Physicochemical and Bacteriological Characterization of Water from Selected Hand-dug Wells and Boreholes in Senior Staff Quarters, Obafemi Awolowo University, Ile-Ife, Nigeria

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Abstract:- This study assessed the physicochemical properties of water collected from hand-dug wells and boreholes in the Senior Staff Quarters, Obafemi Awolowo University, Ile Ife. It isolated and identified the bacterial contaminants in the water samples. It also evaluated the total coliforms and the total heterotrophic bacteria in the water samples. These were with a view to providing information on the quality of water from different water sources in the study area. Twenty out of 40 hand-dug wells and five out of 10 boreholes were selected for the study. A total of 100 water samples were collected and examined, comprising four from each water source made up of two each in the wet and dry seasons. Information on the wells and boreholes were provided by their owners using a structured questionnaire. Temperature, colour, hydrogen ion concentration (pH), dissolved oxygen (DO), biochemical oxygen demand (BOD), total dissolved solids (TDS), total suspended solids (TSS), total solids (TS), conductivity, acidity, alkalinity, calcium (Ca^{2+}), magnesium (Mg^{2+}), chloride (Cl^-) and sulphate (SO_4^{2-}) were measured in each sample using instrumental, colorimetric and titrimetric methods. Total bacterial (TBC) and total coliform counts (TCC) were assessed by pour plate technique on nutrient and MacConkey agar plates, respectively, at 37°C for 24 h. Preliminary identification of bacterial isolates was based on cultural and morphological characteristics. Identity of isolates was confirmed using conventional biochemical tests. The data obtained were analyzed using descriptive, One-sample T Test, Analysis of Variance (ANOVA) and correlation. The results showed the following: pH (boreholes 6.35±0.56, wells 6.82±0.79), TSS (boreholes 0.02±0.01, wells 0.20±0.01), conductivity (boreholes 196.34±79.93, wells 254.18±119.28), alkalinity (boreholes 54.86±30.81, wells 82.67±50.70) and Ca^{2+} (boreholes 0.34±0.21, wells 0.55±0.27) were significantly ($p < 0.05$) higher in wells than boreholes. All the values for the physico-chemical parameters were within World Health Organization permissible limits, while the TBC and TCC were above permissible standards. In addition, faecal coliform such as *Escherichia coli* were among bacteria isolates belonging to 12 genera isolated from the water samples.

Keywords:- *Physicochemical, Bacteriological, Boreholes, Hand-dug Wells.*

I. INTRODUCTION

Water is often perceived to be pretty ordinary but it is the most remarkable renewable resource (Martin, 2001)[30]. According to the World Health Organization's 2017 report, safe potable water is water that does not represent any significant risk to health over a lifetime of consumption, including different sensitivities that may occur between life stages (WHO, 2017)[48].

Water pollution is defined as the introduction of substances through natural or anthropogenic process in water bodies which built up to such an extent that they cause problems for humans or animals (Woodford, 2006)[49].

Water quality refers to the chemical, physical, biological, and radiological characteristics of water (Diersing, 2009)[22]. It is a measure of the condition of water relative to the requirements of one or more biotic species and or to any human need or purpose (Johnson *et al.*, 1997)[28]. The parameters for water quality are determined by the intended use. Work in the area of water quality tends to be focused on water that is treated for human consumption, industrial use, or in the environment (EPA, 2016)[23].

This study aimed at evaluating the physicochemical properties of water samples from selected hand-dug wells and boreholes in the study area, assess the total coliforms and the total heterotrophic bacteria in the water samples, isolate and identify the bacterial contaminants in the water samples.

II. MATERIALS AND METHOD

- *Description of the study area and sampling location*

Obafemi Awolowo University, Ile-Ife, is a Federal University, located in the ancient city of Ile-Ife, Osun State, Nigeria. Obafemi Awolowo University, Ile-Ife, Nigeria lies between latitudes 7° 31' 14.7612" N and 7° 31' 14.7612" N and longitudes 4° 32' 3.161" E and 4° 32' 2.591" E of the Greenwich Meridian (Akinsanya and Adewusi, 2017)[5]**.** The Staff Quarters is located within the University and it occupies an expanse of land with efficient road networks in a serene environment. It covers eighteen (18) out of twenty-four (24) roads that are within the built up area of the University (figure 1). At present, the university has about 35,000 students, 13 Faculties and two colleges (i.e. the Postgraduate College and the College of Health Sciences) (Akinsanya and Adewusi, 2017)[5].

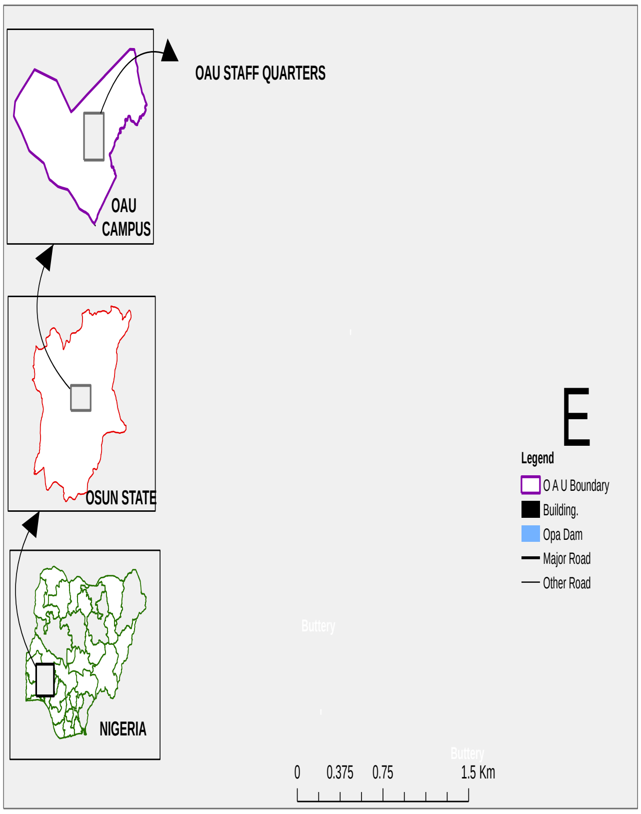

Fig 1: Map of Obafemi Awolowo University, Ile-Ife showing staff quarters

- *Collection of Samples and Physicochemical Analysis*

Water samples were collected from identified fixed sources, namely: hand-dug wells and boreholes. Fifty percent (to a maximum of 25 samples) consisting of households with five boreholes and twenty hand-dug wells within Senior Staff Quarters, Obafemi Awolowo University, Ile-Ife, were randomly selected for the investigation.

Collections of water samples at different locations for laboratory analysis were taken following standard procedure. Duplicate water samples for bacteriological and physico-chemical analyses were collected from each source mostly in the morning hours (between 7.00 am to 11 am) in sterile universal bottles and one liter plastic sampling bottles, all water samples were collected from storex tap. Samples were collected from each source twice during the dry and wet seasons (March to November, 2018). These were stored in an ice chest containing ice cubes and transported to the laboratory for analysis within 24 h. The water sampling, preservation and tests were performed according to standard methods (APHA, 1995)[7].

- *Statistical Analysis*

The results are expressed as Mean ±SD (standard deviation). Differences in means were also determined by Analysis of Variance (ANOVA) ($P < 0.05$).

III. RESULTS AND DISCUSSION

- *Physico-chemical Properties of Boreholes and Hand-dug Wells Water in the Senior Staff Quarters, O.A.U, Ile-Ife*

Sources variation in the concentration of physico-chemical properties of boreholes and hand-dug wells water in the Senior Staff Quarters, O. A. U, Ile-Ife is presented in table 1. The mean ambient (air) temperature value around boreholes was 20.37±3.67°C, while hand-dug wells recorded 21.15±3.08°C. The mean water temperature value for boreholes was 19.58±2.66°C, while hand-dug wells recorded 19.67±2.59°C. The values of apparent colour ranged from 64.34±15.30 Pt-Co in the boreholes to 66.39±15.50 Pt-Co in the hand dug wells. The mean value of true colour for boreholes was 66.58±16.12 Pt-Co while that of hand-dug wells was 67.19±14.58 Pt-Co. The mean dissolved oxygen (DO) value of boreholes was 5.63±2.58 mg/L while that of hand-dug wells was 6.28±1.86 mg/L. The mean biochemical oxygen demand (BOD_5) value of boreholes was 2.21±1.75 mg/L while that of hand-dug wells was 2.82±1.78 mg/L. The mean total dissolved solids (TDS) value of boreholes was 112.66±54.61 mg/L while that of hand-dug wells was 135.87±70.09 mg/L. The mean total solids (TS) value of boreholes was 112.68±54.60 mg/L while that of hand-dug wells was 135.89±70.09 mg/L. The mean acidity value of boreholes was 11.10±5.81 mg/L while that of hand-dug wells recorded 11.66±6.75 mg/L. The mean magnesium value of boreholes was 1.09±1.35 mg/L while that of hand-dug wells was 1.28±0.85 mg/L. The mean sulphate value of boreholes was 2.81±2.63 mg/L while that of hand-dug wells was 3.27±2.20 mg/L. The mean chloride value of boreholes was 0.21±0.08 mg/L while that of hand-dug wells was 0.20±0.11 mg/L. The mean values of these parameters are not statistically significantly different ($p > 0.05$). The mean pH value of boreholes was 6.35±0.56 while that of hand-dug wells was 6.82±0.79. The mean total suspended solids (TSS) value of boreholes was 0.02±0.01 mg/L while that of hand-dug wells was 0.20±0.00 mg/L. The mean electrical conductivity (EC) value of boreholes was 196.34±79.93 µS/cm while that of the hand-dug wells was 254.18±119.28 µS/cm. The mean value of alkalinity for boreholes was 54.86±30.81 mg/L while that of hand-dug wells was 82.67±50.70 mg/L. The mean calcium value of boreholes was 0.34±0.21 mg/L while that of hand-dug wells was 0.55±0.27 mg/L. The mean values of these parameters are statistically significantly different ($p < 0.05$).

3.1 *Ambient (Air) temperature*

The mean air temperature was 20.37±3.67°C around the boreholes and 21.15±3.08°C around hand-dug wells. Thus, air temperature around the boreholes and hand dug wells was not significantly different ($p > 0.05$) (Table 3.1). The mean air temperature was 19.45±2.78°C during rainy season and 22.54±2.85°C during dry season. Hence, the air temperature was significantly different ($p < 0.001$) in both seasons (Table 3.2).

3.2 *Water temperature*

The mean water temperature of boreholes was 19.58±2.66°C while that of hand-dug wells was 19.67±2.59°C. The difference was not statistically significant

($p > 0.05$) (Table 3.1). The mean water temperature was 18.70±2.27°C during rainy season and 20.60±2.57°C during dry season. Hence, the water temperature was significantly different ($p < 0.001$) in both seasons (Table 3.2). The mean water temperature value of boreholes and hand-dug wells water were lower than WHO recommended standard (Tables 3.3 – 3.4).

3.3 Apparent colour

The values of apparent colour ranged from 64.34±15.30 Pt-Co in the boreholes to 66.39±15.50 Pt-Co in the hand dug wells. The difference was also not statistically significant ($p > 0.05$) (Table 3.1). Apparent colour value during the rainy season was 57.71±17.86 Pt-Co and 74.21±4.64 Pt-Co during the dry season. Thus, apparent colour was significantly different ($p < 0.001$) in both seasons (Table 3.2). The mean apparent colour value of boreholes and hand-dug wells water were higher than WHO recommended standard (Tables 3.3 – 3.4).

3.4 True colour (Pt-Co)

The mean value of true colour for boreholes was 66.58±16.12 Pt-Co while that of hand-dug wells was 67.19±14.58 Pt-Co. The difference was not statistically significant ($p > 0.05$) (Table 3.1). True colour value during the rainy season was 58.84±17.31 Pt-Co and 75.29±2.16 Pt-Co during the dry season. Hence, true colour was significantly different ($p < 0.001$) in both seasons (Table 3.2). The mean apparent colour value of boreholes and hand-dug wells water were higher than WHO recommended standard (Tables 3.3 – 3.4).

3.5 Hydrogen ion concentration (pH)

The mean pH value of boreholes was 6.35±0.56 while that of hand-dug wells was 6.82±0.79. The difference was however significantly different ($p < 0.05$) (Table 3.1). The mean pH value during the rainy season was 6.54±1.99 and 6.90±0.96 during the dry season. The values were significantly different ($p < 0.05$) in both seasons (Table 3.2). The mean pH value of boreholes water was lower while that of hand-dug wells water was higher than WHO recommended standard (Tables 3.3 – 3.4).

3.6 Dissolved oxygen (DO)

The mean DO value of boreholes was 5.63±2.58 mg/L while that of hand-dug wells was 6.28±1.86 mg/L. The difference was not statistically significant ($p > 0.05$) (Table 3.1). Dissolved oxygen recorded the mean value of 6.25±1.99 mg/L during rainy season and 6.02±2.09 mg/L during dry season. However, the values were not statistically different ($p > 0.001$) in both seasons (Table 3.2). The mean dissolved oxygen value of boreholes and hand-dug wells water were higher than WHO recommended standard (Tables 3.3 – 3.4)

3.7 Biochemical oxygen demand (BOD5)

The mean BOD5 value of boreholes was 2.21±1.75 mg/L while that of hand-dug wells was 2.82±1.78 mg/L. The difference was not statistically significant ($p > 0.05$) (Table 3.1). The BOD mean value during the rainy season was 2.63±1.93 mg/L and 2.75±1.65 mg/L during dry season. The values were not also statistically different ($p > 0.001$) in both seasons (Table 3.2). The mean biochemical oxygen demand value of boreholes and hand-dug wells water were lower than WHO recommended standard (Tables 3.3 – 3.4).

3.8 Total dissolved solids (TDS)

The mean TDS value of boreholes was 112.66±54.61 mg/L while that of hand-dug wells was 135.87±70.09 mg/L. The difference was not statistically significant ($p > 0.05$) (Table 3.1). TDS recorded the mean value of 134.05±63.56 mg/L during rainy season and 127.94±71.84 mg/L during dry season. The values were not statistically different ($p > 0.001$) in both seasons (Table 3.2). The mean biochemical oxygen demand value of boreholes and hand-dug wells water were lower than WHO recommended standard (Tables 3.3 – 3.4).

3.9 Total suspended solids (TSS)

The mean TSS value of boreholes was 0.02±0.01 mg/L while that of hand-dug wells was 0.20±0.00 mg/L. The difference was also significantly different ($p < 0.05$) (Table 3.1). The TSS mean value during the rainy season was 0.02±0.01 mg/L and 0.02±0.01 mg/L during dry season. The values were not statistically different ($p > 0.001$) in both seasons (Table 3.2). The mean total suspended solids value of boreholes and hand-dug wells water were lower than WHO recommended standard (Tables 3.3 – 3.4).

3.10 Total solids (TS)

The mean TS value of boreholes was 112.68±54.60 mg/L while that of hand-dug wells was 135.89±70.09 mg/L. The difference was not statistically significant ($p > 0.05$) (Table 3.1). TS recorded the mean value of 134.08±63.56 mg/L during rainy season and 127.96±71.84 mg/L during dry season. The values were not statistically different ($p > 0.001$) in both seasons (Table 3.2). The mean total solids value of boreholes and hand-dug wells water were lower than WHO recommended standard (Tables 3.3 – 3.4).

3.11 Electrical conductivity (EC)

The mean EC value of boreholes was 196.34±79.93 µS/cm while that of the hand-dug wells was 254.18±119.28 µS/cm. The difference was significantly different ($p < 0.05$) (Table 3.1). EC recorded the mean value of 237.06±111.61 mg/L during rainy season and 247.00±117.82 mg/L during dry season. The values were not statistically different ($p > 0.001$) in both seasons (Table 3.2). The mean electrical conductivity value of boreholes and hand-dug wells water were lower than WHO recommended standard (Tables 3.3 – 3.4).

3.12 Acidity (ACD)

The mean acidity value of boreholes was 11.10±5.81 mg/L while that of hand-dug wells recorded 11.66±6.75 mg/L. The difference was not statistically significant ($p > 0.05$) (Table 3.1). The acidity mean value during the rainy season was 11.82±7.84 mg/L and 11.20±4.96 mg/L during dry season. The values were not statistically different ($p > 0.001$) in both seasons (Table 3.2). The mean acidity value of boreholes and hand-dug wells water were higher than WHO recommended standard (Tables 3.3 – 3.4).

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3.13 Alkalinity (AKL)

The mean value of alkalinity for boreholes was 54.86±30.81 mg/L while that of hand-dug wells was 82.67±50.70 mg/L. The difference was significantly different ($p < 0.05$) (Table 3.1). The alkalinity mean value during the rainy season was 77.20±46.63 mg/L and 76.46±50.67 mg/L during dry season. The values were not statistically different ($p > 0.001$) in both seasons (Table 3.2).The mean alkalinity value of boreholes and hand-dug wells water were lower than WHO recommended standard (Tables 3.3 – 3.4).

3.14 Calcium (Ca2+)

The mean calcium value of boreholes was 0.34±0.21 mg/L while that of hand-dug wells was 0.55±0.27 mg/L. The difference was also significantly different ($p < 0.05$) (Table 3.1). Calcium recorded the mean value of 0.52±0.27 mg/L during rainy season and 0.49±0.28 mg/L during dry season. The values were not also statistically different ($p > 0.001$) in both seasons (Table 3.2). The mean calcium value of boreholes and hand-dug wells water were lower than WHO recommended standard (Tables 3.3 – 3.4).

3.15 Magnesium (Mg2+)

The mean magnesium value of boreholes was 1.09±1.35 mg/L while that of hand-dug wells was 1.28±0.85 mg/L. The difference was not statistically significant ($p > 0.05$) (Table 3.1). The magnesium mean value during the rainy season was 1.28±0.98 mg/L and 1.20±0.53 mg/L during dry season. The values were not statistically different ($p > 0.001$) in both seasons (Table 3.2). The mean magnesium value of boreholes and hand-dug wells water were lower than WHO recommended standard (Tables 3.3 – 3.4).

3.16 Sulphate (SO42-)

The mean sulphate value of boreholes was 2.81±2.63 mg/L while that of hand-dug wells was 3.27±2.20 mg/L. The difference was also not statistically significant ($p > 0.05$) (Table 3.1). Sulphate recorded the mean value of 2.40±1.91 mg/L during rainy season and 3.94±2.39 mg/L during dry season. The values were however statistically different ($p < 0.05$) in both seasons (Table 3.2).The mean sulphate value of boreholes and hand-dug wells water were lower than WHO recommended standard (Tables 3.3 – 3.4).

3.17 Chloride (Cl-)

The mean chloride value of boreholes was 0.21±0.08 mg/L while that of hand-dug wells was 0.20±0.11 mg/L. The difference was also not statistically significant ($p > 0.05$) (Table 3.1). The mean chloride value during the rainy season was 0.20±1.12 mg/L and 0.19±0.09 mg/L during dry season. The values were not statistically different ($p > 0.001$) in both seasons (Table 3.2) The mean chloride value of boreholes and hand-dug wells water were lower than WHO recommended standard (Tables 3.3 – 3.4).

Table 1: Sources Variation in the Concentration of Physico-chemical Properties of Boreholes and Hand-dug Wells Water in the Senior Staff Quarters, O.A.U, Ile-Ife.

Parameters	Boreholes	Hand-dug Wells	P-Value
No Investigated	5	20	
Amb. Temp. (°C)	20.37±3.67	21.15±3.08	NS
Water Temp. (°C)	19.58±2.66	19.67±2.59	NS
App. Colour (Pt-Co)	64.34±15.30	66.39±15.50	NS
True Colour (Pt-Co)	66.58±16.12	67.19±14.58	NS
pH	6.35±0.56	6.82±0.79	<0.05
DO (mg/L)	5.63±2.58	6.28±1.86	NS
BOD_5 (mg/L)	2.21±1.75	2.82±1.78	NS
TDS (mg/L)	112.66±54.61	135.87±70.09	NS
TSS (mg/L)	0.02±0.01	0.20±0.01	<0.05
TS (mg/L)	112.68±54.60	135.89±70.09	NS
EC (µS/cm)	196.34±79.93	254.18±119.28	<0.05
ACD (mg/L)	11.10±5.81	11.66±6.75	NS
AKL (mg/L)	54.86±30.81	82.67±50.70	<0.05
Ca^{2+} (mg/L)	0.34±0.21	0.55±0.27	<0.05
Mg^{2+} (mg/L)	1.09±1.35	1.28±0.85	NS
SO_4^{2-} (mg/L)	2.81±2.63	3.27±2.20	NS
Cl^- (mg/L)	0.21±0.08	0.20±0.11	NS

Table 3.2: Seasonal Variation in the Concentration of Physico-chemical Properties of Boreholes and Hand-dug Wells Water in the Senior Staff Quarters, O.A.U, Ile-Ife.

Parameter	Rainy Season		Dry Season		P-Value
	BH	DW	BH	DW	
No Investigated	5	20	5	20	
Amb. Temp. (°C)	19.45±2.78		22.54±2.85		<0.001
Water Temp. (°C)	18.70±2.27		20.60±2.57		<0.001
App. Colour (Pt-Co)	57.71±17.86		74.21±4.64		<0.001
True Colour (Pt-Co)	58.84±17.31		75.29±2.16		<0.001
pH	6.54±1.99		6.90±0.96		<0.05
DO (mg/L)	6.25±1.99		6.02±2.09		NS
BOD_5 (mg/L)	2.63±1.93		2.75±1.65		NS
TDS (mg/L)	134.05±63.56		127.94±71.84		NS
TSS (mg/L)	0.02±0.01		0.02±0.01		NS
TS (mg/L)	134.08±63.56		127.96±71.84		NS
EC (µS/cm)	237.06±111.61		247.00±117.82		NS
ACD (mg/L)	11.82±7.84		11.20±4.96		NS
AKL (mg/L)	77.20±46.63		76.46±50.67		NS
Ca^{2+} (mg/L)	0.52±0.27		0.49±0.28		NS
Mg^{2+} (mg/L)	1.28±0.98		1.20±0.53		NS
SO_4^{2-} (mg/L)	2.40±1.91		3.94±2.39		<0.05
Cl^- (mg/L)	0.20±1.12		0.19±0.09		NS

Key: BH: Boreholes, DW: Dug Wells

Table 3.3: Comparison of Investigated Boreholes Water Quality in the Senior Staff Quarters, O.A.U, Ile-Ife with WHO Drinking Water Standard

Parameters	Mean±SD	WHO Standard	P-Value
Amb. Temp. (°C)	20.37±3.67	29	<0.001
Water Temp. (°C)	19.56±2.72	31	<0.001
App. Colour (Pt-Co)	64.03±15.63	15	<0.001
True Colour (Pt-Co)	66.02±16.33	15	<0.001
pH	6.36±0.57	6.50	NS
DO (mg/L)	5.59±2.64	2	<0.001
BOD_5 (mg/L)	2.29±1.79	4	<0.001
TDS (mg/L)	112.14±55.97	500	<0.001
TSS (mg/L)	0.02±0.01	75	<0.001
TS (mg/L)	112.16±55.97	500	<0.001
EC (µS/cm)	196.95±81.95	750	<0.001
ACD (mg/L)	11.10±5.93	1.5	<0.001
AKL (mg/L)	55.30±31.55	500	<0.001
Ca^{2+} (mg/L)	0.35±0.21	50	<0.001
Mg^{2+} (mg/L)	1.07±0.34	50	<0.001
SO_4^{2-} (mg/L)	2.68±2.62	100	<0.001
Cl^- (mg/L)	0.21±0.09	250	<0.001

Table 3.4: Comparison of Investigated Hand-dug Wells Water Quality in the Senior Staff Quarters, O.A.U, Ile-Ife with WHO Drinking Water Standard

Parameters	Mean±SD	WHO Standard	P-Value
Amb. Temp. (°C)	21.15±3.08	29	<0.001
Water Temp. (°C)	19.68±2.58	31	<0.001
App. Colour (Pt-Co)	66.65±15.41	15	<0.001
True Colour (Pt-Co)	67.33±14.49	15	<0.001
pH	6.82±0.79	6.50	<0.05
DO (mg/L)	6.27±1.85	2	<0.001
BOD_5 (mg/L)	2.79±1.79	4	<0.001
TDS (mg/L)	135.71±69.66	500	<0.001
TSS (mg/L)	0.20±0.01	75	<0.001
TS (mg/L)	135.73±69.66	500	<0.001

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EC (µS/cm)	253.30±118.78	750	<0.001
ACD (mg/L)	11.61±6.72	1.5	<0.001
AKL (mg/L)	82.21±50.55	500	<0.001
Ca^{2+} (mg/L)	0.54±0.27	50	<0.001
Mg^{2+} (mg/L)	1.29±0.86	50	<0.001
SO_4^{2-} (mg/L)	3.30±2.20	100	<0.001
Cl^- (mg/L)	0.20±0.11	250	<0.001

- *Bacteriological Parameters of Boreholes and the Hand-dug Wells in the Study Area*

- *Total viable Bacterial Count (TBC)*

The mean TBC value of boreholes was 7.30±8.51 cfu/ml while that of hand-dug wells was 12.45±16.46 cfu/ml. The difference was not statistically significant ($p > 0.05$) (Table 3a). Also, the mean TBC value during the rainy season was 15.52±15.92 cfu/ml and 7.32±13.70 cfu/ml during the dry season. The difference was statistically different ($p < 0.05$) in both seasons (Table 3b). The mean TBC value of boreholes and hand-dug wells water were higher than WHO recommended standard (Table 3c)

- *Total Coliform Count (TCC)*

The mean TCC value of boreholes was 0.40±0.97 cfu/ml while that of hand-dug wells was 3.55±11.85 cfu/ml. The difference was also not statistically significant ($p > 0.05$) (Table 3a). The mean TCC value during the rainy season was 5.36±14.78 cfu/ml and 0.48±0.93 cfu/ml during the dry season. The difference was not statistically different ($p > 0.05$) in both seasons (Table 3b). The TCC value of boreholes and hand-dug wells water were higher than WHO recommended standard (Table 3c)

Table 3a: Sources Variation in the Concentration of Bacteriological Properties of Boreholes and Hand-dug Wells Water in the Senior Staff Quarters, O.A.U, Ile-Ife

Parameters	*Boreholes*	*Hand-dug Wells*	*P-Value*
No Investigated	*5*	*20*	
TBC (cfu/ml)	*7.30±8.51*	*12.45±16.46*	*NS*
TCC (cfu/ml)	*0.40±0.97*	*3.55±11.85*	*NS*

Key: TBC: Total Bacteria Count, TCC: Total Coliform Count, cfu: Coliform Forming Unit

Table 3b: Seasonal Variation in the Concentration of Bacteriological Properties of Boreholes and Hand-dug Wells Water in the Senior Staff Quarters, O.A.U, Ile-Ife.

Parameter	*Rainy Season*		*Dry Season*		*P-Value*
	BH	*DW*	*BH*	*DW*	
No Investigated	*5*	*20*	*5*	*20*	
TBC (cfu/ml)	*15.52±15.92*		*7.32±13.70*		*< 0.05*
TCC (cfu/ml)	*5.36±14.78*		*0.48±0.93*		*NS*

Key: BH: Boreholes, DW: Dug Wells, cfu: Coliform Forming Unit
TBC: Total Bacteria Count, TCC: Total Coliform Count

Table 3c: Comparison of Investigated Boreholes and Hand-dug Wells Water Quality in the Senior Staff Quarters, O.A.U, Ile-Ife with WHO Drinking Water Standard

Parameters	*N*	*Mean±SD*	*WHO Standard*	*P-Value*
TBC (cfu/ml)	*25*	*11.42±15.27*	*10*	*NS*
TCC (cfu/ml)	*25*	*2.92±10.66*	*0*	*NS*

Key: TBC: Total Bacteria Count, TCC: Total Coliform Count, cfu: Coliform Forming Unit

- *Percentage Distribution of Bacterial Isolate*

The percentage distribution of the bacterial isolates is shown in table 3d. A total of sixty-four (64) bacteria species were isolated from both boreholes and hand-dug wells sampled. *Aeromonas hydrophila* has the highest percentage distribution of (18.8%), followed by *Bacillus* spp with 15.6%, *Staphylococcus* spp with 10.9%, *Listeria* spp has 9.4%, *Escherichia coli* has 7.8%, *Acinetobacter* spp has 7.8%, *Enterobacter intermedius* has 6.3%, while *Corynecbacterium* spp 4.7%, *Arthrobacter* spp 4.7%, *Pseudomonas aeruginosa* 4.7%, *Klebsiella* spp 4.7% and *Micrococcus* spp 4.7% had the least percentage distributions.

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Table 3d: Percentage Distribution of the Isolated Bacteria from Boreholes and Hand-dug Wells in the Senior Staff Quarters, O.A.U, Ile-Ife

Isolated Bacteria	No in Borehole	No in Hand-dug Wells	(%) of Isolates
Aeromonas hydrophila	4	8	18.8
Bacillus spp.	3	7	15.6
Staphylococcus spp.	NA	7	10.9
Listeria spp.	2	4	9.4
Escherichia coli	NA	5	7.8
Acinetobacter spp.	NA	5	7.8
Enterobacter intermedius	NA	4	6.3
Corynecbacterium spp.	NA	3	4.7
Arthrobacter spp.	NA	3	4.7
Pseudomonas aeruginosa	NA	3	4.7
Klebsiella spp.	NA	3	4.7
Micrococcus spp.	1	2	4.7
Total	**10**	**54**	**100.**

Key: No- Number, %- Percentage, spp- Species, NA- Not Available

➢ *Correlation of the Physic-chemical and Bacteriological Properties of the Boreholes and Hand-dug Wells water in Senior Staff Quarters, O.A.U, Ile-Ife*

- *The correlation coefficient of the investigated parameters in the boreholes and hand-dug wells is presented in Table 3e.*

The ambient temperature of all the investigated boreholes and hand-dug wells showed a positive correlation (r) at 0.01 significant level to water temperature, apparent colour, true colour and biochemical oxygen demand (BOD_5) and negative correlation to calcium while a positive correlation at 0.05 significant level existed between pH, magnesium and ambient temperature with total dissolved solids (TDS), total suspended solids (TSS) and total solids (TS) exhibiting negative correlation with ambient temperature. The temperature of investigated boreholes and hand-dug wells also showed positive correlation at 0.01 significant level with biochemical oxygen demand (BOD_5) and magnesium and negative correlation with calcium at 0.05 significant level. Significant correlation of apparent colour was found positive with true colour and negative with acidity and magnesium at 0.01 while biochemical oxygen demand (BOD_5) and total bacteria count (TBC) showed positive and negative significant at 0.05. The analysed boreholes and hand-dug wells true colour displayed negative correlation with acidity and magnesium while positive correlation was observed in total bacteria count (TBC) at 0.01 significant level, negative and positive correlation was however observed in biochemical oxygen demand (BOD_5) and sulphate (SO_4) at 0.05 significant level.

The hydrogen ion concentration (pH) exhibited positive correlation with total suspended solids (TSS), Electrical conductivity (EC) and sulphate (SO_4) at 0.05 significant level. Biochemical oxygen demand (BOD_5) positively correlated with acidity and magnesium (Mg^{2+}) at 0.05 and 0.01significant level respectively. Total dissolved solids (TDS) showed positive correlation with total solids (TS), electrical conductivity (EC), alkalinity and calcium (Ca^{2+}) at 0.01 significant level while positive correlation was seen with total bacteria count (TBC) at 0.05 level of significance. The total suspended solids (TSS) in the examined boreholes and hand-dug wells showed positive correlation with alkalinity and electrical conductivity (EC) at 0.01 and 0.05 levels of significant respectively. Total Solids (TS) has positive correlation with electrical conductivity (EC), alkalinity and calcium (Ca^{2+}) at 0.01 significant level and 0.05 significant level positive correlation with total bacteria count (TBC).

The electrical conductivity of the examined boreholes and hand-dug wells showed a positive correlation with alkalinity and calcium (Ca^{2+}) at 0.01 significant level. The acidity showed positive correlation with alkalinity, magnesium (Mg^{2+}) and total bacteria count (TBC) at 0.01 significant level. The alkalinity of the analysed boreholes and hand-dug wells showed positive correlation only with calcium (Ca^{2+}) at 0.01 significant level. The calcium concentration in the analysed boreholes and hand-dug wells has positive correlation with total bacteria count (TBC) at 0.05 significant level. The magnesium concentration showed negative correlation with total bacteria count (TBC) at 0.05 significant level. Total coliforms count (TCC) has positive correlation with total bacteria counts (TBC) at 0.01 significant level.

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Table 4.15: Correlation Coefficient (r) Matrix of all the Investigated Boreholes and Hand-dug Wells Water in Senior Staff Quarters, O.A.U, Ile-Ife.

	A.T	W.T	ARC	TRC	pH	DO	BOD	TDS	TSS	TS	EC	ACD	ALK	Ca	Mg	SO_4	Cl	TCC	TBC
A.T	1																		
W.T	.864**	1																	
ARC	.285**	.131	1																
TRC	.268**	.122	.961**	1															
pH	.210*	.178	.127	.111	1														
DO	.081	.140	-.042	-.045	.077	1													
BOD	.313**	.263**	-.200*	-.213*	.030	-.007	1												
TDS	-.214*	-.150	.082	.116	.093	-.068	.017	1											
TSS	-.145	-.147	-.080	-.104	.251*	-.026	.004	.184	1										
TS	-.214*	-.150	.082	.116	.093	-.068	.017	1.000**	.184	1									
EC	-.100	-.023	-.012	.001	.207*	.026	.053	.878**	.255*	.878**	1								
ACD	.089	.079	-.386**	-.388**	-.112	-.031	.224*	-.006	-.016	-.006	.142	1							
ALK	-.132	-.102	-.018	-.070	.176	-.143	.160	.657**	.366**	.657**	.697**	.260**	1						
Ca	.291**	-.251*	.122	.088	.120	-.113	.036	.656**	.187	.656**	.546**	.019	.571**	1					
Mg	.204*	.267**	-.366**	-.317**	-.031	-.038	.320**	-.035	-.008	-.035	.048	.270**	-.007	-.183	1				
SO_4	.163	.053	.195	.241*	.237*	-.078	-.051	.097	-.034	.097	.037	-.056	.122	.127	-.055	1			
Cl	-.023	.002	.013	.020	.049	.109	.109	.147	-.004	.147	.192	.085	-.028	.124	.102	.060	1		
TCC	-.063	-.082	.120	.106	-.030	-.134	.018	.118	-.014	.118	.037	-.136	.026	.172	-.148	-.124	-.044	1	
TBC	-.128	-.176	.254*	.267**	-.120	.170	-.195	.214*	-.041	.214*	.019	.274**	-.011	.208*	-.238*	-.121	.013	.574**	1

***. Correlation is significant at the 0.01 level (2-tailed).*

**. Correlation is significant at the 0.05 level (2-tailed).*

IV. DISCUSSION

Physico-chemical and bacteriological parameters are indices used for the determination of water quality. These parameters were therefore used to assess the quality of water from hand dug wells and boreholes established in the senior staff quarters of Obafemi Awolowo University to curtain increasing scarcity of water supply from public taps.

Temperature is a measure of the warmness or coldness of a substance in allusion to some standard value. The little variations in ambient temperature recorded in this study compared to other studies by Obasi and Talabi (2015)[34]; Ayandele *et al*. (2015)[10] and Bello *et al*. (2013)[13] which related observed temperature to changes in sunshine intensity. The overall mean water temperature of 19.58±2.66°C recorded in this study among the hand dug wells investigated agree with the findings of Obasi and Talabi (2015)[34] in their study of boreholes around Ekiti State University, Ado Ekiti but lower than 23°C reported by Ayandele *et al*. (2015)[10] in Mosimi and Environs, Ogun State. It was also lower than 22°C to 28°C and 21°C to 27°C reported by Bello *et al*. (2013)[13] in boreholes and wells water in Ijebu-Ode, respectively. Water temperature most times depends on environmental factors like geographic location, season and sampling time (Devangee *et al*., 2013)[21]. According to Chang (2006)[15], increased temperature causes the growth of thermo-tolerant microorganisms, increased rate of biological activities and decomposition of organic matter. The observed significant seasonal variation in water temperature is an indication that these activities that depend on temperature will also vary seasonally and affect seasonal quality of water (Chikere and Okpokwasili, 2002)[17].

Drinking water is expected to have no visible colour. Colour in drinking-water is usually due to the presence of algae and coloured organic matter (primarily humic and fulvic acids) associated with the humus fraction of soil. Colour is also strongly influenced by the presence of iron and other metals, either as natural impurities or as corrosion products (Czuba *et al.*, 2011)[18]. It may also result from contamination of the water source with industrial effluents and may be the first indication of a hazardous situation (Canadian Council of Ministers of the Environment, 2001)[14] Total solids are a significant factor in observing water clarity (Langland and Cronin, 2003)[29]. Total Dissolved Solids is a measure of the combined content of all inorganic and organic substances contained in a liquid in molecular, ionized or micro-granular (colloidal) suspended form. The more solids present in the water, the less clear the water will be (Langland and Cronin, 2003)[29]. The recorded water apparent and true colour of 64.34±15.30 Pt-Co and 66.58±16.12 Pt-Co for boreholes 66.39±15.50 Pt-Co and 67.19±14.58 Pt-Co for wells respectively in this study, were significantly higher than 5.2 Pt-Co reported by Ahmed and Eyaife (2014)[4] for hand dug wells and 6.5 Pt-Co reported by Devangee *et al*. (2013)[21] for boreholes. The Total Solids which was the sum total of total dissolved solids (TDS) and Total Suspended Solids in the investigated boreholes and hand-dug well recorded the overall mean value of 112.68±54.60 mg/L for boreholes and 135.89±70.09 mg/L for hand-dug wells, respectively. The TS mean value recorded during this investigation was lower than 153.21 mg/L reported by Ayandele *et al*. (2015)[10] for boreholes in Mosimi and Environs, Ogun State and 210.0 mg/L reported by Aribisala *et al*. (2017)[8] for wells in Ado-Ekiti. Thus, it is evident that the clarity of the investigated boreholes and hand-dug wells water in Senior Staff Quarters, Obafemi Awolowo University cannot be dissociated from the low value of total solids recorded from the sources.

In terms of water quality, high levels of total suspended solids will increase water temperatures and decrease Dissolved Oxygen levels (Wetzel, 2001)[46]. This is because suspended particles absorb more heat from solar radiation than water molecules. This heat is then transferred to the surrounding water by conduction. Warmer water cannot hold as much dissolved oxygen as colder water, so DO levels will drop as water temperature increases (Hickin, 1995)[26]. Thus, the low total suspended solids of 0.02±0.01 mg/L recorded in boreholes and 0.02±0.00 mg/L recorded in wells investigated may explain the relatively high DO concentration (5.63±2.58 mg/L and 6.28±1.86 mg/L) in boreholes and wells, respectively. The seasonal variation in DO may also be explained by a corresponding variation in TDS concentration, temperature changes and fluctuation in biological activities in the water (Chapman and Kimstach, 1992)[16]. Dissolved oxygen is also an important limnological parameter which in conjunction with BOD is a good indicator of water quality and organic pollution in water bodies (Wetzel and Likens, 2006)[47]. Although, the BOD_5 values do not actually indicate water quality but it has the potential of removing dissolved oxygen from the water and strength of sewage and industrial waste. Ukpong *et al*. (2013)[43] reported that high BOD_5 indicates the presence of a large amount of organic matter. The relatively high concentration of DO recorded in the samples can be attributed to low level of intrusion of microbes into the sampled boreholes and hand-dug wells. Biochemical Oxygen Demand (BOD) is the amount of oxygen required by bacteria to break down decomposable organic matter in water into simpler form. It is measured after incubating the water sample at room temperature for 5 days. The biodegradation of organic materials exerts oxygen tension in the water and increases the BOD (Abida and Harikrishna, 2008)[1]. The level of BOD_5 recorded by this study (2.21±1.75 mg/L and 2.82±1.78 mg/L for boreholes and wells, respectively), is an indication of low organic pollution of the water bodies. Biochemical oxygen demand is therefore inversely proportional to DO as shown in this study and those of Olutiola *et al*. (2000)[38].

Hydrogen ion concentration (pH) is one of the important parameters used in determining water quality, since it affects the corrosive nature of water and other chemical reactions such as metal toxicity and solubility (Fakayode, 2005)[24]. Gupta (2009)[25] reported positive correlation of pH with electrical conductivity and total alkalinity. The conductivity of a solution depends on the concentration of all the ions present, the greater the concentrations, the greater the conductivity. Electrical conductivity (EC) in natural water is the normalized measure of the water's ability to conduct electric current (Ahmed and Eyaife, 2014)[4]. Alkalinity of water can be linked to the presence of mineral salt in it. It is

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primarily caused by the bicarbonates and carbonates ions (Singh *et al*., 2010)[41]. For this study, mean pH was 6.35±0.56 in boreholes and 6.82±0.79 in hand-dug wells. These values are significantly different from 6.5 and 6.8 recorded for boreholes and hand-dug wells in a study by Aribisala *et al*. (2017)[8] in Ado-Ekiti. During this study, low pH values were recorded during the rainy season, while higher pH values were recorded during the dry season. Overall mean acidity was 11.10±5.81 mg/L for boreholes and 11.66±6.75 mg/L for hand-dug wells indicating slight acidic nature of the water samples. Meanwhile, Aribisala *et al*. (2017)[8] reported 16.00 mg/L for boreholes in Ado Ekiti which was higher than the value recorded in this study, while Olajire and Imeokparia (2011)[37] reported 12.00 mg/L for hand-dug wells which was also higher than the value reported in this investigation. Acidity was observed to be higher in rainy season than the dry season. Ademoroti (1996)[2] observed a similar trend and attributed it to anthropogenic activities that discharge organic acids into the water sources or it could also be as a result of low pH values during this period. Electrical conductivity of the investigated boreholes and hand-dug wells were 196.34±79.93 µS/cm and 254.18±119.28 µS/cm. Mensah Kwame (2011)[31]; Tay (2004)[42] and Darko-Mantey, *et al*. (2005)[20] reported lower and higher values of 73.69 µS/cm, 117.0 µS/cm and 1179 µS/cm for wells and Dahunsi, *et al*. (2014)[19] and Afolabi *et al*. (2012)[3] reported lower values of 22.4 µS/cm and 31.3 µS/cm, respectively, for boreholes. The high electrical conductivity value recorded during the dry season corroborate with the report of Venkatesharaju *et al*. (2010)[44] while it's in contrast with the report of Ocheri and Ahola (2015)[35] where higher EC value was reported during rainy season. Patil *et al*. (2012)[39] reported that conductivity showed significant correlation with ten parameters such temperature, pH, alkalinity, total hardness, calcium and so on. In this study, conductivity correlated significantly ($p < 0.05$) with alkalinity and calcium. The overall mean value recorded for alkalinity in boreholes and hand-dug wells sampled were 54.86±30.81 mg/L for boreholes and 82.67±50.70 mg/L for hand-dug wells. The recorded values were higher than the values reported by Amadi *et al*. (2014)[6] and Aribisala *et al*. (2017)[8] who reported 32.5 mg/L for boreholes and 41.05 mg/L for hand-dug wells. Although, the seasonal variation in the alkalinity showed a higher value in the rainy season than in the dry season, the reason for this variation could be as a result of decline in the rate of mineral salt deposition into the water bodies in dry season; reduction in bicarbonates; evaporation and decomposing organic matter. This result agrees with the findings of Ocheri and Ahola (2005)[35] and that of Priyanka *et al*. (2010)[40] that reported lower values but in contrast with the report of Venkatesharaju *et al*. (2010)[44] who reported higher alkalinity value during the dry season. Thus, the relatively high hydrogen ion concentration (pH) recorded for this research work can be linked to the high electrical conductivity (EC) while it confirms the slight acidic nature of water sampled in both sources.

Calcium (Ca^{2+}) and Magnesium (Mg^{2+}) ions are both common in natural waters and both are essential elements for all organisms. Calcium and Magnesium when combined with bicarbonates, carbonate, sulphate and other species (anions), contribute to the hardness of natural water. Normally hardness due to calcium predominates, although in certain regions magnesium hardness can be high. In some river catchments, hardness can vary seasonally reaching peak values during low flow conditions (Wetzel, 2001)[46]. Mihir *et al*. (2014)[32] reported that drinking water with excess sulphate concentrations has a bitter taste and a strong 'rotten-egg' odour. He added that sulphate can also interfere with disinfection efficiency by scavenging residual chlorine in distribution systems. Weiner (2000)[45] also reported that chlorides in water are more of a taste than a health concern, although high concentrations may be harmful to people with kidney or heart problems. This study recorded calcium concentration of 0.34±0.21 mg/L for boreholes and 0.55±0.27 mg/L for hand-dug wells. Magnesium concentration was 1.09±1.35 mg/L for boreholes and 1.28±0.85 mg/L for hand-dug wells, while sulphate concentration was 2.81±2.63 mg/L for boreholes and 3.27±2.20 mg/L for hand-dug wells. Mean chloride concentration in boreholes and hand-dug wells was 0.21±0.08 mg/L and 0.20±0.11 mg/L respectively. The overall mean concentration of these parameters was higher during the rainy season than the dry season. The seasonal trend observed by this study contradicts Ayaana *et al*. (2015)[9] which reported higher values in the dry season. The low value of magnesium content in the boreholes and hand-dug wells was attributed by earlier investigations to low rate of natural deposits in the aquifer and direct pumping of the water into the storex tank as against fetching which brings about runoff. In addition, the low concentration of sulphate in the investigated boreholes and hand-dug wells could be responsible for the unobjectionable taste and odour observed in the water samples (Badmus *et al*., 2015)[11]. Also, the low chloride values recorded in both boreholes and hand-dug wells in Senior Staff Quarters, Obafemi Awolowo University may be responsible for the freshness of the groundwater in this area and a reflection of minimal treatment of the water with chlorine. Thus, the water examined in the boreholes and hand-dug wells in Senior Staff Quarters, Obafemi Awolowo University can be classified as soft in hardness because of the low concentration of cations and anions.

Comparison of the physico-chemical parameters values of water in the investigated boreholes and hand-dug wells with the World Health Organization (WHO) permissible standard limits revealed full compliance suggesting that the quality of water from all these water sources are acceptable and require only minimal treatment. However, compliance with bacteriological standards was not as clear-cut as the physico-chemical quality. This is because some of the water sources were not totally free of bacteria and coliform contamination. The bacteriological study revealed that the investigated boreholes has total bacterial count mean value of 7.30±8.51 cfu/ml and total coliform count mean value of 0.40±0.97 cfu/ml, this was lower to the mean value of 12.45±16.46 cfu/ml obtained as total bacterial count and 3.55±11.85 cfu/ml obtained as total coliform count in hand-dug wells. However, the mean total bacteria and total coliform count value obtained in boreholes and hand-dug wells in this research was lower than what was obtained in a report by Jacinta *et al*. (2017)[27] in their assessment of microbiological quality of boreholes and wells water sources in Amai Kingdom, Ukwuani Local Government Area of

Delta State, Nigeria, where the mean total heterotrophic bacterial and total coliforms count values were reported to be 9 cfu/ml and 2.5 cfu/ml in borehole water samples as well as 26 cfu/ml and 6.4 cfu/ml in well water samples. Similarly, Dahunsi *et al*. (2014)[19] reported TBC mean value of 8.0 cfu/ml in boreholes and 135.0 cfu/ml in hand-dug wells. Meanwhile, lower total bacterial and total coliform mean value counts was reported by Odeyemi *et al*. (2018)[36] where total bacterial and total coliform mean value count of 9.7 cfu/ml and 1.2 cfu/ml in well water samples from hostels in Osekita, Iworoko-Ekiti, Ekiti State, Nigeria was obtained. The low coliform and bacteria presence in the examined boreholes and hand-dug wells can be attributed to their far distance away (above 20 meters) from septic tank. As expected, total coliform and total bacterial counts were generally higher during the rainy season than the dry season. Increase in the bacterial count during the rainy season may be attributed to increase in the amount of rainfall which increases the porosity of the soil and makes it easier for the bacteria to penetrate faster. The nature of the hand-dug wells and other wastes from anthropogenic activities could be responsible for the increase in bacterial count during the rainy season. Bakare *et al*. (2013)[12] reported the presence of coliforms especially *Escherichia coli* as an indication of faecal contamination, but this study attributed the presence of the few recorded coliform to anthropogenic activities since the examined boreholes and hand-dug wells were located above 20 meters away from septic tank where faecal contamination can be introduced. The values obtained for the total bacterial count and total coliform count was higher than WHO recommended standard for total bacteria and total coliform count in potable water.

Most of the bacterial isolates from the twelve (12) bacterial genera isolated from the investigated boreholes and hand-dug wells in Senior Staff Quarters, Obafemi Awolowo University had been previously reported as common microbial contaminants in water bodies. Jacinta *et al.* (2017)[27] in their assessment of microbiological quality of boreholes and wells water sources in Amai Kingdom, Ukwuani Local Government Area of Delta State, Nigeria reported isolation of eleven (11) bacterial genera. Similarly, Bello *et al.* (2013)[13] in their published research work on bacteriological and physico-chemical analyses of borehole and well water sources in Ijebu-Ode, South-western Nigeria reported isolation of eight bacterial genera. However, the persistence presence of these bacterial isolates in any of these sources can result into detrimental effect on the health of its consumers (Nicholas *et al*., 2001)[33].

V. CONCLUSIONS

The study revealed that the concentration of most of physico-chemical parameters including temperature, biochemical oxygen demand, total dissolved solids, total suspended solids, total solids, electrical conductivity, alkalinity, calcium, magnesium, sulphate and chloride of water in the investigated boreholes and hand-dug wells were lower while hydrogen ion concentration, dissolved oxygen and acidity were within WHO regulatory permissible standards suggesting that water from the water sources are of acceptable quality. However, bacteriological quality of some of the water sources fell short of permissible standards suggesting a need for additional treatment before use.

In order to enhance the quality of water from these sources, the following recommendations need to be considered and implemented.

i. Households with hand-dug wells and boreholes without coliforms recovery should sustain the good hygienic maintenance.

ii. Those that were contaminated with coliform should ensure frequent cleaning of water storage tank, flowing channels and strict adoption of good hygienic practices.

iii. The conventional domestic techniques of water treatment should also be sustained by the users' of both hand-dug wells and boreholes in order to reduce the risk of contracting water borne diseases.

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