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Dynamic Distribution of Physicochemical and Bacteriological Characteristics of Water Samples from Water Supply Sources in Rural Settlements of Ibarapa East Local Government Area, Oyo State, Nigeria

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Abstract

Purpose: This study aimed at examining the dynamic distribution of physicochemical and bacteriological characteristics of water samples from water supply sources in rural settlements of Ibarapa East Local Government Area of Oyo State, Nigeria.

Methodology: A Systematic random sampling technique was adopted in the selection of five rural settlements namely: Adiekola (AD), Maya (MA), Akeete (AK), Okolo (OK) and Alapa (AL). Two water supply sources were randomly sampled in each of the settlements. In all, ten water samples were collected from Hand Pump Boreholes (HPBHs), Motorised Boreholes (MBHs), Hand-Dug Wells (HDWs) and a Stream (STR) using standard sampling procedures. Geographic coordinates of the water sources were obtained using a Global Positioning System (GPS), while the Average Nearest Neighbour (ANN) analysis in ArcGIS was employed to determine the spatial distribution of water supply sources. Physicochemical and bacteriological parameters of the water samples were subjected to laboratory analysis using the universally acceptable laboratory procedures. The results were compared with WHO drinking water quality standards.

Findings: The results revealed that water supply sources exhibited a weakly clustered spatial pattern indicating an uneven distribution of water infrastructure and disparities in access to potable water across the study area. Most physicochemical parameters, including pH, temperature, electrical conductivity, total dissolved solids, total hardness, nitrate, sulphate, phosphate, calcium and potassium, were within WHO permissible limits. However, elevated turbidity was recorded in the Hand-Dug Well at Adiekola (AD2) and the stream at Akeete (AK 2), while dissolved oxygen values were below the recommended standard in all samples. Iron concentrations exceeded the WHO limit in five water samples, and manganese concentrations exceeded the permissible limit in the stream and one Hand-Dug Well. Bacteriological analysis revealed contamination of Hand-Dug Wells and the Stream with *Bacillus* spp., *Salmonella* spp. and *Escherichia coli*, accompanied by high total coliform counts, whereas most Motorised and Hand Pump Boreholes recorded zero coliform counts and no detectable pathogenic bacteria. The results indicated that protected boreholes generally provide safer drinking water than hand-dug wells and surface water sources. Therefore, it was suggested that water from the contaminated sources should be adequately treated before consumption while improved sanitation infrastructure and protection of water sources are necessary to safeguard public health in the study area.

Unique Contribution to Theory, Practice and Policy: This study contributes to the understanding of rural water quality by integrating geospatial analysis with physicochemical and bacteriological assessments to evaluate both the accessibility and safety of rural water supply sources. Theoretically, it advances the application of spatial analytical techniques in rural water quality assessment by linking infrastructure distribution with water quality status. Practically, the findings provide baseline information for prioritising water quality monitoring, groundwater protection and community-based water safety interventions in rural communities. From a policy perspective, the study provides empirical evidence to support equitable spatial planning of water infrastructure, routine water quality surveillance, rehabilitation of contaminated water sources, and to strengthen implementation of rural water supply and sanitation policies aimed at providing adequate access to safe and clean drinking water.

Keywords: *Physicochemical Characteristics, Bacteriological Assessment, Water Quality, Rural Water Supply, Spatial Distribution, Ibarapa East, Nigeria*

JEL Codes: *Q25, Q53, I18, R11*

INTRODUCTION

Water is considered as one of the most indispensable resources of human environment. It has been described as a chemical element that without it, no form of life can survive in the universe. In fact, there are numerous academic proofs (both economic and scientific) that inadequate water supply can cause severe decrease in productivity and deaths of living species (Aboyeji, 2013).

It has been established that three-quarter of the earth surface is made up of water (Ogundele, 2012) and existed in liquid, solid or gaseous forms. Specifically, water of the earth is found mostly in oceans and other large water bodies such as seas, rivers, lakes, streams etc. The implication of this is that water is unevenly distributed across the earth, with approximately 96.5% of the planet's total water occurring in oceans, seas and bays, while only about 2.5% is freshwater. Of this freshwater, approximately 68.7% is stored in ice caps, glaciers and permanent snow, about 30.1% occurs as freshwater groundwater, and only about 1.2% is present as surface water, including lakes, rivers and swamps (U.S. Geological Survey [USGS], 2019).

Despite the importance of water to life and its abundance in nature, evidences around the world and most especially in the Sub- Sahara Africa show that this important resource in potable form is in inadequate supply to most citizens. Abdulsalam and Sule (2020) described potable water as that which possesses the quality that renders it fit and safe for drinking. Nigeria Standard for Drinking Water Quality, (2007) said it must be totally free of deleterious pathogens, devoid of undesirable taste, smell, colour, turbidity and must contain no harmful chemicals.

Taking into consideration the fact that water supply in most urban centres of the developing countries is inadequate due to increase population and the government defective water supply policies. It is not surprising that most rural settlements are lacking adequate water supply due to the same reason. Hence, the most common sources of water supply available to most rural settlements are streams, rivers, hand-dug wells, mono pumps, rainfall harvest etc. Though, most water sources in the rural settlements may be free from contamination by heavy metals unlike the urban centres as a result of concentration of industries in the later. However, several studies have shown that physicochemical and microbiological quality of drinking water in rural settlements can be affected by the utilization of fertilizers in crop production near water sources, the presence of livestock around water points, as well as industrial activities close to the catchment area of the water source. Hence, the non-standard concentrations of nitrates and ammonium found in analyzed water samples from rural settlements and even urban centres are attributable to fertilization with nitrogen fertilizers.

Most of these water supply sources are highly unhygienic and inadequate especially during the dry season. The health and economic implications of this situation have continued to receive global attention. World Health Organization, WHO (2003) stated that the reported cases of diarrhea is estimated to be 4 billion annually around the world, in addition to millions of other cases of illness associated with lack of access to clean water.

Ogundele (2012) reported defective water supply sources in Ibarapa East Local Government area due to inadequate modern pipe borne water supply, non-functional boreholes, occasioned by defective government water supply policies among others factors. The people, therefore, depend on streams, rivers, lakes, shallow wells and rain harvesting from dirty rooftops for their water supply needs.

The water supply scenario in most rural settlements is by far worse than anticipated due to poor rural development policies as well as defective implementation. This to a greater extent has reduced the economic benefits that are supposed to be derived from the rural settlements, described as sources of more than 75% of food supply to the urban centres (Ogundele, 2021).

This study, therefore, attempts to investigate the dynamic distribution of physicochemical and bacteriological characteristics of the water samples from water supply sources in rural settlements of Ibarapa East Local Government Area of Oyo State, Nigeria.

LITERATURE REVIEW

Safe drinking water, proper sanitation and good hygiene are crucial to health, survival, growth and development. This link between water and wellbeing is based on the premise that clean water, sanitation services and sustainable water management open windows of opportunities for the poor, reduce deprivations and is a progressive strategy for economic development. (Olokesusi, 2004).

In this regard, Olawale,Wada, Afolalu and Asogbon (2020) observed that water quality may be considered a social issue because securing a quality of life consistent with human dignity requires access to safe drinking water and sustainable water resources for other purposes. The quality of a community portable water supply cannot be compromised without risk to public health.

In underdeveloped countries especially the rural areas where portable water supply is very scarce, the dwellers rely mainly on water in streams, brooks, rivers, ponds and lakes, well, borehole, tube wells. (Ogundele, 2012; Ogundele & Ogunjimi, 2013; Machado, dos Santos, Quindeler & Alves, 2019; Khan, Niang, Jurji & Mahato, 2018; WHO, 2011). Olawale et al (2020) reported that the provision of a sustainable water supply system in rural areas in developing countries has been a challenge for several years, which has resulted in the dependency of rural dwellers on polluted water from various sources. Olawale et al (2020) also observed that the sustainability of rural water supply is an acute problem due to widespread of water infrastructural decay and frequent system breakdowns which inadvertently lead to scarcity of safe water in the Sub-Saharan African region.

Research works have established that most water samples from water supply sources in rural settlements are contaminated with heavy metals. For instances, Akinde, Olaitan and Ajani (2019) reported the pollution of water supply sources in rural areas of Southwestern Nigeria while Ajibade, Adewuyi and Ogunjobi (2018) reported the presence of microbiological contamination of water sources in Igboora in Ibarapa area of Oyo State. Olaoye and Olagunju (2024) reported similar finding in Eruwa in the same region due to risk factors such as human activities, lack of well protection structures and the hydrogeological characteristics in the area. Adekunle, Adetunji, Gbadebo and Banjoko (2007) observed similar occurrence of feacal contamination of water sources in the rural communities of South Western Nigeria.

Studies by WHO (2003), Nimorsi, Egwunyenga, Ukwandu and Nwokolo, (2005), Pukuma and Musa (2017) and Abdusalam and Sule (2020) revealed that there are increasing cases of typhoid, diarrhea, schistosomiasis and trachoma in different parts of Nigeria. These situations call for concern on the quality of water people obtain from different sources for consumption. Hence, taking appropriate steps in monitoring the quality of water consumed by the people will not only ensure healthy living but also ensure economic development of the nation.

The above research findings, therefore, call for work of this nature in rural settlements of Ibarapa East Local Government Area so as to ascertain the quality of water use for domestic and industrial purposes.

Theoretical Framework

This study is premised on the Land-Use Contaminant Transport Model and Quantitative Microbial Risk Assessment (QMRA) framework

The Land-Use Contaminant Transport Model provides a useful conceptual basis for understanding the dynamic distribution of physicochemical and bacteriological characteristics of water from different supply sources in rural settlements. The model explains the relationship between human activities occurring on the land, the generation of contaminants, their movement through environmental pathways, and their eventual influence on the quality of surface water and groundwater. This relationship is particularly relevant to the present study because rural water sources are not isolated from their surrounding environments. Rather, their quality is influenced by the interaction between land use, rainfall, surface runoff, soil characteristics, infiltration, groundwater movement, drainage systems, and human activities around water sources. Overall, the land-use contaminant transport model provides a logical explanation of the relationship between land use, contaminant generation, environmental transport processes and water-quality outcomes in Ibarapa East Local Government Area.

The model does not merely describe how contaminants move through the environment; it provides a framework for interpreting why water-quality characteristics differ between settlements, between water-source types, and between seasons. By relating laboratory measurements to surrounding land-use activities and environmental transport pathways, the model can strengthen the scientific interpretation of the dynamic distribution of water quality in the sampled settlements and provide a basis for developing more effective water-resource protection and management strategies in the study area.

The Quantitative Microbial Risk Assessment (QMRA) framework on the other hand provides a useful theoretical basis for examining the potential health implications of bacteriological contamination in water supply sources (World Health Organization, 2016). QMRA is designed to establish a logical relationship between the presence and concentration of microorganisms in an environmental medium, the degree of human exposure to those microorganisms, and the probability of infection or illness. In the context of this study, the framework provides a means of interpreting the bacteriological characteristics of water beyond simply determining whether a water source is contaminated or not. It provides a conceptual pathway through which microbial contamination can be related to human exposure and potential health consequences. This relationship is particularly useful for interpreting spatial differences between the various water sources. For example, a hand-dug well situated close to a poorly managed sanitation facility may have a greater potential for faecal contamination than a protected borehole located farther from such sources. Similarly, a stream receiving runoff from settlements, livestock areas or agricultural land may be exposed to multiple contamination pathways. QMRA provides the theoretical basis

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www.iprjb.org

for connecting these differences in environmental exposure with possible differences in microbial health risk.

Objectives of the study

This study attempted to examine the dynamic distribution of physicochemical and bacteriological characteristics of water samples from water supply sources in rural settlements of Ibarapa East Local Government Area of Oyo State, Nigeria.

In order to achieve this aim, we sought the following objectives.

(i) To identify the types of water supply sources in the study area.
(ii) To examine their spatial distribution.
(iii) To investigate whether their physicochemical and bacteriological qualities meet the World Health Organization (WHO) potable water standard.

Statement of the Problem

Studies, over the years have established the challenges of acute water scarcity in Ibarapa Region of Oyo State (Ogundele, 2012; Ogundele, Oladapo & Aweto, 2012; Ogundele & Ogunjimi, 2013; Ogundele, 2014; Adewuyi & Ogunjobi 2018; Akinde, Olaitan & Ajani, 2019). This water supply situation has been attributed to the geological formation that hinder the construction of modern water supply sources as well as population increase which put pressure on the available water resources. As a result, people obtain their water supply from different unhygienic sources such as ponds, lake, perennial streams, and shallow hand dug-wells as well as poorly constructed boreholes. Water from these sources is found to have been compromised by a combination of physicochemical and bacteriological contaminant, making them unsafe for consumption. Consumption of water from these sources have been attributed to health issues relating to water borne diseases such as cholera, typhoid fever, dysentery, bilharzia, gastrointestinal infections, among others.

Of recent, concerted efforts from individuals, community, non-governmental organization, philanthropists as well as government at all levels on water supply and management to a greater extent have improved access to water availability mostly in urban centres of Ibarapa region. However, the rural settlements which are the sources of food supply and for which the area is otherwise known as the “food basket” of Oyo State are still facing the challenges of water supply. For instance, utilization of fertilizers and pesticides in food productions release substances such as nitrates and other chemicals into the water sources, this as well as poor sanitation habit of the rural dwellers which manifest in defective waste disposal threaten public health and hence, the need to determine the physicochemical and bacteriological qualities of water samples from water supply sources. This study therefore attempts to investigate the major water supply sources in the rural settlements of Ibarapa East Local Government Area and the quality of their water contents in meeting the physicochemical and bacteriological water quality standards of the World Health Organization (WHO) as well as their spatial distribution within the study area.

METHODOLOGY

Study Area

The study was carried out in selected rural settlements of Ibarapa East Local Government Area of Oyo State, Nigeria. The Local Government Area lies between latitude 7^0 25^1 and 7^0 45^1 North and between longitude 3° 15^1 and 3^0 35^1 East (Fig. 1). The major settlements in the local government area include Eruwa (the Local Government Area headquarters) and Lanlate. These two major towns and Maya a market settlement serve as commercial centres for over two hundred smaller settlements within the local government area (Oladapo, Ogundele & Akindele 2008).

The Local Government Area has a total population of about 118, 288 as at 2006 population census (Oladapo, Ogundele & Akindele, 2008) with a total land mass of 705.78km^2. The local government area falls within the Tropical Hinterland (wet) climatic belt with mean annual temperature of 27^0c and annual range of 8^0c. Annual rainfall is between 150cm and 200cm with double peaks.

Ibarapa East Local Government Area is found in the wide upland plain of the Western highlands surrounded by rocks outcrops and ridges of varying height. The geological features are of basement complex rocks. These features serve as hindrances during sinking of boreholes and hand dug wells. Prominent hills include Agasa, Akolu, Apanpa, Okele, Owewe and Obaseeku. The vegetation is a mixture of tall luxury grasses and scattered trees. Major streams and rivers include Ago- ada, Setemepele, Atio, Amogemu, Opeki, among others. Some of these drainage features serve as sources of water for the people in the area especially rural dwellers. The outcrops, bushes and rivers, especially near residential areas have been greatly abused by turning them into dumpsites for refuse and human excreta. This thus limits their usage and encourages poor sanitation habit.

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Vol.9, Issue 2, No.5. pp 55 - 72, 2026

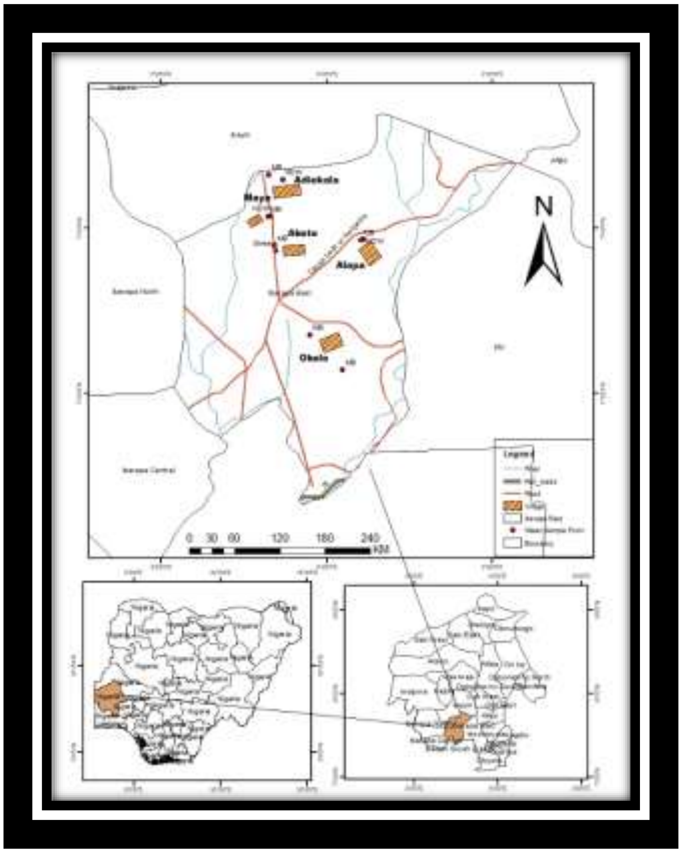

Fig 1: The Study Area and the Sampled Water Supply Sources

Samples and Sampling Techniques

Systematic random technique was used in the selection of five rural settlements in the study area and each settlement was coded by the first two alphabets of her name. These are Adiekola (AD), Maya (MA), Akeete (Ak), Okolo (OK) and Alapa (AL). Similarly, two water supply sources were randomly selected in each settlement and each specific source was named with the code of the settlement and with specific Arabic numeral. Hence, Adiekola (AD 1 & AD 2), Maya (MA 1 & MA 2), Okolo (OK 1 & OK 2) and Alapa (AL1 & AL 2) are designated as the settlements as well as the water supply sources for the study. The types of the water sources were shown in Table 2.

Collections of water samples from hand dug wells and stream were done by using rubber fetchers. The fetchers were sterilized with 70% (V/V) ethanol. The samples were collected from the water sources and poured inside screw capped sterilized plastic bottles. Each sample was labeled accordingly. Water samples from motorized and hand pump boreholes were collected through sterilized funnels into screw capped sterilized plastic bottles. Sample collections were done separately for each settlement on a specific day as a result of the distance to the laboratory which prevented the collection of samples to be done simultaneously in all settlements. On each day, water samples were transported to the laboratory in a cooler filled with ice for physicochemical characteristics and bacteriological analyses within 4 hours of collection. Physicochemical characteristics and analytical techniques adopted were shown in Table 1.

International Journal of Environmental Sciences
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Table 1: Analytical Techniques for Physicochemical Characteristics of Water Samples

Parameters	**Analytical Technique Adopted**
Appearance	These are determined using organoleptic (the sensory organs
Temperature (O^c)	Temperatures of the samples were determined in- situ using mercury-in glass thermometer
pH	pH of water samples was determined electrometrically by using the pH meter
Electrical Conductivity (EC) µS/cm	E A model Suntex SC-120 conductivity meter was used
i. Dissolve Oxygen (DO) (mg/L), ii. Biochemical Oxygen iii. Demand BOD (mg/L), iv. Total Dissolved Solid (TDS) (mg/L)	These are measured in-situ using a multi parameters water quality monitor (Orion Model 1260)
i. Total Hardness (TH) (mg/L)	Titrimetry methods was adopted (APHA, 1985)
ii. Turbidity (NTU)	Nephelometric Method
iii. Nitrate (mg/L)	Brucine method (APHA, 1985)
iv. Sulphate (mg/L)	Turbid metric method (APHA, 1985)
v. Phosphate (mg/L)	Stannous chloride method (APHA, 1985)
i. Total iron (mg/L) ii. Calcium (mg/L) iii. Potassium(mg/L) vi. Zinc (mg/L), vii. Total iron (mg/L) viii. Copper (mg/L) ix. Manganese (mg/L) x. Lead (mg/L) xi. Cadmium (mg/L) xii. Arsenic (mg/L), xiii. Chromium (mg/L)	Analyses were done using an atomic adsorption spectrophotometer (Perkin-Elmer AAS 3110)

Bacteriological Analysis of Water Samples

Identification of bacterial isolates and the total bacterial count in the water samples from the water supply sources were determined using standard methods of APHA (1985) that employed the pour plate technique. A nutrient agar medium was employed to enumerate the bacteria in the samples. The results of the analyses were compared with the World Health Organization (WHO) drinking water standards of 1993, 2006 and 2010.

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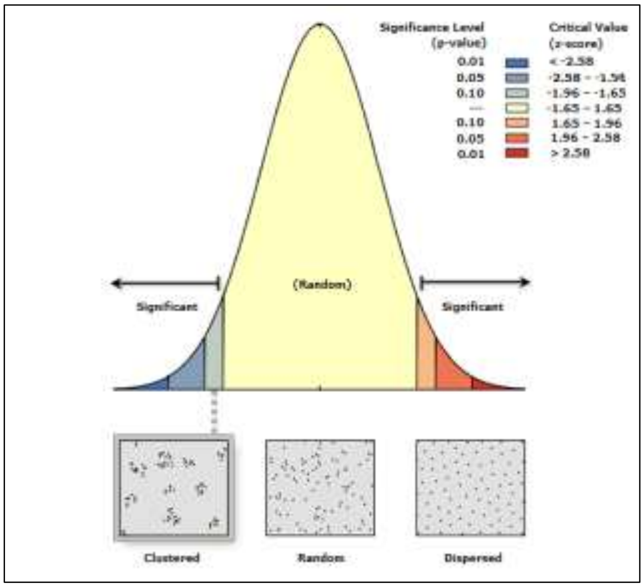
www.iprjb.org

RESULTS AND DISCUSSION

Spatial Distribution of Water Supply Sources in the Study Area



Summary of the Average Nearest Neighbour Statistics	
Observed Mean Distance	1627.0806 Meters
Expected Mean Distance	2353.2577 Meters
Nearest Neighbour Ratio	0.691416
Z-sore	-1.866827
P-value	0.061926

Figure 2: Spatial Distribution of Water Supply Sources

Figure 2 presents the result of the average nearest neighbour statistics used to determine the spatial distribution of the water supply sources in the study area. The result showed that water supply sources in the area exhibited a clustered spatial pattern ($R = 0.691$), as the observed mean distance between facilities is significantly lower than the expected distance under random distribution. The negative Z-score (-1.867) further supported this clustering tendency. However, because the p-value (0.0619) was slightly greater than the 0.05 significance level, the clustering was not statistically significant at the 95% confidence level**.** Therefore, the spatial distribution of water supply sources may be described as weakly clustered or tending toward clustering, but not significantly different from a random distribution**.** This suggests the need for more equitable spatial planning and allocation of water infrastructure to improve accessibility across all rural settlements in the study area.

International Journal of Environmental Sciences
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www.iprjb.org

The Physicochemical Characteristics of Water Samples from the Water Supply Sources

Table 2: Physicochemical Characteristics of the water samples

S/N	Parameters	Settlements and Water Supply Sources										WHO Standard (1993, 2006 & 2010)
		Adiekola		Maya		Akeete		Okolo		Alapa		
		AD 1	AD 2	MA 1	MA 2	AK 1	AK 2	OK 1	OK 2	AL1	AL2	
	Type of Water Source	HPBH	HDW	HDW	MBH	MBH	STR	MBH	MBH	HPBH	HDW	
1.	Appearance	Clear	Muddy	Clear	Clear	Clear	Muddy	Clear	Clear	Clear	Clear	Clear
2.	Ph	6.74	7.07	7.16	7.05	7.66	8.00	7.03	7.20	6.71	7.20	6.5-8.5
3.	Temperature ($^{0}{}_{c}$)	27.8	27.8	28.0	27.8	27.9	29.0.	27.9	28.5	27.8	27.9	>40
4.	Electrical Conductivity (EC) µS/cm	266	440	516	180	298	560	140	260	468	614	1000
5.	Turbidity(mg/L)	2.5	6.0	2.8	2.7	2.8	6.5	3.9	2.4	3.9	2.9	5.0
6.	Dissolved Oxygen (DO) (mg/L)	3.76	2.76	4.11	3.15	3.71	2.71	3.20	3.50	3.91	3.67	5
7.	Biochemical Oxygen Demand (BOD) (mg/L)	2.65	6.51	2.24	3.41	2.92	7.50	2.71	2.40	1.57	2.09	10
8.	Total Dissolved Solid (TDS) (mg/L)	141	232	289	176	169	306	78	156	248	348	500
9.	Total Suspended Solids (TSS) (mg/L)	58	91	143	88	71	102	34	55	99	151	5
10.	Total Hardness (mg/L)	75	128	85	98	100	206	90	95	80	180	500
11.	Lead (Pb) (mg/L)	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.02	0.10
13.	Arsenic (As) (mg/L)	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
14.	Cadmium (Cd) (mg/L)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.003
15.	Chromium (C) (mg/L)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.1
16.	Iron (Fe) (mg/L)	1.70	1.40	0.35	0.13	0.44	1.03	0.19	0.21	1.66	1.57	1.0
17.	Manganese (Mn) (mg/L)	0.01	0.04	0.03	0.00	0.00	0.17	0.00	0.01	0.05	0.10	0.08
18.	Copper (Cu) (mg/L)	0.01	0.00	0.00	0.00	0.01	0.04	0.00	0.00	0.01	0.02	2.0
19.	Zinc (Zn) (mg/L)	0.09	0.06	0.12	0.05	0.05	0.08	0.05	0.06	0.18	0.12	1.0
20.	Nitrate (mg/L)	2.05	5.15	3.68	2.25	4.17	6.87	4.13	2.64	3.78	4.89	11
21.	Sulphate (mg/L)	105.35	246.20	166.35	120.57	174.50	289.40	173.25	145.50	168.08	186.00	500
22.	Phosphate (mg/L)	2.15	3.50	2.60	3.30	2.40	4.20	2.53	3.15	3.23	3.80	5
23.	Calcium (Ca) (mg/L)	89.61	100.32	150.20	125.30	132.35	164.38	114.50	115.10	122.10	154.40	200
24.	Potassium (K) (mg/L)	20.01	25.23	19.93	15.05	24.05	37.05	21.82	21.92	30.01	34.15	42.45

Source: Field Survey, 2025

****MBH-Motorised Borehole **HPBH-Hand Pump Borehole **HDW-Hand Dug Well **STR-Stream**

Results of the analysis showed that other water samples from other sources appeared clear and clean except the water samples from Hand-Dug Well at Adiekola and the Stream at Akeete that were muddy in appearance, The clear samples were an indication of low level of visible impurities or contaminants (Ogundele, 2014) while the muddy appearance depicted the presence of suspended particles, possible adulteration from surface runoff and erosion as well as anthropogenic activities (Lemessa, Simane, Seyoum & Gebresenbet, 2023).The implication of this finding was that the muddy water samples require adequate purification before they can be utilized.

The pH values for the Motorised Boreholes in all the sampled settlements ranged between 7.03 and 7.20. For Hand Pump Boreholes, the values ranged between 6.71 and 6.74. The pH values for the Hand-Dug Well ranged between 7 07 and 7.20 while that of the only Stream was 8.00. However, the values, irrespective of the settlement or source were within the WHO standards of 6.5-8.5. The implication of these findings was that pH values of the water samples are neither strongly acidic nor alkaline and are therefore suitable for domestic utilization as far as pH is concerned.

The temperature values ranged between 27.8 ^{0}C and 29.0 ^{0}C for all settlements and sources. However, the lowest value was recorded in the water samples from Hand Pump Boreholes at both Adiekola and Alapa as well as Hand-Dug Well at Adiekola while the highest temperature value was detected at the only Stream sampled in the study area. These findings are similar to the finding of Oladapo, Ogundele, Oladipo, Oyedemi and Aderounmu (2023) but fell within the WHO (2010) standard for temperature value.

The lowest value of 140µS/cm recorded for the Electrical Conductivity (EC) was at the Motorised Borehole at Okolo while the highest value of 614 µS/cm was documented for the water sample from the Hand-Dug Well at Alapa. Irrespective of the samples from the water sources and the settlements involved the values are within the standard limit set by the WHO for potable water. In other words, none of the water samples had value above the WHO 1000µS/cm permissible value for potable water. These values indicated moderate mineralization of the groundwater and surface water sources. Oparaocha, Iroegbu and Obi (2010) reported that the elevated EC in some wells may result from the dissolution of mineral-bearing rocks and soil constituents. Hence, the elevated EC in the Hand- Dug wells sampled maybe as a result of this phenomenon.

Turbidity which refers to the clarity or cloudiness of water due to the suspended particles like Clay, Silt etc of the water samples ranged between 2.4 NTU in the water sample from Motorised Borehole at Okolo and 6.5NTU in the water sample from the Stream (Akeete). Except the water samples from the Stream (Akeete) and Hand-Dug well (6.0 NTU) at Adiekola, other water samples have values that were considered lower than the WHO permissible limit of 5 NTU. The low turbidity values indicated good water clarity and suggest minimal interference with disinfection processes. However, Yasin, Ketema and Bacha (2015) posited that high turbidity is often associated with higher levels of suspended organic matter and microorganisms including bacteria and other parasites.

The Dissolved Oxygen (DO) is an important water property parameter and has special significance for aquatic organisms in natural water (Yasin, Ketema & Bacha, 2015). DO values for the water samples ranged between 3.15 and 4.11 mg/L. Though, all samples are below the WHO permissible value of 5 mg/L, elevated values were recorded for the Hand -Dug Wells and the Stream. These values are similar to the values recorded by Oladapo et al (2023).

The Biochemical Oxygen Demand (BOD) values ranged between 1.57 mg/L and 7.50mg/L. The highest value was obtained in the water sample from the Stream at Akeete while the lowest was recorded for the water sample from the Hand Pump Borehole at Alapa. All the samples are significantly lower than the WHO threshold of 10 mg/L.

The lowest value of Total Suspended Solid (TSS) of 34 mg/L was recorded for the water sample from the Motorized Borehole at Okolo while the highest value of 151 mg/L was obtained in the water sample from the Hand-Dug Well at Alapa. The values for the Total Dissolved Solids ranged between 78 mg/L recorded for the water sample from Motorised Borehole at Okolo and 348 mg/L recorded for the water sample from the stream at Akeete. Irrespective of the water source, the result showed the values are below the WHO permissible limit. The low TDS values suggested that the water from the sources is suitable for consumption.

The Total Hardness (TH) represents the Calcium and Magnesium ion concentration in water (Oladapo et al, 2023). All the water samples from the various sources displayed the TH of between 75 mg/L and 206 mg/L. The recorded values fell below the WHO standard value of 500mg/L. Based on the conventional nomenclature; the water samples can be categorized as moderately hard to hard water. The elevated value (206mg/L) at the Stream (Akeete) suggested an indication of Calcium and Magnesium ions.

Heavy Metals

Lead concentration in the water samples ranged from 0.00 mg/L to 0.02 mg/L. Detectable concentrations were found only in samples from in Stream (AK2) and Hand-Dug Well (AL 2). Though, all values are within the WHO standard, there is the need for constant monitoring of AK 2 and AL 2 because of the toxicity of lead that can result to its accumulation in the human body.

The values for Arsenic remained constant at 0.01 mg/L in all water samples which is the standard set by the WHO. The implication of this finding was that the concentrations of this metal are at the maximum permissible threshold and therefore, the need for regular monitoring to prevent potential health risk that pcan emanate from excessive accumulation of Arsenic.

The analysis also established that there was no trace of Cadmium and Chromium in all the water samples. This implies that the water samples were free from these two heavy metals and hence, compliance with WHO standards. The concentration of Iron ranged from 0.13 mg/L recorded at a Motorised Borehole (MA1) and 1.70 mg/L recorded at a Hand Pump Borehole (AD 1). However, several samples, AD 1 (1.70 mg/L), AD 2 (1.40 mg/L), AK 2 (1.03 mg/L), AL 1 (1.66Mmg/L) and AL 2 (1.57mg/L) exceeded the WHO permissible limit of 1.0 mg/L. Olaoye and Olagunju (2024) also recorded elevated Iron in water samples from Hand-Dug Wells in Eruwa, Ibarapa East Local Government Area of Oyo State, Nigeria. Excessive Iron value in potable water was responsible for unpleasant taste, staining of laundry and discoloration of water (Ugbaja & Ephraim, 2019). Also, Yasin et al (2015) reported that Iron is one of the heavy metals that are linked to human poisoning at higher dose. The elevated values of the samples may not be unconnected to the weathering of iron-rich geological formations of the study area.

Manganese concentrations ranged from 0.00 mg/L and 0.17 mg/L. The Stream sample AK 2 (0.17 mg/L) and AL 2 (0.10 MG/L) exceeded the WHO limit of 0.08 mg/L. Olaoye and Olagunju (2024) also recorded an elevated Manganese in water samples from Ibarapa East. Higher concentration of Manganese affects water taste and appearance and at the same time poses health concern after long term exposure (Akinola, 2016). Copper concentrations ranged from 0.00 to 0.04 mg/L far below the WHO limit of 2.0 mg/L. Similarly, Zinc concentrations ranged from 0.05 to 0.18 mg/L which

International Journal of Environmental Sciences
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Vol.9, Issue 2, No.5. pp 55 - 72, 2026

was also below the WHO standard limit of 1.0 mg/L. Therefore, the concentrations of Copper and Zinc in the water samples pose no significant health risk if consumed.

Nitrate values ranged from 2.05 to 6.87 mg/L. The values are below the WHO limit of 11 mg/L. However, elevated values were recorded at AD 2 (5.15 mg/L) and AK 2 (6.87 mg/L). Sulphate concentrations ranged from 105.35 to 289.40 mg/L, remaining below the WHO permissible limit of 500 mg/L. Similarly, Phosphate concentrations ranged from 2.15 mg/L to 4.20 mg/L and remained below the WHO threshold of 5mg/L. The relative concentration of Nitrate, Sulphate and Phosphate maybe linked to agricultural activities and domestic inputs (Ogunbode & Akinola, 2019).

The major cations tested in the water samples are Calcium and Potassium. The analysis showed that the concentration of Calcium in the water samples ranged from 89.61 to 164.38 mg/L and below the WHO limit of 200mg/L. The elevated values of calcium in Ak 2 (164 .38 mg/L) and AL 2 (154.40 mg/L) may not be unconnected with slightly hardness observed in their samples. Ugbaja and Ephraim (2019) posited that the presence of carbonate in geological formation can also influence the presence of calcium in water samples. Potassium values ranged from 15.05 mg/L to 37.05 mg/L. The values are below the WHO limit of 42.45 mg/L. The concentrations indicate natural mineral dissolution and possible contributions from agricultural activities.

Analysis of Bacteriological Characteristics of Water Samples

Table 3: Bacteriological Characteristics of Water Samples from Water Supply Sources

S/N	Parameters	Settlements and Water Supply Sources									
		Adiekola		**Maya**		**Akete**		**Okolo**		**Alapa**	
		AD 1	AD 2	MA 1	MA 2	AK 1	AK 2	OK 1	OK 2	AL 1	AL2
	Water Source	HPBH	HDW	HDW	MBH	MBH	STR	MBH	MBH	HPBH	HDW
1.	Bacteria Isolation	Bacillus sp	Bacillus sp + Salmonella sp	Salmonella sp	Nil	Nil	E. coli sp + Salmonella sp	Nil	Nil	Nil	E. coli sp
2.	Total Coliform Count	0.0×10^4	4.6×10^4	2.5×10^4	0.0×10^4	0.0×10^4	3.5×10^4	0.0×10^4	0.0×10^4	0.1×10^4	2.8×10^4

Source: Field Survey, 2025

****MBH-Motorised Borehole **HPBM-Hand Pump Borehole **HDW-Hand Dug Well **STR-Stream**

Table 3 shows the bacteriological characteristics of water samples collected from potable water supply sources in the study area. The analysis was mainly on bacterial isolation and total coliform counts. These two parameters are formidable indicators of microbiological water quality and potential public health risks**.**

Bacterial Isolation

The bacteriological analysis revealed visible variations in microbial water properties among the water samples. The presence of Bacillus sp. was detected in the Hand Pump Borehole (AD1) at Adiekola, while the Hand -Dug well (AD 2) was infested with both Bacillus sp. and Salmonella sp. suggesting environmental contamination and possible fecal pollution (Ajibade, Adewuyi & Ogunjobi, 2018). Similarly, Salmonella sp. was isolated in the Hand -Dug Well (MA1). Both Salmonella sp. and E. coli were detected in the Stream (AK 2) at Akeete. This indicated severe fecal contamination and a high risk of water borne disease transmission. Also, the presence of E. coli was also recorded in the Hand-Dug Well (AL 2) at Alapa. This result was similar to the finding of Olaoye and Olagunju (2024) who discovered the presence of E. coli in Hand-Dug Wells in Ibarapa East Local Government Area. Others water sources Motorised Boreholes (MA 2), (AK 1), (OK 1) and (OK2) as well as the Hand Pump Borehole were free from detectable bacterial contamination. The findings indicated that borehole sources generally exhibited better bacteriological quality than hand-dug well and surface water sources. This finding was similar to those reported by Ajibade et al (2019), Ugbaja and Ephraim, (2019) and Wemedo and Dimkpa (2019). In other words, the occurrences of these bacterial species highlighted the vulnerability of hand-dug wells and stream to contamination from human and animal wastes making them unsuitable for direct consumption without adequate treatment.

The coliform counts varied substantially among the sampled water sources, ranging from 0.0×10^4 CFU/mL to 4.6×10^4CFU/mL. Of all the water sources, HPBH (AD 1), MBH (MA 2), MBH (AK 1), MBH (OK 1) and MBH (OK 2) recorded zero coliform counts. These findings indicated an excellent bacteriological quality and suggest that the boreholes are adequately free from the surface contamination. However, other sources recorded presences of coliform with the highest (4.6×10^4 CFU/mL) detected in the Hand-Dug Well (AD 2) at Adiekola, 3.5×10^4 CFU/mL recorded in the Stream (AK 2) at Akeete, 2.8×10^4 CFU/mL in the Hand-Dug Well (AL 2) at Alapa, 2.5×10^4 CFU/mL in the Hand-Dug Well (MA 1) and 0.1×10^4 CFU/mL in the Hand Pump Borehole (AL 1) at Alapa. The high coliform counts recorded in the Hand-Dug Wells and the Stream are indications of poor sanitary conditions and possible contamination from human activities, livestock wastes, agricultural runoff and infiltration of surface water.

CONCLUSION AND RECOMMENDATIONS

Conclusion

The study revealed that the distribution of water supply sources exhibited a weakly clustered pattern. The implication of this is that water sources are not evenly distributed across the study area and the clustering nature is an indication of disparities in access to potable water among the settlements. This uneven distribution highlights the need for improved spatial planning and equitable provision of water infrastructure to ensure adequate access to safe water for all rural residents.

The study also showed that most of the measured water physicochemical characteristics complied with the World Health Organization (WHO) permissible standards, indicating that the majority of the sampled water sources are chemically suitable for domestic use. However, elevated parameters values beyond WHO standards limit observed in certain water supply sources was an indication of poor water quality and increased susceptibility to microbial contamination. Although these exceedances may largely be attributed to the natural geological characteristics of the area, anthropogenic activities especial agriculture, poor environmental sanitation as well as poorly constructed water supply sources especially the Hand- Dug Wells equally play significant roles. Prolonged consumption of such water without treatment may pose aesthetic and potential health concerns.

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The bacteriological assessment of the water samples presented a more significant public health concerns. The isolation of Bacillus spp., Salmonella spp. and Escherichia coli as well as the high total coliform counts recorded in some of the water supply sources demonstrated varying degrees of microbial contamination. These are indications of significant sanitary deficiencies and possible contamination from agricultural runoff, surface infiltration, livestock activities and poor environmental sanitation. In contrast, Motorised Boreholes and most Hand Pump Boreholes recorded no microbial contamination. Hence, it is confirmed that constructed and protected groundwater sources generally provide safer drinking water than shallow wells and surface water sources.

Finally, the physicochemical characteristics of most of the water sources in the study area are generally satisfactory but the microbiological quality of some of them rendered them unsuitable for direct human consumption without adequate treatment.

Recommendations

The study underscores the importance of strengthening rural water supply systems through the provision of additional protected boreholes, regular water quality monitoring, improved environmental sanitation, protection of water sources from contamination, and sustained community hygiene education. These measures, to a greater extent, will significantly reduce the risk of waterborne diseases and enhance access to safe and sustainable drinking water in the rural settlements of the study area.

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Credit Authorship Contribution Statement

All authors declared no vested interest.

OAT: Conceptualization, drafted the proposal, methodology, data collection, writing of the final draft.

OAO: Re-drafted proposal, data collection, review, editing.

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