





Research

Urbanization impact on groundwater quality of selected rural and urban areas in Ondo State, Nigeria using Water Quality Index

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Abstract

Groundwater is the primary source of water in Ondo state, Nigeria, the study area for the research. However, there has been a rising concern in recent times with regard to the contamination of this important water source as a result of urbanization. This study quantified 13 physicochemical parameters (Turbidity, Conductivity, pH, Mg^{2+} Hardness, Ca^{2+} Hardness, Total hardness, Alkalinity, Chloride, Nitrate, Sulphate, Phosphate, Total Dissolved Solids (TDS) and Total Suspended Solids (TSS)) in ten groundwater samples collected from dug wells in urban and rural study areas and compared them with the WHO drinking water standards. The comparison reveals that 30.8% of the parameters had levels above the World Health Organisation (WHO) standard limits in the study areas, while 69.2% were within the recommended limits. Water Quality Index (WQI) computations were also carried out which revealed that 60% of samples from the urban study area were of good quality and 40% were poor, while in the rural, 80% of the samples were good and the remaining 20% were poor. Based on the statistical and WQI results, groundwater in the urban study area is generally of lower quality than that of the rural. Possible factors influencing this include surface sealing, seepage of domestic and industrial effluents into aquifers and over-exploitation of groundwater, which characterize urbanized areas. The study thus recommends regular monitoring of groundwater quality, integration of effective systems for safe sewage disposal and strategic city planning of urbanized zones to maximize runoffs for groundwater recharge to improve groundwater quality.

Keywords Groundwater quality · Water Quality Index · Physicochemical · Urbanization · Water contamination

1 Introduction

Due to its natural and widespread occurrence, minimal seasonal variations, storage, ease of exploitation and protection from surface contaminants and pollutants, groundwater is an essential supply of drinking water and has increasingly become the most preferred source of sustainable water supply to meet human needs in rural, suburban, and urban settings in almost all developing countries [1–3]. It is also largely used for agricultural and industrial purposes globally. Groundwater quality has attracted much interest in recent years as urban settlements and agricultural fields have grown [4].

Groundwater has been contaminated for decades and is deteriorating daily, causing numerous water quality issues in both ground and surface water systems that affect a large number of people [5]. Natural processes such as lithology, groundwater velocity, recharge water quality, rock–water interaction, and contact with various types of aquifers all play a role in groundwater quality in a given area and are being greatly influenced by changes in irrigation, industrialization,

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and urbanization [6]. Urbanization is a human-induced process that changes land use and land cover (LULC), as well as the amount and quality of surface and groundwater resources, particularly in urban and peri-urban areas [7, 8]. The massive increase in imperviousness of land surface due to urbanization could result in decreased infiltration, thereby affecting groundwater recharge and storage [9, 10]. Also, domestic, agricultural and industrial effluents applied to the land surface leak through the soil medium to the water table, making groundwater reservoirs extremely vulnerable to contamination [4].

If the quality of this extremely important resource is not properly managed, it can become a severe limiting factor for future economic development, public health, and the environment, resulting in huge long-term costs to society [11]. This research seeks to address issues based on Sustainable Development Goal 6, which calls for clean, accessible water for all. Moreover, the right to water security guarantees that everyone has access to enough water that is sufficient, safe, acceptable, physically accessible, and that is inexpensive for home usage [12].

Assessment of groundwater quality is crucial in identifying the major groundwater contaminants. This will aid planners and stakeholders in initiating suitable actions for ensuring optimal groundwater quality for human consumption and other purposes [13]. A water quality index is beneficial for certifying that a water sample is fit for human consumption in addition to risk assessment. The relative grading of the water quality of a group of water samples using an index would also be user-friendly [14]. Water Quality Index (WQI), which is used to inform stakeholders about water quality for better understanding and decision-making, is one of the most effective concepts that researchers have utilised to better understand massive datasets of water quality characteristics [15].

WQI, which was first proposed by Horton [16], is a useful mathematical instrument that uses a single value to evaluate the overall water quality for drinking at a particular location and time [17]. It accomplishes this by ranking the composite influence of each water quality parameter on the overall water quality to assess if the water quality is suitable for human consumption or not [18, 19]. It can classify waters according to various quality levels by assigning relative weights to various parameters and has been used in numerous studies to evaluate the quality of rivers, groundwater, and surface water [17, 20]. Due to its ability to characterize water quality information completely, the WQI method is one of the most useful and important tools used for managing and evaluating the quality of groundwater [21].

While groundwater contamination poses a significant threat to human populations, it also provides an excellent opportunity for researchers to learn more about the evolution of our subsurface aquifers and for decision-makers to comprehend how we can safeguard both the quality and quantity of these resources [22]. This study aims to assess the physico-chemical quality of groundwater in selected urban and rural areas in Ondo State, Nigeria using WQI to determine its suitability for drinking and the effect of urbanization on the quality of groundwater. The specific objectives of this paper include the following; firstly, a comparison of the concentrations of physicochemical parameters in groundwater samples with WHO drinking water standards. Secondly, the determination of the water quality indices (WQIs) of the groundwater samples. Lastly, a comparison of the groundwater quality of the urban study area with that of the rural study area.

2 Materials and methods

2.1 Description of study areas

Alagbaka and Ijare, both in Ondo state, Nigeria, were the study areas for the research. Alagbaka is a town in the Akure South Local Government Area (L.G.A.) of Akure, Ondo State. Ondo State, which is located in the southwest region of Nigeria, has Akure as its capital city. The city is situated at latitude 7° 15' 0" North and longitude 5° 12' 0" East [23]. In contrast, the town of Ijare is located in the Ifedore L.G.A. of the Ondo State. The town lies 10.3 km north of Akure and is situated at latitude 7° 22' 0" North and longitude 5° 10' 0" East [24]. Figure 1 shows the location of the study areas on the map of Ondo state in Nigeria. Ijare is the study area representing the rural setting in Ondo state and street views of the town are shown in Fig. 2. Alagbaka, on the other hand, is the study area representing the urban setting and street views of the urban community are shown in Fig. 3.

The land cover map of Ijare town as presented in Fig. 4a is mainly composed of built-up areas which include residential settlements, open markets, worship centres and schools, with the town being bordered by vegetation including crops and trees. The land cover of the Alagbaka community is presented in Fig. 4b and is mainly composed

Fig. 1 Location of the study areas in Ondo state, Nigeria

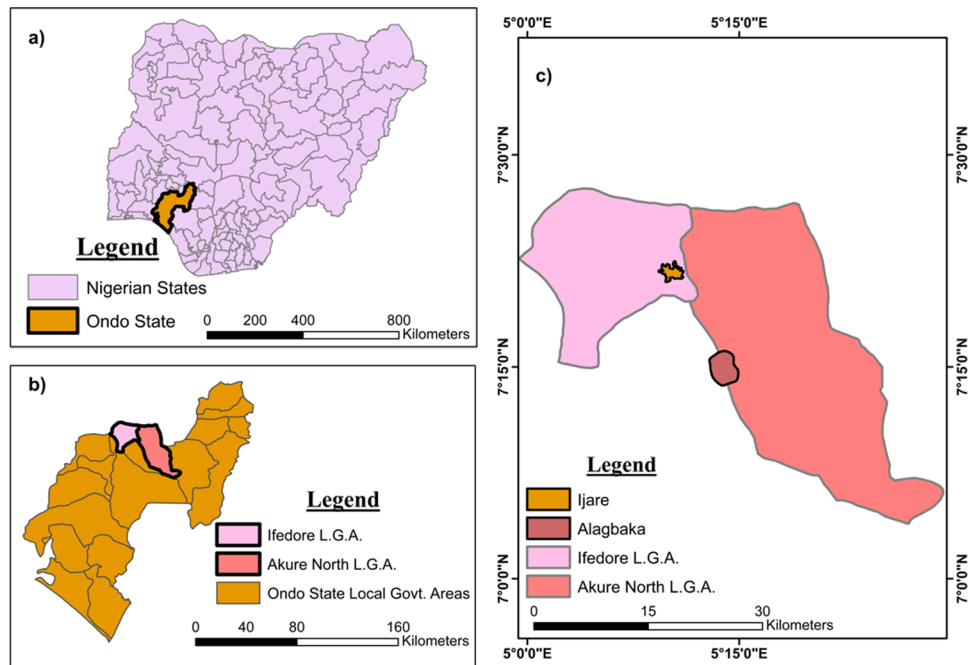


Fig. 2 Street views of ljare (rural setting)



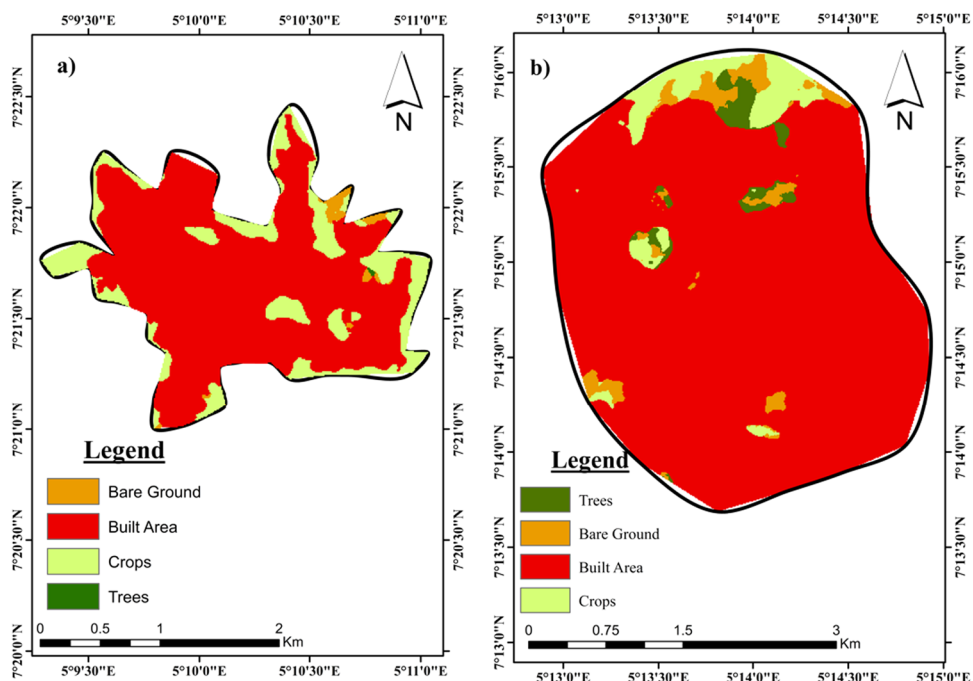
Fig. 3 Street views of Alagbaka (urban setting)



of built-up areas which are made up of residential settlements, commercial and industrial buildings, road and street pavements etc.

The 3D satellite view of ljare shown in Fig. 5 shows that the community is surrounded by thick vegetation and mountains while the town itself is composed mainly of built-up areas. Alagbaka however is mainly composed of built-up areas and also surrounded by other built-up areas as seen from the satellite view in Fig. 6.

Fig. 4 Land cover maps of Ijare (a) and Alagbaka (b)



It was also observed during the visitation of the study areas that the streets and compounds of buildings of the rural area (Ijare) were not paved but bare ground was exposed. Only the major roads within the community were paved with bituminous asphalt. There were very few or no man-made drainage channels constructed within the rural community. Alagbaka on the other hand had many streets and compounds of buildings (both residential and commercial) paved with layers of either concrete or asphalt. Drainage channels were also constructed in most parts of the community (along roads, streets, within compounds etc.) to transport runoff away from the urban area to prevent flooding. Furthermore, in most urban and rural communities in Nigeria, including Ijare and Alagbaka, the study areas for the research, there is unregulated planning of the depth and relative position of soakaway pits, septic tanks and groundwater wells, without any due consideration to the level of the water table at maximum recharge, the direction of groundwater flow within the water table etc.

Fig. 5 3D Satellite view showing Ijare town (Google Earth)

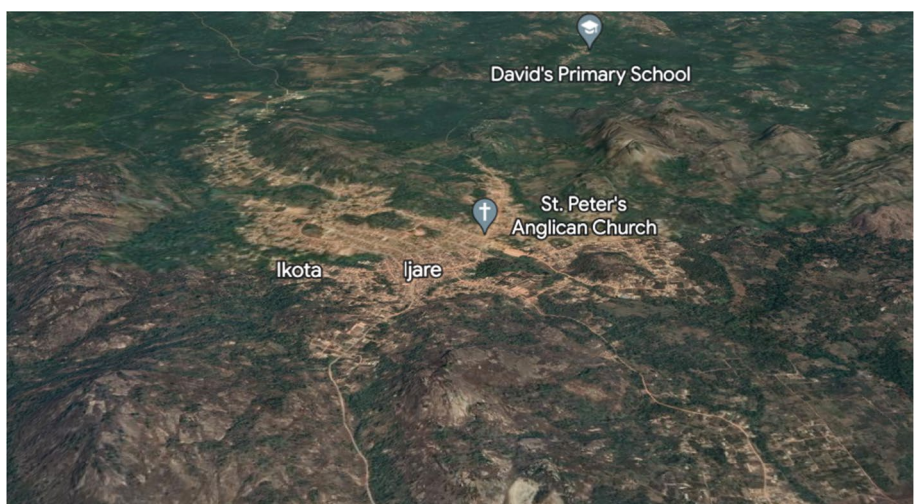


Fig. 6 Satellite image of Alagbaka (Google Earth)



2.2 Sample collection

In Alagbaka and Ijare, water samples were taken from ten (10) distinct wells located in various areas. Five groundwater samples were taken from Alagbaka, which represents urban land use, while the remaining five were taken from Ijare, which represents rural land use. The locations for sample collection were selected at random. Using the Google Map mobile app, the geographic coordinates of each well location were obtained. The coordinates of the groundwater wells are presented in Table 1.

A clean fetcher was used to collect well water at the sample collection points. Before water was drawn, the well water was agitated to allow settled particles to rise to the surface and get suspended, in order to improve the accuracy of the water quality test. 1.5 L sampling bottles used for storing the groundwater sample were labelled appropriately and thoroughly cleaned with distilled water prior to sample collection. The bottles and their caps were washed three times with the water to be sampled. In order to preserve the integrity of the water samples after sample collection, the bottles were properly corked, kept in a cooler, and transported to the laboratory for analysis within 4 h of collection [25].

Table 1 Geographical coordinates of sampled groundwater wells

| Groundwater | Latitude | Longitude |
|-------------|----------|-----------|
| U1 | 7.255014 | 5.219304 |
| U2 | 7.255454 | 5.220446 |
| U3 | 7.253524 | 5.218707 |
| U4 | 7.251192 | 5.218291 |
| U5 | 7.248972 | 5.218363 |
| R1 | 7.359262 | 5.169494 |
| R2 | 7.358603 | 5.167156 |
| R3 | 7.358599 | 5.167161 |
| R4 | 7.358065 | 5.169643 |
| R5 | 7.357530 | 5.172125 |

U1 to U5 are the sampled groundwater wells in Alagbaka (Urban)

R1 to R5 are the sampled groundwater wells in Ijare (Rural)

2.3 Water analysis

All physicochemical parameters of water samples were analysed in accordance with the APHA [26] recommended methods. By observing the water samples in a transparent plastic bottle and smelling them during sampling, the apparent colour and odour of each sample were determined. The temperature of the samples was measured using a thermometer. The turbidity of the samples was evaluated using a Lovibond Water Test TB 210 IR turbidimeter. The electrical conductivity of samples was determined using the conductivity meter. pH of the samples was determined using a pH meter. Gravimetric analysis was used in determining total suspended solids (TSS) and total dissolved solids (TDS) in water samples. Nitrate (NO_3^-), sulphate (SO_4^{2-}) and phosphate (PO_4^-) in water samples were determined using the colourimetric method via the V721 visible spectrophotometer. Titrimetric method was used for determining chloride (argentometric titrimetric method), alkalinity, calcium, magnesium and total hardness (EDTA titrimetric method) in water samples. Physicochemical laboratory analyses of water samples were carried out in the Chemistry Department at the Federal University of Technology, Akure, Nigeria.

2.4 Statistical analysis

Using IBM SPSS 2015 (Version 23), separate analyses were performed on the test results gathered from groundwater sample tests. Using Duncan's Multiple Range Test [27], the mean values of the urban and rural study regions were statistically compared for each water quality indicator, and significant differences were declared at $P < 0.05$.

The means of the water quality parameter levels in each of the study areas were compared with the WHO drinking water standard to determine the potability of groundwater samples. The maximum limits of water quality parameters as recommended by the World Health Organization (WHO) standard for Drinking water as shown in Table 2.

2.5 Water Quality Index (WQI)

WQI was used to give a complete representation of groundwater quality, and it is defined as an effective mathematical tool which uses a single number to assess the overall water quality for drinking at a specific location and time [17]. WQI for each water sample was calculated with the following steps.

Firstly, each water quality parameter to be considered was assigned a suitable weight (w_i) according to their relative importance in the overall quality of water for drinking purposes as presented in Table 3. The assigned weights were based on their effects on the health and significance of the overall quality of water for drinking purposes [28].

Then, the relative weight (W_i) of the parameters, was computed using the equation:

Table 2 WHO Standards for Drinking Water

| Water quality parameter | WHO Standard limit(s) in drinking water |
|----------------------------------|---|
| Turbidity (NTU) | 5 |
| Conductivity (Ohms) | 750 |
| pH | 6.5–8.5 |
| Mg^{2+} hardness (mg/L) | 50 |
| Ca^{2+} hardness (mg/L) | 100 |
| Total hardness (mg/L) | 500 |
| Alkalinity (mg/L) | 200 |
| Chloride (mg/L) | 250 |
| Nitrate (mg/L) | 50 |
| Sulphate (mg/L) | 250 |
| Phosphate (mg/L) | 5 |
| Total dissolved solids (%) | 0.05 |
| Total suspended solids (%) | 0.01 |

Source: [30]

Table 3 Water quality parameters, their assigned weight and calculated relative weight

| Parameters | Weight (w_i) | Relative weight (W_i) | Standard limit (S_i) |
|------------------|------------------|---------------------------|--------------------------|
| Conductivity | 2 | 0.0571 | 750 |
| pH | 4 | 0.1143 | 8.5 |
| Mg ²⁺ | 2 | 0.0571 | 50 |
| Ca ²⁺ | 2 | 0.0571 | 100 |
| Total hardness | 2 | 0.0571 | 500 |
| Alkalinity | 3 | 0.0857 | 200 |
| Chlorine | 3 | 0.0857 | 250 |
| Nitrate | 5 | 0.1429 | 50 |
| Sulphate | 4 | 0.1143 | 250 |
| Phosphate | 4 | 0.1143 | 5 |
| TDS | 4 | 0.1143 | 0.05 |
| Total | 35 | 1.0000 | |

Source: [19, 29]

$$W_i = \frac{w_i}{\sum_{i=0}^n w_i}$$

where W_i is the relative weight of the i th parameter; w_i is the weight of the i th parameter; n is the number of parameters considered.

Thirdly, a quality rating scale (q_i) for each parameter was determined using the equation:

$$q_i = C_i/S_i \times 100$$

where q_i is the quality rating for the i th parameter in the water sample; C_i is the concentration of the i th parameter in the water sample; S_i is the standard maximum limit of the i th parameter as recommended by WHO drinking water standards.

To compute the WQI, the SI was determined first, for each water parameter using the equation:

$$SI_i = W_i \times q_i$$

Thereafter, the WQI for each groundwater sample was determined using the equation:

$$WQI = \sum_{i=1}^n SI_i$$

where SI_i is the sub-index of the i th parameter; q_i is the rating based on the concentration of the i th parameter; n is the number of parameters considered.

The computed WQI values were categorized into five types, "excellent water" to "water unsuitable for drinking" as shown in Table 4

3 Results and discussion

3.1 Physicochemical parameters

3.1.1 Colour and odour

The groundwater samples were colourless and odourless in both rural and urban study areas. The colour of water gives a general impression of its quality to most consumers who usually desire colourless water for domestic and industrial

Table 4 Water quality classification according to WQI

| WQI level | Definition |
|-----------|-------------------------------|
| < 50 | Excellent water |
| 50–100 | Good water |
| 100–200 | Poor water |
| 200–300 | Too poor water |
| > 300 | Water unsuitable for drinking |

Source: [20]

uses. The odour of water also indicates its quality and can hint to the observer about the chemical constituent of the water. Water that is not odourless is usually not safe for human consumption.

3.1.2 Turbidity

The turbidity levels of groundwater samples in the study wells in both urban and rural areas ranged from 7 to 10 NTU and were all greater than the maximum desirable limit of 5 NTU as recommended by WHO standard for drinking water as presented in Table 5. Turbidity describes the cloudiness of water caused by suspended organic and inorganic particles or organisms in water. Above turbidity levels of 5 NTU, drinking water becomes visibly cloudy and therefore might be aesthetically unsightly to consumers [30].

3.1.3 pH

In both study areas, the pH level of water varied from 7.08 to 8.09 and were all within the WHO drinking water standard limits of 6.5 to 8.5 as presented in Table 5. According to WHO [30], pH usually has no direct health impact on consumers, however, it is an important operational water quality parameter, particularly for monitoring water treatment processes.

3.1.4 Total dissolved solids (TDS) and total suspended solids (TSS)

The concentrations of TDS in the study wells ranged from 0.002 to 0.015% and were all within the WHO drinking water standard limit of 0.05% as presented in Table 5. However, levels of TSS varied from 0.009 to 0.042%, nine-tenth of the

Table 5 Levels of physicochemical parameters in groundwater samples collected from the urban and rural study areas

| Water quality parameters | U1 | U2 | U3 | U4 | U5 | R1 | R2 | R3 | R4 | R5 | WHO limit |
|----------------------------------|-------|--------|--------|--------|--------|-------|--------|--------|--------|--------|-----------|
| Turbidity (NTU) | 10 | 9 | 8 | 10 | 10 | 9 | 8 | 7 | 8 | 7 | 5 |
| Temperature (°C) | 32 | 29 | 30 | 28 | 31 | 27 | 26 | 28 | 29 | 27 | - |
| Conductivity (Ohms) | 900 | 850 | 1000 | 700 | 1000 | 900 | 800 | 1000 | 750 | 700 | 750 |
| pH | 8.05 | 7.9 | 8.03 | 7.7 | 8.09 | 7.6 | 7.5 | 8.01 | 7.6 | 7.08 | 6.5–8.5 |
| Mg ²⁺ Hardness (mg/L) | 10 | 16.67 | 6.66 | 36.67 | 123.3 | 12.33 | 43.33 | 30 | 46.67 | 76.67 | 50 |
| Ca ²⁺ Hardness (mg/L) | 46.66 | 43.33 | 56.66 | 30.66 | 76.7 | 40 | 35 | 29 | 50 | 60 | 100 |
| Total hardness (mg/L) | 56.66 | 60 | 63.32 | 67.33 | 200 | 53.33 | 78.33 | 59 | 96.67 | 136.67 | 500 |
| Alkalinity (mg/L) | 70.83 | 62.5 | 54.16 | 45.83 | 133.3 | 45.83 | 33.33 | 25 | 16.66 | 12.5 | 200 |
| Chloride (mg/L) | 134.9 | 101.76 | 183.41 | 118.33 | 224.83 | 88.75 | 84.01 | 178.68 | 59.16 | 152.65 | 250 |
| Nitrate (mg/L) | 13.6 | 12.4 | 6 | 9.6 | 20.4 | 6.8 | 12 | 8.8 | 14.5 | 11.6 | 50 |
| Sulphate (mg/L) | 52.4 | 45.6 | 18.4 | 9.2 | 18 | 60.4 | 20 | 42 | 40.8 | 14 | 250 |
| Phosphate (mg/L) | 8 | 6 | 8.4 | 44.4 | 42.8 | 24 | 16.8 | 4.8 | 25.2 | 31.2 | 5 |
| TDS (%) | 0.007 | 0.002 | 0.005 | 0.004 | 0.006 | 0.006 | 0.0039 | 0.0044 | 0.0152 | 0.0057 | 0.05 |
| TSS (%) | 0.026 | 0.023 | 0.015 | 0.016 | 0.014 | 0.042 | 0.017 | 0.0153 | 0.0092 | 0.018 | 0.01 |

U Urban, R Rural

sampled wells had TSS levels beyond the WHO drinking water standard limit of 0.01% as presented in Table 5. High levels of TDS in water for domestic and industrial use cause excessive scaling in pipes, heaters, and household appliances, thus becoming objectionable to consumers at levels above 0.05% [30].

3.1.5 Electrical conductivity

Electrical conductivities ranged from 700 and 1000 Ohms in the study areas. Table 5 shows that seven out of the ten study wells had conductivity levels greater than the WHO drinking water standard limit for drinking water of 750 Ohms, while only three had levels within the recommended limit. The electrical conductivity of water gives an indication of properties such as alkalinity, dissolved inorganic substances and hardness of water. Electrical conductivity also differs with the source of water e.g. groundwater, rainwater, water polluted by agricultural or industrial wastewater etc.

3.1.6 Alkalinity

Alkalinities of sampled wells varied between 12.5 and 133.3 mg/L and were all within the WHO drinking water standard limit of 200 mg/L as shown in Table 5. Alkalinity in natural water is predominantly caused by bicarbonates, although it can be associated with carbonates and hydroxides in water which are often induced by salts, rocks, biological activities, industrial and agricultural wastewater discharge into water bodies etc.

3.1.7 Calcium, magnesium and total hardness

As presented in Table 5, the calcium hardness of sampled wells which ranged from 29 to 76.7 mg/L, were all within the WHO drinking water standard limit of 100 mg/L. Magnesium hardness on the other hand ranged from 6.66 and 123.3 mg/L in study areas and two of the study wells had levels beyond the WHO drinking water standard limit of 50 mg/L, while the remaining eight wells were within the recommended limit as shown in Table 5. Total hardness in samples ranged between 53.33 and 200 mg/L and were all within the recommended limit of 500 mg/L. Hardness caused by calcium and magnesium may result in the need for excess use of soap to achieve cleaning, scale deposition in the treatment works, distribution system and pipework and tanks within buildings [30].

3.1.8 Nitrate (NO_3^-)

The levels of nitrate in the study area ranged from 6.0 to 20.4 mg/L and were all within the WHO drinking water standard limit of 50 mg/L as shown in Table 5. Nitrate can reach natural freshwater sources (surface water and groundwater) as a result of agricultural activities (including excessive application of fertilizers and manures), from untreated wastewater disposal and from improper sewage disposal. Excessive nitrate concentrations can cause a health condition known as methemoglobinaemia, particularly in bottle-fed infants and can also give rise to symptoms of gastrointestinal infection (diarrhoea) [30].

3.1.9 Phosphate (PO_4^{3-})

Phosphate in study wells which had levels ranging between 4.8 and 44.4 mg/L had nine out of the ten wells with levels above the WHO drinking water standard limit of 5 mg/L as presented in Table 5. Although phosphate is not harmful to humans, high levels of phosphate in natural water sources are well known to have a significant impact on ecosystems and can damage the health of rivers and lakes via eutrophication [31].

3.1.10 Chloride (Cl^-)

Chloride had concentrations in sampled wells ranging from 59.16 to 224.83 mg/L and were within the WHO drinking water standard limit of 250 mg/L as shown in Table 5. Chloride in drinking water is usually sourced from natural origins, sewage and industrial effluents, urban runoff and intrusion of saline water into freshwater. Chloride concentrations above 250 mg/L can give rise to noticeable taste in water and depending on the alkalinity of the water, excessive chloride concentrations can increase rates of corrosion of metals in water.

3.1.11 Sulphate (SO_4^{2-})

Sulphate had concentrations in sampled wells ranging from 9.2 to 60.4 mg/L and were within the WHO drinking water standard limit of 250 mg/L as shown in Table 5. Sulphate in drinking water can cause evident taste, and very high concentrations might even cause a laxative effect (purging) in consumers.

3.2 Statistical analysis

The descriptive statistics of groundwater quality in urban and rural study areas are presented in Table 6. By comparing the arithmetic means of the concentrations of the parameters in urban groundwater wells with that of rural groundwater wells, the groundwater quality of urban and rural land uses can be compared.

As presented in Table 6, the mean concentrations of 9 out of the 13 water quality parameters considered are generally lower in the rural sampled groundwater wells than in the urban wells. These parameters include Turbidity, Conductivity, pH, Ca^{2+} Hardness, Total hardness, Alkalinity, Chloride, Nitrate and Phosphate. This might be due to better access of aquifers to groundwater recharge through infiltration of rain and surface water in the rural area. This is facilitated by the presence of natural land covers such as bare soil and vegetation around the rural area as shown in the satellite view of Ijare in Fig. 2. Contrarily, the pavements and drainage channels which characterize the urban area might reduce access of its groundwater resources to adequate recharge. Adequate groundwater recharge provides a sufficient volume of water to groundwater, which in turn reduces the concentration of contaminants in groundwater.

On the other hand, Mg^{2+} Hardness, Sulphate, TDS and TSS had levels greater in rural groundwater wells than in urban groundwater wells. The relatively high levels of TDS and TSS in the rural area might be due to the general conditions of the groundwater wells and the method of drawing water from the well for use. While the exploitation of groundwater resources in the urban area is predominantly through pumping from wells, residents of the rural area mostly draw water locally from wells by using the rope and bucket system, thus increasing the disturbance of groundwater, especially since many of the rural wells did not have internal concrete linings to keep groundwater from direct interaction with the wall of the wells. Moreover, it was observed that some of the wells in the rural area were not properly covered, thus leaving them prone to direct contamination of groundwater by wind-blown particles and so on.

The statistical analysis presented in Table 6 shows that the levels of Turbidity, pH, Alkalinity and Chloride were significantly higher ($P < 0.05$) in the urban study area than in the rural study area. Aside from surface sealing by pavements and drainages in urban areas, the significantly higher levels of groundwater quality parameters in the urban study area might also be due to an accelerating increase in human activities (commercial, industrial etc.), intensive deforestation for the expansion of settlement areas, over-exploitation of groundwater resources etc. as a result of industrialization, urbanization and population growth in the urban land use.

However, concentrations were not significantly different ($P > 0.05$) in the rural and urban groundwater wells for the other water quality parameters: Conductivity, Mg^{2+} Hardness, Ca^{2+} Hardness, Total hardness, Nitrate, Sulphate, Phosphate,

Table 6 Descriptive statistics of groundwater quality in urban and rural study areas

| Parameters | Mean \pm S.D for urban land use | Mean \pm S.D for rural land use | P-value |
|--------------------|-----------------------------------|-----------------------------------|---------|
| Turbidity | 9.40 \pm 1.99 | 7.80 \pm 2.11 | 0.040 |
| Conductivity | 910.00 \pm 176.47 | 830.00 \pm 148.56 | 0.190 |
| pH | 7.96 \pm 0.27 | 7.57 \pm 0.36 | 0.003 |
| Mg^{2+} Hardness | 38.66 \pm 45.15 | 41.80 \pm 21.99 | 0.811 |
| Ca^{2+} Hardness | 50.80 \pm 15.98 | 42.86 \pm 11.43 | 0.129 |
| Total hardness | 89.46 \pm 57.36 | 84.66 \pm 31.41 | 0.778 |
| Alkalinity | 73.32 \pm 32.23 | 26.66 \pm 12.42 | 0.000 |
| Chloride | 152.65 \pm 46.85 | 112.65 \pm 46.78 | 0.027 |
| Nitrate | 12.40 \pm 4.96 | 10.74 \pm 3.03 | 0.278 |
| Sulphate | 28.72 \pm 17.71 | 35.44 \pm 17.33 | 0.303 |
| Phosphate | 21.90 \pm 18.36 | 20.40 \pm 9.49 | 0.781 |
| TDS | 0.0048 \pm 0.0021 | 0.0070 \pm 0.0044 | 0.086 |
| TSS | 0.0188 \pm 0.0058 | 0.0203 \pm 0.0121 | 0.668 |

S.D Standard deviation

TDS and TSS. This might be due to practices such as the unregulated planning of the position and depth of septic tanks, soak-away pits and groundwater wells which is peculiar to both the urban and rural study areas and can cause contamination of groundwater resources.

3.3 Water Quality Index (WQI)

The water quality index (WQI) for each groundwater sample was calculated to assess the suitability of water for drinking purposes as presented in Table 7. Based on the categorization of WQI into water quality ratings as presented in Table 4, the classification of the water quality of sampled wells in the urban and rural areas based on their WQIs is presented in Table 8.

The calculated WQIs in study areas show that the WQIs range from 53.39 to 161.75 in the urban study area and from 51.03 to 114.33 in the rural study area as presented in Table 7.

Table 8 shows that in the urban study area, the classification of WQI indicates that three out of the five sampled wells were rated as having good water quality, while the remaining two were rated poor. For the rural study areas however, four of the five sampled wells were rated as good water based on the WQI quality rating while the remaining one was rated as poor. This shows that the groundwater from the rural study area was generally of higher water quality than those from the urban study area, although, the groundwater of both study areas had either of good or poor quality according to the WQI quality rating.

This agrees with a study carried out on fourteen groundwater samples from rural and urban study areas in Lagos, Nigeria [19]. It was discovered that according to the WQI classification, of the seven groundwater wells sampled in the rural study areas, 58.09% of the sampled water was very poor while 21.73%, 9.08% and 11.1% were rated poor, good and excellent water, respectively. However, in the urban study areas, 76.55% of the sampled water was unfit for drinking while 14.4%, 6.42% and 2.63% were very poor, good and excellent water, respectively. Thus, revealing that groundwater samples from the rural study areas were of higher quality than those from the urban areas.

Possible factors that are responsible for this difference in groundwater quality between Alagbaka, the urban study area and Ijare, the rural study area is the rise in industrialization and urbanization which can introduce contaminants (from industrial effluent) into groundwater and hinder adequate groundwater recharge.

4 Conclusion

This study found that levels of pH, Alkalinity, Calcium Hardness, Magnesium Hardness, Total Hardness, Total Dissolved Solids, Nitrate, Chloride and Sulphate in most of the groundwater samples collected in the study areas were within the WHO drinking water standard limit. On the other hand, Turbidity, Electrical conductivity, Total Suspended Solids and Phosphate in most groundwater samples were above the recommended limits. Furthermore, Turbidity, pH, Alkalinity and Chloride had significantly higher levels in the urban study area than in the rural study area, while there was no significant difference between the urban and rural areas for the rest of the parameters. Water quality index (WQI) ranged

Table 7 Sub-Indices (SI) of Water Quality Parameters and WQI of each sampled well in study areas

| Parameters | U1 | U2 | U3 | U4 | U5 | R1 | R2 | R3 | R4 | R5 |
|-----------------------|-------|-------|-------|--------|--------|-------|-------|-------|-------|--------|
| E. Conduct | 6.86 | 6.48 | 7.62 | 5.33 | 7.62 | 6.86 | 6.10 | 7.62 | 5.71 | 5.33 |
| pH | 10.82 | 10.62 | 10.80 | 10.35 | 10.88 | 10.22 | 10.08 | 10.77 | 10.22 | 9.52 |
| Mg ²⁺ Hard | 1.14 | 1.91 | 0.76 | 4.19 | 14.09 | 1.41 | 4.95 | 3.43 | 5.33 | 8.76 |
| Ca ²⁺ Hard | 2.67 | 2.48 | 3.24 | 1.75 | 4.38 | 2.29 | 2.00 | 1.66 | 2.86 | 3.43 |
| Total Hard | 0.65 | 0.69 | 0.72 | 0.77 | 2.29 | 0.61 | 0.90 | 0.67 | 1.10 | 1.56 |
| Alkalinity | 3.04 | 2.68 | 2.32 | 1.96 | 5.71 | 1.96 | 1.43 | 1.07 | 0.71 | 0.54 |
| Chloride | 4.63 | 3.49 | 6.29 | 4.06 | 7.71 | 3.04 | 2.88 | 6.13 | 2.03 | 5.23 |
| Nitrate | 3.89 | 3.54 | 1.71 | 2.74 | 5.83 | 1.94 | 3.43 | 2.51 | 4.14 | 3.31 |
| Sulphate | 2.40 | 2.08 | 0.84 | 0.42 | 0.82 | 2.76 | 0.91 | 1.92 | 1.87 | 0.64 |
| Phosphate | 18.29 | 13.71 | 19.20 | 101.49 | 97.83 | 54.86 | 38.40 | 10.97 | 57.60 | 71.31 |
| TDS | 7.09 | 5.71 | 3.43 | 4.11 | 4.59 | 5.03 | 4.78 | 4.27 | 4.32 | 4.69 |
| WQI | 61.45 | 53.39 | 56.93 | 137.18 | 161.75 | 90.98 | 75.86 | 51.03 | 95.90 | 114.33 |

R Rural, U Urban, WQI Water Quality Index, TDS Total dissolved solids

Table 8 Categorization of sampled groundwater based on WQI quality rating

| Parameters | U1 | U2 | U3 | U4 | U5 | R1 | R2 | R3 | R4 | R5 |
|--------------------------|------------|------------|------------|------------|------------|------------|------------|------------|------------|------------|
| Suitability for drinking | Good water | Good water | Good water | Poor water | Poor water | Good water | Good water | Good water | Good water | Poor water |

R Rural, U Urban

from 53.39 to 161.75 in Alagbaka, the urban study area and from 51.03 to 114.33 in Ijare, the rural study area. In the urban study area, 60% of sampled wells were rated as “good” while the rest were rated as “poor” according to the WQI classification of water quality, while in the rural study area, 80% of the groundwater samples were rated as “good” while the remaining 20% were rated as “poor”. The relatively lower quality of groundwater in the urban study area might be due to high population growth, industrialization and urbanization which can encourage the seepage of contaminants into groundwater resources, surface sealing, groundwater over-exploitation and other factors that deteriorate groundwater quality. However, some other practices linked to groundwater pollution such as the unregulated planning of the location and size of soak-away pits and septic tanks especially within residential vicinities that utilize groundwater resources, are peculiar to both the urban and the rural study areas. Furthermore, many groundwater wells in the rural study area were prone to contamination due to the poor general conditions of the wells such as using rope and bucket systems for water collection rather than pumps, absence of internal concrete linings along the walls of the wells, exposure of groundwater to external influences as a result of inadequate protection of wells etc. Thus, there is a rising risk of groundwater contamination not only in urban areas but also in rural areas. To alleviate the risk of further groundwater contamination and improve groundwater quality, the following recommendations can be concluded from the study: (a) quality of groundwater sources i.e. dug wells and boreholes, should be regularly examined in both urban and rural communities and proper awareness should be made to their residents on the condition of their groundwater resources; (b) efficient, economical and environmentally-friendly sewerage systems should be designed and integrated for use in urban and rural communities to alleviate the risk of sewage seepage into groundwater resources; and (c) urban planning of present and future urbanized zones should ensure that runoffs are controlled and managed in such a way that adequate groundwater recharge is achieved.

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Declarations

Ethics approval and consent to participate This research complies with internationally accepted standards for research practice and reporting. Informed consent was taken from the owners of the groundwater wells used for the study after explaining the purpose, nature, and procedures used in the study.

Consent for publication Not applicable.

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