Original Research Article

Quality Assessment of Sokoto Water Distribution Networks

Abstract

The research is on the quality assessment of Sokoto water distribution networks. Sample coordinates of the study area were taken using GPS, the experiments were carried out at different consumer locations with thirty (30) samples of water collected weekly for four (4) weeks, to determine various purification parameters that are related to both bulk (k_b) and wall (K_W) reactions coefficients for Sokoto water distribution pipe network, these include residual chlorine, pH, dissolved oxygen (DO), temperature and conductivity.pH, dissolved oxygen (DO) and conductivity have average values ranging from 6.7 to 7.5; 1.1 to 6.5ppm; 310 to 520µs/cm respectively and conform to the Nigerian Standard for Drinking Water Quality (NSDWQ), except temperature which has the average values between 29^{o}C, and32.6^{o}C, and the individual values between 26^{o}C, and 38.4^{o}C, chlorine residual average values obtained, ranging from 0.11mg/l to 0.26mg/l with the lowest individual value obtained being 0.011mg/l.The age of water supply from the treatment plants in the distribution network is 6 hours and both first and second-order decay reactions were ascertained from the graph and first-order decay having the highest number of occurrences was used in Epanet 2.0 water quality modeling. The k_b values ranged from 0.0025 to $0.013md^{-1}$. A total of 86 out of the 120 samples, which constitute 71.7% were straight lines which indicate first-order and thus, the average k_b was determined to be 0.006/day (0.144/hour). It was observed that of all the 120 samples examined in the study, chlorine reaction with natural organic matter (NOM) was small. The average k_w for Sokoto WDS was deduced to be 0.078m/h, considering, the following steel pipe conditions used in the network area.k_W (ft/h), $-\alpha = -38.5$, H-W C=150, $k_W = 38.5/150 = 0.257$ft/h = 0.078m/h (-0.078m/h).

Keywords: Quality Assessment, Water Distribution Network, Pipe Network, Geographical Information System (GIS). Bulk and Wall decay coefficients.

1.0 INTRODUCTION

Everywhere in the world, drinking water utilities face the challenge of providing water of good quality to their consumers as significant water quality changes can occur within drinking water distribution systems due to contamination. Chlorine disinfection is one of the key factors in the drinking water treatment process. However, chlorine disinfection may cause unpleasant tastes and odours to the chlorine residual, corrosion of pipes, and disinfection by-products among others (Ahn*et al*, 2012)

Water service providers must practice, disinfection before supplying water to consumers to prevent the outbreak of waterborne infectious diseases (Clark, 1998). Bacteriological contamination of water is a major contributor to waterborne diseases. Millions of such cases occur annually in developing countries, including Nigeria (WHO, 2004).

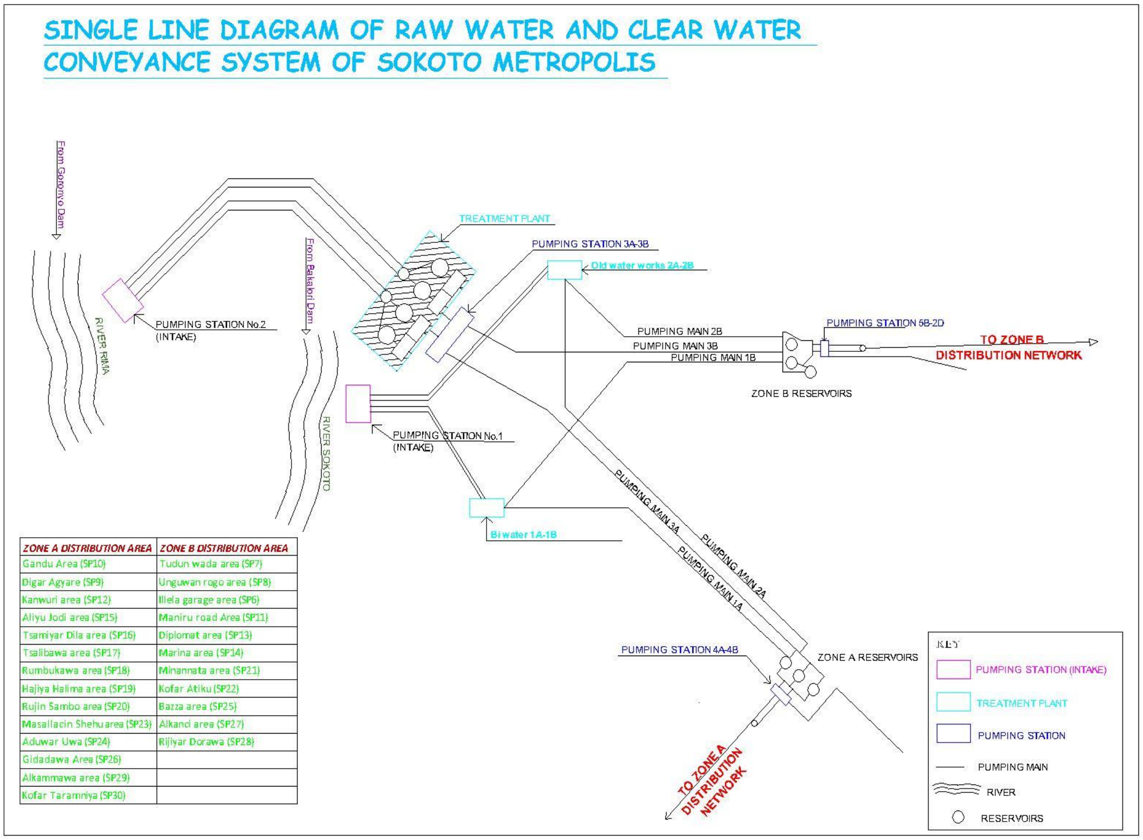
Disinfection of water using chlorine is an essential water treatment process step that renders the water supplied to consumers bacteriologically safe. The amount of chlorine added for disinfection is controlled in such a way that there is adequate residual chlorine present as the water flows through the distribution system until it reaches the consumers. The presence of minimum residual chlorine guarantees that recontamination does not occur as well as deterioration in the aesthetic quality of water due to the growth of organisms within the distribution system does not occur. Excess chlorination is the chlorination of water over and above the minimum dose that is required to ensure potable water quality. Practices of excess chlorination give rise to the formation of disinfection by-products (DBPs) in water, which are compounds known to be associated with health risks related to cancer. The problem related to the maintenance of residual chlorine is increased by water supply interruptions that lead to the formation of stagnant water, which, during the resumption of supply, may be drawn with no chlorine residual left as the water reaches the consumers. Old water supply systems with pipes that have deteriorated linings encourage microbial growth in the distribution pipe, which in turn results in rapid loss of chlorine due to the wall decay reaction (Ababuet al, 2019)

Decay of chlorine residual, caused by reacting in the bulk of flow and at walls of network elements, may lead to the disappearance of disinfectant at network extremities and hence increasing the probability of microbiological contamination of drinking water (Vieira *et al* 2004, and Castro *et al* 2003)

2.0 MATERIALS AND METHODS

2.1 Sokoto Water Distribution Network (WDN)

The location of the Sokoto metropolis from the purification plant to the pumping stations and the distribution areas is shown in Figure 3. Raw water from Goronyo dam on River Sokoto intake is treated at the new extension purification plant and also draw water from Bakalori dam on River Rima, is treated at Old water and Bi-water treatment plants being transported with pumps to Zone A (Old market), and Zone B (Mabera Ali Akilu road) plants. Water from the distribution plant reservoirs at both zone A and zone B underground reservoirs are pumped up to overhead tanks at Old Market and Mabera respectively, it is then, distributed by gravity to the Sokoto metropolis supply area. It is suitable for modelling because the major water source in the state is Goronyo and Bakalori dams which feed the Sokoto metropolis through the treatment plants. Pipes of almost all diameters are considered in modelling (50mm, 75mm, 77mm, 100mm, 150mm, 200mm, 250mm, 300mm, 350mm, 450mm, 500mm 550mm and 600mm). Hazen-Williams formula is used as a head loss equation. Most pipes in Sokoto town were buried between 1960-1980. Almost all pipes in the metropolis are steel pipes and not lined.



ZONE A DISTRIBUTION AREA	ZONE B DISTRIBUTION AREA
Gandu Area (SP10)	Tudun wada area (SP7)
Digar Agyare (SP9)	Unguwan rogo area (SP8)
Kanwuri area (SP12)	Illela garage area (SP6)
Aliyu Jodi area (SP15)	Maniru road Area (SP11)
Tsamiyar Dila area (SP16)	Diplomat area (SP13)
Tsalibawa area (SP17)	Marina area (SP14)
Rumbukawa area (SP18)	Minannata area (SP21)
Hajiya Halima area (SP19)	Kofar Atiku (SP22)
Rujin Sambo area (SP20)	Bazza area (SP25)
Masallacin Shehu area (SP23)	Alkanci area (SP27)
Aduwar Uwa (SP24)	Rijiyar Dorawa (SP28)
Gidadawa Area (SP26)	
Alkammawa area (SP29)	
Kofar Taramniya (SP30)	

Figure 1: Existing Water Distribution Components of Sokoto Water Supply.

2.2Water Sampling Program (field sampling studies)

1. The Pipe Distribution Map of the township was used to locate suitable sample points that represent the source and demands nodes in the metropolis.

2.The chlorinated treated water sample was collected from thirty (30) sample points, within the township, which includes samples from the source nodes and demand nodes respectively i.e. treatment plants, distribution stations, and consumers tap.

3. The samples were collected in sterilized bottles and then brought to the laboratory.

4. The samples were collected hourly every week, a total of thirty (30) treated water samples were collected weekly, examined accordingly and continuously for the period of four (4) weeks (April 2017 to May 2017).

5. The laboratory tests carried out are residual chlorine, pH, temperature, conductivity, dissolved solids (DO), and bulk and wall chlorine decay coefficients.

2.2.1 Water Sample Points (Hydrants) for the Investigation

Data were collected from field sampling studies that were performed for the period of four (4) weeks April 2017 to May 2017. Sampling points (hydrants) are shown below.Grabbed samples of treated chlorinated water were taken from the following thirty (30) different points, representing the areas being served with surface water in the Sokoto metropolis.Water samples were collected weekly, and examined accordingly and continuously for the period of the investigation. Samples were collected following the standard sampling guidelines and methods, the samples were collected into sterilized bottles and transported immediately to the laboratory for analysis.

(1) Sample ‘1’ at treatment Plant
(2) Sample '2' at Old waterworks
(3) Sample ‘3’ at Bi-water works
(4) Sample ‘4’ at Pumping Station 4(Old Market)
(5) Sample ‘5’ at Pumping Station 5 (Mabera)
(6) Sample ‘6’ at Illela garage area.
(7) Sample ‘7’ Tudunwada area.
(8) Sample ‘8’ at UnguwanRogo area
(9) Sample ‘9’ at DigarAgyare
(10) Sample ‘10’ at Gandu area.
(11) Sample ‘11’ at Maniru road area
(12) Sample ‘12’ at Kanwuri area.
(13) Sample ‘13’ at Diplomat area.
(14) Sample ‘14’ at Marina area.
(15) Sample ‘15’ at Aliyu Jodi area
(16) Sample ‘16’ TsamiyarDila area.
(17) Sample ‘17’ at Tsalibawa area.
(18) Sample ‘18’ at Rumbukawa area
(19) Sample ‘19’ at Hajiya Halima area
(20) Sample ‘20’ at RujinSambo area
(21) Sample ‘21’ at Minannata area.
(22) Sample ‘22’ at KofarAtiku
(23) Sample ‘23’ MasallacinShehu area
(24) Sample ‘24’ AduwarUwa
(25) Sample ‘25’Bazza area
(26) Sample ‘26’ Gidadawa area
(27) Sample ‘27’ Alkanci area
(28) Sample ‘28’ RijiyarDorowa
(29) Sample ‘29’ Alkammawa area
(30) Sample ’30’ KofarTaramniya

2.2.2 Global Positioning System (GPS) Sample coordinates for the Study Area

Global positioning system (GPS) Garmin instrument, was used to determine the sample coordinate for the study area, from the Google earth to effectively locate the consumer demand point within the metropolis as shown in Table 1

Table 1: Showing GPS Coordinate values for the Study Area

GLOBAL POSITIONING SYSTEM (GPS) SAMPLE COORDINATES FOR THE STUDY AREA

S/No.	NORTHING	EASTING	SAMPLE ID	SAMPLE NAME	DEPTH	IC
1	13.0813	5.2595	Sample 1	Treatment Plant	249m	6
2	13.07687	5.25652	Sample2	Old water works	253m	8
3	13.07597	5.25752	Sample 3	Bi-water works	280m	7
4	13.06434	5.23598	Sample 4	Pumping St. 4 (Old Market)	282m	25
5	13.0384	5.24912	Sample 5	Pumping Station 5 (Mabera)	292m	23
6	13.07573	5.25713	Sample 6	Illela garage area	281m	8
7	13.0641	5.25679	Sample 7	Tudunwada area	280m	18
8	13.04448	5.25126	Sample 8	UnguwanRogo area	286m	21
9	13.06646	5.23625	Sample 9	DigarAgyare	288m	28
10	13.06631	5.22341	Sample 10	Gandu Area	287m	31
11	13.0598	5.25169	Sample 11	Maniru road Area	288m	16
12	13.06805	5.24817	Sample 12	Kanwuri area	287m	12
13	13.04643	5.2465	Sample 13	Diplomat area	278m	20
14	13.05507	5.24825	Sample 14	Marina area	283m	15
15	13.05927	5.23059	Sample 15	Aliyu Jodi area	292m	26
16	13.06564	5.23565	Sample 16	TsamiyarDila area	291m	30
17	13.07461	5.25127	Sample 17	Tsalibawa area	293m	9
18	13.0744	5.23529	Sample 18	Rumbukawa area	294m	5
19	13.05858	5.22587	Sample 19	Hajiya Halima area	294m	27
20	13.06768	5.21841	Sample 20	RujinSambo area	278m	32
21	13.04744	5.25931	Sample 21	Minannata area	276m	22
22	13.05562	5.24147	Sample 22	KofarAtiku	280m	19
23	13.06637	5.24823	Sample 23	MasallacinShehu area	278m	13
24	13.07641	5.25055	Sample 24	AduwarUwa	264m	10
25	13.06353	5.25399	Sample 25	Bazza area	276m	17
26	13.06564	5.23565	Sample 26	Gidadawa Area	283m	11
27	13.07009	5.25032	Sample 27	Alkanci area	269m	11
28	13.06768	5.21841	Sample 28	RigiyarDorawa	264m	23
29	13.05778	5.23736	Sample 29	Alkammawa area	264m	24
30	13.05913	5.25009	Sample 30	KofarTaramniya	259m	14

2.3Water Distribution Network Hydraulics of Sokoto City

The potable water distribution network (WDN), under study, serves Sokoto City, the capital of Sokoto state, Nigeria and has been in service since the 1960s. The network is fed through two surface water sources (from three plants producing (81, 445 m^3 d^{-1}). Sokoto City was initially divided into four zones; zone A; is the northern part of the town served by reservoirs located at the old market area Zone B; is the eastern sector of the town served by reservoirs located at Ali Akilu road Zone C; occupies the western sector of the town and is served by reservoirs located at Arkilla and zone D; occupies the southern part of the town and is served by reservoirs located at Gwiwa, serving a population of 635,000 up till the end of 2010. At present, zone C &D is being connected to the underground water source at the Asare water treatment plant. The research area covers zones A and B, which serves the main township and the old Sokoto metropolis, connected by surface sources. The network following the above-mentioned description consists of 31 pipes with diameters of 100, 150, 200, 250, 300, 350, 400 and 600 mm. The modelled pipes were fabricated mainly from steel iron installed in the late 1960s.

Developing the hydraulic model for Sokoto city, water distribution network involved the following steps: (1) Creating a pipe network from the water system GPS files to locate the sampling points (2) Spatially allocating demands, pipe and node properties; (3) Assigning elevations to pipe network nodes from GPS data; (4) Incorporating boundary condition elements (e.g., pumps, ground storage reservoirs); and (5) Performing calibration, validation and a quality control review of the resulting model.

2.3.1 Hydraulic Modeling

A Water Treatment Plant (WTP) with an overall capacity of 32,000m^3/d (370 l/s) was used for this study. The WTP treats source water by conventional processes including pre-chlorination, coagulation/flocculation, sedimentation, rapid sand filtration and post-chlorination. The distribution system has two service tanks, four reservoirs and two pumping stations. The distribution system consists of two zones: Old Market (OM) zone and Ali Akilu (AK) zone. The finished water is supplied to both (OM) and (AK) zones by gravity because it is in a hilly area. Customers' water usage, pipe diameters, elevation and other related data were inputted, to perform hydraulic network modelling with Epanet 2.0. The network model consisted of 31 pipes and 30 junctions. The network model was simulated with a 6-hour demand pattern for an extended period simulation (EPS). The EPS is a tool for the simulation of distribution system behaviour under time-varying demand and operational conditions.

2.3.2Epanet 2.0 Model Setup for Sokoto Water Distribution Network

Epanet models a water distribution system as a collection of links connected to nodes. The links represent pipes, pumps and control valves. The nodes represent junctions, tanks and reservoirs. Each one of these objects requires basic input data for the proper operation of the model.

2.4 Experimental Procedures of the Parameters 2.4.1 Determination of Temperature:-

Temperature degree centigrade was determined by inserting the thermometer into the glass containing water samples and the reading was read on it. The temperature is usually measured in degree centigrade (^{o}C) Fahrenheit (F).

2.4.2 Determination of pH: -

Procedure: -The vial of the pH Sension portable meter was washed and cleaned with the samples to be tested. The vial was filled with 20ml of the sample and placed into the compartment of the sensitive digital pH meter 2100 and the electrode of the meter was inserted. The 'on' button was pressed and thepH reading wasselected pH reading of the samples was displayed on the screen and the procedure was repeated for all the samples of water.

2.4.3 Determination of Conductivity: - **Procedure:-**The vial of the conductivity sensor portable meter was washed and cleaned with the samples to be tested. The vial was filled with 20ml of the sample and placed into the compartment of the sensitive digital conductivity meter 2100 and the electrode of the meter wasinserted. The 'on' buttonwas pressed and the conductivity reading wasselected, conductivity reading of the samples was displayed on the screen and the procedure was repeated for all the samples of water.

2.4.4 Determination of Residual Chlorine:- **Procedure:**Testing for chlorine residual:-The most common test is the dpd (diethyl para phenylenediamine) indicator test, using a comparator. This test is the quickest and the simplest method for testing chlorine residual, with this test, a tablet reagent is added to a sample of water, colouring it red, the strength of colour is measured against standard colours on a chart to determine the chlorine concentration. The stronger the colour, the higher the concentration of chlorine in the water. (WHO, 2004)

2.4.5 Residual Chlorine Modeling Procedure

The measurement was conducted weekly in the laboratory, the chlorinated water samples were obtained in sterilized bottles from the distribution network and the overhead reservoirs (OHR) through the metropolis map and were placed in a 75cl bottle, space free, at ambient water temperature, individual bottles are then opened at different times and the residual chlorine was measured at 3hour intervals (i.e., at 0, 3 and 6 hour, between 9:00am and 3:00pm) at the laboratory, after all the samples were collected from the study area.

Chlorine decay was measured by drawing samples from the bottle at fixed time intervals. The average pH, conductivity, dissolve oxygen, and temperature of the sample were observed respectively. The data was plotted on a semi-log graph of chlorine residual vs. time , with the slope representing the decay rate over the period of measurement for each weekly samples, and consequently, the average values were determined for all the weeks. The chlorine concentration was determined at the start and end of the experiment respectively. From the graph plot, some are found to be straight line, some curved inward (concave), and some curved outward (convex). The resulting straight-line graphs are considered first-order kinetics and also the value of k_b was determined from the graph to be both 1st and 2nd order, but, first order was applied based on the dominance reaction occurring in the system. The same is used for water quality simulations. The first sampling point (sample1), contains chlorine concentration after the complete mixing in the overhead reservoir (OHR) and represents the actual initial chlorine entering the system, meanwhile, if chlorine reacts with the natural organic matter (if present) in the source water, which is also a contributing factor for bulk decay coefficient. $K_w$is determined (calculated) based on the type of material and the headloss roughness coefficient used and the following equation is used:

$K_w = (\alpha / Cc)$ (2.0)

$K_w(ft/d)$, $-\alpha = -38.5$, *and* **Cc=C**

Hazen William (H-W) C=150, for steel pipes.

Table 2: Input Properties for Epanet 2.0 Sokoto Model

S/N	PIPES ;ID	Node1	Node2	Length (m)	Diameter (mm)
1	1	39	45	1775	600
2	2	36	41	2000	600
3	3	40	46	1500	600
4	4	35	41	1775	450
5	5	38	45	1500	600
6	6	37	42	1995	375
7	8	48	32	30	100
8	10	43	33	30	100
9	11	32	8	850	350
10	12	8	15	950	200
11	13	15	16	825	200
12	14	16	17	700	200
13	15	15	10	850	200
14	18	26	25	600	200
15	19	24	25	500	200
16	20	24	23	500	200
17	21	8	18	950	200
18	23	8	20	950	200
19	24	8	21	995	200
20	25	33	14	900	300
21	26	10	9	700	200
22	28	14	22	900	150
23	29	14	13	600	300
24	30	27	11	450	200
25	31	11	12	400	200
26	32	13	34	850	200
27	33	34	12	650	200
28	34	32	23	900	200
29	35	33	28	650	300
30	36	28	29	600	250
31	37	29	30	900	200
32	38	30	31	900	150
33	39	18	19	950	200

34	42	47	32	30	100
35	45	44	33	30	100

3.0 RESULTS AND DISCUSSIONS

3.1 Water Analysis of Essential Parameters

The Results of five parameters that are crucial to water quality are discussed, they are: - pH, Temperature, Dissolved Oxygen (DO), Conductivity and Residual Chlorine:

3.1.1 pH Value (Hydrogen iron concentration)

The concept of the acidity or alkalinity of either water or any solution is based on the pH scale, which ranges from 0-14 (Corington et al, 2001; WRN, 2016). pH is an acronym which stands for the *potential of hydrogen* and is simply a measure of the concentration of hydrogen ions [H+] or activity in water. The chemists define pH as the negative logarithm of hydrogen ion [H+] concentration (mol/L) in an aqueous solution and can be represented by the equation: pH = -log10 [H+] = log10 1/[H+] OR [H+] = 10 –pH, as an indication of whether water or any solution is acidic or alkaline and the intensity. pH value is a good indicator of whether water is hard or soft. Pure water has a pH of 7, thus pH below 7 is considered acidic and pH above 7 is alkaline. Surface water has pH range from 6.5 to 8.5, while pH of groundwater is between 6 to 8.5. Alkalinity is defined as the capacity of water to resist pH changes that would tend to make the water more acidic. pH also determines whether water is corrosive or toxic, thus pH measurement is needed to determine the corrosiveness of the water. pH affects most chemical and biological processes in water and it is one of the most important environmental factors limiting the distribution of species in aquatic habitats. Where the pH exceeds 8.0, disinfection is less effective. From the results in Table 4, all the average pH value for the 120 samples observed in the metropolis were found to be within the range of 6.7 to 7.5 which conforms with the Nigerian Standard for Drinking Water Quality (NSDWQ) guidelines and World Health Organization (WHO) maximum permissible limits of 6.5-8.5. (W.H.O. 2004), with the exception of only sample 12 (Kanwuri area) for the third week of the individual samples which is found to be 6.2, which signifies that the disinfectant is effective and the drinking water is pure even though excess pH does not have any health impact on human. Sample average (SA), Sample variance (SV), and Standard deviation (SD) of the parameter is 7.16, 0.033, and 0.18 respectively.

Table 3: Average pH in Comparison with NSDWQ & WHO Standards

S/N	**Sampling Points (Junctions)**	**Av. pH** Value	**pH Sample Average**	**NSDWQ MPL**	**WHO MPL**	**Health Impact**
1	Treatment Plant	7.2	7.16	6.5 -8.5	6.5 -8.5	None
2	Old water works	7.4	7.16	6.5 -8.5	6.5 -8.5	None
3	Bi-water works	7.3	7.16	6.5 -8.5	6.5 -8.5	None
4	Pumping Station 4(Old Market)	7	7.16	6.5 -8.5	6.5 -8.5	None
5	Pumping Station 5(Mabera)	7	7.16	6.5 -8.5	6.5 -8.5	None
6	Illela Garage Area	7.1	7.16	6.5 -8.5	6.5 -8.5	None
7	Tudunwada Area	7.2	7.16	6.5 -8.5	6.5 -8.5	None

8	UnguwanRogo	7.2	7.16	6.5 -8.5	6.5 -8.5	None
9	DigarAgyare	7.1	7.16	6.5 -8.5	6.5 -8.5	None
10	Gandu Area	7.1	7.16	6.5 -8.5	6.5 -8.5	None
11	Maniru road area	7.4	7.16	6.5 -8.5	6.5 -8.5	None
12	Kanwuri area	6.7	7.16	6.5 -8.5	6.5 -8.5	None
13	Diplomat area	7.2	7.16	6.5 -8.5	6.5 -8.5	None
14	Marina area	7	7.16	6.5 -8.5	6.5 -8.5	None
15	Aliyu Jodi	7.3	7.16	6.5 -8.5	6.5 -8.5	None
16	TswamiyarDila	7.3	7.16	6.5 -8.5	6.5 -8.5	None
17	Tsalibawa area	7.3	7.16	6.5 -8.5	6.5 -8.5	None
18	Rumbukawa area	7.4	7.16	6.5 -8.5	6.5 -8.5	None
19	Hajiya Halima area	7	7.16	6.5 -8.5	6.5 -8.5	None
20	RunjinSambo	7	7.16	6.5 -8.5	6.5 -8.5	None
21	Minanata	6.9	7.16	6.5 -8.5	6.5 -8.5	None
22	KofarAtiku	7.5	7.16	6.5 -8.5	6.5 -8.5	None
23	MasallacinShehu	7	7.16	6.5 -8.5	6.5 -8.5	None
24	AduwarUwa	7.1	7.16	6.5 -8.5	6.5 -8.5	None
25	Bazzah area	7.1	7.16	6.5 -8.5	6.5 -8.5	None
26	Gidadawa area	7.2	7.16	6.5 -8.5	6.5 -8.5	None
27		7.1	7.16	6.5 -8.5	6.5 -8.5	None
28	RijiyarDorawa	7	7.16	6.5 -8.5	6.5 -8.5	None
29	Alkammawa area	7.4	7.16	6.5 -8.5	6.5 -8.5	None
30	KofarTaramniya	7.4	7.16	6.5 -8.5	6.5 -8.5	None

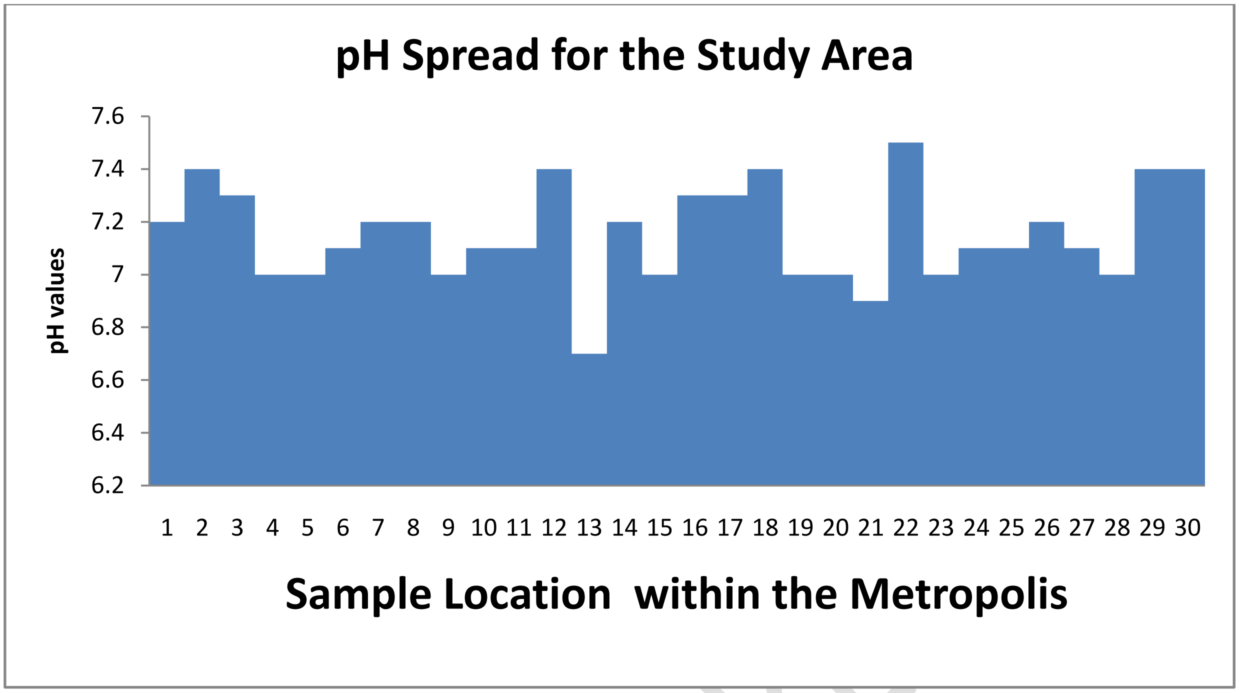


Figure 2: pH Distribution for the Study Area

3.1.2Temperature (°C):-

Domestic drinking water supply systems (DDWSs) are the final step in the delivery of drinking water to consumers. Temperature is one of the rate-controlling parameters for many chemical and microbiological processes and is, therefore, considered as a surrogate parameter for water quality processes (Urban Water Journal, 2017). The temperature of drinking water at the customers' tap is not allowed to exceed 25°C. To limit the regrowth of microorganisms, the World Health Organization also recommends this maximum value (WHO, 2006). From the results in Table 4, all the average temperature values for the 120 samples examined in the metropolis were found to be within the range of 29^{o}C and 32.6^{o}C at UnguwanRogo&Kanwuri areas respectively. Lowest tempt. of 26^{o}C recorded at KofarTaramniya (3rd week) and the highest tempt., of 38.4 recorded at KofarAtiku area. Because Sokoto is located in a tropical region it has a peculiar case of having higher temperatures above the WHO permissible limits and NSDWQ MPL is at ambient temperature and it does not have a health impact on humans as a result of higher temperature values. The sample average (SA), Sample variance (SV), and Standard deviation (SD) of the parameter are 30.8^{o}C, 0.824^{o}C, and 0.91^{o}C respectively.

Table 4: Average Temperature in Comparison with NSDWQ & WHO Standards

S/N	Sampling Points (Junctions)	Av. Tempt. Value(^{o}C)	Tempt. Sample Average (^{o}C)	NSDWQ MPL	WHO MPL	Health Impact
1	Treatment Plant	31.3	30.8	Ambient	25	None
2	Old water works	30.3	30.8	Ambient	25	None
3	Bi-water works	30.2	30.8	Ambient	25	None

4	Pumping Station 4(Old Market)	30	30.8	Ambient	25	None
5	Pumping Station 5(Mabera)	31.5	30.8	Ambient	25	None
6	Illela Garage Area	30	30.8	Ambient	25	None
7	Tudunwada Area	30	30.8	Ambient	25	None
8	UnguwanRogo	29	30.8	Ambient	25	None
9	DigarAgyare	29.4	30.8	Ambient	25	None
10	Gandu Area	31.4	30.8	Ambient	25	None
11	Maniru road area	32	30.8	Ambient	25	None
12	Kanwuri area	32.6	30.8	Ambient	25	None
13	Diplomat area	31	30.8	Ambient	25	None
14	Marina area	30.7	30.8	Ambient	25	None
15	Aliyu Jodi	30.9	30.8	Ambient	25	None
16	TswamiyarDila	30	30.8	Ambient	25	None
17	Tsalibawa area	30.6	30.8	Ambient	25	None
18	Rumbukawa area	31	30.8	Ambient	25	None
19	Hajiya Halima area	30.8	30.8	Ambient	25	None
20	RunjinSambo	30.5	30.8	Ambient	25	None
21	Minanata	30	30.8	Ambient	25	None
22	KofarAtiku	32.6	30.8	Ambient	25	None
23	MasallacinShehu	32.5	30.8	Ambient	25	None
24	AduwarUwa	31.1	30.8	Ambient	25	None
25	Bazzah area	30.9	30.8	Ambient	25	None
26	Gidadawa area	30.4	30.8	Ambient	25	None
27	Alkanci area	31.8	30.8	Ambient	25	None
28	RijiyarDorawa	37.3	30.8	Ambient	25	None
29	Alkammawa area	38	30.8	Ambient	25	None
30	KofarTaramniya	32	30.8	Ambient	25	None

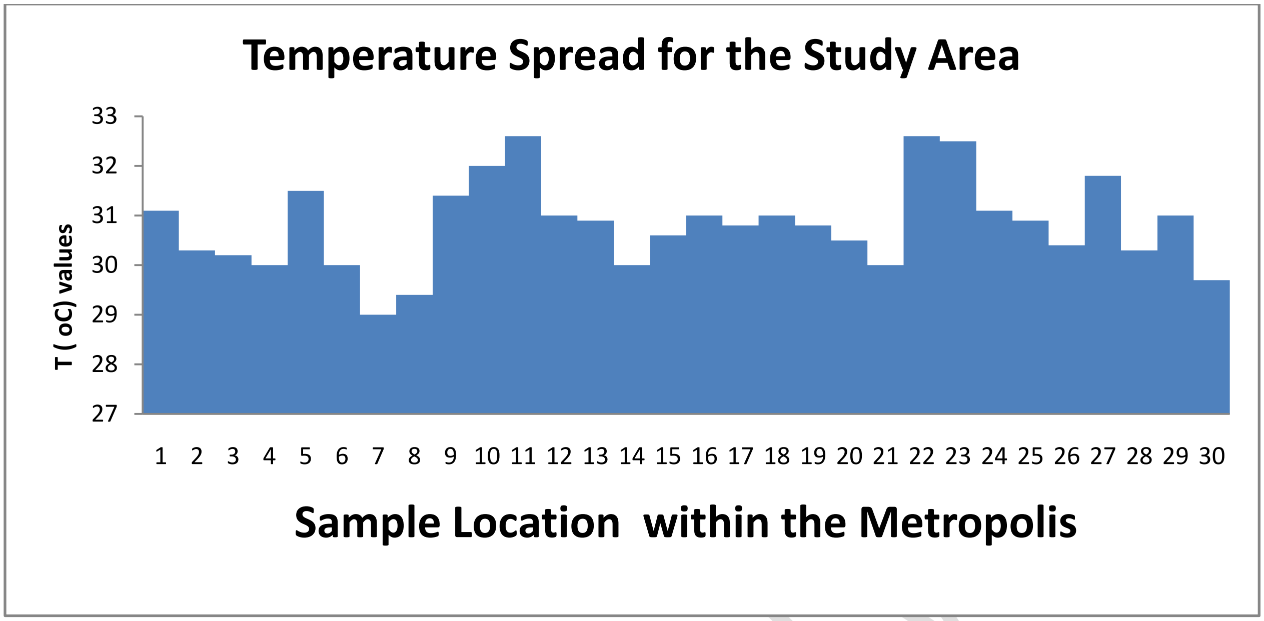


Figure 3: Temperature Distribution for the Study Area

3.1.3 Dissolved Oxygen (DO)

All living organisms depend upon oxygen to maintain the metabolic processes that produce energy for growth and reproduction. Dissolved oxygen is important in precipitation and dissolution of inorganic substances in waterand it is an important factor in corrosion. (NEERI, 2017). From the results, all average DO value for the 120 samples examined in the metropolis were found to be within the range of 1.1 to 6.5ppm. A reasonable DO level in a community water supply is good because it makes drinking water taste better. However, high DO level speed up corrosion in water pipes and causes decay of the chlorine content. Garg, 2008, states thatoxygen gas is generally absorbed by water from the atmosphere, but is being consumed by unstable organic matter for their oxidation. Hence if the oxygen present in water is found to be less than its saturated level (1-10ppm), it indicates the presence of organic matter and consequently making the waters suspicious. The amount of D.O. for potable waters should not be less 1ppm and should not exceed 10ppm. The result obtained signifies that the drinking water supply of Sokoto metropolis is free from organic matter, if less than 1 or more than 10ppm the water must be analysed to determine the wholesomeness of the water. The sample average (SA), Sample variance (SV), and Standard deviation (SD) of the parameter is 3.07mg/l, 1.347mg/l, and 1.16mg/l respectively.

Table 5: Dissolve Oxygen (DO) in Comparison with the Standard

S/N	**Sampling Points (Junctions)**	**Av. DO** Value(ppm)	**DO Sample Average**(ppm)	**NSDWQ**	**WHO MPL** (ppm)	**Health Impact**
1	Treatment Plant	2.1	3.07	-	10	Suspicious
2	Old water works	1.6	3.07	-	10	Suspicious

3	Bi-water works	2.1	3.07	-	10	Suspicious
4	Pumping Station 4(Old Market)	3.3	3.07	-	10	Suspicious
5	Pumping Station 5(Mabera)	2.9	3.07	-	10	Suspicious
6	Illela Garage Area	6.5	3.07	-	10	Suspicious
7	Tudunwada Area	3.6	3.07	-	10	Suspicious
8	UnguwanRogo	2.6	3.07	-	10	Suspicious
9	DigarAgyare	2.2	3.07	-	10	Suspicious
10	Gandu Area	2.1	3.07	-	10	Suspicious
11	Maniru road area	1.4	3.07	-	10	Suspicious
12	Kanwuri area	4.4	3.07	-	10	Suspicious
13	Diplomat area	3.1	3.07	-	10	Suspicious
14	Marina area	4.6	3.07	-	10	Suspicious
15	Aliyu Jodi	3.4	3.07	-	10	Suspicious
16	TswamiyarDila	4.1	3.07	-	10	Suspicious
17	Tsalibawa area	2.2	3.07	-	10	Suspicious
18	Rumbukawa area	2.4	3.07	-	10	Suspicious
19	Hajiya Halima area	2.5	3.07	-	10	Suspicious
20	RunjinSambo	4.2	3.07	-	10	Suspicious
21	Minanata	1.1	3.07	-	10	Suspicious

22	KofarAtiku	4.5	7.16	-	10	Suspicious
23	MasallacinShehu	7	7.16	-	10	Suspicious
24	AduwarUwa	7.1	7.16	-	10	Suspicious
25	Bazzah area	7.1	7.16	-	10	Suspicious
26	Gidadawa area	7.2	7.16	-	10	Suspicious
27	Alkanci area	7.1	7.16	-	10	Suspicious
28	RijiyarDorawa	7	7.16	-	10	Suspicious
29	Alkammawa area	7.4	7.16	-	10	Suspicious
30	KofarTaramniya	7.4	7.16	-	6.5 - 8.5	Suspicious

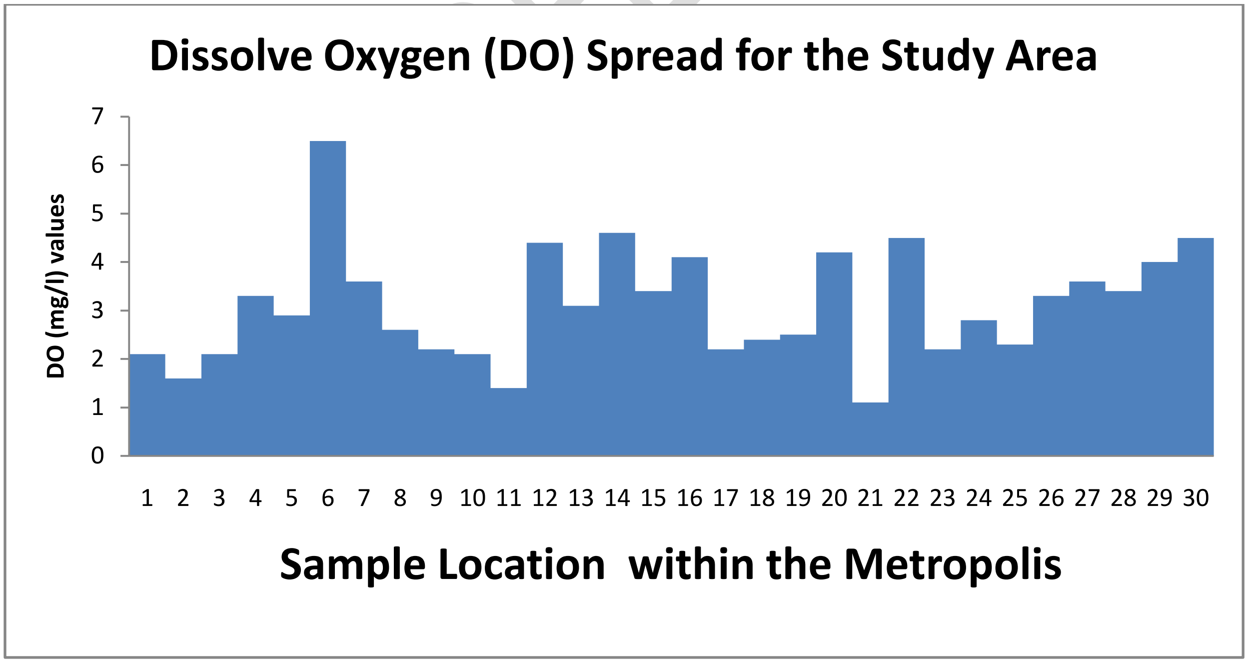


Figure 4: Dissolve Oxygen Distribution for the Study Area

3.1.4 Conductivity:

Electrical conductivity is the measure of water capacity to conveying electricity (Scott *et al.*, 2001). For water the value in µs/cm is roughly proportional to the concentration of dissolved solids. Thus 150µs/cm corresponds to about 100mg/l of total dissolved solids. Electrical conductivity is also used to monitor changes in the quality of water to check if leachate is seeping (Scott, 2001). Electrical conductor (EC) was done by sensitive digital Conductivity meter 2100 and from the results, all the average Conductivity value for the 120 samples examined in the metropolis were found to be within the range of 310µs/cm to 520µs/cm EC. Individual drinking water samples recorded in Sokoto metropolis were found to range from 180 to 600µs/cm, highest value of 600µs/cm was recorded from Maniru road area, Illela garage area and Gandu areas, these areas have higher dissolved solids while lowest value of 180µs/cm was recorded at Tudun-wada which invariably have the lowest dissolve solids and have good quality monitoring. NSDWQ MPL of 1000µs/cm while WHO recommended EC value for drinking water to be 400µs/cm which means almost all the individual and averages sample values complied with the NSDWQ standard with exception of Bi-water works, Pumping station 5 (Mabera) and Gandu area that are above WHO permissible limits, despite that it does not have any health hazard on human consumption. If total dissolved solid (TDS) is high, the organic matter present will decay chlorine rapidly and if low, organic matter is low and it indicates that water quality is good. The result indicates palatability of water and will have less effect on residual chlorine. Sample average (SA), Sample variance (SV), and the Standard deviation (SD) of the parameter is 350.8µs/cm, 201.06µs/cm, and 44.8µs/cm respectively.

Table 6: Conductivity in Comparison with NSDWQ & WHO Standards

S/N	Sampling Points (Junctions)	Av. Cond.(C)µS/cm	Sample Av. µS/cm	NSDWQ MPL µS/cm	WHO MPLµS/cm	Health Impact
1	Treatment Plant	350	350.8	1000	400	None
2	Old water works	410	350.8	1000	400	None
3	Bi-water works	520	350.8	1000	400	None
4	Pumping Station 4(Old Market)	340	350.8	1000	400	None
5	Pumping Station 5(Mabera)	390	350.8	1000	400	None
6	Illela Garage Area	330	350.8	1000	400	None
7	Tudunwada Area	360.3	350.8	1000	400	None
8	UnguwanRogo	370	350.8	1000	400	None
9	DigarAgyare	450	350.8	1000	400	None
10	Gandu Area	370	350.8	1000	400	None
11	Maniru road area	330	350.8	1000	400	None
12	Kanwuri area	310	350.8	1000	400	None
13	Diplomat area	310	350.8	1000	400	None

14	Marina area	310	350.8	1000	400	None
15	Aliyu Jodi	310.3	350.8	1000	400	None
16	TswamiyarDila	350	350.8	1000	400	None
17	Tsalibawa area	390	350.8	1000	400	None
18	Rumbukawa area	340	350.8	1000	400	None
19	Hajiya Halima area	360.3	350.8	1000	400	None
20	RunjinSambo	330	350.8	1000	400	None
21	Minanata	320	350.8	1000	400	None
22	KofarAtiku	350	350.8	1000	400	None
23	MasallacinShehu	310	350.8	1000	400	None
24	AduwarUwa	350	350.8	1000	400	None
25	Bazzah area	370	350.8	1000	400	None
26	Gidadawa area	340	350.8	1000	400	None
27	Alkanci area	370.3	350.8	1000	400	None
28	RijiyarDorawa	380	350.8	1000	400	None
29	Alkammawa area	320	350.8	1000	400	None
30	KofarTaramniya	350	350.8	1000	400	None

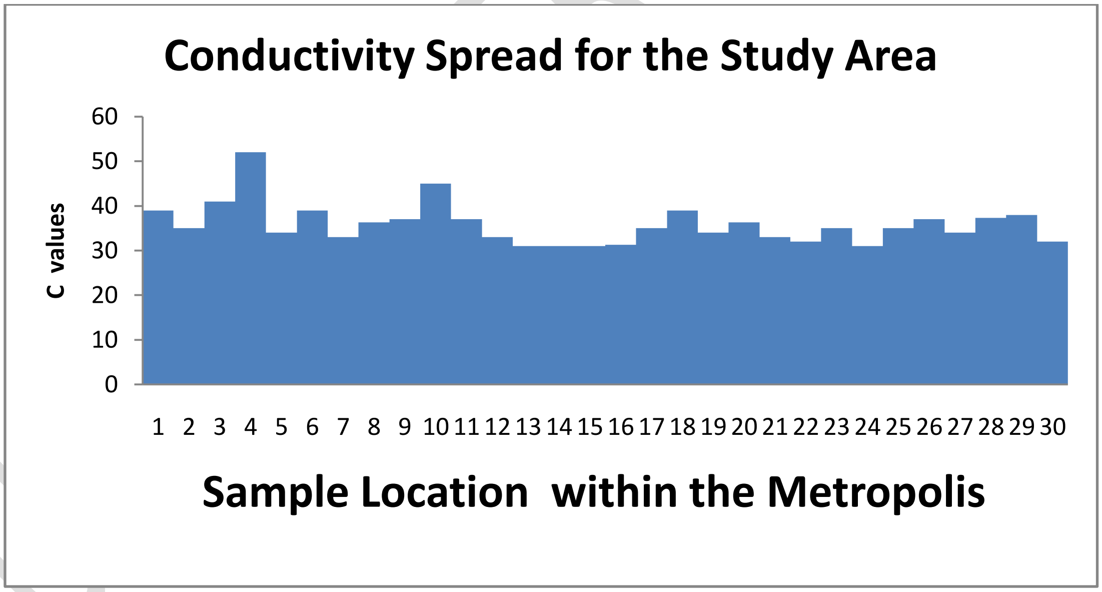


Figure 5: Conductivity Distribution for the Study Area

3.1.5 Residual Chlorine:

Despite the chlorine properties that can control the water bone diseases, its side effects required regulations and standards to limit to a minimum level. World health organization (WHO, 1993), set the free chlorine residual in drinking water to be around 0.2 - 0.3 mg/l. The disinfection of drinking-water supplies constitutes an important barrier against waterborne diseases. Although various disinfectants may be used, chlorine in one form or another is the principal disinfecting agent employed in communities in most countries. Chlorine has a number of advantages as a disinfectant, including its relative cheapness, efficacy, and ease of measurement, both in laboratories and in the field. The method recommended for the analysis of chlorine residual in drinking water is *N*, *N*-diethyl-*p*-phenylenediamine, more commonly referred to as DPD and from the results, all the average chlorine residual values for the 120 samples examined in the metropolis were found to be within the range of 0.11mg/l to 0.26mg/l. and at the treatment plant and RijiyarDorawa respectively. Also the lowest chlorine values for individual samples is 0.01mg/l at Rijiyardorawa (2nd week, SP 28) which is far away from the treatment plant, and requires booster chlorine plant to be installed in the area. The highest value is 0.27 at Old water works (4th week) & the New extension treatment plant (2nd and 3rd week). Higher temperature in the region affects the lower minimum chlorine level to the uniqueness of the state. Presence of free residual chlorine in drinking water indicates the likely absence of disease-causing organisms, it is used as one measure of the potability of drinking water, even though chlorine does not have any serious health impact on human, but if in excess can give rise to disinfectant bye products (DBP) the likes of trihalomethane (THM) and haloacetic acid. Sample average (SA), Sample variance (SV), and the Standard deviation (SD) of the parameter is 0.19mg/l, 0.003mg/l, and 0.06mg/l respectively.

Table 7 Average Residual Chlorine in Comparison with NSDWQ & WHO Standards

S/N	**Sampling Points (Junctions)**	**Average Chlorine** Value(mg/l)	**Chlorine Sample Average** (mg/l)	**NSDWQ MPL**	**WHO MPL**	**Remark**
1	Treatment Plant	0.26	0.19	0.2 - 0.25	0.2 - 0.3	None
2	Old water works	0.25	0.19	0.2 - 0.25	0.2 - 0.3	None
	Bi-water works	0.24	0.19	0.2 - 0.25	0.2 - 0.3	None
4	Pumping Station 4(Old Market)	0.23	0.19	0.2 - 0.25	0.2 - 0.3	None
5	Pumping Station 5(Mabera)	0.23	0.19	0.2 - 0.25	0.2 - 0.3	None
6	Illela Garage Area	0.18	0.19	0.2 - 0.25	0.2 - 0.3	None
7	Tudunwada Area	0.22	0.19	0.2 - 0.25	0.2 - 0.3	None
8	UnguwanRogo	0.2	0.19	0.2 - 0.25	0.2 - 0.3	None

9	DigarAgyare	0.21	0.19	0.2 - 0.25	0.2 - 0.3	None
10	Gandu Area	0.19	0.19	0.2 - 0.25	0.2 - 0.3	None
11	Maniru road area	0.21	0.19	0.2 - 0.25	0.2 - 0.3	None
12	Kanwuri area	0.17	0.19	0.2 - 0.25	0.2 - 0.3	None
13	Diplomat area	0.11	0.19	0.2 - 0.25	0.2 - 0.3	None
14	Marina area	0.16	0.19	0.2 - 0.25	0.2 - 0.3	None
15	Aliyu Jodi	0.16	0.19	0.2 - 0.25	0.2 - 0.3	None
16	Tswamiyar Dila	0.21	0.19	0.2 - 0.25	0.2 - 0.3	None
17	Tsalibawa area	0.22	0.19	0.2 - 0.25	0.2 - 0.3	None
18	Rumbukawa area	0.21	0.19	0.2 - 0.25	0.2 - 0.3	None
19	Hajiya Halima area	0.12	0.19	0.2 - 0.25	0.2 - 0.3	None
20	RunjinSambo	0.13	0.19	0.2 - 0.25	0.2 - 0.3	None
21	Minanata	0.18	0.19	0.2 - 0.25	0.2 - 0.3	None
22	KofarAtiku	0.22	0.19	0.2 - 0.25	0.2 - 0.3	None
23	Masallacin Shehu	0.21	0.19	0.2 - 0.25	0.2 - 0.3	None
24	AduwarUwa	0.22	0.19	0.2 - 0.25	0.2 - 0.3	None
25	Bazzah area	0.2	0.19	0.2 - 0.25	0.2 - 0.3	None
26	Gidadawa area	0.22	0.19	0.2 - 0.25	0.2 - 0.3	None
27	Alkanci area	0.2	0.2	0.2 - 0.25	0.2 - 0.3	None
28	RijiyarDorawa	0.11	0.11	0.2 - 0.25	0.2 - 0.3	None
29	Alkammawa area	0.16	0.16	0.2 - 0.25	0.2 - 0.3	None
30	KofarTaramniya	0.19	0.19	0.2 - 0.25	0.2 - 0.3	None

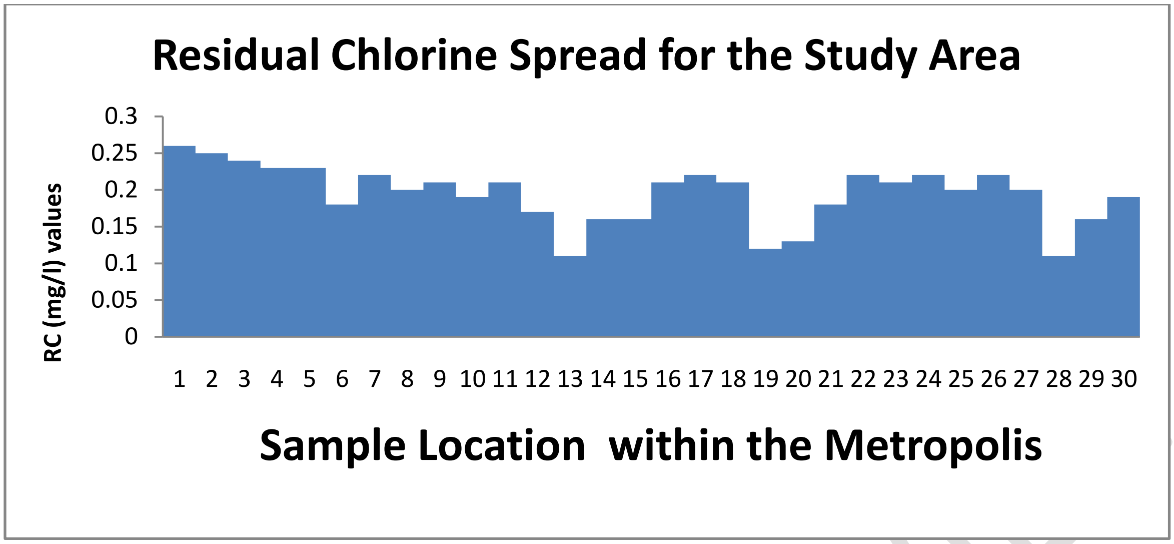


Figure 6: Residual Chlorine Distribution for the Study Area

Table 8: Statistical Analysis for the Chlorine affected Parameter

3.2 Determination of Bulk Decay Coefficient (K_b) value for the research

Results of the residual chlorine at 3hours interval (0, 3 and 6hrs) for the 120 samples are depicted in a semi-log graph of residual chlorine versus time and subsequently average kb was determined from semi-log graphs (Figures 7, 8, 9, 10, and 11), out of the one hundred and twenty (120) bulk water samples from different locations within the metropolis. The data obtained from the bottle test experiments were plotted on a semi-log graph of chlorine residual vs. time, with the slope representing the decay rate.

S/N	Parameters	Sample Average	Sample Variance	Sample Standard Deviation
1	**Conductivity**	**35.8**	**20.16**	**4.49**
2	**DO (mg/l)**	**3.07**	**1.347**	**1.16**
3	**pH**	**7.16**	**0.033**	**0.18**
4	**Chlorine (mg/l)**	**0.19**	**0.003**	**0.06**
5	**Tempt. (^{o}C)**	**30.8**	**0.824**	**0.91**

A total of 86 out of the 120 samples were found to be straight lines (1st order) which constitute 71.7%., while a total of 34 out of 120 samples were found to be curved (2nd order) which constitute 28.3%. The result indicate first order and thus the average pipe chlorine bulk decay coefficient (k_b) was thus determined as 0.006 (-0.144h). It is observed that from all the 120 samples examined in the metropolis, chlorine reaction with natural organic matter (NOM) is insignificant, and which is a contributing factor as well for the order kinetics obtained in the graph. The chlorine concentration was determined at the start and end of the experiment respectively and from the graph plot, some are found to be straight line, while some are curved. The resulting straight line graphs are considered first-order kinetics. Also the value of k_b was determined from the graph to be for 1st order. The same value and order is used for water quality simulations.

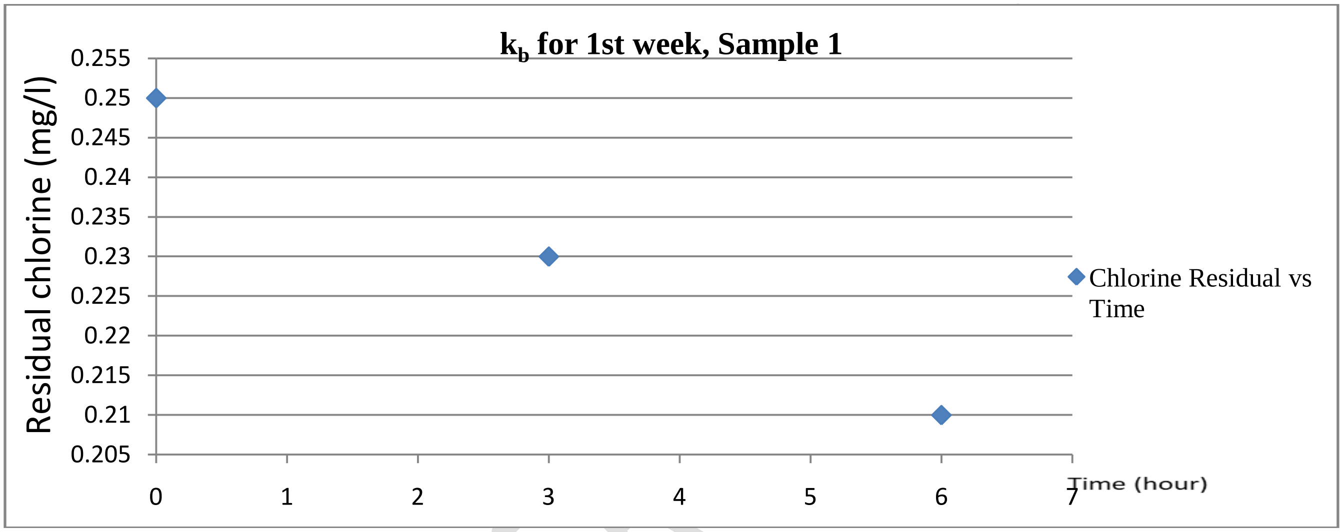


Figure 7: Determination of k_b (Sample 1, Treatment plant),

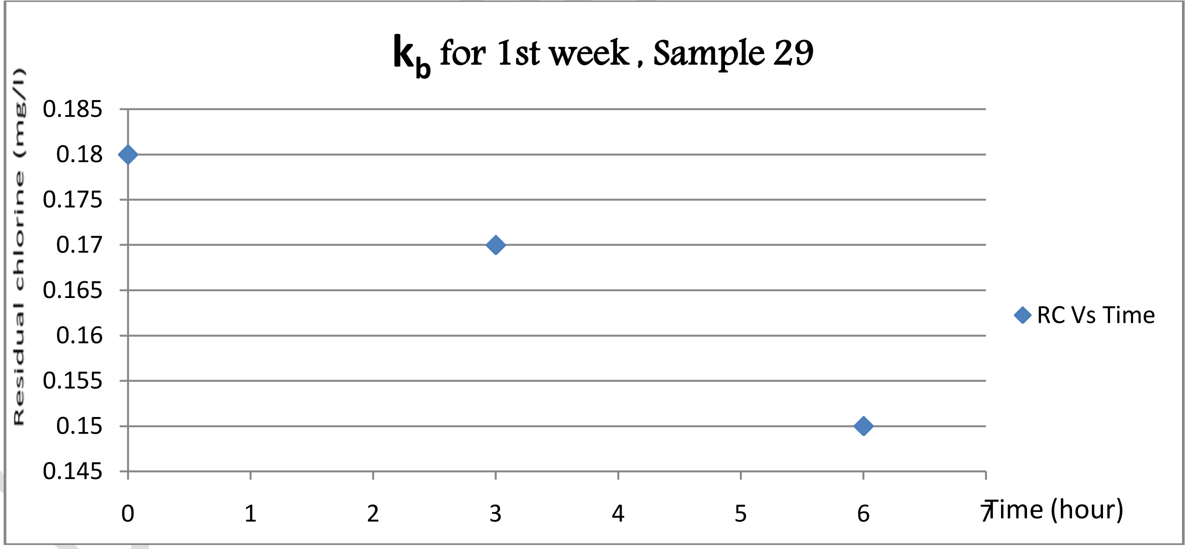


Figure 8: Determination of k_b (Sample 29, Alkammawa),

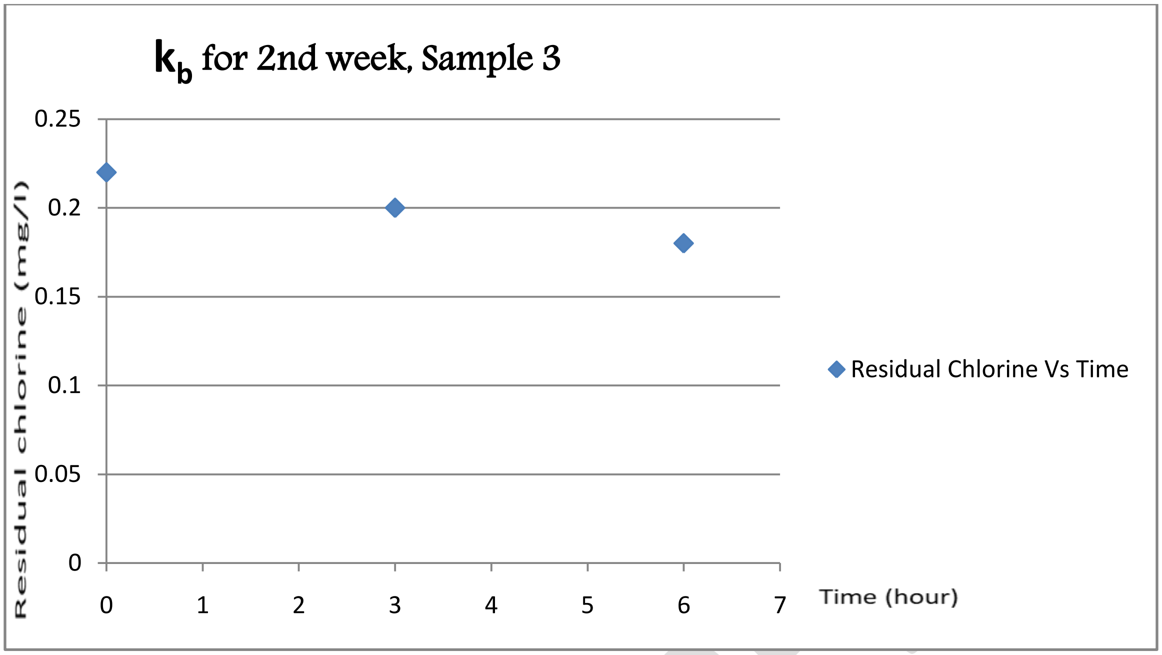


Figure 9: Determination of k_b (Sample 3, Bi-water),

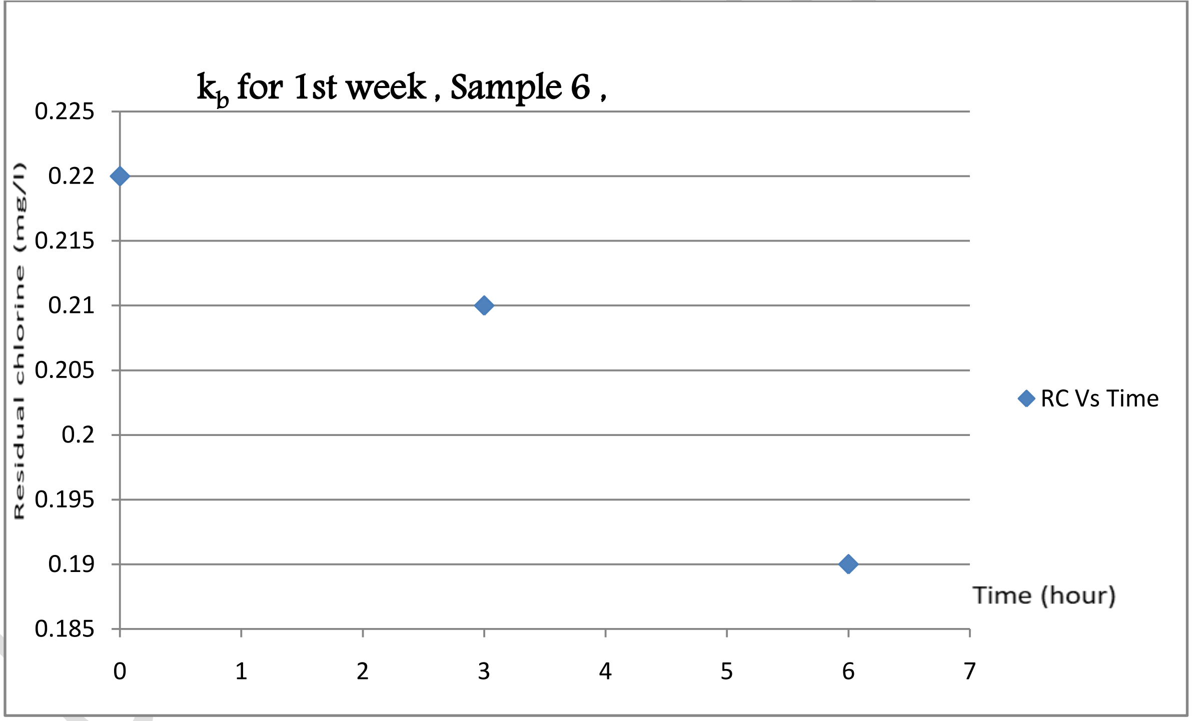


Figure 10: Determination of k_b (Sample 6, Illela garage),

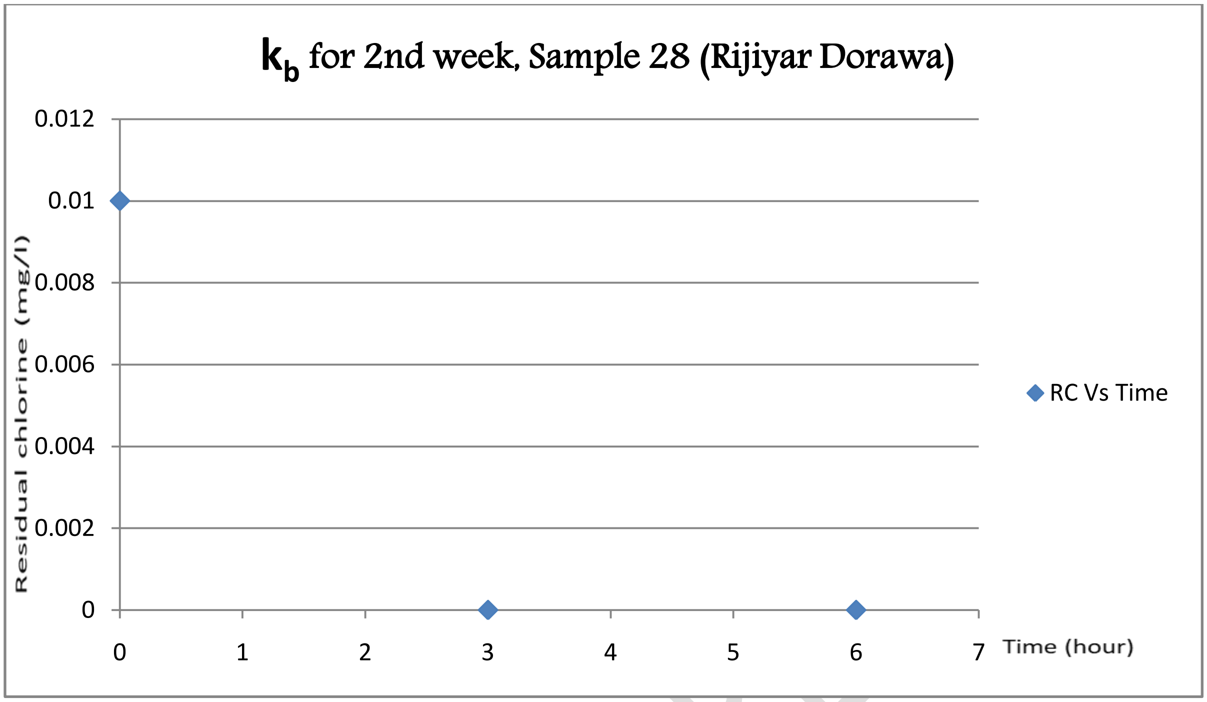


Figure 11: Determination of k_b (Sample 28, RijiyarDorawa),

3.3 Determination of Wall Decay Coefficient (k_w) for the Research Reactions can occur both within the bulk flow and with materials along the pipe wall. (HOCl), reacting with natural organic matter (NOM) in the bulk phase and is also transported through a boundary layer at the pipe wall to oxidize iron (Fe) released from pipe wall corrosion (Rossman, 2000). It might be considered that wall reaction decay depends on actual pipe wall condition and lining material, which makes it very difficult to be determined and in many cases it is been assumed for pipes (Nagatani*et al*, 2008). The dependency of K_w and the reaction order on pipe material and condition (i.e., age, encrustation and corrosion) makes determining the coefficients difficult. Although conceptually K_w may be measured under ideal conditions (i.e., long isolated pipes, no connections, controlled flow, inline chlorine measurements), in real-world conditions such measurements are infeasible therefore, models generally incorporate a calibrated K_w with initial estimates based on pipe roughness coefficients, flow velocity, and pipe diameter, as demonstrated by the Equation (2.0).

Where: α = correlation coefficients of wall reaction and pipe roughness and Cc = calibrated C. This approach is practiced widely in the industry because wall decay coefficients vary greatly due to pipe conditions (material, roughness, corrosion, and biofilms) and cannot be measured reasonably for large distribution systems. Wall decay coefficients were assigned using α of -38.5, and the hydraulically calibrated C. (Elsheikh*et al*, 2013). In line with the aforementioned K_w for Sokoto metropolis water supply was determined (calculated) considering the age of the steel material and the headloss roughness coefficient used. The pipe wall decay coefficient was calculated as follows: -

K_w(ft/d), -α =-38.5, Hazen William (H-W) C=150, for steel pipes.

K_w= 38.5/150 = 0.257ft/d = 0.078m/d.(-0.078m/d).

4.0 CONCLUSIONS AND RECOMMENDATIONS:

4.1 Conclusions

1. Examination of Sokoto water supply quality was carried out through analysis of some critical parameters for the potability of water such as pH, dissolve oxygen (DO), conductivity, temperature, and residual chlorine, all the the of the parameters have average values ranging from 6.7 to 7.5; 1.1 to 6.5ppm; 310 to 520µs/cm respectively and are in conformity to the Nigerian Standard for Drinking Water Quality (NSDWQ), with exception of temperature which has the average values between 29^{o}C and 32.6^{o}C and the individual values between 26^{o}C and 38.4^{o}C, chlorine residual average values obtained, ranging from 0.11mg/l to 0.26mg/l. with lowest individual value obtained being 0.011mg/l.
2. The bulk decay coeffient k_b and wall decay coeffientk_w for the study, used in Epanet 2.0 model was found to be -0.144/hour and -0.078m/h respectively and Epanet 2.0 hydraulic and water quality model for Sokoto water supply system was successfully created.

4.2 Recommendation

The research recommends that, the water quality standard of the Sokoto water distribution network, be maintain and proper mechanism should be used to checkmate any treatment of contamination.

4.3 Contribution to Knowledge

1. Minimum chlorine concentration of the network is achieved in the simulation and can be regulated and increased in terms of deficiency by adding more chlorine at a nearby distribution tank.
2. Dual water supply source for a distribution system may have affected the water quality outcomes of Epanet-MSX and the research also discovered Epanet 2.0 to be more suitable about the measured values at the locations.

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