuous monitoring of water bodies, sensitization and education of the rural populace within and outside Itori community in order to safeguard the clinical safety and general wellness of the inhabitants from the adverse health implications due to presence of threatening and toxic biochemical and microbiological materials that have possibly migrated their ways to the subsurface groundwater environment of the investigated boreholes.

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