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Quality parameter assessment of water, accessible for drinking and general purpose in some selected local government areas in Osun state, South-western Nigeria

Agbaje W. B. [1*], Fadunmade E. O. [1], Azeez L. A. [1], Awojide S. H. [1], Adewale O. O.[2], Wahab A. A. [3], Abiona O. O. [4], Akintade O. O.[5], Oni P.G.[1]

[1]*Department of Pure and Applied Chemistry, Faculty of Basic and Applied Sciences, Osun State University, Osogbo, Nigeria*
[2]*Department of Biochemistry, Faculty of Basic and Applied Sciences, Osun State University, Osogbo, Nigeria.*
[3]*Department of Microbiology, Faculty of Basic and Applied Sciences, Osun State University, Osogbo, Nigeria.*
[4]*Department of Food Science and Technology, Faculty of Basic and Applied Sciences, Osun State University, Osogbo, Nigeria*
[5]*Department of Chemical Sciences, Faculty of Applied Sciences, KolaDaisi University, Ibadan, Nigeria*
**Corresponding author, Email address: wasiu.agbaje@uniosun.edu.ng; agbajewb@gmail.com*

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Abstract: The aim of this study was to investigate four major sources of water: stream (STR), well (WEL), borehole (BHL) and sachet (SHT), accessible for drinking and other purposes by inhabitants of some selected local government areas in Osun State, South-western Nigeria with a view to forestall associated danger which unsafe water could bring when consumed by people. Standard methods were used for sample collection, preparation and analysis. The samples were analyzed for physicochemical properties, water quality index and microbial status. The results showed that all the physicochemical parameters were within the approved permissible national and international standards (WHO, USEPA and Federal Ministry of Environment (FMENV), Nigeria) except some parameters in stream water samples: turbidity (>1 mg/L in all stream samples), hardness (>200 mg/L in STR5), levels of iron (>0.3 mg/L in each of STR6, STR7, STR8, STR9 and STR10) and zinc concentration (<0.5 mg/L in WEL, BHL and SHT water samples). The alkalinity in one of the borehole water samples (BHL2) was lower than the permissible range of 30-500 mg/L approved by the FMENV, Nigeria. The water quality index indicated that, the water samples were suitable for drinking; nevertheless, the Total Plate Counts (CFU/mL), Coliform Count (MPN/100 mL) and *E. coli* count (MPN/100 mL) for each of the four water sources were higher than zero (approved national and international standards) and therefore, none of the samples was suitable for drinking; however, they may be useful for other purposes.

1. Introduction

Water is the universal solvent necessary for life (Kılıç *et al*., 2020). Water is essential for human beings and other animals in terms of supports for cellular structure, food digestion, nutrient transportation, drug delivery, blood circulation and regulation of body temperature, among others. Water can be obtained from different sources including rain, streams, natural ponds/lakes and shallow hand-dug wells; other accessible ones are borehole, sachet and bottle water. Water is essential for drinking, domestic uses (cooking, bathing, washing, etc.) and industrial applications (small, medium and large scales). Each of these enumerated sources has one shortcoming or the other which may make the water unsuitable for drinking and other uses. Rainwater gathers pollutants from the atmosphere as it drips down; consequently, pollutants from surface run-of, sewage discharges, and industrial effluents gather in rivers and streams as they move (Stark *et al*., 2001). Yahaya *et al*. (2022) asserted that indiscriminate dumping of solid wastes, chemicals, sewage from homes and industries, and agricultural runoffs are some of the anthropogenic activities that compromise the quality of water sources. One other source of environmental contaminants in water is dumpsites. Dumpsites are the most widely used methods of disposing of municipal solid wastes, industrial wastes, and hazardous wastes because they are effective and cheap (Ferronato and Torretta, 2019), (Obiekezie *et al*., 2019). Properly managed dumpsites are hygienic, but poor management may cause organic waste degradation and, coupled with acidic rain, elicit leachate which can percolate into the ground and contaminate groundwater (Omorogieva and Andre-Obayanju, 2020), (Ozbay *et al*., 2021). Leachate from dumpsites contains hazardous substances like heavy metals, dissolved organic matter, inorganic macro components, microorganisms, and xenobiotic organic compounds (Daniel *et al*., 2021). Traditional septic tank and soakaway system have been reported to affect water quality (Keegan *et al*., 2014; Malgwi and Sunday, 2021). Furthermore, poorly treated/processed sachet water can also pose threat to the consumers. Water quality monitoring is imperative, especially when the water is meant for drinking and domestic purposes. For an instance, it has been reported that more than a billion people throughout the world lack access to safe drinking water (Bhatia, 2009). Indeed, unsafe water is a universal threat to public health, putting lives at risk due to a host of infectious diseases as well as chemical intoxication (American Water Works Association, 1971), (Napacho and Manyele, 2010). There is no available information within our reach which recently addresses the quality issue of the four major sources of drinking water in Osun State. In order to forestall associated danger which unsafe water could bring when consumed by innocent citizens, this study was carried out to investigate the physicochemical properties, water quality index and microbial status of water, accessible for drinking and general purposes in some selected local government areas in Osun state, Nigeria.

2. Methodology

2.1. Sampling sites and Sample collection

The area chosen for this study is Osun state with population of about 4.1 million. It is located in south-western Nigeria and comprises of 30 local government areas (LGA), with 69 Local Council Development Areas (LCDA) (www.osunstate.gov.ng). Seven local government areas were chosen for the sampling, which were Osogbo, Olorunda, Odo otin, Ifelodun, Egbedore, Boripe and Boluwaduro. Osogbo is the capital of Osun State and it is situated between latitude 7^o 6' N and 7^o 15' N, and longitude 3^o 17' E and 3^o 25' E with area of about 268 km^2. Osogbo city is located in the south-western part of Nigeria and about 100 km south of Ilorin in Kwara State, 115 km northwest of Akure in Ondo State and 88 km northeast of Ibadan, Oyo State. The capital city consists of Olorunda and Osogbo Local Government Areas with a total population of 300,000 people (Oyelowo *et al*., 2010), (Taiwo *et al*., 2019). The projected population of the seven local government areas under investigation ranged from 53037 to 140631 with the least and highest values from Boluwaduro and Osogbo, respectively. In addition, the land mass of the seven local areas ranged from 46.47 km^2 in Osogbo Local Government to 260.83 km^2 in Odo-Otin Local Government.

Prior to the sample collection, 1 L plastic containers and 2.5 L plastic fetcher meant for this purpose were washed with non-ionic detergents, rinsed with distilled water, washed with 0.05 M HCl and then rinsed with distilled water (APHA, 1992). A total of ten (10) streams were selected from four LGAs: three from Osogbo, one from Odo-Otin, four from Ifelodun and two from Boluwaduro. Before sampling, the bottles were rinsed thrice with sample water before being filled with the samples. The actual stream water samplings were done midstream by dipping each sample bottle at approximately 20-30 cm below the water surface and projecting the mouth of the container against the flow direction.

The well water samples were collected using pretreated plastic fetcher and were obtained from five different LGAs: one in Osogbo, two from each of Ifelodun, Egbedore and Boripe, and three from Boluwaduro. Ten Borehole water samples were collected from different boreholes with four from each of Osogbo and Boluwaduro and one from each of Olorunda and Boripe LGAs. Before the collection, the taps were opened and the water was allowed to flow for about five (5) minutes before water samples were collected. After collection, sample bottles were tightly covered and transported under 4^oC to the laboratory for analysis. The locations of the samples were well documented (Figure 1). Furthermore, sachet water samples were bought from available supermarkets in Osogbo; ten different samples were bought based on manufacturers. The samples were kept in refrigerator at 4^oC.

2.2 Sample Analysis.

Each of all the samples was analyzed for pH: by electrometric method, Turbidity: hexamethylenetetramine and hydrazine spectrophotometric method, Alkalinity: by acid-base titrimetry, Nitrate: phenoldisulphonic acid colorimetric method, Chloride: mercuric nitrate titrimetry method, Sulphate: barium chloride spectrophotometric method, Phosphate: phosphomolybdate colorimetric method, Total Hardness (calcium and magnesium): EDTA titrimetry method, Total Solids, Total Suspended Solids (TSS) and Total Dissolved Solids (TDS): gravimetric method, and metals using ICP-OES (Agilent 720-ES with megapixel CCD detector, USA). The methods are detailed in the standard procedures of the Society for Analytical Chemistry manual (Society for Analytical Chemistry, 1973) and APHA-AWWA-WPCF manual (APHA-AWWA-WPCF (1992)). Total Plate Count (CFU/mL), Coliform count (MPN/100 mL) and Escherichia coli (*E. coli*) counts (MPN/100 mL) were determined according to methods of American Public Health Association (1998) and U.S Environmental Protection Agency (2002).

Appropriate quality assurance procedure and precaution were carried out to ensure reliability of the results. The reagents used were products of BDH Chemical Ltd., United Kingdom and Sigma-Aldrich Chemical (GmbH Germany). Glassware and sample bottles were washed with detergents and deionized water; they were soaked overnight with aqueous 10% HNO_3 and subsequently rinsed with deionized water. In addition to the previous treatments, all containers for microbiological analysis were sterilized in an autoclave at 121^oC for 15 minutes. The water samples were collected in triplicate. For all the samples, pH, dissolved solid and turbidity were measured at the collection sites. In the ICP-OES determination of trace and potentially toxic metals, Calibration and Quality Control (QC) solutions were prepared from appropriate reference material (Agilent Calibration Mix Majors 6610030700, Agilent Calibration Mix2 6610030600 and Ultrapure Merck Lichrosolv water was used for dilution of standards and QC solutions. All of these were also stabilized in high purity 2% v/v concentrated nitric acid (HNO_3).

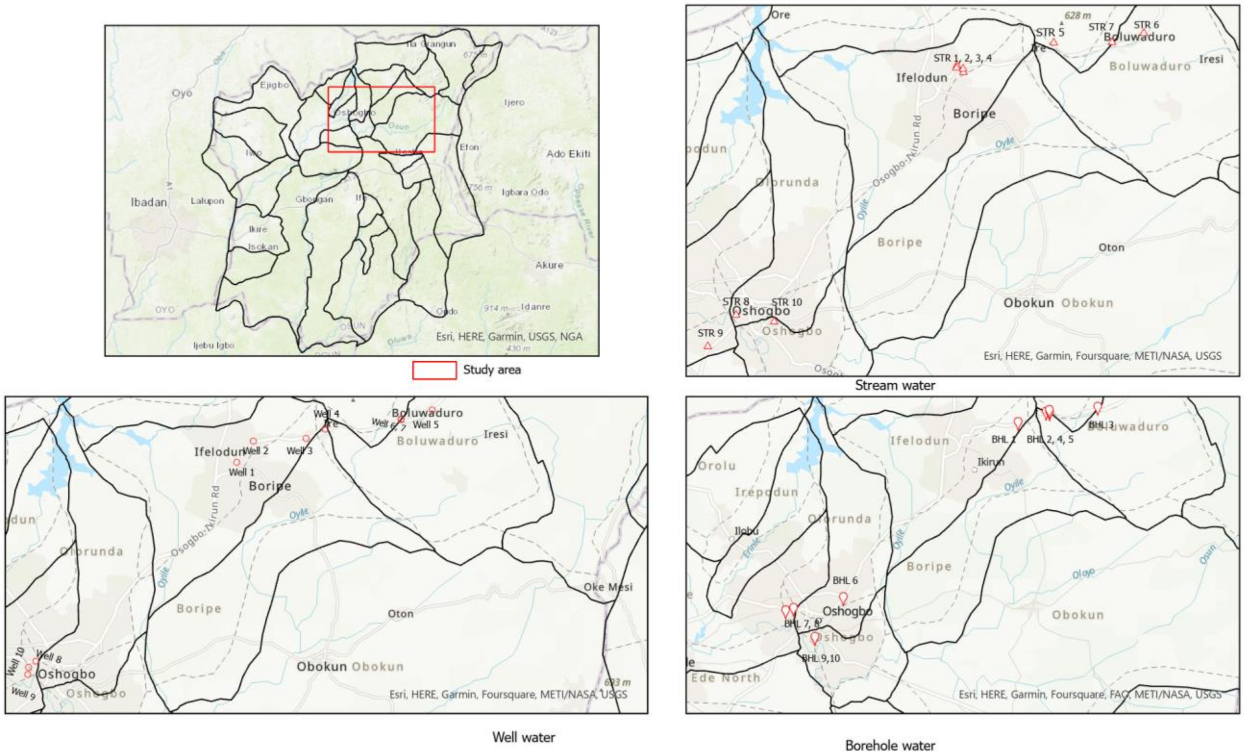

Figure 1. Sample locations for stream, well and borehole water samples
STR: Stream; **WELL:** Well; **BHL**: Borehole

Appropriate concentrations range of working standards from the multi-elements stock standard was prepared through serial dilution method. A new worksheet was created from the ICP-OES Expert software into which was programmed the individual sample codes as well as the optimum instrumental working parameters.

2.3 Water Quality Index and Statistical Analysis

The water quality index (WQI) was computed for each of the water samples using established formula and the results were compared with water quality index rating categories as excellent: 0-25, good: 26-50, poor: 51-75, very poor: 76-100 and unfit for drinking: >100 (Department of Water and Sanitation (DWS), 1998), (WHO, 2017). The measurements were done in triplicate. Data were subjected to descriptive statistics, nonlinear regression and one-way analysis of variance (ANOVA). Duncan's multiple range test (IBM SPSS Statistics 20) was carried out to establish the significant level at $p<0.05$. Results were expressed as means ± Standard Deviation (SD).

3. Results and Discussion

3.1 Physicochemical properties

The results of the physicochemical properties of the stream, well, borehole and sachet water analyzed are as shown in **Table 1**, **Table 2**, **Table 3** and **Table 4**, respectively. The range for each of all the parameters determined is presented in **Table 5**, while the comparison of the means of the results from this study with Nigerian and International Standards are as shown in **Table 6**. The pH of the stream water ranged from 7.6 to 10.6 with the least and highest values in STR8 and STR1 water samples, respectively. In comparison with the other three water sources, all the three stream water samples were slightly alkaline while the well, borehole and sachet water samples were all approximately neutral except one of the sachet water samples produced in SHT7 water factory. The means of the pH of all the water samples were all within the water quality standards of FMENV, Nigeria (1993), USEPA (2002) and WHO (2011) as shown in **Table 6**. Acidic water can catalyse corrosion of metal pipes and plumbing system which can initiate the release of metals into the drinking water. This is undesirable and can cause other concerns if concentrations of such metals exceed recommended limit.

The turbidity of the stream water ranged from 56.0 NTU to 100.0 NTU with the least and highest values from STR4 and STR6 water samples, respectively. The lower limit of the turbidity of the stream water was obviously higher than each of the other three water sources. Also, the means of the turbidity of the ten stream water samples was higher than 1 NTU which was a standard established by Federal Environmental Protection Agency (FEPA), Nigeria (1988), indicating poor quality in terms of turbidity. However, the turbidity of each of the well, borehole and sachet water samples was less than 1 mg/L underscoring good quality with respect to turbidity. Higher turbidity levels have been reported to be associated with higher levels of disease-causing microorganisms such as viruses, parasites, and some bacteria. These organisms can cause short term symptoms such as nausea, cramps, diarrhea, and associated headaches (Environmental Protection Agency (EPA), 2009).

The total suspended solid of the stream water ranged from 0.11 mg/L in STR3 and STR6 to 0.22 mg/L in STR7. This range was the highest of the four water sources under investigation. The mean of the TSS of each of the stream, well, borehole and sachet water samples were approximately zero and were found suitable in terms of their TSS. The total dissolved solid (TDS) of the stream water ranged from 0.02 to 0.56 mg/L. The TDS of sachet water (0.01 mg/L) was the least among the four water sources and was obtained in SHT7 water sample. The highest TDS of the four water sources was obtained in the BHL4 water sample. The total dissolved solid of each of the four water sources was lower than the permissible levels approved by USEPA (500 mg/L). All the water samples were of good quality with respect to TDS. The total dissolved solids could include iron, chlorides, sulphates, calcium or other minerals found on the earth's surface which can produce an unpleasant taste or appearance; they can also contribute to scale deposits on pipe walls, kettles, boilers, etc. All the water samples could be classified as fresh because the value of TDS ranged from 0–1000 mg/L (USEPA, 1994). The lower limit of the total solid was obtained in sachet water while the highest upper limit was obtained in BHL4 water sample. By comparison, the total solid in each of the water samples was very low and less than 500 mg/L set by FMENV, Nigeria (1993). All the water samples were of good quality with respect to their levels of Total Solid.

The total alkalinity, i.e., a measure of capacity of unfiltered water samples to neutralize acid varied among the samples and none of them shared the same lower and upper limits. The least value of the lower limit was observed in BHL2 water while the highest upper limit was obtained in STR5 water. All the water samples are suitable for drinking in terms of alkalinity according to a range of 30-500 mg/L approved by FMENV, Nigeria (1993) and Illinois Department of Public Health (2023) except the alkalinity of BHL2 water sample (<30 mg/L). Moderate alkalinity has been asserted not to be detrimental to humans (Illinois Department of Public Health, 2023). Indeed, moderate alkalinity (<350 mg/L) in combination with hardness forms a layer of calcium and magnesium carbonate system which tends to reduce corrosion and increase useful life of water distribution system. On the other hand, high alkalinity (>500 mg/L) is usually associated with high pH values, hardness and dissolved solid which can result in formation of excessive scale on hot water system. This can reduce the transfer of heat to the water with a consequence of greater power consumption and high cost. Furthermore, water with low alkalinity (<75 mg/L) is subjected to pH change due to dissolved gases that may be corrosive to metallic fittings. Thus, the lower limits of the water samples in this study have alkalinity values that are <75 mg/L and belongs to this category while the upper limits are <350 mg/L.

The total hardness (TH) of the four water sources ranged from 30.55 mg/L in borehole water to 238.00 mg/L in stream water. The mean TH of all the samples ranged from 89.14 mg/L in well water to 131.95 mg/L in stream water. The mean levels of the TH of the samples were significantly different at $p<0.05$. Thus, the mean value of the TH of the well water and sachet water were not significantly different ($p<0.05$) and were significantly lower than the TH of borehole water. However, the mean TH of the stream water was significantly higher than the values of the remaining water samples. The levels of TH of each of the well, borehole and sachet water samples was less than 200 mg/L (the standard permissible level set by FMENV, Nigeria (1993)) except the upper limit (238.00 mg/L) of the stream water which was higher than FEPA's standard of 200 mg/L (FEPA, 1988). It is noteworthy that the total hardness of each of the samples was less than a standard of 500 mg/L set by the WHO. Furthermore, standards have been established for water hardness (mg/L $CaCO_3$: 0-100 (soft), 100-200 (moderate), 200-300 (hard), 300-500 (very hard) and 500-1000 (extremely hard) (Illinois Department of Public Health, 2023). Hard water has tendency to cause deposition on pipes, boilers, etc

The mean of the levels of chloride in the four water sources ranged from 51.55 mg/L in borehole water to 82.85 mg/L in stream water. The level of chloride in the samples was significantly different at $p<0.05$. The level of chloride in borehole water was significantly lower than the levels in the remaining three sources. In terms of the range, the levels of chloride in the four water sources ranged from 0 mg/L in well water to 203 mg/L in stream water. The minimum upper limit was recorded in sachet water while the highest upper limit was observed in stream water. The level of chloride in each water source was less than 250 mg/L, being standard set by FMENV, Nigeria (1993), WHO (2011) and USEPA (2012). High concentrations of chloride have tendency to increase the corrosiveness of water, and in combination with sodium, gives water a salty taste. Chlorides in groundwater can be naturally occurring in deep aquifers or caused by pollution from sea water, brine, or industrial or domestic wastes. Where chloride content is known to be low, a noticeable increase in chloride concentrations may indicate pollution from sewage sources. Thus, high levels of the upper limit of chloride in the stream water in this study could be attributed to sewage.

The level of nitrate in the water sample varied from one sample to the other. The mean of the concentration of the nitrate was significantly different ($p<0.05$). The concentration of nitrate in each of the well and borehole water samples was significantly lower than the levels observed in the stream and sachet water samples. It is worthy of note that, the nitrate concentration in each of the four water sources was less than a standard of 10 mg/L set by USEPA (1988) and FMENV, Nigeria (1993). Concentration greater than local background levels may indicate pollution by feedlot runoff, sewage or fertilizers. Concentrations greater than 10 mg/L, as nitrogen may be injurious to pregnant women, children and the elderly (USEPA, 1994; Benkaddour *et al.*, 2004)

The sulphate content of the water samples also varied from one sample to the other. The mean values of the sulphate contents of the water samples ranged from 2.77 mg/L in well water to 31.10 mg/L in sachet water. The mean values of the sulphate contents of the water samples was significantly different ($p<0.05$). The sulphate content of the well water was significantly lower than the remaining three sources. The sulphate content of each of the water sources was lower than 500 mg/L (FMENV, Nigeria, 1993), (WHO, 2011) and 250 mg/L (USEPA, 2002). Sulphate of calcium and magnesium form hard scale. High concentration of SO_4^{2-} have laxative effect on some people, and in combination with other ions, give water a bitter taste (USEPA, 1994). According to Illinois Department of Public Health (2023), sulphates in groundwater are caused by natural deposits of magnesium sulphate, calcium sulphate or sodium sulphate.

The phosphate content of the water samples varied from one sample to another; the mean values ranged from 1.07 to 2.67 mg/L and were significantly different at $p<0.05$. The phosphate content of the stream water was significantly higher ($p<0.05$) than the other three samples. However, the highest value in this study is in tandem with <5 mg/L standard set by FMENV, Nigeria (1993). Sources of phosphates are human and animal wastes as well as fertilizers (USEPA, 1994) which may account for the highest levels observed in the stream water.

The mean iron contents of the samples ranged from 0.13 to 0.53 mg/L with the least and highest values from well and stream water samples, respectively. The values were significantly different at $p<0.05$. The concentration of iron in the stream water was significantly higher than the values observed in well, borehole and sachet water samples. The value is also higher than the permissible level of 0.3 mg/L set by WHO (2011). The higher iron content observed in the stream water may be attributed to human activities which exposed the stream to scraps of iron. Iron in drinking water can be objectionable because it can give a rusty colour to laundered clothes and may affect taste. It is frequently found in water due to large deposits in the earth's surface; it can also be introduced into drinking water from iron pipes in the water distribution system (Illinois Department of Public Health, 2023). The levels of copper in the four water sources varied from one sample to the other. The lower limit of the stream water sample was 0.10 mg/L while the lower limit in other three water sources was zero. The highest copper content was obtained in stream water sample. The mean copper content in the water sources was significantly different ($p<0.05$) and the highest was obtained in borehole water. The mean Cu content in each of the water sources was higher than a standard of 0.1 mg/L approved by FMENV, Nigeria (1993) and was approximately the same as a standard of 0.2 mg/L approved by WHO (1996). So, in terms of the range, all the samples that fell within the lower limit are suitable for drinking according to FMENV, Nigeria (1993) and WHO (1996). On the other hand, all the samples that fell within the upper limit are not suitable for drinking according to the standard of WHO (1996). Copper is essential for metabolism and its deficiency in infants and young animals results in nutritional anemia. High concentrations of copper are toxic and may cause liver damage. Moderate levels of copper (near the action level) can cause gastro-intestinal distress (USEPA, 1994). The results showed that average of 0.002 mg/L of lead was observed in each of the stream water, borehole and sachet water samples while lead was not detected in the well water samples. Exposure of stream to lead battery may be the cause of the level of lead recorded in the stream; nevertheless, the level was less than 0.01 mg/L (WHO, 2011) and not up to 0.0025 mg/L (FEPA, 1988). Lead is a toxic metal and has dangerous effects on human beings if the level is on the high side.

Cadmium was not detected in any of the water samples. The non detection of this element in the water samples is of great advantage. Indeed, cadmium has been described to be a cumulative poison and very toxic. Biologically, it was not known to be either essential or beneficial. It was believed to promote renal arterial hypertension. Cadmium may cause liver and kidney damage, or even anemia, retarded growth, and death at elevated concentrations (USEPA, 1994). Furthermore, it has been associated with itai itai disease in Japan (Aoshima, 2016). The concentration of zinc varied from one sample to the other. The mean values of zinc (mg/L) ranged from 0.28 (sachet water) to 1.02 (stream water) and were significantly different at $p<0.05$. Thus, the mean level of Zn in the stream water was significantly higher than the values observed in the other three water sources. Zinc in drinking water is commonly derived from galvanized coatings of piping. Zinc is essential and beneficial in metabolism; its deficiency in young children or animals will retard growth and may decrease general body resistance to disease (USEPA, 1994). The mean level of zinc in each of the four water sources was less than standard of 0.5 mg/L set by USEPA (1994) except the stream water samples.

3.2 Water Quality Index

The water quality index (WQI) of the samples also varied from one sample to the other. The lower limit of the values ranged from 0.85 in borehole water to 2.04 in stream water. The mean values of the WQI ranged from 1.06 in borehole to 2.13 in stream water. The mean values of the WQI were significantly different at $p<0.05$; thus, the WQI of stream water was significantly higher than the values observed in well, borehole and sachet water samples. It is noteworthy that, the WQI of each of the water samples was within the range of 0–25 which was reported to be excellent (WHO, 2012), (WHO/UNICEF, 2013).

Table 1. Quality parameters of the stream water

Parameters	Stream Water Samples									
	STR1	**STR2**	**STR3**	**STR4**	**STR5**	**STR6**	**STR7**	**STR8**	**STR9**	**STR10**
pH	10.6	9.8	9.0	8.1	7.7	8.2	7.7	7.6	8.1	8.1
Turbidity (NTU)	91	68	70	56	86	100	87	91	70	63
SS (mg/L)	0.14	0.21	0.11	0.13	0.16	0.11	0.22	0.12	0.19	0.12
DS (mg/L)	0.20	0.18	0.06	0.10	0.56	0.09	0.02	0.39	0.25	0.27
Total Solid (mg/L)	0.34	0.39	0.17	0.23	0.72	0.20	0.24	0.51	0.44	0.39
Total Alkalinity (mg/L)	63.5	60.0	47.5	60.0	162	96.5	93.5	100	80.0	106.5
Total Hardness (mg/L)	116	189	145	87	238	93	127	89.5	123	114
Chloride (mg/L)	76.5	83.5	203	135	25.5	180	29	35	40.5	21.0
Nitrate (mg/L)	0	0	0	0	0	4.00	0	0	0	0
Sulphate (mg/L)	13.0	5.55	8.60	4.50	2.00	28.0	14.0	22.5	14.5	11.5
Phosphate (mg/L)	3.3	3.44	1.90	1.30	3.66	3.30	1.69	2.60	3.87	1.65
Iron (mg/L)	0.25	0.35	0.25	0.35	0.16	0.90	0.75	0.75	0.85	0.65
Copper (mg/L)	0.10	0.22	0.27	0.14	0.10	0.13	0.18	3.20	0.14	0.14
Lead (mg/L)	0.006	0.004	0.002	0.002	0.002	0.002	0.004	0.002	0.002	0.003
Cadmium (mg/L)	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Zinc (mg/L)	0.80	1.09	1.21	1.06	1.41	1.41	0.94	0.89	0.76	0.64
TPC (CFU/mL)	78	65	59	72	64	55	59	74	47	32
CC (MPN/100 mL)	40	35	28	54	42	37	17	11	12	17
ECC (MPN/100 mL)	4	3	2	4	6	5	3	3	2	2
WQI	2.37	2.14	2.10	2.10	2.10	2.20	2.04	2.06	2.10	2.10

STR: Stream; **TPC**: Total Plate Count; **CC**: Coliform Count; **ECC**: E. coli count;
WQI: Water Quality Index; ND: Not Detected

Table 2. Quality parameters of the well water

Parameters	Well Water Samples									
	WEL1	**WEL2**	**WEL3**	**WEL4**	**WEL5**	**WEL6**	**WEL7**	**WEL8**	**WEL9**	**WEL10**
pH	6.9	6.7	6.9	6.8	6.9	6.7	6.9	7.0	6.9	6.7
Turbidity (NTU)	0.44	0.53	0.32	0.49	0.59	0.30	0.57	0.44	0.64	0.51
TSS (mg/L)	0.15	0.11	0.60	0.20	0.08	0.25	0.18	0.02	0.08	0.21
TDS (mg/L)	0.23	0.14	0.27	0.15	0.28	0.16	0.14	0.19	0.22	0.25
Total Solid (mg/L)	0.38	0.25	0.87	0.35	0.36	0.41	0.32	0.21	0.30	0.46
Total Alkalinity (mg/L)	33.5	91.0	44.0	39.0	40.0	93.5	50.5	42.5	35.0	52.0
Total Hardness (mg/L)	102	146	66.1	42.0	72.1	56.1	98.0	62.1	177	70.1
Chloride (mg/L)	99.5	35.5	0	84.0	0	26.0	106	98.5	0	118
Nitrate (mg/L)	0.10	0	0	0	0.05	0.10	0	0	0.20	0
Sulphate (mg/L)	4.05	0	3.00	8.75	0	0	4.00	0	7.90	0
Phosphate (mg/L)	0	1.35	1.78	0.75	0	2.05	0.92	0	2.90	1.51
Iron (mg/L)	0.11	0.12	0.12	0.13	0.14	0.14	0.12	0.16	0.12	0.14
Copper (mg/L)	0	1.85	0	0.55	0	0	0	0.14	0	0
Lead (mg/L)	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Cadmium (mg/L)	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Zinc (mg/L)	0.12	0.35	0.11	0.54	0.11	0.13	0.73	0.10	0.32	0.39
TPC (CFU/mL)	15	13	8	14	13	16	20	17	12	9
CC (MPN/100 mL)	14	7	5	12	8	13	7	9	11	9
ECC (MPN/100 mL)	2	2	3	2	2	2	2	2	2	2
WQI	1.02	1.10	1.02	1.07	1.00	1.11	1.07	1.28	1.10	1.08

TPC: Total Plate Count; **CC**: Coliform Count; **ECC**: E. coli count; **WQI**: Water Quality Index
ND: Not Detected

Table 3. Quality parameters of the borehole water

Parameters	**Borehole Water Samples**									
	BHL1	**BHL2**	**BHL3**	**BHL4**	**BHL5**	**BHL6**	**BHL7**	**BHL8**	**BHL9**	**BHL10**
pH	6.9	6.7	6.9	6.9	6.9	7.0	6.7	6.7	6.9	6.9
Turbidity (NTU)	0.77	0.79	0.79	0.84	0.56	0.59	0.71	0.63	0.79	0.87
TSS (mg/L)	0.60	0.08	0.09	0.03	0.09	0.03	0.36	0.07	0.05	0.07
TDS (mg/L)	0.20	0.23	0.11	1.56	0.36	0.45	0.71	0.15	0.13	0.17
Total Solid (mg/L)	0.80	0.31	0.20	1.59	0.45	0.48	1.07	0.22	0.18	0.24
Total Alkalinity (mg/L)	106	23.5	44.5	81.0	89.0	99.5	134	59.5	48.0	48.5
Total Hardness (mg/L)	105.6	108.5	63.85	59.55	95.50	126.2	77.00	150.1	30.55	84.10
Chloride (mg/L)	43.00	80.50	112.5	28.00	31.50	26.00	0.16	32.00	39.00	46.00
Nitrate (mg/L)	0	0	0	0	0	0	0	0	0.20	0
Sulphate (mg/L)	0	7.50	5.00	13.00	12.00	16.50	0.10	11.50	0	14.0
Phosphate (mg/L)	0	0.60	1.21	0.50	2.00	0.80	5.00	0	2.10	1.78
Iron (mg/L)	0.10	0.11	0.12	0.16	0.14	0.18	0.18	0.14	0.16	0.14
Copper (mg/L)	0	0.73	0	1.31	0.54	0	0.35	0	0	0
Lead (mg/L)	0.002	0.002	0.003	0.003	0.002	0.002	0.002	0.002	0.002	0.002
Cadmium (mg/L)	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Zinc (mg/L)	0.64	0.44	0.24	0.26	0.36	0.23	2.95	0.35	0.49	0.31
TPC (CFU/mL)	22	14	11	30	17	19	13	20	32	23
CC (MPN/100 mL)	6	12	9	7	13	8	8	12	10	10
ECC (MPN/100 mL)	2	2	3	2	3	2	2	2	2	2
WQI	0.85	1.07	1.08	1.08	1.08	1.08	1.14	1.08	1.03	1.07

TPC: Total Plate Count; **CC**: Coliform Count; **ECC**: E. coli count; **WQI**: Water Quality Index
ND: Not Detected

Table 4. Quality Parameters of the Sachet Water

Parameters	Sachet water samples									
	SHT1	**SHT2**	**SHT3**	**SHT4**	**SHT5**	**SHT6**	**SHT7**	**SHT8**	**SHT9**	**SHT10**
pH	6.7	6.9	7.3	7	7.4	7	7.9	6.9	7.3	7.4
Turbidity (NTU)	0.38	0.46	0.44	0.71	0.84	0.69	0.18	0.35	0.57	0.95
TSS (mg/L)	0.21	0.19	0.07	0.08	0.17	0.11	0.08	0.05	0.09	0.03
TDS (mg/L)	0.23	0.22	0.12	0.19	0.04	0.24	0.01	0.22	0.36	0.25
Total solid (mg/L)	0.44	0.43	0.19	0.27	0.21	0.35	0.09	0.27	0.45	0.28
Total Alkalinity (mg/L)	50.0	53.0	38.0	45.0	42.0	40.0	34.0	94.0	95.0	106
Total Hardness (mg/L)	98.0	70.0	42.0	66.0	65.0	72.0	178	55.0	146	106
Chloride (mg/L)	105	122	84.0	74.0	98.0	100	89.0	25.0	35.0	43.0
Nitrate (mg/L)	0	0	0	0	0	2.0	4.0	2.0	0	0
Sulphate (mg/L)	40.0	45.0	32.0	52.0	8.00	29.0	16.0	29.0	41.0	19.0
Phosphate (mg/L)	0.67	1.40	0.67	0.94	1.30	1.20	0.46	0.32	1.70	2.10
Iron (mg/L)	0.18	0.19	0.19	0.19	0.18	0.18	0.18	0.18	0.19	0.18
Copper (mg/L)	2.20	1.60	2.00	2.5	2	1.9	1.85	0	1.20	2.06
Lead (mg/L)	0.001	0.002	0.002	0.002	0.003	0.001	0.001	0.002	0.001	0.001
Cadmium (mg/L)	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Zinc (mg/L)	0.07	0.30	0.31	0.13	0.43	0.71	0.20	0.31	0.34	0.10
TPC (CFU/mL)	8	12	10	9	6	6	17	14	10	15
CC (MPN/100 mL)	7	8	7	9	11	6	12	11	8	9
ECC (MPN/100 mL)	2	2	2	2	3	1	2	2	2	2
WQI	1.11	1.08	1.65	1.08	1.71	1.11	2.02	1.11	1.66	1.73

TPC: Total Plate Count; **CC**: Coliform Count; **ECC**: E. coli count; **WQI**: Water Quality Index
ND: Not Detected

Table 5. Range of the quality parameters for the stream, well, borehole and sachet water samples

	Range of quality parameters for the water samples			
Physicochemical Parameters	**Stream**	**Well**	**Borehole**	**Sachet**
pH	7.60–10.6	6.7–7.0	6.7–7.0	6.7–7.9
Turbidity (NTU)	56.0–100	0.30–0.64	0.56–0.87	0.18–0.95
TSS (mg/L)	0.11–0.22	0.02–0.60	0.03–0.60	0.03–0.21
TDS (mg/L)	0.02–0.56	0.14–0.28	0.11–1.56	0.01–0.36
Total Solids (mg/L)	0.17–0.72	0.21–0.87	0.18–1.59	0.09–0.45
Total Alkalinity (mg/L)	47.5–162	33.5–93.5	23.5–134	34.0–106
Total Hardness (mg/L)	87.0-238	42.0-177	30.55-150.1	42.0-178
Chloride (mg/L)	21.0–203	0–118	0.16–112.5	25.0–122
Nitrate (mg/L)	0–4.0	0–0.2	0–0.2	0–4.0
Sulphate (mg/L)	2.00–28.0	0–8.75	0–16.5	8.0–52.0
Phosphate (mg/L)	1.30–3.87	0–2.90	0–5.0	0.32–2.1
Iron (mg/L)	0.16–0.90	0.11–0.16	0.10 – 0.18	0.18–0.19
Copper (mg/L)	0.10– 3.20	0–1.85	0–1.31	0–2.50
Lead (mg/L)	0.002–0.004	ND	0.002–0.003	0.001–0.003
Cadmium (mg/L)	ND	ND	ND	ND
Zinc (mg/L)	0.64–1.41	0.10–0.73	0.23–0.64	0.07–0.71
TPC (CFU/mL)	32–78	8–20	11–31.5	6–17
CC (MPN/100 mL)	11–54	5–14	6–13	6–12
ECC (MPN/100 mL)	2–6	2–3	2–3	1–3
WQI	2.04–2.37	1.00–1.28	0.85–1.14	1.08–2.02

TPC: Total Plate Count; **CC**: Coliform Count; **ECC**: E. coli count; **WQI**: Water Quality Index
ND: Not Detected

Table 6. Comparison of results from this study with Nigerian and International Standards

	Stream Water	Well Water	Borehole Water	Sachet Water	Water Quality Standard		
Physicochemical Parameters	**Mean ± SD**	**Mean ± SD**	**Mean ± SD**	**Mean ±**	**FMENV (2002) FEPA (1988)**	**USEPA (2012)**	**WHO (2011)**
pH	8.47 ± 0.95^{c}	6.84±0.09^{a}	6.85 ±0.10^{a}	7.18 ± 0.34^{b}	6.5-8.5	6.5-8.5	6.5-8.5
Turbidity (NTU)	78.20± 13.97^{d}	0.48±0.11^{a}	0.73±0.19^{c}	0.56 ± 0.24^{b}	1.0 NTU	5.0 NTU	5.0 NTM
TSS (mg/L)	0.15 ± 0.01^{b}	0.19±0.03^{c}	0.15±0.09^{b}	0.11 ± 0.06^{a}	-	-	-
TDS (mg/L)	0.21 ± 0.06^{a}	0.20±0.05^{a}	0.41±0.44^{b}	0.19±0.10^{a}	500	500	
Total Solids (mg/L)	0.36 ± 0.16^{b}	0.39±0.08^{b}	0.56±0.47^{c}	0.30 ± 0.12^{a}	-	-	-
Total Alkalinity (mg/L)	86.95± 31.84^{d}	52.10±21.97^{a}	63.25±28.73^{c}	59.70 ± 26.34^{b}	30-500		-
Total Hardness (mg/L)	131.95±46.06^{c}	89.14±42.74^{a}	95.79±36.99^{b}	89.80 ± 41.34^{a}	200	-	500
Chloride (mg/L)	82.85± 64.57^{d}	56.75±48.93^{b}	51.55±28.78^{a}	77.50 ± 31.42^{c}	250	250	250
Nitrate (mg/L)	0.40 ± 1.22^{b}	0.05±0.07^{a}	0.02±0.06^{a}	0.80 ± 1.34^{c}	10	10	
Sulphate (mg/L)	12.42±7.76^{c}	2.77±3.39^{a}	8.45±5.83^{b}	31.10 ± 13.30^{d}	500	250	500
Phosphate (mg/L)	2.67 ± 0.92^{b}	1.13±0.98^{a}	1.09±0.82^{a}	1.07 ± 0.54^{a}	5	-	-
Iron (mg/L)	0.53 ± 0.28^{c}	0.13 ± 0.02^{a}	0.16 ± 0.04^{ab}	0.18 ± 0.03^{b}	-		0.3
Copper (mg/L)	0.46 ± 0.16^{b}	0.25 ± 0.09^{a}	0.55±0.05^{b}	1.73 ± 0.69^{c}	0.1	1.3	2
Lead (mg/L)	0.002 ± 0.00^{a}	ND	0.002 ± 0.00^{a}	0.002 ± 0.00^{a}	0.05		0.01
Cadmium (mg/L)	ND	ND	ND	ND	0.01		
Zinc (mg/L)	1.02 ± 0.25^{c}	0.29±0.09^{a}	0.36±0.13^{ab}	0.28 ± 0.19^{a}	-	0.5	
TPC (CFU/mL)	61.0±0.25^{d}	13.7±3.59^{b}	20.0±6.8^{c}	11.0±3.74^{a}			
CC (MPN/100 mL)	29.0±14.59^{b}	9.5±2.92^{a}	10.0±2.3^{a}	9.0±2.00^{a}		0	0
ECC (MPN/100 mL)	3.0±1.34^{b}	2.10±0.32^{a}	2.0±0.42^{a}	2.0±0.57^{a}		0	0
WQI	2.13±.0.09^{b}	1.09±1.08^{a}	1.06±0.08^{a}	1.43±0.36^{a}			

TPC: Total Plate Count; **CC**: Coliform Count; **ECC**: E. coli count; **WQI**: Water Quality Index;
ND: Not Detected

3.3 Microbiological parameters

The results of the total plate count (TPC) of the water samples also varied from one sample to the other. The values (CFU/mL) ranged from 6 (lower limit of the sachet water) to 78 (upper limit of the stream water). Thus, in terms of the lower limit, sachet water proved to be the best of the four sources, followed by well, borehole and stream was the last. The mean value of the total plate count ranged from 13.7 CFU/mL in well water to 60.4 CFU/mL in stream water. The total plate count of each of the water samples was greater than zero which is an indication for non suitability for drinking. TPC of zero was recommended by WHO, UNICEF, USEPA, National Environmental Standards and Regulations Enforcement Agency (NESREA), Nigeria, National Agency for Food and Drug Administration and Control (NAFDAC) and other regulatory bodies.

The coliform count of the water samples varied from one sample to the other. The lower limit ranged from 5 MPN/100 mL in well water to 11 MPN/100 mL in stream water. On the other hand, the mean value of the coliform count ranged from 8.8 MPN/100 mL in sachet water to 29.3 MPN/100 mL in stream water. The values were significantly different at $p<0.05$. Thus, the coliform count of the stream water was significantly higher than the remaining three; comparison of this value with zero (0) tolerance by WHO (2011) and USEPA (2002) and other regulatory agencies indicated that none of the water samples was suitable for human consumption

The *E. coli* counts (ECC) observed from the results also varied from one sample to another. The lower limit ranged from 1 MPN/100 mL in sachet water to 6 MPN/100 mL in stream water. The mean *E. coli* count of the samples was significantly different ($p<0.05$). So, the *E. coli* count of the stream water was significantly higher than the values in each of the other water samples. By and large, the level of ECC of each of the water samples was greater than a standard of 'zero' (0) (WHO, 2011) and therefore, none of the water samples was suitable for drinking. Indeed, the Maximum Contaminant Level Goal (MCLG) for total coliforms has been set at zero by the Environmental Protection Agency (EPA) because there have been waterborne disease outbreaks in which researchers found very low levels of coliforms (EPA, 1989).

Conclusion

The physicochemical properties and approved quality standards, good water quality index, large number of microbes. The study has been able to successfully achieve the investigation of the Quality parameters of the selected water samples with a goal of establishing good quality based on physicochemical properties and water quality index. However, the microbial study established that, all the water samples were not safe for drinking

Disclosure statement

Conflict of interest: The authors hereby declare that there are no conflicts of interest.
Compliance with ethical standard: This article does not contain any studies involving human or animal subject

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