E-ISSN: 1115 – 8492 P-ISSN: 3027 - 0693
MPRI-JNSAR | INTERNATIONAL JOURNAL OF NATURE AND SCIENCE ADVANCE RES.
VOL. 09 NO. 9 JULY-2025

ASSESSMENT OF PHYSICO-CHEMICAL AND BACTERIOLOGICAL CONTAMINATION OF GROUNDWATER USING INTEGRATED MULTIVARIATE TECHNIQUES IN SELECTED PARTS OF OGUN STATE SOUTH-WEST NIGERIA

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DOI: https://doi.org/10.70382/mejnsar.v9i9.060

Abstract

Aside from the significance of groundwater quality in human health, its potency in attracting a great deal of interest cannot be overemphasized. In an attempt to evaluate the physico-chemical and bacteriological characteristics of groundwater in selected parts of Ogun State, integrated Multivariate techniques were employed on the acquired sampled datasets involving Descriptive statistics using mean and standard error; Correlation Analysis (CA), Duncan Multiple Range Test (DMRT) and Principal Component Analysis (PCA) were carried out characterize and determine the relationship and contribution of the parameters to the variation within a group of entries. The parameters were determined from a total of 240 samples collected from

Keywords: Bacteriological, E-coli, Groundwater, Hand-dug wells, Multivariate, Samples

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30 communities across the 5 investigated Local Government Area of Ogun State both in Wet and Dry season. The data were processed and analyzed using SPSS statistical package. the results were grouped into four risk categories, namely low risk (<1 per 100 mL), medium risk (1-10 per 100 mL), high risk (11-100 per 100 mL) and very high risk (>100 per 100 mL) where 86.6% and 63.33% accounted for medium risk while 13.33% and 36.66% accounted for high risk with no exhibited recorded value for low and very high risk in both in both wet and dry season respectively based on the allowable standards of the Nigerian Industrial Standard which recommends zero E.coli per 100 mL of drinking water samples. There is therefore need for the existence of a statutory unit charged with responsibility for continuous monitoring of water bodies, sensitization and education of the rural populace of the study area on the adverse health implications of the presence of toxic materials in their water supply sources.

INTRODUCTION

Background Statement

Water, a universal solvent and natural resources tapped by man, plants and animals either in vapour, liquid or solid form is one of the important needs of life that guarantees living (Amadi et al., 2015). It`s quality, which can be traceable to chemical composition of precipitation, mineral composition of aquifer and beds through which the water moves, and the chemical reaction occurring on lands and in soil zones, as well as anthropogenic activities within the vicinity of the source of abstraction, either promotes or reduces life (Aminu & Amadi, 2014). Traditionally, the spread and extent of human settlement beyond the major riparian zones of Sub-Saharan Africa and across many other arid regions of the world, has been determined by availability of groundwater supplies, accessed through hand-dug wells and springs (Pavelic et al., 2012). In more recent times, groundwater is the preferred means of supplying water to meet the growing demand of the rural, dispersed communities and the small urban towns across Sub-Saharan Africa. About 84 percent of the Sub-Saharan Africa people (326 million) who lives in rural areas, lack adequate access to safe domestic water. Majority of this population obtain their water from a combination of unprotected and untreated surface water and groundwater sources (including unimproved hand-dug wells). It is estimated that about 100 million of the rural population throughout Sub-Saharan Africa are serviced by groundwater for domestic supplies and livestock rearing, with most of the villages and small towns having access to groundwater supplies (Masiyandima & Giordano, 2007; Adelana & MacDonald, 2008).

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Water is very important in the maintenance of human health and this has resulted in three crucial concerns in the relationship between water and health. Firstly: managing quantity constraints faced by water-poor countries and their impact on human activities; secondly: the maintenance of water quality in the face of growing demand; and thirdly the direct link between health and water as pertains to diseases. Most of the diseases that contaminate water are equally linked to animal or human waste and are communicable. These diseases have health effects that are heavily concentrated in the developing world (Batterman et al., 2009).

However, the degradation of physical and chemical quality of water due to natural or human influence is often gradual and may not always be readily detected until a dramatic shift in ecosystem condition occurs. Additionally, subsurface water flow and solute transport through heterogenous porous media is greatly influenced by the flow dynamics as well as the recharge components. Many water-borne diseases such as diarrhea, dysentery, cholera, and thyphoid occurred because of consumption of contaminated water. The importance of groundwater quality in human health has recently attracted a great deal of interest (Vasanthavigar et al., 2012). About 80% of all illness in developing countries is related to water and sanitation and 15% of all child mortality below the age of five years in developing countries is attributed to diarrhoeal diseases (Thompson & Khan, 2003).

The townships in the study area have no standard treated pipe borne water supply systems due to the absence and inefficiencies of public water supply from the government. Utilization of water for domestic and industrial purposes is primarily dependent on groundwater resources tapped through hand-dug wells constructed in households. This has resulted in indiscriminate drilling of boreholes and hand-dug wells without proper regulations and considerations for groundwater quality. Therefore, knowledge of the bacteriological characteristics of groundwater is important because the contents of the shallow aquifers often end up being tapped through wells for various uses by households (Fig. 1a and Fig. 1b).



Fig. 1a: hand-dug well located at Mr. Soneye House, Paramount Estate, Owode Afon



Fig. 1b: poor well completion and unhygienic abstraction practices-Ijoun.

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These hand-dug wells are of varying depth depending on the geological formation through which the well is dug. However, septic systems that are not properly sited, designed, constructed or maintained, indiscriminate waste disposal, industrial discharge and other form of environmental pollution can contaminate groundwater with bacteria, viruses, metals, nitrates and other chemical substances that may have adverse effects on human life, more especially pregnant women, nursing mothers and children.

Total coliforms are a group of bacteria commonly found in the environment, for example in soil or vegetation, as well as the intestines of mammals, including humans. The presence of total coliform bacteria in water indicates that the water supply may be vulnerable to contamination by more harmful microorganisms. Escherichia coli (E. coli) is the only member of the total coliform group of bacteria that is found only in the intestines of mammals, including humans. The presence of E. coli in water indicates recent fecal contamination and may indicate the possible presence of disease-causing pathogens, such as bacteria, viruses, and parasites (Amadi et al., 2015). Although most strains of E. coli bacteria are harmless, certain strains, such as E. coli 0157:H7, may cause illness. Total coliforms and E. coli are used as indicators to measure the degree of pollution and sanitary quality of well water, because testing for all known pathogens is a complicated and expensive process. The main source of pathogens in drinking water is through recent contamination from human or animal waste, from improperly treated septic and sewage discharges, leaching of animal manure, storm water runoff. Bacteria and other harmful microorganisms from domestic animals may be washed into groundwater sources through runoff after rain. Poor well construction or poor maintenance can also increase the risk of groundwater contamination of coliform bacteria (Somaratne & Hallas, 2015). The maximum acceptable concentration for drinking Water is 0 per 100 mL This means that in order to conform to drinking water guidelines; for every 100 mL of drinking water tested, no total coliforms or E. coli should be detected (Standards Organisation of Nigeria [SON], 2007; World Health Organization [WHO], 2008).

The health effects of exposure to disease-causing bacteria, viruses, and parasites in drinking water area varied. The most common symptoms of waterborne illness include nausea, vomiting, cholera, typhoid, dysentery and diarrhea (Vinodhini & Narayanan, 2008). Infants, the elderly, and those with compromised immune systems may suffer more severe effects. In extreme cases, some pathogens may infect the lungs, skin, eyes, nervous system, kidneys, or liver and the effects may be more severe, chronic, or even fatal (Elsas et al., 2011).

Since the physical, chemical and biological composition of water affects its ability to sustain healthy ecosystem and an abundant supply of clean, usable water is a basic

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requirement for many of the fundamental uses of water on which human existence depends, the research is considered relevant and expedient (GEMS, 2008).

Study area

Location and Accessibility

The study area is located in the western part of Ogun State and lies within Latitude 6°30¹N to 7°50¹N and Longitude 2°40¹ to 3°15¹E. The study area as shown in figure 2, consists of 30 selected communities from five Local Governments Areas (Ipokia, Yewa South, Yewa North, Imeko-Afon and Ado-Odo/Ota) within the sedimentary terrain of Ogun State. The area covered include Ihunbo, Idiroko, Agosasa, Ijofin and Ipokia in Ipokia Local Government Area; Ilaro, Idogo, Owode, Ajilete, Oke-Odan, in Yewa South Local Government Area; Ayetoro, Joga, Ibooro, Imasai, Ibese, Igbogila, Eggua, Igan Alade, Tata, Owode Ketu, Ijoun, Ebute Igbooro, Oja-Odan and Ohunbe in Yewa North Local Government Area; Idi-Emi, Afon, Imeko, Idofa and Ilara in Imeko Afon Local Government Area as well as Ado-Odo in Ado-Odo/Ota Local Government Area. A total of 240 samples were collected from the 30 communities across the 5 Local Government Areas of the study location in both wet and dry seasons. All the Local Government Area investigated and their respective sample location points are well represented in a georeferenced map of the study area as shown in Fig.2

Climate and Vegetation

The study area is typified by the moderately hot, humid tropical climatic zone of southwestern Nigeria. It has two distinct seasons, namely, the rainy season (April-October) and the dry season (November-March). The temperature is relatively high during the dry season with the mean around 30°C. The harmattan, which brings in the northeasterly winds from December to February, has ameliorating effects on the dry season high temperatures. Low temperatures are experienced during the rains, especially between July and August when the temperatures could be as low as 24°C (Omigbogun, 2013). The rainfall is bimodal with peaks in July and September and the onset of the rain varies from late March to April. The wet season is about 200 days in length finishing around late October. The rain is convectional and can sometimes come with heavy showers. The rain of the second modal is small showers and frontal. The distribution of annual rainfall ranges from 960-1200 mm (Adejuwon & Odekunle, 2006; Ayanlade et al., 2018).

The study area has two main types of vegetation, namely, tropical rain forest and derived Savanna. The tropical rain forest is found in the coastal areas of Ipokia and the southern part of Yewa South LGAs. The derived Savanna is found most in Yewa North, Imeko Afon

and Ado-Odo/Ota LGAs. The derived Savanna, with relict forest, was originally the drier part of the high forest. Due to bush burning and overgrazing, cultivation and hunting activities over a long period in the zone, the high forest trees were destroyed and the forest that used to exist is now replaced with a mixture of grasses and scattered trees. However, along the streams and in wet low-lying areas where surface water accumulates there are still some traces of forests (Eroarome, 2009).

Soils of the study area can be classified into the interior zones of laterite soils and southern belt forest soils (quaternary, tertiary and cretaceous) (Fig. 3). The interior zone of laterite soils is made up of sands and clays (Oyenuga, 1967). They are grey to black, poorly drained, and seasonally flooded clays, forming the "fadama". Soil in this zone is deeply corroded, generally sticky and impervious to water and has low fertility. When the virgin forest on them is cleared, it reduces the fertility further, thus making available soil of little agricultural value. However, the Southern belt of forest soils on the other hand broadly represent those of the humid, tropical forest climate zones of the south where the wet season is long, the *harmattan* season short and forest cover is dense. Local soil types depend largely on parent rock. Where the underlying rocks are granite or clay, the soils are rich clayey loam. The forest soils yield cocoa, oil palm, rubber and they are of considerable importance in Nigerian agriculture. Soils of the study area are further classified into the following: *Soils under a low base saturation* (Humid tropical zone) – Oxisols and Ultisols under forest vegetation (Sobulo, 1985).

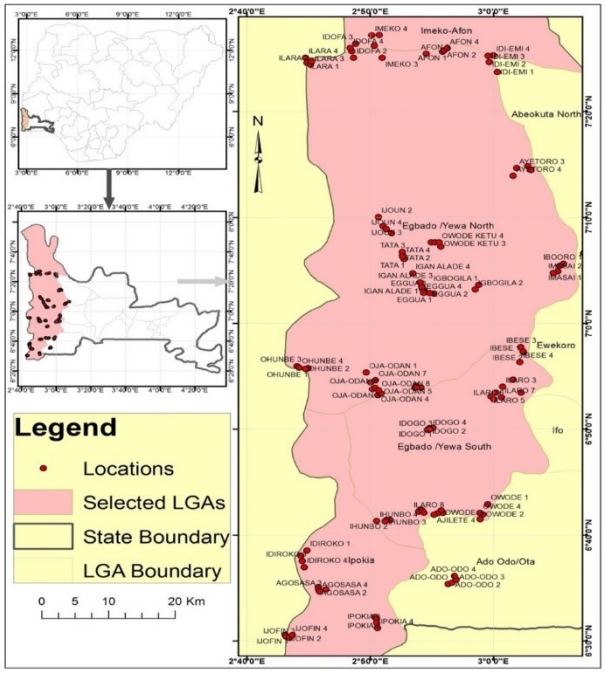

Fig. 2: Georeferenced Map of Study Area Showing Sample Location Points

Geology and Hydrogeology of the study area

The geology of the study area consists mainly the younger and older sedimentary rocks of both the tertiary and secondary ages (Iloeje, 1981). These sedimentary rock units consist of the Abeokuta Formation lying directly above the Basement complex (Fig. 4). The Abeokuta Formation is overlain by Ewekoro

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Formation which is in turn overlain by Oshosun and Ilaro Formations (Jones & Hockey, 1964; Adegoke, 1977; Olurin et al., 2015).

The Coastal Plain Sands overlie the Ilaro Formation (Fig.4). The lithology of the Abeokuta Formation consists of sands, sometimes reddish brown in colour. It contains intercalcations of argillaceous sediments with the rocks being soft and friable, but in some places cemented by ferruginous siliceous materials (Offodile, 2002). The Ewekoro Formation consists of a limestone unit of several meters in thickness, which is overlain by a shale unit. The Ilaro Formation consists of continental fluvialtile sandstones. The sands are usually coarse, angular and poorly sorted containing significant clay formation. The Coastal Plain Sands, however, consist of yellow and white sands with pebbles at some levels (Ako et al., 1980).

The Quaternary to recent age alluvial deposits which includes recent littoral sandy alluvium also occur along main river valleys (Jones & Hockey, 1964; Longe et al., 1987). The alluvial deposits consist of gravel, coarse and fine sands, silt and clay.

Major aquifers in the coastal zone of Western Nigeria occur in sands and overburden/superficial deposits while shales and clays form the impermeable horizons (Longe et al., 1987).

The hydrogeology of the study area as shown in Fig. 4 below comprises; **Abeokuta Formation:** which are soft, gritty, white clay or tough, silicified, ferruginous sandstone (Ilara, Idofa, Imeko, Afon, Idi-Emi, Ayetoro, Igbogila, Imashai and Ibooro). **Ewekoro Formation**:consisting of limestone member overlain by shale (Eggua, Igan-Alade, Ibese, Ijoun, Ijale Ketu, Owode Ketu, and Tata). **Ilaro Formation**: consisting of coarse sands, angular and poorly sorted with considerable clay formation (Ilaro, Oja-Odan, and Ohunbe). **Alluvial Deposits**: Consisting of coarse, clayey, unsorted sands with clay lenses and occasional pebble beds. **Coastal Plain Sands**-consist of soft, very poorly sorted, clayey sand, pebbly sands, sandy clays and rare thin lignite (Idiroko, Ipokia, Agosasa, Ijofin, Ihunbo, Oke-Odan, Ajilete, Owode, and Eredo).

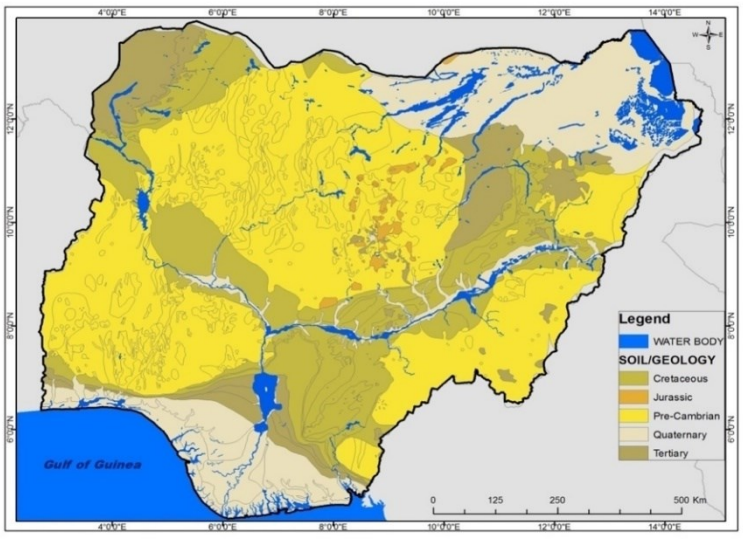

Figure 3: Generalised Rock Map of Nigeria. (Adapted from Obaje, 2009)

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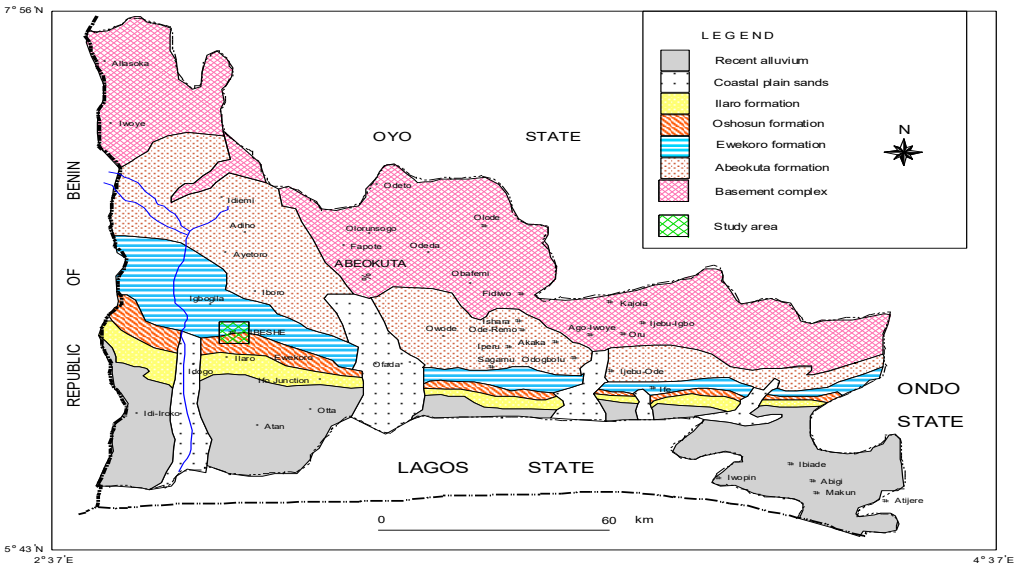

Fig. 4: Map of Ogun State showing the Geology of the Study Area (Adapted from Fasunwon *et al*. 2010).

Materials and Methods

Field Sample Collection and Analysis

Water samples were collected from existing hand-dug wells at strategic sampling points within the study area. Most of the samples were obtained from wells which serve as sources of household water supply. Physico-chemical and bacteriological Parameters measured in the field include temperature, static water level, total well depth, and the presence of possible pollution sources within 30m of the hand-dug location were also identified with the aid of measuring tape. The coordinates of individual hand dug well, as well as the altitude above mean sea level were measured using geographical positioning system (GPS-Etrex legend model). These measurements were carried out both in dry and wet season putting the sample location and respective sizes shown in table into consideration.

Table 1: Sample location and sample size

S/N	Local Government Area	Community	Number of Samples	
1	**Imeko Afon**		**Wet Season**	**Dry Season**
		Idi-Emi	4	4
		Afon	4	4
		Imeko	4	4

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		Idofa	4	4
		Ilara	4	4
2	**Yewa North**	Ayetoro	4	4
		Joga	2	2
		Ibooro	2	2
		Imasai	2	2
		Igbogila	2	2
		Ibese	4	4
		Eggua	4	4
		Igan-Alade	4	4
		Tata	4	4
		Owode-Ketu	4	4
		Ijoun	4	4
		Ebute-Igbooro	4	4
		Ohunbe	4	4
		Oja-Odan	8	8
3	**Yewa South**	Ilaro	8	8
		Idogo	4	4
		Owode	4	4
		Ajilete	4	4
		Oke-Odan	4	4
		Ado-Odo	4	4
4	**Ipokia**	Ihunbo	4	4
		Idi-Iroko	4	4
		Agosasa	4	4
		Ijofin	4	4
		Ipokia	4	4
	Total		**120**	**120**
	Grand Total		**240**	

Laboratory Analysis of Water Sample Samples

Standard methods for the examination of water and waste water were used to analyze all the parameters and this was conducted at the Federal Ministry of Water Resources Regional Water Quality Laboratory, Akure, Nigeria. Total coliform count was determined using membrane filter method (APHA, 2002). Fifty milliliters (50 mL) of sample were measured into sterile bottle and an air space was left to facilitate mixing of the sample

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prior to filtration. Alcohol-flame forceps were used to pick absorbent pad and absorbent pad placed in sterile petri dish bottom. One sterile pad was used for each sample. The absorbent pad was soaked with 2.0 mL of nutrient medium (M-Endo Broth). The nutrient medium was dispensed with a sterile pipette. The tips of the blunt-ended forceps were sterilized in a flame and allowed to cool. Sterilized membrane filter was carefully removed from its package holding it only by the tips and placed in the filter apparatus and clamped in place. Sample was mixed thoroughly by gentle agitation for 30 seconds. Twenty (20 mL) sample was measured with sterile pipette and the sample was filtered under partial vacuum. Membrane filter was removed from filtration unit using the sterile forceps and rolled on the absorbent pad avoiding entrapment of air and dish half was replaced. Filter was rinsed using three 20mL portion of sterile dilution water. Petri dish was left at environmental temperature for 2 hours to acclimatize; thereafter it was inverted and incubated for 24 hours at 35 ℃. Coliform density was computed from the membrane filter count within the 20-80 coliform colony range. The formula for calculating the total coliform is presented in equation 1 below.

$$\textbf{Total Coliform/100mL} = \frac{\textbf{coliform colonies counted x 100}}{\textbf{mL sample filtered}}$$

E-Coli were also determined using the membrane filter method (APHA, 2002). To achieve this, one (1 mL) of water sample was inoculated into Petri-dish containing 0.2mL of MacConkey Agar. The content was mixed thoroughly by gentle agitation and allowed to cool. This was then incubated at 44 ℃ for 24 hours. If the sample water contains bacteria, there is a tendency for the growth of microbes to occur in colonies. Growth with the production of gas in the lactose peptone water confirms the presence of thermotolerant coliforms. Production of a red colour indicates the synthesis of indole from tryptophan and confirms the presence of E. coli. To determine the fitness of water sources in the study area for drinking, the bacteria species Escherichia coli (E. Coli) which is the most commonly recommended faecal indicator were measured both at the in the groundwater drawn from hand-dug wells.

Analyses of Acquired Water Sample Data

Descriptive and Multivariate analyses were performed on a series of water quality data. The adherence to the analytical quality control was ensured through procedural blank measurements, duplicate analyses of water samples and standardization of analytical laboratory devices (APHA, 2002; Ishola, 2024). Statistical Package for Social Sciences (SPSS) software package version 22.0 was used to analyze the water quality data. The statistical tools used include: descriptive statistics such as minimum, maximum, mean,

standard deviation and standard error. Inferential statistics such as analysis of variance and principal component analysis were also employed. The effect of season on the water quality parameters was tested using a t-test. Duncan Multiple Range Test (DMRT) was used to determine the significance of the means at 0.05 probability level. Relationship between the parameters was determined through Pearson`s product moment correlation. Principal component analysis was also used to identify which water quality parameters contribute most to the variation within a group of entries.

Results and Discussion

Descriptive Statistics of Bacteriological Parameters of Sampled Water

Based on the analysis mean values obtained from the entire study area there is no wide difference between total depth, temp, and pH in the groundwater environment of the study area but Electrical conductivity and TDS were found to be higher in Wet season than in the dry season while Total coliform and E. coli exhibited lower concentration value in wet season than in dry season as shown respectively for dry and wet season in Table 2 and Table 3 and complemented in a pictorial representation in Fig. 5. The results were grouped into four risk categories, based on the allowable standards, which recommends zero E. coli per 100 mL of drinking water samples namely low risk (<1 per 100 mL), medium risk (1-10 per 100 mL), high risk (11-100 per 100 mL) and very high risk (>100 per 100 mL) (Standards Organization of Nigeria [SON], 2007). As displayed in Table 4, 86.6% and 63.33% accounted for medium risk while 13.33% and 36.66% accounted for high risk while no recorded value was exhibited for low and very high risk in both wet and dry season respectively.

Table 2: Descriptive Statistics of Bacteriological Parameters of Water from Hand- Dug Wells Sampled in Dry Seasons

Parameters	Range	Min.	Max.	Mean	WHO	SON
Static Water Level (m)	61.99	2.83	64.82	25.53±1.55	NA	NA
Total Depth (m)	74.69	3.27	77.96	25.54±1.72	NA	NA
Temperature (˚C)	4.70	27.10	31.80	29.38±0.98	NS	NS
pH	3.67	4.74	8.41	6.86±0.76	6.5-8.5	6.5-8.5
EC (μScm^{-1})	1150	10.00	1160	204.84±245.99	1000	1000
TDS (mgL^{-1})	574	6.00	580	100.98±121.63	500	500
Total Coliform (cfu/mL)	107	4.00	111	36.05±17.22	0.00	10
E-Coli (cfu/100mL)	61.00	0.00	61.00	9.84±6.84	0.00	0.00

Min-Minimum, Max-Maximum, NS-Not Specified, NA-Not Applicable, (Standards Organisation of Nigeria [SON], 2007; World Health Organization [WHO] (2017).

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Table 3: Descriptive statistics of bacteriological parameters of water from hand-dug-wells sampled in wet seasons

Parameters	Range.	Min.	Max.	Mean	WHO	SON
Static Water Level (m)	60.90	2.10	63.00	21.93±1.56	NA	NA
Total Depth (m)	74.69	3.27	77.96	25.564±1.72	NA	NA
Temperature (°C)	8.10	26.40	34.50	28.98±0.12	NS	NS
pH	2.95	4.73	7.68	6.32±0.05	6.5-8.5	6.5-8.5
EC (µScm^{-1})	1100	22.00	1122	242.21±22.32	1000	1000
TDS (mgL^{-1})	554	10.00	564	120.57±11.17	500	500
Total Coliform (cfu/mL)	124	0.00	124	28.16±1.530.00		10
E-Coli (cfu/100mL)	52	0.00	52.00	8.00±0.59	0.00	0.00

Min-Minimum, Max-Maximum, NS-Not Specified, NA-Not Applicable, (Standards Organisation of Nigeria [SON], 2007; World Health Organization [WHO] (2017).

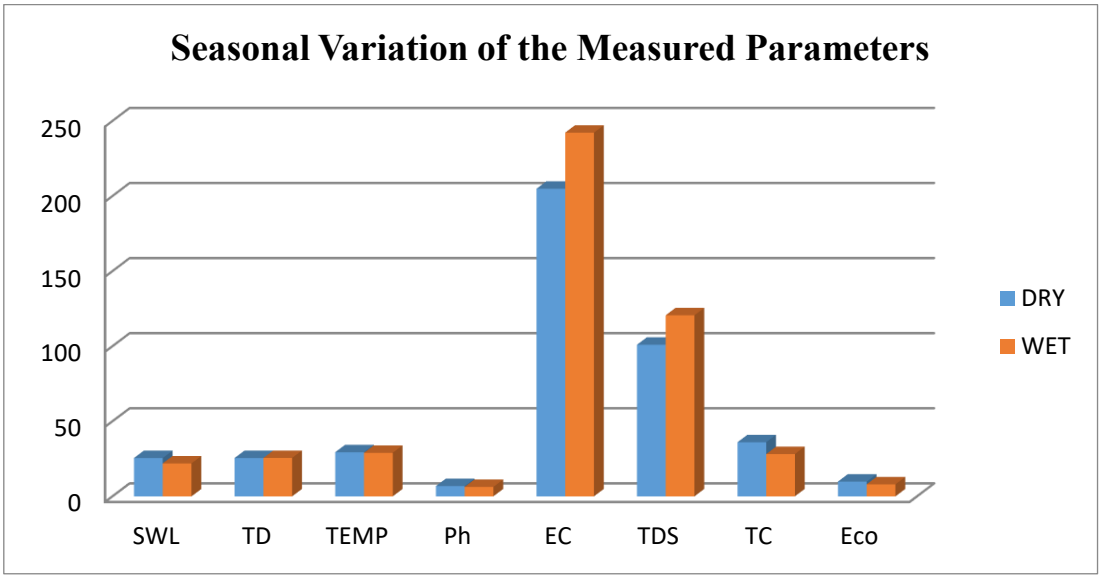

Fig. 5: Seasonal Variation of the Measured Parameters in the Study Area

Table 4: Description of Water Quality of the study area based on by E-Coli contamination

Quality	Wet Season Average (%)	Dry Season Average (%)
Low (<1 per 100mL)	0.00	0.00
Moderate (1-10 per 100mL)	86.66	63.33
High (11-100 per 100mL)	13.33	36.66
Very High (>100 per 100mL)	0.00	0.00
Total	**99.99**	**99.99**

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Correlation Analysis of Physico-Chemical and Bacteriological Parameters

The output of Pearson`s correlation analysis of groundwater parameter from hand-dug wells sampled in the study area revealed High positive correlation at P≤0.01 observed between electrical conductivity and total dissolved solids, total hardness, chloride and bicarbonate (r=0.99, 0,81, 0.83 and 0.72) in Imeko-Afon LGA (Table 5); between electrical conductivity and total dissolved solids, total hardness and chloride (r =1.00, 0.79 and 0.83) in Yewa North LGA (Table 6); between electrical conductivity and total dissolved solids, total hardness and chloride (r-0.99, 0.86 and 0.94) in Ipokia LGA (Table 8); The strong correlation between EC and TDS (r=0.99 -Imeko Afon, r =1.00 -Yewa North, r = 0.99 -Ipokia) indicate a common chemical behavior. Significant correlation at P≤0.01 was also observed between Nitrate and E-coli in Yewa South (r=0.56), Nitrate and Total coliform in Ipokia (r=0.41), Phosphate and total coliform in Imeko Afon (r=0.51), phosphate and total coliform in Yewa south (r=0.42) (Table 7); this observed correlation can be attributed to the poor management of human excreta in the study area since phosphate and nitrate can find their way into groundwater sources through poor sewage systems.

Table 5: Mean values of physico-chemical and bacteriological parameters of water from hand-dug wells sampled in Imeko Afon LGA (wet and dry seasons)

Location	SWL	Depth	Temp.	pH	EC	TDS	T. Colif.	E-Coli
Idi-Emi	42.43^{b}	44.98^{b}	29.29^{b}	6.52^{ab}	52.50^{ab}	26.00^{bc}	40.87^{a}	9.13^{a}
Afon	37.31^{b}	41.80^{b}	29.55^{b}	6.75^{a}	73.50^{ab}	36.37^{abc}	35.25^{a}	10.25^{a}
Imeko	47.17^{ab}	52.92^{ab}	30.20^{b}	6.53^{ab}	99.75^{ab}	49.87^{ab}	37.50^{a}	8.63^{a}
Idofa	37.99^{b}	41.32^{b}	29.96^{b}	6.72^{a}	114.13^{a}	57.13^{a}	29.50^{a}	6.00^{a}
Ilara	57.97^{a}	61.21^{a}	32.10^{a}	6.17^{b}	39.87^{b}	16.2^{5c}	13.50^{b}	7.50^{a}
SE	3.51	3.29	0.32	0.16	20.02	9.38	4.82	1.46

abc.... Means with same alphabets along each column were not significantly different (P>0.05)

SE-Standard Error

Table 6: Mean values of physico-chemical and bacteriological parameters of water from hand-dug wells sampled in Yewa North LGA (wet and dry seasons)

Location	SWL	Depth	Temp.	pH	EC	TDS	T. Colif.	E-Coli
Ayetoro	18.75^{bc}	23.08^{b}	29.05^{bcd}	6.88^{ab}	118.37^{bc}	60.37^{bc}	78.13^{a}	18.00^{ab}
Joga	10.61^{cde}	12.88^{bcd}	28.38^{cd}	5.83^{d}	267.75^{abc}	132.25^{abc}	28.75^{cd}	8.00^{c}
Ibooro	9.37^{cde}	11.71^{bcd}	28.4^{5cd}	6.15^{cd}	55.00^{c}	27.25^{c}	19.75^{d}	6.00^{c}
Imasai	22.13^{b}	23.61^{b}	29.05^{bcd}	6.16^{cd}	254.00^{abc}	125.00^{abc}	28.25^{cd}	11.50^{bc}

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Igbogila	11.99^{bcde}	13.58^{bcd}	29.06^{bcd}	6.56^{b}	444.13a	220.63^{a}	33.87^{cd}	10.37^{bc}
Ibese	15.93^{bcd}	20.15^{bc}	29.10^{bc}	6.58^{b}	374.5ab	186.50^{ab}	27.75^{cd}	7.13^{c}
Eggua	3.98^{e}	5.23^{d}	28.81^{bcd}	6.78^{ab}	341.37^{abc}	170.50^{abc}	27.50^{cd}	7.63^{c}
Igan-Alade	3.87^{e}	6.19^{d}	28.88^{bcd}	7.12^{a}	286.37^{abc}	141.75^{abc}	28.75^{cd}	8.63^{c}
Tata	4.94^{de}	6.69^{d}	29.13^{bc}	6.73^{ab}	173.00^{abc}	86.00^{abc}	39.63^{bc}	11.50^{bc}
Owode-Ketu	4.56^{e}	7.14^{d}	28.40^{d}	6.51^{bc}	268.75^{abc}	134.63^{abc}	50.63^{b}	24.37^{a}
Ijoun	5.97^{de}	7.81^{cd}	29.25^{b}	6.64^{b}	300.87^{abc}	147.75^{abc}	53.37^{b}	17.00^{ab}
Ebute-Igbooro	5.33^{de}	6.78^{d}	28.79^{bc}	6.63^{b}	338.13^{abc}	168.25^{abc}	30.13^{cd}	9.00^{c}
Ohunbe	37.51^{a}	45.92^{a}	30.00^{a}	6.73^{ab}	61.25^{c}	32.13^{c}	20.00^{d}	4.50^{c}
Oja-Odan 1	6.89^{de}	8.44^{cd}	29.33^{b}	7.13^{a}	336.87^{abc}	169.37^{abc}	32.63^{cd}	8.25^{c}
Oja-Odan 2	5.42^{de}	6.92^{d}	28.80^{cd}	6.52^{bc}	417.00ab	204.87^{ab}	26.25^{cd}	8.13^{c}
SE	2.24	2.54	0.207	0.126	91.978	45.813	5.643	2.514

abc.... Means with same alphabets along each column were not significantly different (P>0.05), SE-Standard E

Table 7: Mean values of physico-chemical and bacteriological parameters of water from hand-dug wells sampled in Yewa South LGA (wet and dry seasons)

Location	SWL	Depth	Temp.	pH	EC	TDS	T. Colif.	E-Coli
Ilaro 1	29.94^{abc}	31.54^{a}	29.65	6.20^{bc}	143.50^{b}	71.50^{b}	22.75^{cd}	5.25^{c}
Ilaro 2	22.55^{bc}	24.32^{ab}	29.80	5.67^{c}	419.75^{ab}	207.00^{ab}	21.50^{d}	4.87^{c}
Idogo	3.68^{d}	4.95^{ab}	28.21	5.78^{c}	510.37^{a}	252.25^{a}	38.37^{a}	13.50^{a}
Owode	37.52^{a}	42.87^{a}	29.11	6.95^{a}	157.00^{b}	78.13^{b}	35.37^{ab}	9.75^{b}
Ajilete	18.62^{c}	23.03^{ab}	28.85	6.69^{ab}	205.63^{b}	100.00^{b}	30.37^{abc}	6.75^{bc}
Oke-Odan	36.26^{ab}	39.30^{a}	29.33	6.92^{a}	296.25^{ab}	147.87^{ab}	27.87^{bcd}	6.75^{bc}
Ado-Odo	20.57^{c}	34.99^{a}	28.91	7.06^{a}	153.13^{b}	76.13^{b}	23.63^{cd}	6.25^{bc}
SE	3.32	5.32	0.24	0.19	86.41	42.95	2.69	1.24

abc.... Means with same alphabets along each column were not significantly different (P>0.05), SE-Standard Error.

Table 8: Mean values of physico-chemical and bacteriological parameters of water from hand-dug wells sampled in Ipokia LGA (wet and dry seasons)

Location	SWL	Depth	Temp.	pH	EC	TDS	T. Colif.	E-Coli
Ihunbo	46.41^{a}	49.30^{a}	29.30^{a}	6.96^{a}	98.00^{b}	49.88^{b}	24.37^{b}	5.37^{b}
Idi-Iroko	30.21^{b}	34.39^{b}	28.76^{ab}	7.14^{a}	100.75^{b}	50.13^{b}	23.86^{b}	7.87^{a}
Agosasa	24.82^{c}	27.92^{c}	28.93^{ab}	6. 21bc	312.50a	155.50^{a}	27.13^{b}	6.13^{ab}

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Location	SWL	Depth	Temp.	pH	EC	TDS	T. Colif.	E-Coli
Ijofin	14.47[d]	15.85[d]	28.64[b]	6.78[ab]	128.37[b]	62.25[b]	35.63[a]	6.63[ab]
Ipokia	13.04[d]	15.17[d]	27.55[c]	6.16[c]	127.37[b]	59.63[b]	27.50[b]	5.63[ab]
SE	1.21	1.19	0.19	0.20	40.81	20.10	2.43	0.76

abc.... Means with same alphabets along each column were not significantly different (P>0.05)
SE-Standadr Error.

Duncan Multiple Range Test (DMRT) of Physico-Chemical and Bacteriological Parameters

According to the Duncan Multiple Range Test (DMRT) analysis, at P>0.05), there are no significant differences in the mean values of temperature, turbidity, total hardness, bicarbonate, total coliform and E-coli obtained in water from hand-dug wells sampled in Idi-Emi, Afon, Imeko and Idofa all in Imeko Afon LGA (Table 9). Likewise, no significant differences were observed in the mean values of total coliform obtained in water samples from hand-dug wells in Joga, Imasai, Igbogila, Ibese, Eggua, Igan-Alade, Ebute Igbooro, Oja-Odan 1 and Oja-Odan 2 in Yewa North LGA (Table 10). In Yewa south LGA, there was no significant difference in the mean of pH obtained in Owode, Ajilete, Oke-Odan and Ado-Odo. Similar trends were observed in the mean values of electrical conductivity, total dissolved solids in Ilaro 1, Owode, Ajilete and Ado-Odo; turbidity in Ilaro 1, Ilaro 2 and Oke-Odan; total hardness in Ilaro 1, Owode, Ajilete and Ado-Odo; total hardness in Ilaro 1, Owode, Ajilete and Ado-Odo; chloride in Ilaro 1, Owode, Ajilete, Oke-Odan and Ado-Odo; phosphate in Ilaro and Ajilete; nitrate in Ilaro 1, Ilaro 2 and Owode; sulphate in Ilaro 1, Ilaro 2, Owode, Ajilete, Oke-Odan and Ado-Odo while there were no significant difference in the mean value of bicarbonate in water from hand-dug wells from all the location in the LGA (Table 10). In Ipokia LGA, no significant difference was observed at P>0.05 in the mean value of turbidity and bicarbonate in Ihunbo, Idi-Iroko, Agosasa, Ijofin and Ipokia as well as total hardness and chloride in Ihunbo, Idi-Iroko, Ijofin and Ipokia. However, significant variation across location and season were observed at P>0.05 for temperature; pH and sulphate; total depth; temperature, pH and sulphate in Imeko-Afon, Yewa North, Yewa South and Ipokia LGA respectively (Table 10).

Table 9: Correlation among Physico-Chemical and Bacteriological Parameters in Imeko-Afon LGA. (N=40)

Parameter	Temp.	pH	EC	TDS	Turb	T. Colif.		E-Coli
Temprature °C		-0.32*	-0.12	-0.19	-0.11	-0.40*	0.13	
pH				0.44**	0.45**	0.03	0.11	0.08
Electrical Conductivity (μScm^{-1})				0.99**	0.06	0.00	0.04	
Total dissolved solids (mgL^{-1})						0.07	0.02	0.00
Total Coliform (cfu/mL)						0.65**		
E-Coli (cfu/100mL)								

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*Correlation is significant at 5% level (2 tailed) **Correlation is significant at 1% level (2 tailed)

Temp.-Temperature, EC-Electrical conductivity, TDS-Total dissolved solids, Turb. - Turbidity, TH-Total Hardness,

CH-Calcium hardness, MH-Magnessium hardness, T. Colif (cfu/mL), Total coliform (cfu/100mL

Table 10: Correlation among Physico-Chemical and Bacteriological Parameters in Yewa North LGA (N=120)

Parameter	Temp.	pH	EC	TDS	Turb	TH	CH	MH	Cl^-	PO_4^{3-}	NO_3^-	SO_4^{2-}	HCO_3^-	T. Colif.	E-Coli
Temp °C		0.167	0.074	0.074	-0.189*	0.076	0.10	0.049	-0.018	0.074	0.121	-0.240**	-0.041	0.090	-0.060
pH			0.028	0.029	-0.066	0.068	138	-0.035	0.006	0.063	0.213*	-0.121	0.285**	0.114	-0.003
Electrical Conductivity (μScm^{-1})		1.00**	-0.203**	0.793**	0.724**	0.741**	0.833**	0.011	0.246**	0.107	0.365**	-0.157	-0.149		
Total dissolved solids (mgL^{-1})			-0.202*	0.790**	0.722**	0.737**	0.832**	0.011	0.244**	0.110	0.362**	-0.151	-0.144		
Turbidity (NTU)						-0.139	-0.138	-0.138	-0.266	-0.035	-0.079	0.322	0.179	0.128	0.066
Total hardness (mgL^{-1})						0.948**	0.869**	0.739	0.012	0.287	0.143	0.608	-0.119	-0.137	
Calcium hardness (mgL^{-1})							0.679**	0.666	-0.026	0.291	0.083	0.584	-0.035	-0.094	
Magnessium hardness (mgL^{-1})							0.702	0.071	0.204	0.191	0.513	0.187	0.170		
Cl^-(mgL^{-1})									0.145	0.191*	0.080	0.338**	-0.150	-0.108	
PO_4^{3-}(mgL^{-1})										0.212*	0.014	0.044	0.288	0.216	
NO_3^- (mgL^{-1})											-0.009	0.102	-0.048	-0.120	
SO_4^{2-} (mgL^{-1})												0.268**	-0.184*	0.120	
HCO_3^- (mgL^{-1})													-0.064	-0.114	
Total Coliform(cfu/mL)														0.809**	
E-Coli(cfu/100mL)															

*Correlation is significant at 5% level (2 tailed) **Correlation is significant at 1% level (2 tailed)

Temp.-Temperature, EC-Electrical conductivity, TDS-Total dissolved solids, Turb. - Turbidity, TH-Total Hardness,

CH-Calcium hardness, MH-Magnessium hardness, T. Colif (cfu/mL), Total coliform (cfu/100mL)

Table 11: Correlation among Physico-Chemical and Bacteriological Parameters in Yewa South LGA (N=56)

Parameter	Temp.	pH	EC	TDS	Turb	TH	CH	MH	Cl^-	PO_4^{3-}	NO_3^-	SO_4^{2-}	HCO_3^-	T. Colif.	E-Coli	SWL	T. Depth
Temp °C		0.23	0.06	0.06	-0.36	0.06	0.05	0.07	0	-0.06	-0.03	-0.08	-0.05	0.12	0.02	.210	0.14
pH			-0.51	-0.51	0.11	-0.37	-0.27	-0.44	-0.5	0.16	-0.5	-0.27	0.02	0.13	0.03	0.33*	0.37**
Electrical Conductivity (μScm^{-1})				1.00	-0.21	0.92	0.88	0.84	0.93	0.01	0.55	0.27	0.23	0.22	0.39	-0.20	-.240
Total dissolved solids (mgL^{-1})					-0.22	0.92	0.87	0.84	0.92	0.01	0.55	0.27	0.23	0.22	0.39	-0.19	-.230
Turbidity (NTU)						-0.17	-0.17	-0.15	-0.18	-0.08	-0.22	0.02	0.04	-0.16	-0.13	-0.15	-.120
Total hardness (mgL^{-1})							0.96	0.9	0.81	0.07	0.46	0.28	0.41	0.21	0.35	-0.10	-.070
Calcium hardness (mgL^{-1})								0.74	0.78	0.07	0.48	0.31	0.43	0.26	0.4	-0.16	-.060
Magnesium hardness (mgL^{-1})									.062	0..34**	0.29*	0.72**	0.19	0.11	0.23	0.00	-.089
Cl^-(mgL^{-1})										.070	0.63**	.110	0.13	0.39**	0.56**	-0.26	-.297*
PO_4^{3-}(mgL^{-1})											.200	.010	.050	0.48**	0.42**	0.24	0.17
NO_3^- (mgL^{-1})												0.36**	.030	0.42**	0.56**	-.383**	-.426**
SO_4^{2-} (mgL^{-1})													-0.17	-.110	-.020	-.296*	-.287*
HCO_3^- (mgL^{-1})														.180	.110	0.11	0.23
Total Coliform(cfu/mL)															0.87**	-0.06	-0.01
E-Coli(cfu/100mL)																-0.20	-0.18
Static water level (m)																	0.84**

*Correlation is significant at 5% level (2 tailed) **Correlation is significant at 1% level (2 tailed)

Temp.-Temperature, EC-Electrical conductivity, TDS-Total dissolved solids, Turb. - Turbidity, TH-Total Hardness,

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CH-Calcium hardness, MH-Magnessium hardness, T. Colif (cfu/mL), Total coliform (cfu/100mL)

Table 12: Correlation among Physico-Chemical and Bacteriological Parameters in Ipokia LGA (N=40)

Parameter	Temp.	pH	EC	TDS	Turb	TH	CH	MH	Cl^-	PO_4^{3-}	NO_3^-	SO_4^{2-}	HCO_3^-	T. Colif.	E-Coli
Temp °C	0.46**	0.07	0.08	-0.04	0.16	0.24	-0.07	0.07	0.20	-0.19	-0.09	0.04	0.32	0.32	
pH			-0.50**	-0.49**	0.07	0.34*	0.10	0.48**	0.46**	-0.10	0.07	-0.12	0.23	0.25	0.27
Electrical Conductivity (μScm^{-1})				0.99**	-0.14	0.86**	0.74**	0.51**	0.94**	0.41**	-0.18	0.03	0.04	-0.09	-0.12
Total dissolved solids (mgL^{-1})					-0.14	0.86**	0.75**	0.51	0.95**	0.41**	-0.20	0.03	0.03	-0.09	-0.12
Turbidity (NTU)						0.13	0.07	-0.14	-0.11	-0.13	0.10	0.29	0.13	-0.09	0.04
Total hardness (mgL^{-1})							0.84**	0.63**	0.78**	0.33**	-0.33*	-0.06	0.24	-0.11	-0.08
Calcium hardness (mgL^{-1})								0.11	0.60**	0.33*	-0.26	-0.07	0.46**	0.04	0.07
Magnessium hardness (mgL^{-1})									0.56**	0.13	-0.23	0.00	-0.23	-0.25	-0.25
Cl^- (mgL^{-1})										0.38*	-0.19	-0.01	-0.07	-0.08	-0.05
PO_4^{3-} (mgL^{-1})											-0.15	0.37*	-0.14	-0.13	-0.21
NO3- (mgL^{-1})												0.34*	-0.24	0.41**	0.19
SO_4^{2-} (mgL^{-1})													-0.23	-0.00	-0.27
HCO_3^- (mgL^{-1})														0.03	0.04
Total Coliform (cfu/mL)															0.73**
E-Coli(cfu/100mL)															

*Correlation is significant at 5% level (2 tailed) **Correlation is significant at 1% level (2 tailed)

Temp.-Temperature, EC-Electrical conductivity, TDS-Total dissolved solids, Turb. - Turbidity, TH-Total Hardness,

CH-Calcium hardness, MH-Magnessium hardness, T. Colif (cfu/mL), Total coliform (cfu/100mL)

Principal Component Analysis of Physico-Chemical and Bacteriological Parameters

Principal component analysis was conducted on the raw data set. Four components (Eigen value>1) accounted for 31.67, 49.79, 62.88 and 70.16% of the total variance in water from hand-dug wells sampled in Imeko Afon LGA (Table 13); 40.72, 51.20, 59.82 and 67.23% of the total variance in Yewa North (Table 14); 48.39, 59.91, 67.79 and 75.04% in Yewa South (Table 15); 38.95, 53.66, 64.44 and 72.71% of the total variance in Ipokia LGA (Table 16). The first principal component (P1) had high contributions from total hardness, electrical conductivity and total dissolved solids with a strong positive correlation of 0.95, 0.89 and 0.88 in Imeko Afon, 0.95, 0.92 and 0.92 in Yewa North, 0.96, 0.97 and 0.97 in Yewa South, 0.92, 0.97 and 0.98 in Ipokia LGA. The three parameters are therefore the largest contributors towards the groundwater quality of the study area. Poor sewage systems which typically produce chloride, phosphate and nitrate, would result to increased conductivity of the receiving water body (Tsimplis, 2008). The second principal component (P2) explained 18.12, 10.48, 11.52 and 14.71% of the total variance attributed to static water level and total depth of the hand-dug wells sampled with a positive correlation of 0.94 and 0.95, 0.86 and 0.86, 0.73 and 0.74, 0.95 respectively in Imeko-Afon,

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Yewa North, Yewa south and Ipokia LGAs. The third component (P3) explains just 13.08 and 8.62% of the total variance and the parameters involved are turbidity and magnesium hardness, turbidity and sulphate respectively in Imeko Afon and Yewa North LGAs.

Table 13: PCA of Physico-Chemical and Bacteriological Parameters of Water from Hand-Dug Wells Sampled in Imeko-Afon LGA

Component	P1	P2	P3	P4
Eigen Value	6.34	3.63	2.62	1.46
Variance Accounted for (%)	31.67	18.12	13.08	7.28
Cumulative Variance (%)	31.67	49.79	62.88	70.16
Static Water Level (m)	-0.12	**0.94**	0.02	0.04
Total Depth (m)	-0.14	**0.95**	-0.03	0.01
Temperature °C	-0.18	-0.46	-0.10	**0.58**
pH	0.48	0.37	-0.18	0.30
Electrical Conductivity(μScm^{-1})	**0.89**	0.18	-0.27	0.10
Total dissolved solids (mgL^{-1})	**0.88**	0.21	-0.27	0.06
Turbidity (NTU)	0.15	0.20	**0.61**	0.26
Total hardness (mgL^{-1})	**0.95**	-0.18	0.05	0.10
Calcium hardness (mgL^{-1})	**0.81**	-0.01	-0.33	0.38
Magnesium hardness (mgL^{-1})	**0.51**	-0.27	**0.66**	-0.32
Cl^{-} (mgL^{-1})	0.16	**0.85**	-0.03	-0.19
PO_4^{3-}(mgL^{-1})	0.07	0.21	0.37	-0.07
NO_3^{-}(mgL^{-1})	**0.57**	0.35	-0.43	-0.10
SO_4^{2-}(mgL^{-1})	-0.23	0.53	0.43	0.31
HCO_3^{-}(mgL^{-1})	**0.86**	-0.28	-0.06	0.14
Total Coliform (cfu/mL)	-0.03	**0.77**	0.35	0.17
E-Coli (cfu/100mL)	-0.02	**0.55**	0.22	0.4

Table 14: PCA of physico-chemical and bacteriological parameters of water from Hand-dug wells sampled in Yewa North LGA

Component	P1	P2	P3	P4
Eigen Value	8.14	2.09	1.72	1.48
Variance Accounted for (%)	40.72	10.48	8.62	7.41
Cumulative Variance (%)	40.72	51.20	59.82	67.23
Static water level (m)	-0.23	**0.86**	0.10	0.33
Total depth (m)	-0.24	**0.86**	-0.09	0.31

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Component	P1	P2	P3	P4
Temperature °C	0.07	0.34	0.40	0.26
pH	0.07	0.34	0.07	**0.69**
Electrical Conductivity (μScm^{-1})	**0.92**	0.01	0.07	0.11
Total dissolved solids (mgL^{-1})	**0.92**	0.02	0.07	0.11
Turbidity (NTU)	0.21	0.23	**0.67**	0.19
Total Hardness (mgL^{-1})	**0.95**	0.01	0.10	0.12
Calcium Hardness (mgL^{-1})	**0.87**	0.10	**0.08**	0.21
Magnessium Hardness (mgL^{-1})	**0.88**	0.10	0.09	0.03
Chloride (mgL^{-1})	**0.88**	0.04	0.06	0.27
Phosphate (mgL^{-1})	0.07	0.46	0.21	0.12
Nitrate (mgL^{-1})	0.30	0.22	0.06	0.41
Sulphate (mgL^{-1})	0.14	0.51	**0.56**	0.03
Bicarbonate (mgL^{-1})	0.54	0.10	0.41	0.47
Total Coliform (cfu/mL)	0.19	**0.80**	0.46	0.14
E-Coli (cfu/100mL)	0.18	**0.70**	0.47	0.29

Table 15: PCA of Physico-Chemical and Bacteriological Parameters of Water from Hand-Dug Wells Sampled in Yewa South LGA

Component	P1	P2	P3	P4
Eigen Value	9.68	2.30	1.58	1.45
Variance Accounted for (%)	48.39	11.52	7.88	7.25
Cumulative Variance (%)	48.39	59.91	67.79	75.04
Static water level (m)	-0.29	**0.73**	-0.38	-0.07
Total depth (m)	-0.31	**0.74**	-0.38	0.05
Temperature °C	0.05	0.16	0.51	**-0.58**
pH	-0.49	0.40	0.50	0.15
Electrical Conductivity (μScm^{-1})	**0.97**	-0.11	-0.02	-0.06
Total dissolved solids (mgL^{-1})	**0.97**	-0.11	-0.03	-0.07
Turbidity (NTU)	-0.23	-0.18	-0.20	**0.69**
Total Hardness (mgL^{-1})	**0.96**	-0.10	0.12	0.11
Calcium Hardness (mgL^{-1})	**0.91**	-0.02	0.09	0.13
Magnessium Hardness (mgL^{-1})	**0.88**	-0.22	0.14	0.05
Chloride (mgL^{-1})	0.92	0.09	-0.13	-0.05
Phosphate (mgL^{-1})	0.11	**0.65**	-0.10	0.11
Nitrate (mgL^{-1})	**0.59**	0.29	-0.53	-0.19

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Component	P1	P2	P3	P4
Sulphate (mgL^{-1})	0.23	-0.23	-0.58	-0.12
Bicarbonate (mgL^{-1})	0.31	0.06	0.45	**0.56**
Total Coliform (cfu/mL)	0.33	**0.87**	-0.05	0.08
E-Coli (cfu/100mL)	0.48	**0.78**	-0.16	0.0

Table 16: PCA of Physico-Chemical and Bacteriological Parameters of Water from Hand-Dug Wells Sampled in Ipokia LGA

Component	P1	P2	P3	P4
Eigen Value	7.79	2.94	2.16	1.65
Variance Accounted for (%)	38.95	14.71	10.79	8.26
Cumulative Variance (%)	38.95	53.66	64.44	72.71
Static water level (m)	0.03	**0.95**	-0.15	0.02
Total depth (m)	0.03	**0.95**	-0.15	0.01
Temperature °C	0.09	**0.56**	0.09	-0.19
pH	-0.51	0.54	-0.08	0.00
Electrical Conductivity (μScm^{-1})	**0.97**	0.05	0.07	0.04
Total dissolved solids (mgL^{-1})	**0.98**	0.06	0.07	0.04
Turbidity (NTU)	-0.17	-0.01	-0.08	0.39
Total Hardness (mgL^{-1})	**0.92**	0.14	-0.15	-0.04
Calcium Hardness (mgL^{-1})	**0.75**	**0.55**	-0.20	0.19
Magnesium Hardness (mgL^{-1})	**0.62**	-0.54	0.12	-0.36
Chloride (mgL^{-1})	**0.93**	-0.02	0.12	-0.08
Phosphate (mgL^{-1})	0.45	0.03	0.25	0.46
Nitrate (mgL^{-1})	-0.30	0.05	**0.73**	0.11
Sulphate (mgL^{-1})	0.00	-0.21	0.51	**0.66**
Bicarbonate (mgL^{-1})	0.04	0.54	**-0.57**	0.22
Total Coliform (cfu/mL)	-0.16	**0.60**	0.54	-0.36
E-Coli (cfu/100mL)	-0.15	**0.61**	0.24	-0.52

Conclusions

Safe drinking water has been recognized globally as a basic requirement for good health. While microbiological contaminated drinking water can lead to diarrhoel diseases including shigellosis and cholera, other pathogens in drinking water can cause hepatitis, typhoid and polio myelitis (Alijanzadeh Maliji et al., 2023). Based on the analyses of the mean values obtained from the entire study area there is no wide difference between

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total depth, temp, and pH in the groundwater environment of the study area but Electrical conductivity and TDS were found to be higher in Wet season than in the dry season while Total coliform and E. coli exhibited lower concentration value in wet season than in dry season as shown respectively for dry and wet seasons. Also, based on the allowable standards of the Standards Organisation of Nigeria (SON), 2007; which recommends zero E.coli per 100 mL of drinking water samples namely low risk (<1 per 100 mL), medium risk (1-10 per 100 mL), high risk (11-100 per 100 mL) and very high risk (>100 per 100 mL) revealed that 86.6% and 63.33% of the microbial loads of E. coli accounted for medium risk, 13.33% and 36.66% accounted for high risk while no recorded value was exhibited for low and very high risk in both wet and dry season respectively. The output of Pearson`s correlation analysis of groundwater parameter from hand-dug wells sampled in the study area revealed High positive correlation at P≤0.01 observed between electrical conductivity and total dissolved solids, total hardness, chloride and bicarbonate in Imeko-Afon LGA; between electrical conductivity and total dissolved solids, total hardness and chloride in Yewa North LGA; between electrical conductivity and total dissolved solids, total hardness and chloride in Ipokia LGA; The strong correlation between EC and TDS in Imeko Afon, Yewa North, and Ipokia) indicate a common chemical behavior. Significant correlation at P≤0.01 was observed between Nitrate and E-coli in Yewa South, Nitrate and Total coliform in Ipokia, Phosphate and total coliform in Imeko Afon, phosphate and total coliform in Yewa south; this observed correlation can be attributed to the poor management of human excreta in the study area since phosphate and nitrate can find their way into groundwater sources through poor sewage systems. Duncan Multiple Range Test (DMRT) analysis, revealed at P>0.05) that there are no significant differences in the mean values of temperature, turbidity, total hardness, bicarbonate, total coliform and E-coli obtained in water from hand-dug wells sampled in Idi-Emi, Afon, Imeko and Idofa all in Imeko Afon LGA. Likewise, no significant differences were observed in the mean values of total coliform obtained in water samples from hand-dug wells in Joga, Imasai, Igbogila, Ibese, Eggua, Igan-Alade, Ebute Igbooro, Oja-Odan 1 and Oja-Odan 2 in Yewa North LGA. In Yewa south LGA, there was no significant difference in the mean of pH obtained in Owode, Ajilete, Oke-Odan and Ado-Odo. Similar trends were observed in the mean values of electrical conductivity, total dissolved solids in Ilaro 1, Owode, Ajilete and Ado-Odo; turbidity in Ilaro 1, Ilaro 2 and Oke-Odan; total hardness in Ilaro 1, Owode, Ajilete and Ado-Odo; total hardness in Ilaro 1, Owode, Ajilete and Ado-Odo; chloride in Ilaro 1, Owode, Ajilete, Oke-Odan and Ado-Odo; phosphate in Ilaro and Ajilete; nitrate in Ilaro 1, Ilaro 2 and Owode; sulphate in Ilaro 1, Ilaro 2, Owode, Ajilete, Oke-Odan and Ado-Odo while there were no significant difference in the mean value of bicarbonate in water from hand-dug wells from all the location in the LGA. In Ipokia LGA, no significant

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difference was observed at P>0.05 in the mean value of turbidity and bicarbonate in Ihunbo, Idi-Iroko, Agosasa, Ijofin and Ipokia as well as total hardness and chloride in Ihunbo, Idi-Iroko, Ijofin and Ipokia. However, significant variation across location and season were observed at P>0.05 for temperature; pH and sulphate; total depth; temperature, pH and sulphate in Imeko-Afon, Yewa North, Yewa South and Ipokia LGA respectively. Furthermore, the principal component analysis conducted on the raw data set revealed Four components (Eigen value>1) which accounted for 31.67, 49.79, 62.88 and 70.16% of the total variance in water from hand-dug wells sampled in Imeko Afon LGA; 40.72, 51.20, 59.82 and 67.23% of the total variance in Yewa North (Table 14); 48.39, 59.91, 67.79 and 75.04% in Yewa South; 38.95, 53.66, 64.44 and 72.71% of the total variance in Ipokia LGA ((Table 16). The first principal component (P1) had high contributions from total hardness, electrical conductivity and total dissolved solids with a strong positive correlation of 0.95, 0.89 and 0.88 in Imeko Afon, 0.95, 0.92 and 0.92 in Yewa North, 0.96, 0.97 and 0.97 in Yewa South, 0.92, 0.97 and 0.98 in Ipokia LGA. The three parameters are therefore the largest contributors towards the groundwater quality of the study area. Poor sewage systems which typically produce chloride, phosphate and nitrate, would result to increased conductivity of the receiving water body (Tsimplis, 2008). The second principal component (P2) explained 18.12, 10.48, 11.52 and 14.71% of the total variance attributed to static water level and total depth of the hand-dug wells sampled with a positive correlation of 0.94 and 0.95, 0.86 and 0.86, 0.73 and 0.74, 0.95 respectively in Imeko-Afon, Yewa North, Yewa south and Ipokia LGAs. The third component (P3) explains just 13.08 and 8.62% of the total variance and the parameters involved are turbidity and magnesium hardness, turbidity and sulphate respectively in Imeko Afon and Yewa North LGAs. Sources of the pollution may include among others, wastes from domestic and agricultural activities, leachates from waste dumps and sewer tanks. The existing hand-dug wells are relatively shallow and susceptible to contaminant loads migrating from the surface. These groundwater bodies invariably, are unfit for human consumption. There is therefore need for the existence of a statutory unit charged with responsibility for continuous monitoring of water bodies, sensitization and education of the rural populace on the adverse health implications of the presence of toxic materials in their water supply sources.

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