Groundwater Quality Assessment of Ikorodu Local Government Area of Lagos State in Nigeria

Oritsedere Pessu a, John N. Ugbebor a,b and Ejikeme Ugwoha a,b*

a Centre for Occupational Health, Safety & Environment, Institute of Petroleum Studies, University of Port Harcourt, Nigeria.
b Department of Civil & Environmental Engineering, University of Port Harcourt, Nigeria.

Authors’ contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/JERR/2022/v22i417534

Open Peer Review History:

This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://www.sdiarticle5.com/review-history/85529

ABSTRACT

An assessment of the quality of groundwater in Ikorodu Local Government Area (LGA) was carried out in September 2020 (Late wet season). A total number of 29 samples were collected from different selected locations of the study area. The samples were collected from private and government bore holes. The pH, Total dissolved solids (TDS), Salinity, Turbidity, Hardness, Biochemical oxygen demand (BOD), Chemical oxygen demand (COD), Phosphate, Nitrate, Sulphate, and Total bacterial count (TBC) were determined according to American Public Health Association (APHA) standard techniques. The results showed that the mean pH, TDS, Salinity, Turbidity, Hardness, BOD, COD, Phosphate, Nitrate, Sulphate, and TBC in the water samples were 7.0 ±0.59, 176.0 ±132.2mg/L, 0.14 ±0.11g/kg, 0.32 ±0.05 NTU, 59.58 ±34.89mg/L, 11.59 ±3.41mg/L, 14.90 ±4.18mg/L, 0.97 ±0.46mg/L, 2.62 ±1.27mg/L, 9.44 ±5.94mg/L, and 4.92 ±2.94 x 10² cfu/mL, respectively. The calculated Water quality index (WQI) of the different sampling points showed the least WQI was 50.3 and the highest WQI was 66.9. Overall, the WQI indicated “Poor” quality of groundwater in the Ikorodu Local Government Area of Lagos State.

Keywords: Water quality index; groundwater quality assessment; physicochemical analysis; biological analysis; Ikorodu.
1. INTRODUCTION

Groundwater is an important source of water supply throughout the world. Groundwater occurs almost everywhere beneath the earth surface not in a single widespread aquifer but in thousands of local aquifer systems and compartments that have similar characters [1]. Knowledge of the occurrence, replenishment and recovery of groundwater has special significance in arid and semi-arid regions due to discrepancy in monsoonal rainfall, insufficient surface waters and over drafting of groundwater resources [2-4].

It is important to always ensure high quality groundwater so that the consumer’s health is not compromised. Groundwater resources are affected principally by three major activities. These activities are excessive use of fertilizers and pesticides in agricultural area, disposal of untreated/partially treated wastewater to the environment and excessive pumping and improper management of aquifers [5,6]. The activity of solid waste disposal in open un-engineered landfill sites is one of the factors that cause the groundwater pollution due to lack of pollution control interventions such as water proof layer, leachate treatment pond, and monitoring wells [7-10].

According to WHO organization, about 80% of all the diseases in human beings are caused by polluted water. High rates of mortality and morbidity from water borne diseases are well known in Nigeria. Access to safe drinking water remains an urgent necessity, as 30% of urban and 90% of rural households still depend completely on untreated surface or groundwater [11-13]. The quality of water is defined in terms of its physical, chemical, and biological parameters, its development and management play a vital role in agricultural production, poverty reduction, environmental sustenance and sustainable economic development [1,14,15]. In Nigeria, most of the population is dependent on groundwater as the only source of drinking water supply.

2. MATERIALS AND METHODS

2.1 Study Area

This study was carried out in Ikorodu Local Government Area of Lagos State, Nigeria (Fig. 1). It has a population of about 836,5100 as reported 2017 by Lagos State population census. Ikorodu is about 26km from Ikeja and 36km from Lagos Island (Eko). Ikorodu is largely bounded at the south by Lagos Lagoon. Its geographical location lies between latitudes 6º 41' 51.13" N and 6º 31' 20.95" N also on longitudes 3ºC 26' 31.82" E and 3º 43' 5.13" E.

2.2 Sample Collection

Stratified sampling method was adopted for this study, the 29 administrative wards that make up the local government area were taken as strata. A total number of 29 samples were collected from the selected locations in each ward of Ikorodu LGA. The groundwater samples were transferred into sample bottles and carefully labelled with the appropriate identification codes. Prior to collection, and as part of quality control measures, all bottles were washed with non-ionic detergent and rinsed with deionized water before usage. Also, the sample bottles were rinsed three times with the groundwater samples. Table 1 shows all sample points, locations, and the wards they are situated in.

2.3 Sample Analysis

The samples were analyzed for pH, TDS, Turbidity, BOD, Phosphate, Nitrate, Salinity, COD, Coliform count, Bacteria count, Sulphate, Hardness. All the analyses were carried out according to the standard procedures prescribed in American Public Health Association manual (APHA, 2012). Table 2 shows the methods and instrumentation deployed for analysis.

2.4 Water Quality Index (WQI)

WQI was calculated using the Weighted average water quality index (WAWQI) method, and it was done in three steps. In the first step, each of the 11 parameters (pH, Dissolved solids, Turbidity, BOD, Phosphate, Nitrate, Salinity, COD, TBC, Sulphate, Hardness) were assigned a weight (wi) according to its relative importance in the overall

by evaluating groundwater sources to generate the WQI of each of the selected Ikorodu water source.
quality of water for drinking purposes in Table three. The maximum weight of five was assigned to the parameter nitrate due to its major importance in water quality assessment. In the second step, the relative weight (Wi) was computed as shown in Equation (1).

\[ Wi = \frac{wi}{\sum_{i=1}^{n} wi} \]  

(1)

Where Wi and wi are the relative weight and weight of each parameter, respectively, and n is the number of parameters.

In the third step, a quality rating scale (Qi) for each parameter was assigned by dividing its concentration in each water sample by its respective standard according to the guidelines in the Nigerian industrial standards (NIS), and the result for the same was multiplied by 100 as shown in Equation (2).

\[ Qi = \frac{Ci \times 100}{Si} \]  

(2)

where Qi is the quality rating, Ci is the concentration of each chemical parameter in each water sample in mg/L, and Si is the upper limit of Nigerian drinking water standard for each chemical parameter in mg/L.

For computing the WQI, the SI was first determined for each chemical parameter, which was then used to determine the WQI using Equations (3) and (4).

\[ SI_i = Wi \times Qi \]  

(3)

\[ WQI = \sum_{i=1}^{n} SI_i \]  

(4)

where SIi is the sub index of ith parameter, Qi is the rating based on concentration of ith parameter, and n is the number of parameters.

The computed WQI values are categorized into five types as “excellent water” to “water unsuitable for drinking” using Table 4.

2.5 Statistical Analysis

The data was presented using descriptive statistics (mean, minimum, maximum, standard deviation). The Pearson’s correlation analysis was used to assess the associations of the parameters measured. All analyses were done using the SPSS software version 25.

Fig. 1. Map of Ikorodu showing sampling points
Table 1. Sample locations in their administrative wards of Ikorodu LGA

<table>
<thead>
<tr>
<th>Sample Code</th>
<th>Area</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1</td>
<td>Ikorodu Central Ward F</td>
<td>Owode or Grammar school junction</td>
</tr>
<tr>
<td>S2</td>
<td>Ikorodu Central Ward B</td>
<td>T.O.S Benson (New Baale) Road</td>
</tr>
<tr>
<td>S3</td>
<td>Ikorodu Central Ward A</td>
<td>Eyita Palace</td>
</tr>
<tr>
<td>S4</td>
<td>Igbogbo/Baiyeku Ward C1</td>
<td>Jauitu Primary School</td>
</tr>
<tr>
<td>S5</td>
<td>Igbogbo/Baiyeku Ward C5</td>
<td>Elepe Secretariat</td>
</tr>
<tr>
<td>S6</td>
<td>Igbogbo/Baiyeku Ward C2</td>
<td>Olorunfumi Bashorun Secretariat</td>
</tr>
<tr>
<td>S7</td>
<td>Imota Ward C</td>
<td>Ojege House &amp; Itunuobun</td>
</tr>
<tr>
<td>S8</td>
<td>Imota Ward B</td>
<td>Anibaba &amp; Owoyele</td>
</tr>
<tr>
<td>S9</td>
<td>Imota Ward D</td>
<td>Baale Oko-Oto &amp; Oke Agbo</td>
</tr>
<tr>
<td>S10</td>
<td>Ijede Ward D</td>
<td>Abule Eko Secretariat</td>
</tr>
<tr>
<td>S11</td>
<td>Ijede Ward C</td>
<td>Okeoyinbo/Obetodun Secretariat</td>
</tr>
<tr>
<td>S12</td>
<td>Ijede Ward B</td>
<td>Shitta-Secretariat</td>
</tr>
<tr>
<td>S13</td>
<td>Ikorodu West Ward C</td>
<td>Owo/Ojokoro Secretariat</td>
</tr>
<tr>
<td>S14</td>
<td>Ikorodu West Ward B</td>
<td>Ogolonto/Majidun Secretariat</td>
</tr>
<tr>
<td>S15</td>
<td>Ikorodu West Ward A</td>
<td>Ipakodo Secretariat</td>
</tr>
<tr>
<td>S16</td>
<td>Ikorodu North Ward E2</td>
<td>Agbala (Abitoye House First Gate)</td>
</tr>
<tr>
<td>S17</td>
<td>Ikorodu North Ward E1</td>
<td>Odogunyan (No. 1 Ogunlade street)</td>
</tr>
<tr>
<td>S18</td>
<td>Ikorodu North Ward E3</td>
<td>Erikorodu (Parafa Myadamo)</td>
</tr>
<tr>
<td>S19</td>
<td>Ikorodu Central Ward D</td>
<td>Jauitu Primary School</td>
</tr>
<tr>
<td>S20</td>
<td>Imota Ward A</td>
<td>Araromi</td>
</tr>
<tr>
<td>S21</td>
<td>Ikorodu Central Ward C</td>
<td>Ituuwolo</td>
</tr>
<tr>
<td>S22</td>
<td>Ijede Ward A</td>
<td>Itaukan/Egbia Secretariat</td>
</tr>
<tr>
<td>S23</td>
<td>Igbogbo/Baiyeku Ward C4</td>
<td>Ibeshe Secretariat</td>
</tr>
<tr>
<td>S24</td>
<td>Ikorodu Central Ward E</td>
<td>Jaiyesimi compound Obuu-ale</td>
</tr>
<tr>
<td>S25</td>
<td>Ikorodu West Ward D</td>
<td>Ajakuro Secretariat</td>
</tr>
<tr>
<td>S26</td>
<td>Ikorodu West Ward E</td>
<td>Isawo Secretariat</td>
</tr>
<tr>
<td>S27</td>
<td>Ikorodu North Ward B3</td>
<td>Isiwu Township (Town hall Eweyeroad)</td>
</tr>
<tr>
<td>S28</td>
<td>Igbogbo/Baiyeku Ward C</td>
<td>Baiyeku &amp; Offin Irele Secretariat</td>
</tr>
<tr>
<td>S29</td>
<td>Ikorodu North Ward E4</td>
<td>Obrunda (Araromi Town Hall)</td>
</tr>
</tbody>
</table>

Table 2. Analytical methods and instruments used

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Units</th>
<th>Analytical methods/ Instrumentation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature</td>
<td>°C</td>
<td>Infra-red Temperature gun (Fluke 568)</td>
</tr>
<tr>
<td>PH</td>
<td>Nil</td>
<td>Digital pH meter (HANNA 9813-6)</td>
</tr>
<tr>
<td>Dissolved Oxygen</td>
<td>mg/L</td>
<td>DO meter (Hach HQ40d)</td>
</tr>
<tr>
<td>Hardness</td>
<td>mg/L</td>
<td>Titrimetric Method</td>
</tr>
<tr>
<td>Salinity</td>
<td>g/kg</td>
<td>Salinometer (MP 521 multipurpose meter)</td>
</tr>
<tr>
<td>Total Dissolved Solids</td>
<td>mg/L</td>
<td>Temperature Controlled Oven</td>
</tr>
<tr>
<td>Turbidity</td>
<td>NTU</td>
<td>Digital Turbidity Meter</td>
</tr>
<tr>
<td>Biochemical Oxygen</td>
<td>mg/L</td>
<td>Winkler’s method (incubation for 5days at 20°C)</td>
</tr>
<tr>
<td>Demand</td>
<td></td>
<td>used BOD CUM Humidity Chamber</td>
</tr>
<tr>
<td>Chemical Oxygen Demand</td>
<td>mg/L</td>
<td>COD by potassium permanganate method using (HANNA HI83099)</td>
</tr>
<tr>
<td>Nitrates</td>
<td>mg/L</td>
<td>HACH Spectrophotometer (DR 3900)</td>
</tr>
<tr>
<td>Sulphates</td>
<td>mg/L</td>
<td>Spectrophotometer (HANNA HI83099)</td>
</tr>
<tr>
<td>Phosphates</td>
<td>mg/L</td>
<td>HACH Spectrophotometer (DR 3900)</td>
</tr>
<tr>
<td>Total Bacteria count</td>
<td>cfu/mL</td>
<td>Incubation (BIONICS Vertical Autoclave)</td>
</tr>
</tbody>
</table>

3. RESULTS

Table 5 shows the variations in the different parameters measured from the 29 sampling points while Table 6 summarizes the data on Table 5 showing the mean value of each parameter measured across the 29 sampling points as well as the standard deviation values obtained for each parameter.

From the tables it was observed that minimum pH ranged from 5.65 to 7.88 with a mean of 7.0
Total dissolved solids ranged from 22.40 to 526.80mg/L with a mean of 176.0 ±132.2mg/L. Salinity ranged from 0.01 to 0.49g/kg with a mean of 0.14 ±0.11g/kg. Turbidity ranged from 0.00 to 3.15NTU with a mean of 0.32 ±0.05NTU. Water Hardness ranged from 16.0 to 155.0mg/L with a mean of 59.58 ±34.89mg/L. The BOD was found to range from 4.83 to 21.44mg/L with a mean of 11.59 ±3.41mg/L. The COD ranged from 6.28 to 25.12mg/L with a mean of 14.90 ±4.18mg/L. The Phosphate concentration ranged from 0.15 to 5.81mg/L with a mean of 0.97 ±0.46mg/L. The Nitrate ranged from 0.06 to 5.52mg/L with a mean of 2.62 ±1.27mg/L. Sulphate concentration ranged from 3.02 to 26.20mg/L with a mean of 9.44 ±5.94mg/L. TBC ranged from 1.0 to 11.20 x10² cfu/mL with a mean of 4.92 ±2.94 x 10² cfu/mL.

Table 7 shows correlation matrix of the parameters measured in the different collection sites. There were positive correlations of pH with BOD, COD, Phosphate, Nitrate, Sulphate, and TBC, while there were negative correlations with Salinity and Hardness also pH parameter was noticed to generally have weak correlation with other parameters. TDS had negative correlation with COD and Sulphate but had no correlation with TBC and was positively correlated with Salinity, Turbidity, Hardness, BOD, Phosphate, and Nitrate. There were negative correlations of Salinity with Turbidity, BOD, COD, Phosphate, and TBC but was positively correlated with Hardness and Nitrate while no correlation was observed with Sulphate. There were negative correlations of Turbidity with Hardness and Phosphate but no correlation with TBC while positive correlations were observed with BOD, COD, Nitrate and Sulphate. Hardness on the other hand had negative correlations with BOD, COD, Phosphate, Nitrate, Sulphate, and no correlation with TBC. The correlation of BOD with Phosphate, Sulphate and TBC were observed to be negative while there was strong positive correlation with COD and weak positive correlations with Phosphate and TBC were observed. COD was negatively correlated with Phosphate, Sulphate, and TBC but was weakly positively correlated with Nitrate. The correlation of Phosphate with Nitrate and Sulphate were observed to be weakly positive while no correlation was observed with TBC. Similarly, weak positive correlation of Nitrate with Sulphate and TBC were observed also. Sulphate on the other hand had no correlation with TBC.

Table 3. Details of chemical parameters with their relative weight and assigned weight with drinking water standards as per NIS (2015)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Si</th>
<th>Weight</th>
<th>Wi</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>8.5</td>
<td>4</td>
<td>0.0952</td>
</tr>
<tr>
<td>Dissolved solids</td>
<td>500</td>
<td>5</td>
<td>0.0047</td>
</tr>
<tr>
<td>Turbidity</td>
<td>1</td>
<td>3</td>
<td>1.5445</td>
</tr>
<tr>
<td>BOD</td>
<td>5</td>
<td>3</td>
<td>0.0431</td>
</tr>
<tr>
<td>Phosphate</td>
<td>0.1</td>
<td>5</td>
<td>0.8613</td>
</tr>
<tr>
<td>Nitrate</td>
<td>50</td>
<td>05</td>
<td>0.3180</td>
</tr>
<tr>
<td>Salinity</td>
<td>600</td>
<td>4</td>
<td>4.9320</td>
</tr>
<tr>
<td>COD</td>
<td>10</td>
<td>5</td>
<td>0.0559</td>
</tr>
<tr>
<td>Coliform count</td>
<td>0</td>
<td>3</td>
<td>0.0000</td>
</tr>
<tr>
<td>Bacteria count</td>
<td>10</td>
<td>3</td>
<td>0.1017</td>
</tr>
<tr>
<td>Sulphate</td>
<td>100</td>
<td>3</td>
<td>0.0530</td>
</tr>
<tr>
<td>Hardness</td>
<td>150</td>
<td>3</td>
<td>0.0084</td>
</tr>
</tbody>
</table>

Table 4. Range of WQI for drinking purposes

<table>
<thead>
<tr>
<th>Water Quality Index Level</th>
<th>Water Quality</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 – 50</td>
<td>Excellent</td>
</tr>
<tr>
<td>50 – 50</td>
<td>Good</td>
</tr>
<tr>
<td>51 – 75</td>
<td>Poor</td>
</tr>
<tr>
<td>76 – 100</td>
<td>Very poor</td>
</tr>
<tr>
<td>&gt;100</td>
<td>Unsuitable for drinking</td>
</tr>
</tbody>
</table>

Source: (Chatterjee and Raziuddin, 2002).
Table 5. Variation in parameters from 29 sampling points for September 2020 (Late wet season)

<table>
<thead>
<tr>
<th>Sample Code</th>
<th>pH</th>
<th>TDS (mg/L)</th>
<th>Salinity (g/kg)</th>
<th>Turbidity (NTU)</th>
<th>Hardness (mg/L)</th>
<th>BOD (mg/L)</th>
<th>COD (mg/L)</th>
<th>PO₄ (mg/L)</th>
<th>NO₃⁻ (mg/L)</th>
<th>SO₄ (mg/L)</th>
<th>TBC (cfu/mL *10⁵)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>7.55</td>
<td>121.3</td>
<td>0.05</td>
<td>0.686</td>
<td>44.1</td>
<td>10.3</td>
<td>13.38</td>
<td>0.264</td>
<td>3.482</td>
<td>10.2</td>
<td>11.2</td>
</tr>
<tr>
<td>2</td>
<td>7.65</td>
<td>218</td>
<td>0.18</td>
<td>1.28</td>
<td>65</td>
<td>14.21</td>
<td>18.23</td>
<td>0.291</td>
<td>3.22</td>
<td>11.5</td>
<td>5.1</td>
</tr>
<tr>
<td>3</td>
<td>7.45</td>
<td>332</td>
<td>0.02</td>
<td>3.151</td>
<td>18</td>
<td>21.44</td>
<td>25.12</td>
<td>0.149</td>
<td>2.999</td>
<td>11.8</td>
<td>1.9</td>
</tr>
<tr>
<td>4</td>
<td>6.64</td>
<td>400.12</td>
<td>0.21</td>
<td>0.831</td>
<td>128.02</td>
<td>14.06</td>
<td>18.32</td>
<td>0.161</td>
<td>2.952</td>
<td>13.9</td>
<td>8.3</td>
</tr>
<tr>
<td>5</td>
<td>6.95</td>
<td>54.07</td>
<td>0.08</td>
<td>0.943</td>
<td>49.21</td>
<td>9.24</td>
<td>12.93</td>
<td>0.327</td>
<td>3.998</td>
<td>5.75</td>
<td>11</td>
</tr>
<tr>
<td>6</td>
<td>6.69</td>
<td>158</td>
<td>0.14</td>
<td>0.662</td>
<td>65.2</td>
<td>13.92</td>
<td>18.07</td>
<td>0.493</td>
<td>3.0765</td>
<td>3.018</td>
<td>4.7</td>
</tr>
<tr>
<td>7</td>
<td>6.4</td>
<td>370</td>
<td>0.29</td>
<td>0.099</td>
<td>105</td>
<td>5.46</td>
<td>6.28</td>
<td>0.443</td>
<td>1.982</td>
<td>6.81</td>
<td>5.1</td>
</tr>
<tr>
<td>8</td>
<td>5.78</td>
<td>276</td>
<td>0.16</td>
<td>0.00</td>
<td>100</td>
<td>9.23</td>
<td>12.09</td>
<td>0.287</td>
<td>2.581</td>
<td>7.83</td>
<td>7.2</td>
</tr>
<tr>
<td>9</td>
<td>6.15</td>
<td>36.9</td>
<td>0.29</td>
<td>0.848</td>
<td>107</td>
<td>15.79</td>
<td>20.52</td>
<td>0.675</td>
<td>2.881</td>
<td>8.6</td>
<td>1.1</td>
</tr>
<tr>
<td>10</td>
<td>6.21</td>
<td>49.9</td>
<td>0.09</td>
<td>0.121</td>
<td>36</td>
<td>10.79</td>
<td>14.92</td>
<td>0.292</td>
<td>3.691</td>
<td>10.4</td>
<td>2.3</td>
</tr>
<tr>
<td>11</td>
<td>5.65</td>
<td>138.3</td>
<td>0.01</td>
<td>0.00</td>
<td>21</td>
<td>12.31</td>
<td>14.02</td>
<td>0.362</td>
<td>3.961</td>
<td>8.4</td>
<td>1</td>
</tr>
<tr>
<td>12</td>
<td>6.87</td>
<td>96.3</td>
<td>0.08</td>
<td>0.03</td>
<td>16</td>
<td>9.18</td>
<td>11.93</td>
<td>3.689</td>
<td>2.987</td>
<td>26.2</td>
<td>4</td>
</tr>
<tr>
<td>13</td>
<td>7.65</td>
<td>153.2</td>
<td>0.18</td>
<td>0.099</td>
<td>42.9</td>
<td>9.69</td>
<td>12.63</td>
<td>1.195</td>
<td>2.328</td>
<td>22.7</td>
<td>1.4</td>
</tr>
<tr>
<td>14</td>
<td>7.88</td>
<td>526.8</td>
<td>0.12</td>
<td>0.019</td>
<td>24</td>
<td>11.19</td>
<td>14.49</td>
<td>5.124</td>
<td>3.784</td>
<td>9.8</td>
<td>9</td>
</tr>
<tr>
<td>15</td>
<td>7.48</td>
<td>217</td>
<td>0.19</td>
<td>0.078</td>
<td>56</td>
<td>13.96</td>
<td>15.74</td>
<td>1.991</td>
<td>2.388</td>
<td>9.3</td>
<td>1.5</td>
</tr>
<tr>
<td>16</td>
<td>7.42</td>
<td>232</td>
<td>0.16</td>
<td>0.096</td>
<td>64</td>
<td>4.83</td>
<td>6.28</td>
<td>0.881</td>
<td>0.737</td>
<td>4.7</td>
<td>4.5</td>
</tr>
<tr>
<td>17</td>
<td>7.1</td>
<td>22.4</td>
<td>0.19</td>
<td>0.03</td>
<td>49</td>
<td>10.19</td>
<td>13.24</td>
<td>0.375</td>
<td>3.785</td>
<td>19.3</td>
<td>9</td>
</tr>
<tr>
<td>18</td>
<td>7.09</td>
<td>24.8</td>
<td>0.04</td>
<td>0.02</td>
<td>30.6</td>
<td>8.86</td>
<td>11.39</td>
<td>0.321</td>
<td>1.323</td>
<td>21</td>
<td>5</td>
</tr>
<tr>
<td>19</td>
<td>6.97</td>
<td>27.8</td>
<td>0.07</td>
<td>0.05</td>
<td>98.9</td>
<td>9.02</td>
<td>11.85</td>
<td>2.02</td>
<td>0.152</td>
<td>4.07</td>
<td>7</td>
</tr>
<tr>
<td>20</td>
<td>6.67</td>
<td>88.1</td>
<td>0.02</td>
<td>0.00</td>
<td>56</td>
<td>12.24</td>
<td>16.2</td>
<td>0.1991</td>
<td>0.056</td>
<td>6.2</td>
<td>6</td>
</tr>
<tr>
<td>21</td>
<td>6.89</td>
<td>320.9</td>
<td>0.25</td>
<td>0.069</td>
<td>84.7</td>
<td>10.65</td>
<td>13.21</td>
<td>0.211</td>
<td>2.42</td>
<td>6.1</td>
<td>6</td>
</tr>
<tr>
<td>22</td>
<td>6.72</td>
<td>40.2</td>
<td>0.01</td>
<td>0.00</td>
<td>51</td>
<td>13.71</td>
<td>17.81</td>
<td>0.29</td>
<td>1.107</td>
<td>4.2</td>
<td>4.1</td>
</tr>
<tr>
<td>23</td>
<td>6.63</td>
<td>125.2</td>
<td>0.13</td>
<td>0.07</td>
<td>52</td>
<td>12.92</td>
<td>17.68</td>
<td>0.252</td>
<td>0.528</td>
<td>5.6</td>
<td>3.2</td>
</tr>
<tr>
<td>24</td>
<td>7.49</td>
<td>237</td>
<td>0.08</td>
<td>0.00</td>
<td>25.9</td>
<td>10.99</td>
<td>13.89</td>
<td>0.311</td>
<td>2.076</td>
<td>3.7</td>
<td>4.1</td>
</tr>
<tr>
<td>25</td>
<td>7.72</td>
<td>297</td>
<td>0.19</td>
<td>0.07</td>
<td>77</td>
<td>11.58</td>
<td>15.26</td>
<td>0.337</td>
<td>2.282</td>
<td>9.1</td>
<td>1</td>
</tr>
<tr>
<td>26</td>
<td>6.77</td>
<td>335</td>
<td>0.49</td>
<td>0.066</td>
<td>155</td>
<td>8.74</td>
<td>11.74</td>
<td>0.322</td>
<td>3.841</td>
<td>5.3</td>
<td>1.3</td>
</tr>
<tr>
<td>27</td>
<td>7.23</td>
<td>104</td>
<td>0.06</td>
<td>0.02</td>
<td>48</td>
<td>18.24</td>
<td>23.85</td>
<td>0.774</td>
<td>2.786</td>
<td>5.3</td>
<td>6.02</td>
</tr>
<tr>
<td>28</td>
<td>7.66</td>
<td>54.7</td>
<td>0.08</td>
<td>0.02</td>
<td>29</td>
<td>13.19</td>
<td>17.08</td>
<td>0.21</td>
<td>3.082</td>
<td>5.1</td>
<td>6.5</td>
</tr>
<tr>
<td>29</td>
<td>7.65</td>
<td>46.9</td>
<td>0.06</td>
<td>0.03</td>
<td>29.2</td>
<td>10.19</td>
<td>13.82</td>
<td>5.812</td>
<td>5.521</td>
<td>7.83</td>
<td>4.02</td>
</tr>
</tbody>
</table>
### Table 6. Statistical summary of parameters measured

<table>
<thead>
<tr>
<th></th>
<th>PH</th>
<th>TDS (mg/L)</th>
<th>Salinity (g/kg)</th>
<th>Turbidity (NTU)</th>
<th>Hardness (mg/L)</th>
<th>BOD (mg/L)</th>
<th>COD (mg/L)</th>
<th>PO₄ (mg/L)</th>
<th>SO₄ (mg/L)</th>
<th>TBC (cfu/mL *10²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>7.00</td>
<td>176.00</td>
<td>0.14</td>
<td>0.32</td>
<td>59.58</td>
<td>11.59</td>
<td>14.90</td>
<td>0.97</td>
<td>2.62</td>
<td>4.92</td>
</tr>
<tr>
<td>Min</td>
<td>5.65</td>
<td>22.40</td>
<td>0.01</td>
<td>0.00</td>
<td>16.00</td>
<td>4.83</td>
<td>6.28</td>
<td>0.15</td>
<td>0.06</td>
<td>3.02</td>
</tr>
<tr>
<td>Max</td>
<td>7.88</td>
<td>526.80</td>
<td>0.49</td>
<td>3.15</td>
<td>155.00</td>
<td>21.44</td>
<td>25.12</td>
<td>5.81</td>
<td>5.52</td>
<td>11.20</td>
</tr>
</tbody>
</table>

### Table 7. Correlation coefficient matrix of analyzed water quality parameters for all samples

<table>
<thead>
<tr>
<th></th>
<th>PH</th>
<th>TDS</th>
<th>Salinity</th>
<th>Turbidity</th>
<th>Hardness</th>
<th>BOD</th>
<th>COD</th>
<th>PO₄</th>
<th>SO₄</th>
<th>NO₃</th>
<th>TBC</th>
</tr>
</thead>
<tbody>
<tr>
<td>PH</td>
<td>1.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TDS</td>
<td>0.1</td>
<td>1.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Salinity</td>
<td>-0.1</td>
<td>0.4</td>
<td>1.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Turbidity</td>
<td>0.1</td>
<td>0.2</td>
<td>-0.1</td>
<td>1.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hardness</td>
<td>-0.3</td>
<td>0.3</td>
<td>0.8</td>
<td>-0.1</td>
<td>1.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BOD</td>
<td>0.1</td>
<td>0.0</td>
<td>-0.3</td>
<td>0.6</td>
<td>-0.2</td>
<td>1.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>COD</td>
<td>0.1</td>
<td>-0.1</td>
<td>-0.2</td>
<td>0.5</td>
<td>-0.2</td>
<td>1.0</td>
<td>1.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PO₄</td>
<td>0.4</td>
<td>0.1</td>
<td>-0.1</td>
<td>-0.2</td>
<td>-0.3</td>
<td>-0.2</td>
<td>1.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NO₃</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
<td>0.2</td>
<td>-0.1</td>
<td>0.1</td>
<td>0.1</td>
<td>0.3</td>
<td>1.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SO₄</td>
<td>0.1</td>
<td>-0.1</td>
<td>0.0</td>
<td>0.1</td>
<td>-0.3</td>
<td>-0.1</td>
<td>0.2</td>
<td>0.2</td>
<td>1.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TBC</td>
<td>0.1</td>
<td>0.0</td>
<td>-0.2</td>
<td>0.0</td>
<td>0.0</td>
<td>-0.2</td>
<td>-0.2</td>
<td>0.0</td>
<td>0.1</td>
<td>0.0</td>
<td>1.0</td>
</tr>
</tbody>
</table>
A summary of the water quality index of the different samples is presented in Table 8. The table show that the minimum WQI was 50.3 and the highest WQI was 66.9. The table indicated that the quality of water at all sites were poor.

Table 8 show water quality category of the WQI results obtained from the sampled groundwater sources of Ikorodu.

Table 8. Water quality index and category of analyzed samples

<table>
<thead>
<tr>
<th>Sample Code</th>
<th>WQI</th>
<th>Quality</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>61.72</td>
<td>Poor</td>
</tr>
<tr>
<td>2</td>
<td>66.91</td>
<td>Poor</td>
</tr>
<tr>
<td>3</td>
<td>57.12</td>
<td>Poor</td>
</tr>
<tr>
<td>4</td>
<td>66.96</td>
<td>Poor</td>
</tr>
<tr>
<td>5</td>
<td>66.39</td>
<td>Poor</td>
</tr>
<tr>
<td>6</td>
<td>50.30</td>
<td>Poor</td>
</tr>
<tr>
<td>7</td>
<td>66.53</td>
<td>Poor</td>
</tr>
<tr>
<td>8</td>
<td>55.06</td>
<td>Poor</td>
</tr>
<tr>
<td>9</td>
<td>57.01</td>
<td>Poor</td>
</tr>
<tr>
<td>10</td>
<td>57.23</td>
<td>Poor</td>
</tr>
<tr>
<td>11</td>
<td>63.34</td>
<td>Poor</td>
</tr>
<tr>
<td>12</td>
<td>65.90</td>
<td>Poor</td>
</tr>
<tr>
<td>13</td>
<td>64.13</td>
<td>Poor</td>
</tr>
<tr>
<td>14</td>
<td>59.63</td>
<td>Poor</td>
</tr>
<tr>
<td>15</td>
<td>52.65</td>
<td>Poor</td>
</tr>
<tr>
<td>16</td>
<td>64.16</td>
<td>Poor</td>
</tr>
<tr>
<td>17</td>
<td>56.16</td>
<td>Poor</td>
</tr>
<tr>
<td>18</td>
<td>53.45</td>
<td>Poor</td>
</tr>
<tr>
<td>19</td>
<td>67.23</td>
<td>Poor</td>
</tr>
<tr>
<td>20</td>
<td>53.99</td>
<td>Poor</td>
</tr>
<tr>
<td>21</td>
<td>59.91</td>
<td>Poor</td>
</tr>
<tr>
<td>22</td>
<td>62.91</td>
<td>Poor</td>
</tr>
<tr>
<td>23</td>
<td>67.23</td>
<td>Poor</td>
</tr>
<tr>
<td>24</td>
<td>62.47</td>
<td>Poor</td>
</tr>
<tr>
<td>25</td>
<td>54.98</td>
<td>Poor</td>
</tr>
<tr>
<td>26</td>
<td>53.40</td>
<td>Poor</td>
</tr>
<tr>
<td>27</td>
<td>59.68</td>
<td>Poor</td>
</tr>
<tr>
<td>28</td>
<td>54.88</td>
<td>Poor</td>
</tr>
<tr>
<td>29</td>
<td>62.80</td>
<td>Poor</td>
</tr>
</tbody>
</table>

4. DISCUSSION

Assessing the quality of groundwater gives appropriate information on the quality of water accessible to people in Ikorodu. The quality of ground water is also a good indicator for water treatment in areas with poor water quality and the need to maintain the “status quo” in areas with good and excellent water quality.

The pH of water plays an important role in clarification process and disinfection of drinking water. For effective disinfection with chlorine, the pH should preferably be less than eight, however, lower-pH water (<7) is more likely to be corrosive [3]. Failure to minimize corrosion can result in the contamination of drinking water and adverse effect on its taste and appearance [12,13]. Nigerian Industrial Standard (NIS) for drinking water as published by the Standards Organization of Nigeria (SON) has prescribed permissible limit of pH to be 6.5 – 8.5. The pH value of groundwater samples ranged from 5.65 to 7.88. Although the average pH of the water samples was 7.0 ±0.59. Four locations (Imota ward B, Imota ward D, Ijede ward C, and Ijede ward D) were found to have pH levels below the lower permissible limit of 6.5.

The presence of dissolved solids in water may affect its taste. The palatability of drinking water has been rated by panels of tasters in relation to its TDS level as follows: excellent (less than 300 mg/L), good (300–600 mg/L); fair (600–900 mg/L), poor (900–1,200 mg/L) and unacceptable (>1,200 mg/L) [14,16]. NIS has prescribed ≤500mg/L as the acceptable limit and 2,000 mg/L as the permissible limit for TDS of water to be used for drinking purpose. In the present study, Total dissolved solids ranged from 22.40 to 526.80 mg/L, with a mean of 176.0 ±132.2mg/L. It is inferred that TDS of all Ikorodu groundwater samples were well within the permissible limit prescribed by NIS except sample 14 (Ogolonto/Majidun secretariat), where the TDS concentration was found to be 526.8mg/L.

The requirement for drinking water Turbidity in Nigeria as prescribed by NIS is a maximum of 5NTU with no known health implications for higher Turbidity values (NIS, 2015). The Turbidity of the samples observed were in the range 0.00 – 3.15NTU with a mean of 0.32 ±0.05 NTU. This means all Ikorodu groundwater samples were within the NIS recommended limits of Turbidity for drinking water.

In groundwater sources, Hardness is mainly due to the presence of Calcium and Magnesium salts, and this is known as temporary Hardness. Temporary Hardness of more than 200mg/L as CaCO₃ may cause scale deposition in the treatment works, distribution system and pipe work and tanks within buildings [14,17,16]. Water with Hardness less than 100mg/L may in contrast, have a low buffering capacity and will be more corrosive for water pipes [1,5]. The NIS has prescribed ≤150mg/L as the acceptable limit for Hardness in drinking water. However, the Hardness of groundwater samples in Ikorodu
ranged from 16.0 to 155mg/L with a mean of 59.58 ±34.89mg/L. Ikorodu groundwater sources were well within NIS permissible limit stipulated at ≤150mg/l except for sample 26 (Isawo secretariat) having high water Hardness of 155mg/L.

BOD test is carried out to determine the presence and concentration of aerobic bacteria in water sample. NIS has no recommended limit for BOD but WHO prescribes ≤5mg/L of BOD as the acceptable limit for drinking water. BOD observed presently in Ikorodu groundwater was within the range of 4.83 to 21.44mg/L with a mean of 11.59 ±3.41mg/L. The groundwater samples from Ikorodu LGA with exception of sample 16 (Agbala area of Ikorodu north) were above WHO permissible limit and sample 16 was at the borderline of the acceptable limit.

COD is a parameter of key concern in wastewater treatment. However, in groundwater it can be used as one of the tools to determine effluence contamination of groundwater. NIS and WHO have no COD permissible limit for drinking water but the Food and Agriculture Organization (FAO) of the United Nations stipulate the permissible limit for COD effluent discharge as ≤120mg/l. COD observed in Ikorodu LGA ranged from 6.28 to 25.12mg/L, with a mean of 14.90 ±4.18mg/L. Ikorodu groundwater COD level was well below the effluent discharge limit indicating it has little or no contact with effluents.

Nitrate is found naturally in the environment and is an important plant nutrient. Some groundwater may also have Nitrate contamination as a consequence of leaching from natural vegetation [9,10]. The presence of Nitrate in drinking water is a potential health hazard when present in large quantities, as the combination of Nitrates with amines, amides, or other nitrogenous compounds through the action of bacteria in the digestive tract results in the formation of nitrosamines, which are potentially carcinogenic [13,18]. The concentration of Nitrate in Ikorodu groundwater samples ranged from 0.06 to 5.52mg/L with a mean of 2.62 ±1.27mg/L. This was observed to be well within NIS permissible limit stipulated at ≤50mg/L.

Phosphorous occur in an oxygenated environment such as groundwater as Phosphate. NIS has no recommendations on Phosphate in drinking water but WHO sets the permissible limit to be ≤0.1mg/L. Ikorodu groundwater Phosphate concentration ranged from 0.15 to 5.81mg/L with an average of 0.97 ±0.46mg/L. Phosphate levels observed for the entire Ikorodu LGA groundwater were above WHO permissible limits. This could be attributed to the high use of fertilizer to boost farm harvest as farming is the predominant occupation in Ikorodu [19].

The most common form of Sulphur in oxygenated water is Sulphate. The presence of Sulphate in drinking water can cause noticeable taste and very high levels might give a laxative effect in unaccustomed consumers [16]. Taste thresholds have been found to range from 250mg/L for Sodium sulphate to 1,000mg/L for Calcium sulphate [1,15]. The Sulphate concentration of Ikorodu groundwater ranged from 3.02 to 26.20mg/L with a mean of 9.44 ±5.94mg/L. NIS maximum permissible limit for Sulphate in drinking water is 100mg/L. Sulphate concentration in all the samples were found to be within the acceptable limit prescribed by NIS for drinking water.

Total bacteria count (TBC) is an important parameter to note. It gives the summary of all micro-organisms present in the water sample and referred to as Total plate count. Nigerian standards for drinking water quality states that for every 100ml of drinking water, Total bacteria count should be non-detectable [20]. Total bacterial count of Ikorodu groundwater ranged from 1.0 to 11.20 x10^5 cfu/mL with a mean of 4.92 ±2.94 x 10^5 cfu/mL. This puts the groundwater sources in Ikorodu LGA above NIS allowable limits for drinking. High TBC levels in drinking water depending on the bacteria present have been linked to many health issues with diarrhea been the most common [21].

The correlation coefficients indicates that, the pH of the water samples tend to increase as BOD, COD, Phosphate, Nitrate, Sulphate, and Total bacteria count (TBC) increases. Salinity of the water samples tend to decrease as Turbidity, BOD, COD, Phosphate, and Total bacteria counts increases. The phosphate levels were also observed to increase as Nitrate, Sulphate, and Total bacteria count increases, while the Nitrate concentrations increased as the Sulphate and Total bacteria count increases. The minimum WQI obtained from Ikorodu groundwater sources was 50.3 and the highest WQI was 66.9. This is an indication that the quality of groundwater in the study area is generally poor. The variations in the parameters measured at the different sampling points could be attributed to anthropologic activities or
industrial activities that have affected groundwater sources as reported in similar studies carried out in south-west, Nigeria [2, 1, 17, 5, 18, Oyelakin et al., 2020).

5. CONCLUSION

This study showed that, the quality of groundwater in Ikorodu LGA was generally “Poor”. The findings of the study make a case for the treatment of the groundwater in the area before consumption as drinking water. It also calls for a review of anthropological and semi-industrial activities that could affect the quality of water for use among residents in Ikorodu LGA. In addition, it solicits for implementation of public policies regarding the quality of water used by the population, aiming at a better quality of life, which will reduce health problems.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

11. Asadi S, Raju MVS, Asadi SS. Estimation of Water Quality Index by...


