Chapter

Analysis of Ground Water from Selected Sources in Jalingo Metropolis, Nigeria

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Abstract

Water is very significant in the development of a stable community, but many societies are confronted with the challenges of poor wastes management system with indiscriminate waste disposal and bad land practices, which easily pollute water sources and consequently degrade water quality. This study was to analyze the physicochemical properties of ground water from multiple point sources in Jalingo, Taraba state of Nigeria. Water samples were collected from twenty seven (27) sites from the study area during the raining and dry seasons. The analysis was carried out to determining the physico-chemical properties of the ground water and comparing with the World Health Organization (WHO) standard for drinking water. The physicochemical properties of ground water analyzed include; odor, taste, temperature and electrical conductivity were tested in the field using water meter tester. Whereas pH, total dissolved solids, alkalinity, hardness, salinity, iron, manganese, fluoride, nitrate, nitrite, chloride, sulphate and dissolved oxygen were analyzed in the laboratory using Wagtech potable water testing equipment. The physical properties of water analyzed were temperature, odor, taste, and turbidity. Whereas the chemical properties of water analyzed were pH, electrical conductivity (EC), total dissolved solids (TDS), alkalinity, hardness, salinity, iron (Fe), manganese (Mn), fluoride (F^-), nitrate (NO_3^-), nitrite (NO_2^-), Chloride (Cl^-), sulphate (SO_4^{2-}), dissolved oxygen (DO).The result shows the range of the mean values of the temperature(26.7–33.1) °C, p H(6.5–8.9), Fe (0.01–0.08 mg/L), NO_3^- (0.01–38.5 mg/l), NO_2^- (0.01–0.09 mg/l), Mn (0.01–0.17 mg/l), F(0.01–0.82 mg/l), alkalinity(39-204 mg/l), salinity (42-508 mg/l), SO_4(14-93 mg/l), total dissolved solids (6–637) mg/l, turbidity(0.4–10.6 mg/l), hardness(48-187 mg/l), and fecal coliforms(1–4)fcu/100mi, dissolved oxygen(1.1–6.87)mg/l, EC (10.99–1066)ohm/cm, Cl (10-320 mg/l). All except alkalinity and hardness are within the WHO permissible standards of quality drinking water. The highest alkalinity (204 mg/l), hardness (187 mg/l) and low dissolved oxygen (6.87 mg/l) attributed to the high concentration of dissolved salts and basic cations in the water. The methodology applied in the study was effective in analyzing the physicochemical properties of water in the study area. Therefore, it was recommended that there should be frequent water source testing by stakeholder in water resources with the view to treating the water. Policy maker should also enforce the regulation of the use of chemical fertilizers, agrochemicals and the indiscriminate waste disposal.

Keywords: ground water, physicochemical properties, water quality, multiple sources

1. Introduction

Water plays a vital role in the development of a stable community and society, since human being can exist for days without food, but absence of water for a few days may lead to death [1]. The essential nature of water to man's daily usage vis-à-vis quantity and quality right from time immemorial has been on the increase [2]. Unfortunately, drinking water in developing countries especially in Nigeria in particular is susceptible to toxins as a result of effluents and pollutants [3, 4].

Water is a common natural chemical substance containing two atoms of Hydrogen and an atom of Oxygen. Its common usage refers to liquid form, though has other forms: solid water- ice and gaseous forms - water vapor and steam. Water is indispensable for life and socioeconomic development of any society. It is used in domestic activities (cooking, drinking, washing, bathing etc.), agricultural activities (e.g. irrigation, gardening), generation of power (hydroelectric power plants), running industries, recreational activities etc. It is very essential for human existence and sustenance of life. Water constitutes 60–70% of the total body weight. A man can live for several days without food but will only survive for few days without water. Therefore, water is indispensable for normal physiological function of plants and animals (Guyton, 1996 cited in [5]). In spite of its importance in sustenance of live and livelihood, it is the major cause of morbidity and mortality because of limitations in access and quality [5]. The basic physiological requirement for drinking water has been estimated at about 2 liters per capita per day which is just enough for survival [6]. World Health Organization (WHO) states that domestic water consumption of 30–35 liters per capita per day is the minimum requirement for maintaining good health. However, the amount of water required by individuals varies depending on climate, standard of living, habit of the people and even age and sex.

One factor that impinges more on the accessibility to enough quality drinking water is the distance of the source from house. This condition forces the individual most especially the women and children (especially girls) to transverse many kilometers to get safe drinking water (which deprives them from engaging in productive ventures or going to school like their male counterparts). In addition to this, in order to reduce the hardship in getting water, they may resort to reducing the quantity of water used in the house far below the recommended volume and also they may resort to fetching water from unimproved sources e.g. unprotected well, pond, stream etc. [7].

Water quality refers to the chemical, physical and biological characteristics of water [8]. It is a measure of the conditions of water relative to the requirement of one or more biotic species, and or to any human need or purpose. It is most frequently used by reference to a set of standards against which compliance can be assessed. The most common standards used to access water quality relate to health of ecosystems, safety of human contact and consumption [9].

Safe (quality) drinking water is that which does not present any significant health risk over a life time consumption, including any sensitivities that may occur in different stages of life [10]. It is water which is free from pathogenic microbes, hazardous chemicals/substance and esthetically acceptable (i.e. pleasing to sight, odorless and good taste). It is important that this type of water should not only be available, but also be available in enough quantity all the time, i.e. twenty-four hours a day, seven days a week ("24/7").

In assessing quality of drinking water, physical, chemical and bacteriological parameters must be considered. Although water from a source may not pose any health threat to consumers, they may abhor it due to its color, odor, or taste [10]. Physical parameters include color, smell, temperature, pH, turbidity etc. There are myriad of chemical substances which may be naturally present or introduced (even chemicals used for water treatment) into water; those that are naturally present seldom pose risk to health. However, chemicals released due to anthropogenic activities (fertilizer, pesticides, herbicides, industrial effluents and byproducts etc.) carry more health risk to consumers.

Fortunately, whether chemical naturally present or introduced into water, there are maximum allowable concentration (limit) of most of them proposed by World Health Organization (WHO), which serves as guide. Some of the chemical substances include residual chlorine (RC), Iron (Fe), Fluoride (Fl), Nitrate/Nitrite, Lead (Pb), Mercury (Hg) [10, 11].

Bacteriological (microbial) parameter is used to assess drinking water quality using the index /indicator concept as advocated by Waite (1991, cited in [5]). The infectious risks associated with drinking water are primarily those posed by fecal pollution and their control depends on being able to assess the risk from any water source and applying suitable treatment to eliminate the risk. Rather than trying to detect the presence of pathogens at which time the consumer is being exposed to possible infection, it is better practice to look for organisms, while not pathogenic themselves, that show the presence of fecal pollution and therefore the potential for the presence of pathogens. For this reason, *E. coli* (*E.coli*) is universally used as an indicator organism to assess water treatment and widely preferred as index organism for fecal contamination. Thermo-tolerant coliform count (Fecal coliform) is acceptable where *E. coli* detection is not possible [10].

The presence of other microbes may indicate fecal contamination as well e.g. fecal streptococci indicate recent contamination of water sources with feces. While planet earth is made up of predominantly water, only 3% is fresh water, and of this, 99% is trapped in icecaps and glaciers. Even the 1% of the fresh water available for human use is not evenly distributed [11]. According to WHO and UNICEF report [7], safe water which is a basic necessity is still a luxury for many poor developing countries of the world today. It has been estimated that over 1.1 billion people do not have access to drinking water from improved sources. Eighty percent of the unserved populations live in these three regions – Sub-Saharan Africa, Eastern Asia and Southern Asia. Eighty- four percent of these people are the rural dwellers.

In 2004, 83% of the world population (5.3 billion) had access to drinking water from improved sources. This seemingly high global statistics hide a critical situation in some developing countries. In sub-Saharan Africa and Oceania only 54% and 50% of their populations respectively are served with improved sources of drinking water in 2004. Whereas at the same period, the population that had access to water from improved sources is over 90% in the Caribbean, Northern Africa and Western Asia [12].

Although over 80% of the developing world population has access to some type of improved drinking water source, only 44% have access through household connection from piped system. There are large disparities between regions. While access to drinking water through household connection is as low as 16% in Sub-Saharan Africa, 20% in South-Eastern and 21% in Oceania; it is much higher in Eastern Asia 70%, Northern Africa 76%, and 80% in Latin America and the Caribbean [12].

Jalingo metropolis, which is located in sub-Saharan Africa, has no official record of households' connection to water, but with the heavy dependence on ground water, it is evident that there is little or no connection to improved drinking water within the study area. This necessitated the current study on physicochemical properties of ground water from multiple sources in Jalingo metropolis.

Jalingo as an urban centre is confronted with the challenges of poor waste management system and fast urban sprawl that is evident within the township. Indiscriminate waste disposal coupled with bad land practices are common scenes in the metropolis. These unguided practices according to Ndabula & Jidauna [13] and Dabi Jidauna [3] can easily pollute surface water, and consequently degrading of the water quality. The residents of Jalingo Metropolis depend on both surface and ground water sources for their different water uses. The most dependable sources observed include tap water from the water board, water vendors, wells, and6sometimes riverbed are used as sources of water supply. These sources are often prone to pollutants that are categorized as heavy metals that are often associated to human activities and further exacerbated by urban sprawling and poor waste management [4]. Therefore, the need to access a reliable, secure, safe, and sufficient source of fresh water is a fundamental requirement for the survival, well-being, and socio-economic development of all humanity [14]. Hence, the desire and the need for portable water supply cannot be over emphasized. Irrespective of sources, domestic water supply should be water of high quality, while water for other uses can be of moderate quality. Moreover, most people in the urban centers often depend on the water vendors for domestic water supply, and in many cases, the water accessed is used directly without treatment. Drinking water is water of highest quality, while water of good quality can be put into any other use [2].

There has been heavy investment in terms of pipe borne or tap water in order to increase access of residents to quality water for drinking and domestic uses, yet it is no news that the residents of Jalingo have no access to quality drinking water especially as the sources are diverse. Thus, this study analyzed the physicochemical properties of ground water from different sources within the metropolis, hence to create awareness towards developing a strategy for monitoring and protecting groundwater quality of the area.

2. Method and materials

2.1 Study area

The study area is Jalingo metropolis in Taraba state located at latitude 8^0 47′ to $9^0$01′N of the equator and longitude $11^0$09′ to $11^0$30′E of the Greenwich Meridian (**Figure 1**). It is situated within the Northern Guinea Savannah ecological zone. It is bounded to the North by Lau LGA, to the East by Yorro LGA, to the South and West by Ardo-Kola LGA. Jalingo has a total land area of about 195.071km^2. Nine of the ten (10) wards are located within the metropolis. These include Barade, Kona, Maji Dadi, Sarkin Dawaki, Sintali A, Sintali B, Turaki A, Turaki B and Kachalla Sembe wards [15]. Presently, Jalingo has a projected population [16] of 191,443 people at 2.83% annual growth rate [17] (**Figure 2**).

The WHO standards follow these classifications also (**Table 1**).

2.2 Research design

The study adopted the experimental research design. This involves studying phenomenon in a laboratory or natural setting, and hypotheses are amenable to statistical testing because it is possible to observe and measure variables in the investigation.

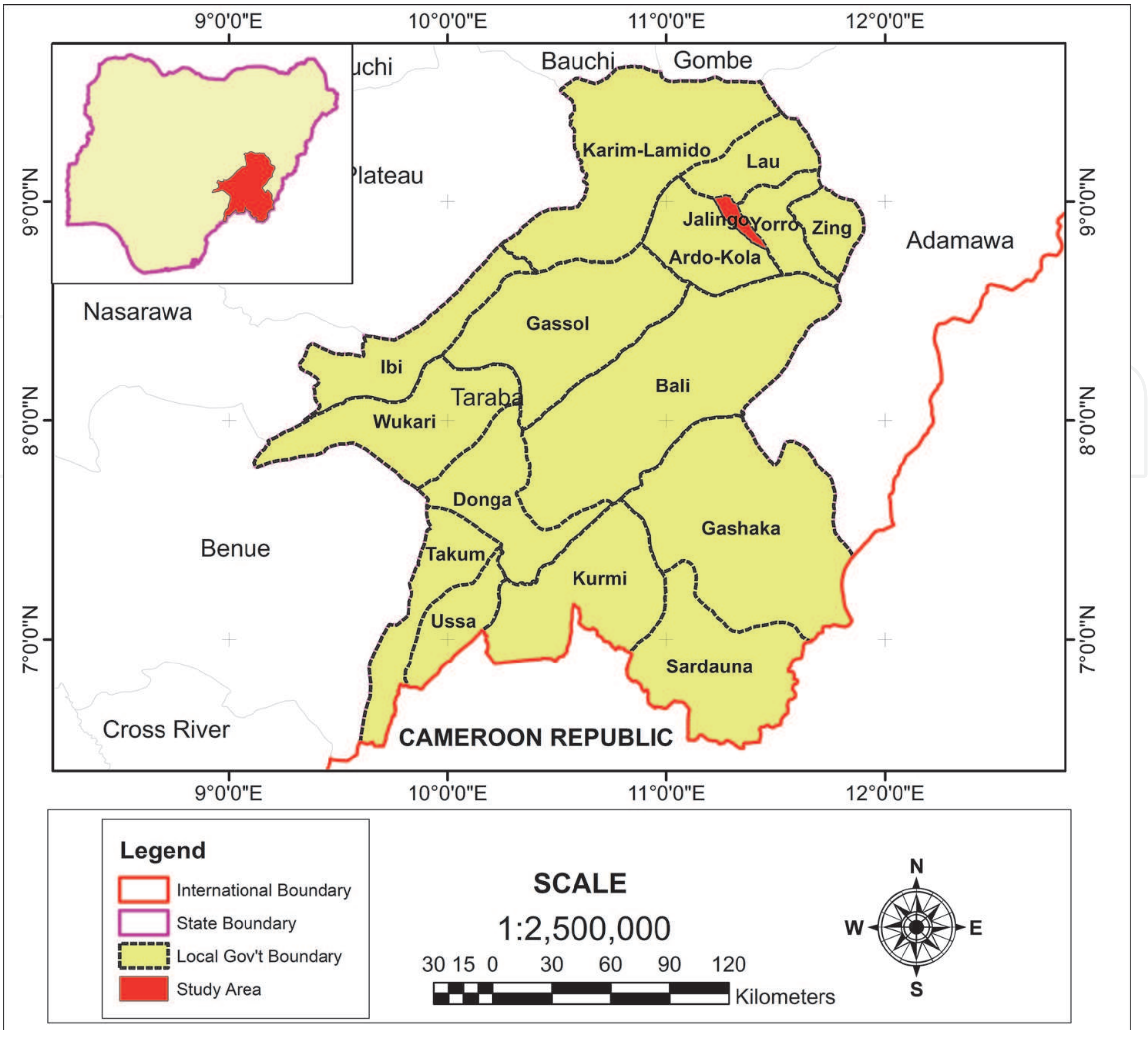

Figure 1.
Map of Taraba showing study area.

2.3 Population of the study

The population of the study comprises all drinking water sources within Jalingo metropolis. Due to the vastness of the metropolis, the researcher, randomly sampled three water sources from each of the nine wards in the metropolis making 27 sampling points.

2.4 Sample size and sampling technique

The sample size for the study is 27 water sources (sampling sites) within Jalingo metropolis. Purposive sampling was used to select the nine (9) wards in Jalingo metropolis. Random sampling was used to select 27 sampling sites, three (3) sampling sites each per ward.

2.5 Sources of data

The primary data was sourced through Ground Truth Observations (GTOs) in the field. This includes collection of water samples from three (3) major locations from each of the nine wards; Sarkin Dawaki(SD), TurakiA(TA), Turaki B(TB), Majidadi(MD), Kachalla Sembe(KS), Kona(KL), Sintali A(SA), Sintali B(SB) and Barade(BR) in Jalingo Metropolis.

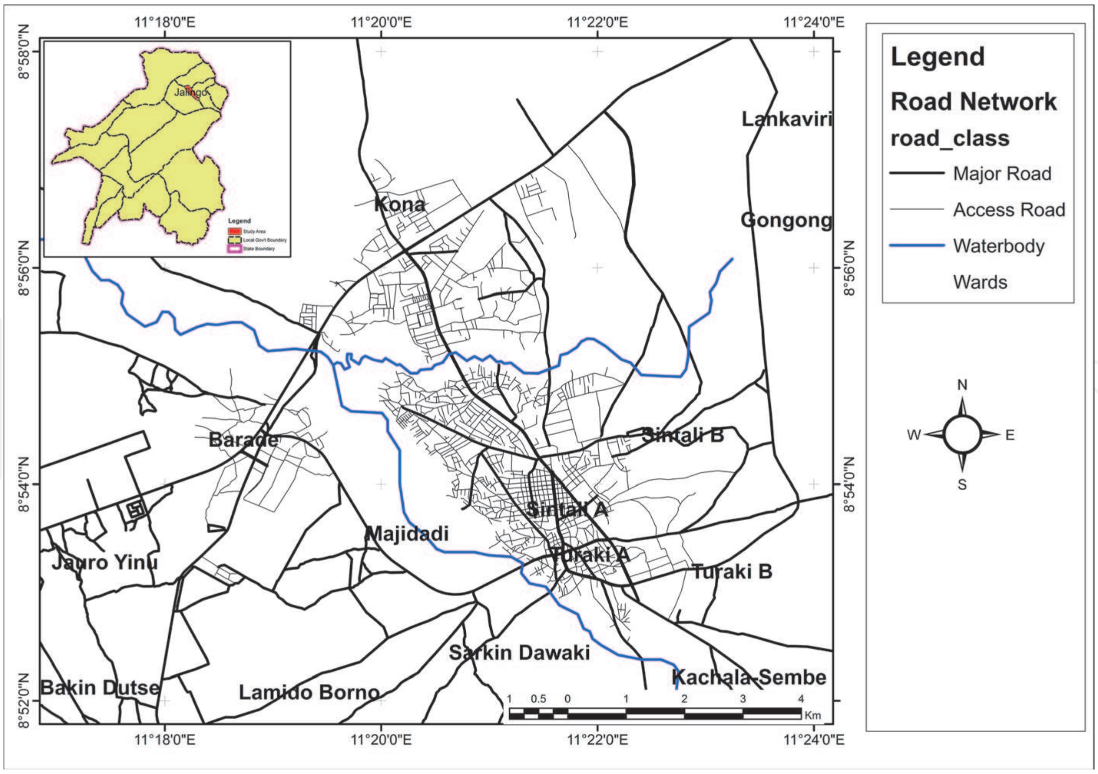

Figure 2.
Administrative map of the study area (min. Of Land & Survey, Jalingo).

S/N	Parameter	Maximum permissible limits in water				
		NAFDAC	SON	FEPA	UNICEF	WHO
1	Conductivity (S/m)	1000	1000	70	1000	0–1500
2	Total dissolved solids (mg/l)	500	500	500	500	1000
3	Hydrogen ion concentration	6.5–8.5	6.5–8.5	6.0–9.0	6.5–8.5	6.8
4	Total hardness (mg/l)	100	100	—	150	100
5	Total alkalinity (mg/l)	100	100	—	200	100
6	Nitrate (mg/l)	10	10	20	50	50
7	Water temperature (^{0}C)	—	—	26	6.5–8.5	40
8	Dissolved oxygen (mg/l)	—	—	≥4		≤6
9	Turbidity (NTU)	—	—	—	15	5 NTU
10	Iron (mg/l)	—	—	—	0.2	0.1–0.5
11	Fluoride (mg/l)	—	—	—	1.5	0.5–1.5
12	Nitrite (mg/l)	—	—	—	0.2	50
13	Chloride (mg/l)	—	—	—	250	250
14	Sulphate (mg/l)	—	—	—	250	100
15	Manganese (mg/l)	—	—	—	0.2	0.1–0.5
16	Salinity (mg/l)	—	—	—	500	≤ 600

Source: Adejuwon and Adelakun [18]. Where: NAFDAC-National Administration for Food, Drugs and Control, SON-Standard Organization of Nigeria, FEPA-Federal Environmental Protection Agency, United Nation International Children's Emergency Fund-UNICEF and WHO-World Health Organization.

Table 1.
Selected national and international water quality standard guidelines.

The secondary data were obtained from journal publications, books, WHO water standards, online articles, published and unpublished theses.

2.6 Data collection and preparation of samples

One-liter capacity sample bottles were used for collection of water samples. The bottles and their covers were washed and properly sterilized. When collecting water samples, the sterilized bottles were rinsed with the water to be sampled three times before finally collecting the samples.

Water samples from taps, well and boreholes were collected using the one-liter sterilized bottles fitted with its cover. The sample bottles were filled with water by a gentle flow, for water samples from taps and boreholes. The bottles were then covered and labeled for easy identification. Water samples from wells were fetched to fill a sterilized plastic bucket and transferred immediately into the 1-liter sample bottles. All water samples were stored in cooler containing ice packs and were transported immediately within some few hours to the laboratory where the analysis was carried out.

In this study, 26 samples of ground water and one sample pipe-borne water were collected. The samples were collected from twenty-seven (27) sites in nine (9) locations (KL, BR, SB, SD, MD, TA, TB, KS and SA) all Jalingo Metropolis. The coordinates of each water source sample site were obtained using handheld GPS. The coordinates were recorded and labeled accordingly. This was the data used for drawing the map of water sampling points (**Figure 3**).

2.7 Analytical procedure

Data analysis involves analytical methods of sorting, scrutinizing, processing and translating data into research findings based on the set objectives of research. Some of thesimple measurements were made on-site like temperature, pH, and conductivity, in direct contact with the water source in question. More complex

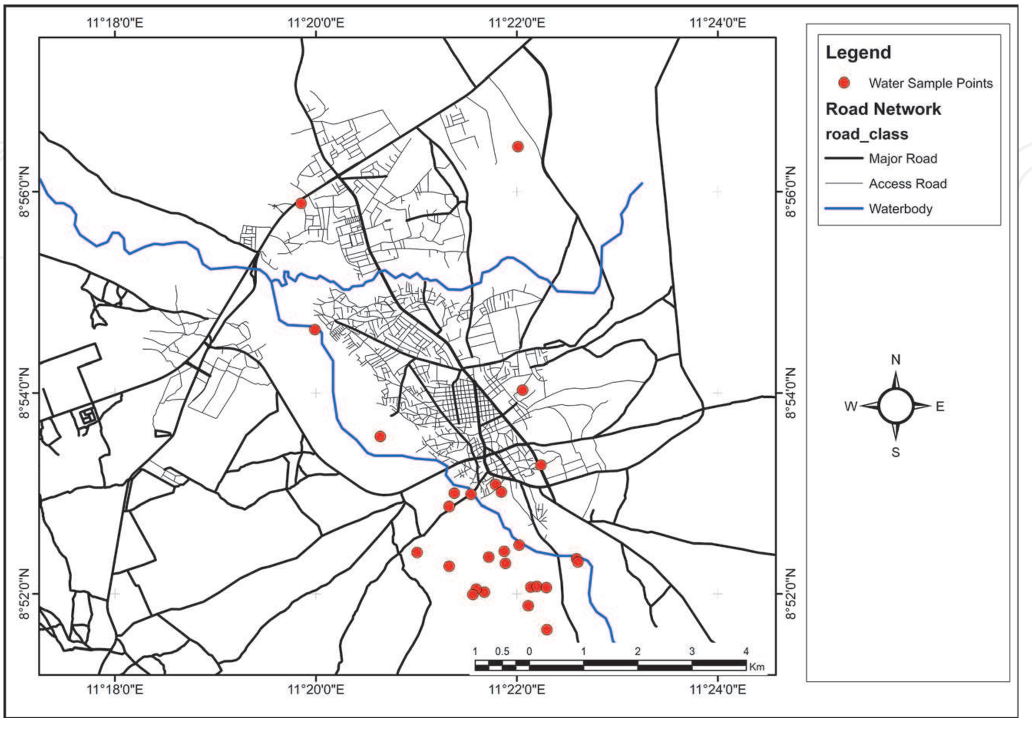

Figure 3.
Map of study area showing sampling points.

measurements were made in a laboratory setting where water samples were collected, preserved, and analyzed in the laboratory. For the purpose of this study, only some properties were examined. These include pH, turbidity, color, odor, hardness, alkalinity, salinity, total dissolved solids (TDS), dissolved oxygen (DO) chloride (Cl), nitrate (NO^3)/nitrite (NO^2), fluoride (F), iron (Fe), sulphate (SO_4^{2-}), manganese (Mn^{2+}), fecal coliform and total fecal coliform.

2.7.1 Physicochemical parameters

pH: Water pH was analyzed using Wagtech WE30200 pH meter. The acceptable pH for drinking Water ranges from 6.5–8.5.

Turbidity: Turbidity was measured using Wagtech WE30140 Potalab Turbidimeter. The turbidity measurement was conducted by placing the meter on a flat surface, filling a clean sample vial to mark, placing in a sample well and covering the vial with light shield cap. The display reading was recorded as sample turbidity. The maximum acceptable value for turbidity of drinking water is 5NTU.

Total Dissolved Solids (TDS) and Electrical Conductivity: were determined using Wagtech WE30120 conductivity/TDS meter.

Chloride: was measured by complexometric titration of 100 ml sample using 0.141$moldm^{-3}$ silver nitrate ($AgNO_3$) in the presence of 1 ml potassium chromate indicator (K_2CrO_4) at pH of 7–8. At the endpoint titration color changes from yellow to pinkish-yellow and the chloride concentration was computed by calculation as follows:

Mg/l Chloride = (A-B) x N x35,450/ vol.of sample.

Where A = Sample titer value, B = Blank titer value and N = 0.0141.

Nitrate/Nitrite: was determined via reduction method and the resulting, nitrite determined by reaction with sulphanilic acid in the presence of N – (1-naphathyl)-ethylene diamine to form reddish dye. The intensity of color produced is directly proportional to the nitrate transmittance obtained was converted to concentration with aid of nitratest calibration chart and mg/l NO_3 obtained by multiplying the result by a factor of 4.4. The Photometer was calibrated with the water sample to be tested.

Fluoride: was analyzed by adding Zirconyl chloride and Eriochrome Cyanine reagents tablets to a 10 ml sample of water in acid solution to form a red colored complex. This is destroyed by fluoride ion to give a pale yellow. The color produced was directly proportional to the fluoride concentration and was measured using Wagtech WE10441 Potalab Photometer 7100 at 570 nm wavelength. Percent transmittance obtained was converted to mg/l F with the aid of fluoride calibration chart. The Photometer was calibrated with the water sample to be tested.

Iron (Fe): was measured by using Wagtech spectrophotometer. The photometer was calibrated with the water sample to be tested. The color produced was directly proportional to the iron concentration and was measured using the Wagtech photometer at wavelength 570 nm. Percent transmittance obtained was converted to mg/l Fe with aid of iron calibration chart.

Sulphate: was determined by modified turbidimetric method with barium in sulpha Ver 4 sulphate reagent. The color produced was directly proportional to the sulphate concentration and was measured using DR/2010 Hach Spectrophotometer at 450 nm wavelength. The spectrophotometer was calibrated with the water sample to be tested.

Manganese: was determined by direct aspiration into an Air- Acetylene Flame using Atomic Absorption Spectrometer.

Total Alkalinity: was measured by titrating 100 ml sample using 0.01$moldm^{-3}$ of H_2SO_4, phenolphthalein indicator, methyl orange indicator and pH meter at endpoint p H OF 4.5 and the Total Alkalinity as mg/l $CaCO_3$ = Titer value/vol. of sample x 1000.

Total Hardness: was measured by complexometric titration of 100 ml sample using 0.01moldm^{-3} disodium slat of ethylene diamine tetra acetic acid (EDTA) in the presence of Eriochrome Black T. at the titration endpoint color changes from wine red to bluish-green and the total hardness content was computed by calculation as follws:

Total Hardness as mg/l $CaCO_3$ = Titer value/vol. of sample x 1000.

Dissolved Oxygen(DO): Was determined using Wagtech potalab spectrophotometer water analysis kit.

Total coliforms: Was determined using the membrane filtration technique using Wagtech field kits.

Temperature: The temperature was determined using the Wagtech field water meter.

Water Taste and Odor: were determined in field by drinking and perceiving the smell and taste of the water at sites.

2.8 Statistical analysis

ANOVA analysis was carried out using statistical software (SPSS version 23.0) to compare the relationship between water sources and the physicochemical characteristics of water in Jaingo Metropolis.

3. Results and discussion

This section presents the results of the analysis of the data collected during the field survey carried out, and the interpretation and discussion of the results. The variables analyzed in the study include the physicochemical properties of the drinking water, comparison of physical and chemical characteristics of drinking water in Jalingo side-by-side WHO standard quality of drinking water in developing countries and the relationship between water sources and the physicochemical characteristics of water in Jaingo Metropolis. In all, the study examined twenty (20) physicochemical parameters of water.

3.1 Temperature

The temperature of water samples from all sites during the dry season range from 26.7°C – 33.1°C as shown in **Table 2** with mean value range of 28.3°C to 31.8°C as shown in **Table 3** and the values of temperature recorded during the rainy season ranged from 21.2°C to 28.5°C as shown in **Table 4** with mean value of 22.35 to 27.37°C as shown in **Table 5**. The high temperature values obtained from sites BR3 (33.1°C), MD3 (32.4°C) and SA3 (32.2°C) during the dry season were higher than the values of 25.87 to 27.56°C reported by Ikhuoriah and Oronsaye [19] from water samples collected from river source. The temperature values obtained from this study are within the WHO permissible limit of 40°C.

3.2 pH

pH is one of the important water quality parameters. Measurement of pH relates to the acidity or alkalinity of the water. A sample is said to be acidic if the pH is below 7.0 and it is said to be alkaline if the pH is higher than 7.0. Acidic water can

Site	Taste	Odor	Temp°C	pH	EC	TDS	TURB	Alkalinity	Hardness	Salinity	DO (mg/1)
KL1	Unob	Unob	30	7.8	10.99	6	3	120	121	42	1.4
KL2	Unob	Unob	27.5	6.5	452	226	6.2	168	182	68	4.8
KL3	Unob	Unob	27.5	8.1	89.5	45	4.8	39	48	42.8	4.3
BR1	Unob	Unob	26.7	7.6	766	383	0.2	168	147	78	1.1
BR2	Unob	Unob	27.9	8.1	573	282	1.2	140	138	42	1.72
BR3	Unob	Unob	33.1	8.4	343	171	1.1	121	110	58.2	1.4
SB1	Unob	Unob	29.3	8.6	320	160	1	110	90	42	1.13
SB2	OBJ	Unob	27.7	8.2	480	240	1.6	123	171	58.2	1.5
SB3	Unob	Unob	30.5	8.4	423	211	1.1	140	187	65	1.2
SD1	Unob	Unob	29.2	8.8	93.5	47	2	84	67	33.4	5.6
SD2	OBJ	Unob	28.1	8.9	921	460	1.9	194	148	482	4.53
SD3	Unob	Unob	30.6	8.9	963	482	1.4	168	171	120	1.83
MD1	Unob	Unob	29.6	8.6	143.4	72	3.6	110	121	48	2.73
MD2	OBJ	Unob	30.8	8.9	915	452	2	182	148	496	1.14
MD3	OBJ	Unob	32.4	8.4	1261	630	1.8	204	138	508	5.8
TA1	Unob	Unob	28.1	8.7	958	480	0.4	161	128	52.7	4.85
TA2	OBJ	Unob	29.1	8.7	1066	533	0.8	198	132	71	5.6
TA3	Unob	Unob	28.1	8.4	637	637	0.7	144	114	64	5.22
TB1	Unob	Unob	30.5	8.8	827	414	10.6	182	148	56	4.63
TB2	OBJ	Unob	30.7	8.2	708	354	2.4	130	186	71	6.87
TB3	OBJ	Unob	30.5	8.6	703	352	1.8	128	126	65	4.4
KS1	OBJ	OBJ	29.4	8.9	685	343	1.4	160	132	74	2.64
KS2	Unob	Unob	29.3	8.6	762	381	1.2	161	128	64	1.7
KS3	Unob	Unob	30.1	7.9	633	316	0.9	142	113	64	3.2
SA1	Unob	Unob	31.7	7.8	465	233	0.9	140	131	58	3.62
SA2	Unob	Unob	31.5	8.4	640	320	1.4	144	118	61	4.61
SA3	Unob	Unob	32.2	8.2	404	202	0.8	160	181	72	3.51

Table 2.
Physicochemical properties of water in Jalingo Metropolis during dry season.

lead to corrosion of metal pipes and plumbing system as well as harmful to human life.

The pH values from this range from (6.5–8.9) as shown in **Table 2** with mean value of 7.5 ± 0.85–8.9 ± 0.06 shown in **Table 3** during the dry season and values of 5.2–6.7 as shown in **Table 4** with mean value of 5.93 ± 0.67–6.6 ± 0.1 as shown in **Table 5** during the rainy season.

The highest pH value recorded during the rainy season was 6.7 which were higher than the range of 5.76 to 6.01 reported by Ikhouriah and Oronsaye [19] in Ossiomoo river ologbo - a tributary of Benin River, Southern Nigeria.

The pH values reported in this study is also higher than the range of 5.96–5.54 reported by Ohinedu, Nwinyi, Oluwadamisi and Eze [20] is assessing the water quality in cananland, Ota, Southwest Nigeria.

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Site	Temp°C	pH	EC	TDS	TURB	Alkalinity	Hardness	Salinity	DO (mg/1)
KL	28.3 ± 1.44^{a}	7.5 ± 0.85^{a}	184.2 ± 235.3^{a}	92.3 ± 117.4^{a}	4.7 ± 1.6^{a}	109 ± 65.19^{a}	117 ± 67.09^{a}	50.9 ± 14.79^{a}	3.5 ± 1.7^{a}
BR	29.2 ± 3.40^{a}	8 ± 0.40^{a}	560.7 ± 211.8^{a}	278.7 ± 106.03^{a}	0.83 ± 0.55^{a}	143 ± 23.63^{a}	131.7 ± 19.29^{a}	59.4 ± 18.03^{a}	1.41 ± 0.3^{a}
SB	29.2 ± 1.40^{a}	8.4 ± 0.2^{b}	407.7 ± 81.1^{a}	203.7 ± 40.5^{a}	1.2 ± 0.32^{a}	124.3 ± 15.04^{a}	149.3 ± 52.0^{a}	55.1 ± 11.82^{a}	1.28 ± 0.2^{b}
SD	29.3 ± 1.25^{a}	8.9 ± 0.06^{b}	659.2 ± 490.3^{a}	329.7 ± 245.04^{a}	1.8 ± 0.32^{a}	148.7 ± 57.49^{a}	128.7 ± 54.63^{a}	211.8 ± 237.97^{a}	3.99 ± 1.9^{a}
MD	30.9 ± 1.40^{a}	8.6 ± 0.25^{a}	773.1 ± 572.1^{a}	384.7 ± 285.03^{a}	2.5 ± 0.98^{a}	165.3 ± 49.17^{a}	135.7 ± 13.65^{a}	350.7 ± 262.19^{a}	3.22 ± 2.4^{a}
TA	28.4 ± 0.58^{a}	8.6 ± 0.17^{b}	887 ± 223.1^{a}	550 ± 79.9^{a}	0.6 ± 0.21^{b}	167.7 ± 27.61^{a}	124.7 ± 9.45^{a}	62.6 ± 9.23^{a}	5.22 ± 0.4^{a}
TB	30.6 ± 0.13^{b}	8.5 ± 0.31^{a}	746 ± 70.2^{a}	373.3 ± 35.2^{a}	4.9 ± 4.92^{a}	146.7 ± 300.62^{a}	153.3 ± 30.35^{a}	64 ± 7.55^{a}	5.3 ± 1.4^{a}
KS	29.6 ± 0.43^{a}	8.5 ± 0.51^{a}	693.3 ± 64.9^{a}	346.7 ± 32.7^{a}	1.2 ± 0.25^{a}	154.3 ± 10.69^{a}	124.3 ± 10.02^{a}	67.3 ± 5.77^{a}	2.51 ± 0.8^{a}
SA	31.8 ± 0.36^{a}	8.1 ± 0.31^{a}	503 ± 122.5^{a}	351.7 ± 61.2^{a}	1 ± 0.32^{a}	148 ± 10.58^{a}	143.3 ± 33.26^{a}	63.7 ± 7.37^{a}	3.91 ± 0.6^{a}

Means with the same letter are not significantly different from each other ($a = P > 0.05$; $b = P < 0.05$).

Table 3.
Mean scores of selected physicochemical parameters of water during dry season.

Site	Taste	Odor	Temp°C	pH	EC	TDS	TURB	Alkalinity	Hardness	Salinity	DO (mg/1)
KL1	Unob	Unob	27	6.2	11.91	8	1	115	86	33	2.6
KL2	Unob	Unob	25.1	5.3	456	231	4.1	142	112	46	5.9
KL3	Unob	Unob	28.3	6.7	88.6	48	3.2	31	22	32.4	6.2
BR1	Unob	Unob	22.8	5.2	769	388	0.1	146	114	64	3.4
BR2	Unob	Unob	21.2	6.5	578	289	0.6	131	118	34	3.81
BR3	Unob	Unob	23.1	6.1	352	176	0.8	117	79	39.1	4.6
SB1	Unob	Unob	26.3	6.4	329	169	0.5	102	64	33	4.33
SB2	OBJ	Unob	22.7	6.3	488	246	1.1	89	120	36.3	3.7
SB3	Unob	Unob	26.2	6.5	431	218	0.8	121	126	47	4.3
SD1	Unob	Unob	25.6	6.6	96.8	52	1.2	56	36	28.1	6.4
SD2	OBJ	Unob	24	6.5	934	469	1.1	146	97	329	6.45
SD3	Unob	Unob	25.2	6.7	971	488	0.8	132	122	98	4. 53
MD1	Unob	Unob	22.4	6.5	146.8	76	1.4	87	78	32	4.81
MD2	OBJ	Unob	26.3	6.5	921	459	1.2	141	94	384	3.42
MD3	OBJ	Unob	24.1	6.3	1273	636	1.1	183	106	476	7.4
TA1	Unob	Unob	26.1	6.4	964	487	0.2	121	91	38.5	6.5
TA2	OBJ	Unob	28.2	6.5	1072	538	0.3	145	89	62	7.3
TA3	Unob	Unob	26.4	6.5	641	641	0.4	115	79	48	7.12
TB1	Unob	Unob	27.1	6.7	834	419	7.5	131	96	36	6.51
TB2	OBJ	Unob	26.5	6.5	711	361	1.2	121	123	43	8.45
TB3	OBJ	Unob	28.1	6.4	713	359	0.7	87	93	39	6.5
KS1	OBJ	OBJ	26.5	6.8	689	348	0.9	126	106	48	4.35
KS2	Unob	Unob	24.8	6.5	768	389	0.6	118	116	37	3.4
KS3	Unob	Unob	27.6	5.8	642	321	0.4	112	88	39	5.6
SA1	Unob	Unob	27.5	5.5	469	239	0.5	121	102	32	5.2
SA2	Unob	Unob	26.1	6.5	648	328	1.1	119	83	36	6.5
SA3	Unob	Unob	28.5	6.1	412	207	0.5	127	132	41	5.7

Table 4.
Physicochemical properties of underground water in Jalingo Metropolis during rainy season.

All sites in the study area during the dry season were within the WHO permissible limit of 6.5–8.5 except sites SB_1 (8.6) SD_1 (8.8) SD_2 (8.9) SD_3 (8.9), MD, (8.6) KS_1 (8.9) band KS_2 (8.6) these high values show alkalinity and it could be due to high concentration of basic cations e.g. magnesium, calcium, potassium etc. in the sampled sites.

All sites in the rainy season were within the WHO permissible limit of 6.5–8.5.

3.3 Electrical conductivity

Electrical conductivity is the ability of any medium, water in this case, to carry an electric current. The presence of dissolved solids such as calcium, chloride, and magnesium in water samples carries the electric current through water. Conductivity values obtained in this study showed that all the sample sites contained

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Site	Temp°C	pH	EC	TDS	TURB	Alkalinity	Hardness	Salinity	DO (mg/1)
KL	26.8 ± 1.61^{a}	6.07 ± 0.71^{a}	185.50 ± 237.37^{a}	95.67 ± 118.89^{a}	2.77 ± 1.60^{a}	96 ± 57.89^{a}	73.33 ± 46.32^{a}	37.13 ± 7.68^{a}	4.9 ± 1.99^{a}
BR	22.35 ± 1.02^{a}	5.93 ± 0.67^{a}	566.33 ± 208.74^{a}	284.33 ± 106.10^{a}	0.5 ± 0.36^{a}	131.33 ± 14.50^{a}	103.67 ± 21.46^{a}	45.7 ± 16.05^{a}	3.94 ± 0.61^{a}
SB	25.07 ± 2.05^{a}	6.4 ± 0.1^{b}	416 ± 80.55^{a}	211 ± 38.97^{a}	0.8 ± 0.3^{a}	104 ± 16.09^{a}	103.33 ± 34.20^{a}	38.77 ± 7.32^{a}	4.11 ± 0.36^{a}
SD	24.93 ± 0.83^{a}	6.6 ± 0.1^{b}	667.27 ± 494.38^{a}	336.33 ± 246.42^{a}	1.03 ± 0.21^{b}	111.33 ± 48.42^{a}	85 ± 44.24^{a}	151.7 ± 157.47^{a}	6.43 ± 0.04^{a}
MD	24.27 ± 1.96^{a}	6.43 ± 0.12^{b}	780.27 ± 576.14^{a}	390.33 ± 286.24^{a}	1.23 ± 0.15^{b}	137 ± 48.12^{a}	92.67 ± 14.05^{a}	297.33 ± 234.35^{a}	5.21 ± 2.02^{a}
TA	26.9 ± 1.14^{a}	6.47 ± 0.06^{b}	892.33 ± 224.26^{a}	555.33 ± 78.45^{a}	0.3 ± 0.1^{b}	127 ± 15.87^{a}	86.33 ± 6.43^{a}	49.5 ± 11.82^{a}	6.97 ± 0.42^{a}
TB	27.23 ± 0.81^{a}	6.53 ± 0.15^{b}	752.67 ± 70.44^{a}	379.67 ± 34.08^{a}	3.13 ± 3.79^{a}	113 ± 23.07^{a}	104 ± 16.52^{a}	39.33 ± 3.51^{a}	7.15 ± 1.12^{a}
KS	26.3 ± 1.41^{a}	6.37 ± 0.51^{a}	699.67 ± 63.67^{a}	352.67 ± 34.24^{a}	0.63 ± 0.25^{b}	118.67 ± 7.02^{a}	103.33 ± 14.19^{a}	103.33 ± 5.86^{a}	4.45 ± 1.10^{a}
SA	27.37 ± 1.21^{a}	6.03 ± 0.50^{a}	509.67 ± 123.14^{a}	258 ± 62.70^{a}	0.7 ± 0.35^{a}	122.33 ± 4.16^{a}	105.67 ± 24.70^{a}	36.33 ± 4.51^{a}	5.8 ± 0.66^{a}

Means with the same letter are not significantly different from each other (a = $P > 0.05$; b = $P < 0.05$).

Table 5.
Mean scores of physicochemical parameters of water during rainy season.

appreciable amount of dissolved ions (10.00–958.00 S/m). Sampling sites TA2 and MD3 contained 1,066 and 1,261 ohm/cm. The EC range obtained in this study is higher than the range of 62.03 to 70.11ohm/cm reported by Ikhuoriah and Oronsaye [19] in assessing the physicochemical characteristics and some heavy metals of Ossiomo River, Ologbo – a tributary of Benin River, Southern Nigeria. This high EC values observed in some sites may be as a result of the chemicals present in ionic form in the dump sites that sink into the ground. The EC of all sites fall within the WHO recommended limit of 500–1,500 ohm/cm.

3.4 Total dissolved solids (TDS)

These are the inorganic matters and small amounts of organic matter, which are present as solution in water. The study found TDS values from the drinking water samples are all within the maximum limit of 1000 mg/L. The highest TDS values of 637 mg/L and the lowest TDS values of 6 mg/L correspond to samples from KL1 and TA3, respectively. The highest TDS values were recorded from site MD3 (630) and TA3 (637). This is higher than the range of 37.67 mg/L to 476.67 mg/L reported by Moses and Ishaku [21] in the evaluation of physicochemical properties of well water qualities in selected villages in Zing Local Government Area of Taraba State, Nigeria. The standard or allowable value of the TDS set by WHO is 1000 mg/L. Therefore, the TDS values obtained in this study are within the WHO permissible standards.

3.5 Turbidity

Turbidity is the cloudiness of water caused by a variety of particles and is a key parameter in drinking water analysis. It is also related to the content of diseases causing organisms in water, which may come from surface runoff. The turbidity values obtained from the study sites range from 0.4–10.6. The standard recommended maximum turbidity limit, set by WHO for drinking water is 5 nephelometric turbidity units (NTU). The lowest turbidity values of 0.4 NTU and highest value of 10.6 NTU were found for samples from site TA1 and TB1, respectively (**Table 4**). The mean turbidity for sample locations revealed that KL and TB have values of 4.7 ± 1.6 and 4.9 ± 4.2. This may be as a result of the open nature of the water making it easy for impurities that could block light reception to flow into it. All sites in the study area except for sites KL2 and TB1 were below the WHO permissible levels of 5NTU.

3.6 Alkalinity

Alkalinity is the measure of the acid – neutralizing capacity of water. In most natural waters, it is due to the presence of carbonate ($CO3^{-}$), carbonate (HCO-) and hydroxyl anions. The alkalinity levels recorded in this study range from 39 mg/l – 204 mg/l as shown in **Table 2** with a mean range of 109 ± 65.19–167.7 ± 27.61 as shown in **Table 3** during the dry season. The value of alkalinity obtained during the rainy season range from 31 mg/l –183 mg/l as shown in **Table 4** with a mean range of 96 ± 57.89–131.33 ± 14.50 shown in **Table 5**. These are higher than the range of 4.4 ± 0.38 mg/c – 17.8 ± 0.25 mg reported by Dimowo [22] in an assessment of some physicochemical Parameters of River Ogun (Abeokuta, Ogun State, South Western Nigeria).

This study revealed that all sites were above the WHO permissible levels of 1.0 – 100 mg.c except sites KL_3 (39) and SD, (84) during the dry season and sites KL_3 (31), MD, (87), SD, (56) SB_2 (89) and TB_3 (87). The high alkalinity levels could be due to high concentration of basic cations such as calcium (Ca), magnesium (Mg), Sodium (Na) and Potassium (K).

3.7 Hardness

The hardness recorded in this study ranged from (22 to 132) mg/l as shown in **Table 4** with a mean value range of (73.33 to 105,67)mg/l as shown in **Table 5** during the rainy season and the value range of (48 to 187)mg/l as shown in **Table 2** with a mean value of (117 to 153)mg/l as shown in **Table 3** during the dry season. In this study only three sampled sites $KL_{3,}$(48 mg/l), SD_1(67 mg/l) and SB_1(90 mg/l) recorded hardness within the WHO permissible limit of 100 mg/l. The remaining sampled sites are above the WHO (100 mg/l) permissible limit while during the rainy season, fifteen of the sampled sites water hardness ranged from(22 to 97)mg/l as shown in **Table 4** are within the WHO permissible limit of 100 mg/l and twelve of the sampled sites water hardness ranged from(102 to 132)mg/l are above the WHO permissible limit of 100 mg/l These high values could be due to the high concentrations of dissolved salts such as $MgSO_{4,}$ $CaSO_{4,}$ $CaCO_4$ found in rocks and soils. Most commonly associated with the ability of water to precipitate soap. As hardness increases, more soap is needed to achieve the same level of cleaning due to the interactions of the hardness ions with the soap. Chemically, hardness is the sum of polyvalent caution concentrations dissolved in water. In fresh waters, the principal hardness-causing ions are Calcium and Magnesium; Strontium, Iron, Barium and Manganese ions also contribute. The hardness recorded in this study range from 48 mg/l – 187 mg/l (**Table 4**), and a mean value of 117 ± 67.09 mg/l – 153.3 ± 30.35 mg/l. This is above the mean hardness range of 45.5 ± 4.79 mg/l – 105.0 ± 46.74 mg/l reported by Dimowo [22] in an assessment of some physico-chemical parameters of River Ogun (Abeokuta, Ogun State, Southwestern Nigeria) in Comparison with National and International Standards. These values exceed the maximum permissible WHO standards of 100 mg/l. this could be due to high concentrations of dissolved salt such as $MgSO_{4,}$ $CaCO_3$, found in rocks and soils.

3.8 Salinity

The salinity of the samples collected from the sites in the study area range from 42 mg/l – 508 mg/l. The high values recorded were from sample sites SD2 (483 mg/l), MD2 (496 mg/l) and MD3 (508 mg/l). The salinity values for all sample sites are higher than the value range of 1.36 ± 0.13 mg/l to 5.27 ± 0.21 mg/l, with a mean value of 2.55 ± 0.109 mg/l reported by Bolarinwa, Fasakin and Fagbenro [23] in the analysis of the physicochemical parameters of coastal waters of Ondo State, Nigeria. The results obtained in this study are within WHO's permissible range of ≤600 mg/L.

Salinity: The salinity of water samplwes collected from the sites in the study area ranged from (28.1 476nmg/l) as shown in **Table 4** with a mean value of 36.33 ± 4.51–297.33 ± 234.35 during the rainy season and the value range of (33.4 – 508 mg/l) as shown in table with a mean value of 50.9 ± 14.79–350.7 ± 262.19 as shown in **Table 5** the salinity levels obtained in this study revealed that both in the dry and rainy season the results were within the WHO permissible limit of ≤600 mg/l.

3.9 Iron (Fe^{2+})

The Fe^{2+} concentrations recorded for all sites range between 0.01–0.08 mg/l. The mean concentration of Fe^{2+} range from 0.007–0.047 mg/l in all sample sites in the study area as shown in **Table 6**. These values are lower than the range of

Site	Fe^{2+}	Mn^{2+}	F^-	$NO3^-$	$NO2^-$	Cl^-	$SO4^{2-}$
KL	0.02 ± 0.01^b	0.023 ± 0.01^a	0.13 ± 0.15^b	0.56 ± 0.90^a	0.01 ± 0.01^a	27.17 ± 13.05^a	26.33 ± 7.37^a
BR	0.02 ± 0.01^b	0.07 ± 0.09^b	0.08 ± 0.07^b	0.98 ± 0.83^a	0.03 ± 0.01^b	99.67 ± 23.86^a	47 ± 10.54^a
SB	0.02 ± 0.05^a	0.09 ± 0.09^b	0.12 ± 0.11^b	0.09 ± 0.04^b	0.02 ± 0.01^a	121.47 ± 105.94^a	54.67 ± 33.55^a
SD	0.04 ± 0.02^b	0.03 ± 0.02^b	0.04 ± 0.02^b	0.4 ± 0.41^a	0.03 ± 0.01^a	112 ± 87.07^a	51.33 ± 37.63^a
MD	0.06 ± 0.01^b	0.02 ± 0.01^a	0.28 ± 0.38^a	13.56 ± 21.88^a	0.08 ± 0.04^b	185.43 ± 140.84^a	53 ± 22.65^a
TA	0.02 ± 0.01^b	0.08 ± 0.09^b	0.04 ± 0.01^b	0.86 ± 1.49^a	0.06 ± 0.03^b	110.33 ± 237.29^a	46.33 ± 13.05^a
TB	0.05 ± 0.03^b	0.03 ± 0.02^b	0.5 ± 0.42^a	7.8 ± 6.52^a	0.09 ± 0.11^b	221.67 ± 135.57^a	59.67 ± 7.57^a
KS	0.06 ± 0.04^b	0.02 ± 0.01^a	0.31 ± 0.28^a	1.54 ± 0.53^a	0.02 ± 0.01^a	91.67 ± 88.635^a	61.67 ± 21.39^a
SA	0.02 ± 0.02^b	0.02 ± 0.02^b	0.24 ± 0.24^a	0.48 ± 0.39^a	0.02 ± 0.01^a	43 ± 2^a	49.67 ± 9.29^a

Means with the same letter are not significantly different from each other ($a = P > 0.05$; $b = P < 0.05$).

Table 6.
Mean values of ions in water in Jalingo during rainy season.

0.15 mg/l and 3.26 mg/L reported by Popoola, Yusuf and Aderibigbe [24] in assessment of natural groundwater physico-chemical properties in major industrial and residential locations of Lagos metropolis. The WHO recommended limit for in drinking water is 0.3 mg/l. Therefore, the Fe concentrations recorded in the sampled water are just traces and not harmful to life.

3.10 Manganese (Mn^{2+})

The concentrations of Mn^{2+} from the study range from 0.01 mg/l – 0.17 mg/l in the sampled water sites as shown in **Table 7**. All the values obtained from the sample sites except for sites BR1 (0.12 mg/l), SB2 (0.15 mg/l) and TA3 (0.17 mg/l) are within the WHO [25] permissible levels of 0.1 mg/l to 0.5 mg/l. The mean concentration of Mn^{2+} ranged from(0.003–0.063) mg/l in all the sample sites as reported in **Table 6**. The

Site	Fe^{2+}	Mn^{2+}	F^-	$NO3^-$	$NO2^-$	Cl^-	$SO4^{2-}$
KL1	0.01	0.03	0.03	1.6	0.01	13	18
KL2	0.01	0.02	0.05	0.05	0.02	29.8	29
KL3	0.03	0.02	0.3	0.02	0.01	38.7	32
BR1	0.01	0.17	0.02	1.3	0.02	83	57
BR2	0.03	0.02	0.05	1.6	0.02	127	36
BR3	0.02	0.02	0.16	0.03	0.04	89	48
SB1	0.02	0.02	0.24	0.05	0.02	52	16
SB2	0.03	0.19	0.08	0.09	0.03	243.4	76
SB3	0.02	0.05	0.04	0.13	0.01	69	72
SD1	0.01	0.02	0.03	0.04	0.03	17	9
SD2	0.09	0.05	0.02	0.84	0.03	188	81
SD3	0.01	0.02	0.06	0.32	0.02	131	64
MD1	0.08	0.03	0.71	1.81	0.09	38.3	29
MD2	0.04	0.02	0.03	0.06	0.03	199	74
MD3	0.06	0.01	0.09	38.8	0.11	319	56
TA1	0.01	0.03	0.05	0.06	0.03	38	61
TA2	0.02	0.02	0.03	0.98	0.09	252	42
TA3	0.03	0.19	0.042	1.53	0.05	41	36
TB1	0.02	0.05	0.48	1.9	0.13	69	55
TB2	0.08	0.02	0.93	14.8	0.11	328	63
TB3	0.04	0.01	0.09	6.7	0.03	268	61
KS1	0.09	0.02	0.6	1.8	0.02	194	75
KS2	0.06	0.03	0.29	0.93	0.02	42	37
KS3	0.02	0.02	0.04	1.9	0.01	39	73
SA1	0.04	0.01	0.02	0.04	0.02	43	54
SA2	0.02	0.02	0.5	0.8	0.01	45	39
SA3	0.01	0.04	0.2	0.6	0.02	41	56

Table 7.
Ions from water in Jalingo Metropolis during rainy season.

highest value of 0.17 mg/l was recorded for site TA3, which is higher than the value of (0.057–0.010)mg/l reported by Ayeki, Asikhia and Ojeh [26] in the study of seasonal and spatial variation in physicochemical & biological quality of rainwater in Benin City, Edo State. All the mean values obtained from the locations were within the WHO [27] permissible levels of (0.1 to 0.5)mg/l.

Manganese (Mn^{2+}): The concentration of manganese from the study range from (0.00–0.17)mg/l in the sampled water as shown in **Table 2** with mean value of 0.01 ± 0.02 – o.6 ± 0.09 as shown in **Table 8** during the dry season and value range of (0.01–0.19)mg/l as shown in **Table 7** with the mean value range of 0.02 ± 0.02–-0.09 ± 0.09 mg/l as show in **Table 6** during the rainy season were all within the WHO permissible levels of 0.1 mg/l to 0.5 mg/l. The highest value of 0/17 mg/l recorded for site TA_3 and 0.19 mg/l in dry season and rainy season respectively are higher than the value of (0.10–0.57)mg/l.

3.11 Fluoride(F^-)

The fluoride concentration recorded in this study range from(0.01–0.82)mg/l. The high levels were recorded in sample sites TB1 (0.4 mg/l), KS1 (0.4 mg/l) and TB2 (0.82 mg/l). The permissible range of fluoride by WHO is(0.5 to 1.5)mg/l. The fluoride concentrations found in the study are within the permissible WHO standards. Therefore, the fluoride found in the drinking water in the study area is not detrimental to life.

3.12 Nitrate (NO_3^-)

The nitrate (NO_3^-) levels obtained in the study range from 0.01–38.5 mg/l for the sample sites. The high values of (6.2 mg/l),(l4.4mg/l) and (38.5 mg/l were observed at site TB3, TB2 and MD3, respectively. This is higher than the range of 0.33 and 2.37 mg/L reported by Popoola, Yusuf and Aderibigbe [24] in assessment of natural groundwater physico-chemical properties in major industrial and residential locations of Lagos metropolis. All the nitrate values obtained in the study are lower than the WHO [27] recommended guideline value of 50 mg/l. This implies that the nitrate concentrations obtained in the study are within the permissible standards and might not pose any health risk.

Nitrate (NO_3^-) The nitrate levels obtained in this study range from 0.01–38.5 mg/l as shown in **Table 9** with mean value range of 0.06 ± 0.03–7.4 ± 6.48 as shown in **Table 8** during the dry season and the value range of 0.02–38.8 mg/l as shown in **Table 7** with mean value of range of 0.09 ± 0.04–13.56 ± 21.88 as shown in **Table 6** during the rainy season.

The high values of TB_3 (6.7), TB_{2+} (14.8) and MD_3 (38.8) during thee rainy season and TB_3 (6.2 mg/l) TB_2 (14.4 mg/l) and MD_3 were higher than the range of 0.33 and 2.37 mg/l reported by Popoola, Yusuf and aderigbe [24] in assessment of natural groundwater physicochemical properties in major industries and residential locations of Lagos metropolis.

All the Nitrate values obtained during the dry and rainy season are lower than the WHO [27] recommended guidelines value of 50 mg/l which implies that the nitrate concentrations obtained in the study were within the WHO standard and might not cause any health risk (**Tables 10** and **11**).

3.13 Nitrite (NO_2^-)

The nitrite (NO_2^-) levels obtained in this study range from 0.01 mg/l – 0.09 mg/l for all the sampled sites. The highest value of 0.09 mg/l was observed at site TB2 and MD3. This is lower than the value of 0.27 ± 0.005 mg/l reported by Bolarinwa,

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Site	Fe^{2+}	Mn^{2+}	F^-	$NO3^-$	$NO2^-$	Cl^-	$SO4^{2-}$
KL	0.007 ± 0.01^a	0.013 ± 0.02^b	0.047 ± 0.05^b	0.48 ± 0.79^a	0 ± 0^b	24.17 ± 12.69^a	33 ± 9.8^a
BR	0.01 ± 0.01^b	0.043 ± 0.07^b	0.05 ± 0.04^b	0.87 ± 0.74^a	0.017 ± 0.01^a	94.67 ± 22.3^a	52 ± 9.5^a
SB	0.013 ± 0.01^a	0.053 ± 0.08^b	0.097 ± 0.09^b	0.06 ± 0.03^b	0.01 ± 0.01^a	117.13 ± 106.2^a	63 ± 36.4^a
SD	0.027 ± 0.04^b	0.01 ± 0.02^b	0.02 ± 0.02^b	0.28 ± 0.31^a	0.013 ± 0.01^a	107.33 ± 86.9^a	64 ± 43.4^a
MD	0.047 ± 0.04^b	0.01 ± 0.01^b	0.023 ± 0.34^a	13.43 ± 21.7^a	0.057 ± 0.04^b	179.93 ± 137.9^a	69.33 ± 22.0^a
TA	0.013 ± 0.02^b	0.063 ± 0.09^b	0.028 ± 0.01^a	0.82 ± 0.72^a	0.043 ± 0.04^b	104 ± 118.7^a	56.67 ± 14.4^a
TB	0.03 ± 0.03^b	0.017 ± 0.02^b	0.433 ± 0.37^a	7.4 ± 6.48^a	0.063 ± 0.04^b	214.33 ± 135.2^a	79.33 ± 7.6^a
KS	0.037 ± 0.04^b	0.003 ± 0.03^a	0.21 ± 0.19^b	1.33 ± 0.46^a	0.007 ± 0.01^a	86 ± 82.3^a	74.67 ± 25.9^a
SA	0.01 ± 0.01^b	0.007 ± 0.01^b	0.13 ± 0.15^b	0.41 ± 0.39^a	0.003 ± 0.01^a	62.67 ± 2.08^a	62.67 ± 4.5^a

Means with the same letter are not significantly different from each other ($a = P > 0.05$; $b = P < 0.05$).

Table 8.
Mean values of selected ions in water in Jalingo during dry season.

Site	Fe^{2+}	Mn^{2+}	F^{-}	$NO3^{-}$	$NO2^{-}$	Cl^{-}	$SO4^{2-}$
KL1	0.01	0.01	0.01	1.4	0	10	22
KL2	0.01	0.03	0.03	0.04	0	28	36
KL3	0	0	0.1	0.01	0	34.5	41
BR1	0.02	0.12	0.03	1.2	0.01	78	61
BR2	0.01	0.01	0.02	1.4	0.03	120	42
BR3	0	0	0.1	0.02	0.01	86	53
SB1	0.01	0.01	0.2	0.03	0	48	21
SB2	0.02	0.15	0.06	0.07	0.01	239.4	82
SB3	0.01	0	0.03	0.09	0.02	64	86
SD1	0	0	0.01	0.02	0.01	12	14
SD2	0.07	0.03	0.01	0.62	0.02	182	92
SD3	0.01	0	0.04	0.21	0.01	128	86
MD1	0.06	0.01	0.62	1.76	0.07	36.8	48
MD2	0	0	0.01	0.04	0.01	191	92
MD3	0.08	0.02	0.07	38.5	0.09	312	68
TA1	0.01	0.01	0.03	0.04	0.01	32	73
TA2	0.03	0.01	0.02	0.96	0.08	241	51
TA3	0	0.17	0.034	1.46	0.04	39	46
TB1	0.01	0.04	0.4	1.6	0.08	62	71
TB2	0.06	0.01	0.82	14.4	0.09	320	86
TB3	0.02	0	0.08	6.2	0.02	261	81
KS1	0.07	0	0.4	1.6	0.01	181	93
KS2	0.04	0.01	0.21	0.8	0.01	39	45
KS3	0	0	0.02	1.6	0	38	86
SA1	0.02	0	0	0.02	0	41	63
SA2	0.01	0	0.3	0.4	0	42	58
SA3	0	0.02	0.1	0.8	0.01	38	67

Table 9.
Ions from water in Jalingo Metropolis during dry season.

Fasakin and Fagbenro [23] in the analysis of the physicochemical parameters of coastal waters of Ondo State, Nigeria. All the nitrite values obtained in the study are lower than the WHO [27] recommended guideline value of 50 mg/l. This implies that the nitrite concentrations obtained in the study are only traces and might not cause any health risk to human life.

3.14 Chloride(Cl^-)

The chloride levels recorded in this study range from 10 mg/l – 320 mg/L.The high values were recorded in three sites; TB3 (261 mg/l), MD3 (312 mg/l) and TB2 (320 mg/l). The values for all sample sites are higher than the range of 0.23 mg/L – 9.0 mg/L and mean concentration of 1.81 mg/L reported by Moses and Ishaku [21] in the evaluation of physicochemical properties of well water qualities in selected villages in Zing Local Government Area of Taraba State, Nigeria. This high values of

Parameter	Well	Borehole	Pipewater	WHO	NSDW
Taste	Unob	Unob	OBJ	—	—
Odor	Unob	Unob	Unob	—	—
Temp °C	29.79 ± 0.01^b	29.63 ± 0.01^b	30.7 ± 0.02^b	40	
pH	8.37 ± 0.8^a	8.34 ± 0.12^a	8.7 ± 0.1^a	6.5–8.5	—
EC	289.5 ± 0.6^b	766 ± 0.02^b	708 ± 0.01^b	500–1500	1000
TDS	45 ± 0.2^a	383 ± 0.61^b	354 ± 2.36^b	500	500
TURB	4.8 ± 2.5^a	0.2 ± 0.19^a	2.4 ± 4.26^b	5NTU	
Alkalinity	39 ± 0.3^b	168 ± 0.5^b	$130 \pm 0.1.6^b$	100	100
Hardness	48 ± 0.13^b	147 ± 0.017^b	186 ± 0^b	100	150
Salinity	42.8 ± 1.2^b	78 ± 0.2^b	71 ± 0.02^b	≤600	

Means with the same letter are not significantly different (a = P > 0.05; b = P < 0.05).

Table 10.
Variation in selected physicochemical parameters as influenced by water sources.

Water Source	Well	Borehole	Pipe water	WHO	NSDW
Fe	0.18 ± 0.02^b	0.12 ± 0.01^b	0.06 ± 0.01^b		
Mn	0.11 ± 0.07^b	0.08 ± 0.01^b	0.01 ± 0.01^b	0.05	
F	0.17 ± 0.01^b	0.13 ± 0.01^b	0.82 ± 0.02^a	0.5–1.50	
NO3	2.81 ± 0.8^a	0.6 ± 0.12^a	14.4 ± 1.6^a	50	
NO2	0.16 ± 0.6^b	0.11 ± 0.02^b	0.09 ± 0.01^b	50	
Cl	265.71 ± 0.2^a	269.1 ± 0.61^a	320 ± 18.36^a		
SO4	55.1 ± 2.5^a	78.8 ± 0.19^a	86 ± 4.96^a	400	100
DO	2.97 ± 0.3^a	4.85 ± 0.43^a	$6.87 \pm 0.1.6^a$	≥6	—

Means with the same letter are not significantly different (a = P > 0.05; b = P < 0.05).

Table 11.
Variation in selected ions as influenced by water sources.

chloride found in the study area which is more than the WHO permissible limit of 250 mg/l could be due to the high concentration of chloride in the rocks, soils and spraying of agro-chemicals like DDT and atrazine.

3.15 Sulphate (SO_4^{2-})

The sulphate (SO_4) concentration of the samples collected from the sites in the study area range from 14 mg/l – 93 mg/l. The concentration is below the range of 3.10 mg/l to 66.10 mg/L reported by Moses and Ishaku [21] in the evaluation of physicochemical properties of well water qualities in selected villages in Zing Local Government Area of Taraba State, Nigeria. In contrast, the range found in the present study is higher the range of 13–63 mg/L reported by Popoola, Yusuf and Aderibigbe [24] in assessment of natural groundwater physico-chemical properties in major industrial and residential locations of Lagos metropolis. The permissible values by WHO and NSDWQ are 250 mg/L and 100 mg/L respectively. Therefore, the sulphate concentrations found in the water from the sampled sites are within the permissible limit of WHO standards for good quality water.

3.16 Dissolved oxygen (DO)

Dissolved Oxygen (DO) levels from the study revealed a range of 1.1 mg/l – 6.87 mg/l and 2.6–8.45, and mean range of 1.28 ± 0.2–5.3 ± 1.4 and 3.94 ± 0.61–7.15 ± 1.12 for dry and rainy seasons respectively. This is lower than the values of 6.51 ± 1.47 mg/l – 8.43 ± 0.21 mg/l reported by Bolarinwa, Fasakin and Fagbenro [23] in the analysis of the physicochemical parameters of coastal waters of Ondo State, Nigeria. The WHO permissible standard for DO is >6 mg/l. Most of the dissolved oxygen concentrations found in water from the sampled sites do not meet the WHO standard for quality drinking water. This could be as a result of the high concentrations of dissolved salts, suspended particles and hardness of the water that preclude the dissolution of oxygen in most of the water from the sampled sites.

The water samples for this study were collected from three main sources. These include well, borehole and pipewater. The taste of water samples from the different sources differ as the pipewater is objectionable as compared to well and borehole sources, which are unobjectionable. In terms of the odor, water from all the sources recorded no odor. The temperature difference across the water sources is not statistically significant. pH across the sources is not significantly different. There is significant difference in Total Dissolved Solids and Turbidity across the various water sources. All other variables are not significantly different across the all sources.

The selected metal ions in water from the three sources are presented in **Table 9**. There was significant difference recorded in fluoride (F^-) across the water sources. All other variables recoded no significant difference across the different water sources in the study area. This implies that, there is not marked difference between the composition and concentration of physicochemical parameters in water from all water sources.

3.17 Discussion

The water temperature from all sites ranges between 26.7°C – 33. The temperature values obtained from this study were within the WHO permissible limit of 40°C. This is in support of the work by Moerman, Blokker, Vreeburg, and Van Der Hoek [28] that water temperature within the range of 28 – 380c is consider safe for drinking.

pH measure the acidity or alkalinity of the water. The pH values from this range from (6.5–8.9) also reported by Ikhouriah and Oronsaye [19] in Ossiomoo river Ologbo - a tributary of Benin River, Southern Nigeria. All sites in the study area during the dry season were within the WHO permissible limit of 6.5–8.5 except sites SB_1 (8.6) SD_1 (8.8), SD_2 (8.9) SD_3 (8.9), MD, (8.6), KS_1 (8.9) band KS_2 (8.6) these high values indicates alkalinity, and it could be due to high concentration of basic cations, e.g. magnesium, calcium, potassium etc. in the sampled sites. Electricity conductivity values obtained in this study showed that all the sample sites contained an appreciable amount of dissolved ions (10.00–958.00 S/m). The EC of all sites falls within the WHO recommended limit of 500–1,500 ohm/cm.

Turbidity is the impurity status of the water caused by a variety of particles and is a key parameter in drinking water analysis. It is also related to the content of diseases causing organisms in water, which may come from surface runoff. The turbidity values obtained from the study sites range from 0.4–10.6. The standard recommended maximum turbidity limit set by WHO for drinking water is five nephelometric turbidity units (NTU). These results from the open nature of the water, making it easy for impurities that could block light reception to flow into it. All sites in the study area except for sites two sites were below the WHO permissible levels of 5NTU.

The alkalinity levels recorded in this study range from 39 mg/l – 204 mg/l with a mean range of 109 ± 65.19–167.7 ± 27.61.during dry season and 31 mg/l–183 mg/l, with a mean range of 96 ± 57.89–131.33 ± 14.50 during the wet season. These are higher than the range of 4.4 ± 0.38 mg/c – 17.8 ± 0.25 mg reported by Dimowo [22] in an assessment of some physicochemical Parameters of River Ogun (Abeokuta, Ogun State, South-Western Nigeria). All sites were above the WHO permissible levels of 1.0 – 100 mg.c except for sites few sites. The high alkalinity levels could be due to a high concentration of basic cations such as calcium (Ca), magnesium (Mg), Sodium (Na) and Potassium (K).

Salinity: The salinity of water samples collected from the sites in the study area ranged from (28.1 mg/l to 476 mg/l) as shown in **Table 4** with a mean value of 36.33 ± 4.51 mg/l – 297.33 ± 234.35 mg/l during the rainy season and the value range of (33.4 mg/l – 508 mg/l) as shown in **Table 2** with a mean value of 50.9 ± 14.79–350.7 ± 262.19 as shown in **Table 3** during the dry season. The salinity values for all sample sites are higher than the value range of 1.36 ± 0.13 mg/l to 5.27 ± 0.21 mg/l, with a mean value of 2.55 ± 0.109 mg/l reported by Bolarinwa, Fasakin and Fagbenro [23] in the analysis of the physicochemical parameters of coastal waters of Ondo State, Nigeria. The salinity levels obtained in this study revealed that both in the dry and rainy season, the results are within the WHO permissible limit of ≤600 mg/l.

The Fe^{2+} concentrations recorded for all sites range between 0.01 mg/l – 0.08 mg/l The values obtained in the study are lower than the range of 0.15 mg/l and 3.26 mg/L reported by Popoola, Yusuf and Aderibigbe [24] in the assessment of natural groundwater physicochemical properties in major industrial and residential locations of Lagos metropolis. The values of Fe recorded both in dry and rainy seasons are within the WHO permissible limit of 0.3 mg/l. Therefore, the Fe concentrations recorded in the sampled water are just traces and not harmful to life.

The concentration of manganese from the study range from (0.0–0.17)mg/l. The highest value of 0.17 mg/l and 0.19 mg/l recorded for site TA_3 in the dry season and rainy season, respectively, are higher than the value of (0.010–0.057)mg/l reported by Ayeki, Asikhia and Ojeh [26] in the study of seasonal and spatial Variation in Physico-chemical and biological quality of water in Benin City, Edo State, Nigeria. All the manganese values obtained from the study are within the WHO [27] permissible standard of (0.1 to 0.5)mg/l.

The Nitrate (NO_3^-) levels obtained in this study ranged from 0.01–38.5 mg/l during the wet and dry season. All the Nitrate values obtained during the dry and rainy seasons are lower than the WHO [27] recommended guidelines value of 50 mg/l, which implies that the nitrate concentrations obtained in the study are within the acceptable limit and might not cause any health risk.

The nitrite (NO_2^-) levels obtained in this study range from 0.01 mg/l – 0.09 mg/l with a mean value range of 0.01–0.063 during the dry season and the levels obtained during the rainy season ranged from 0.01 mg/l to 0.13 mg/l with a mean value range of 0.01 mg/l to 0.09 mg/l are all within the WHO [27] permissible nitrite limit of 50 mg/l. The highest value of 0.09 mg/l was observed at site TB2 and MD3. This is lower than the value of 0.27 ± 0.005 mg/l reported by Bolarinwa, Fasakin and Fagbenro [23] in the analysis of the physicochemical parameters of coastal waters of Ondo State, Nigeria. This implies that the nitrate concentrations obtained in the study are only traces and might not cause any health risk to human life.

The chloride levels recorded in this study range from 10 mg/l – 320 mg/L with a mean value range of 24.17 mg/l to 2114.33 mg/l during the dry season and the value range from 13 mg/l to 328 mg/l with a mean value range of 27.17 mg/l to 221.67 mg/l during the rainy season. The high values were recorded in three sites; TB3 (261 mg/l), MD3 (312 mg/l) and TB2 (320 mg/l) during the dry season and TB3(268 mg/l), MD3 (319 mg/l) and TB2(328 mg/l) during the rainy season are higher than the WHO permissible limit of chloride (250 mg/l) but the rest of the sampled sites are within the permissible limit of the WHO. The high values of chloride found in the study area could be due to the high concentration of chloride in the rocks, soils and spraying of agrochemicals like DDT and atrazine.

The sulphate (SO_4) concentrations of the sampled water range from 14 mg/l – 93 mg/l with the mean range of 33 mg/l to 79.33 mg/l during the dry season and the levels during the rainy season ranged from 9 mg/l to 81 mg/l with a mean value range of 26.33 mg/l to 61.67 mg/l. The concentrations recorded in this study are below the range of 3.10 mg/l to 66.10 mg/L reported by Moses and Ishaku [21] in the evaluation of physicochemical properties of well water qualities in selected villages in the Zing Local Government Area of Taraba State, Nigeria. In contrast, the range found in the present study is higher than the range of 13–63 mg/L reported by Popoola, Yusuf and Aderibigbe [24] in the assessment of natural groundwater physicochemical properties in major industrial and residential locations of the Lagos metropolis. The permissible level of WHO for sulphate is 100 mg/l and the concentrations recorded in this study both in dry and rainy seasons are within the permissible limit of the WHO standard for good quality water.

Dissolved Oxygen (DO) levels from the study revealed a range of 1.1 mg/l – 6.87 mg/l and 2.6–8.45, and a mean range of 1.28 ± 0.2–5.3 ± 1.4 and 3.94 ± 0.61–7.15 ± 1.12 for dry and rainy seasons, respectively. This is lower than the values of 6.51 ± 1.47 mg/l – 8.43 ± 0.21 mg/l reported by Bolarinwa, Fasakin and Fagbenro [23] in the analysis of the physicochemical parameters of coastal waters of Ondo State, Nigeria. The WHO permissible standard for DO is >6 mg/l. Most of the dissolved oxygen concentrations found in water from the sampled sites do not meet the WHO standard for quality drinking water. This could be as a result of the high concentrations of dissolved salts, suspended particles and hardness of the water that preclude the dissolution of oxygen in most of the water from the sampled sites.

4. Conclusion

The study set out to undertake the physicochemical analysis of water quality from multiple sources in Jalingo Metropolis, Nigeria. In Nigeria today, the use of ground water has become an agent of development because the government is unable to meet the ever increasing demand of water supply.

Water from natural sources is never completely pure. Most of the earth's water sources get their water supplies through precipitation. During precipitation water passes over (runoff) and through the ground (infiltration), acquiring a wide range of dissolved or suspended impurities that intensely alters its usefulness. The physicochemical parameters identified include temperature, electrical conductivity, total dissolved solids, manganese (Mn), iron (Fe), nitrate (NO3), sulphate (SO4), salinity, fluoride (F) and nitrite (NO2), which were within the permissible standards of WHO. Other parameters examined included pH, turbidity, chloride, hardness, alkalinity and dissolved oxygen, which were either lower or higher values outside the permissible standards of WHO and NSDW.

The study sampled three sources; well, borehole and tap water. The findings revealed that the tastes of water samples from the different sources differ. Tap water was found to be objectionable as compared to well and borehole sources. All the water sources recorded no odor. Physicochemical parameters of Total Dissolved Solids, Turbidity, and fluoride (F^-) recorded significant difference across the various water sources. All other variables recorded no significant difference across the different water sources in the study area.

5. Recommendations

Based on the findings of this study, the following recommendations are made:

i. There should be frequent water and treatment within Jalingo metropolis because of the bad practices of the indiscriminate waste disposal, excessive use of agro-chemicals that could contaminate the water sources.

ii. Policy makers and non-governmental organizations should intensify efforts in providing water that is safe for human consumption as some of the physicochemical parameters of the water in the study area (Jalingo Metropolis) are outside the recommended limits of WHO.

iii. Health officials and regulatory bodies should ensure that boreholes are not indiscriminately sited especially close to dumpsites and domestic sewages.

iv. Government should enforce the regulations on the excessive use of chemical fertilizers and on the indiscriminate waste disposal.

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