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Health Risk Assessment of Groundwater from Selected Areas of Ijebu North, Ogun State, Nigeria

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Abstract:

Safe drinking water is essential to all forms of life and poor water quality is a critical public health concern in many rural areas. This study examined the water qualities and health risk indices of the groundwater samples from selected areas of Ijebu-North Local Government Area of Ogun State, Nigeria. The samples were evaluated for physico-chemical, total metal load, microbial load, targeted health hazard quotient (HQ), health hazard indices (HI), water quality indices (WQI), heavy metal evaluation indices (HMEI), heavy metal toxicity indices (HMTI), heavy metal pollution indices (HMPI) and the environmental water quality index (EWQI) parameters. The results obtained indicate variations in the parameters assessed which were mainly within the World Health Organization recommended limits for drinking water. The hardness, nitrate, the total coliform count and confirmatory fecal coliform counts, iron and cadmium contents were higher than recommended limits. Using the WQI ratings, 25% of the groundwater samples were 'excellent' and 'suitable' for drinking while 75% were unsuitable for drinking. HEI of the groundwater varied from 'medium' to 'high' class while HMPI varied from low to medium and HMTI was in a high class for all the water samples. EWQI values placed Awa and Ijebu Igbo borehole water samples as the best water samples and Oru well water as the worst water sample. Cluster analyses show that Awa and Ijebu Igbo boreholes clustered together and have similar qualities distinct from other locations. Proper treatment of the water samples before use as they can pose health hazards is recommended.

Keywords: Groundwater, Health Risk, Ijebu-North, WHO Standards, Water Quality

1- Introduction

Groundwater is one of the most important sources of drinking water. Groundwater is expected to be clean and free from contamination. Unfortunately, through anthropogenic activities, numerous contaminants often find their way into the groundwater affecting the water quality and consequently impairing human health (Rahmanian *et al* 2017).

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Groundwater qualities are also affected by changes in topography, hydrology, squeezing and catchment system, atmospheric amalgamation, different surface and subsurface geochemical process (Vasanthavigar *et al* 2010). Decline in water quality has been attributed to the population increase, urbanization, industrialization, and concentrated agricultural actions (Poonam *et al* 2013). Pollution of drinking water is responsible for a large number of mortalities and morbidities (WHO, 2017) and about 9.1% of global burden disease and 6.3% of global deaths are due to unsafe water, inadequate sanitation and poor hygiene (Pruss-Ustun *et al* 2008).

Water quality is important in determining the health of individuals and communities (Boadi *et al* 2020). It gives the necessary information on the availability and quantities of solutes and contaminants in water (Tawati *et al* 2018). It is determined based on physico-chemical and microbiological properties (Pal *et al* 2018). Water quality parameters provide a basis for assessing the suitability of water for its intended use and consumption (Akter *et al* 2016).

Groundwater monitoring is necessary to ensure their safety for use (Kot *et al* 2000) and help decision-makers to achieve and sustain universal access to safe drinking water (Charles *et al* 2020). The different models for assessing water quality include multivariate statistical method, modeling techniques and methods based on multi-metric indices (Wu *et al* 2017), water quality index and health risk index.

Water quality index (WQI) is a significant criterion in matching water demand and supply. It is the most effective method of measuring water quality (Akter *et al* 2016). It is commonly based on a comparison of physico-chemical, bacteriological, and metallic parameters with established water quality guidelines (Tian *et al* 2019). WQI integrates numerous physical, chemical and biological parameters into a single number and can represent a comprehensive picture of the water quality level (Bordalo *et al* 2006; Sanchez *et al* 2007). WQIs minimize the data volume to a great extent and simplify the expression of water quality status. They give the overall water quality of a specific area (Tian *et al* 2019). WQI not only makes results easy to understand (Ohwo and Abotutu 2014), it eliminates the variations between different water quality parameters that are used individually or unilaterally. It relates the composition of water with the effects of natural processes and human activities (Meride and Ayenew, 2016).

Assessment of health risks associated with the water quality is inevitable due to serious risks to human health associated with poor water quality (Dwight *et al* 2005). Human health risk assessment determines the nature and probability of adverse health effects on humans exposed to chemicals in a contaminated environment (Li *et al* 2014). It links environmental pollution with human health and qualitatively describes the risk of pollution to human health (Xiaogang, 2011). It can be used as guidance in water environment protection, pollution remediation and water environment risk management (Kavcar *et al* 2009).

Hitherto, there is no comprehensive assessment of water quality and no health risk associated with water quality for the groundwater in Ijebu North LGA of Ogun State Nigeria. This study was carried out to determine the quality of groundwater sources available to the majority of the human population in the selected location of Ijebu North LGA, Ogun State. It compared the quality of borehole and well water from the locations and estimated the health risk associated with drinking water from the boreholes and wells in the location.

2. Materials and Methods

2.1. Study area

Our study area included Ilaporu, Awa, Ijebu Igbo and Oru areas of Ijebu North LGA, Ogun State, Nigeria which (Table 1). This area had an average annual atmospheric temperature of 32 °C.

Table 1. The location and geologic information of the study area

Location	Water type	Latitude (°)	Longitude (°)
Ilaporu	Borehole	6.9578N	3.94268E
	Well	6.99411N	3.30284E
Awa	Borehole	6.75652N	3.93759E
	Well	6.74985N	3.93719E
Ijebu Igbo	Borehole	6.97334N	3.99063E
	Well	6.96701N	3.99531E
Oru	Borehole	6.94511N	3.94105E
	Well	6.9488N	3.94448E

2.2. Sample Collection

Two samples were collected from each borehole and well water from the selected locations in pre-cleaned and capped polyethylene bottles according to standard procedures described in the sampling guide (APHA, 2005). Each bottle was carefully labeled according to the samples and was transported to Lagos State Environmental Protection Agency Alausa, Ikeja Lagos, Nigeria same day for analyses.

2.3. Determination of the Physical and Chemical Parameters of Water Samples

The colour and the odour of the water samples were determined as described in Khediya (2016) and Omer (2020) respectively. The total suspended solid (TSS) content, turbidity, electrical conductivity, dissolved oxygen, the temperature and total hardness of the water samples were determined as described in Baird and Bridgewater (2017). The nitrate, phosphate and sulphate contents of the water samples were determined using a colorimeter at 500nm, 490nm and 680nm wavelengths respectively (Baird and Bridgewater, 2017). The pH of the water samples was determined using BOECO pH bench Top Meter BT-675. The chloride ion was determined with silver nitrate in a neutral or slightly alkaline medium in the presence of potassium chromate indicating the final titration point (Rahmanian *et al* 2017). Total hardness was estimated as follows:

$$\text{Total Hardness } \left(\frac{\text{mg}}{\text{L}}\right) = \frac{Volume\ of\ EDTA\ used\ \times\ Molarity\ of\ EDTA\ used\ \times 1000}{Volume\ of\ Sample\ used}$$

2.4. Determination of Metals Contents of the Water Samples

The digestion and determination of metal contents of the water samples were according to the method prescribed by Sharma and Tyagi (2013) using an atomic absorption spectrometer (AAS) (Perkin Elmer Analyst 100 model).

2.5. Microbiological Analysis of the Water Samples

This involved the estimation of total heterotrophic bacteria (THB) by plate count technique, the estimation of total coliform bacilli by most probable number (MPN) presumptive test and confirmation fecal coliform test (CFCT) as described by Ibe and Okpelenye (2005).

2.6. Estimation of Water Quality Indices

The water quality index was calculated as described in Rahman *et al.* (2020) as:

$WQI = \sum WiQi / \sum Wi$

$Qi = 100[(Vn - Vi)/(Vs - Vi)]$

Vn = the actual amount of nth parameter and Vi = the ideal value of this parameter. (Vi = 0, except for pH (Vi=7.0) and DO (Vi=14.6 mg/L). Vs = the recommended standard of the corresponding parameter. Wi = 1/S; S = recommended standard

The environmental water quality index (EWQI) for the different samples was calculated as described by Zakir *et al* (2020) using the formula: $EWQI = \frac{Water\ Quality\ Index}{Heavy\ metal\ toxicity\ Index}$

The heavy metal toxicity index (HTMI) was calculated as $HMTI = \sum_{i=1}^{n} C\ X\ TS$, C = concentration of metal and TS = Toxicity score/total score of metal

2.7. Estimation of Health Risks Associated with the Consumption of the Water Samples

The health risks were estimated following the procedures outlined in Oyem *et al.* (2015) by calculating the chronic daily intakes (CDI), health quotients (HQ) and health indices (HI) of the metals

$CDI = \frac{Concentration\ of\ metal\ X\ Average\ Daily\ Intake}{Body\ weight}$

$HQ = \frac{chronic\ daily\ intake}{Reference\ dose}$

$H_I = \sum(H_{Q1}, H_{Q2}, \ldots, H_{Qn})$.

The heavy metal evaluation index (HMEI) was calculated as was described in Zakir *et al* (2020) as: $HMEI = \sum_{i=1}^{n}(\frac{HMc}{HMmpc})$ where HM_c = the concentration of heavy metal; HM_{mpc} = maximum permissible concentration of the heavy metal

The Heavy Metal Pollution Index (HMPI) was determined according to the following equation:

$HMPI = \frac{\sum_{i=1}^{n} WiQi}{\sum_{i=1}^{n} Wi}$ (Rahman *et al* 2020)

2.8. Water Quality Classification

Water quality classification using WQI rating (Tyagi *et al* 2013) while the degree of pollution was based on (Rezaei *et al* 2019) (Table 5)

2.9. Statistical Analysis:

Results were presented as mean ± SEM from which a two-way ANOVA was conducted and significant differences were reported when $P < 0.05$ using Graphpad 9.0 software. Correlation and hierarchical cluster analyses were done using PAST software

3. Results and Discussion

3.1. Physico-chemical Parameters of the water Samples

All the water samples were colourless and odourless and the temperatures were within the recommended standards of 25-35˚C (Table 2). The TSS and electrical conductivity values were below the WHO maximum permissible limit of 30mg/L and 1.0 ms/cm (1000µs/cm) respectively. The turbidity values of Ilaporu well water (8.15±1.35 NTU) and Oru well water

(21.75±21.45NTU) were significantly higher than the WHO standard of 5.0 NTU ($p<0.05$ and $p<0.001$ respectively). Higher turbidity leads to the greater the chances of waterborne diseases (De Roos *et al* 2017) and outbreaks of gastrointestinal illness have been linked to incidents in which turbidity exceeded acceptable limits (Mann *et al* 2007). Thus, the well water from Ilaporu and Oru with high turbidity may pose waterborne diseases problems.

The pH values of the groundwater in this study were slightly acidic although most of the water samples had pH within the WHO standards of 6.5-8.5 which is similar to the reports of Dirisu *et al* (2016). Acidic pH has been linked to metallic or sour taste of drinking water, stained laundry; blue-green staining of sinks and other household fixtures and it is an indicator of pollution and potential health risk (Dirisu *et al* 2016).

The total hardness of water from Ilaporu, Awa and Ijebu-Igbo boreholes were significantly higher than the WHO maximum standard of 100 mg/L ($p<0.001$). The high level of hardness such water sources makes them unfit for domestic purposes (Asuquo and Etim, 2012). Hard water can lead to dry itchy skin and other health problems like cardiovascular disease, growth retardation and reproductive failure (Sengupta , 2013).

The nitrate contents of the water in the majority of the locations were more than the WHO permissible limits of 10mg/L hence a source of concern as it can serve as an indicator that the water samples may pose health risks to some individuals. High nitrate levels in the water samples possibly could be due to contamination of the groundwater by discharges from septic tanks, leakage from urban drainage and/or run-off from fertilized soil (Ward *et al* (2018). High nitrate content in drinking water is dangerous to pregnant women and also poses a serious health threat to infants less than 6 months of age because of its ability to cause methaemoglobinaemia or Blue Baby Syndrome (McCasland *et al* 2007). It is a high risk factor for various diseases (Kumar and Puri, 2012), algae bloom and eutrophication in water.

3.2. Metal Contents of the Water Samples

The total metal load occurred in the trend Awa well>Ilaporu borehole>Ilaporu borehole>Ijebu-Igbo borehole>Oru well>Ijebu-Igbo well>Awa borehole>Oru borehole (Table 3). Although the lead content of the Ijebu-Igbo borehole and well water samples was within the WHO permissible limit of 0.015mg/L (WHO, 2017), long-term exposure to lower levels leads to a buildup in kidneys and lungs which can cause future kidney disease, lung damage and fragile bones (Yu *et al* 2020). This suggests long term consumption of water from the boreholes and wells tested in this study in their present state can lead to some health challenges. Iron levels in water samples from Ilaporu were more than the 0.03 mg/L recommended by WHO (2017).

High amounts of iron may produce neurological effects (Martin and Grisworld, 2009) as well as overproduction of reactive oxygen species which result in DNA damage (Sousa *et al* 2020). Except for the Ijebu-Igbo well water sample, other water samples had Ni levels equal to or greater than WHO standard. Such high level of Ni can cause allergy, cardiovascular and kidney diseases, lung fibrosis, lung and nasal cancer are some health issues related to high levels of Ni (Genchi *et al* 2020). Except for Awa and Ijebu-Igbo borehole water samples, the water samples had cadmium content of 0.01mg/l which is higher than the WHO standard. Ingesting high levels of cadmium severely irritates the stomach, leading to vomiting and diarrhea (Bernard, 2008). It should be noted that although some of the metals are below the stipulated WHO limit (WHO, 2017), continuous accumulation of such metals through drinking of the water samples assessed in this study can lead to biomagnification of such in the human system and subsequent health hazards.

Table 2: Physico-chemical Parameters of Borehole and Well Water from the Different Locations.

Locations	**Ilaporu**		**Awa**		**Ijebu-Igbo**		**Oru**		**WHO Standards**
Parameters	Borehole	Well	Borehole	Well	Borehole	Well	Borehole	Well	
Appearance	Colourless								**colourless**
Odour	Odourless								**odourless**
Temperature (˚C)	27.55± 0.05	27.70± 0.10	27.60± 0.00	27.80± 0.10	27.55± 0.05	27.65± 0.05	27.40± 0.00	27.65± 0.05	**37**
TSS (mg/l)	0.50± 0.50	1.00± 0.00	2.00± 1.00	1.00± 0.00	0.00± 0.00	5.50± 5.50	0.00± 0.00	8.00± 8.00	**30**
Turbidity (NTU)	6.35± 3.45	8.15± 1.35*	5.05± 0.55	1.90± 0.50	0.10± 0.00	0.90± 0.50	0.10± 0.00	21.75± 21.45***	**5**
Conductivity (ms/cm)	0.73± 0.05	0.66± 0.00	0.67± 0.00	0.84± 0.00	0.81± 0.05	0.24± 0.05	0.24± 0.00	0.23± 0.04	**1**
pH	6.50± 0.01	6.40± 0.01	6.45± 0.15	6.50± 0.01	6.20± 0.00	5.85± 0.35	6.30± 0.00	5.50± 0.70	**6.5-8.5**
Hardness (mg/l)	224.00± 6.0***	262.00± 0.0***	215.0± 3.0***	263.0± 7.0***	70.0± 10.0	238.0± 8.0***	72.00± 6.0	77.0± 1.00	**100**
Chloride (mg/l)	65.00± 5.0	51.50± 4.50	93.0± 1.0	91.0± 1.00	20.5± 10.5	89.0± 2.00	20.00± 5.0	8.50± 1.50	**250**
Nitrate (mg/l)	13.60± 1.30	15.70± 0.10	22.8± 3.00	20.4± 0.6	21.6± 1.40	36.2± 3.3*	17.00± 0.2	7.70± 1.40	**10**
Phosphate (mg/l)	1.60± 0.30	2.30± 0.1	1.20± 0.20	1.30± 0.2	0.60± 0.40	1.40± 1.0	0.60± 0.0	1.40± 0.0	**5**
Sulphate (mg/l)	38.50± 2.50	29.00± 3.00	32.5± 1.50	27.0± 1.00	0.50± 0.50	42.5± 4.50	2.00± 1.0	0.0± 0.0	**250**
Dissolved Oxygen	4.10± 0.50	3.10± 0.00	4.20± 0.10	4.10± 0.10	4.90± 0.3	5.60± 0.00	5.00± 0.4	5.5± 0.6	**5**

Key: NTU (Nephelometric Turbidity Unit), ms/cm (micros/centimeter), * = $p<0.05$; ** = $p<0.01$; *** = $p<0.001$. Source for WHO Standard: WHO (2017)

3.3. **Microbial Load of the Water Samples**

The total plate counts of the water samples were above the WHO maximum permissible limit of 100 cfu/ml and all the water samples had total coliform count that were significantly higher than the WHO standard of 0 cfu/ml ($p<0.05$) (Table 4). All the water samples with the exception of Awa borehole water were positive for the Confirmatory Fecal Coliform Test against the WHO recommendation that drinking water should test negative for fecal coliforms. Oloruntade *et al.*, (2012) also reported the presence of *Escherichia coli* in water samples used in their study. The presence of coliforms in drinking water has been attributed to the lack of sanitary facilities, discharge of waste water without prior treatment, indiscriminate dumping of waste and open defecation and suggests that pathogens may be present in the water samples.

3.4. The Health Quotient (HQ) and Health Indices (HI) of the Water Samples based on the metal contents

The HQ and HI values for the children were generally higher than those of the adults for corresponding water samples (Table 5). In all the samples, cadmium had the highest HQ values except for the Awa and Ijebu-Igbo boreholes (HQ = 0.00) followed by nickel. This suggests that cadmium is the major health hazard metal predisposing both the adult and children populations to undesirable health conditions (Antoine *et al* 2017) and that there could be higher risk of cadmium

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poisoning than the other metals. It could imply that, consumers are possibly going to be exposed to more adverse health risks due to cadmium contaminations than the other metals contaminants in the groundwater of these locations.

Table 3: Metal Content (mg/L) of the Borehole and Well Waters from the Locations Under Study

Site	Ilaporu		Awa		Ijebu-Igbo		Oru		WHO
	Borehole	Well	Borehole	Well	Borehole	Well	Borehole	Well	Standard
Ca	2.850±0.99	0.520±0.2	0.890±0.89	2.160±0.45	1.500±0.08	0.120±0.12	0.010±0.010	0.070±0.070	**200**
Na	3.320±1.900	3.710±0.200	1.450±0.010	3.160±0.76	1.540±0.460	1.990±0.250	1.240±0.220	2.390±0.210	**200**
K	1.810±1.410	0.610±0.010	0.360±0.040	2.990±0.69	2.510±0.170	0.270±0.120	0.280±0.020	0.410±0.110	**20**
Cu	0.002±0.002	0.010±0.002	0.004±0.001	0.010±0.005	0.004±0.004	0.004±0.004	0.002±0.002	0.011±0.005	**0.5**
Mn	0.026±0.004	0.000±0.000	0.019±0.004	0.000±0.000	0.001±0.001	0.014±0.006	0.008±0.002	0.003±0.003	**0.5**
Co	0.000±0.00	0.000±0.00	0.000±0.00	0.000±0.000	0.000±0.000	0.010±0.010	0.000±0.00	0.000±0.00	**NS**
Ag	0.00±0.00	0.000±0.000	0.00±0.00	0.000±0.00	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.00	**NS**
Pb	0.000±0.00	0.000±0.000	0.00±0.00	0.000±0.00	0.010±0.000	0.010±0.010	0.000±0.000	0.000±0.00	**0.015**
Zn	0.250±0.16	0.370±0.050	0.10±0.01	0.220±0.100	0.090±0.020	0.060±0.010	0.020±0.010	0.190±0.03	**1.5**
Fe	0.110±0.08	0.080±0.02	0.03±0.01	0.010±0.010	0.000±0.000	0.020±0.020	0.000±0.000	0.010±0.01	**0.03**
Ni	0.030±0.010	0.040±0.03	0.03±0.01	0.040±0.010	0.020±0.010	0.010±0.010	0.020±0.000	0.040±0.03	**0.020**
Cd	0.010+0.01	0.010±0.0	0.00±0.00	0.010±0.010	0.00±0.00	0.010±0.010	0.010±0.010	0.010±0.00	**0.003**
Total Metal Load	**5.580**	**4.825**	**1.993**	**6.436**	**4.175**	**2.368**	**1.580**	**3.104**	

Table 4: Microbial Load of the Water Samples under Study.

Locations	**Ilaporu**		**Awa**		**Ijebu-Igbo**		**Oru**		**WHO Standards**
Parameters	Borehole	Well	Borehole	Well	Borehole	Well	Borehole	Well	
TPC (cfu/ml)	45.0± 25.0	25.0± 5.0	12.5± 2.5	30.0± 10.0	35.0± 5.0	70.0± 10.0	100.0 ± 0.0	65.0± 35.0	**100**
TCC	2400.0 ± 0.0***	2400.0 ± 0.0***	72.0 ± 38.0**	2400.0 ± 0.0***	483.0 ± 437.0*	2400.0 ± 0.0***	1660.0 ± 740.0***	2400.0 ± 0.0***	**0**
CFCT	positive	positive	negative	Positive	Positive	positive	positive	positive	**negative**

Key: TPC (Total Plate Count); TCC (Total Coliform Count); CFCT (Confirmatory Fecal Coliform Test); *= p<0.05; **= p<0.01; ***= p<0.001.

All the metals had HQ values which suggest that the adults and children consuming water from the sites are only exposed to safe levels of the heavy metals and not at undue risk of non-carcinogenic health effects due to the presence of heavy metals (Ezugwu et al 2020). The HQ values show that the order of impact of these metals to cause chronic health hazards for adults and children follow similar trend of Cd>Ni>Mn>Zn. The samples may expose the children population to a higher chronic risk than adults due to metal ingestion.

The HI values we obtained in this study support the HQ values which indicate there are no potential non-carcinogenic harmful health risks to the consumers of the water samples. The risk associated with water contaminated with metals is that though at present such may seem to be free of health risks, however, the bioaccumulation of metals may lead to building of such metals to toxic levels. Therefore, care should be taken in drinking water from the sources studied in this research to avoid danger of metal poisoning due to bioaccumulation and biomagnification.

Table 5: The Health Hazard Quotient (HQ) and Health Hazard Indices (HI) of the water Samples

Water Sample	Population	**The HQ Values**									**HI**
		Na	K	Cu	Mn	Pb	Zn	Fe	Ni	Cd	
Ilaporu	Adult	0.002	0.001	0.001	0.052	0.000	0.023	0.004	0.042	0.282	**0.409**
Borehole	Children	0.005	0.002	0.003	0.122	0.000	0.055	0.010	0.099	0.658	**0.953**
Ilaporu	Adult	0.002	0.000	0.004	0.000	0.000	0.035	0.003	0.056	0.282	**0.382**
Well	Children	0.005	0.001	0.008	0.000	0.000	0.081	0.008	0.132	0.658	**0.892**
Awa	Adult	0.001	0.000	0.003	0.038	0.000	0.009	0.001	0.042	0.000	**0.095**
Borehole	Children	0.002	0.000	0.007	0.089	0.000	0.022	0.003	0.099	0.000	**0.222**
Awa	Adult	0.002	0.001	0.004	0.000	0.000	0.021	0.000	0.056	0.282	**0.367**
Well	Children	0.005	0.003	0.010	0.000	0.000	0.048	0.001	0.132	0.658	**0.855**
Ijebu-	Adult	0.001	0.001	0.003	0.002	0.081	0.008	0.000	0.028	0.000	**0.124**
Igbo Borehole	Children	0.002	0.002	0.007	0.005	0.188	0.020	0.000	0.066	0.000	**0.289**
Ijebu-Igbo	Adult	0.001	0.000	0.003	0.028	0.081	0.006	0.001	0.014	0.282	**0.415**
Well	Children	0.003	0.000	0.007	0.066	0.188	0.013	0.002	0.033	0.658	**0.969**
Oru	Adult	0.001	0.000	0.001	0.016	0.000	0.002	0.000	0.028	0.282	**0.330**
Borehole	Children	0.002	0.000	0.003	0.038	0.000	0.004	0.000	0.066	0.658	**0.771**
Oru well	Adult	0.001	0.000	0.008	0.006	0.000	0.018	0.000	0.056	0.282	**0.372**
	Children	0.003	0.000	0.018	0.014	0.000	0.042	0.001	0.132	0.658	**0.868**

3.5 . Suitability of Water for Drinking

The parameters used in the assessment of water for suitability of drinking with their rating and degree of pollution along with recommendations are presented in Table 6. Only 2 (25%) samples (Awa and Ijebu-Igbo boreholes) had the 'excellent' quality with 'A' grades and 6 (75%) samples were of 'Very poor' quality and 'Unsuitable' for drinking with 'E' grades. Zakir *et al*. (2020) made similar report where 95% of water samples studied had 'very poor' to 'unsuitable' qualities for drinking with 'D' and 'E' grades. Water samples from the well had higher WQI values (poorer qualities) than samples from boreholes except for the Ilaporu where the reverse was the case. This generally suggests that borehole waters are better than well water for drinking and domestic purposes. The variance of the WQI in the different localities could be attributed to anthropogenic influences and land use in these localities.

The HMEI is helpful in judging the overall quality of waters in the context of heavy metal contents and identifying and quantifying contamination trends in water (Singh et al 2017). Based on the HMEI values we obtained, Ijebu-Igbo borehole sample had a moderate degree of pollution for drinking water while others had a high degree of pollution and therefore, unfit for drinking. On the other hand, the HMTI values categorized all the water samples as 'high' in heavy metal toxicity. The HMPI values varied significantly (P≤0.05) and only Awa and Ijebu-Igbo boreholes were graded as 'low degree of pollution' while others were graded as 'high degree of pollution'. According to Mohan *et al*. (2015), critical condition arises when HMPI value for water is ≥100 and it will be unsafe for drinking, domestic and irrigation usages. These results have coincided with the related WQI value, which also indicated only those water samples with low HMPI had excellent WQI for drinking purposes.

EWQI integrates WQI and HMTI values and higher EWQI values signify higher level of pollution (Tyagi *et al* 2013) and lower the water quality (Genchi et al 2020). Among the water samples, Oru borehole had the highest EWQI value suggesting such water as the low water quality. Awa and Ijebu-Igbo boreholes with lowest EWQI can be characterized as the best water quality among all the sampled locations. The EWQI values obtained by this study showed almost similar trends with other water quality parameters with a few exceptions.

Table 6. Suitability of the Ground Water Quality for Drinking

Location	Water Type	WQI Value	Rating	Grading	HMEI Value	Degree of pollution	HMTI Value	Degree of Pollution	HMPI Value	Degree of Pollution	EWQI Value
Ilaporu	Borehole	267.375	Unsuitable	E	10.17	High	293.552	High	18.40	medium	0.91
	Well	265.668	Unsuitable	E	8.25	High	394.735	High	17.27	medium	0.67
Awa	Borehole	22.440	Excellent	A	2.57	High	139.453	High	0.84	Low	0.16
	Well	249.778	Unsuitable	E	5.81	High	258.590	High	17.24	medium	0.97
Ijebu-Igbo	Borehole	19.573	Excellent	A	1.73	Medium	121.357	High	1.77	Low	0.16
	Well	245.718	Unsuitable	E	5.21	High	107.578	High	19.56	Medium	2.28
	Borehole	237.144	Unsuitable	E	4.34	High	59.286	High	17.57	medium	4.00
Oru	Well	249.799	Unsuitable	E	5.79	High	237.616	High	17.37	medium	1.05

3.6 The Relationship Between the Different Parameters.

Awa and Ijebu-Igbo boreholes formed a cluster distinct from other locations (figure 1a) which suggests that they have similar water quality. This is obvious from the different water quality indices used in this study. For instance, water samples from both location have same WQI grade (A) and same HMPI degree of pollution (Low) which are different what are obtainable in the samples from other locations. The EWQI of the water samples had a negative correlation (r = -0.49) with the metal load and very slight positive correlation (r =0.02) with the HMEI of the water samples. The negative correlation between EWQI and total metal load could be due to the fact that EWQI is obtained as quotient of WQI and HTMI (Zakir *et al* 2020) which suggests that higher the denominator (HMTI), the lower the quotient (EWQI). The HMEI of the water samples had a high positive correlation (r = 0.80) with the WQI and HI for children and adults (figure 1b). The EWQI values had a positive correlation with the WQI (r = 0.47) and the HI for adults and children (r = 0.43). The WQI of the water samples had very high positive correlation (r = 0.98) with the HI of the water samples. This can infer that the WQI, HI and HMEI had similar trends thus samples with low WQI will likely have low HI and low HMEI. The perfect correlation of HI values for the adult with those of the children (r =1.00) suggests they are affected at same magnitude in a similar manner while the high correlation that occurred between WQI and HI of adults and children suggests a closer relationship between HI and WQI.

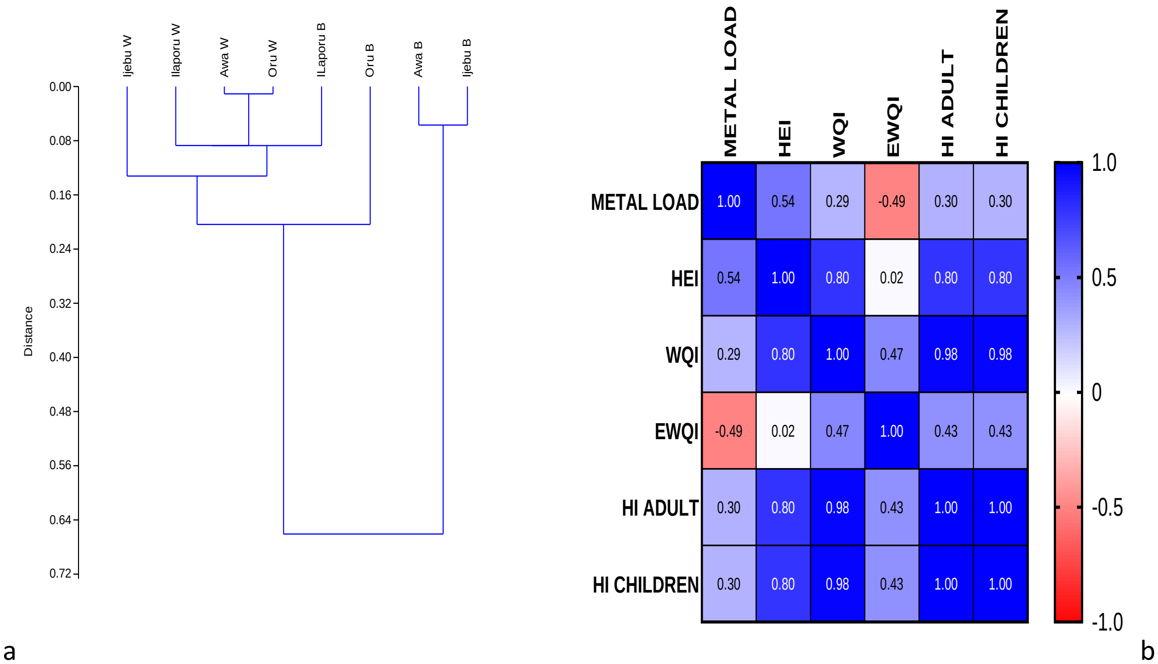

Figure 1 Relationships between the different water parameters (a): Cluster Diagram of the water quality parameters from different locations; (b): Correlation analysis of the different water quality indices

4.Conclusions

This study shows that there is a difference in the well and borehole water samples assessed in each location. The coliform count, WQI, HMEI and EWQI values observed in all water samples in this study is indicate poor water quality. The HI and the HQ values indicate that there are no potential non-carcinogenic harmful health risks to the residents of those locations of the study area. The HMEI values also suggest that the water samples are polluted with metals. All the indices of the water measured placed Awa and Ijebu-Igbo borehole waters suitable for drinking and the others unsuitable.

Conflict of interest

The authors declare that there is no competing interest to influence the work reported in this paper.

CRediT author statement

KLN: Conceptualization, Supervision, Editing; **OOO**: Collection of water sample, determination of water parameters; **EOU**: Data Analyses, Writing; **PNO**: Original Draft Preparation; **POI**: Reviewing, Editing

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