

Physicochemical analysis of water samples from Lafia metropolis, Nasarawa State, Nigeria

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Abstract: The irreplaceable role water plays in human survival makes it pertinent to investigate its physicochemical facets. The study aimed at ascertaining the physicochemical parameters of some water sources in different locations in the three areas that make up Lafia metropolis (Lafia East, Lafia Central and Lafia North) using standard methods. Sampling was done for boreholes, hand dug wells and streams within the study area. Parameters analyzed in the study include: Chloride (mg/L), Phosphate (mg/L), Sulphate (mg/L), Nitrate (mg/L), Total hardness (mg/L), Total alkalinity (mg/L), Temperature (°C), pH, TDS (mg/L), Electric Conductivity ($\mu\text{S}/\text{cm}$), Turbidity (NTU) and Odour. Analysis of Variance (ANOVA) was used in analyzing study results and only differences considered significant at $P \leq 0.05$ for each parameter were reported. The findings indicate that chlorides, sulphates, nitrates, temperature, alkalinity levels in the water sources sampled did not exceed WHO and SON permissible limits. However, findings for total hardness, TDS and turbidity exceeded WHO and SON standards in some of the samples, particularly wells and boreholes. Phosphate levels in the water source sampled ranged from zero mg/l to 70.53 ± 0.02 mg/l. Some of the samples had a pH range starting from 6.02 which points to slight acidic. EC levels were above SON standard in some of samples studied while odour was objectionable in stream and well water sources. The study recommends bi-annual assessments of water sources in the study area, especially wells and streams in order to determine their efficacy for human consumption.

Keywords: physicochemical, water samples, Lafia, parameters, standards

Date of Submission: 15-08-2019

Date of Acceptance: 30-08-2019

I. Introduction

Water is fundamental to survival in any society as its applications in drinking, cooking, cleaning, manufacturing and transportation make life on earth possible. Therefore, it is important to understand the physicochemical facets of domestic water supply which has been covered by a number of studies in Nigeria (Obi & Okocha, 2007; Chukwu, 2008; Bello, Osho, Bankole, & Bello, 2013) and other parts of the world (Reza, Jain, & Singh, 2009; Dissmeyer, 2000; Khan, et al., 2013; Radulescu, et al., 2014; Lobina & Mercy, 2015). However, there are concerns about the efficacy of water made available for consumption and utilization in many parts of Nigeria, including Lafia metropolis Nasarawa State, Nigeria. Hence it is not surprising that physicochemical analysis of water samples from selected locations in southwestern Nigeria identified that Total Dissolved Solids (TDS) ranged between 192.1 and 473.7 ppm while Total Hardness (TH) was as high as 248.6mg/l in some sampled locations (Bisi-Johnson, Adediran, Akinola, Popoola, & Okoh, 2017). Furthermore, fresh water sources like rivers have significant potential for pollution by phosphate contamination from agricultural runoff, industrial effluent and household sewerage (Kharat & Pagar, 2009). Studies have also shown that nitrates and sulphates that pollute river systems have been implicated in various ailments and eco-system imbalances (Sharma & Kaur, 2016).

Due to severe infrastructural challenges, potable water supply in many Nigeria urban centers is usually from boreholes as well as packaged water in nylon sachets. On that note, analysis of water samples from different districts in Abuja Nigeria shows that bacteriological concentrates are evident in borehole, well and river waters with only sachet water having low bacterial contamination (Atiku, Ogbaga, Alonge, & Nwagbara, 2018). Physicochemical analysis of sachet water samples from Abuja metropolis as well as Samaru Zaria, both in Nigeria showed that even though the physicochemical parameters are in compliance with WHO standards, the samples had varying levels of bacteria pathogens (Agwu & Avoaja, 2013) which may be from natural underground contamination (Ugochukwu, Giwa, & Giwa, 2015). Similarly, water samples from wells, boreholes and rivers in some parts of Ikorodu area in Lagos state, Nigeria showed that only borehole water was within WHO permissible limits and potable enough from the parameters tested while significant pollution potentials were determined from water samples from wells and rivers within the study area. (Awoyemi, Achudume, & Okoya, 2014). The situation is not different in Idi ayunre, Oyo state where well water sampled for physicochemical analysis were identified to be suitable for domestic use even though some samples exceeded

WHO limit for drinking water (Adegboyega, Olalude, & Odunola, 2015). In the same vein, water samples from well, stream and river water in Abeokuta, Ogun state were determined to have impermissible levels of bacterial pathogens as well as total coliform of more than 1,600 MPN/ml (Shittu, Olaitan, & Amusa, 2008). In terms of chloride content, analysis of water samples from Ogbomoso, Nigeria for physicochemical parameters including chloride content showed that none of the samples had chloride content anywhere close to 250mg/l which is the standard (Oladipo & Adeboye, 2015). In the same vein, evaluation of 200 water samples collected from three communities in India indicates that over 65% of them were hard and very hard, mostly due to leaching of minerals within the earth crust like calcium, magnesium, zinc among others (Ramya, Babu, Reddy, & Rao, 2015). In terms of standards for water quality, World Health Organization (WHO) and Standards Organization of Nigeria (SON) both have permissible limits for various physicochemical parameters commonly found in water for domestic use (WHO, 2011; SON, 2012). A study on the Varuna river basin underground water system in India shows that mostly nitrates and fluorides are significantly present in some of the analyzed samples with secondary alkalinity (due to carbonate hardness) established in over 50% of the water samples (Raju, Ram, & Dey, 2009).

Excessive increment in water temperature can result in enhanced microbial growth, thereby making the water develop foul Odour, have bad taste and also become caustic (Okoye & Okoye, 2008). The pH level in water is very important for water quality evaluation; a lower pH value indicates acidity which may be as a result of hydrogen ions in the atmosphere reacting with rain water to create acid rain which then finds its way into other fresh water sources (Orisakwe, 2018). Increase in Total Dissolved Solids (TDS) in fresh water sources like rivers and streams can have significant inhibitions especially the ability of sunlight to penetrate the water body (Harrison, 2007). Electrical Conductivity (EC) of water is its capacity to conduct electric current usually determined by the movement of ions in the solution which in turn depends on the nature and amount of ions in the solution. Results from analyses of boreholes sampled from Fagge Kano State Nigeria indicate that EC averaged $856.1 \mu\text{Scm}^{-1}$ (Sa'eed & Mahmoud, 2014). Turbidity level is vital to water quality and assessment. A study conducted on physicochemical properties of samples from streams in Okene, Nigeria identified that while most parameters fall within WHO standards, sampled water had high turbidity due to sustained pollution and contamination which fosters microbial growth (Aremu, et al., 2014).

This research aimed at determining the physicochemical parameters of some water sources in Lafia metropolis. It is aimed at determining the suitability of drinking water sources in Lafia Metropolis for human utility. In doing this, the study investigated water sources in Lafia for physicochemical properties, compared the physicochemical quality of water from different locations in Lafia metropolis. Information from the study can help fast track responses to the health hazard posed by contaminated water sources within Lafia metropolis.

II. Materials and Methods

2.1 Study area

The study was carried out in Lafia Local Government Area, Nasarawa State, North Central Nigeria, about 192km from Abuja, along Abuja-Makurdi road. The study area lies between latitudes $8^{\circ}30'27''\text{N}$ to $8^{\circ}34'15''\text{N}$ and longitudes $8^{\circ}30'19''\text{E}$ to $8^{\circ}38'19''\text{E}$.

2.2 Samples

All samples used in this research work were water samples from borehole, well and stream. The samples were collected between the months October and November (dry season period in Nigeria)

The sampling locations, water sources and sample identification are shown in the tables below.

Table 1. Sampling locations in Lafia Central, water sources and sample identifications.

S/NO	Sample ID	Sample Location	Sample Source
1	LCC1	Emir's Palace	Borehole
2	LCC2	Emir's Palace	Well
3	LCC3	Science School Lafia	Boerhole
4	LCC4	Railway market Lafia	Well
5	LCC5	Lafia modern market	Well
6	LCC6	Lafia modern market	Borehole
7	LCC7	Lafia Water Board	Borehole
8	LCM1	Mararaba	Well
9	LCM2	Mararaba	Borehole
10	LCM3	Federal University Lafia	Borehole
11	LCG1	Gandu	Borehole
12	LCG2	Gandu	Well
13	LCG3	Gandu	Stream
14	LCB1	Bukankoto	Borehole
15	LCB2	Bukankoto	Well 1
16	LCB3	Bukankoto	Well 2

Table 2. Sampling locations in Lafia East, water sources and sample identifications.

S/NO	Sample ID	Sample Location	Sample Source
1	LEAS1	Assakio	Borehole 1
2	LEAS2	Assakio	Borehole 2
3	LEAS3	Assakio	Borehole 3
4	LEAS4	Assakio	Well
5	LEAD1	Adogi	Borehole 1
6	LEAD2	Adogi	Borehole 2
7	LEAD3	Adogi	Borehole 3
8	LEAD4	Adogi	Well
9	LEASH1	Ashige	Borehole 1
10	LEASH2	Ashige	Borehole2
11	LEASH3	Ashige	Borehole 3
12	LEASH4	Ashige	Well

Sample locations were coded with specific identification (ID) to distinguish between the various samples (see Table 1, 2 and 3). The first two letters in the sample ID indicates the areas in Lafia metropolis: Lafia Central (LC), Lafia East (LE) and Lafia North (LN). The remaining letter(s) and number(s) indicate the specific sample location where the sample was collected.

Table 3. Sampling locations in Lafia North, water sources and sample identifications.

S/NO	Sample ID	Sample Location	Sample Source
1	LNS1	Shabu	Borehole 1
2	LNS2	Shabu	Borehole 2
3	LNS3	Shabu	Borehole 3
4	LNS4	Shabu	Well
5	LNO1-1	Ombi 1	Borehole 1
6	LNO1-2	Ombi 1	Borehole 2
7	LNO1-3	Ombi 1	Well
8	LNO1-4	Ombi 1	Stream
9	LNO2-1	Ombi 2	Borehole 1
10	LNO2-2	Ombi 2	Borehole 2
11	LNO2-3	Ombi 2	Borehole 3
12	LNO2-4	Ombi 2	Well
13	LNA1	Azuba	Borehole 1
14	LNA2	Azuba	Borehole 2
15	LNA3	Azuba	Borehole 3
16	LNA4	Azuba	Well

Note: there are Ombi 1 and Ombi 2 location areas of sample collections.

2.3 Sample Collections

Water samples for analysis were collected from borehole, well, and stream in different locations. Selections of locations were based on the population density, and areas of industrial and/or anthropogenic activities. Plastic containers were used to collect the water samples. The containers for sample collections were washed with detergent (except for samples meant for phosphates, nitrates and sulphates determinations), then rinsed with distilled water and also rinsed with the sample to be collected at the point of collection to ensure it was free of contaminants.

To collect well water samples a stone of suitable weight was dried in an oven. The stone was tied in an already washed, dried polyethene material. The stone was attached to the sampling container by means of a thread in a manner in which it enhanced the sinking of the sampling container. A dried rope was attached to the handle of the container and used in lowering and drawing the container after it was filled with the sample (Nwachukwu & Ume, 2013). Grab method was used for sampling of water from the streams. The sampling container was dipped partially into the stream with the opening in opposite direction to flow of stream. The samples were collected at three different points along the stream.

The samples collected were properly sealed and kept in dark environment at a temperature range of -4°C to -10°C using ice block to avoid any contamination and effects of light and temperature variation. Samples for physicochemical analysis were preserved between the time of collection and analysis in the laboratory by the use of nitric acid (APHA, 1999).

Preparation of Reagents

The preparation of reagents for analyses was carried out according to the standard method as specified by American Public Health Association (1999) procedures. The reagents used during the analysis were analytical grade reagents.

Determination of Physicochemical Parameters

Physicochemical parameters of water samples were determined according to the method described by American Public Health Association APHA (1999) procedures. Determination of each parameter was carried out in triplicate. Highly unstable parameters such as pH, Electrical Conductivity and Temperature of the sample were determined in-situ (at the point of sampling).

Determination of pH

The pH of the samples was determined according to the electrometric method as specified by APHA (1999) procedures. A pH meter (Model 300408.1, Denver Instruments Company, Bohemia, New York, USA) was used. The pH meter was calibrated using potassium hydrogen tartrate buffer solution. On-site pH measurements were carried out by dipping the electrodes of the pH meter into the sample. The sample was stirred gently to ensure homogeneity. The pH value was recorded when equilibrium was established between the electrodes and the sample. The electrodes were removed from the sample, blot dry, and rinsed with distilled water and sample portion. It was immersed in a fresh sample and the pH recorded after equilibrium establishment. The pH reading was taken in triplicate with fresh samples.

Temperature Determination

The temperature of the samples was determined according to method as specified by APHA (1999). Temperature was determined using mercury-filled Celsius thermometer. The thermometer was checked against a precision thermometer.

On-site temperature measurement was carried out by rinsing the thermometer with distilled water and a portion of the sample. The thermometer was partially immersed in the sample. The reading was recorded at equilibration. Temperature measurement was carried out in triplicate for each of the samples.

Determination of Electrical Conductivity

The electrical conductivity of samples was determined according to method (2510) as specified by APHA (1999). A conductivity meter (Model HI 988130, HANNA, BDH, UK) was used as described below; the conductivity meter was calibrated using standard potassium chloride solution.

On-site measurement was carried out by dipping the electrodes of the meter into the sample and recording the reading at equilibrium. Before each measurement, the electrodes were blotted dry, rinsed with distilled water and sample. The procedure was carried out trice with fresh samples.

Determination of Phosphate

APHA (1999) procedure was used to determine the phosphate content of the water samples. The sample was filtered using whattman filter paper. Fifty (50 cm³) cubic centimeter of the filtrate was measured into a beaker. Four (4 cm³) cubic centimeter of ammonium molybdate reagent and 5 drops of stannous chloride reagent were added to the sample. After 10 minutes, the colour developed was measured photometrically at 690 nm using UV-Visible Spectrophotometer, PG Instrument, Model T60U. Calibration curve for different concentration-absorbance values were prepared. A reagent blank was run with same treatment with distilled water instead of sample. The value of phosphate was obtained by comparing absorbance of sample with the standard curve and expressed in mg PO₄³⁻ per dm³ of solution.

Determination of Nitrate

Analysis of nitrate content in water samples were carried out using ultraviolet spectrophotometric method as specified by APHA (1999). Fifty cubic centimeter of the standard nitrate solution was placed in 250 cm³ beaker and 50 cm³ of the filtrate of the sample in another beaker. One cubic centimeter of 1M HCl was added to each beaker. The mixtures were thoroughly mixed with a magnetic stirrer. Redistilled water was used as blank to zero the UV-Visible Spectrophotometer (PG Instrument, Model T60U) at zero absorbance level. Absorbance of standards was read at 225 nm while that of samples were read at 225 nm and 275 nm to differentiate interference from organics. Twice the absorbance of samples at 275 nm was subtracted from the absorbance at 225 nm to obtain the absorbance due to nitrate ion. The concentration of samples was calculated from the nitrate standard curve. The result was expressed in milligramme nitrate per dm³ (mg NO₃⁻/dm³) of solution.

Determination of Sulphate

APHA (1999) procedure was used in the evaluation of the sulphate content of the water samples. Twenty cubic centimeter of filtered sample was introduced into 100 cm³ glass beaker. One cubic centimeter of gelatin-BaCl₂ solution was added to the sample and mixed thoroughly. The mixture was allowed to stand for 30 minutes. Thereafter, the absorbance of the sample mixture was read at 420 nm using the UV-Visible Spectrophotometer (PG Instrument, Model T60U). Absorbance value was calculated from the sulphate standard curve, and result was expressed in milligrammesulphate per dm³ (mg SO₄²⁻/dm³) of solution.

Determination of Chloride

Argentometric method as specified by APHA (1999) was used in the determination of chloride content of water samples. Half cubic centimetre of potassium chromate indicator solution was added to 50 cm³ of filtered sample in a conical flask. Sample mixture and blank were titrated against standard silver nitrate solution respectively till silver dichromate started precipitating. The volume of silver nitrate consumed by sample and blank were recorded. The chloride concentration in sample solution was calculated using the expression;

$$\text{Chloride (mg/dm}^3\text{)} = \frac{(A-B) \times M \times 35.45 \times 1000}{V}$$

Where; A = volume of silver nitrate consumed by sample, in cm³

B = volume of silver nitrate consumed by blank, in cm³

M = molarity of silver nitrate,

V = volume of sample in cm³

35.45 = relative molecular mass of chlorine,

1000 = conversion factor from cm³ to dm³

Determination of Total Hardness

APHA (1999) procedure was adopted for the evaluation of the total hardness of the water samples. Fifty cubic centimeter of the water sample was measured into 250 cm³ conical flask. Half a cubic centimeter of ammonia buffer solution was added to the sample, followed by the addition of 2 drops of Eriochrome Black T indicator (a wine red colour was developed). The sample mixture was properly mixed by stirring using a magnetic stirrer. Fifty cubic centimeter glass burette was filled with 0.01M EDTA solution. The sample mixture was titrated against the EDTA solution until the color changed from wine red to pure blue. The volume of EDTA used was recorded. The titration was repeated trice. The average titre value was used for the calculation of total hardness of water. The result was expressed in milligram calcium carbonate per dm³ (mg CaCO₃/dm³) of solution. Total Hardness was calculated using the mathematical expression;

$$\text{Total Hardness} = \frac{A \times M \times 1000}{V}$$

Where; A is the volume of EDTA used, in cm³,

M is the molarity of EDTA, in moldm⁻³,

V is the volume of water sample used, in cm³,

1000 = conversion factor from cm³ to dm³.

Determination of Turbidity

Turbidity of samples was determined following the method adopted by Atikuet *al.* (2018). A digital turbidity meter (Model HI 988150, HANNA, BDH, UK) was used. The meter was standardized with deionised water. At sampling point, the electrode of the meter was rinsed with portions of the sample. It was then partially immersed in sample and turbidity reading of each sample was recorded.

Determination of Total Alkalinity

Total alkalinity of water samples were evaluated using titrimetric method as specified by APHA (1999). Fifty cubic centimeter of the water sample was measured into 250 cm³ conical flask. Five drops of mixed indicator was added to the sample and the color turned blue. Fifty cubic centimeter glass burette was filled with 0.1M HCl. The sample mixture in the conical flask was titrated against the acid till the solution turned red. The volume of acid used was recorded. The titration procedure was carried out in triplicate. Average titre value was used for calculation of total alkalinity, and the result expressed in milligram calcium carbonate per dm³ (mg CaCO₃/dm³) of solution. The mathematical expression for calculating total alkalinity is;

$$\text{Total Alkalinity} = \frac{A \times M \times 50000}{V}$$

Where; A is the volume of the acid used, in cm³,

M is the molarity of the acid, mol/dm³,

V is the volume of sample, in cm³.

Total Dissolved Solids (TDS)

Evaluation of total dissolved solid was carried out following the APHA (1999) procedures. One hundred cubic centimeters capacity evaporating dish was heated at 550°C in a muffle furnace for 15 minutes, cooled in a desiccator and weighed. The process continued until a constant weight was obtained. One hundred cubic centimeter of filtered sample was measured into the evaporating dish. The evaporating dish was placed on a hot plate and the sample evaporated at 98°C. The residues collected were heated at 103-105°C in an oven for one hour and final weight was recorded after cooling in a desiccators. TDS was calculated using the expression;

$$\text{TDS in mg/L} = \frac{(A-B) \times 1000}{V}$$

Where; A = Final weight of the dish in grammes,
B = Initial weight of the dish in grammes, and
V = Volume of sample taken in cm³.

III. Statistical analysis

Analytical data obtained from the study was subjected to statistical analysis with the aim of verifying and evaluating the differences between the physicochemical parameters of the studied water samples. The data was expressed as mean ± standard error of mean.

Comparison of mean was carried out using one way analysis of variance (ANOVA) on a statistical program SPSS (version 21). Differences were considered significant at $P \leq 0.05$.

IV. Results and discussion

The results of physicochemical analysis on water samples are presented in Tables 4 to 9. From Table 4 and Table 5, the chloride content in the studied samples varied between 3.05 ± 0.04 mg/l in Gandu stream (LCG3) and 35.15 ± 2.51 mg/l in Lafia modern market well water (LCC5). Similar chloride levels in water were reported by Agwu and Avoaja (2013). The chloride values for all water samples are within the acceptable limit of 250 mg/l set by WHO (2011) and SON (2012). Chlorides in water could be due to contamination of water source by wastes and domestic discharges (Agwu and Avoaja, 2013). It is noteworthy that maximum chloride level was recorded in Lafia modern market well water, this is not a surprise as salt is one of the major products sold in the market. Phosphate level in samples ranged from zero mg/l in Shabu borehole water (LNS3) to 70.53 ± 0.02 mg/l in Gandu stream water (LCG3) (See Tables 5 and 6). Similar values for phosphates in river water were reported by Kharat & Pagar (2009). Phosphates in water could be as a result of the use of phosphate-containing pesticides, detergents and fertilizers. These substances are carried by runoff water and introduced into water sources (Kharat & Pagar, 2009). Sulphates in the studied samples varied between 3.54 ± 0.17 mg/l in Gandu stream (LCG3) and 85.82 ± 2.3 mg/l in Assakio well water (LEAS4) (See Tables 5 and 8). Sulphate level in all samples are within the permissible limit of 400 mg/l and 100 mg/l set by WHO (2011) and SON (2012). Sulphates in water could be attributed to influx of industrial wastes and leaching into water sources from mineral deposits such as gypsum and epsom salt, which at high concentrations may have a purging effect when combined with calcium and magnesium, resulting to dehydration and diarrhea in humans (Sharma & Kaur, 2016). From Table 5 and Table 7, nitrate content in the samples ranged from zero mg/l in Azuba borehole water (LNA3) to 62.56 ± 1.31 mg/l in Mararaba well water (LCM1). According to WHO (2011) and SON (2012), the acceptable limit for nitrate in drinking water is 50 mg/l. All the samples except Mararaba well water and Azuba well water are fit for drinking on the basis of nitrate content. Nitrates in water could be attributed to agricultural activities, leakage of septic systems, garbage dumps among other sources (Adegboyega et al., 2015). Nitrates when excess in drinking water causes methaemoglobinaemia in children (Sharma & Kaur, 2016).

Table 4. Results of Physicochemical Analysis of Water Samples From Lafia Central A

Parameter	Sample			Location			Reference	Standard		
	LCC1	LCC2	LCC3	LCC4	LCC5	LCC6			LCC7	LCB3
Chloride (mg/L)	8.08 ± 0.07	6.01 ± 0.12	6.12 ± 0.10	5.11 ± 0.09	3.05 ± 0.04	7.35 ± 0.13	9.06 ± 0.24	15.05 ± 1.04	250	250.0
Phosphate (mg/L)	0.15 ± 0.01	0.52 ± 0.01	0.24 ± 0.03	0.37 ± 0.01	0.21 ± 0.01	0.05 ± 0.00	0.15 ± 0.03	12.05 ± 0.07	NS	NS
Sulphate (mg/L)	20.21 ± 0.06	7.35 ± 0.03	25.02 ± 0.29	6.32 ± 0.18	5.13 ± 0.09	15.05 ± 1.18	8.30 ± 0.20	4.21 ± 0.10	400.0	100.0
Nitrate (mg/L)	0.94 ± 0.02	0.53 ± 0.01	0.23 ± 0.05	0.15 ± 0.00	0.72 ± 0.02	1.03 ± 0.09	5.64 ± 0.35	56.05 ± 0.68	50.00	50.0
Total hardness (mg/L) CaCO ₃	180.03 ± 3.06	188.30 ± 4.44	136.64 ± 3.27	132.26 ± 2.63	120.44 ± 2.86	164.71 ± 3.37	165.54 ± 2.77	351.27 ± 3.75	200.0	150.0
Total alkalinity (mg/L) CaCO ₃	40.31 ± 2.63	70.42 ± 2.86	45.61 ± 0.80	80.12 ± 0.22	86.02 ± 2.08	30.35 ± 0.65	52.31 ± 1.12	65.02 ± 1.95	120.0	120.0
Temperature (°C)	28.2 ± 0.15	26.90 ± 0.21	30.30 ± 0.12	25.90 ± 0.25	27.50 ± 0.26	28.60 ± 0.10	30.10 ± 0.12	29.30 ± 0.05	32.0	Ambient
pH	6.45 ± 0.10	6.92 ± 0.04	6.55 ± 0.12	6.95 ± 0.08	6.75 ± 0.29	6.35 ± 0.07	6.96 ± 0.06	7.95 ± 0.04	6.5 - 8.5	6.5 - 8.5
TDS (mg/L)	80.13 ± 2.60	230.19 ± 4.84	330.20 ± 2.86	599.83 ± 1.76	500.00 ± 9.74	450.02 ± 5.67	124.83 ± 2.42	620.0 ± 1.15	500.00	500.00
EC (µs/cm)	40.33 ± 5.49	76.00 ± 5.57	168.00 ± 2.52	120.00 ± 0.58	160.00 ± 2.89	140.00 ± 4.62	267.00 ± 4.93	270.05 ± 8.30	500.0	1000.0
Turbidity (NTU)	4.21 ± 0.015	7.04 ± 0.031	4.26 ± 0.015	8.39 ± 0.006	7.05 ± 0.029	3.49 ± 0.010	3.85 ± 0.012	9.53 ± 0.040	5.00	5.00
Odour	-	-	-	+	+	-	-	-	-	-

Key: + = objectionable; - = unobjectionable; NS = Not stated.

Table 5. Results of Physicochemical Analysis of Water Samples From Lafia Central B

Parameter	Sample			Location			Reference	Standard		
	LCM1	LCM2	LCM3	LCG1	LCG2	LCG3			LCB1	LCB2
Chloride (mg/L)	10.21 ± 0.30	9.30 ± 0.24	6.05 ± 0.05	8.03 ± 0.12	4.14 ± 0.06	3.05 ± 0.04	8.12 ± 0.12	6.21 ± 0.11	250.0	250.0
Phosphate (mg/L)	1.34 ± 0.16	0.45 ± 0.02	0.17 ± 0.01	0.95 ± 0.03	0.62 ± 0.03	0.02 ± 0.00	0.64 ± 0.03	0.02 ± 0.00	NS	NS
Sulphate (mg/L)	6.11 ± 0.27	27.13 ± 1.24	19.04 ± 1.00	28.62 ± 1.57	12.34 ± 0.18	3.54 ± 0.17	20.31 ± 0.89	5.39 ± 0.14	400.0	100.0
Nitrate (mg/L)	62.56 ± 1.31	41.03 ± 2.13	10.58 ± 0.85	52.35 ± 1.50	55.58 ± 1.84	10.32 ± 0.11	53.81 ± 2.10	59.01 ± 1.0	50.0	50.0
Total hardness (mg/L) CaCO ₃	370.41 ± 5.14	373.45 ± 3.28	267.25 ± 2.66	280.75 ± 3.00	235.43 ± 3.06	62.87 ± 2.43	263.7 ± 2.49	260.61 ± 2.80	200.0	150.0
Total alkalinity(mg/L) CaCO ₃	60.15 ± 2.09	49.62 ± 0.67	40.10 ± 1.46	61.15 ± 3.03	80.34 ± 6.93	120.39 ± 2.4	43.17 ± 1.08	80.43 ± 1.07	120.0	120.0
Temperature (°C)	29.20 ± 0.17	30.30 ± 0.06	29.20 ± 0.15	30.10 ± 0.06	27.40 ± 0.15	28.20 ± 0.06	31.50 ± 0.06	29.20 ± 0.06	32.0	Ambient
pH	6.75 ± 0.08	6.04 ± 0.02	6.98 ± 0.07	7.29 ± 0.06	6.52 ± 0.13	7.95 ± 0.02	6.53 ± 0.03	6.39 ± 0.19	6.5 - 8.5	6.5 - 8.5
TDS (mg/L)	600.17 ± 5.92	754.23 ± 6.61	250.0 ± 5.0	360.17 ± 5.60	550.1 ± 7.74	700.1 ± 7.62	390.23 ± 2.26	580.13 ± 3.00	500	500.0
EC (µS/cm)	252.00 ± 6.81	119.00 ± 2.65	273.00 ± 2.65	210.00 ± 1.53	186.00 ± 3.46	79.00 ± 2.08	203.00 ± 1.53	197.00 ± 2.70	500.0	1000.0
Turbidity (NTU)	7.73 ± 0.012	5.01 ± 0.021	4.15 ± 0.036	5.25 ± 0.03	9.13 ± 0.02	10.18 ± 0.18	6.07 ± 0.02	7.20 ± 0.03	5.00	5.00
Odour	+	+	-	-	+	+	-	+	-	-

Key: + = objectionable; - = unobjectionable; NS = Not stated.

Key: + = objectionable; - = unobjectionable; NS = Not stated.

Table 6. Results of Physicochemical Analysis of Water Samples From Lafia North A

Parameter	Sample				Location				Reference	Standard
	LNS1	LNS2	LNS3	LNS4	LNO1-1	LNO1-2	LNO1-3	LNO1-4	WHO	SON
Chloride (mg/L)	12.02 ± 0.07	10.30 ± 0.15	5.02 ± 0.06	7.20 ± 0.10	10.10 ± 0.10	8.26 ± 0.03	9.30 ± 0.08	9.01 ± 0.05	250.00	250.0
Phosphate (mg/L)	0.09 ± 0.00	0.02 ± 0.00	0.00 ± 0.00	0.33 ± 0.02	0.02 ± 0.00	0.0 ± 0.0	0.31 ± 0.02	0.28 ± 0.02	NS	NS
Sulphate (mg/L)	7.32 ± 0.14	9.01 ± 0.06	6.47 ± 0.21	8.24 ± 0.12	10.15 ± 0.08	12.04 ± 0.04	15.38 ± 0.19	17.06 ± 0.28	400.0	100.0
Nitrate (mg/L)	2.52 ± 0.10	1.50 ± 0.07	0.96 ± 0.03	1.05 ± 0.03	3.02 ± 0.04	1.35 ± 0.03	0.19 ± 0.01	3.58 ± 0.09	50.0	50.0
Total hardness (mg/L) CaCO ₃	100.50 ± 0.77	70.06 ± 2.54	137.25 ± 1.44	89.46 ± 2.21	69.57 ± 1.63	108.45 ± 1.68	77.90 ± 2.76	192.30 ± 1.65	500.0	150.0
Total alkalinity (mg/L) CaCO ₃	48.05 ± 1.03	45.32 ± 2.72	59.12 ± 2.17	80.48 ± 1.49	73.54 ± 1.60	27.03 ± 1.02	64.25 ± 0.96	55.62 ± 3.06	120.0	120.0
Temperature (°C)	29.20 ± 0.06	30.00 ± 0.10	28.10 ± 0.10	29.50 ± 0.06	30.10 ± 0.06	29.53 ± 0.03	31.13 ± 0.07	27.53 ± 0.03	32.0	Ambient
pH	6.53 ± 0.01	6.28 ± 0.01	6.93 ± 0.01	6.68 ± 0.01	6.55 ± 0.03	6.79 ± 0.03	7.21 ± 0.05	6.02 ± 0.01	6.5 - 8.5	6.5 - 8.5
TDS (mg/L)	85.35 ± 1.59	86.23 ± 3.49	90.50 ± 2.48	555.81 ± 7.56	85.48 ± 2.79	78.25 ± 1.64	105.0 ± 2.61	872.50 ± 5.07	500.0	500.0
EC (µs/cm)	153.0 ± 1.53	80.0 ± 9.24	185.0 ± 7.64	302.0 ± 2.00	215.0 ± 2.52	137.0 ± 1.15	98.0 ± 5.69	356.0 ± 4.48	500.0	1000.0
Turbidity (NTU)	5.26 ± 0.031	4.52 ± 0.01	4.37 ± 0.01	8.01 ± 0.021	4.28 ± 0.02	3.97 ± 0.02	7.03 ± 0.04	9.51 ± 0.02	5.00	5.00
Odour	-	-	-	+	-	-	-	+	-	-

Key: + = objectionable; - = unobjectionable; NS = Not stated.

Table 7. Results of Physicochemical Analysis of Water Samples From Lafia North B

Parameter	Sample				Location				Reference	Standard
	LNO2-1	LNO2-2	LNO2-3	LNO2-4	LNA1	LNA2	LNA3	LNA4	WHO	SON
Chloride (mg/l)	8.36 ± 0.06	7.38 ± 0.15	5.20 ± 0.04	10.02 ± 0.07	8.03 ± 0.03	6.40 ± 0.10	10.06 ± 0.09	5.05 ± 0.06	250.00	250.00
Phosphate (mg/l)	3.86 ± 0.02	2.64 ± 0.01	3.08 ± 0.03	10.0 ± 0.09	3.36 ± 0.01	5.61 ± 0.04	4.13 ± 0.06	8.09 ± 0.05	NS	NS
Sulphate (mg/l)	9.05 ± 0.05	8.12 ± 0.04	10.06 ± 0.09	7.24 ± 0.05	12.13 ± 0.29	15.09 ± 1.70	11.57 ± 0.30	20.28 ± 1.01	400.0	100.0
Nitrate (mg/l)	12.03 ± 0.04	15.16 ± 0.14	4.59 ± 0.22	20.45 ± 0.85	10.31 ± 0.15	5.00 ± 0.11	0.00 ± 0.00	53.09 ± 1.55	50.0	50.0
Total hardness (mg/L) CaCO ₃	91.01 ± 2.52	76.09 ± 1.68	71.23 ± 1.43	109.13 ± 0.74	80.78 ± 0.95	115.06 ± 1.10	83.29 ± 1.59	55.40 ± 2.48	100.0	100.0
Total alkalinity (mg/L) CaCO ₃	60.34 ± 1.33	54.01 ± 0.36	40.11 ± 0.49	31.21 ± 0.55	70.31 ± 1.54	80.92 ± 1.00	77.58 ± 1.39	40.26 ± 1.93	200.0	150.0
Temperature (°C)	29.00 ± 0.06	28.93 ± 0.03	30.10 ± 0.06	28.10 ± 0.00	29.1 ± 0.00	28.5 ± 0.06	30.10 ± 0.00	28.40 ± 0.00	32.0	Ambient
pH	6.51 ± 0.01	7.25 ± 0.01	6.63 ± 0.01	6.05 ± 0.02	7.05 ± 0.05	6.82 ± 0.01	7.31 ± 0.01	6.50 ± 0.01	6.5-8.5	6.5-8.5
TDS (mg/L)	98.50 ± 0.36	112.04 ± 1.05	120.80 ± 0.57	450.50 ± 2.50	95.82 ± 3.03	102.55 ± 0.81	125.38 ± 0.26	515.02 ± 2.54	500.0	500.0
EC (µS/cm)	155.00 ± 2.52	234.00 ± 1.53	115.00 ± 2.53	298.0 ± 11.02	99.00 ± 5.51	153.0 ± 1.53	194.0 ± 1.15	293.0 ± 1.53	500.0	1000.0
Turbidity (NTU)	6.35 ± 0.05	5.04 ± 0.03	6.15 ± 0.03	7.24 ± 0.3	5.63 ± 0.03	5.58 ± 0.25	3.05 ± 0.03	8.73 ± 0.03	5.00	5.00
Odour	-	-	-	+	-	-	-	+	-	-

Key: + = objectionable; - = unobjectionable; NS = Not stated.

Table 8. Results of Physicochemical Analysis of Water Samples From Lafia East A

Parameter	Sample Location						Reference	Standard
	LEAS1	LEAS2	LEAS3	LEAS4	LEAD1	LEAD2	WHO	SON
Chloride (mg/L)	15.00 ± 0.06	10.05 ± 0.08	5.36 ± 0.07	50.21 ± 0.41	10.00 ± 0.04	15.75 ± 0.27	250.00	250.00
Phosphate (mg/L)	0.53 ± 0.01	0.32 ± 0.01	0.61 ± 0.02	0.44 ± 0.10	0.75 ± 0.02	0.91 ± 0.05	NS	NS
Sulphate (mg/L)	10.01 ± 0.03	15.37 ± 0.19	20.03 ± 0.57	25.01 ± 0.61	10.32 ± 0.14	9.034 ± 0.02	400.00	100.00
Nitrate (mg/L)	1.43 ± 0.01	1.01 ± 0.00	2.38 ± 0.05	20.43 ± 0.29	7.11 ± 0.06	1.18 ± 0.02	50.00	50.00
Total hardness (mg/L) CaCO ₃	145.35 ± 2.28	99.00 ± 1.16	178.71 ± 1.79	215.21 ± 1.58	141.43 ± 2.42	100.85 ± 2.87	200.00	150.00
Total alkalinity (mg/L) CaCO ₃	43.12 ± 0.80	68.3 ± 1.14	70.05 ± 0.98	11.30 ± 0.36	92.54 ± 1.32	32.08 ± 0.41	120.00	120.00
Temperature (°C)	29.50 ± 0.06	30.20 ± 0.00	28.70 ± 0.06	26.50 ± 0.10	30.10 ± 0.00	30.50 ± 0.10	32.0	Ambient
pH	6.62 ± 0.01	6.90 ± 0.01	6.93 ± 0.01	6.90 ± 0.01	7.62 ± 0.01	6.53 ± 0.01	6.5-8.5	6.5-8.5
TDS (mg/L)	78.05 ± 1.48	98.30 ± 2.77	118.00 ± 4.32	842.00 ± 6.55	203.06 ± 1.59	105.60 ± 2.80	500.00	500.00
EC (µS/cm)	158.67 ± 8.97	119.33 ± 13.86	95.00 ± 2.65	315.67 ± 6.36	202.00 ± 3.79	178.33 ± 4.63	500.00	1000.00
Turbidity (NTU)	4.93 ± 0.02	4.50 ± 0.03	5.12 ± 0.06	6.50 ± 0.03	5.12 ± 0.06	4.90 ± 0.03	5.00	5.00
Odour	-	-	-	+	-	-	-	-

Key: + = objectionable; - = unobjectionable; NS = Not stated.

Table 9. Results of Physicochemical Analysis of Water Samples From Lafia East B

Parameter	Sample Location						Reference	Standard
	LEAD3	LEAD4	LEASH1	LEASH2	LEASH3	LEASH4	WHO	SON
Chloride (mg/L)	30.82 ± 0.26	10.00 ± 0.05	15.10 ± 0.10	29.38 ± 0.34	10.33 ± 0.18	9.35 ± 0.10	250.00	250.00
Phosphate (mg/L)	2.38 ± 0.02	4.01 ± 0.06	0.85 ± 0.03	2.01 ± 0.01	3.00 ± 0.01	5.92 ± 0.02	NS	NS
Sulphate (mg/L)	8.14 ± 0.03	30.31 ± 0.98	15.02 ± 0.06	10.43 ± 0.05	7.84 ± 0.13	15.21 ± 0.11	400.00	100.00
Nitrate (mg/L)	5.39 ± 0.41	11.05 ± 0.03	6.33 ± 0.06	1.11 ± 0.07	1.25 ± 0.01	19.32 ± 0.16	50.00	50.00
Total hardness (mg/L) CaCO ₃	124.09 ± 1.91	117.03 ± 3.46	213.79 ± 1.86	147.78 ± 1.49	75.37 ± 1.62	99.07 ± 0.87	200.00	150.00
Total alkalinity (mg/L) CaCO ₃	85.90 ± 1.57	15.33 ± 0.18	52.05 ± 1.10	78.01 ± 0.55	64.15 ± 0.61	6.19 ± 0.10	120.00	120.00
Temperature (°C)	28.3 ± 0.06	27.00 ± 0.00	28.5 ± 0.10	29.10 ± 0.00	30.67 ± 0.38	28.30 ± 0.00	32.0	Ambient
pH	6.88 ± 0.01	6.45 ± 0.01	7.25 ± 0.01	7.89 ± 0.01	6.73 ± 0.01	6.57 ± 0.01	6.5-8.5	6.5-8.5
TDS (mg/L)	201.00 ± 2.00	608.50 ± 4.26	89.42 ± 3.87	304.10 ± 2.08	178.09 ± 4.20	600.40 ± 2.44	500.00	500.00
EC (µS/cm)	99.67 ± 5.58	276.33 ± 5.93	186.00 ± 3.79	63.00 ± 3.00	90.00 ± 2.52	458.00 ± 3.21	500	1000.00
Turbidity (NTU)	6.03 ± 0.04	5.27 ± 0.02	4.93 ± 0.02	8.07 ± 0.03	5.53 ± 0.04	9.42 ± 0.04	5.00	5.00
Odour	-	-	-	-	-	+	-	-

Key: + = objectionable; - = unobjectionable; NS = Not stated

From Table 5, total hardness of samples varied between 55.40 ± 2.48 mg/l CaCO₃ in Azuba well water (LNA4) and 373.45 ± 3.28 mg/l CaCO₃ in Mararaba borehole water (LCM2). Hardness values obtained for most samples are consistent with values reported for well and borehole water by Ramya et al. (2015) and Atiku et al. (2018). According to WHO (2011) and SON (2012), the permissible limit for total hardness of water is 200 mg/l CaCO₃ and 150 mg/l CaCO₃ respectively. Thus, all sampled water met the set standards except Mararaba well water (LCM1), Mararaba borehole water (LCM2), Gandu borehole water (LCG1) and bukankwoto well water (LCG3). Hardness in water is primarily due to calcium and magnesium ions present in water. Other metallic ions may contribute to water hardness but they are mostly present in much lower concentrations (Ramya et al., 2015). Hard water may results to wastage of resources both industrially and domestically. Also, hard water may have adverse effects on people with kidney and bladder stones (Adegboyega et al., 2015). From Table 4 and Table 5, total alkalinity determined in the samples ranged between 30.35 ± 0.65 mg/l CaCO₃ in Lafia modern market borehole water (LCC6) to 120.39 ± 2.40 mg/l CaCO₃ in Gandu stream (LCG3). Atiku et al. (2018) reported similar alkalinity values in which total alkalinity level was highest in river followed by well water and borehole water. Except for Gandu stream, alkalinity values for all the samples are within the acceptable limit of

120 mg/l CaCO₃ set by WHO (2011) and SON (2012). Alkalinity in water could be attributed to leaching from carbonates and bicarbonates into water sources (Raju *et al.*, 2009).

Temperature of samples varied between $26.90 \pm 0.21^{\circ}\text{C}$ in Emir's Palace well water (LCC2) and $31.50 \pm 0.06^{\circ}\text{C}$ in Bukankoto borehole water (LCB1) (See Table 4 and Table 5). Similar temperature values for river, well and borehole water was reported by Atiku *et al.* (2018). Temperature recorded for all samples are within the SON (2012) recommendation of ambient temperature for drinking water. Elevated water temperature may favour the growth of microorganisms and microbial activities, leading to deterioration of water quality in terms of colour, taste, odour, corrosiveness and as well as microbial hazards (Okoye and Okoye, 2008). The pH of water is its degree of acidity or basicity determined by measuring the amount of hydrogen ions present. The pH of water samples had lower limit of 6.02 ± 0.01 in Ombi 1 stream (LNU14) and upper limit of 7.95 ± 0.02 in Bukankoto well water (LCB3) (See Table 4). The permissible range of pH for potable water is 6.5 to 8.5 (WHO, 2011; SON, 2012). Atiku *et al.* (2018) and Adegboyega *et al.* (2015) obtained pH values in water which are in agreement with those obtained in this study. Water is taken to be neutral with a pH of 7. Some of the samples were found to be slightly acidic. This acidity could result from the dissolution of carbon(iv) oxide present in the atmosphere in rain water forming acid rain. This acid rain may find its way into the sampled water sources leading to acidity (Orisakwe, 2018). Acid water is reported to cause stomach upset when consumed and as well corrosive to metallic plumbing materials which may serve as mechanism in exposing humans to harmful metals (Atiku *et al.*, 2018).

Results in Table 5 and Table 8 showed that total dissolved solids in the samples varied between 78.05 ± 1.48 mg/l in Assakio borehole water (LEAS1) and 754.23 ± 6.61 mg/l in Mararaba well water (LCM1). Atiku *et al.* (2018) reported TDS values in borehole, river and well water. Adegboyega *et al.* (2015) reported similar TDS levels in some well water in Idi Ayunre, Oyo State. According to WHO (2011) and SON (2012), the acceptable limit for TDS in drinking water is 500 mg/l. TDS in water is attributable to dissolved inorganic salts, chlorides, bicarbonates, and sulphates from minerals (Adegboyega *et al.*, 2015). As reported by Harrison (2007), higher TDS in water result to reduction in water clarity which may in turn lead to reduced photosynthetic activities and as well elevation in water temperature. The study results in Table 4 and Table 9 showed that electrical conductivity of samples ranged from 40.33 ± 5.49 $\mu\text{S}/\text{cm}$ in Emir's Palace borehole water (LCC1) to 458.00 ± 3.21 $\mu\text{S}/\text{cm}$ in Ashige well water (LEASH4). Electrical conductivity values obtained for samples are similar to that reported by Sa'eed and Mahmoud (2014). All samples meet electrical conductivity acceptable limit of 1000 $\mu\text{S}/\text{cm}$ set by SON (2012) while some samples have EC values exceeding WHO (2011) permissible limit of 500 $\mu\text{S}/\text{cm}$. Electrical conductivity of water could result from inorganic ions (such as metallic, bicarbonate and chloride ions) which are induced into water and precipitated out due to adsorption and also as a mechanism for self-cleansing of water (Adegboyega *et al.*, 2015; Atiku *et al.*, 2018).

Turbidity of investigated samples varied between 3.05 ± 0.04 NTU in Azuba borehole water (LNA3) and 10.18 ± 1.19 NTU in Gandu stream (LCG3) (See Table 5 and Table 7). The acceptable limit for turbidity in drinking water is 5.0 NTU (WHO, 2011; SON, 2012). The higher turbidity levels in some samples could be an indication of the presence of suspended matter, microorganisms and dissolved inorganic as well as organic substances (Aremu, *et al.*, 2014). Odour in the samples was classified as either objectionable or unobjectionable based on the recommendations of WHO (2011) and SON (2012). For water to be considered potable, its odour must not be objectionable. On the basis of odour, all the stream and well water sampled are not fit for human consumption as their odour were objectionable, while all borehole samples recorded unobjectionable odour. Odour in water could be attributed to the presence of decaying organic matter, microbial activities and the presence of mineral fragments in the water (SON, 2012; WHO, 2011).

V. Conclusion

Physicochemical analysis of water samples from Lafia metropolis has provided pertinent insights into water quality in the study area. The results show that chlorides, sulphates, nitrates, temperature, alkalinity were within WHO and SON permissible limits. Furthermore, results for total hardness, TDS, turbidity were above WHO and SON standards in some of the samples, especially well and borehole water sources. Phosphate levels in the water source sampled ranged from zero mg/l to 70.53 ± 0.02 mg/l. A pH range starting from 6.02 indicated slight acidity in some of the samples studied. Few samples were identified to have EC levels above the SON standard. Water in some areas in Lafia Metropolis is safe for drinking and other domestic activities while in some areas, odour, nitrate content, TDS, turbidity and total hardness make it unfit for human utilities. In terms of odour, stream and well water sources had objectionable odour while samples from boreholes were odour-free. Therefore, it is important to carry out bi-annual assessments of water sources in the study area, especially wells and streams in order to determine their efficacy for human consumption. In the same vein, adequate sensitization should be carry out on the dangers of dumping organic and inorganic waste in streams and wells in the study area, while commensurate penalties for indiscriminate dumping should be effectively enforced.

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IOSR Journal of Applied Chemistry (IOSR-JAC) is UGC approved Journal with Sl. No. 4031, Journal no. 44190.

S.P.I. Ogah. " Physicochemical analysis of water samples from Lafia metropolis, Nasarawa State, Nigeria." *IOSR Journal of Applied Chemistry (IOSR-JAC)* 12.8 (2019): 08-18.