Assessment of Microbial and Physicochemical Characteristics of Groundwater in Selected Local Government Areas of Oyo State, Southwest Nigeria

Gbadebo A. M.[1] Ishola S. A[2*] Gbadebo O. O.[3] and Adebambo O. A.[4]

1. Department of Geology, College of Environmental Resource Management, Federal University of Agriculture Abeokuta P.M.B 2240, Abeokuta, Nigeria.
2. Department of Earth Sciences, Faculty of Science, Olabisi Onabanjo University Ago-Iwoye, P.M.B 2002, Ago-Iwoye, Nigeria.
3. Department of Biomedical Sciences, Faculty of Medical Sciences, University of East London, E16-2RD, Docklands Campus University Way London, United-Kingdom.
4. Department of Environmental Management and Toxicology, College of Environmental Resource Management, Federal University of Agriculture Abeokuta P.M.B 2240, Abeokuta, Nigeria.

* Corresponding author: ishola.sakirudeen@oouagoiwoye.edu.ng

Abstract: Negative impacts of contaminated groundwater on human health are chronic and are very difficult to detect. This study assessed the extents of groundwater contaminations based on the level of microbial and physicochemical characteristics in selected local government areas (LGAs) of Oyo-State, Southwestern Nigeria. Groundwater samples were collected from 10 wells per each LGA (50 wells in total), *in-situ* measurement of physicochemical parameters namely pH, temperature, electrical conductivity (EC) among others and microbial analyses were also carried out using standard laboratory procedures through isolation and identification of microbes, confirmation of isolates and protozoan analysis. The acquired data were subjected to Analysis of variance (ANOVA) and Duncan multiple range test (DMRT) to evaluate their level of significance. The results revealed that the mean distribution of the physicochemical parameters ranged from 4.7±0.15−8.9±0.21b; 26.7°C±3.06c−30.9°C±1.63b; 119±0.58a−599.7±9.07g (mg/l); 15.6±0.51a−82±2.0f (µs/cm) respectively for pH, temperature, TDS, EC. The results of the microbial analyses revealed that most of the water samples were contaminated with a total number of ten (10) isolates namely *Citrobacter freundii, Shigella dysenteriae, Enterobacter aerogenes, Escherichia coli, Proteus vulgaris, Klebsiella pneumoniae, Salmonella typhi, Bacillus subtilis, Pseudomonas aeruginosa* and *Vibrio cholerae*. In terms of maximum exhibited bacteria loads, the most contaminated area is Oja-Oba (OJB) with 4.0×10^2 cfu/ml and the least contaminated area is Iwo-road (IWR) with 2.0×10^2 cfu/ml while in terms of compliance level, the most contaminated area is OJB and the least contaminated area is Apata (APT) with 10% and 60% compliance levels. Therefore, the investigated areas, most particular OJB groundwater are hereby recommended for comprehensive treatment.

Key word: *Escherichia coli,* physicochemical parameters, electrical conductivity, isolates

INTRODUCTION

Groundwater accounts for nearly 95 percent of the nation's fresh water resources. It can stay underground for hundreds of thousands of years, or it can come to the surface and help fill rivers, streams, lakes, ponds, and wetlands (Palamulenu and Akoh, 2015; Paul *et al.,* 2025). The common ways of obtaining groundwater is when they naturally flow to the surface as springs or when they are artificially pumped from an existing well (IAH, 2020). About 50 percent of our municipal, domestic, and agricultural water supply is groundwater. Groundwater accounts for about 50% of livestock and irrigation usage and just under 40% of water supplies, whilst in rural areas, 98% of domestic water use is from groundwater (Todd, 1980). Utilization of groundwater as a source for domestic, municipal, agricultural and industrial activities continue to increase principally because of the heavy capital outlay and maintenance of surface water development through Dams especially in developing countries (Sangodoyin and Agbawhe, 1992). Another factor which is responsible for the attention being diverted to this source is improved technology manifest by deep boring in form of borehole which satisfies WHO drinking water quality standard (Osot, 2000).

Groundwater contamination is defined as the addition of undesirable substances to groundwater caused by human activities (GOC, 2017). These can be caused by

chemicals, road salt, bacteria, viruses, medications, fertilizers, and fuel. Contaminants in groundwater are usually colourless and odourless. In addition, the negative impacts of contaminated groundwater on human health are chronic and are very difficult to detect (Chakraborti *et al.,* 2015). Groundwater is a critical natural resource that can be degraded by contamination. Contaminants can have natural sources (arsenic or salinity) or anthropogenic sources (industrial chemicals, pesticides, or sewage effluent (Koni *et al.,* 2020; Hoang *et al.,* 2022; Li *et al.,* 2024; Paul *et al.,* 2025; Debassi *et al.,* 2025; Shaikh *et al.,* 2025).

Over the past three decades, chemical contamination is a common theme reported in groundwater studies. While groundwater contamination is a great challenge to human populations, many of the contaminants in groundwater are of geogenic origin as a result of dissolution of the natural mineral deposits within the Earth's crust (Basu *et al.,* 2014; Pandey *et al.* 2016; SubbaRao *et al.,* 2020; He *et al.,* 2020a). However, due to rapid expansion of the global population, urbanization, industrialization, agricultural production, and the economy, we are undoubtedly faced with the challenge of tackling the negative impacts of contaminants of anthropogenic origin. Also, groundwater contamination can negatively affect the quality of lands and forests. Contaminated groundwater can lead to soil contamination and degradation of land quality. For example, in many agricultural areas in arid regions, high groundwater salinity is one of the major factors influencing soil salinization (Wu *et al.,* 2014). The soluble salts and other contaminants, such as toxic metals, can accumulate in the root zone, affecting vegetation growth. Groundwater contaminants also can be transported by surface -groundwater interactions, leading to deterioration of surface water quality (Teng *et al.,* 2018). Groundwater can become contaminated in many ways. If surface water that recharges an aquifer is polluted, the groundwater will also become contaminated. Contaminated groundwater can then affect the quality of surface water at discharge areas. Groundwater can also become contaminated when hazardous liquid substances soak down through the soil into groundwater (Akram *et al.,* 2022). Contaminants that can dissolve in groundwater will move along with the water, potentially to wells used for drinking water. If there is a continuous source of contamination entering moving groundwater, an area of contaminated groundwater, called a plume, can form. A combination of moving groundwater and a continuous source of contamination can, therefore, pollute very large volumes and areas of groundwater (Crovota *et al.,* 2022; Izah *et al*. 2022).

Once contaminated, remediation is challenging and costly, because groundwater is located in subsurface geological strata and residence times are long (Wang *et al*., 2020; Su *et al*., 2020). The natural purification processes for contaminated groundwater can take decades or even hundreds of years, even if the source of contamination is cut off (Tatti *et al.,* 2019).

Cleaning up contaminated groundwater often takes longer than expected because groundwater systems are complicated and the contaminants are invisible to the naked eye (GOC, 2017; Wang *et al.,* 2023; Adeniran *et al.,* 2023). Aside from this, groundwater moves at a slower pace than surface water making it difficult to identify and address contamination sources quickly; persistence of contaminants in the subsurface for extended periods either due to their chemical nature or because they are adsorbed to soil and rock particles; clean-up methods like pump and treat can be effective but often require years or even decades to achieve desired results especially with large plumes or persistent contaminants; remediation efforts especially those involving advanced technologies can be very expensive, requiring significant investment in monitoring equipment and treatment systems; even with advanced techniques,

predicting the exact timeframe and effectiveness of groundwater cleanup can be challenging, as various factors like contaminant type, soil properties and natural attenuation processes can influence the outcome; effectively addressing the source of contamination is crucial for long-term success, but identifying and removing all sources can be difficult and time consuming and while attenuation processes can help degrade or remove contaminants, they often work slowly and the effectiveness varies greatly depending on site conditions (Talabi and Kayode, 2019; Wang *et al.,* 2024). This makes it more difficult to find contaminants and to design a treatment system that either destroys the contaminants in the ground or takes them to the surface for cleanup. Groundwater contamination is not only an environmental issue but also a social issue, demanding collaboration between both natural scientists and social scientists. The use of groundwater as a source of drinking-water is often preferred because of its generally good microbial quality in its natural state (Crovota *et al.,* 2022). but various factors can lead to the formation of microbial plumes, which are zones of concentrated microbial activity. These plumes can be influenced by factors like groundwater flow, nutrient availability, and the presence of contaminants which can pose risks to water quality and human health. Nevertheless, it is readily contaminated and outbreaks of disease from contaminated groundwater sources are reported from countries at all levels of economic development. However, understanding the impact of groundwater on public health is often difficult and the interpretation of health data is complex. This is made more difficult as many water supplies that use groundwater are small and outbreaks or background levels of disease are unlikely to be detected, especially in countries with limited health surveillance. Furthermore, in outbreaks of infectious disease, it is often not possible to identify the cause of the outbreak and many risk factors are typically involved. Throughout the world, there is evidence of contaminated groundwater leading to outbreaks of disease and contributing to background endemic disease in situations where groundwater sources used for drinking have become contaminated (Curtis *et al.,* 2000; Izah *et al.,* 2004). However, diarrheal disease transmission is also commonly due to poor excreta disposal practices and the improvement of sanitation is a key intervention to reduce disease transmission (Esrey *et al.,* 1991; Curtis *et al.,* 2000). Furthermore, water that is of good quality at its source may be re-contaminated during withdrawal, transport and household storage. This may then require subsequent treatment and safe storage of water in the home (Sobsey, 2002). Groundwater pollution due to anthropogenic activities may impact overall groundwater quality. Organic and inorganic pollutants have been routinely detected at unsafe levels in groundwater rendering this important drinking water resource practically unusable. Vulnerability of groundwater pollution and subsequent impact has been documented in various studies across the globe. Field studies as well as mathematical models have demonstrated increasing levels of pollutants in both shallow and deep aquifer systems (Manini *et al.,* 2004; Griebler and Lueder, 2009). Increased vulnerability coupled with ever growing demand for groundwater may pose a greater threat of pollution due to induced recharge and lack of environmental safeguards to protect groundwater sources. In this project report, comprehensive assessment of groundwater quality impact due to human activities such as improper management of organic and inorganic waste, and natural sources is documented. The natural quality of groundwater also makes its use well valued in industry, and it may provide environmental benefits through recharge of streams and rivers or for the growth of vegetation; these other benefits reinforce the need for its protection.

Assessment of microbial analyses and physicochemical characteristics of groundwater is crucial for safeguarding public health because it helps in identifying

the potential contaminants and ensure the water is safe for consumption and other uses. This assessment helps prevent water borne diseases and long-term health complications (Adesakin *et al.,* 2020). Though a vital source of drinking water, groundwater can be susceptible to contamination from various sources including natural geological formations, human activities (like agriculture and waste disposal) and faulty sanitation systems (Palamulenu and Akoh, 2015). Microbial analysis, particularly the testing for coliorm bacteria including E. coli helps identify faecal contamination which indicates the potential presence of disease-causing pathogens like bacteria, viruses and parasites. Regular microbial analyses helps track changes in water quality over time and identify potential sources of contamination; by identifying and addressing microbial contamination, we can prevent the spread of waterborne diseases like diarrhea, dysentery, cholera and typhoid which can be particularly harmful to vulnerable populations like children (Abdul-Aziz *et al.,* 2017; Kayowa and Ayanfemi, 2018; Adesakin *et al.,* 2020; Majedul-Islam *et al.,* 2021; Ayeta *et al.,* 2023; Amponsah *et al.,* 2024; Odewande *et al.,* 2025; Paul *et al.,* 2025; Ngandwe *et al.,* 2025). Physicochemical analysis assesses inorganic contaminants with typical parameters like pH, turbidity, conductivity, and the presence of heavy metals and other chemicals that can affect water quality and potentially pose health risks; these parameters most significantly pH and turbidity affect the taste and appearance of water while heavy metals can have toxic effects. Monitoring these parameters ensures the water is palatable and safe for consumption. This analysis helps detect contamination from industrial discharges, agricultural runoff, and other sources that can introduce harmful chemicals into groundwater (APHA/AWWA/WEF, 2012; Baig *et al.,* 2012; Owumi, 2013; Koni *et al.,* 2020; Khan *et al.,* 2020; Akram *et al.,* 2020; WHO, 2022; Hoang *et al.,* 2022; Boussouga *et al.,* 2024; Li *et al.,* 2024; Paul *et al.,* 2025; Debassi *et al.,* 2025; Shaikh *et al.,* 2025; Valiero, 2025). Integration of microbial analysis and physicochemical assessment of groundwater is highly significant for safeguarding public health by identifying and addressing contamination; we can prevent the spread of waterborne diseases and protect the health of individuals and communities (Raheem *et al.,* 2015; Abu *et al.,* 2023; Etuk *et al.,* 2025). This assessment is important for ensuring the safety of water used for drinking, cooking, bathing, and other domestic purposes as well as for industrial and agricultural applications (Haldar *et al.,* 2022). The results of these analyses can be used to develop appropriate water treatment strategies, implement effective sanitation practices and manage groundwater resources responsibly (Shneis, 2018; Talabi and Kayode, 2019; Some *et al.,* 2021).

In conclusion, assessing the microbial and physicochemical characteristics of groundwater in the study area is crucial for safeguarding public health by identifying potential contaminants and ensuring the water is safe for consumption and various other uses. These proactive approaches help in preventing water borne diseases, protecting vulnerable populations, and promote sustainable water management which are fundamental for public health and sustainable development (Shneis, 2018; Talabi and Kayode, 2019).

MATERIALS AND METHODS

Location and accessibility of study area: Ibadan (Oyo-State, South-West Nigeria) is the largest city in West Africa and the second largest in Africa with land size covering an area of 240 km^2. Ibadan is located within latitudes 7º 150N and 7º 300N of the equator and longitudes 3º 450E and 4º 000E of the Greenwich meridian. Spatially, Ibadan is located near the forest-grassland boundary of south-western Nigeria, situated at an approximate distance of 150 km from the Atlantic coast and 530km south-west of Abuja, the Federal Capital Territory (OSGOF, 2014; Raheem *et*

al., 2015). Ibadan metropolis presently hosts the administrative capital of Oyo State**.** Ibadan is situated at an average height of 200m above sea level, drained by three major river basins (Ogunpa, Ona and Ogbere) and surrounded by secondary rainforest as well as a savanna. Spatially, it sprawls over a radius of 12 to 15 km and experiences a mainly tropical climate with an estimated annual rainfall of about 1250 mm. Of the eleven local government areas that make up Ibadan region, five are generally regarded as Ibadan metropolis. These included Ibadan North, Ibadan Northwest, Ibadan Northeast, Ibadan Southeast, and Ibadan Southwest, while the six peri-urban local government areas were Egbeda, Akinyele, Ido, Ona-Ara, Oluyole and Lagelu. The city was for a long time the largest in tropical Africa (Oguntoyinbo, 1978; OSGOF, 2014).

Climate and vegetation of the study area: Ibadan has a tropical wet and dry climate (Köppen climate classification, *Aw*), with a lengthy wet season and relatively constant temperatures throughout the year (Eguaroje *et al.,* 2015; OSGOF, 2014). Ibadan's wet season runs from March through October, though August sees somewhat of a lull in precipitation. This lull divides the wet season into two different wet seasons. November to February forms the city's dry season, during which Ibadan experiences the typical West African harmattan. The mean total rainfall for Ibadan is approximately 1,230 millimeters or 48 inches, falling over about 123 days. There are two peaks for rainfall, June and September. The mean daily temperature is 26.46°C or 79.63°F, the mean minimum 21.42°C or 70.56°F, and the relative humidity 74.55%. The vegetation pattern in Ibadan is a patchwork of broken forest, savannah woodland, dense thickets and large tracts of forbs vegetation dominated by *Chromolaena* (*Eupatorium*) and *odorata* (Siam weed) (Eguaroje *et al.,* 2015).

Drainage and topography of study area: The city of Ibadan is naturally drained by four rivers with many tributaries namely Ona river in the North and West; Ogbere river towards the East; Ogunpa river flowing through the city and Kudeti river in the Central part of the metropolis. Since water responds to slope, a hilly area will discharge its water to lower elevation areas. Ibadan has a combination of high, low and undulating terrain (Figure 2). The northern part of the area has a relatively high elevation which gradually progresses towards the southern part of the area. The city ranges in elevation from 150m in the valley area, to 275m above sea level on the major north–south ridge which crosses the central part of the city. The city covers a total area of 3,080 square kilometers (1,190 sq mi), the largest in Nigeria after Bauchi (OSGOF, 2014).

Geology of the study area: The Ibadan metropolis occurs within the south-west zone of the basement complex of southwestern Nigeria. Major rock types in Ibadan are the undifferentiated meta-sediments which are quartzite of the meta-sediment series, migmatite–gneiss complex comprising banded gneiss, augen gneiss, granite gneiss and migmatites. There are five soil types for the study area. These include litixols, fluvisols, acrisols, luvisols and regosols. The dominant soil type is lyxitols with an area of 1,295.4 km^2 followed by regosols, 1,458 km^2, fluvisols 204.2 km^2, luvisols 65.8 km^2 and acrisols 39.5 km^2 as displayed in Figure 3 (Eguaroje *et al.,* 2015).

Climate and vegetation of the study area: Ibadan has a tropical wet and dry climate (Köppen climate classification, *Aw*), with a lengthy wet season and relatively constant temperatures throughout the year (Eguaroje *et al.,* 2015; OSGOF, 2014). Ibadan's wet season runs from March through October, though August sees somewhat of a lull in precipitation. This lull divides the wet season into two different wet seasons. November to February forms the city's dry season, during which Ibadan experiences the typical West African harmattan. The mean total rainfall for Ibadan is approximately 1,230 millimeters or 48 inches, falling over about 123days. There are two peaks for rainfall, June and September. The mean

daily temperature is 26.46°C or 79.63°F, the mean minimum 21.42°C or 70.56°F, and the relative humidity 74.55%. The vegetation pattern in Ibadan is a patchwork of broken forest, savannah woodland, dense thickets and large tracts of forbs vegetation dominated by *Chromolaena* (*Eupatorium*) and *Odorata* (Siam weed) (Eguaroje *et al.,* 2015).

Drainage and topography of study area: The city of Ibadan is naturally drained by four rivers with many tributaries namely Ona river in the North and West; Ogbere river towards the East; Ogunpa river flowing through the city and Kudeti river in the Central part of the metropolis. Since water responds to slope, a hilly area will discharge its water to lower elevation areas. Ibadan has a combination of high, low and undulating terrain (Figure 2). The northern part of the area has a relatively high elevation which gradually progresses towards the southern part of the area. The city ranges in elevation from 150m in the valley area, to 275m above sea level on the major north–south ridge which crosses the central part of the city. The city covers a total area of 3,080 square kilometers (1,190 sq mi), the largest in Nigeria after Bauchi (OSGOF, 2014).

Geology of the study area: The Ibadan metropolis occurs within the south-west zone of the basement complex of southwestern Nigeria. Major rock types in Ibadan are the undifferentiated meta-sediments which are quartzite of the meta-sediment series, migmatite–gneiss complex comprising banded gneiss, augen gneiss, granite gneiss and migmatites. There are five soil types for the study area. These include litixols, fluvisols, acrisols, luvisols and regosols. The dominant soil type is lyxitols with an area of 1,295.4 km^2 followed by regosols, 1,458 km^2, fluvisols 204.2 km^2, luvisols 65.8 km^2 and acrisols 39.5 km^2.

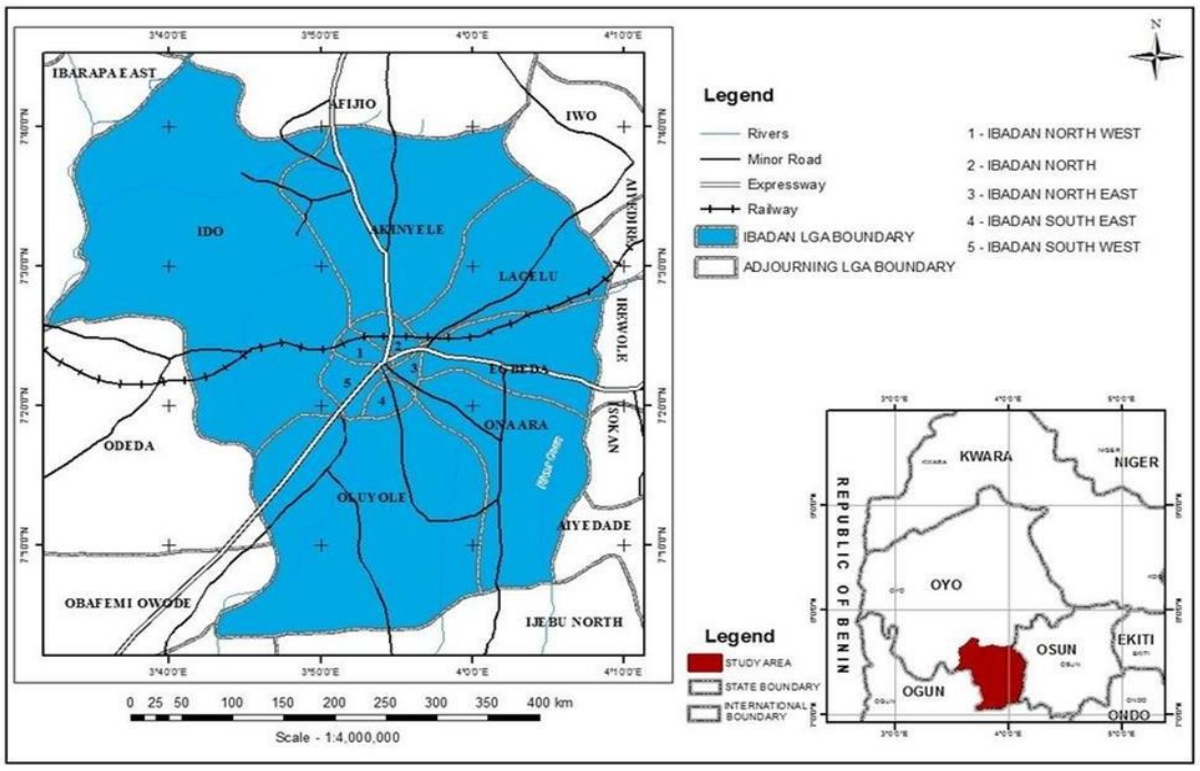

Figure 1: Map of Ibadan Metropolis of study Local Government Area (Inset: Oyo State with the Study Area). Source: Office of Surveyor General of the Federation (OSGOF, 2014).

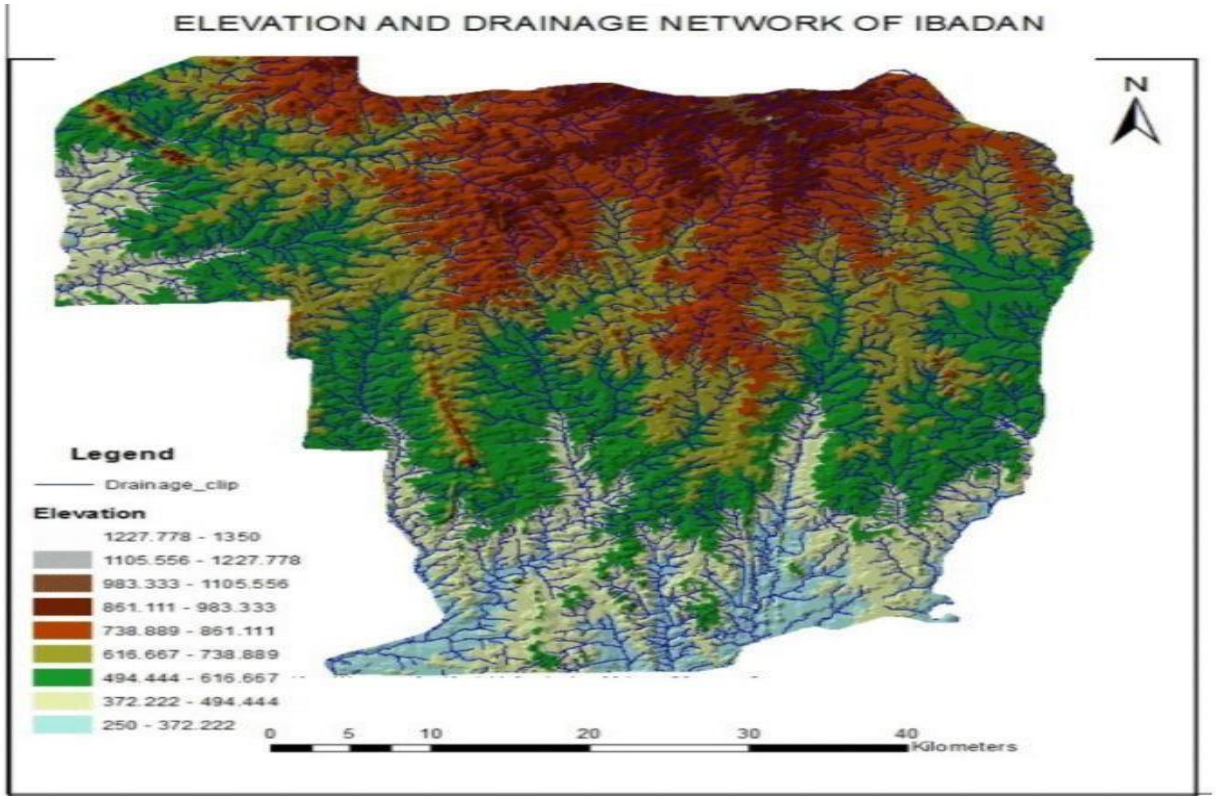

Figure 2: Elevation map of Ibadan city (Eguaroje *et al.*, 2015)

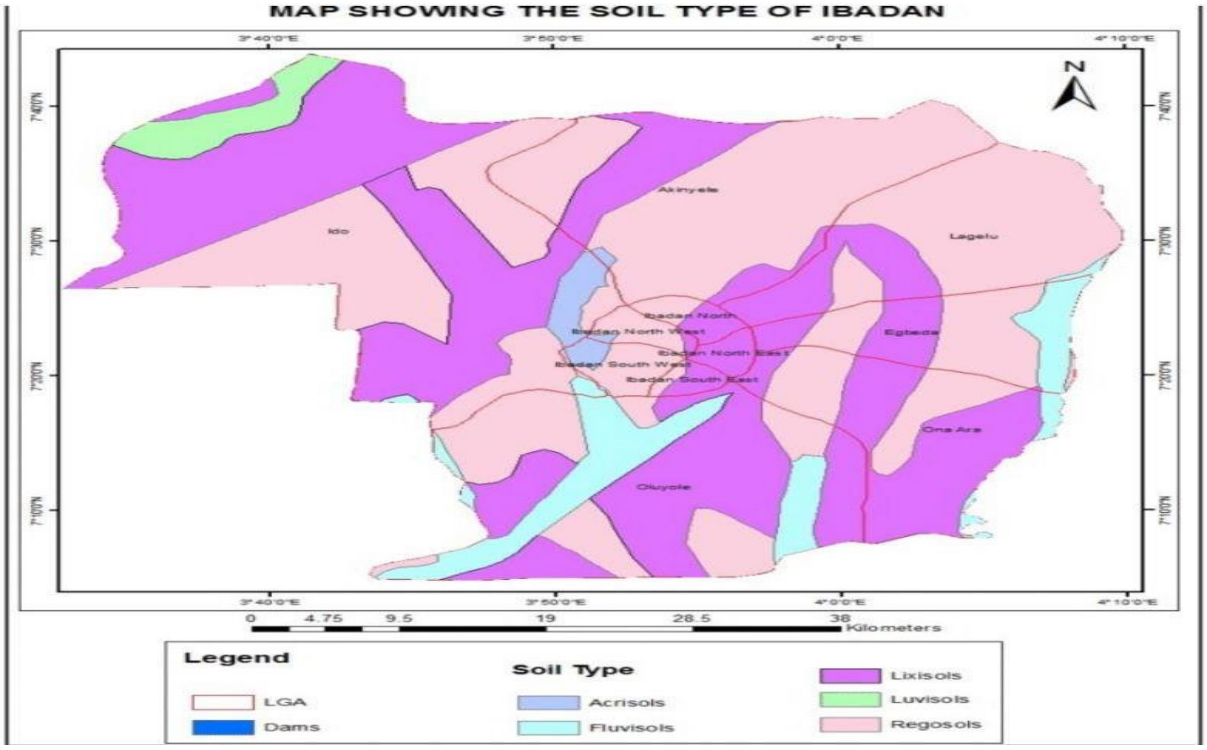

Figure 3: Map of Ibadanof the soil types (Eguaroje *et al.*, 2015).

Table 1: Physical characteristics of sampled well at Oja-Oba

Parameters	pH	Temp	TDS	EC	Environmental Parameters
OJBW1	6.1±0.05^{de}	30.5±0.98^{b}	599.7±9.07^{g}	82±2.0^{f}	1 ring above ground, No metal cover, clean environment, no dumpsite, No gravesite
OJBW2	5.7±0.64^{cd}	29.9±1.06^{ab}	511.7±15.1^{e}	72.67±4.04^{e}	1 ring aboveground cover with metal lid Clean environment
OJBW3	5.5±0.12b^{cd}	29.2±1.08^{ab}	590±18.33^{g}	81±3.61ef	Half ring above ground, Not covered, Close to a soak away, No gravesite.
OJBW4	5.03±0.49^{abc}	29.8±0.61^{ab}	182±7.93^{a}	24.33±1.53^{a}	1 ring above ground, muddy environment, Not covered, Dirty environment.
OJBW5	4.7±0.15^{a}	30.9±1.63^{b}	295.3±9.02^{b}	40.33±1.52^{b}	1ring above ground, Not covered, clean environment, No dumpsite.
OJBW6	5.4±0.53^{abc}	30.2±0.81^{ab}	391.3±2.51^{c}	42.33±13.2^{b}	Half ring above ground, close to a gutter, not covered, no dumpsite.
OJBW7	5.6±0.26^{bcd}	29.7±1.71^{ab}	374.3±13.8^{c}	51.33±2.08^{c}	Half ring above ground, covered with metal lid, clean environment.
OJBW8	4.9±0.49^{ab}	28.9±0.42^{ab}	180.6±1.53^{a}	26±2.64^{a}	Half ring above ground, covered with a metal lid, dirty environment, no dumpsite.
OJBW9	5.6±0.17^{bcd}	29.6±0.76^{ab}	566.7±11.68^{f}	78.33±2.08^{ef}	1 ring above ground, not covered, clean environment, no dumpsite.
OJBW10	6.4±0.26^{e}	28.4±0.26^{a}	429.3±5.51^{d}	62.33±3.21^{d}	1ringabove,notcovered,dirtyenvironment No dumpsite.
WHO	6.5-8.5	<40	<1200	<400	

Keys: Values are mean±SD different superscripts along each column indicate significant difference at p<0.05 according to DMRT. OJB - Oja-Oba Wells; WHO-World Health Organization; DMRT-Duncan Multiple Range Test

Table 2: Physical characteristics of sampled well at Iwo-Road

Parameters	pH	Temp	TDS	EC	Environmental Parameters
IWDW1	7.5±0.4^{a}	30.5±1.56^{d}	316.6±21.6^{e}	43.6±3.21^{d}	1 ring above ground, metal cover, clean environment, no dumpsite, no gravesite
IWDW2	7.9±0.26^{abc}	28.5±0.7^{ab}	225.6±17.0^{c}	33.67±1.15^{c}	Half ring above ground, covered With a metal lid, clean environment, no dumpsite
IWDW3	8.1±0.61^{abc}	30.4±0.2^{cd}	195±6.24^{b}	28±1.0^{b}	Half ring above ground, covered with a metal lid, clean environment, No gravesite.
IWDW4	8.2±0.36^{abc}	30±0.66^{bcd}	251±3.60^{d}	34.3±0.58^{c}	1 ring above ground, clean environment, covered with a metal lid.
IWDW5	8.3±0.53^{bc}	28.7±0.36^{ab}	311±1.0^{e}	43.3±2.52^{d}	Half ring above ground, not covered with a metal lid, clean environment, No dumpsite.
IWDW6	7.7±0.21^{ab}	29.0±0.90^{abcd}	166±2.0^{a}	22±1.0^{a}	Half ring above ground, bushy environment, covered with a metal lid, no dumpsite.
IWDW7	7.9±0.31^{abc}	28.8±0.65^{abc}	216±3.05^{c}	29.3±1.16^{b}	Half ring above ground, not covered with metal lid, bushy environment.
IWDW8	8.0±0.36^{abc}	27.8±0.7^{a}	363±18.0^{f}	51±1.0^{e}	Half ring above ground, covered with a metal lid, ,clean environment, no dumpsite.
IWDW9	8.4±0.25^{c}	28.5±0.58^{ab}	188.6±10.1^{b}	26.67±1.15^{b}	1ring above ground, wooden cover, clean environment, no dumpsite.
IWDW10	8.2±0.1^{abc}	29.6±1.15^{bcd}	223±8.5^{c}	60.3±0.58^{f}	Half ring above, covered with a metal lid, clean environment No dumpsite.
WHO	6.5-8.5	<40	<1200	<400	

Keys: Values are mean±SD different superscripts along each column indicate significant difference at p<0.05 according to DMRT. IWDW – Iwo-Road Wells; WHO-World Health Organization; DMRT-Duncan Multiple Range Test

Table 3: Physical characteristics of sampled well at Alakia community

Parameters	pH	Temp	TDS	EC	Environmental Parameters
ALKW1	8.26±0.56^{bc}	29.6±1.11^{ab}	168.7±4.51^{a}	22±1.73^{a}	1 ring above ground, metal cover, clean environment, no dumpsite,no gravesite
ALKW2	7.6±0.17^{a}	32.8±4.71^{b}	226±1.0^{c}	32±1.73^{c}	Half ring above ground, covered With a metal lid, clean environment
ALKW3	7.97±0.21^{abc}	29.1±0.64^{a}	207±1.0^{bc}	28±0^{b}	Half ring above ground, covered with a metal lid, clean environment, No gravesite.
ALKW4	7.63±0.58^{a}	28.5±0.32^{a}	233±44.8^{bc}	27.3±2.82^{b}	1 ring above ground, clean environment, covered with a metal lid.
ALKW5	7.83±0.21^{ab}	30.4±0.10^{ab}	231.3±0.58^{bc}	31.7±0.58^{c}	1ringaboveground, covered with a metal lid, clean environment, No dumpsite.
ALKW6	8.26±0.58^{bc}	29.3±0.42^{a}	256±4.58^{d}	35±1.0^{d}	Half ring above ground, clean environment, covered with a metal lid, no dumpsite.
ALKW7	8.07±0.58^{bc}	29.0±0.42^{a}	287.7±1.53^{e}	39.7±0.58^{e}	1ringaboveground,coveredwith Metal lid, clean environment.
ALKW8	8.1±0.17^{bc}	28.5±0.25^{a}	190±2.31^{ab}	27±1.73^{b}	1ringaboveground,coveredwitha metal lid, clean environment, no dumpsite.
ALKW9	8.3±0.20^{c}	26.7±3.06^{c}	233.7±3.06^{cd}	32±0^{c}	1ringaboveground,metalcover, clean environment, no dumpsite.
ALKW10	8.2±0.10^{bc}	28.9±0.50^{a}	347±14.7^{f}	48±2.0^{f}	Half ring above ground, covered with a metal lid,clean environment No dumpsite.
WHO	6.5-8.5	<40	<1200	<400	

Keys: Values are mean±SD different superscripts along each column indicate significant difference at p<0.05 according to DMRT. ALK- Alakia Wells; WHO-World Health Organization; DMRT-Duncan Multiple Range Test

Table 4: Physical characteristics of sampled well at Odo-Ona community

Parameters	pH	Temp	TDS	EC	Environmental Parameters
ODNW1	8.6±0.38^{bc}	28.9±0.58^{a}	201.7±4.93^{c}	27.7±0.58^{c}	1ringaboveground,coveredwitha metal lid, clean environment, no dumpsite
ODNW2	8.4±0.20^{ab}	28.8±0.5^{a}	145.7±2.08^{a}	19.3±0.58^{a}	Half ring above ground, covered With a metal lid, clean environment
ODNW3	8.5±0.15^{abc}	28.4±0.42^{a}	218±3.06^{de}	29.7±0.57^{de}	Half ring above ground, covered with a metal lid, clean environment, No gravesite.
ODNW4	8.6±0.1^{abc}	28.8±0.55^{a}	158±4.0^{b}	21±1.0^{b}	1ringaboveground,bushyenvironment,coveredwithametal lid.
ODNW5	8.6±0.20^{abc}	28.5±0.87^{a}	162±3.6^{b}	21.7±0.58^{b}	1 ring above ground, not covered with a metal lid, clean environment, No dumpsite.
ODNW6	8.7±0.21^{bc}	29.3±0.45^{a}	226±7.0^{e}	31±1.0^{e}	1 ring above ground, clean environment, covered with a metal lid, no dumpsite.
ODNW7	8.9±0.057^{c}	29.4±0.64^{a}	341±7.8^{f}	47±1.0^{f}	Half ring above ground, not covered with metal lid, clean environment.
ODNW8	8.6±0.21^{abc}	29.8±2.02^{a}	354±10.6^{g}	48.7±1.52^{g}	1ringaboveground,coveredwitha metal lid, clean environment, no dumpsite.
ODNW9	8.7±0.15^{bc}	29.1±1.04^{a}	213±5.0^{d}	29±1.0^{c}	1ring above ground, metal cover, muddy environment, no dumpsite.
ODNW10	8.3±0.058^{a}	29.7±1.27^{a}	223±8.5^{de}	60±0.58^{h}	Half ring above ground, covered with a metal lid, clean environment No dumpsite.
WHO	6.5-8.5	<40	<1200	<400	

Keys: Values are mean±SD different superscripts along each column indicate significant difference at p<0.05 according to DMRT. ODNW - Odo-Ona Wells; WHO-World Health Organization; DMRT-Duncan Multiple Range Test

Table 5: Physical characteristics of sampled well at Apata community

Parameters	pH	Temp	TDS	EC	Environmental Parameters
APTW1	8.7±0.06^{ab}	30.9±2.06^{c}	152±13.2^{c}	20.3±2.08^{b}	Half ring above ground, metal cover, muddy environment, close to dumpsite
APTW2	8.7±0.10^{ab}	30.5±1.30b^{c}	190±8.8^{d}	25.6±1.52^{c}	1ringaboveground,Coveredwith A metal lid, clean environment.
APTW3	8.7±0.20^{ab}	30±0.53ab^{c}	254±3.0^{f}	34.7±0.58^{e}	Half ring above ground, covered with a metal lid, clean environment, No gravesite.
APTW4	8.9±0.21^{b}	29.0±0.47^{ab}	521±10.0^{g}	71.6±1.52^{f}	1 ring above ground, clean environment, covered with ametal lid.
APTW5	8.8±0.30^{ab}	29.7±0.40^{abc}	152±2.0^{c}	20.3±0.57^{b}	Half ring above ground, not covered with a metal lid, clean environment, No dumpsite.
APTW6	8.4±0.81^{ab}	29.5±0.35^{abc}	120±3.46^{a}	15.6±0.51^{a}	Half ring above ground, clean environment, covered with a metal lid, no dumpsite.
APTW7	8.2±0.05^{a}	29.5±0.35^{abc}	119±0.58^{a}	15.7±0.51^{a}	Half ring above ground, covered With metal lid, clean environment.
APTW8	8.2±0.15^{a}	28.8±0.25^{a}	147±1.0^{c}	19.6±0.58^{b}	1ringaboveground,covered with a metal lid, clean environment, no dumpsite.
APTW9	8.4±0.06^{ab}	28.9±0.34^{a}	134±11.5^{b}	17.6±1.52^{a}	Half ring above ground, metal cover, clean environment, no dumpsite.
APTW10	8.4±0.10^{ab}	29.3±0.10^{abc}	232±4.35^{e}	31.7±0.57^{d}	Half ring above ground, covered with a metal lid, clean environment No dumpsite.
WHO	6.5-8.5	<40	<1200	<400	

Keys: Values are mean±SD different superscripts along each column indicate significant difference at $p<0.05$ according to DMRT. APTW – Apata Wells; WHO-World Health Organization; DMRT-Duncan Multiple Range Test

Table 6: Bacterial load and types of isolates in Oyo groundwater samples

S/N	Sample identity	Bacterial load (cfu/ml)	Bacterial types
1	ALKW1	2.0×10^{2}	*Citrobacter freundii*, *Enterobacter aerogenes*
2	ALKW2	2.0×10^{2}	*Enterobacter aerogenes, Escherichia coli*
3	ALKW3	2.0×10^{1}	*Enterobacter aerogenes*
4	ALKW4	2.0×10^{2}	*Enterobacter aerogenes, Escherichia coli*
5	ALKW5	1.0×10^{1}	*Klebsiella pneumoniae, Proteus vulgaris*
6	ALKW6	3.0×10^{1}	*Enterobacter aerogenes, Escherichia coli*
7	ALKW7	2.0×10^{1}	*Escherichia coli* and *Proteus vulgaris*
8	ALKW8	2.0×10^{1}	*Enterobacter aerogenes, Escherichia coli*
9	ALKW9	1.3×10^{2}	*Pseudomonas aeruginosa, Proteus vulgaris*
10	ALKW10	1.0×10^{2}	*Escherichia coli, Bacillus subtilis*
11	APTW1	1.0×10^{1}	*Enterobacter aerogenes*
12	APTW2	3.0×10^{1}	*Proteus vulgaris, Klebsiella pneumoniae*
13	APTW3	1.0×10^{1}	*Enterobacter aerogenes*
14	APTW4	1.0×10^{1}	*Proteus vulgaris*
15	APTW5	2.0×10^{1}	*Proteus vulgaris and Bacillus subtilis*
16	APTW6	1.0×10^{1}	*Enterobacter aerogenes*
17	APTW7	1.0×10^{1}	*Enterobacter aerogenes*
18	APTW8	1.0×10^{2}	*Escherichia coli, Bacillus subtilis*
19	APTW9	4.0×10^{2}	*Enterobacter aerogenes, Salmonella typhi*
20	APTW 10	1.0×10^{1}	*Enterobacter aerogenes*
21	IWDW1	2.0×10^{1}	*Pseudomonas aeruginosa, Klebsiella pneumoniae*
22	IWDW2	2.0×10^{2}	*Enterobacter aerogenes, Escherichia coli*
23	IWDW3	1.0×10^{1}	*Enterobacter aerogenes*
24	IWDW4	1.0×10^{2}	*Pseudomonas aeruginosa, Enterobacter aerogenes*
25	IWDW5	1.0×10^{1}	*Enterobacter aerogenes*

26	IWDW6	1.0×10^2	*Enterobacter aerogene, Bacillus subtilis*
27	IWDW7	2.1×10^2	*Klebsiella pneumoniae, Bacillus subtilis*
28	IWDW8	2.1×10^2	*Klebsiella pneumoniae, Escherichia coli*
29	IWDW9	1.1×10^2	*Klebsiella pneumoniae*
30	IWDW10	2.1×10^2	*Klebsiella pneumoniae, Bacillus subtilis*
31	ODNW1	3.1×10^2	*Klebsiella pneumoniae, Escherichia coli*
32	ODNW2	2.1×10^2	*Klebsiella pneumoniae*
33	ODNW3	2.0×10^1	*Vibrio cholerae, Klebsiella pneumoniae*
34	ODNW4	1.0×10^2	*Enterobacter aerogenes*
35	ODNW5	3.1×10^2	*Vibrio cholerae, Klebsiella pneumoniae*
36	ODNW6	2.1×10^2	*Klebsiella pneumoniae*
37	ODNW7	2.3×10^2	*Klebsiella pneumoniae, Escherichia coli*
38	ODNW8	1.0×10^1	*Enterobacter aerogenes*
39	ODNW9	2.0×10^2	*Vibrio cholerae, Klebsiella pneumoniae*
40	ODN 10	1.0×10^1	*Enterobacter aerogenes*
41	OJBW1	2.1×10^2	*Klebsiella pneumoniae, Salmonella typhi*
42	OJBW2	2.0×10^2	*Enterobacter aerogenes, Escherichia coli*
43	OJBW3	1.0×10^2	*Enterobacter aerogenes, Salmonella typhi,*
44	OJBW4	1.0×10^2	*Shigella dysenteriae, Enterobacter aerogenes*
45	OJBW5	3.0×10^2	*Shigella dysenteriae, Enterobacter aerogenes*
46	OJBW6	1.0×10^2	*Enterobacter aerogene, Escherichia coli*
47	OJBW7	4.0×10^2	*Klebsiella pneumoniae, Escherichia coli*
48	OJBW8	3.0×10^2	*Salmonella typhi, Klebsiella pneumoniae*
49	OJBW9	2.0×10^2	*Salmonella typhi, Klebsiella pneumoniae*
50	OJBW10	1.0×10^1	*Citrobacter freundii*

Table 7: Presence of faecal coliforms in Oyo groundwater samples

S/N	Sample identity	Production of Acid	Production of Gas	Remarks
1	ALKW1	No	No	Negative
2	ALKW2	Yes	Yes	Positive
3	ALKW3	No	No	Negative
4	ALKW4	Yes	Yes	Positive
5	ALKW5	No	No	Negative
6	ALKW6	Yes	Yes	Positive
7	ALKW7	Yes	Yes	Positive
8	ALKW8	Yes	Yes	Positive
9	ALKW9	No	No	Negative
10	ALKW10	Yes	Yes	Positive
11	APTW1	No	No	Negative
12	APTW2	No	No	Negative
13	APTW3	No	No	Negative
14	APTW4	No	No	Negative
15	APTW5	No	No	Negative
16	APTW6	No	No	Negative
17	APTW7	No	No	Negative
18	APTW8	Yes	Yes	Positive
19	APTW9	No	No	Negative
20	APTW10	No	No	Negative
21	IWDW1	No	No	Negative
22	IWDW2	Yes	Yes	Positive
23	IWDW3	No	No	Negative
24	IWDW4	No	No	Negative
25	IWDW5	No	No	Negative
26	IWDW6	No	No	Negative
27	IWDW7	No	No	Negative

28	IWDW8	Yes	Yes	Positive
29	IWDW9	No	No	Negative
30	IWDW10	No	No	Negative
31	ODNW1	Yes	Yes	Positive
32	ODNW2	No	No	Negative
33	ODNW3	No	No	Negative
34	ODNW4	No	No	Negative
35	ODNW5	No	No	Negative
36	ODNW6	No	No	Negative
37	ODNW7	Yes	Yes	Positive
38	ODNW8	No	No	Negative
39	ODNW9	No	No	Negative
40	ODNW10	No	No	Negative
41	OJBW1	No	No	Negative
42	OJBW2	Yes	Yes	Positive
43	OJBW3	No	No	Negative
44	OJBW4	No	No	Negative
45	OJBW5	No	No	Negative
46	OJBW6	Yes	Yes	Positive
47	OJBW7	Yes	Yes	Positive
48	OJBW8	No	No	Negative
49	OJBW9	No	No	Negative
50	OJBW10	No	No	Negative

Table 8: Compliance of sample with WHO standard of drinkable water

S/N	Sample identity	Bacterial load (cfu/ml)	Bacterial Counts	Compliance with WHO standard
1	ALKW1	2.0×10^2	200	No
2	ALKW2	2.0×10^2	200	No
3	ALKW3	2.0×10^1	20	No
4	ALKW4	2.0×10^2	200	No
5	ALKW5	1.0×10^1	1	Yes
6	ALKW6	3.0×10^1	3	No
7	ALKW7	2.0×10^1	2	Yes
8	ALKW8	2.0×10^1	2	Yes
9	ALKW9	1.3×10^2	130	No
10	ALKW10	1.0×10^2	100	No
11	APTW1	1.0×10^1	1	Yes
12	APTW2	3.0×10^1	3	No
13	APTW3	1.0×10^1	1	Yes
14	APTW4	1.0×10^1	1	Yes
15	APTW5	2.0×10^1	2	Yes
16	APTW6	1.0×10^1	1	Yes
17	APTW7	1.0×10^1	1	Yes
18	APTW8	1.0×10^2	10	No
19	APTW9	4.0×10^2	4	No
20	APTW 10	1.0×10^1	1	No
21	IWDW1	2.0×10^1	2	Yes
22	IWDW2	2.0×10^2	20	No
23	IWDW3	1.0×10^1	1	Yes
24	IWDW4	1.0×10^2	10	No
25	IWDW5	1.0×10^1	3	No
26	IWDW6	1.0×10^2	10	No
27	IWDW7	2.1×10^2	21	No
28	IWDW8	2.1×10^2	21	No
29	IWDW9	1.1×10^2	11	No

30	IWDW10	2.1×10^2	21	No
31	ODNW1	3.1×10^2	31	No
32	ODNW2	2.1×10^2	21	No
33	ODNW3	2.0×10^1	2	Yes
34	ODNW4	1.0×10^2	10	No
35	ODNW5	3.1×10^2	31	No
36	ODNW6	2.1×10^2	21	No
37	ODNW7	2.3×10^2	23	No
38	ODNW8	1.0×10^1	1	Yes
39	ODNW9	2.0×10^2	20	No
40	ODN W10	1.0×10^1	1	Yes
41	OJBW1	2.1×10^2	21	No
42	OJBW2	2.0×10^2	20	No
43	OJBW3	1.0×10^2	10	No
44	OJBW4	1.0×10^2	10	No
45	OJBW5	3.0×10^2	30	No
46	OJBW6	1.0×10^2	10	No
47	OJBW7	4.0×10^2	40	No
48	OJBW8	3.0×10^2	30	No
49	OJBW9	2.0×10^2	20	No
50	OJBW10	1.0×10^1	1	Yes

Table 9a: Morphological characteristics of bacterial isolates

Isolate No	Pigmentation/colour	Shape	Edge	Opacity	Consistency	Colony surface	Spore formation	Gram's reaction	Motility
1	White	Circular	Entire	Translucent	Butyrous	Smooth	Negative	-ve rod	+
2	White	Irregular	Lobate	Translucent	Viscid	Smooth	Negative	-ve rod	+
3	Milky white	Circular	Entire	Opaque	Butyrous	Smooth	Negative	-ve rod	+
4	Milky white	Circular	Entire	Translucent	Swarmy	Smooth	Negative	-ve rod	+
5	Black	Circular	Entire	Translucent	Butyrous	Smooth	Negative	-ve rod	+
6	Milky white	Circular	Entire	Opaque	Butyrous	Smooth	Positive	+ve rod	+
7	White	Irregular	Lobate	Translucent	Viscid	Smooth	Negative	-ve rod	+
8	Milky white	Circular	Entire	Opaque	Butyrous	Smooth	Negative	-ve rod	+
9	Milky white	Circular	Entire	Opaque	Mucoid	Smooth	Negative	-ve rod	+
10	Green	Circular	Entire	Translucent	Butyrous	Smooth	Negative	-ve rod	+

Table 9b: Biochemical characteristics of bacterial isolates

Isolate no	Cat	Oxi	Ind	H_2S	Nit red	Ure	Lact	Fruc	Malt	Gala	Glu	Arab	Raf	Man	MR	VP	Identified organism
1	+	-	+	+	-	+	-	+	-	-	+	-	-	-	+	-	*Enterobacter aerogenes*
2	+	-	-	-	-	+	+	+	+	+	+	-	-	+	+	+	*Escherichia coli*
3	-	-	-	-	+	-	+	+	+	+	+	+	+	-	+	+	*Klebsiella pneumonia*
4	+	+	-	+	+	+	-	+	+	+	-	+	+	-	+	+	*Proteus vulgaris*
5	+	+	-	+	-	-	-	+	+	-	+	-	-	+	+	+	*Salmonella typhi*
6	+	-	+	+	-	+	-	+	-	-	+	-	-	-	+	-	*Bacillus subtilis*
7	+	-	-	-	-	+	+	+	+	+	+	-	-	+	+	+	*Vibrio cholerae*
8	-	-	-	-	+	-	+	+	+	+	+	+	+	-	+	+	*Citrobacter freundii*
9	+	+	-	+	+	+	-	+	+	+	-	+	+	-	+	+	*Shigella dysenteriae*
10	+	+	-	+	-	-	-	+	+	-	+	-	-	+	+	+	*Pseudomon as aeruginosa*

Keys: + = Bacteria positive to the enzymatic test; − = Bacteria negative to the enzymatic test

Table 10: Presence of protozoan in the water samples

S/N	Sample identity	*Entamoeba histolytica*	*Balantidium coli*	*Giardia intestinalis*	*Cryptosporidium* spp	Others/Worms
1	ALK1	-	-	-	-	-
2	ALK2	-	-	-	-	-
3	ALK3	-	-	-	-	-
4	ALK4	-	-	-	-	-
5	ALK5	-	-	-	-	-
6	ALK6	-	-	-	-	-
7	ALK7	-	-	-	-	-
8	ALK8	-	-	-	-	-

9	ALK9	-	-	-	-	-
10	ALK10	-	-	-	-	-
11	APT1	-	-	-	-	-
12	APT2	-	-	-	-	-
13	APT3	-	-	-	-	-
14	APT4	-	-	-	-	-
15	APT5	-	-	-	-	-
16	APT6	-	-	-	-	-
17	APT7	-	-	-	-	-
18	APT8	-	-	-	-	-
19	APT9	+	-	-	-	-
20	APT10	-	-	-	-	-
21	IWR1	-	-	-	-	-
22	IWR2	-	-	-	-	-
23	IWR3	-	-	-	-	-
24	IWR4	-	-	-	-	-
25	IWR5	-	-	-	-	-
26	IWR6	-	-	-	-	-
27	IWR7	-	-	-	-	-
28	IWR8	-	-	-	-	-
29	IWR9	-	-	-	-	-
30	IWR10	-	-	-	-	-
31	ODN1	-	-	-	-	-
32	ODN2	-	-	-	-	-
33	ODN3	-	-	-	-	-
34	ODN4	-	-	-	-	-
35	ODN5	-	-	-	-	-
36	ODN6	-	-	-	-	-
37	ODN7	-	-	-	-	-
38	ODN8	-	-	-	-	-
39	ODN9	-	-	-	-	-
40	ODN10	-	-	-	-	-
41	OJB1	+	-	-	-	-
42	OJB2	+	-	-	-	-
43	OJB3	+	-	-	-	-
44	OJB4	+	+	-	-	-
45	OJB5	+	+	-	-	-
46	OJB6	+	+	-	-	-
47	OJB7	+	+	-	-	-
48	OJB8	+	+	-	-	-
49	OJB9	+	+	-	-	-
50	OJB10	+	+	-	-	-

Keys: + = Present; - = Absent

Plate 1: ***Entamoeba histolytica***

Plate 2: ***Bacillus***

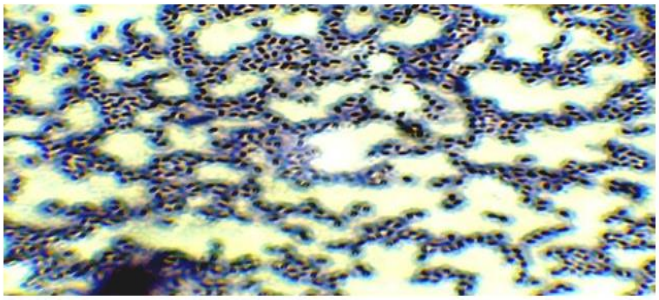

Plate 3: ***Citrobacter***

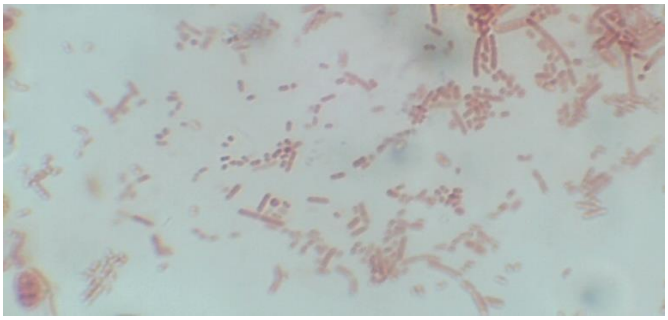

Plate 4: ***Escherichia coli***

RESULTS AND DISCUSSION

Table 1 shows the results of the physico-chemical quality of the groundwater samples that was comprising of pH, Temperature, Electrical conductivity and Total dissolved solids of the water samples. The noticeable environmental conditions of the well, the well parameters which includes the total depth as well as the static water level of the well and the coordinates (Longitude, Latitude and Altitude) pointing to the exact location of the wells. The output for each locations were recorded using specific letter code for each selected area namely; Oja-Oba: OJB; Iwo-Road: IWD; Alakia: ALK; Odo-Ona: ODN; Apata: APT.

The pH values for the ten (10) sampled wells at Oja-Oba ranged from 4.7±0.15 to 6.4±0.26. pH concentration revealed that the water was acidic (Table 1). The pH of the sampled wells across the investigated locations in Oja-Oba falls within the permissible limit set by World Health Organization (WHO, 2011, WHO, 2022) standard of 6.5-8.5 in potable water. Despite the acidic nature of pH in Oja-Oba; the state of pH parameter plays a significant role in determining the bacteria population growth and diversity in water. According to Ojekunle and Lateef, 2017; increase in pH could be as a result of basic metabolic waste products caused by increasing bacteria pollution.

The temperature of the sampled wells ranged from 28.4±0.26 to 30.9±1.63 ºC (Table 1). The temperature falls within the WHO standard of <40°C. Hence, the temperature in these selected wells at Oja-Oba may not pose any health problem on residents. The TDS obtained from the analysis at Oja-Oba ranged from 182±7.93 to 599.7±9.07 mg/L.OJBW1 had the highest (599 mg/L) followed by OJBW3 (590mg/L) and the lowest was at OJBW4 (182mg/L). All the values obtained at the sampled wells fall below WHO standard of <1200 mg/L. The values of EC ranged from 24.33±1.53 to 82±2.0 µs/cm. OJBW1 and W3 had the highest (82 and 81µs/cm). All the well sampled were within WHO limit of 400µs/cm. this shows that water samples are not saline and the concentration of salt in the ground water is minimal. The level of EC which was found to be above WHO standards can pose serious health issue such as brain damage based on prolonged exposure (WHO, 2011; WHO, 2022).

The pH values for the ten (10) sampled wells at Iwo ranged from 7.5±0.4 to 8.4±0.25. The exhibited pH High concentrations ranged from 7.5 in IWDW1 to 8.4 in IWDW9 (8.4). The pH values of the sampled wells across the location were within the permissible range set by World Health Organization (WHO, 2011) standard of 6.5-8.5 in potable water. The pH base was alkaline in nature which may be unlikely to cause health problem such as acidosis. The temperature of the sampled wells ranged from 27.8±0.7 to 30.5±1.56 ºC (Table 2). The temperature falls within the WHO standard of <40°C. The TDS obtained from the analysis at Iwo ranged from 166±2.0 to 363.7±18.01. IWDW8 had the highest (363mg/L) followed by IWDW1 (316mg/L) and the lowest is at IWDW6 (166 mg/L); all the observed values of the sampled wells fall below WHO standard of <1200 mg/L. The values of EC ranged from 22±1.0 to 60.33±0.58 µs/cm. IWDW10 had the highest (60.33µs/cm) while the least was at IWDW6; with all the sampled wells within the permissible WHO limit of 400 µs/cm.

This indicated that well-water samples are not saline and the concentration of salt in the ground water is minimal. According to WHO (2011), EC level above recommended standard can pose serious health issue such as brain damage based on prolonged exposure (Table 2).

The pH values for the ten (10) sampled wells at Alakia ranged from 7.6±0.17 to 8.3±0.2. The concentrations ranged from ALKW2 (7.6) to ALKW9 (8.3). The pH of the sampled wells across the location were within the permissible range set by World Health Organization (WHO, 2011; WHO, 2022) standard of 6.5-8.5 in potable water. The temperature of the sampled wells ranged from 28.9±0.5 to 32.7±4.71 (Table 3). The temperature falls within the WHO standard of <40°C. The TDS obtained from the analysis at Alakia ranged from 168.6±4.50 to 287.7±1.52. ALKW7 had the highest (287 mg/L) followed by ALKW8 (233mg/L) and the lowest is at ALKW1 (168 mg/L); all the obtained values at the sampled wells fall below WHO standard of <1200mg/L. The values of EC ranged from 22±1.73 to 39.6±0.58µs/cm where ALKW7 had the highest (39.6µs/cm) while the least was at ALKW6; the EC of all the sampled wells in Alakia were within WHO limit of 400 µs/cm.

The pH values for the ten (10) sampled wells at Odo-Ona ranged from 8.2±0.06 to 8.8±0.06. where ODNW7 (8.8) exhibited the highest value and least value was recorded at ODNW10 (8.2). About 80% of the sampled wells across the location were above the permissible limit set by World Health Organization (WHO, 2011) standard of 6.5-8.5 in potable water. The pH base was alkaline in nature. The temperature of the sampled wells ranged from 28.4±0.42 to 29.8±0.64 ℃ (Table 4). ODNW7 recorded highest value (29.8℃) while the least value was at ODNW3 (28.4 ℃). The temperature falls within the WHO standard of <40°C. The TDS obtained from the analysis at Odo-Ona ranged from 145.67±2.08 to 354.67±10.69 mg/L. ODNW8 had the highest (354.67 mg/L) and the lowest is at ODNW2 (145.67 mg/L); all the obtained values of TDS concentrations at the sampled wells fall below WHO standard of <1200 mg/L. The values of EC ranged from 19.33±0.57 to 60.33±0.58 µs/cm. ODNW10 had the highest EC (60.33 µs/cm) while the least was at ODNW2 (19.33 µs/cm) with all the sampled wells exhibiting EC statuses within WHO limit of 400 µs/cm. The EC is the ease with which a substance allows free flow of electricity through the ions in electrolytes of water samples and the amount of dissolved solid in them. According to WHO, 2011; any EC level above the recommended standard can pose health risk of defective endocrine functions with prolonged exposure. The levels of EC in this study were lower than the tolerable values. Generally, the more ions that are present, the higher the conductivity in water (Table 4).

Table 5 presents the results of the physical characteristics of well water samples for the 10 wells sampled at Apata. The pH measures the concentration of hydrogen ion and is the

scale of intensity of acidity and alkalinity of water. The mean pH values recorded during the period of study ranged from 8.2±0.06 to 8.9±0.21 with APTW4 (8.9) having the highest pH concentration while the lowest was recorded at APTW7 (8.2). About 70% of the assessed sampled wells were above the recommended limit of WHO for 6.5-8.5 (WHO, 2011; WHO, 2022). The mean temperature values ranged from 28.8±0.25to 30.8±2.6 ℃. APTW1 (30.8℃) had the highest level of temperature. The values obtained falls within the limits recommended for drinking water which is 21℃ to32℃ (WHO, 2011). These values were in agreement with the study conducted by Samuel *et al.* (2017) who reported the temperature of hand-dug wells in Awka metropolis which ranged from 28 to 29℃. High temperature in water enhances the growth of micro-organism and may increase the taste, colour and corrosion in water (WHO, 2011; WHO, 2022). Based on the DMRT analysis, there was significant differences in the well sampled across the sampled sites. The TDS measure the total inorganic substances dissolved in water and this reveals the salinity behavior of groundwater substances (Samuel *et al.,* 2017). TDS ranged from 120±3.46 to 521±10.0 mg/L. APTW4 had the highest while APTW6 (120 mg/L) recorded the lowest concentration of TDS. Mean concentration of TDS were within permissible limit of 500mg/L except APTW4. There was significant ($p<0.05$) difference in the TDS values across the sampling points. EC ranged from15.63±0.51 to 71.67±1.52 µs/cm. The EC varied across each sampling points with the highest was recorded value at APTW4 (71.67µS/cm). The mean EC across the sampling points were found to be lower than the permissible limit of 400 µS/cm by WHO, 2011 and WHO, 2022 for drinking water (Table 5).

Table 6 reveals the bacterial load and types of isolates identified in Oyo Groundwater Samples. Table 7 reveals the results of faecal coliform test performed at a conditioned temperature of 44.5ºC; Table 8 shows the compliance levels of individual samples with WHO standard of drinkable water quality; Table 9a reveals the morphological characteristics of the bacterial isolates while Table 9b is a representation of biochemical characteristics of bacterial isolates in the study area.

Table 6 reveals the bacterial load and types of bacteria isolated from each of the sample analyzed for enteric bacteria group. The predominant bacteria were *Enterobacter aerogenes, Klebsiella pneumonia* and *Escherichia coli*. The samples with the highest bacterial load were ALKW9 and OJBW7 with load of 1.3×10^2 and 4.0×10^2 cfu/ml respectively. From these samples, two (2) different bacteria were identified from each and they include *Pseudomonas aeruginosa, Proteus vulgaris, Klebsiella pneumonia* and *Salmonella typhi.* Table 7 shows the number of samples that had no form of coliform in them and were tagged negative while Table 8 defined the level of compliance of the samples to WHO approved standard for drinking water. Fifteen samples complied with the WHO standard, while thirty-five (35) samples were not compliant while the outputs of the biochemical characteristics of the identified isolates are displayed in Table 9b.

The results of the protozoan analyses showed that most of the samples recorded no form of protozoan except APTW9 that exhibited positive presence of *Entamoeba histolytica* while all the samples in Oja-Oba showed positive affinity to *Entamoeba histolytica and Balantidium coli* (Table 10). The pictures of the protozoan seen in one of the water samples analyzed are hereby displayed in Plate 1, Plate 2, Plate 3 and Plate 4 respectively for *Entamoeba histolytica, Bacillus, Citrobacter* and *Escherichia coli.* From the results of the microbial analysis of groundwater samples of the study area, most of the water samples were contaminated with pathogenic bacteria such as *Salmonella, Shigella* and *Vibrio* all of which are diarrhoeagenic in nature with Oja-Oba area exhibiting the highest level of contamination. The thirty-five samples that

did not comply with the drinking water standard in this study were adjudged polluted (WHO, 2022). Others were in one way or the other contaminated by enteric bacteria that includes *Escherichia coli* but not in high number. All other samples (15 of them); though none is sterile met the WHO standard for drinking water as the number of colonies per ml was minimal. Therefore, thirty-five (35) samples out of the total (50) treated samples were not fit for drinking based on the WHO standard for drinking water (WHO, 2022). The analysis of the colony count in the water samples revealed the presence of heterotrophic bacteria in some of the water sources. The compliance assay showed that fifteen (15) of the samples complied or met the allowable limits of World Health Microbiological requirements for safe drinking water amounting to 30 % level of compliance (WHO, 2022). The WHO standard for heterotrophic bacteria in potable water states that the total heterotrophic bacteria count should not be more than 2.0 cfu/ml (WHO, 2011; WHO, 2022). The presence of bacteria counts exceeding the WHO limits indicates that the water samples contain high concentration of bacteria that could make the water unsafe for drinking (EPA, 2005; GOC, 2017; He *et al.,* 2020a; He *et al*., 2020b). Some of these identified and quantified microorganisms are significant human pathogens associated with a variety of infectious diseases such as gastroenteritis, urinary tract infections and others (Nwidu *et al*., 2018). They are known as causative agents of many waters borne diseases and might indicates that these water sources are not advisable for domestic uses such as drinking, bathing and cooking. Their entry into water sources could be attributed to seepages from nearby septic tanks, as opined by (Pedley and Howard, 1997; Nguendo-Tongsi, 2011 and Willocks *et al*., 2014) or through deliberate and indiscriminate deposition of animal waste and human faeces into streams as commonly observed in some riverine areas. It is important to note that even if the water meets the compliance level for drinking water microbiologically, the comprehensive analysis of the protozoan assay will have to be considered. According to Cheesbrough (2000), some of these intestinal protozoans observed in some of these water samples pose a more public health threats than some of the bacteria isolated. This is because some of the bacteria are easy to eliminate especially heat-labile bacteria such as *Enterobacter aerogenes* that was common in the water samples. Some of these bacteria and protozoans when found in water are potential threat to blanked vegetable salad and other raw delicacies that are common in our society today (Omid *et al.,* 2023; Udokpoh *et al.,* 2024). Also, the water Samples have minimal bacteria pollution as only one of the water samples (APTW9) recorded the presence of *Entamoeba histolytica* as the protozoan seen. Also, none of the water samples was sterile, while less than 50% tend to meet the WHO standard for drinking water in terms of bacterial, and protozoan affinity. The Oja-Oba groundwater samples were more polluted with coliforms than other group of samples in the study area

CONCLUSION

None of the investigated groundwater sample in the study area was sterile; thirty-five (35) samples out of the total (50) treated samples were not fit for drinking based on the WHO standard for drinking water (WHO, 2022). The Oja-Oba wells (OJBW samples) were more polluted with coliforms than other group of samples as drinking water that they are based on their positive affinity to *Entamoeba histolytica and balantidium coli*. The microbiological quality analysis of the fifty (50) water samples showed that a number of bacteria were predominantly isolated and identified using standard microbiological procedures. These bacteria were *Citrobacter freundii*, *Shigella dysenteriae, Enterobacter aerogenes, Escherichia coli, Proteus vulgaris, Klebsiella pneumoniae, Salmonella typhi, Bacillus subtilis, Pseudomonas aeruginosa* and *Vibrio cholerae*. The total

numbers of bacteria isolated from all the samples were ten (10) all together. The compliance revealed that fifteen (15) of the samples complied and met the World Health Microbiological requirements for safe drinking water amounting to thirty percent (30 %) level of compliance. Thirty-five (35) other samples had either slight bacterial pollution of low number or counts of coliform (*Escherichia coli*) while other samples were moderately polluted with pathogenic bacteria (*Klebsiella pneumoniae, Salmonella typhi, Vibrio cholerae, Pseudomonas aeruginosa* and *Bacillus subtilis*) in addition to *Enterobacter aerogenes*. Therefore, The Oja-Oba wells (OJBW samples) were mostly unsuitable for drinking and are hereby recommended for comprehensive treatment while regular monitoring of groundwater quality is crucial to ensure the safety of drinking water and prevent potential health hazards.

REFERENCES

Abdul-Aziz, H., Abu-Amr, S.S., and Hung, Y.T (2017). Surface water quality and analysis In Integrated Natural Resource Management. Chapter 10: in part of the book series. *Handbook of Environmental Engineering,* 20(1): 66-113.

Abu, M., Egbueri, J.C, and Agbasi, J.C. (2023). Kringing-interpolated mapping and predictive modelling of groundwater F^{-1} and NO_3^- contamination with chemometric health risk assessments in Ghana's Birmian Province. *Environmental Geochemistry and Health,* 47(165); 1782-1783.

Adeniran, M.A., Oladunjoye, M.A and Doro, K.O. (2023). Soil and groundwater contamination by cruse oil spillage. A review and implications for remediation projects in Nigeria. Sec. Soil Processes. *Frontiers Environmental Sciences*, 22.

Adesakin, T.A., Oyewole., A.T., Byena, U., Ahmed, P.Z., Abubakar, N.D., and Banje, I.B. (2020). Assessment of bacteriological quality and physico-chemical parameters of domestic water sources in Samariu community, Northwest Nigeria. *Heliyon,* 6(8): 113-118.

Addo, K., Mensah, G.I., Donker, B and Akyeh, M.L. (2009). Bacteriological quality of bottled water sold on the Ghanian Market. *African Journal of Food Agriculture Nutrition and Development,* 9(6): 33-37.

Akram, A.P., Solangi, G.S., Shehzad, F.R., Khandhro, A.A., Arain, S.S., Kamboh, S.S., and Kamboh, M.A.. (2020). Quality assessment using a water quality index (WQI) in nine cities of Sindhi. *Pakistan International Journal of Research in Environmental Science*, 6(1): 18-76.

Akaho, A.A., Tikeri, G.B., David A.O (2022). Physico-chemical analysis of potable water in Braham Community, Western Region of Cameroon. *Journal of Applied Science and Environmental Management,* 26(7): 1203-1309.

Amponsah, B., Boadi, N.O., Soah, S.A., Sakyi, P.O., Agonku, E.S., Okyere, H and Nyamfuel, A. (2024). Evaluation of groundwater quality in communities near Sokoban-Wood Village. *Heliyon,* 10(12): 322-329.

Anisah, U., Iswanto, B., and Rinanti, A. (2018). Distribution Pattern study of *Escherichia coli* as an indicator for groundwater quality at Matraman District, East Jakarta. *IOP Conference Series*, 106(1): 274-276.

APHA/AWWA/WEF (2012). Standard methods for examination of water and wastewater. *American Public Health Association*, 2012.

Arya, S. (2023a). Most Probable Number: test for water quality. Microbe Notes. Basic *Microbiology,* 23-25.

Arya, S. (2023b). Biochemistry: carbohydrate fermentation test (sugar

fermentation). Microbe Notes. *Biochemistry,* 17-21.

Ayeta, E.G., Ya-Fello, L., Lutterodt, G., Ogbonna, J.F and Miyittah, M.K. (2023). Seasonal variations and health risk assessment of microbial contaminations of groundwater in selected coastal communities of Ghana. *Heliyon*, 9(3): 375-377.

ASM. (2020). American Society of Microbiology. Identifying bacteria look growth, stain and strain. *ASM Bulletin*, 42-44.

Baig, S.A., Xiu, X., and Khan, R.N. (2012). Microbial water quality risks to public health potable water assessment for a flood-affected town in Northern Pakistan. *Rural and Remote Health,* 12(3): 2196.

Balogun, S., Ejelonu, B., Adeogun,A and Lasisa, A.A. (2013). Microbiological and chemical assessment of spring water from a rural setting in Ondo State, South-West Nigeria. *African Journal of Environment Science and Technology*, 7(6): 555-559.

Basu, A., Saha, D., Saha, R., Ghosh, T., Saha, B. (2014). ArCview on sources, toxicity and remediation Technologies for removing arsenic from drinking water. *ResChem. Intermediation,* 40(1): 447–485

Bonadonna, L., Briancesco, R., and La-Racia, G. (2019). Innovative analytical methods for monitoring microbiological and virological water quality. *Microchemical Journal,* 150 (1): 47-49.

Bonchardt, M.A., and Spencer, S. (1996). Method of concentrating waterborne protozoan parasites. *Marshfield Medical Research as Education Foundation*. 7-11.

Boujinouni, H.E., Balla, K.N., Belkodi, B., and Rahouti, M. (2022). Comparison between the recovery rate of three concentration protocols of water samples intended for analysis by molecular biology: Membrane Filtration, Filtration, on Gauze pad and centrifugation. *Saudi Journal of Biological Sciences,* 29(3): 1512-1597.

Boussouga, Y., Frey, H., Sohafer, A.I. (2020). Removal of arsenic by nano-filtration: impact of water salinity, pH, and organic matter. *Journal of Member Sciences*, 341-345.

Chakraborti, D,, Rahman, M.M,, Mukherjee A., Alauddin, M., Hassan, M., Dutta, R. N., Pati, S., Mukherjee, S.C., Roy, S., Quamruzzman, Q., Rahman, M., Islam, T., Sorif, S., Selim, M. D., Islam, M. R., Hossain, M. M. (2015). Groundwater arsenic contamination in Bangladesh—21 years of research. *J. Trace Elem Med Biol,* 31:237–248.

Cheesbrough, M. (2000). Microbiological tests in Cheesbrough, M.ED District Laboratory Practice in Tropical Countries, Part II, Low Prices Edition. *Cambridge University Press, Cambridge*, 105-130.

Clarridge, J.E. (2004). The Impact of 165 rRNA Gene sequencing analysis for identification of bacteria on clinical microbiology and infectious diseases in clinical microbiology. *Clinical Microbiology*, 17(2): 840-862.

Crovota, C.A., Senior, L.A., and Conton, M.A. (2022). Factors affecting groundwater quality used for domestic supply in Marcellus-shale Region of North-Central and North-East Pennsylvania, USA. *Applied Geochemistry*, 137(1): 355-359.

Curtis, V., Cairncross, S. and Yonli, R. (2000). Domestic hygiene and diarrhoea - pinpointing the problem. *Tropical Medicine and International Health,* 5(1), 22-32.

Debassi, B., Allaoua, N., Ghanem, N., Halid, H., Benacherie, M., and Chenchoumi, H. (2025). Assessment of water quality of groundwater, surface water, and wastewater using physicochemical parameters and microbiological indicators. *Science Progress*, 18(2): 108-110.

Etuk, M., Re, V., Viaroli, S., Raco, B., and Igwe, O. (2025). Assessing groundwater quality and solute sources in highly anthropized areas. The case of Abuja. Federal Capita Territory, Nigeria. *Groundwater for Sustainable Development*, 29(1): 1001-1011.

Eguaroje (2015). Elevation map of Ibadan city. 3. Esrey, S.A., Potash, J.B., Roberts, L. and Shiff, C. (1991). Effects of improved water supply and sanitation on ascariasis, diarrhoea, dracunculiasis, hookworm infection, schistosomiasis, and trachoma. *Bulletin of the WHO*, 69(5): 609-621.

EPA (2005)."Protecting Water Quality from Agricultural Runoff" Fact-Sheet No. *Bulletin of the United States Environmental Protection Agency,* 841-F-05- 001.

Field, B.N., Knipe, D.M., Chanock, R.M., Hirsh, M.S., Melnick, J.L., Monath, T.P., and Roizman, B. (1991). *Virology*. 2nd Edition. New-York, Raven Press, 1(1): 4002-4003.

Gebresilasie, K.G., Berhe, G.G., Tesfay, A.H., Gebre, S.E. (2021). Assessment of some physic-chemical parameters and heavy metals in hand-dug wells, water samples of Kafta Humera Woreda, Tygray Ethiopia. February, 2021. *International Journal of Analytical Chemistry*, 2021(3): 1-9.

Gebreyohans, G., Batu, N.I., Muche, T., Kalayou, N., Bacha, K., Gershe, S., Ango, Z. (2024). Isolation and identification of major cochroaches associated pathogenic bacteria in Bunga town, Ethiopia. *Microbes*, 5(1): 11-13.

Gilbert, R.A., Ouwerkerk, D., Zhang, L.H., Klieve, A.V. (2010). Cooperative research center for beef genetic technologies. *In vitro* detection and primary cultivation of bacteria producing materals inhibiting to ruminal methanogens. *Journal of Microbiological Method,* 80(1): 217-218.

GOC. (2020). Government of Canada. Guidelines for Canada drinking water quality: guideline technical document on Total Coliforms. *Health Canada*, 220-226.

GOC. (2017). Government of Canada. Groundwater contamination. *Health Canada*, 227-229.

Griebler, C and Lueders, T. (2009). Microbial biodiversity in groundwater ecosystem. *Christian Griebler, Helmoltz Center Munich-German Research Center for Environmental Health Institute of Groundwater Ecology*, Ingolstadter-Landstrasse, Neuherberg, Germany.

Haldar, K., Roelevveld, K.K., Hofestra, N., Daltu, D.K., Jnoarts, H.R. (2022). Microbial contamination in surface water and potential health risks for Peri-urban farmers of the Bengal Delta. *International Journal of Hiegiene and Environmental Health,* 244(1): 2002-2011.

He, X., Wu, J., He, S. (2019). Hydrochemical characteristics and quality evaluation of groundwater in Terms of health risks in Luohe aquifer in WuqiCounty of the Chinese Loess Plateau, Northwest China. *Human Ecological-Risk Assessment,* 25(1):32–51.

He, X., Li, P., Wu, J., Wei, M., Ren, X., Wang, D. (2020a). Poor groundwater quality and high potential health risks in the Datong Basin, Northern China: research from published data. *Environ Geochem Health*.

He, X., Li, P., Ji, Y., Wang, Y., Su, Z., Elumalai, V. (2020b) Groundwater arsenic and fluoride and associated arsenicosis and fuorosis in China: occurrence, distribution and management. *Expo Health,* 22-24.

Health Canada (2000) Waterborne outbreak of gastroenteritis associated with a contaminated municipal water supply, Walkerton, Ontario, May-

June 2000. *Canada Communicable Disease Report,* 26(20): 170-173.

Huang, M.N., Le-Vo, P., Bui, T.V., Hung, P. and Ha, Q.K. (2022). Health risk assessment of Arsenic in drinking groundwater. a case study in central highland area of Vietnam. *IOP Conference Ser-Earth Environment Science,* 222-224.

IAH (2020). International Association of Hydrogeologists (2020). Groundwater—more about the hidden Resources. *IAH Bulletin,* 55-58.

Izah, S.C., Ngun, C.T., and Richard, G. (2022). Microbial quantity of groundwater in the Niger-Delta Region of Nigeria: Chapter 10, *Health Implications and Effective Treatment Technologies,* 6(1): 149-172.

Jain, A., Jain, R and Jain, S. (2020). Sub-culturing of bacteria, fungi and actinomycites. basic techniques in biochemistry in microbiology and molecular biology. *Springer Protocol Handbooks (SPH),* 101-103.

Jandal, J and Abbot, S. (2002). Bacteria identification for publication. When it is enough is enough. *Journal of Clinical Microbiology,* 40(6): 1887-1891.

Jett, B.D., Hatter, K.I., Huycke, M.M., and Gilmore, M.S. (1997). Simplified agar plate method for quantifying viable bacteria. *Biotechniques,* 23(1): 648-650.

Kayowa, O.S and Ayanfemi, A.A. (2018). Microbiological and physico-chemical analysis of hand-dug well-water near pit latrine in a rural area of Western Nigeria. *African Journal of Environnmental Science and Technology,* 12(4): 132-140.

Khan, M.J., Shah, B.A., and Nazr, B. (2020). Groundwater Quality assessment for drinking purpose: a case study from Sindh Industrial Trading Estate, Karachi, Pakistan. *Model Earth System Environment,* 6(1): 263-272.

Koni, A.H., Mahesar, S.A., Jagiani, M.S., Laghari, Z.H., Pahwar, T., Jagiani, M.D. (2020). Human exposure and risk assessment due to toxic heavy metals in groundwater of Larkare city. *Water, Air and Soil Pollution*, 231.

Li, J., Lx, L., Zhe, W., Deng, X., Lin, Q., and Xia, R. (2024). Evaluation of drinking water quality in Xinjiang based on the improved comprehensive Water quality Index. *Heliyon,* 221-224.

MacArthur, R.L., Teye, C., and Darkwa, S. (2021). Microbial contamination in palm oil selected from major markets in major cities of Ghana. *Heliyon,* 7(7): 22-25.

Maheux, A.F., Bouchard, S., Berube, E and Bergeron, M.G. (2017). Comaprison of MI, chrowcult coliform and compass CC chromogenic culture-based methods to detect *Escherichia coli* and total coliforms in water using 16Sr RNA sequencing for colony identification. *Journal of Natural Health,* 353-359.

Majedul-Islam, M.M., Igbal, M.S., N. Dauza., Islam, M.A. (2021). A review on present and future microbial surface water quality worldwide. *Environmental Nanotechnology, Monitoring and Management,* 16(1): 235-237.

Manini, E., Luna, G.M and Danovaro, R. (2004). Benthic bacteria response to variable estuarine water inputs. *FEMS Microbiology Ecology,* 50(3): 185-194.

Martin, M.S., Santos, I.C., Carlton, D.D., Granades, P.S., Hildeinbrand, Z.I., and Schug, K.A. (2018). Characterization of bacteria diversity in contaminated groundwater using matrix-assisted description/ionization time of flight mass spectrometry. *Science of the Total Environment*, 622-623(1): 1562-1571.

Moreno, Y., Mesonero, L.M., Amords, I., Perez, R., Marrilo, J.A., Alonso, J.L.

(2018). Multiple Identification of most important waterborne protozoa in surface water used for irrigation purposes by 18S rRNA amplicon-based metagenomics. *International Journal of Hygiene and Environmental Health,* 221(1): 102-111.

Ngande, S., Ogendi, G.M., Muora, C and Ngoma, J. (2025). Seasonal variations of microbial water quality from shallow wells and prevalence of water related diseases. *Journal of Geoscience and Environmental Protection,* 23(5): 445-449.

Nguendo-Tongsi, H.B. (2011). Microbiological evaluation of drinking water in a sub-saharan urban community (Yaounde). *Am. J. Biochemical and Molecular Biology,* 1: 68-81.

NHI (2025). National Institute of Health: National Library of Medicine. *Drinking Water and Health.* 1(1): 15-32.

Nwidu, L.L., Elmorsy, E., Aprioku, J.S., Siminialayi, Catter, W.G (2018). In Vitro anti-cholinestearase and antioxidant activity of extracts of Moringa Oleifera plants from Rivers State, Niger Delta. *Medicines (Besel*), 5(3): 71.

Odewande, L.O., Imam, A.A., Adesakin, T.A., and Odewande, J.O. (2025). Assessment of human faecal contamination of groundwater quality and reporting consequent waterborne diseases in Funtua metropolis, Katsina State Nigeria. *Frontier Water Supply Security, Water, and Human Health,* 7(1): 234-2237.

Ogbonim, P and Akaraka, N. (2025). The morphological and biochemical characteristics of bacteria isolates of selected borehole water samples in Agbor, Delta State Nigeria. *Newport International Journal of Biological and Applied Sciences,* 3(2): 242.

Oguntoyinbo, J.S, Areola, O.O and M. Filani (1978). A Geography of Nigerian Development, 2nd Edition, Ibadan. *Heinemann Educational Books (Nig) Ltd*, 45-70.

Ojekunle O.Z and Lateef S.T (2017). Environmental impact of abattoir waste discharge on quality of surface water and groundwater in Abeokuta. *International Journal of Environmental and Analytical Toxicology,* 7(5):3-7.

Omid, M.R., Houshang, J., Kafilzadela, F., Borjian, A., Arzaniou (2023). Occurrence of *Staphyloccocus aureus* in the wastewaters from iran. diversity, antimicrobial resistance and virulence potentials. *Journal of Water Health*, 21(2): 178−191.

OSGOF (2014). Office of the Surveyor General of the Federation. A ministerial press briefing to describe its structure and activities. *2014 OSGOF Bulletin,* 24.

Osot (2000). Osot Report on PTF sponsored national rural water supply schemes.

Owumi, S.E (2013). Physico-chemical parameters and selected heavy metals assessment of drinking water at the students' residences of the Nigerian Premier University. *African Journal of Biosciences*, 7(10): 203-209.

Palamlen, L and Akpoh, M. (2015). Physicochemical and microbial analysis of selected borehole water in Manikeng, south Africa. *MDPI International Journal of Environmental Research Public Health,* 12(8): 8619-3690.

Pandey, H.K, Duggal S.K, Jamatia A. (2016). Fluoride contamination of groundwater and its hydrological evolution in District Sonbhadra (U.P.). India. Proc Nat Acad Sci India Sect A. *Physical Sciences,* 86: 81–93.

Paul, A.Y., Haziz, S., Bathsabe, Y.A., Rose, K.N., Nathalie, C., Ibrajhim, K., Lamine, B.M. (2025). Physicochemical and microbiological

characteristics of surface and groundwater frequently used by households in some districts of Dalua, Cote d'voire. Journal of *Advances in Microbiology*, 25(3): 1-12.

Pedley, S and Howard, G. (1997). The public health implications of microbiological contamination of groundwater. *Q. J. Eng. Geol.,* 30: 179-188.

Raheem, S.B., Olawoore, W.A., Olagunju, D.P., and Adeokun, E.M. (2015). The cause, effect and possible solution to traffic congestion in Nigeria Road. (a case study of Basorun-Akobo Road, Oyo-State. *International Journal of Engineering Science and Invention,* 4(9): 6-9.

Rijal, N (2025). Most Probable Number test, principle, pressure and results. *Microbe Online,*147-119.

Rizwan, Dand Masoodi, F.A. (2025). Isolation and characterization of lactic acid bacteria from spontaneously fermented Kohlrabi Pickle of Jammu and Kashmv, India. Applied *Food Research,* 5(2): 341-344.

Roy, D.B and Bhattacharyya, S. (2023). Overview an old and new biochemical test for bacteria identification. *Auctores Journal,* 75-77.

Samuel, C.O., Elasia, R., Okoye, P., and Frederick, J.C.O (2017). An evaluation of physico-chemical characteristics of hand-dug wells in Awka Metropolis, Nigeria. *American Journal of Life Science Researches,* 5(3). 289-101.

Sambrook, J., and Russell, D.W. (2001). Molecular cloning: A Laboratory Manual. 3rd Edition, Cold-Spring Harbour, *Harbour Laboratory Press, New York,* 1231-1237.

Sanders, E.R. (2012). Aseptic laboratory plating techniques: plating methods. *Journal of Visualized Experiment,* 11(63): 3064.

Sanders, E.R., and Muller, J.H.I. (2010). Microbiologist: A discovery-based course in microbial ecology and molecular evolution. *Washington DC. ASM Press*. 1122-1227.

Sandle, T. (2016). Microbial identification. *Pharmaceutical Microbiology,* 103-113.

Sangodoyin A.Y, Agbawhe O.M (1991). Environmental study on surface and groundwater pollutants from abattoir effluents. *Bioresource Technology*, 41 (1992): 193-200.

Shaikh, A.A., Memon, A.G., and Channa, I.A., Sheikh, M.S. (2025). Integrated spatial mapping and arsenic remediation for improved groundwater quality in Larkana. *American Chemical Society Publications, ACS Journal,* 23-27.

Shneis, R.M.A. (2018). Water chemistry and microbiology. National Library of Medicine. *Comparative Analytical Chemstry,* 81(1): 1-56.

Sobsey, M.D (2002). Managing water in the Home: accelerated health gains from improved water supply. *World Health Organization Bulletin*, Geneva. 456-458.

Some, S., Mondai, R., Mitra, D., Jain, D., Verma, D., and Das, S. (2021). Microbial pollution of water with special reference to coliform bacteria and their nexus with environment. *Energy Nexus*, 1(1): 705-708.

Su Z, Wu J, He X, Elumalai V (2020). Temporal changes of groundwater quality within the Groundwater depression cone and prediction of confined groundwater salinity using Grey-Markov model in Yinchuan area of northwest China. *Expo Health*, 12:447–468.

SubbaRao, N, Ravindra, B, Wu, J. (2020). Geochemical and health risk evaluation of fluoride rich Groundwater in Sattenapalle Region, Gunturdistrict, Andhra-Pradesh, India. *Human Ecological Risk Assessment,* 26(1): 2316–2348.

Talabi, A.O., and Kayode, J.J. (2019). Groundwater pollution and remediation. *Journal of Water Resources and Protection,* 11(1): 866-868.

Tatti, F., Papini, M.P., Torretta, V., Mancini, G.. Boni, M.R.,Viotti, P. (2019). Experimental and numerical evaluation of groundwater circulation wells as a remediation technology for persistent, low permeability contaminant source zones. *Journal of Contamination Hydrology,* 222:89–100.

Teng, Y., Hu, B., Zheng, J., Zhai, Y., Zhu, C. (2018). Water quality responses to the interaction between surface water and groundwater along the Songhua River, NE China. *Hydrogeology Journal,* 26:1591–1607.

Therholt, T.A., Procopio, N.A., and Gordrow, S.M. (2017). Seasonality of coliform bacteria detection rates in the New Jersey Domestic Wells. *Groundwater,* 55(6): 346-361.

Todd, K. (1980). Groundwater hydrology. *JohnWiley & Sons, New-York, Chichester*, 2nd Edition. 422-427.

Udokpoh, U., Ndem, U.A., and Abubakar. (2024). Comparative assessment of groundwater and surface water quality for domestic water supply in rural areas surrounding crude oil exploration facilities. *Journal of Environmental Pollution and Human Health,* 9(3): 80-90.

USDHHS/CDCP/NIH (2009). United States Department of Health and Human Sciences, Centres for Disease Control and Prevention and National Institutes of Health. Biosafety in Microbiology and Biomedical Laboratories. 5th Edition Washington D.C, *United States Government Printing Office.* 222.

USP (2015). United States Pharmacopeial. Microbial characterization, identification and strain Typing. USP.38-UF-33. 1180. *USP Bulletin*, 11.

USEPA (2012). United States Environmental Protection Agency, *Office of Water*, 527.

Valiero, D.A. (2025). Fundamentals of water pollution. *Groundwater*, 289-318.

Wang, W., Jia, J., Zhang, B., Xiao, B., Yang, H., Zhang, S., Gao, X., Han, Y., Zhang, S., Liu, Z., Jin, S., and Wu, Y . (2024). A release of sustained release materials for remediation of originally contaminated groundwater, material proportions, applications and prospects for practical applications. *Journal of Hazardous Material Advances,* 13(1): 2261-2267.

Wang, D.,Wu, J.,Wang, Y,Ji, Y. (2020). Findinghigh-quality groundwater resources to reduce the Hydatidosis incidence in the Shiqu County of Sichuan-Province, China: analysis, assessment, and management. *Expo Health*, 12:307–322.

Willocks, L., Crampin, A., Milne, L., Seng, C., Susman, M., Gair, R., Moulsdale, M., Shafi, S., Wall, R., Wiggins, R. and Lightfoot, N. (1998). A large outbreak of cryptosporidiosis associated with a public water supply from a deep chalk borehole: Outbreak Investigation Team. *Communicable Disease and Public Health,* 1(1): 239-243.

WHO (2022). Fourth estimation: Incorporating the first and second addenda guidelines for drinking water quality, *2022 WHO Bulletin*, 665.

WHO (1991). Monitoring health for sustainable development goals, SDGs in World Health Statistics. *World Health Statistics Bulletin*, 4(44): 2.

WHO (2011). WHO guidelines for physico-chemical parameters and water quality standards.

WHO (2004a). World health report, 2004. *2004 WHO Bulletin*, Geneva.

WHO (2004b). Guidelines for drinking-water quality: Recommendations.

2004 WHO Bulletin, 11(2): 13, Geneva.

WHO (1991). Health and water safety in World Health Statistics. *World Health Statistics Bulletin*, 4(44): 198.

WHO (1995). Guidelines for drinking water quality. WHO, Geneva 2nd Edition (1) *1995 WHO Bulletin*, 4(2): 13, Geneva.

Worthington, M., Luo, R.Q., and Pelo, J. (2001). Copacabana method for spreading *E coli* and yeast colonies. *Biotechniques,* 30(1): 738-742.

WSLH (2025). Wiscosin State Laboratory of Hygiene, Water Laboratory. 5-7.

Wu J, Zhang Y, Zhou H (2020) Groundwater chemistry and groundwater quality index incorporating health risk weighting in Dingbian County, Ordos basin of northwest China. *Geochemistry,* 80(4):125607.

Wu, J, Li, P, Qian, H (2015). Hydrochemical characterization of drinking groundwater with special reference to fluoride in an arid area of China and the control of aquifer leakage on its concentrations. *Environmental Earth Sciences*, 73(1): 8575–8588.

Wu J, Li P, Qian H, Fang Y (2014) Assessment of soil salinization based on a low-cost method and its influencing factors in a semi-arid agricultural area, northwest China. *Environmental Earth Sciences*, 71(8):3465–3475.