CHEMISTRY OF POTABLE WATER DURING STORAGE: THE NORTH-WESTERN NIGERIA PERSPECTIVE

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ABSTRACT: Two sources of potable water (tap water and borehole water) were stored in twelve water storage reservoirs (six for each water source) for a period of six weeks. The reservoirs include black plastic tank, blue plastic tank, green plastic tank, coated steel metal tank, uncoated steel metal tank and clay pot. The water quality parameters examined were Temperature, Colour, Total solids, Electrical Conductivity (EC), Dissolved Oxygen (DO), Chlorine residual, Chloride, pH, Total hardness, Alkalinity, Manganese and Total Heterotrophic Bacteria (THB) which were all analyzed at a sampling frequency of seven days interval. Results shows that the growth rate constant of Manganese concentration in water stored in: plastic tanks, coated steel metal tanks, uncoated steel metal tanks and clay pots are 0.0163mg/L per week, 0.0200mg/L per week, 0.1150mg/L per week and 0.0550mg/L per week respectively. Colour of both water sources stored in uncoated steel metal tanks ranges from 5TCU - 20TCU, which is above the permissible limits set by W.H.O Standard (15TCU). On the other hand, values/concentrations of pH, Manganese and THB in all the storage reservoirs were found to exceed the permissible limits set by W.H.O Standard during certain periods (weeks) of retention for both water sources; respectively ranging from 5.8 - 8.7, 0.099mgL - 0.817mg/L and $2.0{\times}10^2$CFU/100mL - $1.56{\times}10^4$CFU/100mL which is contrary to the allowable permissible limits (6.5 - 8.5, 0.0mg/L - 0.2mg/L and 0.00CFU/100mL - $1.0{\times}10^4$CFU/100mL in that order).

Key words: Parameters, potable, water sources, reservoirs.

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INTRODUCTION

Water, air, food and shelter are the essential items for any living being. It is possible to survive without food and shelter for some days, but without water, it is not possible to survive much of the time. Without air, one cannot live for a few minutes. Next to air is water which is of paramount importance to all organisms (Booker, 2002).

Water is readily available all over the world but only a very few proportion of it is potable or fit for human consumption (Nala and Jagals, 2003). Hence, there is the need of storing potable water in containers in order to ensure continuity in supply during interruption or disaster. However, during storage the quality parameters of water never remains constant as there are numerous reactions taking place in the stored water due to changes in the surrounding environment as well as impacts from the material of construction used as storage containers (Agbede and Morakinyo, 1995; Maggy *et al.,* 2003 and Akubuenyi *et al.,* 2013).

In many Nigerian communities, it is a common practice to pump ground water into overhead storage-tanks made from steel metal or plastic (polyethylene) usually installed outdoor. This outdoor location of the water tanks exposes them to solar radiation which generates heat in the enclosure. On the other hand, Clay pots and other small capacity storage vessels such as buckets and basins (made from either plastic or steel metal) are usually kept indoor when used in storing potable water.

The need to understand the chemistry of potable water during storage cannot be overemphasized as it will bring out or suggest the best conditions favorable for storing potable water in different water storage reservoir materials and colours.

STUDY AREA

Between August and September, 2014, the research was carried out and analyzed in the North-Western part of Nigeria; at the Sanitary Chemistry and Microbiology Laboratory of the Department of Water Resources and Environmental Engineering, Ahmadu Bello University, Zaria. Located at approximately latitude 11^0 $9^1 5.94^{11}$N and longitude $7^0 38^1 5.17^{11}$E (GPS). However, water samples were drawn from the water treatment plant of the Ahmadu Bello University water works, Zaria and a borehole in Samaru-Zaria owned by Chitech Engineering Company. Both sampling points are respectively located at 11° 8'17.43"N, 7°39'29.43"E and 11° 9'34.96"N, 7°38'59.86"E (GPS). These sources were chosen because of their close proximity to the laboratory used for the analysis.
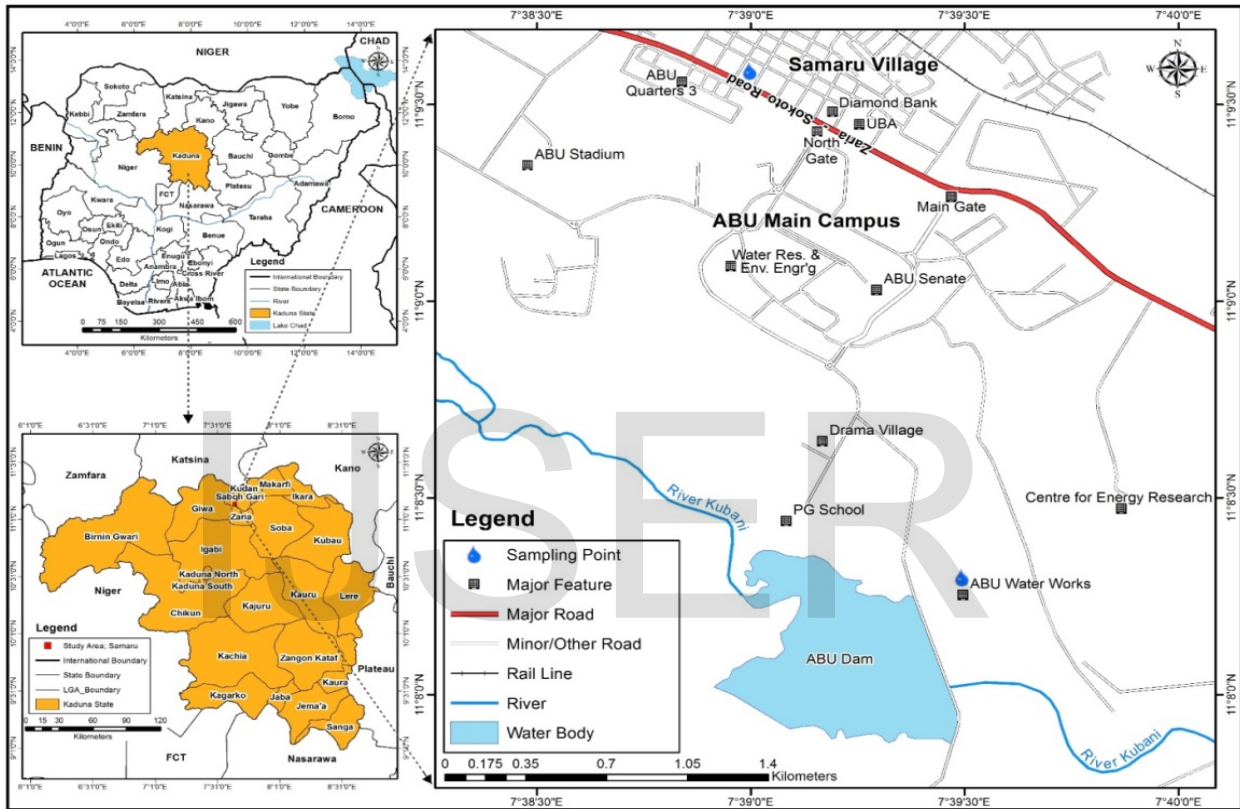

Figure 1: Map of parts of Samaru and ABU showing Sampling Points.

Source: Adapted and Modified from the Administrative Map of Kaduna State/Google Maps/Field Work (2014).

MATERIALS AND METHODS

The apparatuses/equipment used in this research include lovibond 1000 comparator (for colour and residual chlorine determination), FA/JA series weighing balance & steam bath (for total solids determination), HI83200 Multiparameter Photometer (for pH determination), AA 500 Spectrophotometer (for determination of Manganese), HI9835 EC/TDS/NaCl meter (for EC determination), Autoclaving machine, incubator, nutrient agar & glassware (all for the determination of THB) while magnetic stirrer, retort stand, glassware & reagents were used for the determination of: alkalinity, chloride and total hardness.

Tap water was obtained from the water treatment plant of the Ahmadu Bello University water works, Zaria into disinfected tap-fitted

tanks made from Coated Steel Metal (CSM), Uncoated Steel Metal (USM), Black Plastic (BKP), Green Plastic (GRP), Blue Plastic (BLP) and Clay Pot. Another set of these tanks were used in storing water obtained from a commercial borehole in Samaru-Zaria belonging to Chitech Engineering Company. Water stored in clay pots were kept indoor while all other storage vessels containing water were installed outdoor. This is because clay pots used in storing potable water in Nigeria are usually kept indoor while GP tanks (made from plastics) as well as water storage tanks made from galvanized or coated steel metals are usually installed outdoor. The water samples were stored for a period of six weeks (42 days) while analysis of water quality was carried out at a sampling frequency of seven (7) days. The water quality parameters that were considered/investigated are Temperature, Colour, Total solids, Electrical Conductivity (EC), Dissolved Oxygen (DO), Chlorine residual, Chloride, pH, Total hardness, Alkalinity, Manganese and Total Heterotrophic Bacteria (THB).

Before analyzing the above named water quality parameters, the twelve storage tanks/containers were filled with water and were test-run for one week and afterward, suitable modifications were made against leakages. All parameters were analyzed as specified in the Standard Methods for Examination of Water and Waste water (16th edition, APHA. AWWA. WPCF 1985). Water samples used for analysis was obtained by opening the taps fitted in the storage vessels containing the water sources, and allowing the water to run for few minutes before collecting the water in sample bottles. However, the sample bottles used for bacteriological count were disinfected with methylated sprit while the mouth of the taps fitted in the storage reservoirs were flamed for about two minutes. The taps were opened and water was allowed to run for few minutes before filling the sample bottles as earlier explained. Great care was taken during sampling to avoid contamination of the samples being collected as well as proper labeling of the sample bottles to avoid errors.

RESULTS AND DISCUSSION

Temperature: Temperature measurements were taken at about 12 noon on each day of analysis. The temperatures of both water sources were found to be the same (25 ^{0}C) on the first day of the research (week 0).

Table 1: Temperature variations in water stored in tanks/containers during research period (**^{0}C).**

Week	BKP_t	USM_t	GRP_t	CSM_t	BLP_t	CLP_t	BKP_b	USM_b	GRP_b	CSM_b	BLP_b	CLP_b
0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0
1	28.0	29.0	27.5	29.0	27.5	22.0	28.0	29.0	27.5	28.5	27.0	22.0
2	29.0	30.5	28.5	30.5	28.5	21.5	29.0	30.5	28.5	30.5	28.5	21.5
3	27.5	28.0	27.5	28.0	27.5	20.0	27.5	28.0	27.5	28.0	27.5	20.0
4	28.0	27.0	28.0	27.0	28.0	20.0	28.0	27.0	28.0	27.0	28.0	20.0
5	28.0	26.5	27.5	26.5	28.0	20.5	28.0	26.5	27.5	26.5	28.0	20.0
6	28.5	30.0	29.5	30.0	28.5	21.0	28.5	30.0	28.5	29.5	28.5	21.0
Mean	27.7	28.0	27.6	28.0	27.6	21.4	27.7	28.0	27.6	27.9	27.5	21.4
S.D	1.2863	1.9791	1.3758	1.9791	1.2051	1.7423	1.2863	1.9791	1.1902	1.8644	1.2247	1.796

Note: BKP_t = tap water stored in Black Plastic tank, USM_t = tap water stored in Uncoated Steel Metal tank, GRP_t = tap water stored in Green Plastic tank, CSM_t = tap water stored in Coated Steel Metal tank, BLP_t = tap water stored in Blue Plastic tank and CLP_t = tap water stored in Clay Pot. Similarly, BKP_b, USM_b, GRP_b, CSM_b, BLP_b and CLP_b represent borehole water stored in their corresponding storage tanks/containers.
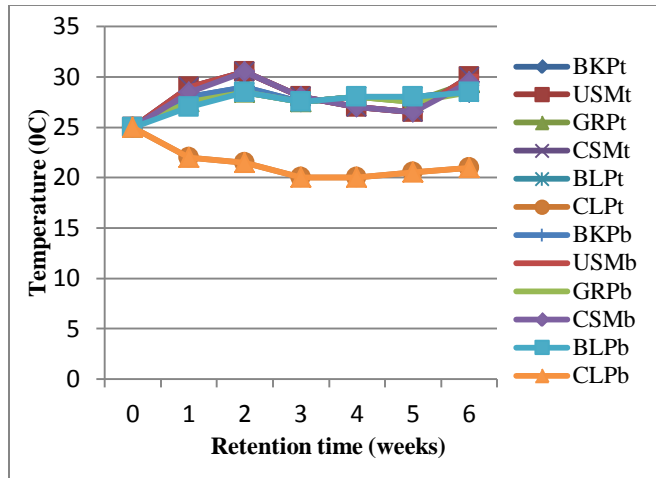
Figure 1: Variations pattern of Temperature in stored water during research period**.**

Figure 1 shows that the sources of water (tap water and borehole water) have no effect on water temperature during storage but rather, it depends on the type and colour of material used in storage as well as the ambient temperature. This is because irrespective of the water source, similar container materials as well as colours overlapped each other.

Also, Figure 1 revealed that there was a remarkable decrease in temperature of water stored in clay pots which can be attributed to the cooling effect caused by evaporation. The temperature gradually dropped from 25 ^{0}C at week 0 (temperature of water source) to 20°C at the third and fourth week. However, there was a slight rise in the temperature in between the fourth and sixth week (20 ^{0}C to 21 ^{0}C). This is because, the continuous withdrawal of water from the pots created a large space above the water surface which in turns might have created vapor pressure (heat) in the reservoir.

All the reservoirs stored exteriorly recorded water temperatures higher than those of the initial sources throughout the research period. Among these, Uncoated Steel Metal (USM) tanks and Coated Steel Metal (CSM) tanks for both water sources were having the highest recorded temperatures with a maximum value of 30.5 ^{0}C on the second week. This is because metals are good conductors of heat. Nevertheless, there was a drop in temperatures of water in USM and CSM for both sources on the fourth and fifth week. This is as a result of the fact that, the surrounding environment on such days were cloudy (highly humid) hence, heat were rather lost to the surrounding from these reservoirs. In other words, as metals are good conductors of heat from an environment having a higher temperature, they are as well good emitters of heat to an environment with lower temperature (Nelkon, 2003).

Water stored in Black Plastic (BKP) tanks for both water sources had slightly higher temperatures than those stored in Blue Plastic (BLP) and Green Plastic (GRP) tanks. This is because all black bodies are good absorbers of heat since the emissivity is one (1).

Colour: Both water sources (tap water and borehole water) had same colour i.e 5TCU before storage which is well acceptable by W.H.O Standard. Figure 2 shows that the water colour in all the reservoirs increased on the first week of the research and thereafter, remains constant throughout the retention period.

Table 2: Colour variations of water stored in tanks/containers during research period (TCU).

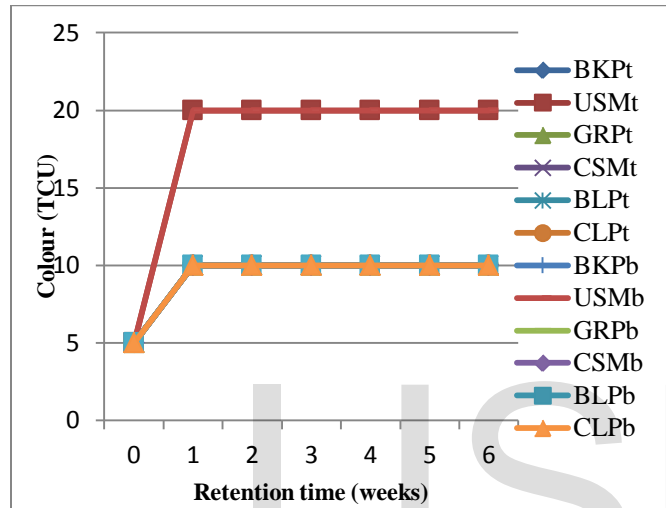| Week	BKP_t	USM_t	GRP_t	CSM_t	BLP_t	CLP_t	BKP_b	USM_b	GRP_b	CSM_b	BLP_b	CLP_b
0	5	5	5	5	5	5	5	5	5	5	5	5
1	10	20	10	10	10	10	10	20	10	10	10	10
2	10	20	10	10	10	10	10	20	10	10	10	10
3	10	20	10	10	10	10	10	20	10	10	10	10
4	10	20	10	10	10	10	10	20	10	10	10	10
5	10	20	10	10	10	10	10	20	10	10	10	10
6	10	20	10	10	10	10	10	20	10	10	10	10
Mean	9.3	17.9	9.3	9.3	9.3	9.3	9.3	17.9	9.3	9.3	9.3	9.3
S.D	1.9	5.7	1.9	1.9	1.9	1.9	1.9	5.7	1.9	1.9	1.9	1.9

Figure 2: Variations pattern of Colour in stored water during research period**.**

It can be deduced from Figure 2 that, all the storage tanks/pots apart from the uncoated steel metals, had a uniform colour variation during the period of experiment. Also, the maximum value recorded in these tanks/pots was 10 TCU, which is much lesser than the permissible limit set by W.H.O Standard (15 TCU), indicating that the water stored in these vessels are okay in terms of colouration.

The variation in water colour stored in uncoated steel metal tanks for both water sources was also the same throughout the six weeks of storage. However, the water stored in these tanks were highly coloured to about 20 TCU which is not in line with the standards set by W.H.O. This colouration can be attributed to rusting which might have resulted from the reaction between the high concentrations of iron in these vessels and the oxygen present in the stored water.

Total Solids: The total solids for both sampling points (tap water and borehole water) were 1.071mg/L and 1.051mg/L respectively.

Table 3: Total solids variations in water stored in tanks/containers during research period (mg/L).

| Week	BKP_t	USM_t	GRP_t	CSM_t	BLP_t	CLP_t	BKP_b	USM_b	GRP_b	CSM_b	BLP_b	CLP_b
0	1.071	1.071	1.071	1.071	1.071	1.071	1.051	1.051	1.051	1.051	1.051	1.051
1	1.031	1.176	1.032	1.031	1.029	1.028	1.029	1.144	1.028	1.029	1.027	1.027
2	1.028	1.178	1.028	1.029	1.028	1.029	1.027	1.138	1.028	1.026	1.027	1.028
3	1.021	1.124	1.022	1.023	1.021	1.021	1.020	1.126	1.021	1.021	1.020	1.021
4	1.018	1.120	1.017	1.019	1.018	1.017	1.018	1.121	1.018	1.018	1.017	1.016
5	1.015	1.116	1.012	1.013	1.012	1.011	1.012	1.116	1.012	1.011	1.010	1.012
6	1.016	1.112	0.998	0.999	0.997	0.998	1.013	1.112	0.998	0.998	0.996	0.997
Mean	1.028	1.128	1.026	1.026	1.025	1.025	1.024	1.115	1.022	1.022	1.021	1.022
S.D	0.020	0.038	0.023	0.022	0.023	0.023	0.013	0.031	0.016	0.016	0.017	0.017
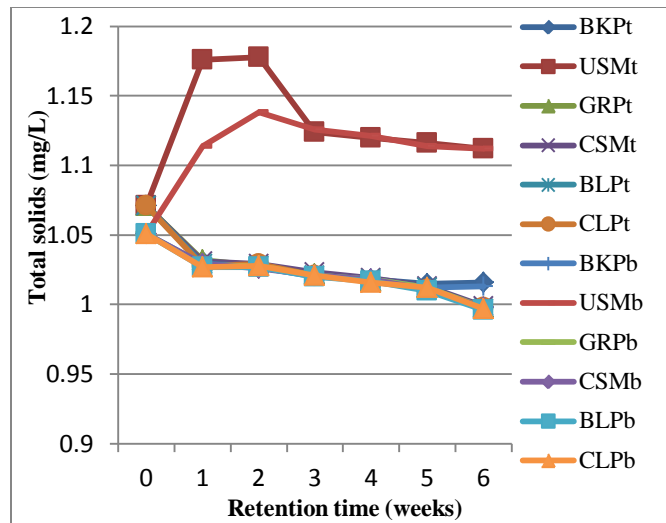
Figure 3: Variations pattern of Total solids in stored water during research period**.**

Figure 3 revealed that there were improvements in total solid concentration with respect to time in the water stored in each of the storage vessels except those in uncoated steel metal tanks (USM_t and USM_b). The results also indicated that the reduction/improvement of total solids with respect to time had no relationship with the type (material and colour) of vessels used in storage. This is because the concentrations of the parameter in question (total solids) in all the storage tanks for a given water source overlapped at any time. The reduction in total solids is due to the fact that, upon storage, big suspended/flocculated particles as well as other impurities bigger than the water molecules settled down at the bottom of the tanks/pots thus reducing the total solids. On a contrary, the tap water and borehole water stored in uncoated steel metal tanks (i.e USM_t and USM_b) recorded higher values of total solids (increase) in the first two weeks of the research when compared to their initial concentrations before storage. These values later dropped gradually during the last four weeks of storage/retention. The initial increase in total solids recorded in these tanks (uncoated steel metals) was as a result of the rusting of the materials which might have dissolved in to the stored water thus increasing total solids.

Electrical Conductivity: There was a remarkable difference between the values of E.C recorded in the reservoirs containing tap water and those containing borehole water during the research period. This high difference was noted right from the first day of the research (week 0) when the E.C value of tap water was recorded to be 118.99μS/cm (micro Mohs per centimeter) while that of borehole water was as high as 707.02μS/cm.

Table 4: EC variations of water stored in tanks/containers during research period (μS/cm).

| Week	BKP_t	USM_t	GRP_t	CSM_t	BLP_t	CLP_t	BKP_b	USM_b	GRP_b	CSM_b	BLP_b	CLP_b
0	118.99	118.99	118.99	118.99	118.99	118.99	707.02	707.02	707.02	707.02	707.02	707.02
1	91.01	97.98	83.95	105.04	90.96	126.04	637.60	626.90	616.05	637.60	644.03	658.08
2	108.49	108.46	118.98	119.01	125.96	136.46	734.96	665.01	728.00	720.95	735.02	664.97
3	136.45	108.39	87.53	136.51	97.95	118.89	706.97	615.99	717.53	706.95	734.99	745.47
4	112.04	136.48	122.54	87.46	98.02	108.55	714.04	714.02	735.01	713.98	735.04	749.03
5	105.04	111.97	112.02	87.52	91.00	122.52	637.50	629.94	616.08	637.71	644.02	658.05
6	108.52	108.54	119.00	119.04	126.00	136.48	735.03	665.00	728.01	721.00	735.03	665.02
Mean	111.51	112.97	109.00	110.51	106.98	123.99	696.16	660.55	692.53	692.17	705.02	692.52
S.D	13.895	12.080	16.229	18.178	16.021	10.060	41.715	38.972	52.994	37.678	42.905	41.022
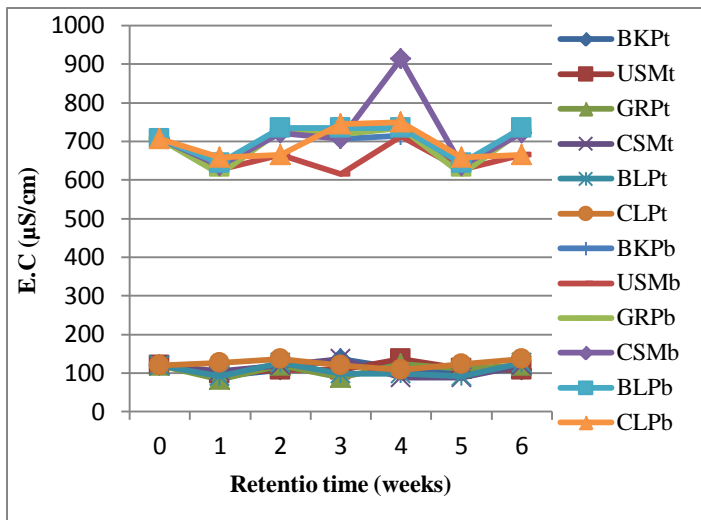
Figure 4: Variations pattern of EC in stored water during research period**.**

The information in Figure 4 suggest that the E.C values of the borehole water stored in all the reservoirs respond to changes more than those of the tap water. It is important to note that irrespective of the different variations displayed

by the different water sources, both water sources recorded an improvement in E.C concentration in the first week and also, all the recorded values were okay with W.H.O standard since the maximum permissible limit set by W.H.O is 1000µS/cm.

Dissolved Oxygen: The tap water obtained from ABU water treatment plant contains more of dissolved oxygen (1.50mg/L) than the water obtained from the commercial borehole (1.30mg/L). This is probably because the tap water undergone unit operation processes such as aeration which might have increased the dissolved oxygen content. However, there was a uniform drop in the concentration of D.O in the second week (Figure 5). This depletion in D.O concentration was as a result of the rise in water temperature recorded in the storage reservoirs during the said period, knowing the fact that a rise in temperature, reduces D.O concentration in water and vice versa.

Table 5: Dissolved Oxygen variations in water stored in tanks/containers during research period (mg/L).

| Week	BKP_t	USM_t	GRP_t	CSM_t	BLP_t	CLP_t	BKP_b	USM_b	GRP_b	CSM_b	BLP_b	CLP_b
0	1.50	1.50	1.50	1.50	1.50	1.50	1.30	1.30	1.30	1.30	1.30	1.30
1	2.00	2.00	2.10	2.10	2.00	2.70	2.10	2.40	2.40	2.10	1.90	2.60
2	1.60	1.00	1.40	1.30	1.10	1.40	1.80	1.10	1.40	1.30	1.30	1.40
3	1.60	1.40	2.40	1.70	1.30	1.40	1.30	1.30	1.30	1.50	1.50	1.30
4	1.30	1.40	1.70	1.70	1.30	1.40	1.60	0.80	1.20	1.30	2.20	1.60
5	1.10	1.20	1.70	1.40	1.40	2.10	1.30	1.10	1.60	1.40	1.60	2.10
6	1.60	0.90	1.80	1.40	1.70	1.50	1.40	2.10	1.30	1.10	1.60	1.40
Mean	1.53	1.34	1.80	1.59	1.47	1.71	1.54	1.44	1.50	1.43	1.63	1.67
S.D	0.281	0.364	0.346	0.273	0.298	0.501	0.310	0.583	0.416	0.320	0.325	0.496
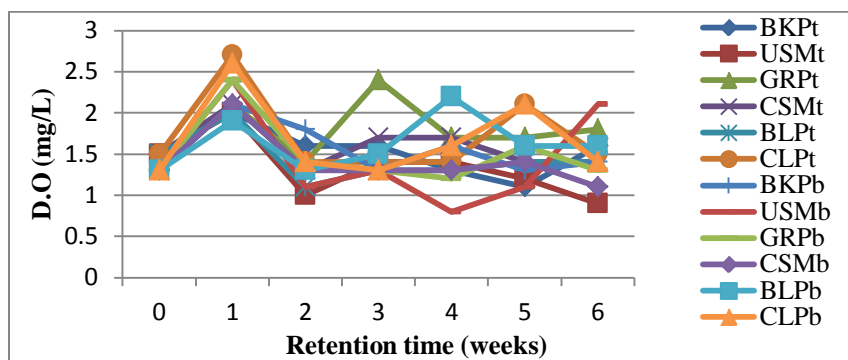
Figure 5: Variations pattern of D.O in stored water during research period**.**

Chlorine Residual

The chlorine content of tap water from the source was 0.05mg/L and it dropped at a constant rate to 0.01mg/L on the second week and thereafter remains constant for all the storage vessels containing tap water as can be seen in Table 6. On the other hand, the concentration of chlorine in the borehole water was 0.01mg/L all through the research period.

Table 6: Chlorine (residual) variations in water stored in tanks/containers during research period (mg/L).

| Week	BKP_t	USM_t	GRP_t	CSM_t	BLP_t	CLP_t	BKP_b	USM_b	GRP_b	CSM_b	BLP_b	CLP_b
0	0.05	0.05	0.05	0.05	0.05	0.05	0.01	0.01	0.01	0.01	0.01	0.01
1	0.03	0.03	0.03	0.03	0.03	0.03	0.01	0.01	0.01	0.01	0.01	0.01
2	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
3	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
4	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
5	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
6	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Mean	0.02	0.02	0.02	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01
S.D	0.016	0.016	0.016	0.016	0.016	0.016	0.000	0.0000	0.000	0.000	0.000	0.000
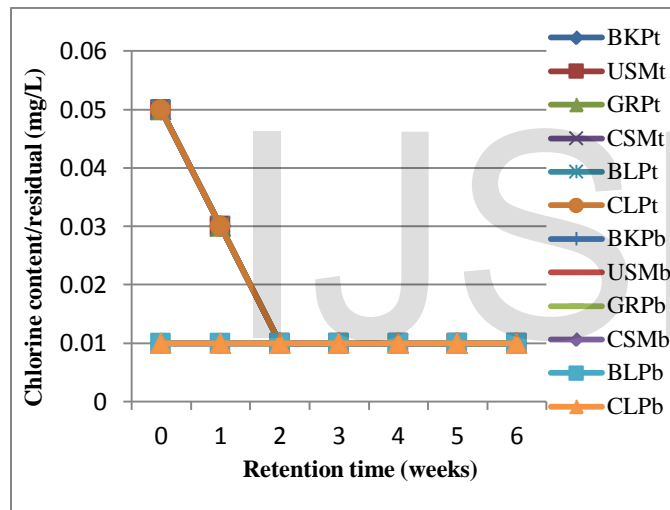
Figure 6: Variations pattern of Chlorine (residual) in stored water during research period**.**

The high chlorine content recorded in tap water compared to borehole water is just because, chlorine is usually added to tap water for the purpose of disinfecting bacteria that may contaminate the water along the transit (distribution pipes) before reaching the consumers.

It is clearly revealed in Figure 6, that the concentration of chlorine in the storage vessels at any time is not a function of the material of construction used nor colour but rather, a function of time (since the legends in Fig 6 overlapped each other with time). This is because chlorine is a gas hence, the residual drops subsequently. Furthermore, Figure 6 also tells that the threshold value of chlorine in both water sources is 0.01mg/L.

Chloride: Just as the case of Electrical conductivity, there was also a high difference between the recorded values of chloride concentration in both reservoirs containing tap water and borehole water all through the research period. The higher values of chloride concentration in tanks/pot containing borehole water as can be seen in Figure 7 emanated from the initial concentration of the source (160.01mg/L) which can be attributed to the geology of the aquifer surrounding the borehole. Unlike the borehole water, the chloride concentration of the tap water prior to storage was very small (21.040mg/L).

Table 7: Chloride variations in water stored in tanks/containers during research period (mg/L).

| Week	BKP$_t$	USM$_t$	GRP$_t$	CSM$_t$	BLP$_t$	CLP$_t$	BKP$_b$	USM$_b$	GRP$_b$	CSM$_b$	BLP$_b$	CLP$_b$
0	21.04	21.04	21.04	21.04	21.04	21.04	160.01	160.01	160.01	160.01	160.01	160.01
1	12.53	15.00	9.95	16.25	12.51	23.44	157.51	154.96	152.58	157.49	160.00	163.66
2	18.33	17.50	19.98	19.95	22.46	24.97	185.04	164.97	182.45	179.92	184.95	165.03
3	24.95	17.55	11.25	24.99	15.04	19.94	177.46	152.48	179.96	177.48	185.03	187.51
4	19.00	24.98	21.25	11.26	14.98	17.51	178.75	178.79	184.95	178.74	185.95	188.75
5	16.24	18.74	18.72	11.25	12.54	21.26	157.54	154.98	152.53	157.49	159.95	163.68
6	18.09	17.53	19.95	21.00	22.49	24.97	184.95	165.02	183.98	179.95	184.94	166.01
Mean	18.60	18.91	17.45	17.96	17.29	21.88	171.61	161.60	170.92	170.15	174.40	170.66
S.D	3.86	3.23	4.77	5.24	4.54	2.75	12.75	9.06	15.14	11.12	13.49	12.08
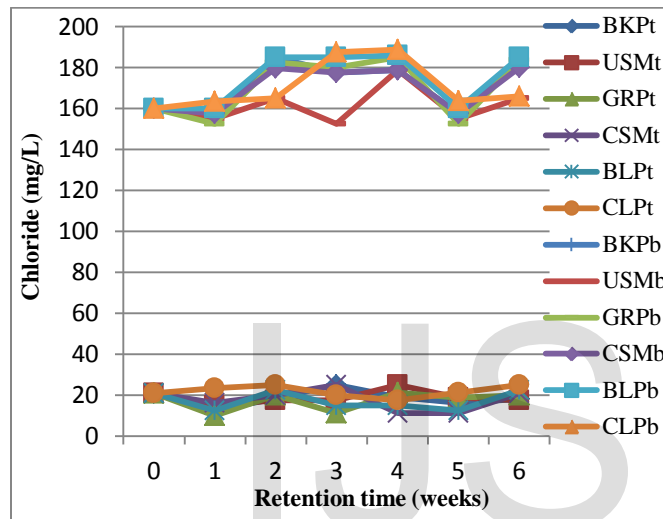
Figure 7a: Variations pattern of Chloride in
stored water during research period**.**

There is a great similarity between Figure 7
(Variations pattern of Chloride in stored water
during research period) and Figure 4 (Variations
pattern of EC in stored water during research
period). This suggests that a linear correlation
exist between EC and Chloride ion which was
obtained by plotting EC values against Chloride
ion values on a linear graph. The exact equation
of the regression line between these two
parameters was estimated as:

$$EC = 3.7822(Cl^*) + 42.5261 \qquad (1)$$

Where; EC = Electrical conductivity and Cl* =
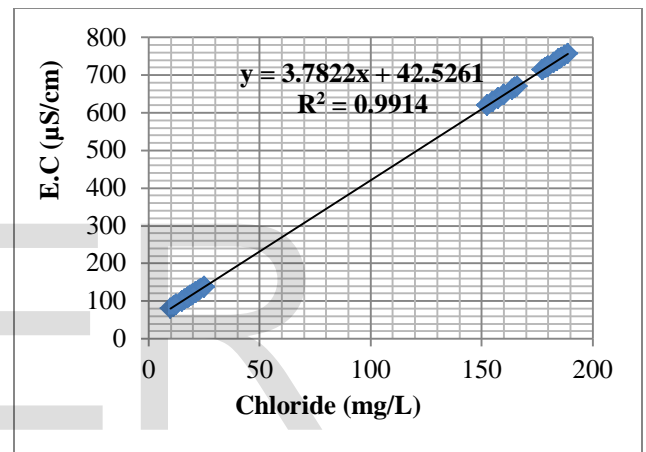Chloride ions.

Figure7b: Relationship between Electrical
conductivity and Chloride.

pH: The initial pH values for both water sources
were 6.6 and 7.0 for tap water and borehole
water respectively which is acceptable by
W.H.O standard. However, during the storage
period, there were instances in which the pH
values recorded were outside the range of the
permissible limits set by W.H.O (6.5-8.5). This
deviation in pH from the permissible limits were
more noticeable in water stored in Uncoated
Steel metal tanks (USM$_t$ and USM$_b$) as can be
seen in Table 8 or Figure 8.

Table 8: pH variations in water stored in tanks/containers during research period**.**

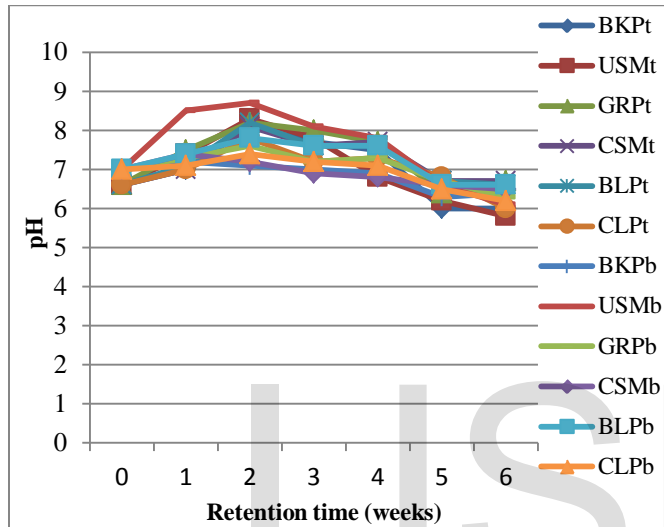| Week	BKP_t	USM_t	GRP_t	CSM_t	BLP_t	CLP_t	BKP_b	USM_b	GRP_b	CSM_b	BLP_b	CLP_b
0	6.6	6.6	6.6	6.6	6.6	6.6	7.0	7.0	7.0	7.0	7.0	7.0
1	7.0	7.4	7.5	7.0	7.1	7.0	7.2	8.5	7.3	7.4	7.4	7.1
2	8.1	8.3	8.2	8.1	8.2	7.8	7.1	8.7	7.6	7.2	7.8	7.4
3	7.7	7.8	8.0	7.6	7.6	7.2	7.0	8.1	7.2	6.9	7.6	7.2
4	7.5	6.8	7.7	7.7	7.6	7.3	6.9	7.8	7.3	6.8	7.6	7.1
5	6.0	6.2	6.4	6.7	6.7	6.8	6.3	6.6	6.7	6.6	6.6	6.5
6	6.0	5.8	6.7	7.4	6.6	6.0	6.4	6.1	6.3	6.5	6.6	6.2
Mean	7.0	7.0	7.3	7.3	7.2	7.0	6.8	7.5	7.1	6.9	7.2	6.9
S.D	0.83	0.89	0.73	0.55	0.62	0.57	0.35	0.99	0.44	0.32	0.50	0.42

Figure 8: Variations pattern of pH in stored water during research period**.**

It is obvious that in Figure 8, there was a serious drop in the pH during the fifth and sixth week. This can be as a result of the high secretion of acid by death bacteria during the death phase which might have occurred this period (5th - 6th week).

Total Hardness: The total hardness (carbonate and non-carbonate hardness) level of the tap water and borehole water before storage were 102.14 mg/L (slightly hard) and 396.30mg/L (very hard) respectively. The high level of hardness in water obtained from borehole water compared to tap water as shown in Figure 9 is because the technology involved in obtaining the former did not requires unit operation processes unlike the later in which the hardness level can be control.

Table 9: Total hardness variations in water stored in tanks/containers during research period (mg/L as $CaCO_3$).

| Week	BKP_t	USM_t	GRP_t	CSM_t	BLP_t	CLP_t	BKP_b	USM_b	GRP_b	CSM_b	BLP_b	CLP_b
0	102.14	102.14	102.14	102.14	102.14	102.14	396.30	396.30	396.30	396.30	396.30	396.30
1	81.08	141.55	101.62	111.13	98.72	77.44	308.77	505.86	400.52	654.91	333.78	421.04
2	121.04	98.85	78.56	91.04	107.81	101.99	661.44	502.81	438.58	561.72	586.81	622.97
3	121.54	101.41	136.64	91.81	112.66	72.56	480.00	512.64	408.70	654.11	537.33	602.54
4	127.60	113.76	108.00	95.67	76.89	118.67	476.66	621.81	503.77	536.66	644.01	603.42
5	88.52	101.41	92.49	110.08	117.55	98.94	502.81	601.72	403.08	409.76	521.34	493.00
6	124.78	104.90	97.84	89.77	92.35	113.41	601.34	391.85	588.72	619.04	402.57	392.45
Mean	109.53	109.15	102.47	98.81	101.16	97.88	489.62	504.71	448.52	547.50	488.88	504.53
S.D	18.89	15.08	17.76	9.05	13.65	17.17	118.22	89.15	72.44	108.15	113.38	103.92
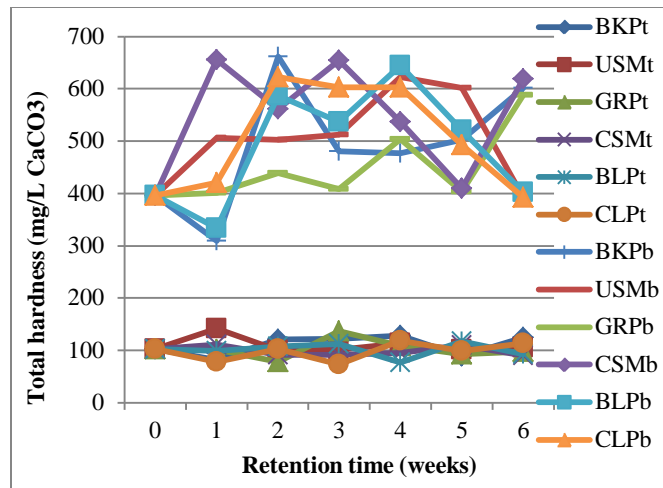
Figure 9: Variations pattern of Total hardness in stored water during research period**.**

Figure 9 suggests that storage of water (irrespective of the water source and the material of construction used as container) does not guaranty the improvement/deterioration of it total hardness quality. This is because the variations (increase or decrease) in the concentrations of this parameter in each of the storage tanks during the retention period were zigzag.

Alkalinity: The level of alkalinity in the water samples obtained from the ABU water treatment plant and the commercial borehole before storage were respectively 54.01mg/L CaCO$_3$ and 126.13mg/L CaCO$_3$. The deviations from these initially recorded values in each of the

reservoirs or container used during the storage/retention period were not large. The high concentrations of alkalinity in the reservoirs containing borehole water compared to those containing tap water as could be seen in Figure 10 explain the reason why reservoirs containing borehole water were more reluctant to changes in pH than those containing tap water (Figure 8).

Alkalinity is known to have a relationship with total hardness however, there is a great difference between Figure 10a (variations pattern of Alkalinity in stored water during research period) and Figure 9 (Variations pattern of Total hardness of stored water during research period). This difference will be caused by the presence of non-carbonate hardness present in the water samples.

Just as in Chloride, there is also similarity between Figure 4 (Variations pattern of EC in stored water during research period) and Figure 10a (Variations pattern of Alkalinity in stored water during research period), which suggests that a high correlation exist between EC and Alkalinity. It was found in Figure 10b that EC established a power function with Alkalinity in the form:

$$EC = 0.0473(Alk)^{1.9579} \qquad (2)$$

Where; EC = Electrical conductivity and Alk = Alkalinity.

Table 10: Alkalinity variations in water stored in storage tanks/containers during research period (mg/L CaCO$_3$).

| Week	BKP$_t$	USM$_t$	GRP$_t$	CSM$_t$	BLP$_t$	CLP$_t$	BKP$_b$	USM$_b$	GRP$_b$	CSM$_b$	BLP$_b$	CLP$_b$
0	54.01	54.01	54.01	54.01	54.01	54.01	126.13	126.13	126.13	126.13	126.13	126.13
1	46.00	47.99	43.96	51.00	45.95	57.50	130.90	129.95	129.01	130.92	131.04	131.99
2	52.03	51.96	56.00	55.97	57.54	60.02	135.96	132.01	136.04	135.02	136.01	132.00
3	59.98	52.01	45.03	61.06	49.04	55.96	134.02	129.94	135.03	133.95	135.99	137.99
4	52.97	59.97	56.21	44.96	48.02	52.00	135.01	134.95	136.03	135.00	136.04	137.00
5	51.97	56.03	53.01	45.04	46.00	56.14	130.94	130.00	128.95	131.84	130.97	132.01
6	52.03	51.95	56.04	56.00	57.52	59.97	136.00	131.95	136.00	134.99	136.04	132.01
Mean	52.71	53.42	52.04	52.58	51.15	56.51	132.71	130.70	132.46	132.55	133.17	132.73
S.D	4.11	3.78	5.30	5.98	5.12	2.95	3.61	2.70	4.26	3.28	3.90	3.91
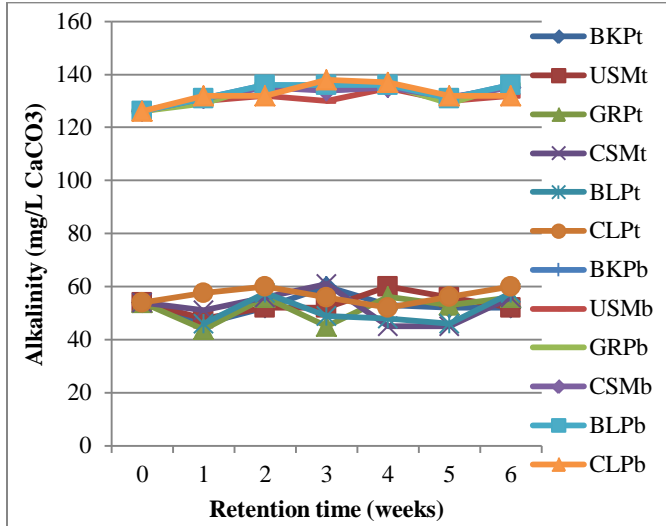
Figure 10a: Variations pattern of Alkalinity in stored water during research period.
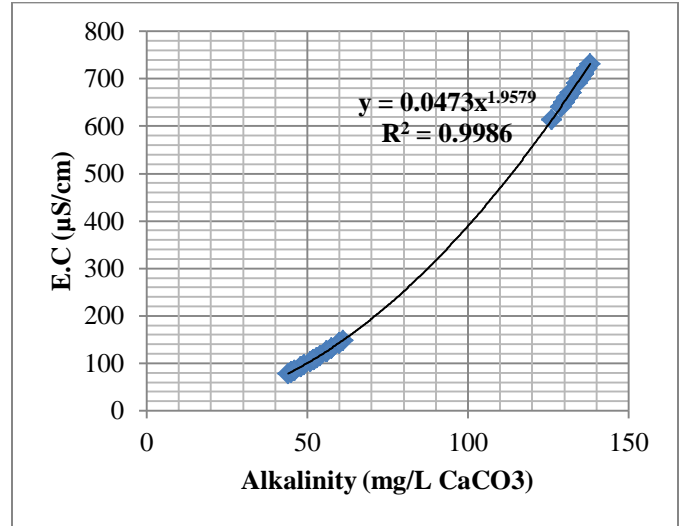
Figure 10b: Relationship between Electrical conductivity and Alkalinity.

Manganese (Mn): Manganese contamination level of the two sampling points (tap water and borehole water) before storage were 0.099mg/L and 0.127mg/L respectively which indicates that the two sampling points met the requirement of W.H.O standard for this parameter (0.2mg/L) as at the time the samples were drawn (25th August, 2014).

Table 11: Manganese variations in water stored in tanks/containers during research period (mg/L).

| Week	BKP_t	USM_t	GRP_t	CSM_t	BLP_t	CLP_t	BKP_b	USM_b	GRP_b	CSM_b	BLP_b	CLP_b
0	0.099	0.099	0.099	0.099	0.099	0.099	0.127	0.127	0.127	0.127	0.127	0.127
1	0.115	0.215	0.115	0.120	0.115	0.155	0.144	0.240	0.144	0.149	0.144	0.183
2	0.133	0.328	0.133	0.141	0.133	0.207	0.161	0.360	0.161	0.166	0.161	0.239
3	0.150	0.449	0.150	0.157	0.150	0.261	0.174	0.474	0.174	0.185	0.174	0.289
4	0.168	0.559	0.168	0.180	0.1680	0.320	0.193	0.584	0.193	0.207	0.193	0.348
5	0.183	0.677	0.183	0.196	0.183	0.375	0.211	0.701	0.211	0.224	0.211	0.402
6	0.201	0.786	0.201	0.222	0.201	0.425	0.226	0.817	0.226	0.246	0.226	0.458
Mean	0.150	0.445	0.150	0.159	0.150	0.263	0.177	0.472	0.177	0.186	0.177	0.292
S.D	0.037	0.248	0.037	0.043	0.037	0.118	0.036	0.248	0.036	0.042	0.036	0.119
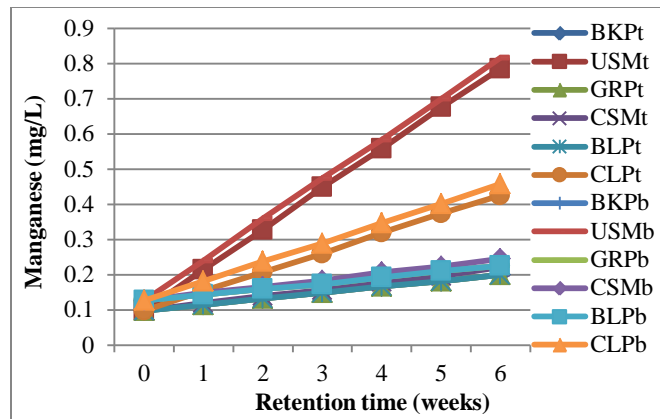
Figure 11: Variations pattern of Manganese in stored water during research period.

time, material of construction used as a storage vessel as well as the initial concentration of the source (before storage). In other words, increase in concentration of Manganese during storage has nothing to do with the colour of the water storage vessel. This is because all materials of construction (irrespective of colours) had the same growth rate constant (slope/gradient) for each of the water samples.

The estimated models (equations) for predicting the concentrations of Mn at any time in the water stored in each of the vessels used are:

$$Mn_{PL} = 0.0163t + C \qquad (3)$$

$$Mn_{CO} = 0.0200t + C \qquad (4)$$

$$Mn_{UN} = 0.1150t + C \qquad (5)$$

$$Mn_{CL} = 0.0550t + C \qquad (6)$$

Where; Mn_{PL}, Mn_{CO}, Mn_{UN} and Mn_{CL} represents concentration of Mn in water stored in: Plastic tanks, Coated steel metal tanks, Uncoated steel metal tanks and Clay pots respectively wile "t" is the retention period (in weeks) and "C" is the initial concentration of the source before storage which are 0.099mg/L and 0.127mg/L for tap water and borehole water respectively. Since equations 3 to 6 are linear equations, it implies the coefficients of "t" are gradients or slopes (in mg/L per week). Hence, the growth rate constants of Manganese concentration in water stored in: plastic tanks, coated steel metal tanks, uncoated steel metal tanks and clay pots are respectively 0.0163mg/L per week, 0.0200mg/L per week, 0.1150mg/L per week and 0.0550mg/L per week.

Total Heterotrophic Bacteria (THB): Both water sources (tap water and borehole water) used for the research were not completely free from Total Heterotrophic Bacteria (THB) before the storage, as they were respectively containing 2 and 6 CFU/mL. This signifies that the sources were these water samples were drawn, met the requirement set by W.H.O Standard for Drinking water Quality in terms of THB (100CFU/mL or 10^4 CFU/100mL) as at the time the water samples were drawn (25th August, 2014).

Table 12: Total Heterotrophic Bacteria variations in water stored in tanks/containers during research period ($\times 10^2$CFU/100mL).

| Week	BKP$_t$	USM$_t$	GRP$_t$	CSM$_t$	BLP$_t$	CLP$_t$	BKP$_b$	USM$_b$	GRP$_b$	CSM$_b$	BLP$_b$	CLP$_b$
0	2	2	2	2	2	2	6	6	6	6	6	6
1	21	36	16	14	33	25	42	18	15	18	15	39
2	49	88	27	31	29	76	53	92	34	29	41	71
3	78	136	63	55	51	104	81	132	67	59	63	120
4	96	64	80	100	76	132	100	172	96	100	84	156
5	116	156	116	112	108	112	112	148	104	116	108	124
6	104	136	92	108	88	104	104	120	96	104	100	116
Mean	67	88	57	60	55	79	71	98	60	62	60	90
S.D	43.58	57.60	42.57	46.46	37.25	48.31	38.95	63.92	41.22	45.26	40.39	53.39
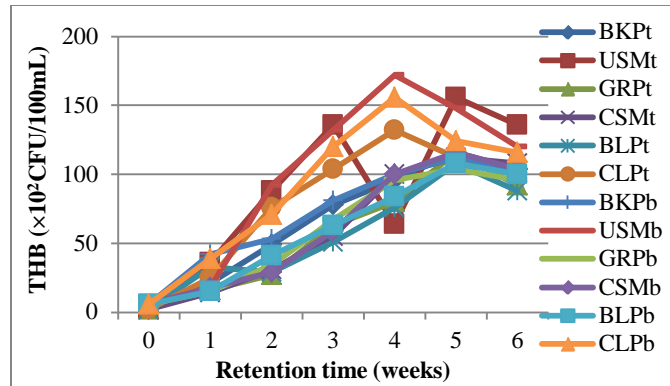
Figure 12: Variations pattern of THB in stored water during research period**.**

The growth of bacteria in the storage tanks suggests that either; the few bacteria present in the water samples prior to storage were spore-forming bacteria that might have shield themselves against the un-conducive environment caused by residual chlorine, or bacteria from the surrounding environment might have find their way into the stored water in the vessels.

Based on the information displayed in Figure 12 it can be conclude that; total bacteria growth rate was higher in water stored in Uncoated Steel Metal tanks (USM_t and USM_b) than water stored in other storage vessels. This higher growth rate of bacteria suggests that the high concentration of irons in these tanks (Ogbozige, 2015) might have nourished some iron bacteria present in these reservoirs. Also, among the plastic tank, total bacteria recorded in water stored in coloured tanks were less than those recorded in black tanks. This is due to the fact that the penetration of ultra violet rays through the coloured plastic reservoirs (Eniola, 2007) might have destroyed some of the bacteria (most especially at the surface of the water) in these reservoirs or tanks. The high level of bacterial contamination recorded in water stored in clay pots can be as a result of the fact that the clay pots were stored indoor hence; the pots were not exposed to the direct effect of the ultra-violet rays which would have destroyed some of the bacteria at the surface of the water in it. It can as

well be attributed to contamination from the surrounding environment since the covering of the clay pots were not air tight (Just as in real situation).

The decline in total bacteria concentration (death phase) during the sixth week of retention is caused by the depletion or exhaustion of nutrient in the stored water which eventually led to the death of some of the bacteria and consequently, these death bacteria (toxic) makes the surviving bacteria to be dying at a fast rate.

CONCLUSION

Based on the results obtained in this research, the following conclusions can be drawn:

i. Provided potable water is stored in a hygienic condition, most quality parameters (physio-chemical) improve (i.e water remain fresh) during the first week of retention thereafter, the quality cannot be assured.

ii. The growth rate of Manganese (Mn) in stored potable water does not depend on the colour of storage vessel but it is a function of time, type of construction material used as storage vessel and the initial concentration before storage.

iii. Bacteria proliferation in stored water is less pronounced in colourd plastic tanks than black plastic tanks; which is accredited to the penetration of ultra violet rays through coloured plastic tanks and consequently destroys bacteria at the surfaces of these tanks (coloured plastics.

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