

**EFFECT OF STORAGE CONTAINER AND TIME ON POTABLE WATER QUALITY**

**BY**

**FRANCIS JAMES OGBOZIGE**

**DEPARTMENT OF WATER RESOURCES AND ENVIRONMENTAL ENGINEERING,  
FACULTY OF ENGINEERING, AHMADU BELLO UNIVERSITY, ZARIA  
NIGERIA.**

**OCTOBER, 2015**

EFFECT OF STORAGE CONTAINER AND TIME ON POTABLE WATER QUALITY

BY

Francis James OGBOZIGE, B.Sc. (Ibadan) 2010M.Sc/ENG/36162/12-13

A DISSERTATION SUBMITTED TO THE SCHOOL OF POSTGRADUTE STUDIES,  
AHMADU BELLO UNIVERSITY, ZARIA IN PARTIAL FULFILMENT FOR THE AWARD  
OF A  
MASTER DEGREE IN ENVIRONMENTAL ENGINEERING.

DEPARTMENT OF WATER RESOURCES AND ENVIRONMENTAL  
ENGINEERING, FACULTY OF ENGINEERING, AHMADU BELLO UNIVERSITY, ZARIA  
NIGERIA.

OCTOBER, 2015

## DECLARATION

I declare that the work in this Dissertation entitled EFFECT OF STORAGE CONTAINER AND TIME ON POTABLE WATER QUALITY has been carried out by me in the Department of Water Resources and Environmental Engineering. The information derived from the literatures has been duly acknowledged in the text and a list of references provided. No part of this dissertation was previously presented for another degree or diploma of this or any other institution.

OGBOZIGE, Francis James

---

Signature

---

Date

## CERTIFICATION

The dissertation entitled:

EFFECT OF STORAGE CONTAINER AND TIME ON POTABLE WATER QUALITY

By

FRANCIS JAMES OGBOZIGE

meets the regulations governing the award of the degree of Master of Science [Environmental Engineering] of Ahmadu Bello University, and is approved for its contribution to knowledge and literary presentation.

---

Engr. (Dr.) D.B. Adie

Chairman, Supervisory Committee

---

Date

---

Engr. (Mrs.) F.B. Ibrahim (Ph.D).

Member, Supervisory Committee

---

Date

---

Prof. A. Ismail

Head of Department

---

Date

---

Prof. Kabir Bala

Dean, Postgraduate School

---

Date

## **DEDICATION**

This work is humbly dedicated to all the SS II and SS III students of Community Secondary School, Emago-Kugbo in between the sessions 2013/2014 and 2014/2015 for their co-operations with me especially the periods I was absent in school in the course of running this program. The Algebra, Trigonometry, Mechanics, Thermodynamics, Optics and Calculus that I taught for the few periods I was with you will never be in vain. I always pray that the reservoir of knowledge (Supreme-being) enable you to become academic giants and excel more than me in all your academic pursuits (So shall it be).

## ACKNOWLEDGEMENTS

All thanks be to the **God** for the opportunity given to me to be an M.Sc. student in the Department of Water Resources and Environmental Engineering of the Ahmadu Bello University, Zaria and also, the chance to finish this program successfully.

I wish to also acknowledge with gratitude; the assistance, advice and suggestions which my supervisors; Engr. (Dr.) D.B. Adie and Engr. (Mrs.) F.B. Ibrahim (Ph.D) rendered during all the stages of this report. Your thorough supervisions of this thesis and the pains you took to correct the write-up are much appreciated. I am highly indebted to both of you for making me discover the potential in me.

I acknowledged with utmost gratitude, the various roles played by Prof. C.A. Okuofu, Prof. O.J. Mudiare, Prof. B.K. Jha, Prof. O.E. Charles-Owaba, Prof. Y. Minjiyawa, Dr. I.A. Oworodo and his family, Engr. Ebitei Charles, Engr. Onome Odonwa, Mr. Idibie Oyege and Engr. Arawo Charles. The assistance rendered by all of you will always be in my heart and my prayer is that the creator of the universe replenished all what you gave me in exponential three (20) times.

I will never forget my unique mother (Pokuta) who continuously prayed for her last born in order to ensure that he gets to this stage in life, and as well ready to discomfort herself just for the sake of making me her last born feel comfortable. In fact, Mummy you are the greatest mother in West Africa.

My sincere thanks go to the following people for their prayers financial support and encouragement during this program; Pastor David Agbontaen, Rev. canon (Prof.) Sogue, Mr. Austin Osain and his family, Mr. Jato James and his family, Mr. Hezekiah Mobutu, Madam Madigiri (Mama Joe), Mrs. Olali (the vice principal during my secondary school days),

MadamMercy, Mr. Akhogba Augustine (Director, Meditech laboratory, Amarata-Yenagoa), my siblings; Sir Godsend, Bhelami, Amfimo, Ampies and Coperate, my divine roommates at Oba Akenzua post-graduate hall; Teddius, Victor, Sunday (Daddy Alex) Raymond and Abbaya, my friends; Mr. Godgift Mercy, Eric, Iwaringo (Joe-wida), Igobasi (Jerry), Obens, John (Evolution café), Jeffson, Oludolapo (Manchester University), Tonye, Oyins, Collins Okoro, Batombari, Akuso, Royal, Moris, Yohana, Ronald, Rufus and Nelson, my colleagues in the department especially Engr. Busari, Amaka, Jijingi, Ahmed (Osau...udede) and Adewale, the managements of Okeybros as well as Universal bookshops (Yenagoa). May the supreme-being (God) bless you all and also bring helpers to you in time of need.

Furthermore, I am grateful to Mr. P.C. Alika, Mr. Geoffrey Ameh and MallamYahaya Yakubu all in the Sanitary Chemistry and Microbiology laboratory of Water Resources and Environmental Engineering Department as well as other departmental staff and others too numerous to mention here, thank you all.

## ABSTRACT

Water tanks are liquid storage containers that store water for human consumption. They are usually made of polyethylene (plastic), steel, clay, ceramics and fiber glass. The need to investigate the changes in water quality during storage in different types of water storage tanks or vessels is very crucial in establishing which tank contributes to deterioration or improvement of stored water during storage. 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 tanks 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, Taste, Odour, Colour, Turbidity, Total solids, Conductivity, pH, Nitrate, Dissolved oxygen, Alkalinity, Total hardness, Calcium hardness, Chloride, Chlorine residual, Manganese, Iron, Total Heterotrophic Bacteria (THB) and Chlorophyll-A. However, all parameters listed above were analyzed at a sampling frequency of seven days interval. The results showed that among the different container materials/colours used, black plastic tank was the best in terms of preserving water quality. The range in the following examined toxic parameters (i.e Nitrate, Manganese, Total heterotrophic bacteria and Chlorophyll-A) in tap water stored in black plastic tank were 8.0mg/L – 13.8mg/L, 0.099mg/L – 0.201mg/L,  $2 \times 10^2$ CFU/100mL –  $116 \times 10^2$ CFU/100mL and 0.000 $\mu$ g/L – 0.959 $\mu$ g/L respectively. On the other hand, the range for the said parameters for borehole water stored in black plastic tank are respectively 8.9mg/L – 13.6mg/L, 0.127mg/L – 0.226mg/L,  $6 \times 10^2$ CFU/100mL -  $112 \times 10^2$ CFU/100mL and 0.000 $\mu$ g/L – 0.954 $\mu$ g/L. Also, findings from the study recommends that, the maximum retention period for storing tap water or borehole water in plastic tanks as well as coated steel metal tanks to be at most 3 weeks while storage in clay pots should not to exceed 6 days. On the other hand, uncoated steel metal tank was suggested not to be used as storage vessel for potable/drinking water regardless of the retention time. The research also modeled the water quality results and identified that Electrical Conductivity (EC) is strongly influenced by Alkalinity, Calcium hardness and Chloride ions with  $R^2$  values of 0.9926, 0.9958 and 0.9995 respectively. From this work, it was established that, black plastic materials should be considered first when selecting a container material for storing water in large capacity.

## SYMBOLS AND ABBREVIATIONS

Alk: Alkalinity

APHA: American Public Health Association

AWWA: American Water Works Association

BKP<sub>b</sub>: Borehole water stored in a black plastic tank

BKP<sub>t</sub>: Tap water stored in a black plastic tank

BLP<sub>b</sub>: Borehole water stored in a blue plastic tank

BLP<sub>t</sub>: Tap water stored in a blue plastic tank

CaHard: Calcium hardness

CFU: Colony Forming Unit

ChlA: Chlorophyll-A

Cl\*: Chloride ions

Cl: Chlorine

CLP<sub>b</sub>: Borehole water stored in a clay pot

CLP<sub>t</sub>: Tap water stored in a clay pot

Conc.: Concentration

CSM<sub>b</sub>: Borehole water stored in a coated steel metal tank

CSM<sub>t</sub>: Tap water stored in a coated steel metal tank

D.O: Dissolved Oxygen

EC: Electrical Conductivity

Fe: Iron

GRP<sub>b</sub>: Borehole water stored in a green plastic tank

GRP<sub>t</sub>: Tap water stored in a green plastic tank

I-Colour: Initial colour of water before storage

I-Con: Initial concentration before storage

I-EC: Initial value of Electrical Conductivity of water before storage

I-Obs: Initial observation before storage

I-pH: Initial pH value of water before storage

I-Temp: Initial temperature of water before storage

Mn: Manganese

NTU: Nephelometric Turbidity Unit

O: Objectionable

TCU: True Colour Unit

THB: Total Heterotrophic Bacteria

UO: Unobjectionable

USM<sub>b</sub>: Borehole water stored in an uncoated steel metal tank

USM<sub>t</sub>: Tap water stored in an uncoated steel metal tank

WPCF: Water Pollution Control Federation

## TABLE OF CONTENT

TITLE PAGE	i
DECLARATION	ii
CERTIFICATION	iii
DEDICATION	iv
ACKNOWLEDGEMENT	v
ABSTRACT	vii
SYMBOLS AND ABBREVIATIONS	viii
TABLE OF CONTENT	ix
LIST OF FIGURES	xiv
LIST OF TABLES	xv
LIST OF PLATES	xvii
LIST OF APPENDICES	xviii
CHAPTER ONE: INTRODUCTION	1
1.1 General background	1
1.2 Statement of the problem	2
1.3 Justification of the tudy	2
1.4 Aim and objectives of the study	3
1.5 Scope of the project	3
1.6 Description of research area	4

CHAPTER TWO: LITERATURE REVIEW	5
2.1 Water supply and human health	5
2.2 Water quality parameters	7
2.2.1 Physical water-quality parameters	7
2.2.2 Chemical water-quality parameters	11
2.2.3 Bacteriological water-quality parameters	19
2.4 Water storage vessels	28
2.4.1 Clay pot	28
2.4.2 Galvanized steel water tank	29
2.4.3 Plastic water tank	31
2.5 Changes in quality of stored water	32
2.6 Nigerian standard for drinking water quality	34
2.7 Spectrophotometry of sun light	38
CHAPTER THREE: MATERIALS AND METHODS	40
3.1 Materials	40
3.1.1 Apparatuses and Reagent Used	40
3.2 Methods	42
3.2.1 Sampling and sampling frequency	42
3.2.2 Test Procedures	43
3.2.2.1 Temperature	43
3.2.2.2 Turbidity	43
3.2.2.3 Odour	44

3.2.2.4	Taste		44
3.2.2.5	Colour	45	
3.2.2.6	Total solids	45	
3.2.2.7	Electrical conductivity		46
3.2.2.8	pH		47
3.2.2.9	Dissolved oxygen		48
3.2.2.10	Total hardness		49
3.2.2.11	Calcium hardness		50
3.2.2.12	Chloride		51
3.2.2.13	Alkalinity		52
3.2.2.14	Residual chlorine		53
3.2.2.15	Nitrate		54
3.2.2.16	Iron		54
3.2.2.17	Manganese		55
3.2.2.18	Total heterotrophic bacteria		55
3.2.2.19	Chlorophyll-A test		56

## CHAPTER FOUR: RESULTS AND DISCUSSION 57

4.	Introduction		57
4.2	Temperature	57	
4.3	Turbidity	59	
4.4	Odour	61	
4.5	Taste	62	
4.6	Colour	64	

4.7	Total solids	66
4.8	Electrical conductivity	68
4.9	pH	68
4.10	Dissolved oxygen	71
4.11	Total hardness	71
4.12	Calcium hardness	74
4.13	Chloride	74
4.14	Alkalinity	77
4.15	Chlorine residual	77
4.16	Nitrate	80
4.17	Iron	80
4.18	Manganese	83
4.19	Total heterotrophic bacteria	85
4.20	Chlorophyll–A	86
4.21	Determination of best storage container material in terms of water Quality preservation	90
4.22	Determination of maximum retention period for Storing water in each of the storage vessels	92
4.23	Modeling of water quality results	95
4.23.1	Flowchart for the models	100
4.23.2	Computer program for the models	101

CHAPTER FIVE: CONCLUSION AND RECOMMENDATIONS	1045.1
Conclusion	104
5.2 Recommendation	105
REFERENCES	107

## LIST OF FIGURES

<b>Figure</b>	<b>Page</b>
2.1 Electromagnetic spectrum of sun light	39
2.2 Wave lengths of colour spectrum of visible light	39
3.1 Map of parts of Samaru and ABU showing Sampling Points	41
4.1 Percentage of minimum coefficients of weekly variation of parameters in tanks containing tap water	91
4.2 Percentage of minimum coefficients of weekly variation of parameters in tanks containing borehole water.	92
4.3 Comparism between observed values of EC and predicted values	99
4.4: Flowchart of the computer program	100

## LIST OF TABLES

Table	Page
2.1	Classification of water with respect to hardness levels <span style="float: right;">14</span>
2.2	Physical parameters and maximum allowable limits for Nigerian standard of drinking water <span style="float: right;">35</span>
2.3	Bacteriological parameters and maximum allowable limits for Nigerian standard of drinking water <span style="float: right;">35</span>
2.4	Inorganic-chemical parameters and maximum allowable limits for Nigerian standard of drinking water <span style="float: right;">36</span>
2.5	Organic-chemical parameters and maximum allowable limits for Nigerian standard of drinking water <span style="float: right;">37</span>
2.6	Disinfectants and maximum allowable limits for Nigerian standard of drinking water <span style="float: right;">37</span>
4.1	Temperature variations in water stored in tanks or containers during research period (°C) <span style="float: right;">58</span>
4.2	Turbidity variations in water stored in tanks or containers during research period (NTU) <span style="float: right;">60</span>
4.3	Odour variations in water stored in tanks or containers during research period <span style="float: right;">62</span>
4.4	Taste variations in water stored in tanks or containers during research period <span style="float: right;">63</span>
4.5	Colour variations in water stored in tanks or containers during research period (TCU) <span style="float: right;">65</span>
4.6	Total solids variations in water stored in tanks or containers during research period (mg/L) <span style="float: right;">67</span>
4.7	Electrical conductivity variations in water stored in tanks or containers during research period (µS/cm) <span style="float: right;">69</span>
4.8	pH variations in water stored in tanks or containers during research period <span style="float: right;">70</span>
4.9	Dissolved oxygen variations in water stored in tanks or containers during research period (mg/L) <span style="float: right;">72</span>
4.10	Total hardness variations in water stored in tanks or containers during research period (mg/L as CaCO <sub>3</sub> ) <span style="float: right;">73</span>
4.11	Calcium hardness variations in water stored in tanks or containers during research period (mg/L Ca) <span style="float: right;">75</span>

4.12	Chloride variations in water stored in tanks or containers during research period(mg/L)	76	
4.13	Alkalinity variations in water stored in tanks or containers during research period(mg/L CaCO <sub>3</sub> )	78	
4.14	Chlorine (residual) variations in water stored in tanks or containers during research period(mg/L)	79	
4.15	Nitrate variations in water stored in tanks or containers during research period(mg/L)	81	
4.16	Iron variations in water stored in tanks or containers during research period(mg/L)	82	
4.17	Manganese variations in water stored in tanks or containers during research period(mg/L)	84	
4.18	Total heterotrophic bacteria variations in water stored in tanks during research period( $\times 10^2$ CFU/100mL)	87	
4.19	Chlorophyll-A variations in water stored in storage tanks or containers during research period( $\mu$ g/L)	88	
4.20:	Number of parameters having minimum coefficients of weekly variations in stored tap water		90
4.21:	Number of parameters having minimum coefficients of weekly variations in stored borehole water		91
4.22	Recommended maximum retention period for storing water in each of the storage vessels	95	
4.23	Relationship between Manganese concentration in stored water and retention time	95	
4.24	Relationship between Chlorophyll-A concentration and retention time in stored tap water or borehole water		97
4.25	Relationship between modeled parameters		98

### LIST OF PLATES

<b>Plate</b>	<b>Page</b>
2.1 Modified clay pots (Sokoto, Nigeria)	29
2.2 A galvanized steel water storage tank	30
2.3 Polyethylene (plastic) water storage tanks	31

3.1a	ABU water treatment plant	41	
3.1b	Commercial borehole	41	
3.2a	Water storage containers installed outdoor (for both water sources)	41	
3.2b	Clay pots installed indoor (for both water sources)	41	
3.3A	turbidimeter	44	
3.4A	lovibond comparator	45	
3.5aA	weighing balance	46	
3.5b	A Steam bath	46	
3.6	An EC/TDS/NaCl meter	47	
3.7A	multiparameter photometer	48	
3.8a	Colour of water samples after adding reagents before titration, in D.O determination	49	
3.8b	Colour of samples after titrating to the end point (colourless)	49	
3.9a	Colour of water samples after adding reagents before titration, in hardness determination.	50	
3.9b	Colour of samples after titrating to the end point (blue colour)	50	
3.10a	Colour of water samples after adding reagents before titration, in determination	53	alkalinity
3.10b	Colour of samples after titrating to the end point (orange colour).	53	
3.11a	Samples ready for inoculation.	56	
3.11b	Counting of bacteria	56	

### **LIST OF APPENDICES**

APPENDIX A: VARIATION PATTERNS OF EXAMINED PARAMETERS WITH TIME	115
APPENDIX B: RELATIONSHIP BETWEEN MANGANESE (Mn) CONCENTRATION AND RETENTION TIME	124
APPENDIX C: RELATIONSHIP BETWEEN CHLOROPHYLL-A CONCENTRATION AND RETENTION TIME	128

APPENDIX D: RESULTS FROM STATISTICAL ANALYSIS SYSTEM (SAS) 9.2	130
APPENDIX E: MAXIMUM RETENTION PERIODS FOR STORING TAP WATER OR BOREHOLE WATER IN STORAGE CONTAINERS	131
APPENDIX F: RESULTS OBTAINED FROM AAS	137

## **CHAPTER ONE**

### **INTRODUCTION**

#### **1.1 GENERAL BACKGROUND**

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, 2000).

Water is a chemical substance that is composed of two atoms of hydrogen and an atom of oxygen (Hayward, 2004). In typical usage, water refers to only its liquid form or state, but the substance also has a solid state known as ice, and a gaseous state called steam or water vapor. According to Parsons and Jefferson (2006), water to be consumed by man/animals should fall within the range of certain limits set by World Health Organization (W.H.O.) often known as drinking water standards. Such water that is fit for human consumption is called potable water.

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. Such containers used in storing water are called water storage reservoirs or tanks. Storage reservoirs are available in various forms based on the material of construction such as clay, galvanized steel, polyethylene, fiberglass, and concrete. They are also available in various shapes/size of container such as buckets, bottles, pots, GP tanks, over-head tanks, etc. A good storage reservoir should be able to maintain the quality (i.e. physio-chemical and bacteriological properties) of the

water during period of storage or have minimal effect on the stored water when compared with the water source/W.H.O. standards; which is the essence of the research.

## **1.2 STATEMENT OF THE PROBLEM**

Over the years, different types of storage containers have evolved. Water storage containers are made of various kinds of materials including clay, concrete, galvanized steel, wood, fiberglass and polyethylene plastic. Plastic tanks are the most commonly used with its advantage being low cost, durability and of low maintenance (Georgia, 1999). While all the types of storage tanks mentioned above have all been considered useful in storing potable water by Standard Organization of Nigeria (SON), the fact remains that they come in variety of colours and the optimum retention periods for storing water in these tanks are not usually stated. Hence, it is still necessary to investigate how each type and colour of storage tank affects the quality of the water stored in it.

## **1.3 JUSTIFICATION OF THE STUDY**

The most commonly used types of water storage containers in Nigeria in terms of material composition are plastic (polyethylene), galvanized steel and clay. Plastic and galvanized steel tanks are commonly used in urban areas while plastic and clay are commonly used in rural areas (Gadgil, 1998). The quality of potable water after storage in containers has always been questionable whether it improves or deteriorates. However, microbiological growth, temperature changes and quality deterioration has been noted and documented in certain storage tanks by several researchers. Hence, this study or research can help in determining whether water storage container materials actually have effect on the deterioration in quality of stored water.

#### **1.4 AIM AND OBJECTIVES OF THE STUDY**

The aim of the research is to determine the changes in quality of potable water (tap water and borehole water) during storage in various types of tanks. The specific objectives of the research are to:

1. Determine how different types of storage container materials and colours affect the physio-chemical and bacteriological properties of potable water.
2. Determine which of the storage container or tank under study best preserves water quality based on parameters examined.
3. Determine the maximum retention period of water in each of the six (6) storage containers for both borehole and tap water.
4. Model the water quality results.

#### **1.5 SCOPE OF THE PROJECT**

- i. Potable water is limited to borehole and tap water.
- ii. Water storage containers/tanks in terms of material of construction are limited to clay, steel metal and plastic (polyethylene). While the colours of plastic are limited to black, green and blue.
- iii. Apart from clay pot, other water storage vessels are limited to GP tanks and overhead metal tanks hence, the water stored in their respective materials of construction (plastic and steel metal) were kept outdoor in order to reflect actual field condition.
- iv. Suitability of water storage containers or tanks was only judged using WHO/Nigerian Standards for Drinking Water.

- v. Examined parameters are limited to Temperature, Odour, Taste, Turbidity, Colour, Total solids, Electrical conductivity, pH, Dissolved oxygen, Total hardness, Calcium hardness, Chloride, Alkalinity, Chlorine residual, Nitrate, Iron, Manganese, Total heterotrophic bacteria and Chlorophyll-A test (for algae concentration determination).

## **1.6 DESCRIPTION OF RESEARCH AREA**

The tap water used for this research was obtained from the water treatment plant of the Ahmadu Bello University water works, Zaria while that of the borehole was obtained in a commercial 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.

## **CHAPTER TWO**

### **LITERATURE REVIEW**

#### **2.1 WATER SUPPLY AND HUMAN HEALTH**

Souter and Cruickshank (2003) reported that, the health of a community depends to a large extent on the ample provision of wholesome water supply. Provision of adequate 'safe' water is essential for good health and economic development. Therefore, waterborne diseases (such as cholera, typhoid fever, amoebic dysentery, gastro-enteritis, etc) arising from the consumption of contaminated water exert a high toll of morbidity and mortality worldwide. Water borne diseases are the second single largest category of communicable disease, after acute respiratory diseases, contributing to infant mortality worldwide, with more than three (3) million deaths per year (Carter, 2005).

Maraj (2006) classified diseases associated with water into infectious and non-infectious, and differentiated the two as explained below. The non-infectious, are those that associate with the chemical properties of water. Some examples are fluorosis, which is associated with high flouride level in drinking water and methemoglobinemia, which is due to high nitrate content. On the other hand, infectious diseases are those caused by transmission of pathogens (disease causing organisms) from one person to another or some times to and from an animal through different routes. Momba and Notshe (2003) opined that the presence of faecal materials in water (either by direct or indirect means) is the most common and widespread health risk associated with drinking water. This is because excrement from communicable disease carriers may contain pathogenic micro-organisms such as bacteria, viruses, protozoa or parasites, which can cause wide range of water borne diseases such as dysentery, hepatitis, cholera, typhoid, etc.

Millions of people die each year as a consequence of consuming unsafe water or inadequate sanitation, and although exact information is difficult to obtain, WHO (2009) data, gives an indication of the magnitude of the problem as follows;

- a. Each year, over five million people die from water associated diseases.
- b. Two million of the annual deaths are of children.
- c. In developing countries, 80 percent of all illness is water associated.
- d. At any time, half of the population in developing countries will be suffering from one or more of the main water associated diseases.
- e. A quarter of the children born in developing countries would have died before the age of five, the great majority from water associated diseases.

Bradley (1977) classified diseases associated with water into four groups viz:

1. ***Waterborne diseases:*** These are diseases that are spread through water. Some examples are cholera, hepatitis, dysentery, typhoid, etc.
2. ***Water-washed diseases:*** These are diseases that emanate as a result of inadequate supply of water for personal hygiene. Such infections include scabies, skin and eye infections, louse-borne relapsing fever, louse-borne typhus, etc.
3. ***Water-insect vector disease:*** These are those that are spread by vectors which requires water for breeding, which include malaria, dengue fever, trypanosomiasis (sleeping sickness), etc.
4. ***Water-based diseases:*** These are infections or diseases that are transmitted through aquatic invertebrate organisms. Examples are guinea worm, paragonimiasis, schistosomiasis, etc.

## **2.2 WATER QUALITY PARAMETERS**

Water quality parameters are measures used to set permissible limit of water quality in order to achieve water that will not affect the health of mankind. These quality parameters depict if the quality of water is good enough for drinking, irrigation and aquatic life. They are usually categorized into physical, chemical and bacteriological parameters.

### **2.2.1 Physical Water-Quality Parameters**

Physical parameters are those characteristics of water that is detectable by human senses. Colour, turbidity, temperature, suspended solids, as well as taste and odour, fall into this category.

**Colour:** According to Howard (2002), the colour of water is directly related to its appearance in a given sample, and it may be caused by the presence of minerals such as iron and manganese or by substance of vegetable origin such as algae and weeds. However, Peavy (1998) reported that industrial wastes from textile and dyeing operations, pulp and paper production, food processing, chemical production, as well as mining, refining, and slaughterhouse operations may add substantial colouration to water in receiving streams. It was outlined in Pickford (1991) that, the colour of water may be apparent (as in the case of partly colour due the presence of suspended matters) or true colour (i.e. colour contributed by dissolved solids that remain after removal of suspended materials).

Coloured water is not aesthetically acceptable to the general public. In fact giving a choice, consumers tend to choose clear, non coloured water of otherwise poorer quality over treated *potable* water supplies with an objectionable colour (Peavy, 1998). Highly coloured water is unsuitable for laundering, dyeing, paper making, beverage manufacturing, dairy production and

other food processing together with textile and plastic production. Thus the colour of water affects its marketability for domestic and industrial use.

***Turbidity:*** The turbidity of water is a measure of how much interference is caused to the passage of light through water. Turbidity is not detrimental to water portability unless it contains disease causing bacteria (Trevett *et al.*, 2005). However, Peavy (1998) stated that the colloidal materials associated with turbidity provide adsorption sites for chemicals that may be harmful or cause undesirable tastes and odours and for biological organisms that may be harmful. In addition, Parsons and Jefferson (2006) stated that, disinfection of turbid waters is difficult because the colloids may partially shield organisms from the disinfectant.

Helmer (1996) recorded that most turbidity in surface waters results from the erosion of colloidal materials such as clay, silt, rock fragments and metal oxides from the soil. However, Peavy (1998) stated that vegetable fibers and microorganisms may also contribute to turbidity, soaps, detergents and emulsifying agents produce stable colloids that result in turbidity.

***Temperature:*** Kim and Cardone (2005) stated that temperature is not used to evaluate directly either potable water or wastewater. It is however, one of the most important parameters in natural surface-water systems. In Howard (2002), it was reported that the temperature of surface waters governs to a large extent the biological species present and their rates of activity. Howard (2002) added that temperature also has an effect on most chemical reactions that occur in natural water systems as well as the solubility of gases in water.

The temperature of natural water systems responds to many factors, the ambient temperature (temperature of the surrounding atmosphere) being the most universal. Generally, shallow bodies of water are more affected by ambient temperatures than deeper bodies. The use of water for

dissipation of waste heat in industry and the subsequent discharge of the heated water may result in temperature changes in receiving streams. Removal of forest canopies and irrigation return flows can also result in increased stream temperature.

Cooler water usually has a wider diversity of biological species. At lower temperatures, the rate of biological activities, i.e. utilization of food supplies, growth, reproduction, etc. is slower. If the temperature is increased, biological activity increases. An increase of 10°C is usually sufficient to double the biological activity, if essential nutrients are present (Peavy, 1998). A review of Howard (2002) reveals that, at elevated temperatures and increased metabolic rates, organisms that are efficient at food utilization and reproduction flourish, while other species decline and are perhaps eliminated altogether. Tebbutt (1998) stated that, accelerated growth of algae often occurs in warm water and can become a problem when cells cluster into algae mats because the natural secretion of oils by algae in these mats and the decay products of dead algae cells can result in taste and odour problems.

***Suspended solids:*** In a review of Rose and Belote (2000), it was stated that suspended solids in water may consist of inorganic or organic particles or of immiscible liquids. They also explained that inorganics solids such as clay, silt and other soil constituents as well as organic material such as plant fiber and biological solids (algal cells, bacteria, etc.) are often natural contaminants resulting from the erosive action of water flowing over surfaces. Rose and Belote (2000) also stated that because of the filtering capacity of the soil, suspended material is seldom a constituent of groundwater and that, other suspended material may result from human use of water.

Peavy (1998) stated that, suspended materials in water may be objectionable in water for several reasons such as; aesthetically displeasing and can provide adsorption sites for chemical and

biological agents. Suspended organic solids may be degraded biologically, resulting in objectionable by-products while biological active (live) suspended solids may include disease-causing organisms as well as organisms such as toxin-producing strains of algae (Sutherland *et al.*, 1990).

***Electrical conductivity:*** Conductivity is the measurement of the ability of a solution to conduct electric current. This ability is dependent upon the presence of ions in solution. According to Twort *et al.* (1985) a conductivity measurement is an excellent indicator of the total dissolved solids in water. For most water, dissolved solid is a product of conductivity and a factor (in the range 0.55-0.70). For waters containing a lot of free acid, the factor may be less than 0.55 while for highly saline waters it is greater than 0.70 (Twort *et al.*, 1985). Conductivity is also temperature dependent and a reference temperature (usually 20 or 25° C) as suggested by Peavey *et al.* (1985) is used in expressing the result. According to a research carried out by Parsons and Jefferson (2006), changes in conductivity denote a changing composition and in raw water, indicate that a change in treatment may be required.

***Taste and odour:*** Many substances with which water comes into contact in nature or during human use may impart perceptible taste and odour. These include minerals, metals, salts from the soil, end products from biological reactions, and constituents of wastewater (Peavy, 1998; Parsons and Jefferson, 2006). In Peavy (1998), it was reported that substances that produce an odour in water will almost invariably impart a taste as well although the converse is not true, as there are many minerals that produce taste but no odour. It was further explained in Peavy (1998) that, inorganic substances are more likely to produce tastes unaccompanied by odour with examples of alkaline material imparting a bitter taste to water while metallic salts giving a salty or bitter taste. Peavy, (1998) also explained that organic material on the other hand, is likely to

produce both taste and odour by setting an example using the biological decomposition of organics which may result in taste and odour producing liquids and gases in water.

Consumers find taste and odour aesthetically displeasing for obvious reasons. Because water is thought of as tasteless and odourless, the consumer associates taste and odour with contamination and may prefer to use a tasteless and odourless water that might actually pose more of a health threat (Peavy, 1998). However, Sangodoyin (1993) reported that an odour produced by organic substances may pose more than a problem of simple aesthetics, since some of those substances may be carcinogenic.

### **2.2.2 Chemical Water-Quality Parameters**

Water has been referred to as a universal solvent and chemical parameters are related to the solvent capability of water. pH, Hardness, alkalinity, dissolved oxygen, biochemical oxygen demand, free chlorine, chloride, iron, sulfites, etc. are the chemical parameters of concern in water quality assessment.

**pH:** pH represents the effective concentration (activity) of hydrogen ions ( $H^+$ ) in water. This concentration could be expressed in the same kind of units as other dissolved species, but  $H^+$  concentrations are much lower than other species in most waters (Graham and Vanderslice, 2007).

According to Kim and Cardone (2005), the activities of hydrogen ions can be expressed most conveniently in logarithmic scale hence; pH is defined as the negative logarithm to base ten of the hydrogen ions concentration in a solution. Mathematically, pH is given as;

$$pH = -\log[H^+](2.1)$$

where  $[H^+]$  is the concentration of hydrogen ions in mole per liter (a mole is a unit of measurement, equal to  $6.022 \times 10^{23}$  atoms). However, Liou and Wang (2004) stated that because hydrogen ions associate with water molecules to form hydronium ions ( $H_3O^+$ ), pH is often expressed in terms of concentration of hydronium ions. Ross and Allison (2000) recorded that in pure water at  $22\text{ }^{\circ}\text{C}$  ( $72\text{ }^{\circ}\text{F}$ ),  $H_3O^+$  and hydroxyl ions ( $OH^-$ ) exist in equal quantities; the concentration of each is  $1.0 \times 10^{-7}$  moles per liter (mol/L). Therefore, pH of pure water is given as;

$$-\log(1.0 \times 10^{-7}) = -(-7.00) = 7.00(2.2)$$

Since pH is defined as  $-\log[H^+]$ , it implies, pH decreases as  $[H^+]$  increases (which will happen if acid is added to the water). Also, pH is a base 10 log scale, hence, the pH changes by 1, for every power of 10 change in  $[H^+]$ . That is, a solution of pH 3 has an  $H^+$  concentration 10 times that of a solution of pH 4. pH scale ranges from 0 to 14. However, pH values less than 0 and greater than 14 have been observed in very rare concentrated solutions (Mechenich and Andrew, 2002).

In a review of Nawal (2003), it was recorded that pH is not static, it changes over time, it can change over the course of single day with further explanation that, it drops at night and rises during the day time. However, Schreiner (2005) stated that pH of stored water could change as the biological processes change in the tank. A solution with a pH value less than 7 is acidic, while a solution greater than 7 is basic. Natural water usually has a pH of between 6 and 9 (Trevett *et al.*, 2005).

A research carried out by Hem (1997) recorded the factors affecting pH to include concentration of carbon dioxide in water. Carbon dioxide ( $CO_2$ ) enters a water body from a variety of sources, including the atmosphere, runoff from land, release from bacteria in water, and respiration by

aquatic organisms. This dissolved  $\text{CO}_2$  forms a weak acid. Naturally, unpolluted rain water can be as acidic as pH 5.6, because it absorbs  $\text{CO}_2$  as it falls through the air. Because plants take in  $\text{CO}_2$  during the day and released it during the night, pH levels in water can change day time to night, geology of soils and watershed; acidic and alkaline compounds can be released into water from different types of rock and soil. When calcite ( $\text{CaCO}_3$ ) is present, carbonates ( $\text{HCO}_3^-$ ,  $\text{CO}_3^{2-}$ ) can be released, increasing the alkalinity of the water, which raises the pH. Also when sulfite minerals such as pyrite, or “fool’s gold”, ( $\text{FeS}_2$ ) are present, water and oxygen interact with the minerals to form sulphuric acid ( $\text{H}_2\text{SO}_4$ ). This can significantly drop the pH of water. Drainage water from forests and marshes is often slightly acidic, due to the presence of organic acids produced by vegetation. Other factors as also reported by Hem (2004) include air pollution and drainage from mine sites.

**Hardness:** According to Cooker and Sridhar (2002), hardness is a measure of polyvalent cations (ions with a charge greater than +1) in water. Hardness generally represents the concentration of calcium ( $\text{Ca}^{2+}$ ) and magnesium ( $\text{Mg}^{2+}$ ) ions, because these are the most common polyvalent cations (Stedman, 2005). However, Mechenich and Andrews (2007) reported that ions, such as iron ( $\text{Fe}^{2+}$ ) and manganese ( $\text{Mn}^{2+}$ ), may also contribute to the hardness of water, but are generally present in much lower concentrations.

Water can be classified with respect to hardness in different ways as shown in Table 2.1.

Table 2.1: Classification of water with respect to hardness levels

Range (mg/L as CaCO <sub>3</sub> )	Hardness Level
0-50	Soft
50-100	moderately soft
100-150	slightly hard
150-200	moderately hard
>200	hard
>300	very hard

Source: Twortet *al.*, (1985)

Hardness affects the amount of soap that is needed to produce foam or lather. Hard water requires more soap because the calcium and magnesium ions form complexes with soap, preventing the soap from forming bubbles. Hardness of water is very important in industrial uses, because it forms scale in heat exchange equipment, boilers and pipe lines. However, some hardness is needed in plumbing system to prevent corrosion of pipes (Garg, 2002).

Hardness is generally measured by titration. A buffer and a colour indicator are added to a volume of water. An acid (the titrant) is then added to the water, and it reacts with the Ca<sup>2+</sup> and Mg<sup>2+</sup> in the water. The volume of acid required to change the colour of the sample reflects the Ca<sup>2+</sup> and Mg<sup>2+</sup> concentration of the sample. The more acid needed, the more Ca<sup>2+</sup> and Mg<sup>2+</sup> in the sample. Hardness is generally expressed in units of milligrams per liter (mg/L) or parts per million (ppm) of CaCO<sub>3</sub> (calcium carbonate).

**Alkalinity:** Alkalinity refers to how well a water body can neutralize acids. It measures the amount of alkaline compounds in the water such as carbonates ( $\text{CO}_3$ ), bicarbonates ( $\text{HCO}_3$ ) and hydroxides ( $\text{OH}^-$ ). These compounds are natural buffers that can remove excess hydrogen ions that have been added from sources such as acid rain or acid mine drainage. Alkalinity does not refer to pH but instead, refers to the ability of the water to resist high-range change in pH (Phillip, 2001). According to Rahman (1996), waters with low alkalinity are very susceptible to change in pH while those with high alkalinity are able to resist major shifts in pH hence, as increasing amounts of acid are added to a water body, the pH of the water decreases, and the buffering capacity of water is consumed. The work of Lloyd and Helmer (1991) shows that alkalinity does not only help to regulate the pH of a water body, but also the metal content hence, bicarbonate and carbonate ions in water can remove toxic metals (such as lead, arsenic, and calcium) by precipitating the metals out of solution.

Alkalinity is measured by titration. An acid of known strength (the titrant) is added to a volume of water sample. The volume of acid required to bring the sample to a specific pH level reflects the alkalinity of the sample. The pH end point is indicated by a colour change. Alkalinity is expressed in units of milligrams per liter (mg/L) of  $\text{CaCO}_3$  (calcium carbonate).

**Dissolved Oxygen:** Dissolved oxygen (DO) is found in microscopic bubbles of oxygen that are mixed in the water and occur between water molecules (Gilleret *al.*, 2002). DO is a very important indicator of a water body's ability to support aquatic lives. Fish "breathe" by absorbing dissolved oxygen through their gills. Colfordet *al.*,(2005) stated that oxygen enters the water by absorbing directly from the atmosphere or by aquatic plant and algae photosynthesis, while the removal is by respiration and decomposition of organic matters.

DO can be measured with a digital titrator by adding a solution of known strength to a water sample. The amount of solution required to change the colour of the sample reflects the concentration of DO in the sample. The amount of oxygen dissolved in water is expressed as a concentration, in milligrams per liter (mg/L) of water.

Increase of DO in drinking water also increase its freshness (Gray, 1994). Temperature affects DO concentration, i.e. as temperature increases, DO decreases and vice versa. However, water may be low in temperature and still low in DO, this is due to the decomposition of organic matters by bacteria (Faniran *et al.*, 2001).

**Biochemical Oxygen Demand (BOD):** This is the amount of oxygen consumed by microorganisms in the oxidation of organic matters. Cairncross and Faechem (1993) reported that, most of the bacteria in water are aerobic (i.e., they use oxygen to perform their metabolic activities of decomposition). It was also stated in Henry (2002) that, natural levels of oxygen in aquatic systems are always somewhat depleted by normal levels of aerobic bacterial activity.

In BOD measurement, oxygen consumed from a sample placed in an air-tight container, and kept in a controlled environment for a preselected period of time is determined. In the standard test, a 300-mL BOD bottle is used and the sample is incubated at 20° C for 5 days. However, Obi (2003) suggested that light must be excluded from the incubator to prevent algal growth that may produce oxygen in the bottle. A BOD result with a low value generally means little pollution and/or little aerobic activities while, a high BOD means the reverse. In BOD measurement, it is reported as milligrams of oxygen consumed per liter (mg/L) of water.

**Fluorides:** Fluorides occur naturally in public water supplies as they are regarded as an essential constituent of drinking water, particularly with regard to the prevention of dental caries in children.

According to Tunji and Ismail (2000), Epidemiological studies of possible adverse effects of the long term ingestion of fluoride via drinking water have established the fact that fluoride produces effects on skeletal tissues (bones and teeth). Also, Khan *et al.*,(2003) confirmed that, low concentration of 0.5mg/L provide protection against dental caries especially in children, concentration as high as 1.5 mg/L may cause dental fluorosis while greater than 1.5mg/L may cause endemic cumulative fluorosis with resulting skeletal damage in both children and adults. However, the optimum fluoride concentration should be set taking into consideration the climatic conditions and the amount of water likely to be consumed. A pointer to this was provided by large scale epidemiological studies by several authors cited by Standards Organization of Nigeria (2003) which claimed that in areas with temperate climate, dental fluorosis manifests at concentrations above 1.5-2 mg of fluoride per litre of drinking water while in warmer areas, it occurs at lower concentrations because of the greater amount of water consumed.

**Nitrates:**Drinking water high in nitrate is potentially harmful to human and animal health. According to Nugent *et al.*, (1996), children or babies under six months of age are highly susceptible to nitrate poisoning because bacteria that live in the digestive tracts of newborn babies convert nitrate to nitrite (NO<sub>2</sub>). Nitrite then reacts with haemoglobin which carries oxygen in the blood to form methaemoglobin, which cannot carry oxygen, thus the affected baby suffers oxygen deficiency. The resulting condition is known as methaemoglobinaemia or "blue baby syndrome" (a situation in which a baby turns blue few minutes after death). Most reported cases of blue baby syndrome is due to contaminated water used in preparing infant formula with nitrate concentration greater than 40mg/L. However, a study of methaemoglobin levels in infants receiving low dietary nitrates in Eastern Nigeria

conducted by Enaboret *al.*, (1998) concluded that, there was no significant association between high methaemoglobin levels in the blood of infants and levels of nitrate ingested.

Jenning and Sneed (1996) recorded that, even though nitrate occurs naturally in drinking water, elevated levels in ground water may result from human activities such as; overuse of chemical fertilizers and improper disposal of human and animal wastes. He further explained that these fertilizers and wastes are sources of nitrogen-containing compounds, which are converted to nitrates in the soil and thereafter, flow through the soil down to the water table thus, contaminating the ground water.

**Free chlorine:** Chlorine is a greenish-yellow gas that dissolves easily in water. It has a pungent, noxious odour that some people can smell at concentrations above 0.3 parts per million (Lumbet *al.*, 2006). Because chlorine is an excellent disinfectant, it is commonly added to most drinking water supplies. In parts of the world where chlorine is not added to drinking water, thousands of people die each day from waterborne diseases like typhoid and cholera (Jawaset *al.*, 1998). Chlorine is also used as a disinfectant in wastewater treatment plants and swimming pools. It is widely used as a bleaching agent in textile factories and paper mills, and it is an important ingredient in many laundry bleaches.

Andrew (2004) reported that free chlorine (chlorine gas dissolved in water) is toxic to aquatic organisms, even in very small amounts. Free chlorine test measures only the free or dissolved chlorine in water while the total chlorine test measures both free and combined forms of chlorine. Andrew (2004) also suggested that care should be taken when adding chlorine to drinking water because chlorine gas even at low concentration can irritate eyes, nasal passage and the lungs. Russell and Hugo (2000) stated that concentration less than 0.5mg/L of chlorine is

needed to kill bacteria without causing the water to smell or taste unpleasant, although most people can't detect the presence of chlorine at double (1mg/L) that amount.

**Chloride:** Chlorides are widely distributed in nature as salts of sodium (NaCl), potassium (KCl) and calcium (CaCl<sub>2</sub>). Chloride in groundwater can be naturally occurring in deep aquifers or caused by pollution from sea water, brine or industrial/domestic wastes (Rosen and Vincent, 2001). Chloride concentration above 250mg/L (which is the limit set by WHO) can produce a distinct taste in water. Where chloride content is known to be low, a noticeable increase in chloride concentrations may indicate pollution from sources such as septic systems, fertilizer, landfills and road salts (Michenich and Andrews, 2007).

No health-based guideline value is proposed for chloride in drinking-water, however, at concentrations greater than 250mg/L, a salty taste may be observed (WHO guidelines for drinking water quality, 2009).

**Iron:** According to Liou (2004), iron is not considered hazardous to health; in fact it essential for good health because it transports oxygen in the blood. However, Ince and Shaw (1999) reported that iron in drinking water can be objectionable because easily changes the appearance of the water, affect taste, causes the growth of iron bacteria and gives a rusty colour to laundered clothes if greater than 0.3mg/L. In addition, Chatterjee (2001) reported that in the presence of hydrogen sulfide, iron causes sediments that may give the water a blackish colour and also, water stored in metal tanks may be polluted by iron if rusting occurs in some parts of the tank.

### **2.2.3 Bacteriological Water-Quality Parameters**

It is impractical to monitor drinking water for every possible microbial pathogen that might occur as a result of contamination. A more logical approach is the detection of organisms

normally present in the faeces of man and other warm-blooded animals as indicators of excremental pollution, as the efficacy of water treatment and disinfection. The presence of such organisms indicates the presence of faecal materials/intestinal pathogens. Clasen and Bastable (2003) stated that the use of normal intestinal organisms as indicators of faecal pollution rather than the pathogens themselves is a universally accepted principle for monitoring and assessing the microbial safety of water supplies.

Below are the characteristics of a good indicator organism (Gunner *et al*, 1966):

The indicator bacterium must be present whenever the pathogens concerned are present.

- i.* The organism must be present only when the presence of pathogens is an imminent danger, i.e. they must not be able to proliferate to any greater extent in the aqueous environment.
- ii.* The indicator organism must occur in much greater number than the pathogens.
- iii.* The indicator organism must be more resistant to disinfectants and to the aqueous environment than the pathogens.
- iv.* The indicator organism must grow readily on a relatively simple media.
- v.* The organism must yield characteristic and simple reactions enabling as far as possible, an unambiguous identification of the group.
- vi.* The organism must be randomly distributed in the sample to be examined, or it should be possible to obtain a uniform distribution by simple homogenization procedure.

- vii.** The indicator organism must grow widely independent of other organisms present, when inoculated in an artificial media, i.e. the indicator bacteria should not be seriously inhibited in their growth by the presence of other bacteria.

According to Mara and Oragui (1985), no ideal faecal indicator exist. However, they reported that in conventional water bacteriology, classical indicators are used which include:

- a.** the coliform group of organisms-reaffirmed as essential indicator of pollution by faecal material such as *Escherichia coli*
- b.** faecal *streptococci* which indicate recent pollution since it dies quickly outside the host.
- c.** *clostridiumperfringens* for indicating remote or intermittent pollution.

The first documented attempt to use the presence of bacteria as an indicator of sanitary quality occurred in 1880, when Von Fritsch described *Klebsiella pneumoniae* and *K. rhinoscleromatis* as micro organisms' characteristic of human contamination. A lot of information had been accumulated on the biochemical and physical characteristics of the coliform group, which consist of numerous species and strain divisions (Feachem, 1977). Recently, *Pseudomonas aeruginosa* and some other members of the anaerobic internal flora notably Bifidobacterium (which distinguish between human and animal faecal pollution) have been proposed as additional indicator bacteria (Edberg *et al.*, 2002).

***The Coliform group of organisms:***The coliform group of organisms belong to the family Enterobacteriaceae that consist of the genera, *Escherichia*, *Citrobacter*, *Enterobacter*, *Hafnia*, *Klebsiella*, *Serratia* and *Yerinia*. According to Feachem and Mara (1979), there are two principal groups of coliform bacteria the non faecal and the faecal coliforms. They stated further that though the non faecal ones are commonly found, they occur naturally in

unpolluted soils and water. Therefore, only the faecal coliforms are definite indicator of faecal pollution. Their work also revealed that, the major difference between the two groups is that, while the faecal coliforms ferment lactose with production of acid and gas within 24-28 hours at 44°C, the non-faecal ones do not.

According to Moe *et al.*, (1991), the ability of the coliforms to produce acid from lactose has been linked to the possession of a gene coding for the production of  $\beta$ -galactosidase. They also reported that, the expression of the gene can be affected by many factors such as time, temperature and medium. Dorman (1992) also stated that, under different conditions, the same organism may or may not ferment sufficient lactose to be registered as a lactose-fermenter under the conditions used.

According to Clasen and Bastable (2003), *E. coli* is the most abundant coliform organism present in the human and animal intestine in numbers approaching 1,000 million per gram of fresh faeces. They further explained that, *E. coli* is rarely found in the soil, vegetation or water in the absence of excremental contamination. However, coliform organisms other than *E. coli* occur in the intestine but their combined, number seldom exceed million per gram of faeces.

Since *E. coli* and other coliform organisms are present in large numbers in faeces and sewage and can be detected in number as small as (1) in 100ml of water, they are the most sensitive indicator bacteria at our disposal for demonstrating excremental contamination (Clasen and Bastable, 2003). Presence of *E. coli* in drinking water sources is regarded as the most reliable measure of public risks (Edberg, *et al.*, 2002). The test for coliforms, including *E. coli* is both qualitative and quantitative since it detects and enumerates their number in order to assess the degree of pollution and hence danger to health.

The study of the risk of diarrheal disease in the Philippines by Moe *et al.*, (1991) showed that *E. coli* is better than faecal coliforms as an indicator of risk of diarrhea disease in children. From their findings, they concluded that more than 1000 *E. coli* per 100ml constitute high diarrheal disease risk, while less than 1000 *E. coli per 100ml* constitute low risk.

Wright *et al.*, (2004) stated that, the presence of other coliform organisms in the absence of *E. coli* may be due to a variety of causes such as:

- remote excremental contamination which has *E. coli* to die out
- the onset of more dangerous pollution in the future.

**Faecal streptococci:** WHO (2003) described faecal streptococci as a member of lancefield's serological Group D (they all possess the lancefield Group D antigen). They are generally present in the faeces of human and animals in varying numbers.

According to Pryseet *al.*, (2000), the species of streptococci occurring in faeces which are likely to be found in polluted water, can be divided into two main groups:

- i. those present in man and animals, for example *Streptococcus faecalis*, *S. faecium* and *S. faecium* and *S. durans*
- ii. those not normally present in man for example, *Streptococcus bovis*, *S. equines* and *S. avium*.

Dorman (1992) reveal in his work that, certain species of faecal streptococci are often associated with particular animals, forexample,

- (1) *S. bovis* – occurs in larger numbers in sheep and cattle,
- (2) *S. equines* – mainly associated with horses and
- (3) *S. avium* – associated with poultry and other birds.

Although *S faecalias*, *S. faecium* and *S. duran* are present in man and animals, Pryseet *al.*, (2000) affirmed that, *S. faecalis* is not as abundant in some animals as in man. This assertion was supported by Wesley and Foley (2004) who found out that *S. faecalis* occur more (29%) in the faeces of man than in that of the gut of farm animals. It was discovered that *S. bovis* is the most predominant faecal streptococci of the gut of farm animals and that it is absent or relatively rare in the faeces of humans (Pryseet *al.*, 2000). Hence, it can be used to distinguish between animal and human faecal pollution.

### ***Clostridium perfringens***

WHO (2003) described *Clostridium perfringens* (formerly *Clostridium welchi*) as anaerobic and spore –forming organisms, which are normally present in small numbers in faeces. This number as reported in Pryseet *al.*,(2000), seldom exceeds  $10^4$  hence; it indicates faecal pollution when coliforms and faecal streptococci are absent. Therefore, it may indicate remote or intermittent faecal pollution.

***New Indicators distinguishing human from animal pollution:*** Distinction between human and animal pollution is very vital in water quality control not only because it helps in tracing the source of faecal pollution but also because it can be used in assessing the adequacy of protection of a water supply especially in developing countries (Pryseet *al.*, 2000). Many methods such as FC/FS ratio have been used in the past, but recently, bifidobacteria have been proposed as indicator organisms for use in tropical waters since they are exclusively faecal in origin and do not grow outside the intestine (Pryseet *al.*, 2000). Feachem and Mara (1979) defined Bifidobacteria as non sporulating anaerobic organisms, which occur in the intestine of man and warm blooded animals. Field work carried out in Nigeria and Zimbabwe by Mara and Oragui (1985) showed that, animal faecal pollution can be identified by the detection and enumeration of

*Rhodococcus coprophilus* using modified M3 agar, while human faecal contamination can be identified by detection of sorbitol-fermenting bifidobacteria.

***Detection and enumeration of Indicator bacteria:*** The detection and enumeration of indicator organisms can be carried out using two methods viz: Membrane filtration technique and Most Probable Number (MPN) or Multiple Tube Fermentation technique. The procedure for these two methods are described in Feachem and Mara (1979) and Helmer (1996).

Membrane filtration (MF) technique involves filtration of a measured volume of sample through a membrane consisting of cellulose esters or equivalent (Gelreich, 1994 and Faniranet *al.*, 2001). The filtration apparatus consists of a base supporting a porous disc to which a graduated filter funnel is secured by means of screw-threads, clamps or magnet. The apparatus is connected to a vacuum source to aid filtration. The membrane filters may be about 47mm in diameter, with a pore size of 0.45 µm or any other that will retain all the bacteria in the sample. Though the MF technique is highly reproducible and can produce result within 18 hours, it is unsuitable for testing water of high turbidity normally encountered in many developing countries (Feachem and Mara, 1979). With high turbidity, the membrane gets blocked before sufficient water is filtered while the accumulated deposit on the membrane may inhibit the growth of indicator organisms.

On the other hand, MPN or Multiple tube fermentation technique involves the measurement of volumes of samples of one or more dilution into series of tubes containing a liquid differential medium and thereafter, the tubes are incubated at  $37 \pm 0.5$  °C, and results of the examination is reported in terms of the most probable number of organisms present (Feachem and Mara, 1979). Unlike the MF technique, which is not suitable for highly turbid water, the MPN technique can be used for turbid, salty or brackish waters as well as mud, sediments and sludge (Gelreich, 1994).

***Heterotrophic or Standard plate count (HPC):*** According to Lindskog (2001), HPC is a procedure for estimating the number of heterotrophic (aerobic) organisms in water, which grow as colonies on plate of nutrient agar under defined conditions. The test can be carried out by pour plate, spread plate or membrane filtration method. Lindskog (2001) also revealed that, of the three methods, the pour plate method can accommodate 0.1-2.0 ml of sample and the colonies are relatively small and compact with fewer tendencies to encroach on each other than those produced by surface growth. However, in a research carried out by Bradley (1977) shows that, submerged colonies are often slower growing and difficult to transfer. According to Lindskog (2001), organisms which grow best at 37 °C usually grow less readily in water and are more likely to have gained access from external sources. Lindskog (2001) also reports that, though HPC is not comparable to detection of indicator organisms for assessing the safety of potable water supplies, nevertheless, it provides:

- i. a means of assessing the efficiency of water treatment process;
- ii. a general indication of bacterial content and hence the hygienic quality of water supplies
- iii. a means of determining the suitability of a given water supply for large scale preparation of foods and drinks, where to reduce the risk of spoilage, water should ideally contain few organisms of any kinds.

WHO (2004) reported that, HPC test measures only a fraction of the microorganisms actually present and does not distinguish between pathogens and non pathogens.

Franceys and Ball (2002) stated in their work that, Total and Faecal coliforms are used worldwide for assessing the potability of drinking water supplies. They also characterized the groups of total coliforms (TC) and faecal coliforms (FC) and evaluated their usefulness as indicators of faecal

pollution in tropical climates. The conclusion they made was that, FC should be considered as the method of choice for determining drinking water pollution of untreated ground water supplies.

The results of a ground water study conducted by the United States Geological Survey from 1993-95, as part of its National Water quality Assessment Program, in lower Susquehanna River Basin Study Unit, Pennsylvania and Maryland showed that, out of 146 household supply (wells) samples, 70 percent had total coliform present while 25 percent had E. coli and hence, not suitable for consumption without treatment. However, the research was able to explain that, most wells from which water was sampled did not have sanitary seal while very few were grouted which might have contributed to the bacteria pollution of the sources. Also, Rahman (1996) in his assessment of ground water as a source of contamination for the three major water sources for domestic use (municipal water supply, vendors and well water) in Karachi, a rapidly growing mega city of Pakistan, discovered that most of the sources except municipal water supply from some areas and during certain periods, contain coliform bacteria and in many cases, faecal coliforms amounts in magnitude higher than any standard permits. Also, many samples contain chromium, lead, nickel and arsenic in amounts higher than permitted standards. He however concluded that, the probable source of contaminants for the various types of sources is predominantly from sewage since only a small fraction of rainfall (3.3 percent) recharges the ground water. The predominant source of recharge comprised of sewage from sewage treatment outfall (53.6 percent) and leakage from sewerage system (5.5 percent).

In Nigeria, Sangodoyin (1993) in a study of contamination of ground water by waste disposal systems in Abeokuta, discovered that the bacteriological quality monitored by coliform counts showed significant negative correlation of 0.74 and 0.60 with distance from polluting source and depth of well respectively.

## **2.4 WATER STORAGE VESSELS**

Presently, there are different types of water storage tanks/containers all adjudged well enough for portable water storage. Since these tanks/containers are made of different materials i.e. fiber glass, polyethylene, stainless steel, galvanized steel, ceramics, clay concrete; they may definitely affect the quality of water stored inside each of them in different ways. Zaidat (2005) reported that, the most commonly used type of tanks for large capacity storage in Nigeria are the plastic and galvanized steel tanks.

### **2.4.1 Clay Pot**

Before the discovery of steel and plastic, clay jars and vessels have been used to store food and water. Different types of clay when used with different mineral and firing conditions are used to produce earthenware, stoneware and porcelain. Prehistoric humans discovered the useful properties of clay, and one of the earliest artefacts ever discovered is a draining vessel made of sun-dried clay (Musa *et al.*, 1999).

Depending on the content of soil, clay can appear in various colours, from dull-gray to deep orange–red. In many cultures, clay pots are the preferred storage containers because as water evaporates through the clay, the water inside the container is cooled. Osibanjo (2006) reported that; in some rural areas in Nigeria, water is transported in clay pots, but in most areas, water is transported in plastic containers and then stored in clay pots. By working with local potters, it is possible to modify clay pots to have a tap as shown in the Plate 2.1. This is to ensure that water can be withdrawn from clay containers without contamination. The advantages and disadvantages of using clay as a water storage material are given below as given by Musa *et al.*, (1999).



Plate 2.1: Modified clay pots (Sokoto, Nigeria).

#### *Advantages of clay storage reservoirs/containers*

- i. Clay pots and vessels are very cheap to produce/purchase.
- ii. Apart from refrigerators, clay pots are the best water storage reservoir material in storing drinking water for the purpose of cooling.
- iii. The physical and chemical constituents of clay storage vessels have not been known to have any major negative effect on water stored in them.

#### *Disadvantages of clay storage reservoirs or containers*

- i. Clay vessels are only produced in small sizes.
- ii. Clay vessels are easily breakable and are not easy to repair.

#### **2.4.2 Galvanized Steel Water Tank**

According to Jawaset *al.*, (1998), galvanized steel water tanks (Plate 2.2) have been in use for decades, and they are good as an option for storing water for both domestic and industrial uses. Galvanization is a metallurgical process by which steel is coated with zinc. This protects rusting

of the steel underneath. In other words, it helps to avoid galvanic corrosion which is a particular form of rust formation. Galvanization is done by non-electrochemical method.



Plate 2.2: A galvanized steel water storage tank.

Galvanization itself is a very old process because steel has been galvanized and been in use for over 150 years (Jawaset *al.*, 1998). Galvanized tanks can be very large, with a storage capacity of up to 5000 gallons (20,000 liters). The tanks are designed in away so that they are protected against wind, snow and heat, hence, they can withstand harsh weather conditions without any difficulty thereby lasting for decades (Rosen and Vincent, 2001).

### 2.4.3 Plastic Water Tank

The type of plastic approved for food as well as potable water storage is polyethylene (Collingnon and Vezina, 2000). Polyethylene is a type of thermoplastic, actually known as polyethylene terephthalate, a polymer invented in 1941 by John Rex Winfield who condensed ethylene glycol with terephthalic acid. The condensate was polyethylene terephthalate (PET or PETE). PET is a thermoplastic that can be drawn into fibers and films. It is the main plastic in food storage bags and water storage containers/tanks (Faniran *et al.*, 2001).



Plate 2.3: Polyethylene (plastic) water storage tanks.

Water stored in plastic containers should not be kept near gasoline, kerosene, pesticides or similar substances because vapour from this substance could penetrate the plastic and affect the water (Henry, 2002). Thick-walled polyethylene containers are significantly less permeable to vapour than thin-walled containers. Clasen and Bastable (2003) suggest that, when selecting a storage container for water, it should have a tight fitting cap or lid to prevent entrance of contaminants and evaporation of water. Because sunlight has an adverse effect on plastic, water should be stored away from direct exposure to sunlight (Agbede and Morakinyo, 2001).

According to Collingnon and Vezina (2000), the following are some of the advantages of using plastic tanks for water storage;

- a. Plastic water tanks are lightweight and can often be moved (empty) by hand into position, which is an advantage on rough terrain.
- b. Plastic water tanks comes in a much wider variety of shapes and sizes/capacities such as buckets, jerry cans, GP tanks, etc.
- c. Plastic water tanks cannot rust over time.
- d. If plastic tank is accidentally punctured, it is easy to repair.
- e. Plastic tanks have UV-inhibitors in the material to fight sunlight.

## **2.5 CHANGES IN QUALITY OF STORED WATER**

Oloruntoba (1995) reported that, the process by which water quality changes upon storage is quite complex because it depends on many factors. However, studies have shown that storage does improve the quality of water (Agbede and Morakinyo, 1995; Agbede, 1991). Upon storage, big suspended flocculated particles and other impurities bigger than the water molecules settle down at the bottom of the reservoir thus ensuring its physical clarification. Bacterial quality also improves (Oluwande, 2003; Twort, *et al.*, 1999), which is partly due to settling and partly the destruction of bacterial by ultra-violet radiation from the sun light near the water surface (Twort *et al.*, 1999).

In the research work of Agbede and Morakinyo (1995), water was obtained from 3 different sources; a relatively wholesome well water, borehole and pipe borne tap water. Each of these 3 samples was stored in a clay pot (covered) for a period of 3 weeks and examinations on changes were carried out at the end of each week. Results obtained showed improvement in

appearance, bacterial quality and reduction in some chemical parameters such as total hardness and chloride.

Eniola (2007) also observed improvement of water quality upon storage; borehole water was stored in different coloured plastic buckets and placed out door. Storage period was 12 days with analysis carried out at 4 days interval. Results showed reduction in total suspended solids as well as that of bacterial concentrations which were more pronounced intransparent buckets. The reduction in pathogens was attributed to the effect of ultra-violet radiation of the sun.

The works of other recent authors indicate deterioration of water quality upon storage. According to Andrew (2004), examination of in use household storage containers of steel, plastic and clay over a month's period showed an increase in microbial contamination in each of the storage containers, however, this was attributed to poor hygiene of the household users rather than the type of storage container.

Hammad (2008) examined the changes in quality of stored water in household and public galvanized steel tanks over a six months period and observed bacterial contamination to have increased. He also observed an increase in iron and copper pollution in tanks that were beginning to rust at the bottom.

The work of Ziadat (2005) also showed deterioration in bacterial quality upon storage and attributed such deterioration to the following:

- i.** Microbial re-growth
- ii.** Chemical and physical changes
- iii.** Loss of chlorine residual
- iv.** Accumulation of sediments

- v. Vulnerability to outside sources of contamination and poor hygiene.

However, one major observation pointed out from sources cited (Russell and Hugo, 2000) suggests that if clean water is stored under hygienic conditions, there should be improvement in quality in terms of reduction in total suspended solids, as the particles within the stored water settle at the bottom of the storage container and /or slow quality deterioration. Agbede and Morankinyo (1995) pointed out that stored water in hygienic conditions may remain fresh for up to seven days after which the quality thereof cannot be guaranteed.

## **2.6 NIGERIAN STANDARD FOR DRINKING WATER QUALITY**

Drinking water quality standard ensures the safety of the drinking water supplies and the protection of public health. Ocheke (2011) stated that, the establishment of Nigerian Standard for Drinking Water Quality (NSDQW) ensures the protection of the consumers and also speed up the process of upgrading non-protected water systems as well as improving the management of all drinking water systems in the country. In addition, Ocheke (2011) went further and explained that, in developing this Standard, references were made to the Nigerian Industrial Standards for Potable Water and Natural Mineral Water, the National Guidelines and Standards for Water Quality in Nigeria, the World Health Organization (WHO) guidelines for drinking water quality (3rd Edition) and Standard Organization of Nigeria (SON). This standard sets; parameters and maximum allowable limits as well as disinfectants and maximum allowable limits as shown in Tables 2.2, 2.3, 2.4, 2.5 and 2.6.

Table 2.2: Physical parameters and maximum allowable limits for Nigerian standard of drinking water

<b>Parameter</b>	<b>Unit</b>	<b>Maximum Permitted Level</b>	<b>Health Impact</b>
Colour	TCU	15	None
Conductivity	µS/cm	1000	None
Odour	-	Unobjectionable	None
Taste	-	Unobjectionable	None
Temperature	°Celsius	Ambient	None
Turbidity	NTU	5	None

Note: TCU means True Colour Unit while NTU stand for Naphelometric Turbidity Unit

Source: Nigerian Standard for Drinking Water Quality (2007).

Table 2.3: Bacteriological parameters and maximum allowable limits for Nigerian standard of drinking water

<b>Parameter</b>	<b>Unit</b>	<b>Maximum Permitted Level</b>	<b>Health Impact</b>
Total coliform count	CFU/mL	10	Indication of faecal contamination.
Thermo tolerant coliform or <i>E. coli</i>	CFU/100mL	0	Urinary track infections, bacteriaemia, meningitis, diarrhea (one of the main cause of morbidity and mortality among children), acute renal failure and hemolytic anaemia.
Faecal streptococcus	CFU/100mL	0	Indication of recent faecal contamination.
<i>Clostridium perfringens</i> spore	CFU/100mL	0	Index of intermittent faecal contamination.

Source: Nigerian Standard for Drinking Water Quality (2007).

A recommendation from the Nigerian standard for Drinking Water Quality (2007) was that, inspectors in charge of Drinking Water Quality Surveillance should conduct regular verification water quality tests and sanitary inspections to determine whether water utilities, community water committees, food processing industries, private or public establishment and private water system owners meet standard for drinking water quality. The standard recommends that the following parameters given or shown in Table 2.3 should be controlled on regular basis.

Table 2.4: Inorganic-chemical parameters and maximum allowable limits for Nigerian standard of drinking water

Parameter	Unit	Maximum Permitted Level	Health Impact
Aluminum	mg/L	0.2	Potential Neuro-degenerative disorder
Arsenic	mg/L	0.01	Cancer
Barium	mg/L	0.7	Hypertension
Cadmium	mg/L	0.003	Toxic to kidney
Chloride	mg/L	250	None
Chromium	mg/L	0.05	Cancer
Copper	mg/L	1.0	Gastrointestinal disorder
Fluoride	mg/L	1.5	Fluorosis, skeletal tissue (bone and teeth) morbidity
Hardness (as CaCO <sub>3</sub> )	mg/L	150	None
Hydrogen sulphide	mg/L	0.05	None
Iron (Fe <sup>+2</sup> )	mg/L	0.3	None
Lead (Pb)	mg/L	0.01	Cancer
Manganese	mg/L	0.2	Neurological disorder
Nitrate	mg/L	50	“Blue-baby syndrome” in infant
pH	-	6.5 to 8.5	None
Total Dissolved Solids	mg/L	500	None

Source: Nigerian Standard for Drinking Water Quality (2007).

Table 2.5: Organic-chemical parameters and maximum allowable limits for Nigerian standard of drinking water.

<b>Parameter</b>	<b>Unit</b>	<b>Maximum Permitted Level</b>	<b>Health Impact</b>
Detergent	mg/L	0.01	Possibly carcinogenic
Mineral oil	mg/L	0.003	Possibly carcinogenic
Pesticides	mg/L	0.01	Possibly carcinogenic
Phenols	mg/L	0.001	Possibly carcinogenic
Poly Aromatic Hydrocarbons	mg/L	0.007	Possibly carcinogenic
Total Organic Carbon	mg/L	5	Cancer

Source: Nigerian Standard for Drinking Water Quality (2007).

Table 2.6: Disinfectants and maximum allowable limits for Nigerian standard of drinking water.

<b>Parameter</b>	<b>Unit</b>	<b>Maximum Permitted Level</b>	<b>Health Impact</b>
Free residual Chlorine	mg/L	0.2 to 0.25	None
Trihalometanes Total	mg/L	0.001	Cancer
2,4,6-trichlorophenol	mg/L	0.02	Cancer

Source: Nigerian Standard for Drinking Water Quality (2007).

However, it was recommended that drinking water providers should increase the amount of residual chlorine during epidemics or special cases according to instructions of Ministry of Health.

## **2.7 SPECTROPHOTOMETRY OF SUN LIGHT**

According to Eugen *et al.*, 2012, spectrophotometry is a measurement of how much a chemical substance absorbs or transmits light. However, Scott and Harry, (2013) reported that, over a certain range of wavelength, every chemical compound absorbs, transmits, or reflects light (electromagnetic radiation). Spectrophotometer is an instrument that measures the amount of the intensity of light absorbed after it passes through sample solution. It can be classified into two different types, depending on the range of wavelength of light source:

- i. UV-visible spectrophotometer: uses light over the ultraviolet range (185 - 400nm) and visible range (400 - 700 nm) of electromagnetic radiation spectrum.
- ii. IR spectrophotometer: uses light over the infrared range (700 - 15000nm) of electromagnetic radiation spectrum. (Murphy and Harvey, 2014)

Although sunlight (or white light) is seen as uniform or homogeneous in color, it is actually composed of a broad range of radiation wavelengths in the ultraviolet (UV), visible and infrared (IR) portions of the spectrum. By passing sunlight through a prism, the component colours of the visible portion can be separated, which acts to bend the light in differing degrees according to wavelengths.

Visible wavelengths cover a range from approximately 400nm to 800nm (Murphy and Harvey, 2014). The longest visible wavelength is red and the shortest is violet. Other colours of the spectrum, in order of decreasing wavelength, may be remembered by the mnemonic: ROY

GBIV. The wavelengths of colours in the visible portion of the spectrum are shown in Figure 2.2.

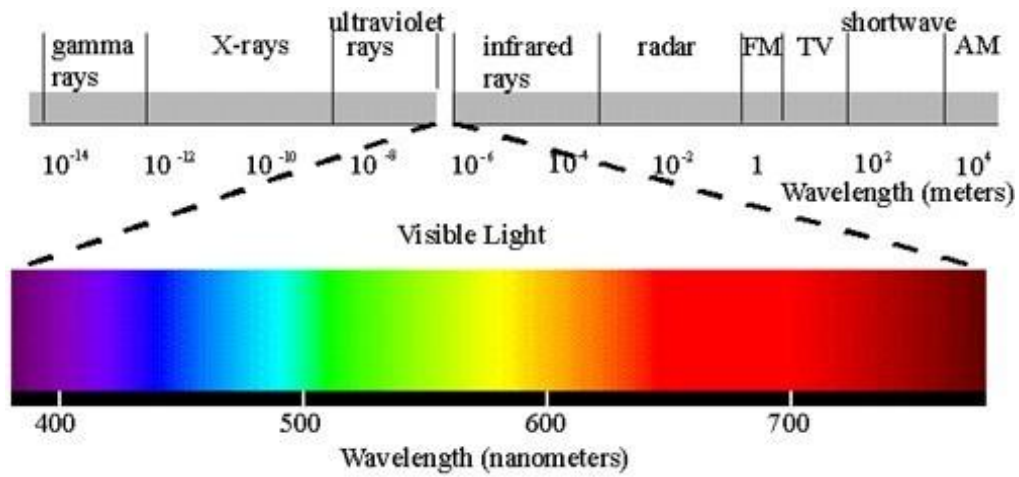


Figure 2.1: Electromagnetic spectrum of sun light.



Figure 2.2: Wave lengths of colour spectrums of visible light.

**CHAPTER THREE**  
**MATERIALS AND METHODOS**

**3.1 MATERIALS**

**3.1.1 Apparatuses and Reagents Used**

- i. Tanks made of Coated Steel Metal (CSM), Uncoated Steel Metal (USM), Black Plastic (BKP), Green Plastic (GRP), Blue Plastic (BLP) and Clay Pot (CLP).
- ii. Lovibond (S1000) comparator made by Tinton LTD, Salisbury, England.
- iii. Weighing balance (FA/JA series) made by HANNA LTD, England.
- iv. Steam bath (GA942-041) made by Gallenkamp Group of Companies, Canada.
- v. HACH 2100N Turbidimeter made by HANNA, LTD, England.
- vi. HI83200 Multiparameter Photometer made by HANNA, LTD, England.
- vii. Spectrophotometer (SP00726) made by Griffin Company, USA
- viii. Atomic Absorption Spectrophotometer (AA 500) made by Fredonia LTD, USA.
- ix. HI9835 EC/TDS/NaCl meter made by HANNA, LTD, England.
- x. Autoclaving machine (GA445-902) made by Gallenkamp Group of Companies, Canada.
- xi. Magnetic stirrer (GA064-331) made by Gallenkamp Group of Companies, Canada.
- xii. BOD bottles, conical flasks, measuring cylinders and burets made by Kimaxcompany, England.

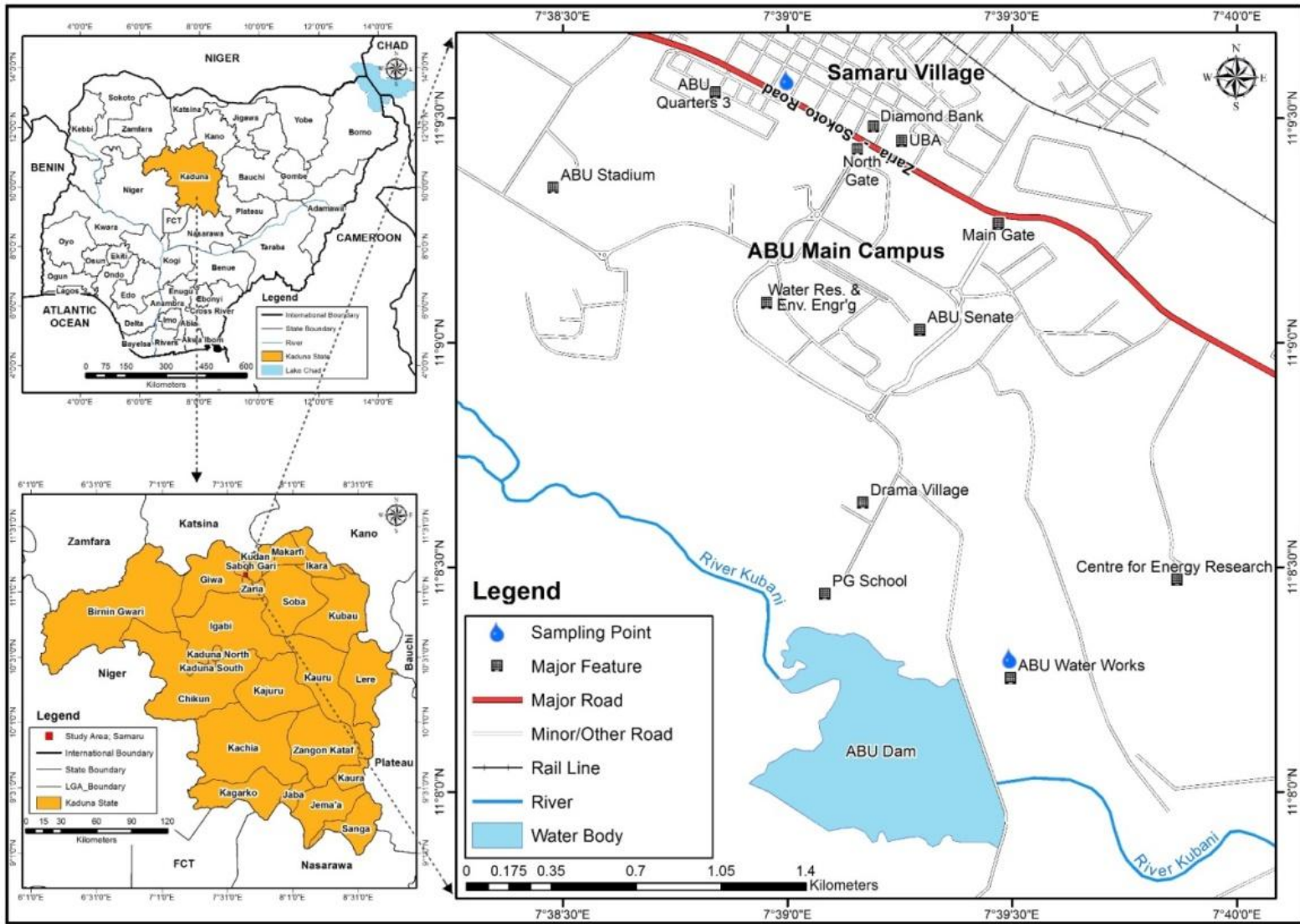


Figure 3.1: Map of parts of Samaru and ABU showing Sampling Points.

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



Plate 3.1a: ABU water treatment plant



Plate 3.1b: Commercial borehole



Plate 3.2a: Water storage containers installed outdoor (for both borehole water and tap water).



Plate 3.2b: Clay pots installed indoor (for both water sources).

## 3.2 METHODS

### 3.2.1 Sampling And Sampling Frequency

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. 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.

The frequency of sampling was seven (7) days interval (i.e weekly basis). This sampling frequency is in line with previous works carried out by Oyinset *al.*, 2012 as well as Henry and Chioma (2014).

### **3.2.2 Test Procedures**

Before analyzing the water quality parameters, the twelve prototypes 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 (16<sup>th</sup> edition, APHA. AWWA.WPCF, 1985). It is important to stress here that, in the course of discussing the analytical procedure for each parameter, singular tenses were used in describing a single sample. Such description is applicable to all the samples for the parameter in question.

#### ***3.2.2.1 Temperature***

Temperature measurement was achieved with the use of a thermometer by extracting sample from the storage container into a test tube and inserting the thermometer immediately into the sample. The temperature reading was recorded at the point where the thermometric fluid in the thermometer remains constant.

#### ***3.2.2.2 Turbidity***

This was determined with the use of HACH 2100N Turbidimeter made by HANNA, LTD, England (Plate 3.3). The device was standardized with respect to the standard cell in the device at 0.14NTU (Naphelometric Turbidity Unit) and after which, the sample was well shaken and poured into another cell. A tissue paper was used in cleaning the walls of the cell in other to

remove any finger print and it was thereafter replaced with the standard cell. The reading was recorded directly from the LCD in NTU.



Plate 3.3: A turbidimeter

### ***3.2.2.3 Odour***

The determination of odour for each sample was carried out by giving the water sample to ten persons selected at random to perceive. The observations from these persons (i.e objectionable/unobjectionable) were the same in each of the water sample.

### ***3.2.2.4 Taste***

Just like odour, the determination of the taste of water stored in each of the tanks was carried out in a similar way like odour. That is, the water samples were given to ten different persons selected at random to taste. The comments from these persons (objectionable/unobjectionable) were also the same in each of the water sample.

### **3.2.2.5 Colour**

A lovibond comparator (S1000) made by Tinton LTD, Salisbury – England, (plate 3.4) was used in determining the colour of water sample. It consists of a housing containing two test tubes. A hazen disc (NSA) was properly slotted into the comparator and thereafter, distilled water was poured into the left test tube while the water sample was poured into the second test tube at the right. The NSA hazen disc was then rotated until the colours in both test tubes became similar. The value shown on the NSA hazen disc was recorded as the colour of the sample in Hazen Units or True Colour Unit (TCU).



Plate 3.4: A lovibond comparator

### **3.2.2.6 Total solids**

In the course of measuring Total Solids (TS), an empty petri-dish was weighed on a weighing balance (FA/JA series) made by HANNA LTD (Plate 3.5a), and the value recorded (say N). The sample was then thoroughly agitated and thereafter, 100ml was measured into the petri-dish. This petri-dish containing the sample was heated in a steam bath (Plate 3.5b) to dryness and was

later taken to an oven for further drying. Afterward, the petri-dish was allowed to cool in a desiccator before reweighing in the weighing balance.

The Total Solids in mg/L of the sample was obtained by employing the formula;

$$TS = \frac{M - N}{Z} \times 1000 \quad (3.1)$$

(Source: APHA, 1985)

Where:

TS = Total Solids

M = Mass of petri dish + dry residue (in gm)

N = Mass of empty petri dish (in gm)

Z = mL of sample used (100).



Plate 3.5a: A weighing balance

Plate 3.5b: A Steam bath

### ***3.2.2.7 Electrical conductivity***

Measurement of electrical conductivity (EC) was carried out with the aid of HI9835 EC/TDS/NaCl meter, made by HANNA, LTD, England (Plate 3.6). It consists of an electrode and a meter. The device was switched “ON” after proper connection of the electrode to the meter and

thereafter, the EC option was selected by continuous pressing of the key labeled “Range” until  $\mu\text{S}$  appeared on the LCD of the apparatus. The sample was thorough shaken and 50mL of it was measured into a test tube and afterward, the electrode was completely deep into the test tube containing the sample. It was ensured that no air bubbles adhere to the electrode. The electrical conductivity of the sample in  $\mu\text{S}/\text{cm}$  (micro Mohs per centimeter) was directly read from the LCD of the device.



Plate 3.6: An EC/TDS/NaCl meter

### ***3.2.2.8pH***

The PH of the water sample was measured with the aid of a HI83200 Multiparameter Photometer, made by HANNA, LTD, England (Plate 3.7). It was achieved by switching “ON” the apparatus and selecting the pH option among the other parameters. Next, was the removal of the cuvette and rinsing it with distilled water and later with the sample to be determined. The sample was well shaken and 10mL of it was measured into the cuvette and after which, it was covered with the cuvette cap. This was followed by cleaning the sides of the cuvette with a tissue paper in order to remove any finger print. The cuvette was then inserted properly into the apparatus and it was zeroed, for the sake of standardizing the machine. The cuvette was removed and then ten

drops of phenol red solution were added into the cuvette which was well mixed with the sample in the cuvette. Again, the cuvette was cleaned with a tissue paper to remove any finger print on the sides. Finally, the cuvette was inserted into the device and the option “READ” was selected and the pH of the sample was displayed on the LCD.



Plate 3.7: A multiparameter photometer

### ***3.2.2.9 Dissolved oxygen***

This was carried out by gently filling a BOD bottle (300mL) with the sample and allowing it open for bubbles to escape. 2ml each for manganese sulphate and alkali iodide were added into the sample and the BOD bottle was gently stoppered to discard excess. The bottle was thereafter shaken and it was observed that flocks were being formed and at the same time settling. After the flocks settled to about 100mL clear super natant, the bottle was inverted which was followed by adding 2mL of concentrated sulphuric acid ( $H_2SO_4$ ). The bottle was again gently stoppered and inverted before decanting 200mL into a conical flask and then pipetting 1mL of starch solution into the conical flask. The solution in the conical flask (Plate 3.8a) was titrated using sodium trisulphate as titrant to a colourless end point (Plate 3.8b).

The volume of titrant used in mL to reach the end point, correspond to the quantity of dissolved oxygen in mg/L in the sample.



Plate 3.8a: Colour of water samples after adding reagents before titration, in D.O determination.



Plate 3.8b: Colour of samples after titrating to the end point (colourless).

### ***3.2.2.10 Total hardness***

Determination of total hardness was achieved by thorough shaking of sample and measuring 25mL into a cylinder which was top to 50mL with distilled water and then poured into a conical flask. 2mL of a buffer solution with a drop of eriochrome black indicator were added into it. The sample was gently shaken and was titrated with a solution of 0.02EDTA as a titrant to a blue coloration as end point (Plates 3.9a and 3.9b).

The actual concentration of total hardness in mg/L as  $\text{CaCO}_3$  was gotten using the formula given below;

$$\text{Total hardness (mgL}^{-1} \text{ as CaCO}_3\text{)} = \frac{A \times B}{Z} \times 1000 \text{ (3.2)}$$

(Source: APHA, 1985)

Where:

A = mL of titrant used to reach end point

B = 2.5252

Z = mL of sample used for analysis (25mL).

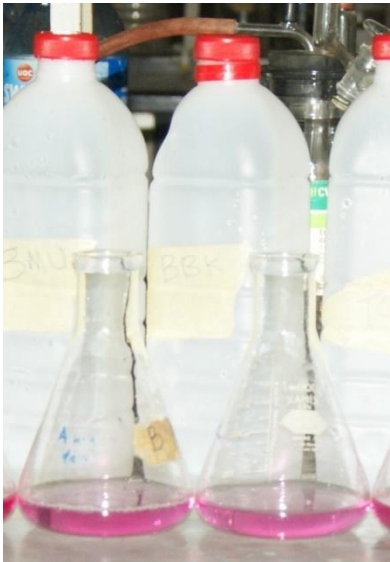


Plate 3.9a: Colour of water samples after adding reagents before titration, in hardness determination.



Plate 3.9b: Colour of samples after titrating to the end point (blue colour).

### ***3.2.2.11 Calcium hardness***

The procedures and reagents used in determining calcium hardness were almost the same with that of total hardness described in the preceding section (i.e section 3.4.9). The only difference is that, the 2mL of buffer solution added into the sample in the case of total hardness was changed

to 2mL of sodium hydroxide (NaOH) solution. Consequently, the concentration of calcium hardness in mg/L was attained by applying the formula stated below;

$$\text{Calcium hardness (mgL}^{-1}\text{ as Ca)} = \frac{A \times B}{Z} \times 400.8(3.3)$$

(Source: APHA, 1985)

Where:

A = mL of titrant used to reach end point

B = 2.5252

Z = mL of sample used for analysis (25mL)

### **3.2.2.12 Chloride**

The method employed here also involved titration. The sample was well agitated, followed by measuring 100ml into a conical flask. 1mL of standard potassium chromate (an indicator) was added and the solution was titrated with standard silver nitrate solution to a redish-brown colouration as end point. Concentration of chloride in mg per liter of the sample was obtained by applying the formula below;

$$\text{Chloride concentration (mgL}^{-1}\text{)} = \frac{A \times N}{Z} \times 35450(3.4)$$

(Source: APHA, 1985)

Where:

A = mL of titrant used to reach end point

N = Normality of silver nitrate solution = 0.0141

Z = mL of sample used for analysis (100mL).

### 3.2.2.13 Alkalinity

Alkalinity was as well determined via titration by thorough shaking of the sample and then measuring 100ml into a conical flask. Three drops of phenolphthalein indicator were added into the sample alongside with three drops of methyl-orange indicator and the solution was well mixed. Finally, the solution was titrated with a 0.02N sulphuric acid (H<sub>2</sub>SO<sub>4</sub>) solution as a titrant to an orange colouration as the end point (Plates 3.10a and 3.10b).

It should be noted that, there was a case where the sample turns pink after the introduction of the first indicator (phenolphthalein). This was removed or discharged by adding some drops of 0.02N sulphuric until the pink colour just disappeared and the volume of acid (in mL) used was recorded. Thereafter, the procedure was continued as explained above by adding three drops of the second indicator (methyl-orange) which was then titrated to the said end point.

As usual, the actual concentration of alkalinity in the water sample is given as follows;

$$\text{Alkalinity (mgL}^{-1} \text{ CaCO}_3) = \frac{A \times N}{Z} \times 5000 \text{ (3.5)}$$

(Source: APHA,

1985)Where:

A = Total mL of titrant used to reach end point

N = Normality of acid = 0.02

Z = mL of sample used for analysis (100mL)



Plate 3.10a: Colour of water samples after adding reagents before titration, in alkalinity determination.



Plate 3.10b: Colour of samples after titrating to the end point (orange colour).

### ***3.2.2.14 Residual chlorine***

This was determined in a similar way as colour as discussed in section 3.4.3 above. Ten milliliters (10mL) each, of distilled water and the sample were measured into two separate conical flasks which was followed by adding 1mL of O-todoline solution into each of the conical flasks. The solutions were allowed to remain still for about ten minutes for colour development and after which, an NCA chlorine disc was properly slotted into a lovibond comparator (Plate 3.4). The solutions were then poured into the two test tubes contained in the lovibond comparator, with that of the distilled water (blank) at the left while that of the sample at the right. The NCA chlorine disc was thereafter rotated and viewed until colours in both test

tubes became similar/same. The concentration of chlorine in mg/L of the sample is equivalent to the value showed on the NCA chlorine disk.

#### ***3.2.2.15 Nitrate***

A multiparameter photometer (HI83200), made by HANNA, LTD, England (Plate 3.8) was used in determining nitrate concentration in the samples. It was executed by switching “ON” the apparatus and selecting the option Nitrate. Next, was rinsing the cuvette of the apparatus with distilled water and also with the sample that was determined and afterward, 6mL of the sample was measured into the cuvette after thorough shaken. The walls/sides of the cuvette were carefully cleaned with a tissue paper for the sake of removing any finger print and was followed by inserting the cuvette properly into the device. The device was standardized by pressing the “zero” key and after which, the cuvette was removed. One drop of phenol disulphonic acid was added into the sample in the cuvette and was mixed thoroughly with the sample. As usual, the cuvette walls were again cleaned with a tissue paper before inserting it into the machine. Immediately, the option “READ” was selected and a value was displayed on the LCD which was converted to the actual concentration of nitrate in mg/L by pressing the option/key “CHEM”.

#### ***3.2.2.16 Iron***

This was carried out with the use of Atomic Absorption Spectrophotometer (AA 500) made by Fredonia LTD, USA. The sample was initially digested by measuring 50mL into a beaker and then adding 10mL of hydrochloric acid (HCL) into the beaker. The beaker was heated and the sample was allowed to boil until it remains half (25mL). Thereafter, the beaker was removed from the heating source and the sample was allowed to cool to room temperature, which was

followed by topping it to 50 mL with 25mL of distilled water. After the digestion, 2mL of lanthanum oxide (2%) was added into the sample before analyzing the said parameters in the AAS. It should be noted that the essence of the digestion was to break any bond into solution that might have caused interference while the addition of lanthanum oxide was to prevent any interference if it occur at all (Hammad, 2008).

### ***3.2.2.17 Manganese***

The procedure or method involved in determining the concentration of Manganese in the water samples was the same with that of Iron as explained in the preceding section (3.2.2.16).

### ***3.2.2.18 Total heterotrophic bacteria***

All the sample bottles used for bacteriological count were disinfected with methylated spirit 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.

The method used in determining total bacteria was Total Viable Count (TVC) using nutrient agar as culture media. Prior to the test, the prepared nutrient agar as well as all apparatus such as petri-dish, pipettes, glass bent rod, etc. were sterilized in an autoclave marching. After sterilization, reasonable quantity of the culture media was poured into a sterilized petri-dish and a mL of the sample was transferred into the petri-dish using a sterilized pipette. This was followed by gradual spreading of the water sample in the petri-dish with a sterile glass bent rod and thereafter, it was turned up-side-down (Plate 3.11a) and then inoculated in an incubator for 24hours. The bacteria colonies observed in the petri-dish after the inoculation was counted via a colony counter (Plate 3.11b).

It should be noted that, in a situation where the colonies were too numerous to count, the back of the petri-dish was divided into four quadrants and the colonies in a quadrant were counted

through the colony counter. The number of colonies counted was multiplied by four (4) which gives the estimated number of colonies in such sample.

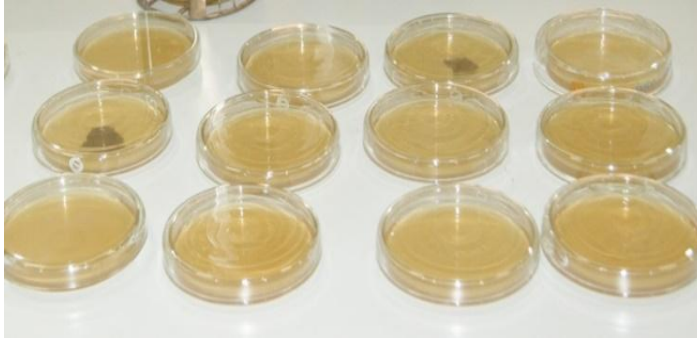


Plate 3.11a: Samples ready for inoculation.



Plate 3.11b: Counting of bacteria.

### ***3.2.2.19 Chlorophyll-A test***

This was carried out in order to know if at all the water contains algae during the storage /research period. In doing this, SHOAF and LIUM procedure for **spectrophotometric** method of chlorophyll-A test was employed and the explanation is as follows;

50mL of the sample was filtered and the filter paper containing the residue was put in an opaque bottle. Thereafter, 3mL of acetone was added into the bottle and was covered immediately. After thirty minutes, the bottle was well shaken and then kept for another fifteen minutes. A spectrophotometer was standardized at 666 nanometer (nm) wave length using acetone solution and thereafter, the absorbance of the sample solution was determined. The spectrophotometer was again standardized at 653nm wave length with the acetone solution and after which, the absorbance of the sample solution in the bottle was as well determined. Below was the formula used in getting the actual concentration of chlorophyll-A:

$$\text{Chlorophyll} - A \text{ (mgL}^{-1}\text{)} = (17.12 \times \text{absorbance @ 666nm}) - (8.86 \times \text{absorbance @ 653nm}) \text{ (3.6)}$$

(Source: APHA, 1985)

## CHAPTER FOUR

### RESULTS AND DISCUSSION

#### 4.1 INTRODUCTION

The water quality parameters examined in each of the twelve water storage tanks or containers used after the research period elapsed (six weeks or 42days) are presented in Tables 4.1 to 4.19 while the variation pattern of each of these parameters are shown in Appendix A.

#### 4.2TEMPERATURE

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 °C) on the first day of the research.

Table 4.1 showed that both sources of water (tap water and borehole water) have no effect on water temperature during storage but rather, depend 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 reservoir materials as well as colours had the same mean temperature.

Also, Table 4.1 reveals that there was a remarkable decrease in temperature of water stored in clay pots which can be attributed to the cooling caused by evaporation. The temperature was observed to gradually drop from 25 °C(temperature of water source before storage) to 20°C at the twenty-first (21<sup>st</sup>) and twenty-eighth (28<sup>th</sup>) day of retention.

Table 4.1: Temperature variations in water stored in tanks or containers during research period ( $^{\circ}\text{C}$ ).

	BKPt	USMt	GRPt	CSMt	BLPt	CLPt	Mean	S.D	CV (%)	BKPb	USMb	GRPb	CSMb	BLPb	CLPb	Mean	S.D	CV (%)
I-Temp	25	25	25	25	25	25	25	0	0	25	25	25	25	25	25	25	0	0
Day 7	28	29	27.5	29	27.5	22	28.2	0.758	2.689	28	29	27.5	28.5	27	22	27	2.550	9.443
Day 14	29	30.5	28.5	30.5	28.5	21.5	29.4	1.025	3.485	29	30.5	28.5	30.5	28.5	21.5	28.083	3.353	11.939
Day 21	27.5	28	27.5	28	27.5	20	27.7	0.274	0.989	27.5	28	27.5	28	27.5	20	26.417	3.153	11.936
Day 28	28	27	28	27	28	20	27.6	0.548	1.985	28	27	28	27	28	20	26.333	3.141	11.928
Day 35	28	26.5	27.5	26.5	28	20.5	27.3	0.758	2.778	28	26.5	27.5	26.5	28	20	26.083	3.056	11.718
Day 42	28.5	30	29.5	30	28.5	21	29.3	0.758	2.588	28.5	30	28.5	29.5	28.5	21	27.667	3.327	12.024
Mean	27.7	28	27.6	28	27.6	21.4	-	-	-	27.7	28	27.5	27.9	27.5	21.4	-	-	-
S.D	1.286	1.979	1.376	1.979	1.205	1.742	-	-	-	1.286	1.979	1.225	1.864	1.190	1.796	-	-	-
CV(%)	4.644	7.068	4.985	7.068	<b>4.366</b>	8.142	-	-	-	4.644	7.068	4.454	6.682	<b>4.328</b>	8.393	-	-	-

**Legend:**

BKP<sub>b</sub> = Borehole water stored in a black plastic tank,

BKPt = Tap water stored in a black plastic tank,

BLP<sub>b</sub> = Borehole water stored in a blue plastic tank,

BLPt = Tap water stored in a blue plastic tank,

CLP<sub>b</sub> = Borehole water stored in a clay pot,

CLPt = Tap water stored in a clay pot,

CSM<sub>b</sub> = Borehole water stored in a coated steel metal tank,

CSMt = Tap water stored in a coated steel metal tank,

CV = Coefficient of variation,

GRP<sub>b</sub> = Borehole water stored in a green plastic tank,

GRPt = Tap water stored in a green plastic tank,

I-Tem = Initial temperature of water before storage,

S.D = Standard deviation,

USM<sub>b</sub> = Borehole water stored in an uncoated steel metal tank

USMt = Tap water stored in an uncoated steel metal tank.

The slight rise in the temperature in between the twenty-eighth (28<sup>th</sup>) and forty-second (42<sup>nd</sup>) day of retention (i.e 20 °C to 21 °C) was 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 storage vessels 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 had the highest recorded temperatures with a maximum value of 30.5°C on the fourteenth (14<sup>th</sup>) day. This could be attributed to the fact that metals are good conductors of heat. Nevertheless, there was a drop in temperatures of water in USM and CSM for both sources on the twenty-eighth (28<sup>th</sup>) and thirty-fifth (35<sup>th</sup>) day of storage. 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(Swarllet, 2012).

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

### **4.3 TURBIDITY**

The turbidity of tap water and borehole water obtained from the sources before storage were respectively 2.000 and 1.091NTU (Table 4.2). In other words, both water sources met the turbidity level set by W.H.O standard (5 NTU).

Table 4.2: Turbidity variations in water stored in tanks or containers during research period (NTU).

	BKP <sub>t</sub>	USM <sub>t</sub>	GRP <sub>t</sub>	CSM <sub>t</sub>	BLP <sub>t</sub>	CLP <sub>t</sub>	Mean	S.D	CV (%)	BKP <sub>b</sub>	USM <sub>b</sub>	GRP <sub>b</sub>	CSM <sub>b</sub>	BLP <sub>b</sub>	CLP <sub>b</sub>	Mean	S.D	CV (%)	
I-Conc	2	2	2	2	2	2	2	0	0	1.091	1.091	1.091	1.091	1.091	1.091	1.091	0	0	0
Day 7	2.08	16.07	2.07	1.19	2.21	1.05	4.112	5.879	143.0	0.214	6.080	0.209	0.799	0.211	0.219	1.289	2.359	183.1	
Day 14	1.96	12.801	1.731	1.71	1.904	2.001	3.685	4.468	121.3	0.197	8.310	0.122	0.142	0.148	0.127	1.508	3.333	221.0	
Day 21	1.83	9.49	1.56	1.41	1.65	0.342	2.714	3.361	123.9	0.303	1.290	0.317	0.806	0.11	1.561	0.731	0.591	80.8	
Day 28	1.795	11.46	1.88	1.427	1.92	1.131	3.269	4.024	123.1	1.957	8.011	0.216	0.523	0.49	0.635	1.972	3.021	153.2	
Day 35	1.955	13.447	1.815	1.3	1.93	0.696	3.524	4.885	138.6	0.259	9.820	0.263	0.803	0.661	0.89	2.116	3.784	178.8	
Day 42	1.915	11.861	1.808	1.479	1.926	1.276	3.378	4.164	123.3	0.206	9.450	0.166	0.471	0.18	0.173	1.774	3.762	212.0	
Mean	1.838	11.018	1.934	1.502	1.934	1.214	-	-	-	0.604	6.293	0.662	0.413	0.341	0.671	-	-	-	
S.D	0.169	4.457	0.098	0.272	0.165	0.62	-	-	-	0.677	3.687	0.308	0.362	0.337	0.543	-	-	-	
CV (%)	9.195	40.452	<b>5.067</b>	18.109	8.532	51.071	-	-	-	112.09	58.59	<b>46.53</b>	87.65	98.83	80.92	-	-	-	

**Legend:**

BKP<sub>b</sub> = Borehole water stored in a black plastic tank,

BKP<sub>t</sub> = Tap water stored in a black plastic tank,

BLP<sub>b</sub> = Borehole water stored in a blue plastic tank,

BLP<sub>t</sub> = Tap water stored in a blue plastic tank,

CLP<sub>b</sub> = Borehole water stored in a clay pot,

CLP<sub>t</sub> = Tap water stored in a clay pot,

CSM<sub>b</sub> = Borehole water stored in a coated steel metal tank,

CSM<sub>t</sub> = Tap water stored in a coated steel metal tank,

CV = Coefficient of variation,

GRP<sub>b</sub> = Borehole water stored in a green plastic tank,

GRP<sub>t</sub> = Tap water stored in a green plastic tank,

I-Conc = Initial concentration before storage,

S.D = Standard deviation,

USM<sub>b</sub> = Borehole water stored in an uncoated steel metal tank,

USM<sub>t</sub> = Tap water stored in an uncoated steel metal tank.

As shown in Table 4.2, the turbidity of tap water stored in Uncoated Steel Metal tank (USM<sub>t</sub>) as well as borehole water stored in Uncoated Steel Metal tank (USM<sub>b</sub>) increased excessively throughout the storage period with values higher than the permissible limit set by W.H.O Standard. On the other hand, turbidity values recorded in the remaining tanks/containers fell within the required limit set by W.H.O standards all through the research period. The high values of turbidity recorded in both USM<sub>t</sub> and USM<sub>b</sub> is as a result of the high colouration of the water in these tanks caused by rust, which might have interfere the passage of light through the samples when analyzed through a turbidimeter (Peavy, 1998).

#### **4.4 ODOUR**

The odours of both water sources (tap water and borehole water) before storage were unobjectionable. However, the water samples stored in uncoated steel metal tanks remained objectionable all through the research period (Table 4.3).

Table 4.3 also suggests that amongst the other vessels used (apart from USM<sub>t</sub> and USM<sub>b</sub>), the water stored in clay pots deteriorated (in terms of odour) faster than those stored in plastics and coated steel metal tanks. This is because the odour of water stored in the former started deterioration on the twenty-eighth (28<sup>th</sup>) day of retention while the later started on the forty-second (42<sup>nd</sup>) day as shown in Table 4.3.

The unpleasant odour recorded in the tanks or containers during the storage period might have emanated from the dead cells (bacteria) that have occurred in the storage vessels during storage.

Table 4.3: Odour variations in water stored intanks or containers during research period.

	BKP <sub>t</sub>	USM <sub>t</sub>	GRP <sub>t</sub>	CSM <sub>t</sub>	BLP <sub>t</sub>	CLP <sub>t</sub>	BKP <sub>b</sub>	USM <sub>b</sub>	GRP <sub>b</sub>	CSM <sub>b</sub>	BLP <sub>b</sub>	CLP <sub>b</sub>
<b>I-Obs</b>	UO	UO	UO	UO	UO	UO	UO	UO	UO	UO	UO	UO
<b>Day 7</b>	UO	O	UO	UO	UO	UO	UO	O	UO	UO	UO	UO
<b>Day 14</b>	UO	O	UO	UO	UO	UO	UO	O	UO	UO	UO	UO
<b>Day 21</b>	UO	O	UO	UO	UO	UO	UO	O	UO	UO	UO	UO
<b>Day 28</b>	UO	O	UO	UO	UO	O	UO	O	UO	UO	UO	O
<b>Day 35</b>	UO	O	UO	UO	UO	O	UO	O	UO	UO	UO	O
<b>Day 42</b>	O	O	O	O	O	O	O	O	O	O	O	O

**Legend:**

BKP<sub>b</sub> = Borehole water stored in a black plastic tank,

BKP<sub>t</sub> = Tap water stored in a black plastic tank,

BLP<sub>b</sub> = Borehole water stored in a blue plastic tank,

BLP<sub>t</sub> = Tap water stored in a blue plastic tank,

CLP<sub>b</sub> = Borehole water stored in a clay pot,

CLP<sub>t</sub> = Tap water stored in a clay pot,

CSM<sub>b</sub> = Borehole water stored in a coated steel metal tank,

CSM<sub>t</sub> = Tap water stored in a coated steel metal tank,

GRP<sub>b</sub> = Borehole water stored in a green plastic tank,

GRP<sub>t</sub> = Tap water stored in a green plastic tank,

I-Obs = Initial observation before storage,

O = Objectionable,

UO = Unobjectionable,

USM<sub>b</sub> = Borehole water stored in an uncoated steel metal tank,

USM<sub>t</sub> = Tap water stored in an uncoated steel metal tank.

**4.5TASTE**

Just as in odour, the tastes of both water sources (tap water and borehole water) before storage were unobjectionable. Furthermore, the variation patterns of water taste in each of the storage tank or container were similar to those obtained in the odour of water corresponding to their respective storage vessels while the reverse was not the case. This confirm the assertion

previously made that the primary source of the odour recorded in the water samples was as a result of the presence of organic matters such as dead cells or bacteria (Tebbutt, 1998).

Table 4.4: Taste variations in water stored in tanks or containers during research period.

	BKP <sub>t</sub>	USM <sub>t</sub>	GRP <sub>t</sub>	CSM <sub>t</sub>	BLP <sub>t</sub>	CLP <sub>t</sub>	BKP <sub>b</sub>	USM <sub>b</sub>	GRP <sub>b</sub>	CSM <sub>b</sub>	BLP <sub>b</sub>	CLP <sub>b</sub>
<b>I-Obs</b>	UO	UO	UO	UO	UO	UO	UO	UO	UO	UO	UO	UO
<b>Day 7</b>	UO	O	UO	UO	UO	UO	UO	O	UO	UO	UO	UO
<b>Day 14</b>	UO	O	UO	UO	UO	UO	UO	O	UO	UO	UO	UO
<b>Day 21</b>	UO	O	UO	UO	UO	O	UO	O	UO	UO	UO	O
<b>Day 28</b>	UO	O	UO	UO	UO	O	UO	O	UO	UO	UO	O
<b>Day 35</b>	UO	O	UO	O	UO	O	UO	O	UO	O	UO	O
<b>Day 42</b>	O	O	O	O	O	O	O	O	O	O	O	O

**Legend:**

BKP<sub>b</sub> = Borehole water stored in a black plastic tank,

BKP<sub>t</sub> = Tap water stored in a black plastic tank,

BLP<sub>b</sub> = Borehole water stored in a blue plastic tank,

BLP<sub>t</sub> = Tap water stored in a blue plastic tank,

CLP<sub>b</sub> = Borehole water stored in a clay pot,

CLP<sub>t</sub> = Tap water stored in a clay pot,

CSM<sub>b</sub> = Borehole water stored in a coated steel metal tank,

CSM<sub>t</sub> = Tap water stored in a coated steel metal tank,

GRP<sub>b</sub> = Borehole water stored in a green plastic tank,

GRP<sub>t</sub> = Tap water stored in a green plastic tank,

I-Obs = Initial observation before storage,

O = Objectionable,

UO = Unobjectionable,

USM<sub>b</sub> = Borehole water stored in an uncoated steel metal tank,

USM<sub>t</sub> = Tap water stored in an uncoated steel metal tank.

Furthermore, Table 4.4 disclosed that all the water samples that recorded objectionable odour as shown in Table 4.3 during the research period equally records objectionable taste.

It should be noted that the reason why arithmetic mean, standard deviation and coefficients of variation were not determined in Tables 4.3 and 4.4 is because the results obtained are not numerical values.

## 4.6 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. Table 4.5 showed that the water colour in all the reservoirs increased on the first week of research and thereafter, remained constant throughout the retention period.

It can be deduced from Table 4.5 that, all the storage vessels apart from the uncoated steel metals, had a uniform colour variation during the period of experiment. Also, the maximum value recorded in these reservoirs 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 metals for both sources was also the same throughout the six weeks or 42 days of storage. However, the water in these tanks (uncoated steel metals) were highly coloured to about 20 TCU which is above the limit set by W.H.O Standard. 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.

Table 4.5: Colour variations in water stored in tanks or containers during research period(TCU).

	BKPt	USMt	GRPt	CSMt	BLPt	CLPt	Mean	S.D	CV (%)	BKPb	USMb	GRPb	CSMb	BLPb	CLPb	Mean	S.D	CV (%)
I-Colour	5	5	5	5	5	5	5	0	0	5	5	5	5	5	5	5	0	0
Day 7	10	20	10	10	10	10	11.67	4.08	34.99	10	20	10	10	10	10	11.67	4.08	34.99
Day 14	10	20	10	10	10	10	11.67	4.08	34.99	10	20	10	10	10	10	11.67	4.08	34.99
Day 21	10	20	10	10	10	10	11.67	4.08	34.99	10	20	10	10	10	10	11.67	4.08	34.99
Day 28	10	20	10	10	10	10	11.67	4.08	34.99	10	20	10	10	10	10	11.67	4.08	34.99
Day 35	10	20	10	10	10	10	11.67	4.08	34.99	10	20	10	10	10	10	11.67	4.08	34.99
Day 42	10	20	10	10	10	10	11.67	4.08	34.99	10	20	10	10	10	10	11.67	4.08	34.99
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	1.90	5.70	1.90	1.90	1.90	1.9	-	-	-	1.9	5.7	1.9	1.9	1.9	1.90	-	-	-
CV (%)	20.40	31.80	20.40	20.40	20.40	20.40	-	-	-	20.40	31.8	20.40	20.40	20.40	20.40	-	-	-

**Legend:**

BKP<sub>b</sub> = Borehole water stored in a black plastic tank,

BKPt = Tap water stored in a black plastic tank,

BLP<sub>b</sub> = Borehole water stored in a blue plastic tank,

BLPt = Tap water stored in a blue plastic tank,

CLP<sub>b</sub> = Borehole water stored in a clay pot,

CLPt = Tap water stored in a clay pot,

CSM<sub>b</sub> = Borehole water stored in a coated steel metal tank,

CSMt = Tap water stored in a coated steel metal tank,

CV = Coefficient of variation,

GRP<sub>b</sub> = Borehole water stored in a green plastic tank,

GRPt = Tap water stored in a green plastic tank,

I-Colour = Initial colour of water before storage,

S.D = Standard deviation,

USM<sub>b</sub> = Borehole water stored in an uncoated steel metal tank,

USMt = Tap water stored in an uncoated steel metal tank.

## 4.7 TOTAL SOLIDS

Table 4.6 showed that total solids at both sampling points (tap water and borehole water) were 1.071mg/L and 1.051mg/L respectively.

It is also revealed in Table 4.6 that there were improvements in total solid concentration with respect to time in the water stored in each of the 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 in question. This is because the concentrations of this parameter (total solids) in each of the storage tanks/containers at any time were approximately equal.

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 containers/tanks thus reducing the total solids. On the contrary, the tap water and borehole water stored in uncoated steel metal tanks (i.e  $USM_t$  and  $USM_b$ ) recorded high values of total solids (i.e increase) in the first fourteen days of the research when compared to the initial concentrations of their sources. These values later dropped gradually during the remaining period of retention/storage. The initial increase in total solids recorded in these reservoirs was as a result of the rusting of the materials which might have dissolved into the stored water thus increasing total solids.

Table 4.6: Total solids variations in water stored in tanks or containers during research period(mg/L).

	BKPt	USMt	GRPt	CSMt	BLPt	CLPt	Mean	S.D	CV (%)	BKPb	USMb	GRPb	CSMb	BLPb	CLPb	Mean	S.D	CV (%)
I-Conc	1.071	1.071	1.071	1.071	1.071	1.071	1.07	0	0	1.051	1.051	1.051	1.051	1.051	1.051	1.051	0	0
Day 7	1.031	1.176	1.032	1.031	1.029	1.028	1.05	0.06	5.65	1.03	1.14	1.03	1.029	1.027	1.027	1.05	0.05	4.52
Day 14	1.028	1.178	1.028	1.029	1.028	1.029	1.05	0.061	5.80	1.03	1.14	1.03	1.026	1.027	1.028	1.05	0.05	4.33
Day 21	1.021	1.124	1.022	1.023	1.021	1.021	1.04	0.042	4.03	1.02	1.13	1.02	1.021	1.02	1.021	1.04	0.04	4.15
Day 28	1.018	1.12	1.017	1.019	1.018	1.017	1.03	0.042	4.03	1.02	1.12	1.02	1.018	1.017	1.016	1.03	0.04	4.09
Day 35	1.015	1.116	1.012	1.013	1.012	1.011	1.03	0.042	4.10	1.01	1.12	1.01	1.011	1.01	1.012	1.03	0.04	4.15
Day 42	1.016	1.112	0.998	0.999	0.997	0.998	1.02	0.046	4.48	1.01	1.11	1.00	0.998	0.996	0.997	1.02	0.05	4.51
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	0.02	0.04	0.02	0.02	0.02	0.023	-	-	-	0.013	0.031	0.016	0.016	0.017	0.017	-	-	-
CV (%)	<b>1.95</b>	3.37	2.24	2.14	2.24	2.24	-	-	-	<b>1.27</b>	2.78	1.566	1.57	1.665	1.663	-	-	-

**Legend:**

BKP<sub>b</sub> = Borehole water stored in a black plastic tank,

BKPt = Tap water stored in a black plastic tank,

BLP<sub>b</sub> = Borehole water stored in a blue plastic tank,

BLPt = Tap water stored in a blue plastic tank,

CLP<sub>b</sub> = Borehole water stored in a clay pot,

CLPt = Tap water stored in a clay pot,

CSM<sub>b</sub> = Borehole water stored in a coated steel metal tank,

CSMt = Tap water stored in a coated steel metal tank,

CV = Coefficient of variation,

GRP<sub>b</sub> = Borehole water stored in a green plastic tank,

GRPt = Tap water stored in a green plastic tank,

I-Conc = Initial concentration before storage,

S.D = Standard deviation,

USM<sub>b</sub> = Borehole water stored in an uncoated steel metal tank,

USMt = Tap water stored in an uncoated steel metal tank.

#### **4.8 ELECTRICAL CONDUCTIVITY**

Before storage, the initial E.C value of tap water was recorded to be 118.99 $\mu$ S/cm while that of borehole water was as high as 707.02 $\mu$ S/cm. The high value of E.C recorded in the borehole water could be attributed to the geology of the aquifer surrounding the borehole (Maxwell and Eddy, 2014).

The results shown in Table 4.7 suggest that the E.C values of the borehole water stored in all the tanks/containers 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 in line with W.H.O standard since the maximum permissible limit set by W.H.O is 1000 $\mu$ S/cm.

#### **4.9 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<sub>t</sub> and USM<sub>b</sub>) as can be observed in Table 4.8.

It is obvious in Table 4.8 that, there was a significant drop in the pH during the thirty-fifth (35<sup>th</sup>) and forty-second (42<sup>nd</sup>) day of retention. This might be as a result of the high secretion of acid by dead bacteria (Jerry, 2014) during the death phase which occurred this period (35<sup>th</sup> – 42<sup>nd</sup> week).

Table 4.7: Electrical conductivity variations in water stored in tanks or containers during research period( $\mu\text{S}/\text{cm}$ ).

	BKPt	USMt	GRPt	CSMt	BLPt	CLPt	Mean	S.D	CV(%)	BKPb	USMb	GRPb	CSMb	BLPb	CLPb	Mean	S.D	CV (%)
I-EC	118.99	118.99	118.99	118.99	118.99	118.99	118.99	0	0	707.02	707.02	707.02	707.02	707.02	707.02	707.02	0	0
Day 7	91.01	97.98	83.95	105.04	90.96	126.04	99.16	14.99	15.12	637.60	626.9	616.05	637.60	644.03	658.08	636.71	14.39	2.26
Day 14	108.49	108.46	118.98	119.01	125.96	136.46	119.56	10.7	8.95	734.96	665.01	728.00	720.95	735.02	664.97	708.15	33.84	4.78
Day 21	136.45	108.39	87.53	136.51	97.95	118.89	114.29	20.12	17.60	706.97	615.99	717.53	706.95	734.99	745.47	704.65	46.10	6.54
Day 28	112.04	136.48	122.54	87.46	98.02	108.55	110.85	17.39	15.69	714.04	714.02	735.01	713.98	735.04	749.03	726.85	14.97	2.06
Day 35	105.04	111.97	112.02	87.52	91	122.52	105.01	13.46	12.82	637.50	629.94	616.08	637.71	644.02	658.05	637.22	14.00	2.20
Day 42	108.52	108.54	119	119.04	126	136.48	119.60	10.69	8.94	735.03	665	728.01	721.00	735.03	665.02	708.18	33.84	4.78
Mean	111.51	112.97	109	110.51	106.98	123.99	-	-	-	696.16	660.55	692.53	692.17	705.02	692.52	-	-	-
S.D	13.90	12.08	16.23	18.18	16.02	10.06	-	-	-	41.715	38.972	52.994	41.022	42.905	37.678	-	-	-
CV (%)	12.46	10.69	14.89	16.45	14.98	<b>8.11</b>	-	-	-	5.992	5.9	7.652	5.926	6.086	<b>5.44</b>	-	-	-

**Legend:**

BKP<sub>b</sub> = Borehole water stored in a black plastic tank,

BKPt = Tap water stored in a black plastic tank,

BLP<sub>b</sub> = Borehole water stored in a blue plastic tank,

BLPt = Tap water stored in a blue plastic tank,

CLP<sub>b</sub> = Borehole water stored in a clay pot,

CLPt = Tap water stored in a clay pot,

CSM<sub>b</sub> = Borehole water stored in a coated steel metal tank,

CSMt = Tap water stored in a coated steel metal tank,

CV = Coefficient of variation,

GRP<sub>b</sub> = Borehole water stored in a green plastic tank,

GRPt = Tap water stored in a green plastic tank,

I-EC = Initial Electrical Conductivity of water before storage,

S.D = Standard deviation,

USM<sub>b</sub> = Borehole water stored in an uncoated steel metal tank,

USMt = Tap water stored in an uncoated steel metal tank.

Table 4.8: pH variations in water stored in tanks or containers during research period.

	BKPt	USMt	GRPt	CSMt	BLPt	CLPt	Mean	S.D	CV(%)	BKPb	USMb	GRPb	CSMb	BLPb	CLPb	Mean	S.D	CV(%)
I-pH	6.6	6.6	6.6	6.6	6.6	6.6	6.6	0	0	7.00	7	7	7.00	7	7	7.00	0	0
Day 7	7	7.4	7.5	7	7.1	7	7.167	0.225	3.14	7.20	8.5	7.30	7.40	7.4	7.10	7.48	0.51	6.84
Day 14	8.1	8.3	8.2	8.1	8.2	7.8	8.117	0.172	2.12	7.10	8.7	7.60	7.20	7.8	7.40	7.63	0.58	7.62
Day 21	7.7	7.8	8	7.6	7.6	7.2	7.650	0.266	3.48	7.00	8.1	7.20	6.90	7.6	7.20	7.33	0.45	6.08
Day 28	7.5	6.8	7.7	7.7	7.6	7.3	7.433	0.344	4.63	6.90	7.8	7.30	6.80	7.6	7.10	7.25	0.39	5.43
Day 35	6	6.2	6.4	6.7	6.7	6.8	6.467	0.320	4.95	6.30	6.6	6.70	6.60	6.6	6.50	6.55	0.14	2.10
Day 42	6	5.8	6.7	7.4	6.6	6	6.417	0.601	9.37	6.40	6.1	6.30	6.5	6.6	6.20	6.35	0.19	2.95
Mean	7.3	7	7	7.3	7.2	7	-	-	-	6.9	7.5	7.1	6.8	7.2	6.9	-	-	-
S.D	0.55	0.89	0.83	0.73	0.62	0.57	-	-	-	0.32	0.99	0.44	0.35	0.5	0.42	-	-	-
CV (%)	<b>7.53</b>	12.71	11.86	10.00	8.61	8.14	-	-	-	<b>4.638</b>	13.2	6.197	5.147	6.944	6.087	-	-	-

**Legend:**

BKP<sub>b</sub> = Borehole water stored in a black plastic tank,

BKPt = Tap water stored in a black plastic tank,

BLP<sub>b</sub> = Borehole water stored in a blue plastic tank,

BLPt = Tap water stored in a blue plastic tank,

CLP<sub>b</sub> = Borehole water stored in a clay pot,

CLPt = Tap water stored in a clay pot,

CSM<sub>b</sub> = Borehole water stored in a coated steel metal tank,

CSMt = Tap water stored in a coated steel metal tank,

CV = Coefficient of variation,

GRP<sub>b</sub> = Borehole water stored in a green plastic tank,

GRPt = Tap water stored in a green plastic tank,

I-pH = Initial pH value of water before storage,

S.D = Standard deviation,

USM<sub>b</sub> = Borehole water stored in an uncoated steel metal tank,

USMt = Tap water stored in an uncoated steel metal

#### **4.10 DISSOLVED OXYGEN**

Table 4.9 divulges that 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 have 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 on the fourteenth (14<sup>th</sup>) day. This depletion in D.O concentration could be as a result of the rise in water temperature recorded in the storage tanks during the said period, since a rise in temperature, reduces D.O concentration in water and vice versa (Raji, 2014).

#### **4.11 TOTAL HARDNESS**

The total hardness (carbonate and non-carbonate hardness) level of the tap water and borehole water before storage were 102.14mg/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 Table 4.10 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 controlled.

Table 4.10 suggests that storage of water (irrespective of the source and material 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 (total hardness) in each of the storage tanks/container during the retention period were not chronological.

Table 4.9: Dissolved oxygen variations in water stored intanks or containers during research period(mg/L).

	BKPt	USMt	GRPt	CSMt	BLPt	CLPt	Mean	S.D	CV(%)	BKPb	USMb	GRPb	CSMb	BLPb	CLPb	Mean	S.D	CV(%)
I-Conc	1.5	1.5	1.5	1.5	1.5	1.5	1.5	0	0	1.3	1.3	1.3	1.30	1.3	1.3	1.30	0	0
Day 7	2	2	2.1	2.1	2	2.7	2.15	0.27	12.74	2.100	2.400	2.4	2.10	1.9	2.60	2.25	0.26	11.50
Day 14	1.6	1	1.4	1.3	1.1	1.4	1.3	0.22	16.85	1.800	1.100	1.4	1.30	1.3	1.40	1.38	0.23	16.75
Day 21	1.6	1.4	2.4	1.7	1.3	1.4	1.63	0.40	24.69	1.300	1.300	1.3	1.50	1.5	1.30	1.37	0.10	7.56
Day 28	1.3	1.4	1.7	1.7	1.3	1.4	1.47	0.19	12.69	1.600	0.800	1.2	1.30	2.2	1.60	1.45	0.47	32.57
Day 35	1.1	1.2	1.7	1.4	1.4	2.1	1.48	0.37	24.65	1.300	1.100	1.6	1.40	1.6	2.10	1.52	0.34	22.62
Day 42	1.6	0.9	1.8	1.4	1.7	1.5	1.48	0.32	21.50	1.400	2.100	1.3	1.10	1.6	1.40	1.48	0.34	23.13
Mean	1.59	1.34	1.8	1.53	1.47	1.71	-	-	-	1.63	1.44	1.5	1.43	1.54	1.67	-	-	-
S.D	0.27	0.36	0.35	0.28	0.30	0.501	-	-	-	0.325	0.583	0.416	0.32	0.31	0.496	-	-	-
CV (%)	<b>17.17</b>	27.16	19.22	18.37	20.27	29.30	-	-	-	<b>19.94</b>	40.49	27.73	22.38	20.13	29.7	-	-	-

**Legend:**

BKP<sub>b</sub> = Borehole water stored in a black plastic tank,

BKPt = Tap water stored in a black plastic tank,

BLP<sub>b</sub> = Borehole water stored in a blue plastic tank,

BLPt = Tap water stored in a blue plastic tank,

CLP<sub>b</sub> = Borehole water stored in a clay pot,

CLPt = Tap water stored in a clay pot,

CSM<sub>b</sub> = Borehole water stored in a coated steel metal tank,

CSMt = Tap water stored in a coated steel metal tank,

CV = Coefficient of variation,

GRP<sub>b</sub> = Borehole water stored in a green plastic tank,

GRPt = Tap water stored in a green plastic tank,

I-Conc = Initial concentration before storage,

S.D = Standard deviation,

USM<sub>b</sub> = Borehole water stored in an uncoated steel metal tank,

USMt = Tap water stored in an uncoated steel metal tank.

Table 4.10: Total hardness variations in water stored in tanks or containers during research period (mg/L as CaCO<sub>3</sub>).

	BKPt	USMt	GRPt	CSMt	BLPt	CLPt	Mean	S.D	CV(%)	BKPb	USMb	GRPb	CSMb	BLPb	CLPb	Mean	S.D	CV(%)
I-Conc	102.14	102.14	102.14	102.14	102.14	102.14	102.14	0	0	396.3	396.3	396.3	396.3	396.3	396.3	396.3	0	0
Day 7	81.08	141.55	101.62	111.13	98.72	77.44	101.92	23.23	22.80	308.77	505.86	400.52	654.91	333.78	421.04	437.48	127.21	29.08
Day 14	121.04	98.85	78.56	91.04	107.81	101.99	99.88	14.48	14.50	661.44	502.81	438.58	561.72	586.81	622.97	562.39	81.19	14.44
Day 21	121.54	101.41	136.64	91.81	112.66	72.56	106.10	22.65	21.35	480	512.64	408.7	654.11	537.33	602.54	532.55	87.40	16.41
Day 28	127.6	113.76	108	95.67	76.89	118.67	106.77	18.12	16.97	476.66	621.81	503.77	536.66	644.01	603.42	564.39	68.26	12.10
Day 35	88.52	101.41	92.49	110.08	117.55	98.94	101.50	10.84	10.68	502.81	601.72	403.08	409.76	521.34	493	488.62	74.32	15.21
Day 42	124.78	104.9	97.84	89.77	92.35	113.41	103.84	13.40	12.90	601.34	391.85	588.72	619.04	402.57	392.45	499.33	114.07	22.85
Mean	109.53	109.15	102.47	98.81	101.16	97.88	-	-	-	489.62	504.71	448.52	547.5	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	-	-	-
CV(%)	17.25	13.82	17.33	<b>9.16</b>	13.49	17.54	-	-	-	24.15	17.66	<b>16.15</b>	19.75	23.19	20.60	-	-	-

**Legend:**

BKP<sub>b</sub> = Borehole water stored in a black plastic tank,

BKPt = Tap water stored in a black plastic tank,

BLP<sub>b</sub> = Borehole water stored in a blue plastic tank,

BLPt = Tap water stored in a blue plastic tank,

CLP<sub>b</sub> = Borehole water stored in a clay pot,

CLPt = Tap water stored in a clay pot,

CSM<sub>b</sub> = Borehole water stored in a coated steel metal tank,

CSMt = Tap water stored in a coated steel metal tank,

CV = Coefficient of variation,

GRP<sub>b</sub> = Borehole water stored in a green plastic tank,

GRPt = Tap water stored in a green plastic tank,

I-Conc = Initial concentration before storage,

S.D = Standard deviation,

USM<sub>b</sub> = Borehole water stored in an uncoated steel metal tank,

USMt = Tap water stored in an uncoated steel metal tank.

#### **4.12 CALCIUM HARDNESS**

The range of hardness caused by Calcium ions, in storage vessels containing tap water was very low throughout the research period (21.95 – 27.61 mg/L Ca). This implies that the variation of this parameter in the said water source (tap water) were approximately constant during the retention period. Also, the low concentrations of this parameter (Table 4.11) compared to total hardness (Table 4.10) suggests that the tap water used was containing more of Magnesium ions ( $Mg^{2+}$ ) and possibly other multivalent metallic ions than calcium ions ( $Ca^{2+}$ ). Contrarily, the variations in the concentration of calcium hardness in the vessels containing borehole water ranges from 138.03 mg/L to 400.200 mg/L which suggests that concentration of calcium hardness were more fluctuated in the borehole water than the tap water used.

#### **4.13 CHLORIDE**

Just as the case of Electrical conductivity, there was also a high difference between the recorded values of chloride concentration in vessels containing tap water and borehole water all through the research period. The higher values of chloride concentration in vessels containing borehole water as can be seen in Table 4.12 emanated from the initial concentration of the source (160.01 mg/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 low (21.040 mg/L).

The high difference between Chloride concentrations in reservoirs containing borehole water and those containing tap water just as the case in Electrical conductivity (Table 4.7) as earlier mentioned suggests that a correlation exist between conductivity and chloride concentration in water. The exact relationship existing between these two parameters is shown in Table 4.25.

Table 4.11: Calcium hardness variations in water stored in tanks or containers during research period(mg/L Ca).

	BKPt	USMt	GRPt	CSMt	BLPt	CLPt	Mean	S.D	CV(%)	BKPb	USMb	GRPb	CSMb	BLPb	CLPb	Mean	S.D	CV(%)
I- Conc	27.61	27.61	27.61	27.61	27.61	27.61	27.61	0.00	0	138.03	138.03	138.03	138.03	138.03	138.03	138.03	0	0
Day 7	23.04	24	21.95	24.36	23.01	24.98	23.56	1.10	4.66	197.03	186.95	177.50	197.04	205.02	222.48	197.67	15.44	7.81
Day 14	24.51	24.49	24.95	25.04	25	25.06	24.84	0.27	1.08	399.97	232.52	374.96	345.02	399.95	232.48	330.82	78.80	23.82
Day 21	25.05	24.45	22.21	25.09	23.96	24.98	24.26	1.24	5.10	305.04	177.52	333.04	305.01	400	400.2	320.14	82.16	25.66
Day 28	24.56	25.1	24.95	22.18	23.95	24.52	24.21	1.07	4.43	325.04	324.95	399.96	325	400.1	439.8	369.14	50.49	13.68
Day 35	24.44	24.61	24.58	22.16	23.04	25	23.97	1.11	4.65	196.96	186.99	177.45	197	204.98	222.46	197.64	15.44	7.81
Day 42	24.49	24.53	24.95	25.04	24.95	25.14	24.85	0.27	1.10	400.12	232.51	375.00	345.03	185.04	232.45	295.03	89.29	30.26
Mean	24.81	25.06	24.46	24.5	24.5	25.33	-	-	-	280.31	276.16	282.28	264.59	211.35	269.7	-	-	-
S.D	1.38	1.3	1.92	1.89	1.58	1.03	-	-	-	104.41	117.99	112.83	85.02	59.87	108.42	-	-	-
CV(%)	5.56	5.19	7.85	7.71	6.45	<b>4.07</b>	-	-	-	37.25	42.73	39.97	32.13	<b>28.33</b>	40.20	-	-	-

**Legend:**

BKP<sub>b</sub> = Borehole water stored in a black plastic tank,

BKPt = Tap water stored in a black plastic tank,

BLP<sub>b</sub> = Borehole water stored in a blue plastic tank,

BLPt = Tap water stored in a blue plastic tank,

CLP<sub>b</sub> = Borehole water stored in a clay pot,

CLPt = Tap water stored in a clay pot,

CSM<sub>b</sub> = Borehole water stored in a coated steel metal tank,

CSMt = Tap water stored in a coated steel metal tank,

CV = Coefficient of variation,

GRP<sub>b</sub> = Borehole water stored in a green plastic tank,

GRPt = Tap water stored in a green plastic tank,

I-Conc = Initial concentration before storage,

S.D = Standard deviation,

USM<sub>b</sub> = Borehole water stored in an uncoated steel metal tank,

USMt = Tap water stored in an uncoated steel metal tank.

Table 4.12: Chloride variations in water stored in tanks or containers during research period(mg/L).

	BKPt	USMt	GRPt	CSMt	BLPt	CLPt	Mean	S.D	CV(%)	BKPb	USMb	GRPb	CSMb	BLPb	CLPb	Mean	S.D	CV(%)
I-Conc	21.04	21.04	21.04	21.04	21.04	21.04	21.04	0	0	160.01	2E+02	160.01	160.01	160.01	160.01	160.01	0	0
Day 7	12.53	15	9.95	16.25	12.51	23.44	14.95	4.70	31.46	157.51	154.96	152.58	157.49	160.00	163.66	157.70	3.86	2.45
Day 14	18.33	17.5	19.98	19.95	22.46	24.97	20.53	2.76	13.44	185.04	164.97	182.45	179.92	184.95	165.03	177.06	9.53	5.38
Day 21	24.95	17.55	11.25	24.99	15.04	19.94	18.95	5.48	28.90	177.46	152.48	179.96	177.48	185.03	187.51	176.65	12.53	7.09
Day 28	19	24.98	21.25	11.26	14.98	17.51	18.16	4.79	26.39	178.75	178.79	184.95	178.74	185.95	188.75	182.66	4.44	2.43
Day 35	16.24	18.74	18.72	11.25	12.54	21.26	16.46	3.90	23.67	157.54	154.98	152.53	157.49	159.95	163.68	157.70	3.87	2.46
Day 42	18.09	17.53	19.95	21	22.49	24.97	20.67	2.79	13.50	184.95	165.02	183.98	179.95	184.94	166.01	177.48	9.45	5.33
Mean	18.6	18.91	17.45	17.96	17.29	21.88	-	-	-	171.61	170.66	170.92	170.15	174.4	161.6	-	-	-
S.D	3.86	3.23	4.77	5.24	4.54	2.75	-	-	-	12.75	12.08	15.14	11.12	13.49	9.06	-	-	-
CV(%)	20.75	17.08	27.34	29.18	26.26	<b>12.57</b>	-	-	-	7.43	7.08	8.86	6.54	7.74	<b>5.16</b>	-	-	-

**Legend:**

BKP<sub>b</sub> = Borehole water stored in a black plastic tank,

BKPt = Tap water stored in a black plastic tank,

BLP<sub>b</sub> = Borehole water stored in a blue plastic tank,

BLPt = Tap water stored in a blue plastic tank,

CLP<sub>b</sub> = Borehole water stored in a clay pot,

CLPt = Tap water stored in a clay pot,

CSM<sub>b</sub> = Borehole water stored in a coated steel metal tank,

CSMt = Tap water stored in a coated steel metal tank,

CV = Coefficient of variation,

GRP<sub>b</sub> = Borehole water stored in a green plastic tank,

GRPt = Tap water stored in a green plastic tank,

I-Conc = Initial concentration before storage,

S.D = Standard deviation,

USM<sub>b</sub> = Borehole water stored in an uncoated steel metal tank,

USMt = Tap water stored in an uncoated steel metal tank.

#### **4.14 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<sub>3</sub> and 126.13mg/L CaCO<sub>3</sub>. The deviations from these initially recorded values in each of the vessels used during the storage/retention period were not large. The high concentrations of alkalinity in the borehole water compared to the tap water in Table 4.13 explain the reason why tanks containing borehole water were more resistant to changes in pH than those containing tap water as shown in Table 4.8. This is because alkalinity acts as a buffer solution (Raymond *et al.*, 2013).

#### **4.15 CHLORINE RESIDUAL**

The chlorine content of tap water before storage was 0.05mg/L and it dropped steadily to 0.01mg/L on the fourteenth (14th) day which thereafter, remained constant (Table 4.14). On the other hand, the concentration of chlorine in the borehole water was 0.01mg/L all through the research period. The high chlorine content recorded in tap water compared to borehole water is because, chlorine is usually added to tap water for the purpose of disinfecting microorganisms that may contaminate the water along the transit (distribution pipes) before reaching the consumers (Taiwo and Zakari, 2014)

It is clearly revealed in Table 4.14 that the concentration of chlorine in the storage vessels at any time is not a function of material used nor colour but rather, a function of time. This is because chlorine is a gas hence, the residual drops gradually (Nelson *et al.*, 2011). Furthermore, Table 4.14 also showed that the threshold value of chlorine in both water sources is 0.01mg/L.

Table 4.13: Alkalinity variations in water stored in tanks or containers during research period(mg/L CaCO<sub>3</sub>).

	BKPt	USMt	GRPt	CSMt	BLPt	CLPt	Mean	S.D	CV(%)	BKPb	USMb	GRPb	CSMb	BLPb	CLPb	Mean	S.D	CV(%)
I-C0nc	54.01	54.01	54.01	54.01	54.01	54.01	54.01	0	0	126.13	126.13	126.13	126.13	126.13	126.13	126.13	0	0
Day 7	46	47.99	43.96	51	45.95	57.5	48.73	4.91	10.08	130.90	129.95	129.01	130.92	131.04	131.99	130.64	1.03	0.79
Day 14	52.03	51.96	56	55.97	57.54	60.02	55.59	3.15	5.67	135.96	132.01	136.04	135.02	136.01	132.00	134.51	1.98	1.47
Day 21	59.98	52.01	45.03	61.06	49.04	55.96	53.85	6.30	11.70	134.02	129.94	135.03	133.95	135.99	137.99	134.49	2.68	2.00
Day 28	52.97	59.97	56.21	44.96	48.02	52	52.36	5.42	10.35	135.01	134.95	136.03	135	136.04	137.00	135.67	0.83	0.61
Day 35	51.97	56.03	53.01	45.04	46	56.14	51.37	4.83	9.39	130.94	130.00	128.95	131.84	130.97	132.01	130.79	1.15	0.88
Day 42	52.03	51.95	56.04	56	57.52	59.97	55.59	3.14	5.64	136.00	131.95	136.00	134.99	136.04	132.01	134.50	1.99	1.48
Mean	52.71	53.42	52.04	52.58	51.15	56.51	-	-	-	132.71	132.55	132.46	130.7	133.17	132.73	-	-	-
S.D	4.11	3.78	5.3	5.98	5.12	2.95	-	-	-	3.61	3.28	4.26	2.7	3.9	3.91	-	-	-
CV(%)	7.80	7.08	10.18	11.37	10.01	<b>5.22</b>	-	-	-	2.72	2.47	3.22	<b>2.07</b>	2.93	2.95	-	-	-

**Legend:**

BKP<sub>b</sub> = Borehole water stored in a black plastic tank,

BKPt = Tap water stored in a black plastic tank,

BLP<sub>b</sub> = Borehole water stored in a blue plastic tank,

BLPt = Tap water stored in a blue plastic tank,

CLP<sub>b</sub> = Borehole water stored in a clay pot,

CLPt = Tap water stored in a clay pot,

CSM<sub>b</sub> = Borehole water stored in a coated steel metal tank,

CSMt = Tap water stored in a coated steel metal tank,

CV = Coefficient of variation,

GRP<sub>b</sub> = Borehole water stored in a green plastic tank,

GRPt = Tap water stored in a green plastic tank,

I-Conc = Initial concentration before storage,

S.D = Standard deviation,

USM<sub>b</sub> = Borehole water stored in an uncoated steel metal tank,

USMt = Tap water stored in an uncoated steel metal tank.

Table 4.14: Chlorine (residual) variations in water stored in tanks or containers during research period(mg/L).

	BKPt	USMt	GRPt	CSMt	BLPt	CLPt	Mean	S.D	CV(%)	BKPb	USMb	GRPb	CSMb	BLPb	CLPb	Mean	S.D	CV(%)
I-Conc	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0	0	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0	0
Day 7	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0	0	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0	0
Day 14	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0	0	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0	0
Day 21	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0	0	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0	0
Day 28	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0	0	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0	0
Day 35	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0	0	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0	0
Day 42	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0	0	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0	0
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	0	0	0	0	0	-	-	-
CV(%)	80.00	80.00	80.00	80.00	80.00	80.00	-	-	-	0.00	0.00	0.00	0.00	0.00	0.00	-	-	-

**Legend:**

BKP<sub>b</sub> = Borehole water stored in a black plastic tank,

BKPt = Tap water stored in a black plastic tank,

BLP<sub>b</sub> = Borehole water stored in a blue plastic tank,

BLPt = Tap water stored in a blue plastic tank,

CLP<sub>b</sub> = Borehole water stored in a clay pot,

CLPt = Tap water stored in a clay pot,

CSM<sub>b</sub> = Borehole water stored in a coated steel metal tank,

CSMt = Tap water stored in a coated steel metal tank,

CV = Coefficient of variation,

GRP<sub>b</sub> = Borehole water stored in a green plastic tank,

GRPt = Tap water stored in a green plastic tank,

I-Conc = Initial concentration before storage,

S.D = Standard deviation,

USM<sub>b</sub> = Borehole water stored in an uncoated steel metal tank,

USMt = Tap water stored in an uncoated steel metal tank.

#### **4.16 NITRATE**

Despite the fact that borehole water does not pass through unit operation processes (quality control), the water in the borehole selected, recorded lower concentration of nitrate (10.2mg/L) than that of the tap water obtained from the ABU water treatment plant (13.8mg/L) prior to storage (Table 4.15). This higher concentration of nitrate in the tap water compared to the borehole water may be as a result of the high rate of use of nitrogen containing compounds such as fertilizers by farmers which have been converted into nitrate and eventually flow into the ABU dam through the soil or water table. Notwithstanding, the concentrations of nitrate recorded all through the research period in all the tanks or containers were far below the maximum permissible limit set by W.H.O standard (50mg/L) which is in accordance with the work of Jubril (2011).

Majority of the water storage tanks or containers recorded an improvement (decrease) in nitrate concentration after a retention period of seven (7) days (Table 4.15). Also, the maximum value ever recorded during the retention period was 14.8mg/L, which is still far below the maximum limit set by W.H.O standard (50mg/L).

#### **4.17 IRON**

The iron content of the two sampling points before storage were 0.308mg/L and 0.503mg/L for tap water and borehole water respectively. This signifies that both sampling points did not meet the requirement set by W.H.O and Nigerian Standard for drinking water (0.3mg/L) as at the time the samples were drawn. Nevertheless, Table 4.16 showed that the concentrations of iron in the stored water (both tap water and borehole water) improved during the first 7days of retention apart from water stored in uncoated steel metal tanks.

Table 4.15: Nitrate variations in water stored in tanks or containers during research period(mg/L).

	BKPt	USMt	GRPt	CSMt	BLPt	CLPt	Mean	S.D	CV(%)	BKPb	USMb	GRPb	CSMb	BLPb	CLPb	Mean	S.D	CV(%)
I-Conc	13.8	13.8	13.8	13.8	13.8	13.8	13.8	0	0	10.2	10.2	10.2	10.20	10.2	10.2	10.20	0	0
Day 7	8	9.2	9.1	7.6	9.2	8.2	8.55	0.70	8.23	11.8	12.6	7.5	10.20	12.10	6.30	10.08	2.62	25.99
Day 14	10.1	14.2	8.4	9.8	13.1	8.8	10.73	2.37	22.08	8.9	10.1	8.9	13.50	10.20	7.10	9.78	2.14	21.85
Day 21	12.1	11.7	14.2	11	9.6	10.2	11.47	1.63	14.19	13.5	14.1	12.4	11.00	13.10	10.70	12.47	1.37	11.01
Day 28	13.1	14.6	9	11.4	10.5	12.1	11.78	1.97	16.68	13.6	10.2	11.9	13.00	12.30	8.50	11.58	1.90	16.43
Day 35	8.8	14.2	10.1	14.8	11.3	7.5	11.12	2.92	26.25	10.6	12.9	7.8	9.30	13.70	12.40	11.12	2.28	20.54
Day 42	8.6	14.1	9.8	11.4	8.6	11.2	10.62	2.09	19.71	10.9	7.4	12.3	7.50	9.60	12.10	9.97	2.18	21.83
Mean	10.60	13.64	10.63	11.4	10.87	10.26	-	-	-	11.6	11.07	10.14	10.67	11.36	9.61	-	-	-
S.D	1.42	2.344	2.371	2.397	1.976	2.266	-	-	-	1.598	2.265	2.116	2.078	1.731	2.381	-	-	-
CV(%)	<b>15.04</b>	22.03	22.30	21.03	18.18	22.09	-	-	-	<b>13.78</b>	20.46	20.87	19.48	15.24	24.78	-	-	-

**Legend:**

BKP<sub>b</sub> = Borehole water stored in a black plastic tank,

BKPt = Tap water stored in a black plastic tank,

BLP<sub>b</sub> = Borehole water stored in a blue plastic tank,

BLPt = Tap water stored in a blue plastic tank,

CLP<sub>b</sub> = Borehole water stored in a clay pot,

CLPt = Tap water stored in a clay pot,

CSM<sub>b</sub> = Borehole water stored in a coated steel metal tank,

CSMt = Tap water stored in a coated steel metal tank,

CV = Coefficient of variation,

GRP<sub>b</sub> = Borehole water stored in a green plastic tank,

GRPt = Tap water stored in a green plastic tank,

I-Conc = Initial concentration before storage,

S.D = Standard deviation,

USM<sub>b</sub> = Borehole water stored in an uncoated steel metal tank,

USMt = Tap water stored in an uncoated steel metal tank.

Table 4.16: Iron variations in water stored in tanks or containers during research period(mg/L).

	BKPt	USMt	GRPt	CSMt	BLPt	CLPt	Mean	S.D	CV(%)	BKPb	USMb	GRPb	CSMb	BLPb	CLPb	Mean	S.D	CV(%)
I-Conc	0.308	0.308	0.308	0.308	0.308	0.308	0.31	0	0	0.503	0.503	0.503	0.503	0.503	0.503	0.503	0	0
Day 7	0.261	0.54	0.241	0.2	0.267	0.148	0.28	0.14	49.49	0.204	1.01	0.19	0.201	0.212	0.222	0.34	0.33	96.95
Day 14	0.189	0.598	0.161	0.163	0.144	0.136	0.23	0.18	77.78	0.26	1.04	0.26	0.259	0.26	0.223	0.38	0.32	84.06
Day 21	0.132	0.62	0.281	0.135	0.223	0.161	0.26	0.19	71.95	0.25	1.01	0.25	0.244	0.266	0.274	0.38	0.31	80.28
Day 28	0.182	0.691	0.158	0.282	0.223	0.18	0.29	0.20	71.05	0.25	1.05	0.27	0.25	0.268	0.233	0.39	0.32	83.94
Day 35	0.201	0.613	0.181	0.284	0.262	0.158	0.28	0.17	59.53	0.20	1.02	0.19	0.205	0.21	0.223	0.34	0.33	97.53
Day 42	0.195	0.62	0.161	0.165	0.141	0.132	0.24	0.19	80.43	0.21	1.02	0.26	0.26	0.261	0.273	0.38	0.31	82.27
Mean	0.21	0.57	0.213	0.22	0.224	0.175	-	-	-	0.269	0.951	0.274	0.275	0.283	0.279	-	-	-
S.D	0.046	0.057	0.063	0.07	0.063	0.061	-	-	-	0.198	0.106	0.106	0.104	0.1	0.102	-	-	-
CV(%)	<b>21.75</b>	27.14	29.58	31.82	28.13	34.86	-	-	-	<b>20.82</b>	39.41	38.69	37.82	35.34	36.56	-	-	-

**Legend:**

BKP<sub>b</sub> = Borehole water stored in a black plastic tank,

BKPt = Tap water stored in a black plastic tank,

BLP<sub>b</sub> = Borehole water stored in a blue plastic tank,

BLPt = Tap water stored in a blue plastic tank,

CLP<sub>b</sub> = Borehole water stored in a clay pot,

CLPt = Tap water stored in a clay pot,

CSM<sub>b</sub> = Borehole water stored in a coated steel metal tank,

CSMt = Tap water stored in a coated steel metal tank,

CV = Coefficient of variation,

GRP<sub>b</sub> = Borehole water stored in a green plastic tank,

GRPt = Tap water stored in a green plastic tank,

I-Conc = Initial concentration before storage,

S.D = Standard deviation,

USM<sub>b</sub> = Borehole water stored in an uncoated steel metal tank,

USMt = Tap water stored in an uncoated steel metal tank.

The increase in concentration of the iron content in water stored in uncoated steel metal tanks ( $USM_t$  and  $USM_b$ ) was as result of the fact that the iron (Fe) constituent of the tank material (steel metal) might have contributed to the initial concentrations of irons in the water stored in these vessels. This is because these storage vessels were not coated hence, the water stored in them had direct contact with their surfaces.

#### **4.18 MANGANESE**

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 (25<sup>th</sup> August, 2014). However, the concentration of manganese increased at a constant rate over time for each of the container material, regardless of the sources in which the water samples were drawn. Table 4.17 suggests that variation of the concentration of manganese in stored water is a function of time as well as the container material used. This is because all plastics (irrespective of colours) had the same rate of increase for each of the water samples.

.The increase in the concentration of manganese over time might be influenced by other physicochemical parameters present in the stored water that were not considered or analyzed during the research. This is because the process by which water quality changes upon storage is quite complex as it depends on many factors or parameters (Benson *et al.*, 2014).

Table 4.17: Manganese variations in water stored in tanks or containers during research period(mg/L).

	BKPt	USMt	GRPt	CSMt	BLPt	CLPt	Mean	S.D	CV(%)	BKPb	USMb	GRPb	CSMb	BLPb	CLPb	Mean	S.D	CV(%)
I-Conc	0.099	0.099	0.099	0.099	0.099	0.099	0.099	0	0	0.127	0.127	0.127	0.127	0.127	0.127	0.127	0	0
Day 7	0.115	0.215	0.115	0.12	0.115	0.155	0.139	0.040	28.96	0.14	0.24	0.14	0.149	0.14	0.18	0.167	0.039	23.14
Day 14	0.133	0.328	0.133	0.141	0.133	0.207	0.179	0.078	43.79	0.16	0.36	0.16	0.17	0.16	0.24	0.208	0.081	38.73
Day 21	0.15	0.449	0.15	0.157	0.15	0.261	0.220	0.121	54.97	0.17	0.47	0.17	0.19	0.17	0.29	0.245	0.121	49.35
Day 28	0.168	0.559	0.168	0.18	0.168	0.32	0.261	0.158	60.65	0.19	0.58	0.19	0.21	0.19	0.35	0.286	0.158	55.18
Day 35	0.183	0.677	0.183	0.196	0.183	0.375	0.300	0.200	66.72	0.21	0.70	0.21	0.22	0.21	0.40	0.327	0.198	60.68
Day 42	0.201	0.786	0.201	0.222	0.201	0.425	0.339	0.236	69.49	0.23	0.82	0.23	0.25	0.23	0.46	0.367	0.239	65.15
Mean	0.15	0.445	0.15	0.159	0.15	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	–	–	–
CV (%)	24.67	55.73	24.67	27.04	27.04	44.87	–	–	–	20.34	52.54	20.34	22.58	20.34	40.75	–	–	–

**Legend:**

BKP<sub>b</sub> = Borehole water stored in a black plastic tank,

BKPt = Tap water stored in a black plastic tank,

BLP<sub>b</sub> = Borehole water stored in a blue plastic tank,

BLPt = Tap water stored in a blue plastic tank,

CLP<sub>b</sub> = Borehole water stored in a clay pot,

CLPt = Tap water stored in a clay pot,

CSM<sub>b</sub> = Borehole water stored in a coated steel metal tank,

CSMt = Tap water stored in a coated steel metal tank,

CV = Coefficient of variation,

GRP<sub>b</sub> = Borehole water stored in a green plastic tank,

GRPt = Tap water stored in a green plastic tank,

I-Conc = Initial concentration before storage,

S.D = Standard deviation,

USM<sub>b</sub> = Borehole water stored in an uncoated steel metal tank,

USMt = Tap water stored in an uncoated steel metal tank.

#### **4.19 TOTAL HETEROTROPHIC BACTERIA**

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

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 found their way into the stored water in the vessels.

Based on the information displayed in Table 4.18, it can be concluded 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 the uncoated steel metal tanks (Table 4.16) might have nourished some iron bacteria present in the tanks (Amrator, 2012). Also, among the plastic tanks, total bacteria recorded in water stored in green and blue tanks were lesser than those recorded in black tanks. This is due to the fact that the penetration of ultra violet rays through the coloured (green and blue) plastic tanks (Eniola, 2007; Kareem *et al.*, 2014) might have destroyed some of the bacteria; most especially on the surface of the water in these 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.

The decline in total bacteria concentration (death phase) recorded on the forty-second (42<sup>nd</sup>) day or sixth week of retention might have been caused by the depletion or exhaustion of nutrient in the stored water which eventually led to the death of some of the bacteria. Consequently, these dead bacteria (toxic) make the surviving bacteria to be dying at a fast rate (Hamilton and Gibson, 2014).

#### **4.20CHLOROPHYLL–A**

The initial concentration of chlorophyll-A in both water sources (tap water and borehole water) before storage were not detectable. However, there were occurrences of chlorophyll-A in the water stored in some of the containers during storage as shown in Table 4.19.

It is also revealed in Table 4.19 that, the growth rate of algae in water during storage is not a function of the source where the water was drawn. Rather, it depends on other factors such as; the type and colour of material used in storage as well as the ambient environment. This is because regardless of the water source, similar container materials as well as colours had the same (approximate) concentration of chlorophyll-A at a given time. Furthermore, it can be deduced from Table 4.19 that, there was no growth of algae in water stored in Uncoated Steel Metal tanks (USM<sub>t</sub> and USM<sub>b</sub>) during the retention period (42 days). Nevertheless, the concentration of chlorophyll-A were more pronounced in water stored in the blue and green plastic tanks than water stored in black plastic tanks, coated steel metal tanks and clay pots.

Table 4.18: Total Heterotrophic Bacteria (THB) variations in water stored in tanks during research period ( $\times 10^2$  CFU/100mL).

	BKPt	USMt	GRPt	CSMt	BLPt	CLPt	Mean	S.D	CV(%)	BKPb	USMb	GRPb	CSMb	BLPb	CLPb	Mean	S.D	CV(%)
I-Conc	2	2	2	2	2	2	2	0	0	6	6	6	6.00	6	6	6.00	0	0
Day 7	21	36	16	14	33	25	24.17	8.93	36.96	42	18	15	18	15	39	24.50	12.50	51.03
Day 14	49	88	27	31	29	76	50.00	26.28	52.55	53	92	34	29	41	71	53.33	24.19	45.35
Day 21	78	136	63	55	51	104	81.17	33.05	40.72	81	132	67	59	63	120	87.00	31.34	36.02
Day 28	96	64	80	100	76	132	91.33	23.92	26.19	100	172	96	100	84	156	118.00	36.46	30.90
Day 35	116	156	116	112	108	112	120.00	17.89	14.91	112	148	104	116	108	124	118.67	15.93	13.43
Day 42	104	136	92	108	88	104	105.33	16.91	16.05	104	120	96	104	100	116	106.67	9.35	8.77
Mean	79	88	57	60	55	67	–	–	–	71	98	60	62	60	90	–	–	–
S.D	48.31	57.6	42.57	46.46	37.25	43.58	–	–	–	38.95	63.92	41.22	45.26	40.39	53.39	–	–	–
CV (%)	<b>61.15</b>	65.45	74.68	77.43	67.73	65.04	–	–	–	<b>54.86</b>	65.22	68.7	73.00	67.32	59.32	–	–	–

**Legend:**

BKP<sub>b</sub> = Borehole water stored in a black plastic tank,

BKPt = Tap water stored in a black plastic tank,

BLP<sub>b</sub> = Borehole water stored in a blue plastic tank,

BLPt = Tap water stored in a blue plastic tank,

CLP<sub>b</sub> = Borehole water stored in a clay pot,

CLPt = Tap water stored in a clay pot,

CSM<sub>b</sub> = Borehole water stored in a coated steel metal tank,

CSMt = Tap water stored in a coated steel metal tank,

CV = Coefficient of variation,

GRP<sub>b</sub> = Borehole water stored in a green plastic tank,

GRPt = Tap water stored in a green plastic tank,

I-Conc = Initial concentration before storage,

S.D = Standard deviation,

USM<sub>b</sub> = Borehole water stored in an uncoated steel metal tank,

USMt = Tap water stored in an uncoated steel metal tank.

Table 4.19: Chlorophyll-A variations in water stored in tanks or containers during research period( $\mu\text{g/L}$ ).

	BKPt	USMt	GRPt	CSMt	BLPt	CLPt	Mean	S.D	CV(%)	BKPb	USMb	GRPb	CSMb	BLPb	CLPb	Mean	S.D	CV(%)
I-Conc	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Day 7	0.171	0	0.245	0.125	0.239	0	0.13	0.11	84.69	0.17	0.00	0.24	0	0	0	0.13	0.11	85.35
Day 14	0.316	0	0.485	0.241	0.487	0	0.25	0.22	86.10	0.31	0.00	0.49	0	0	0	0.26	0.22	86.12
Day 21	0.501	0	0.741	0.357	0.739	0.01	0.39	0.33	85.13	0.50	0.00	0.75	0	1	0	0.39	0.33	85.47
Day 28	0.647	0	0.978	0.498	0.977	0.014	0.52	0.44	84.50	0.65	0.00	0.98	0	1	0	0.52	0.44	84.53
Day 35	0.806	0	1.245	0.614	0.124	0.019	0.47	0.51	108.04	0.80	0.00	1.25	1	1	0	0.65	0.56	85.08
Day 42	0.959	0	1.48	0.701	1.483	0.022	0.77	0.66	85.78	0.95	0.00	1.49	1	1	0	0.78	0.67	85.79
Mean	0.486	0	0.739	0.362	0.578	0.009	–	–	–	0.485	0	0.741	0.362	0.74	0.009	–	–	–
S.D	0.346	0	0.535	0.258	0.527	0.009	–	–	–	0.344	0	0.538	0.259	0.534	0.01	–	–	–
CV(%)	71.19	<b>0.0</b>	72.40	71.27	91.18	100.00	–	–	–	70.93	<b>0.0</b>	72.60	71.55	72.16	111.11	–	–	–

**Legend:**

BKP<sub>b</sub> = Borehole water stored in a black plastic tank,

BKPt = Tap water stored in a black plastic tank,

BLP<sub>b</sub> = Borehole water stored in a blue plastic tank,

BLPt = Tap water stored in a blue plastic tank,

CLP<sub>b</sub> = Borehole water stored in a clay pot,

CLPt = Tap water stored in a clay pot,

CSM<sub>b</sub> = Borehole water stored in a coated steel metal tank,

CSMt = Tap water stored in a coated steel metal tank,

CV = Coefficient of variation,

GRP<sub>b</sub> = Borehole water stored in a green plastic tank,

GRPt = Tap water stored in a green plastic tank,

I-Conc = Initial concentration before storage,

S.D = Standard deviation,

USM<sub>b</sub> = Borehole water stored in an uncoated steel metal tank,

USMt = Tap water stored in an uncoated steel metal tank.

Table 4.19 also indicated that there was no record of chlorophyll-A concentration in water stored in clay pots until the twenty-first (21<sup>st</sup>) day of retention where infinitesimal values were recorded which increased slightly till the last day of storage.

The high concentration of chlorophyll-A in the water stored in coloured (blue and green) plastic tanks compared to others can be attributed to the penetration of ultra violet rays through these materials which might have improved the growth of algae (Hammad, 2008; Ann and Russell, 2014) and as a result, increased the concentration of chlorophyll-A in these tanks. On the other hand, the absence of chlorophyll-A in the water stored in Uncoated Steel Metal tanks can be ascribed to the complex or toxic nature of the stored water in these tanks in terms of acidity or corrosiveness which might have rendered the environment not conducive for the natural growth of algae in these tanks.

The reason why there was no remarkable difference between the concentrations of chlorophyll-A in the blue and green plastic tanks could be attributed to the closeness in their wave lengths which are respectively 450nm – 475nm and 475nm – 530nm (Figure 2.2). This is because the amount of sun light absorbed or reflected by a substance is a function of its wave length (Macocian and Toderas, 2013). It could also be as a result of the reading accuracy of the device used (SP00726 spectrophotometer, made by Griffin Company, USA). However, all the recorded values of chlorophyll-A concentration during the research period were less than the maximum permissible limit set by W.H.O. Standard for Drinking Water Quality. This is because the highest value recorded was 1.49µg/L compared to 50µg/L as set by W.H.O.

#### 4.21 DETERMINATION OF BEST STORAGE CONTAINER MATERIAL IN TERMS OF WATER QUALITY PRESERVATION

The container material and colour that best preserved water quality during storage was determined by calculating the coefficients of weekly variation of the examined parameters (Table 4.1 to 4.19). Thereafter, the minimum values (coefficients of weekly variation) of these parameters in each of the storage materials were noted as shown in Tables 4.20 and 4.21.

The information displayed in Tables 4.20 and 4.21 were represented in pie charts (Figures 4.1 and 4.2) which clearly revealed the best storage container material in terms of preserving water quality.

Table 4.20: Number of parameters having minimum coefficients of weekly variations in stored tap water.

Storage material	Parameter	No. of Parameters
BKP <sub>t</sub>	Total solids, pH, Nitrate, D.O, Iron (Fe)and Total Heterotrophic Bacteria (THB)	6
USM <sub>t</sub>	Chlorophyll-A	1
GRP <sub>t</sub>	Turbidity	1
CSM <sub>t</sub>	Total hardness	1
BLP <sub>t</sub>	Temperature	1
CLP <sub>t</sub>	EC, Chloride, Calcium hardness and alkalinity.	4

**Legend:**

BKP<sub>t</sub> = Tap water stored in a black plastic tank,

CSM<sub>t</sub> = Tap water stored in a coated steel metal tank,

BLP<sub>t</sub> = Tap water stored in a blue plastic tank,

GRP<sub>t</sub> = Tap water stored in a green plastic tank,

CLP<sub>t</sub> = tap water stored in a clay pot,

USM<sub>t</sub> = Tap water stored in an uncoated steel metal tank.

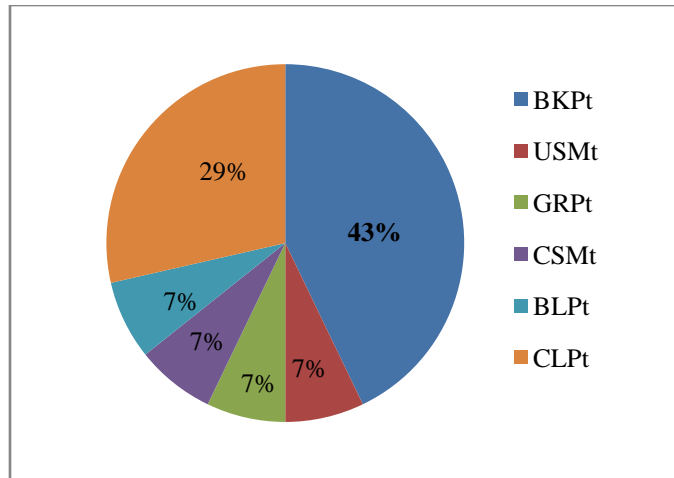


Figure 4.1: Percentage of minimum coefficients of weekly variation of parameters in tanks containing tap water.

**Legend:**

BKPt = Tap water stored in a black plastic tank,

BLPt = Tap water stored in a blue plastic tank,

CSMt = Tap water stored in a coated steel metal tank,

CLPt = Tap water stored in a clay pot,

USMt = Tap water stored in an uncoated steel metal tank.

GRPt = Tap water stored in a green plastic tank,

Table 4.21: Number of parameters having minimum coefficients of weekly variations in stored borehole water.

Storage material	Parameter	No. of Parameters
BKP <sub>b</sub>	Total solids, pH, Nitrate, D.O, Iron (Fe) and Total Heterotrophic Bacteria (THB)	6
USM <sub>b</sub>	Chlorophyll-A	1
GRP <sub>b</sub>	Turbidity and Total hardness	2
CSM <sub>b</sub>	Alkalinity	1
BLP <sub>b</sub>	Calcium hardness and Temperature	2
CLP <sub>b</sub>	Electrical Conductivity (EC) and Chloride	2

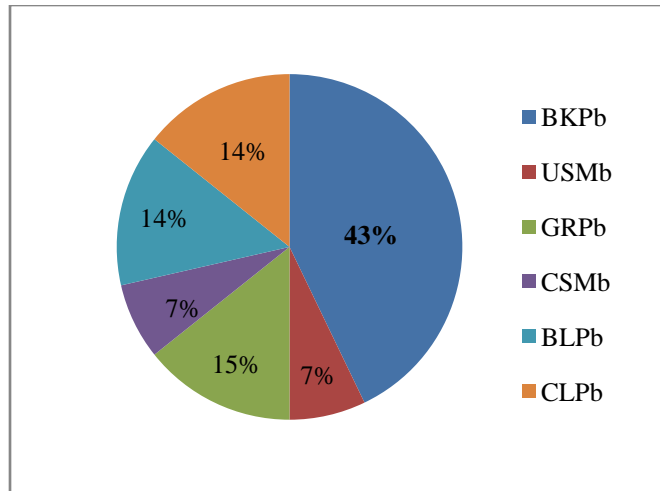


Figure 4.2: Percentage of minimum coefficients of weekly variation of parameters in tanks containing tap water.

**Legend:**

BKP<sub>b</sub> = Borehole water stored in a black plastic tank,

CSM<sub>b</sub> = Borehole water stored in a coated steel metal tank,

BLP<sub>b</sub> = Borehole water stored in a blue plastic tank,

GRP<sub>b</sub> = Borehole water stored in a green plastic tank,

CLP<sub>b</sub> = Borehole water stored in a clay pot,

USM<sub>b</sub> = Borehole water stored in an uncoated steel metal tank.

Since Figures 4.1 and 4.2 showed that the highest percentage of minimum coefficients of variation, for the weekly changes of parameters is 43% (Figure 2 & 3) which corresponds to tap water and bore hole water stored in black plastic tanks (i.e BKP<sub>t</sub> and BKP<sub>b</sub>), it simply suggests that black plastic tank best preserved the water quality parameters among the other water storage vessels used.

**4.22 DETERMINATION OF MAXIMUM RETENTION PERIOD FOR STORING WATER IN EACH OF THE STORAGE VESSELS**

In order to achieve this objective, the permissible limits set by W.H.O for the examined parameters that are health threat (toxic) were noted. Thereafter, the time taken (in days) for the concentrations of each of these parameters to reach the stated permissible limit were

determined for each of the storage containers or vessels. The maximum retention period for water storage in each of the vessels used, correspond to the shortest time duration required for any of these water quality parameters (health threat) to reach the permissible limit set by W.H.O standard.

Among the nineteen (19) water quality parameters examined, only Nitrate ( $\text{NO}_3$ ), Manganese (Mn), Total Heterotrophic Bacteria (THB) and Chlorophyll-A that constitute health threat or toxic when concentration exceed the permissible limits set by W.H.O standard. Consuming water with Nitrate concentration above 50mg/L may lead to “Blue-baby syndrome” in infants (Nigerian Standard for Drinking Water Quality, 2007). However, the highest concentration of Nitrate recorded was 14.8mg/L corresponding to tap water stored in Coated Steel Metal tank (CSM<sub>t</sub>) on the thirty-fifth (35<sup>th</sup>) day of storage (Table 4.15). Hence, the water samples were safe for drinking throughout the storage period in terms of Nitrate concentration.

The consequence of consuming water containing Manganese concentration above 0.2mg/L is neurological disorder (W.H.O standard, 2009). Table 4.17 suggest that; in order for the permissible limit not to be exceeded in terms of manganese concentration (0.2mg/L), the tap water stored in all the plastic tanks (black, green and blue) as well as the coated steel metal tank should not be kept or stored more than thirty five (35) days or 5weeks while storage in clay pots should be at most seven (7) days or 1week. Similarly, the borehole water stored in polyethylene/plastic tanks should not be kept more than twenty eight (28) days or 4weeks while storage in coated steel metals and clay pots should be at most twenty one (21) day or 3weeks and seven (7) days or 1week respectively. On the other hand, uncoated steel metal tanks should not be used at all in storing water since Table 4.17 revealed that the permissible limit for manganese

(0.2mg/L) were exceeded in these tanks before a week (7days) interval in each of the water sources used (tap water and borehole water).

Potable water is not supposed to contain any form of bacteria but it is rare to obtain water of such quality as the environment is usually surrounded with different forms of bacteria (both disease causing and non-disease causing) hence, the permissible limit for Total Heterotrophic Bacteria (THB) or total bacteria in potable water is 100 CFU/mL or  $10^4$  CFU/100mL (W.H.O Standard 2003, 2006). Table 4.18 suggest that for the two water sources (tap water and borehole water) to be safe during storage in terms of THB when stored in plastics and coated steel metal tanks under hygienic condition, then the water should not be kept or stored over a month (28 days or 4weeks) while storage in clay pots should be at most fourteen (14) days or 2weeks.

The concentration of chlorophyll-A in drinking water is recommended not to exceed 50 $\mu$ g/L or  $5.0 \times 10^{-2}$  mg/L because consumption of water containing concentration above such level may lead to short-term adverse health outcomes such as skin irritations and gastrointestinal illness (W.H.O. Standard 2009). Nevertheless, the chlorophyll-A concentration in both tap water and borehole water stored in all the storage tanks/containers used during the research period were much lesser than the above stated permissible limit since Table 4.19 revealed that the highest concentration recorded was  $1.49 \times 10^{-3}$  mg/L which correspond to the value obtained in borehole water stored in green plastic tank (GRP<sub>b</sub>) on the forty-second (42<sup>nd</sup>) day or sixth week of retention.

Table 4.22 gives the recommended maximum retention period for storing water in each of the storage vessels after considering a factor of safety of 0.8. Nevertheless, the detail calculations that lead to Table 4.22 are shown in Appendix E.

Table 4.22: Recommended maximum retention period for storing water in each of the storage vessels

BKP <sub>t</sub>	USM <sub>t</sub>	GRP <sub>t</sub>	CSM <sub>t</sub>	BLP <sub>t</sub>	CLP <sub>t</sub>	BKP <sub>b</sub>	USM <sub>b</sub>	GRP <sub>b</sub>	CSM <sub>b</sub>	BLP <sub>b</sub>	CLP <sub>b</sub>
≤ 3	N.R	≤ 3	≤ 3	≤ 3	≤ 6	≤ 3	N.R	≤ 3	≤ 2	≤ 3	≤ 6
wks		wks	wks	wks	days	wks		wks	wks	wks	days

Note wks = weeks, N.R = Not Recommended (due to the high risk involved)

#### 4.23 MODELING OF WATER QUALITY RESULTS

The concentrations of manganese (Mn) in the stored water (tap water and borehole water) were found to establish a linear relationship with time upon storage for each container material. Hence, regression lines were fitted using Microsoft Excel 2010, which are summarized in Table 4.23.

Table 4.23: Relationship between Manganese concentration in stored water and retention time

S/No.	Storage material	Source of water	Regression Equation	R <sup>2</sup> Value
1	Plastic tanks (i.e black, green and blue colour)	Tap water	Mn (t) = 0.0163t + 0.00988	0.9997
2	Plastic tanks(i.e black, green and blue colour)	Borehole water	Mn (t) = 0.0163t + 0.1265	0.9987
3	Coated steel metal tank	Tap water	Mn (t) = 0.0200t + 0.0993	0.9976
4	Coated steel metal tank	Borehole water	Mn (t) = 0.0199t + 0.1276	0.9948
5	Uncoated steel metal tank	Tap water	Mn (t) = 0.1150t + 0.1001	0.9976
6	Uncoated steel metal tank	Borehole water	Mn (t) = 0.1150t + 0.1273	0.9961
7	Clay pot	Tap water	Mn (t) = 0.0547t + 0.0991	0.9972

8	Clay pot	Borehole water	$Mn(t) = 0.0550t + 0.1273$	0.9989
---	----------	----------------	----------------------------	--------

Note: Mn (t) represents concentration of Manganese in mg/L after storage time 't' weeks

It is clearly shown in Table 4.23 that, irrespective of the sampling point (i.e tap water or borehole water), similar container materials recorded the same gradient or slope. On the other hand, the intercept for all storage materials containing tap water as well as those containing borehole water were approximately equal to their initial concentrations of Manganese before storage (i.e 0.099mg/L and 0.127mg/L respectively). Hence, the equations relating Manganese concentration with respect to retention time in each of the storage material are given as follows;

$$Mn_{PLS}(t) = 0.0163t + C \quad (4.1)$$

$$Mn_{CSM}(t) = 0.0200t + C \quad (4.2)$$

$$Mn_{USM}(t) = 0.1150t + C \quad (4.3)$$

$$Mn_{CLP}(t) = 0.0550t + C \quad (4.4)$$

Where:

$Mn_{PLS}(t)$ ,  $Mn_{CSM}(t)$ ,  $Mn_{USM}(t)$  and  $Mn_{CLP}(t)$  represents the concentration of manganese (mg/L) in water stored in: plastic tanks (black, blue and green colour), coated steel metal tanks, uncoated steel metal tanks and clay pots respectively after a retention period of 't' weeks.

t = Retention or storage period in weeks.

C = Initial concentration of manganese before storage which is 0.099mg/L and 0.127mg/L for the tap water and borehole water used respectively.

Just as in manganese concentration, the concentrations of chlorophyll-A in the stored water were also found to vary linearly with time upon storage. However, the Chlorophyll-A concentrations in the stored water were found to be the same in similar container materials and colours at any time regardless of the sampling points considered. Hence, regression lines were as well fitted using Microsoft Excel 2010 as summarized in Table 4.24.

Table 4.24: Relationship between Chlorophyll-A concentration and retention time in stored tap water or borehole water.

S/No.	Container material/Colour	Regression Equation	R <sup>2</sup> Value
1	Black plastic tank	$ChlA_{BKP}(t) = 0.0001594t$	0.9991
2	Blue plastic tank	$ChlA_{BLP}(t) = 0.0002471t$	0.9899
3	Green plastic tank	$ChlA_{GRP}(t) = 0.0002475t$	0.9986
4	Coated steel metal tank	$ChlA_{CSM}(t) = 0.000171t$	0.9979
5	Uncoated steel metal tank	$ChlA_{USM}(t) = 0.000000t$	1.0000
6	Clay pot	$ChlA_{CLP}(t) = 0.00000375t$	0.9992

**Note:**  $ChlA_{BKP}(t)$ ,  $ChlA_{BLP}(t)$ ,  $ChlA_{GRP}(t)$ ,  $ChlA_{CSM}(t)$ ,  $ChlA_{USM}(t)$  and  $ChlA_{CLP}(t)$  represents the concentrations of Chlorophyll-A (mg/L) after a storage period of 't' weeks in water stored in: black plastic tank, blue plastic tank, green plastic tank, coated steel metal tank uncoated steel metal tank and clay pot respectively.

Unlike Manganese and Chlorophyll-A, the concentrations of certain parameters were observed to be influenced by others. For instance, Electrical conductivity (EC) of water was observed to be a reflection of the resultant effects of the concentrations of Alkalinity, Calcium hardness and Chloride ions present in the water samples. i.e,

$$EC = f(Alk, CaHard, Cl^*) \quad (4.5)$$

Where; Alk is the Alkalinity, CaHard is the Calcium hardness and Cl\* is the Chloride ions.

The effects of each concentration on EC were established by subjecting the data to Statistical Analysis System (SAS) version 9.2. The summary of the regression lines or equations obtained from the software (i.e SAS 9.2) are given in Table 4.25.

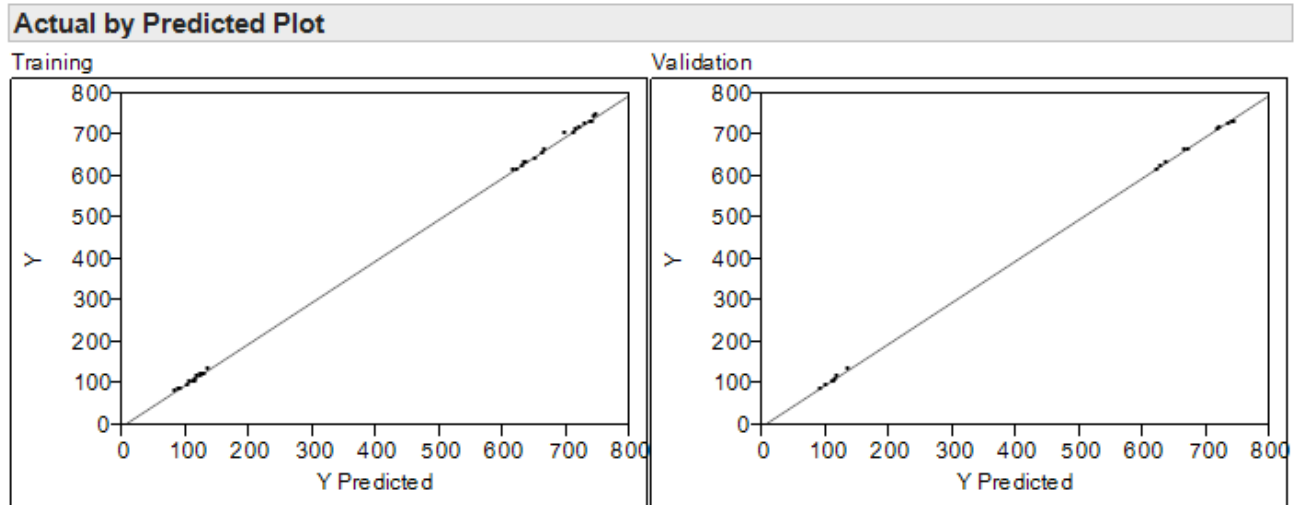
Table 4.25: Relationship between modeled parameters

S/No.	Dependent variable	Independent variable	Regression Equation	R <sup>2</sup>	S.E
1	EC	Alk	EC = 84.49 – 0.99(Alk)	0.9926	0.32
2	EC	CaHard	EC = 84.49 – 0.11(CaHard)	0.9958	0.02
3	EC	Cl*	EC = 84.49 + 4.47(Cl*)	0.9995	0.20
4	EC	Alk, CaHard, Cl*	<b>EC = 84.49 – 0.987(Alk) – 0.109(CaHard) + 4.47(Cl*)</b>	<b>0.9995</b>	<b>0.78</b>

**Note:** EC = Electrical Conductivity(μS/cm), Alk = Alkalinity(mg/L CaCO<sub>3</sub>), CaHard = Calcium hardness (mg/L Ca), Cl\* = Chloride ions (mg/L), S.E = Standard Error.

The high R<sup>2</sup> values accompanied with low values of Standard Error (S.E) as shown in Table 4.25 suggests that the regression equations are highly reliable. This was buttress by plotting the actual values obtained in the field against the predicted values obtained from the regression equation using the same scale via Statistical Analysis System (SAS) version 9.2 as shown in Figure 4.3.

Since most of the plotted points fell on the diagonal of Figure 4.3, it further suggest that, the regression equations are highly reliable.



**Note:** Y = Observed value of EC ( $\mu\text{S}/\text{cm}$ ), Y Predicted = Predicted value of EC ( $\mu\text{S}/\text{cm}$ )

Figure 4.3: Comparism between observed values of EC and predicted values

### 4.23.1 Flowchart For The Models

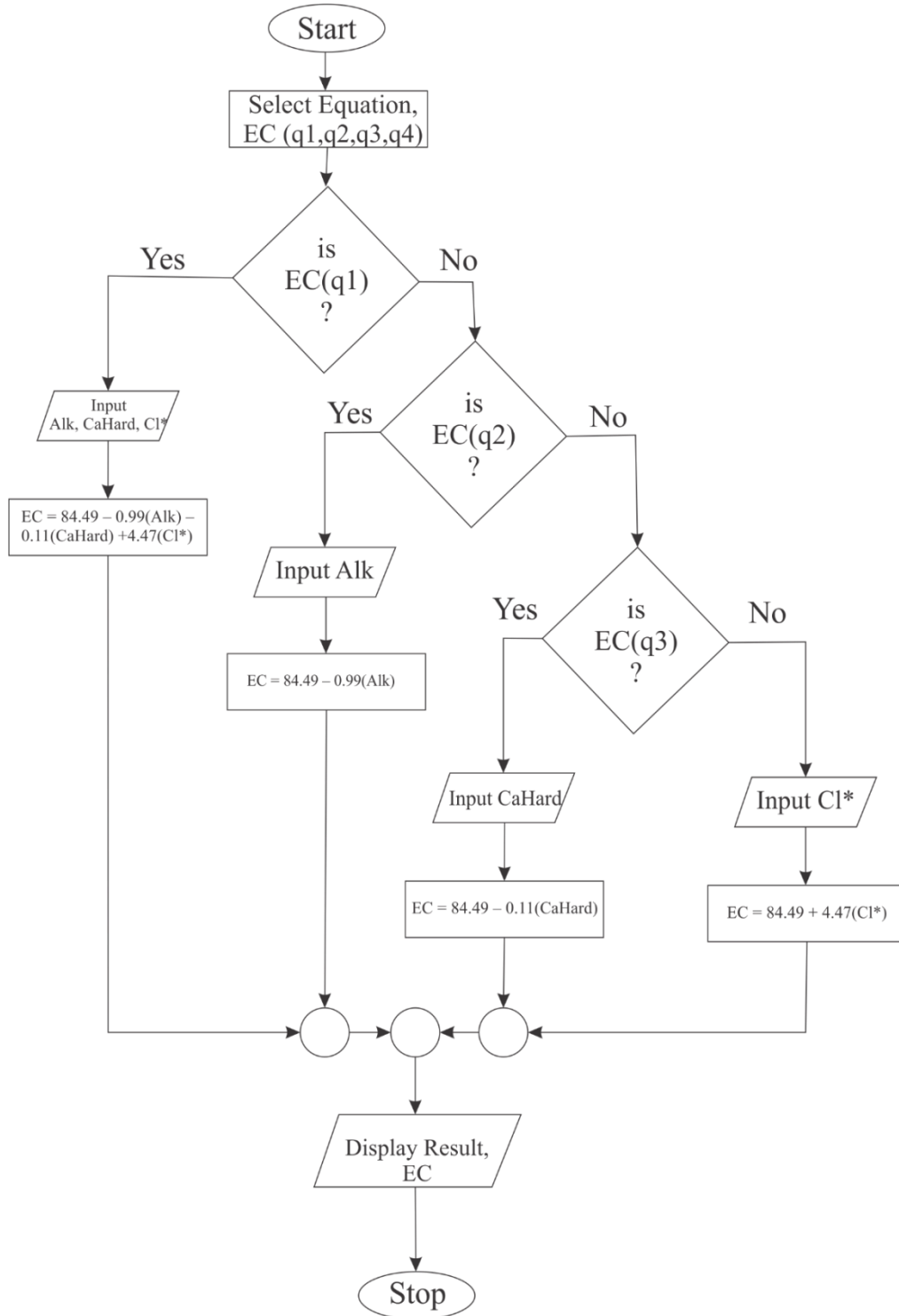


Figure 4.4: Flowchart of the computer program

### 4.23.2 Computer Program For The Models

Program Source Code (written in Visual Basic.Net)

```
PublicClass frmECCalculator
Dim EC, dblA, dblB AsDouble
PrivateSub radEC1_CheckedChanged(ByVal sender As System.Object, ByVal e As
System.EventArgs) Handles radEC1.CheckedChanged
If radEC1.Checked = TrueThen
    grpVariables.Enabled = True
    lblInput1.Text = "Alk:"
    txtInput1.Text = ""
    txtInput2.Text = ""
    lblInput2.Visible = True
    txtInput2.Visible = True
EndIf
EndSub
PrivateSub radEC2_CheckedChanged(ByVal sender As System.Object, ByVal e As
System.EventArgs) Handles radEC2.CheckedChanged
If radEC2.Checked = TrueThen
    grpVariables.Enabled = True
    lblInput1.Text = "Alk:"
    txtInput1.Text = ""
    lblInput2.Visible = False
    txtInput2.Visible = False
EndIf
EndSub
PrivateSub radEC3_CheckedChanged(ByVal sender As System.Object, ByVal e As
System.EventArgs) Handles radEC3.CheckedChanged
If radEC3.Checked = TrueThen
    grpVariables.Enabled = True
    lblInput1.Text = "CaHard:"
    txtInput1.Text = ""
    lblInput2.Visible = False
    txtInput2.Visible = False
EndIf
EndSub
PrivateSub radEC4_CheckedChanged(ByVal sender As System.Object, ByVal e As
System.EventArgs) Handles radEC4.CheckedChanged
If radEC4.Checked = TrueThen
    grpVariables.Enabled = True
    lblInput1.Text = "Cl*:"
```

```

        txtInput1.Text = ""
        lblInput2.Visible = False
        txtInput2.Visible = False
    EndIf
EndSub

PrivateSub txtInput1_KeyPress(ByVal sender As Object, ByVal e As
System.Windows.Forms.KeyPressEventArgs) Handles txtInput1.KeyPress
    Dim KeyAscii As Short = Asc(e.KeyChar)
    If KeyAscii = 8 Or KeyAscii = 46 Or (KeyAscii >= 48 And KeyAscii <= 57) Then
        e.KeyChar = Chr(KeyAscii)
    Else
        Beep() ' Sound error signal.
        e.Handled = True ' Cancel the character.
    EndIf
EndSub

PrivateSub txtInput2_KeyPress(ByVal sender As Object, ByVal e As
System.Windows.Forms.KeyPressEventArgs) Handles txtInput2.KeyPress
    Dim KeyAscii As Short = Asc(e.KeyChar)
    If KeyAscii = 8 Or KeyAscii = 46 Or (KeyAscii >= 48 And KeyAscii <= 57) Then
        e.KeyChar = Chr(KeyAscii)
    Else
        Beep() ' Sound error signal.
        e.Handled = True ' Cancel the character.
    EndIf
EndSub

PrivateSub btnClear_Click(ByVal sender As System.Object, ByVal e As System.EventArgs)
Handles btnClear.Click
    radEC1.Checked = False
    radEC2.Checked = False
    radEC3.Checked = False
    radEC4.Checked = False
    lblInput1.Text = "Alk:"
    txtInput1.Text = ""
    txtInput2.Text = ""
    lblInput2.Visible = True
    txtInput2.Visible = True
    grpVariables.Enabled = False
    txtResult.Text = ""
EndSub

PrivateSub btnSolve_Click(ByVal sender As System.Object, ByVal e As System.EventArgs)
Handles btnSolve.Click

```

```

If radEC1.Checked = FalseAnd radEC2.Checked = FalseAnd radEC3.Checked = FalseAnd
radEC4.Checked = FalseThen
    MessageBox.Show("Please enter input variables to continue", "Null Entry",
    MessageBoxButtons.OK, MessageBoxIcon.Information)
ExitSub
EndIf
If txtInput1.Text = ""Then
    MessageBox.Show("Please enter " & lblInput1.Text.Substring(0, lblInput1.Text.Length -
1) & " value to continue", "Null Entry", MessageBoxButtons.OK, MessageBoxIcon.Information)
    txtInput1.Focus()
ExitSub
Else
Try
    dblA = CDbI(txtInput1.Text)
Catch ex As Exception
EndTry
EndIf
If radEC1.Checked = TrueThen
If txtInput2.Text = ""Then
    MessageBox.Show("Please enter " & lblInput2.Text.Substring(0, lblInput2.Text.Length
- 1) & " value to continue", "Null Entry", MessageBoxButtons.OK,
    MessageBoxIcon.Information)
    txtInput2.Focus()
ExitSub
Else
Try
    dblB = CDbI(txtInput2.Text)
Catch ex As Exception
EndTry
    EC = -224.8066493 + (6.244028022 * dblA) + (0.28204735 * dblB)
EndIf
ElseIf radEC2.Checked = TrueThen
    EC = 0.0473 * (dblA ^ 1.9579)
ElseIf radEC3.Checked = TrueThen
    EC = 9.7713 * (dblA ^ 0.7654)
ElseIf radEC4.Checked = TrueThen
    EC = (3.7822 * dblA) + 42.5261
EndIf
    txtResult.Text = "EC = " & EC & Chr(181) & "S/cm"
EndSub
EndClass

```

## CHAPTER FIVE

### CONCLUSION AND RECOMMENDATIONS

#### 5.1 CONCLUSION

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

- i. The growth of algae in water is more pronounced in water stored in coloured plastic tanks compared to those stored in black plastic tanks while the reverse is the case in terms Total Heterotrophic Bacteria (THB), which are in line with the previous work carried out by Eniola (2007). Also, most of the water quality parameters examined get improved (i.e the water remains fresh) during the first week of retention in all the storage vessels used apart from uncoated steel metal tanks. This confirms the assertion made by Agbede and Morankinyo (1995) that stored water in hygienic condition may remain fresh for a period of one week after which the quality thereof cannot be guaranteed.
- ii. Among the various water storage tanks or containers used, the material of construction that best preserves water quality (irrespective of the sampling point or water source) during storage is black plastic.
- iii. Both sources of water (tap water and borehole water) stored in plastic tanks as well as coated steel metal tanks had a maximum retention period of 3weeks while the maximum retention period when stored in clay pots was 6days. On the other hand, the quality of

water stored in uncoated steel metal tanks were very poor or toxic hence, it is advisable not to use such containers or vessels to store potable water.

- iv. Alkalinity (Alk), Calcium hardness (CaHard) and Chloride ion (Cl\*) established a multi parameter linear regression with Electrical Conductivity (EC) as  $EC = 84.49 - 0.987(\text{Alk}) - 0.109(\text{CaHard}) + 4.47(\text{Cl}^*)$ .

## 5.2 RECOMMENDATIONS

Based on the conclusions above, the following measures are therefore recommended:

1. Polyethylene/plastic water storage tanks (especially black colour) should be considered first when selecting a means of storing potable water in large capacity. However, the storage period should be at most 3 weeks.
2. Clay pots may be used in storing water for cooking and drinking, in as much as the storage period does not exceed 6 days. Nevertheless, care must be taken to ensure that the clay pots had been properly processed in order not to contain harmful constituents that could leach into the stored water.
3. Coated or galvanized steel metal tanks used in storing potable water should always be inspected to know whether the coating materials are still in place and if not, the faded or washed-out parts should be recoated before putting in use. This is because the quality of water stored in uncoated steel metal tanks deteriorated at a very fast rate (less than a week) which is toxic to human health.
4. Stored water must be covered and fitted with taps at the base for means of withdrawal; this will prevent external contamination which could lead to rapid deterioration. However, when installing the taps, space should be provided for the sake of settling.

5. Further studies should include other sources of potable water and physio-chemical parameters as well as other storage container materials or colours that were not considered in this work. More so, the sampling frequency (7 days) can be reduced. Finally, isolation of bacteria into total coliforms, faecal coliforms, *E. coli*, etc. should be carried out in further researches that are of this kind.

## REFERENCES

- Agbede, O.A. (1991). Water Pollution in Ibadan. Proc. 17<sup>th</sup> WEDC Conference on Infrastructural Environment, Water and People. Nairobi, Kenya.
- Agbede, O.A. and Morakinyo, J.A. (1995). Effects of Short Term Storage on Water Quality. *Nigerian Journal of Science*, Vol. 30 No. 2, pp 147-152.
- Agbede, O.A. and Morakinyo, J.A. (2001). Variations in Drinking Water Quality During Storage. *Water Science and Technology*, Vol.52, No 4-9, pp 201-211.
- Amrator, G.G. (2012). Bacteriological Analysis of Industrial Water. *Journal of Applied Microbiology*, Vol. 11(3)pp87-101.
- Andrew, F. (2004). Water Quality Deterioration: A Study of Household Drinking Water Quality in Rural Honduras. *International Journal of Environmental Health Research*. Vol. 14 (4) pp. 273-284.
- Ann, D.K. and Rusel, L.L. (2014). Impact of UV- Light and Metallurgy. 3<sup>rd</sup> Edition, Johnbull and sons Publishers, Texas, USA. Pp 86-89.
- APHA. AWWA. WPCF. (1985) 16<sup>th</sup> edition.
- Benson, K.Y., Korede, K.Y. and Olatunji, O.A. (2014). Mechanisms in Water Quality Changes. *International Journal of American Water Works Association AWWA* .Vol. 10 (6) pp. 65-77.
- Booker, K. R. (2000). The Necessity of Water. Paper Presented at The International Conference on Water, Bonn, 2000. IRC Source Bulletin No. 39 pp3.
- Booker, S.M. (2002). National Toxicology Program (NTP) Taps Disinfection By-Products for Study. *Environmental Health Perspective* Vol. 108, No. 2, pp A64-A66.
- Bradley, D.J. (1977). Health Aspect of Water Supplies in Tropical Countries. In: Water, Wastes and Health in Hot Climates. (eds). Feachem, R.G., M. McGarry and D. Mara. pp 3-17.
- Cairncross, S. and Faechem, R. (1993). Environmental Health Engineering in the Tropics: An Introductory Test. Wiley and sons New-York pp 3-44.
- Cater, M.J. (2005). Enterically Infecting Viruses: Pathogenicity, Transmission and Significance for Food and Water-Borne Infection. *Journal of Applied Microbiology*, 98: 1354-1380.
- Chatterjee, A.O. (2001). Water Supply, Waste Disposal and Environmental Engineering. 7<sup>th</sup> Edition, Khanna Publication. pp 89-91.
- Clasen, T.F. and Bastable, A. (2003). Faecal Contamination of Drinking Water During Collection and Household Storage: The Need to Extend Protection to the Point of Use. *Journal of Water Health* 01, pp 109-115.
- Colford, J., Saha, S., Wade, T. and Eisenberg, J. (2005). A Pilot Randomized, Controlled Trial of an In-Home Drinking Water Intervention Among HIV +ve Persons. 3(2): 173-184.

- Collingnon, B. and Vezina, M. (2000). Independent Water and Sanitation Provider in African Cities: Full Report of a Ten-Country Study. UNDP-World Bank.
- Cooker, A.O. and Sridhar, M.K. (2002). Mini Water Supplies for Sustainable Development, Nigeria. Proceedings of the 28<sup>th</sup> WEDC Conference, Calcutta, India, pp 310-313.
- Dorman, D. (1992). Home Water Treatment Systems. University of Georgia, College of Family & Consumer Sciences and College of Agricultural & Environmental Sciences Cooperating Extension Services, pp 819-820.
- Edberg, S.C., Rice, E.W., Karlin R.J. and Allen M.J. (2002). *Escherichia coli*: The Best Biological Drinking Water Indicator for Public Health Protection. *Journal of Applied Microbiology*, pp1065-1075.
- Enabor, B., Sridhar, M.K. and Olaseha, I.O. (1998). Integrated Water Management by Urban Poor Women: A Nigeria Slum Experience. *Water resources Development*, Vol. 14, No. 4, pp 505-512.
- Eniola, K.I. (2007). Effects of Containers and Storage Conditions on Bacteriological Quality of Borehole Water. *Nigeria Journal of Pure and Applied Science*. 2002; 17: 1223-1226.
- Eugen, M. V., Filip, M. S. and Toderas, A.M. (2012). Base Theory for UV-VIS Spectrophotometric Measurements. Internal Report of Two Countries, One Goal, Joint Success, Hungary-Romania. HURO 1001/121/2.2.2. Pp1-3.
- Faniran, T.A., Ngeba, F.S., Bhat, R.B. and Oche, C.Y. (2001). An Assessment of the Water Quality of Isinuka Springs in the Trankei Region of the Eastern Cape, Republic of South Africa. Vol.27, No. 2, pp 241-250. (<http://www.wrc.org.za>).
- Feachem, R. (1977). Infectious Disease Related to Water Supply and Excreta Disposal Facilities. *Ambio*, Vol.6, No. 1, pp 55-58.
- Feachem, R. and Mara, D. (1979). A Reappraisal of the Role of Faecal Indicator Organisms in Tropical Waste Treatment Processes. *The Public Health Engineer*, Vol. 2, No. 1.
- Franceys, R. and Ball, S. (2002). The Worth of Water: Technical Briefs on HealthPubli Water and Sanitation. Intermediate Technology Publications, London, pp 26-31.
- Gadgil, A. (1998). Drinking Water in Developing Countries. *Annual Reviews of Energy and the Environment*; 23: 253-286.
- Geldreich, E.E. (1994). Sanitary Significance of Faecal Coliforms in the Environment. *Water Pollution Control Research*, Series No. WP-20-3, U.S. Department of Interior, Washington, pp 20-35.
- Georgia, C. (1999). Water Storage. *Journal of Water and Health*. FN176. Retrieved September 20, 2015. <http://www.foodsafety.ifas.ufl.edu/PDF/water.pdf>.
- Giller, J., Paul, S. and Malmqvist, B. (2002). *The Biology of Streams and Rivers*. Oxford University Press. pp47-54.

- Graham, P. and Vanderslice, J. (2007). The Effectiveness of Large Household Water Storage Tanks for Protecting the Quality of drinking Water. *Journal of Water and Health* 052. IWA Publishing.
- Gray, N.F. (1994). *Drinking Water Quality: Problems and Solutions*. John Wiley and Sons, England, pp 314.
- Hamilton, T.Y. and Gibson, D.D. (2014). *Introduction to Microbiology*. 2<sup>nd</sup> Edition, Global Publishers LTD, England. Pp 58-63.
- Hammad, Z. (2008). The Quality of Drinking Water in Storage Tanks in Khartoum State. *American Journal of Public Health*. Vol. 89. No.13.
- Hayward, K . (2004). Water Supply and Sanitation: Africa's Strategic Needs. *Water* 21: December Issue, pp 12-14.
- Helmer, R. (1996). Water Quality Monitoring–National Needs and International Challenges. In *Water Quality Monitoring and Environmental Status in Nigeria*. FEPA Monograph 6, (eds) Aina, O.A. and Adedipe N. O. pp 11-25.
- Hem, J.D. (1997). *Study and Interpretation of the Chemical Characteristics of Natural water*. Third Edition, U.S. Geological Survey Water-Supply Paper 2254.
- Henry, C.I. and Chioma, D.E. (2014). Water Quality Behavior Over Time. *Journal of Tropical Scientific Research*, Vol. 5(10). Pp 38-50.
- Henry, J.B. (2002). Water and Health Glimpse. International Center for Diarrhea Disease Research, Bangladesh (ICDDR, B) Vol. 24, No. 102 (March-June).
- Howard, G. (2002). *Water Quality Surveillance: A Practical Guide*. WEDC, Loughborough University, U.K. pp 53.
- Ince, M. and Shaw, R. (1999). *Health, Water and Sanitation: Technical Briefs on Health, Water and Sanitation*. Intermediate Technology Publications, London, pp 69-72.
- Jawas, M., Ghazali, M. and Khorshid, M. (1998). Effect of Domestic Storage Tanks on the Quality of Drinking Water. *Environmental Monitoring and Assessment* 11: 79-87.
- Jenning, G.D. and Sneed, R.E. (1996). Nitrate in Drinking Water. North Carolina Cooperative Extension Service and Publication No. AG 473-475.
- Jerry, O.O. (2014). Economic Important of pH in Water. *American Journal of Public Health*. Vol. 55. No.17. pp46-51.
- Jubril, A.A. (2011). Evaluation of Water Quality in Household Containers in A.B.U., Zaria Staff Quarters: A case Study of Area A and E, Samaru. Under-Graduate project, Ahmadu Bello University, Zaria, pp 36 (Unpublished).
- Kareem, T. A., Okpeyemi, A. A. and Briggs, J. J. (2014). Comparative Study Between UV-Light and Some Selected Halogens in Disinfecting Water. *International Journal of American Water Works Association AWWA* .Vol. 17 (6) pp. 247-260.

- Khan, F., Husain, T. and Lumb, A. (2003). Water Quality Evaluation and Trend Analysis in Selected Watersheds of the Atlantic Region of Canada. *Environmental Monitoring and Assessment* 88: 221-242. *Khartoum Medical Journal* Vol. 01, No. 02, pp 78-80.
- Kim, A. and Cardone, C. (2005). Scatterscore: A Reconnaissance Method to evaluate Changes in Water Quality. *Environmental Monitoring and Assessment* 111: 277-295.
- Lawoyin, T.O., Ogunbodede, N.A., Olumide, E.A. and Onadeko, M.O. (1999). Outbreak of Cholera in Ibadan, Nigeria. *European Journal of Epidemiology*, 15, No. 4, 367-370.
- Lindskog, P.A. (2001). Bacteriological Contamination of Water in Rural Areas; An International Study from Malawi. *Journal of Tropical Medicine and Hygiene*, Vol. 91, pp 1-12.
- Liou, S., Lo, S. and Wang, S. (2004). A Generalized Water Quality Index for Taiwan. *Environmental Monitoring and Assessment* 96: 32-35.
- Lious, K.M. and Wang, C.C. (2004). Fundamentals of Chemistry for Beginners. 3<sup>rd</sup> Edition. Edward Arnold Publishers Ltd., London, pp 183-191.
- Lloyd, B. and Helmer, H. (1991). Surveillance of Drinking Water Quality in Rural Areas. Essex, Longman Group UK Limited, pp 169.
- Lumb, A., Halliwell, D. and Sharma, T. (2006). Application of CCME Water Quality Index to Monitor Water Quality: A Case Study of the Mackenzie River Basin, Canada. *Environmental Monitoring and Assessment* 113: 411-429.
- Mara, D.D. and Oragui, J.I. (1985). Bacteriological Methods for Distinguishing Between Human and Animal Faecal Pollution: Results of Fieldwork in Nigeria and Zimbabwe. *Bulletin of the World Health Organization*, Vol. 63 (4) pp 773-783.
- Maraj, S. (2006). Microbial Deterioration of Stored Water for Users Supplied by Stanpipes and Ground Tanks in a Peri-Urban Community. *Proceedings of the Water Institute of South Africa (WISA) Biennial Conference Durban 21-25 May, 2006*.
- Maxwell, F.D. and Eddy, R.R. (2014). The Beauty of Hydrogeology. *Water Science and Technology*, Vol.26, No 3-5, pp 12-14
- Mechenich, C. and Andrews, A. (2002). Interpreting Drinking Water Test Results. Retrieved November 18, 2014 from <http://www.aces.edu/pubs/speng/interpretingwatertestresults.pdf>.
- Mechenich, C. and Andrews, E. (2007). Home Water Safety: Interpreting Drinking Water Test Results. *Extension Bulletin G3558-4*, pp 12.
- Moe, C.L., Sobsey, M.D., Samsa, G.P. and Meselo, V. (1991). Bacterial Indicators of Risk of Diarrheal Disease from Drinking-Water in the Philippines. *Bulletin of the World Health Organization*, 69 (3) , pp 305-317.

- Momba, M.N. and Notshe, T.L. (2003). The Microbiological Quality of Groundwater-Derived Drinking Water After Long Storage in Household Containers in Rural Community of South Africa. *Journal of Water Supply Research and Technology AQUA* (52), pp 67-77.
- Murphy, D. A. and Harvey, P.N. (2014). *Solar Thermodynamics*. 4<sup>th</sup> Edition, McGraw-Hill Publishers LTD, Canada. Pp 72-75.
- Musa, H., Shears, P., Kafi, S. and Elsabag, S. (1999). Water Quality and Public Health in Northern Sudan: A Study of Rural and Peri-Urban Communities. *Journal of Applied Microbiology*. 87, 676-682.
- Nala, N. and Jagals, P. (2003). The Effect of a Water-Hygiene educational Programme on the Microbiological Quality of Container-Stored Water in Households. *Water SA* 29 (2) 171-176.
- Nawal, S. (2003). Water Quality and Intermittent Water Supplies. *International Journal of Environmental Health Research*. Vol. 13 (6) pp. 11-17.
- Nelson, J.G., Edmond, C.S. and Kent, W.W. (2011). Efficacy of Chlorine in Water Disinfection. *Journal of Water and Health* 052. IWA Publishing.
- Nigerian Standard for Drinking Water Quality (2007).
- Nugent, M., Kamrin, M.A. and Wolfson, L (1996). Nitrate-A Drinking Water Concern. Michigan State University Extension Bulletin, WQ-19.
- Obi, C. (2003). Scope of Potential Bacterial Agents of Diarrhea and Microbial Assessment of Quality of River Water Sources in Rural Venda Communities in South Africa. *Water Science Technology*. 47 (3) 59-64.
- Ochekpe, S.R. (2011). Potability of Nigerian Sachet Water. Daily Trust News Paper, Kaduna, Nigeria. December 6<sup>th</sup>, 2011. Pp 8-9.
- Oloruntoba, E.O. (1995). A Guide to Hygiene Education for Rural Water Supply and Sanitation Programs in Nigeria. M.Sc. (Eng.) Thesis, University of Leeds, UK, pp 113.
- Oloruntoba, E.O. (2005). Assessment of Quality of Drinking Water From Source to Household in Ibadan. Ph.D. Dissertation, University of Ibadan, Nigeria, 72-74.
- Oluwande, P.A. (2003). Tropical Environment Health and Engineering. *International Journal of Environmental Health Research*. Vol. 14 (5) pp. 46-48.
- Osibanjo, O. (2006). Present Water Quality Status in Nigeria: Water Quality Monitoring and Environmental Status in Nigeria (eds). Aina, E.O. and Adedipe. N.O. FEPA Monograph 6, pp 35-59.
- Oyins, T.A., Gilbert, N. M. and Bright, G.G. (2012). Quality of Water Stored in Clay pots: Analysis and Explanations. *Journal of Public Health and Environmental Research*. Vol 2, Issue 9. Pp 30-42.

- Parsons, S.A. and Jefferson, B. (2006). Introduction to Potable Water Treatment Processes. Blackwell Publication pp 1&2.
- Peavy, A.A. (1998). Environmental Engineering. McGraw-Hill, Singapore. pp 23-50.
- Phillip, M. (2001). Changes in Implementing a Point-of-Use Water Quality Intervention in Rural Kenya. *American Journal of Public Health*. Vol. 91. No.10.
- Pickford, J. (1991). The Worth of Water: Technical Briefs on Health, Water and sanitation. Intermediate Technology Publication, London.
- Pryse, R.R., Briggs, T.A. and Johnson, C.A. (2000). Common Tap Water Contaminants: Health Effects Treatment and Recommendations. Grading Drinking water in U.S. Cities, Chapter 5, pp 44-73.
- Rahman, A. (1996). Groundwater as a Source of Contamination for Water Supply in Rapidly Growing Megacities of Asia: A Case Study of Karachi, Pakistan. *Water Science and Technology*, Vol.34, No 7-8, pp 285-292.
- Raji, M. A. (2014). Basic Water Quality and Explanations. 4<sup>th</sup>Eddition, Intermediate Technology Publications, London, pp 18-21.
- Raymond, Y.Y., Tonteh, D.T. and Edith, A.O. (2013). Drinking Water and it Chemistry. *Proceedings of the Water Institute of South Africa (WISA) Biennial Conference Durban* 14-20 September, 2013.
- Rose, B.B. and Belote, L.S. (2000). Evaluation of Household Water Quality. Intermediate Technology Publications, London, pp 69-72.
- Rosen, S. and Vincent, J.R. (2001). Household Water Resources and Rural Productivity in Sub-Saharan Africa: A Review of the Evidence. African Economic Policy Discussion Paper No. 69.
- Ross, G.Y. and Allison, R.D. (2000). Concerned Physicochemical Parameters of Water. *International Journal of Environmental Health Research*. Vol. 17 (2) pp. 24-31.
- Russell, A.D. and Hugo, W.B. (2000). Principles and Practice of Disinfection, Preservation and Sterilization, 3<sup>rd</sup> Edition Oxford: Blackwell Scientific Publications, Pp 32-36.
- Sangoyin, A.Y. (1993). Contamination of Groundwater by Waste Disposal Systems in Nigeria. *Environmental Technology*, Vol.12 pp 957-964.
- Schreiner, B. (2005). Water Gender and Poverty, Paper Presented at The International Conference on Water, Bonn, 2000. IRC Source Bulletin No. 39 pp3.
- Scott, H.W. and Harry, B. B. (2013). Application of Spectrophotometry in Chemical Industries. *Journal of Applied Science*, 10 (2). Pp 231-249.
- Scouter, A. A and Cruickshank, D. Y. (2003). Water and Human Health. *International Journal of American Water Works Association AWWA* .Vol. 11 (4) pp. 27-34.

- Souter, P.F. and Cruickshank, G.D. (2003). Evaluation of New Water Treatment for Point-of-Use Household Applications to Remove Microorganisms and Arsenic from Drinking Water. *Journal of Water and Health*. 2: 73-84.
- Standards Organization of Nigeria (2003). Nigeria Industrial Standard: Specification of Potable Water NIS 306: 2003.
- Stedman, L. (2005). Groundwater Rules: The Need for Improved Groundwater Management. Water 21. Magazine of International Water Association, April Issue . pp 56-58.
- Sutherland, J.P., Folkard, G.K. and Grant, W.D. (1990). Natural Coagulants for Appropriate Water Treatment: A Novel Approach. *Waterlines*; 8: 30-32.
- Swarllet, A.A. (2012). Basic Principles of Thermodynamics for Beginners. 7<sup>th</sup> Edition. Edward Arnold Publishers Ltd., London, pp 23-25.
- Taiwo, F. A. and Zakari, A.A. (2014). The Limits of Water Disinfectants. *Journal of Applied Microbiology*, Vol.6 (2) pp 78-89.
- Tebbutt, T.H.Y (1998). *Principle of Water Quality Control*. 5<sup>th</sup> Edition, Reed Educational and Professional Publishing Ltd, pp12-20.
- Trevett, A., Carter, R. and Tyrrel, S. (2005). Mechanisms Leading to Post-Supply Water Quality Deterioration in Rural Honduran Communities. WEDC, Loughborough University, U.K. pp 41.
- Tunji, A. O. and Ismail, M. (2009). Epidemiological Studies of Possible Adverse Effects of the Long Term Ingestion of Fluoride Via Drinking Water. *International Journal of Environmental Health Research*. Vol. 14 (5) pp. 33-39.
- Twort, A.C., Law, F.M. and Crowley, F. W. (1985). Water Supply, 3<sup>rd</sup> Edition. Edward Arnold Publishers Ltd., London, pp 200-241.
- Twort, A.C., Law, F.M. and Crowley, F.W. (1999). Water Supply. 4<sup>th</sup> Edition. Edward Arnold Publishers Ltd., London, pp 76-81.
- United States Geological Survey (1995). *Study and Interpretation of the Chemical Characteristics of Natural water*. Paper 1473.
- W.H.O. (2003). Heterotrophic Plate Counts and Drinking Water Supply. The significance of HPC's for water quality and Human Health. pp 38-46.
- W.H.O. (2004). Guidelines for Drinking-Water Quality. 3<sup>rd</sup> Edition. Retrieved September 20, 2014 from <http://www.who.int/entity/water-sanitation-health/dwq/GDWQweb.pdf>.
- W.H.O. (2009). Guidelines for Drinking Water Quality, Vol. 2. 2<sup>nd</sup> Edition. Health Criteria and Supporting Information. Geneva, pp. 271.
- Wesley, N.K. and Foley, B.R. (2004). The Microbiology of Water, Part 1-Drinking Water: Methods for the Examination of Waters and Associated Materials. Reports on Public Health and Medical Subjects No. 71, pp149.

- Wright, J., Gundry, S. and Controy, R. (2004). Household Drinking Water in Developing Countries: A Systematic Review of Microbiological Contamination Between Sources and Point-of-Use. *Tropical Medicine and International Health*. Vol. 9, No. 1, pp 106-107.
- Ziadat, A (2005). Impact of Storage Tanks on Drinking Water Quality. *Journal of Applied Sciences* 5 (4) 634-638.

**APPENDIX A: VARIATION PATTERNS OF EXAMINED PARAMETERS WITH TIME**

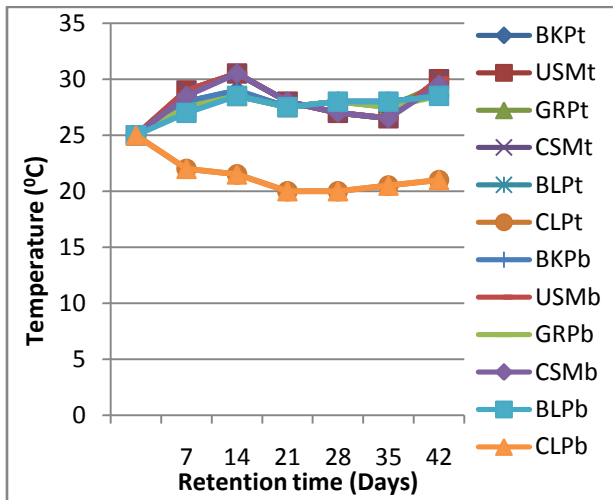


Figure A.1: Variation pattern of water temperature during research period.

**Legend:**

BKP<sub>b</sub> = Borehole water stored in a black plastic tank,

BKPt = Tap water stored in a black plastic tank,

BLP<sub>b</sub> = Borehole water stored in a blue plastic tank,

BLPt = Tap water stored in a blue plastic tank,

CLP<sub>b</sub> = Borehole water stored in a clay pot,

CLPt = Tap water stored in a clay pot,

CSM<sub>b</sub> = Borehole water stored in a coated steel metal tank,

CSMt = Tap water stored in a coated steel metal tank,

GRP<sub>b</sub> = Borehole water stored in a green plastic tank,

GRPt = Tap water stored in a green plastic tank,

USM<sub>b</sub> = Borehole water stored in an uncoated steel metal tank,

USMt = Tap water stored in an uncoated steel metal tank.

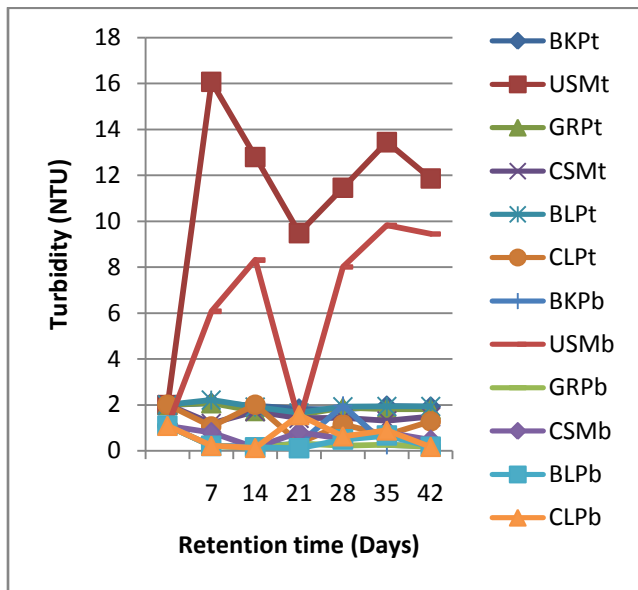


Figure A.2: Variation pattern of water turbidity during research period.

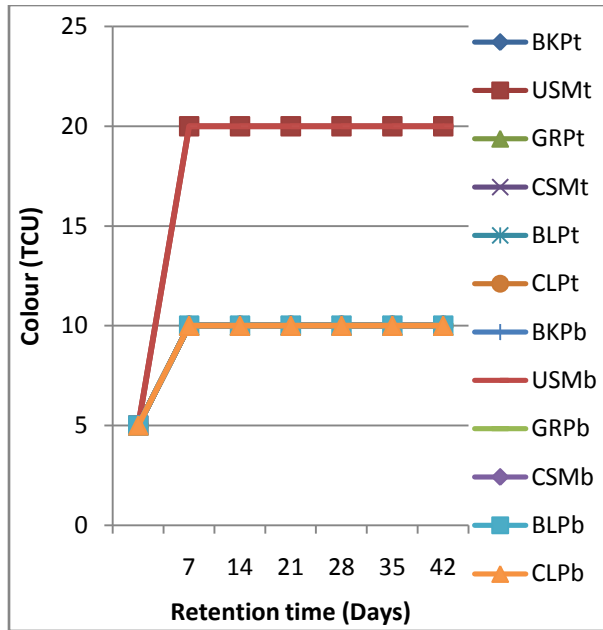


Figure A.3: Variation pattern of colour of water during research period.

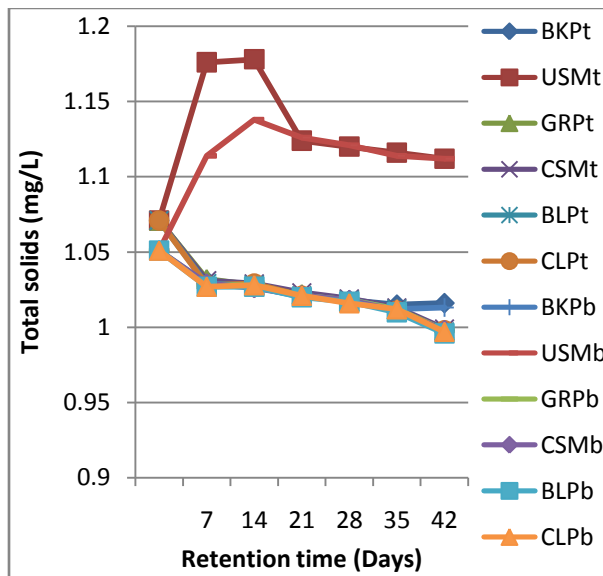


Figure A.4: Variation pattern of total solids in water during research period.

**Legend:**

BKP<sub>b</sub> = Borehole water stored in a black plastic tank,

BKPt = Tap water stored in a black plastic tank,

BLP<sub>b</sub> = Borehole water stored in a blue plastic tank,

BLPt = Tap water stored in a blue plastic tank,

CLP<sub>b</sub> = Borehole water stored in a clay pot,

CLPt = Tap water stored in a clay pot,

CSM<sub>b</sub> = Borehole water stored in a coated steel metal tank,

CSMt = Tap water stored in a coated steel metal tank,

GRP<sub>b</sub> = Borehole water stored in a green plastic tank,

GRPt = Tap water stored in a green plastic tank,

USM<sub>b</sub> = Borehole water stored in an uncoated steel metal tank,

USMt = Tap water stored in an uncoated steel metal tank.

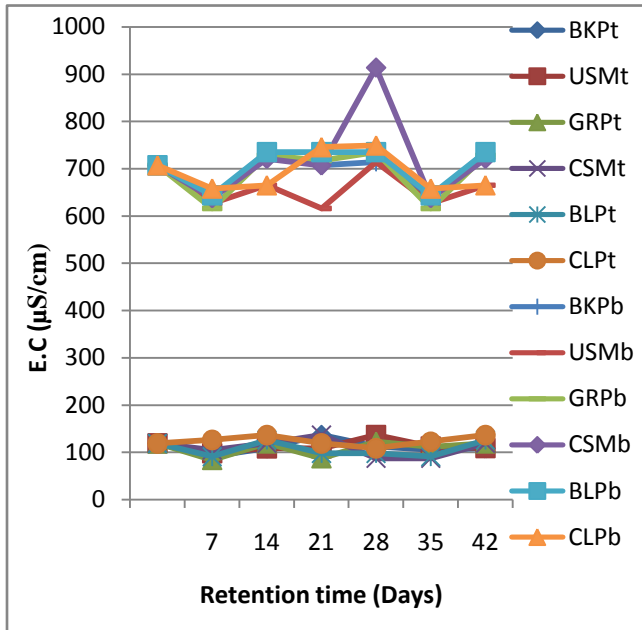


Figure A.5: Variation pattern of EC of water during research period.

**Legend:**

BKP<sub>b</sub> = Borehole water stored in a black plastic tank,

BKPt = Tap water stored in a black plastic tank,

BLP<sub>b</sub> = Borehole water stored in a blue plastic tank,

BLPt = Tap water stored in a blue plastic tank,

CLP<sub>b</sub> = Borehole water stored in a clay pot,

CLPt = Tap water stored in a clay pot,

CSM<sub>b</sub> = Borehole water stored in a coated steel metal tank,

CSMt = Tap water stored in a coated steel metal tank,

EC = Electrical Conductivity,

GRP<sub>b</sub> = Borehole water stored in a green plastic tank,

GRPt = Tap water stored in a green plastic tank,

USM<sub>b</sub> = Borehole water stored in an uncoated steel metal tank,

USMt = Tap water stored in an uncoated steel metal tank.

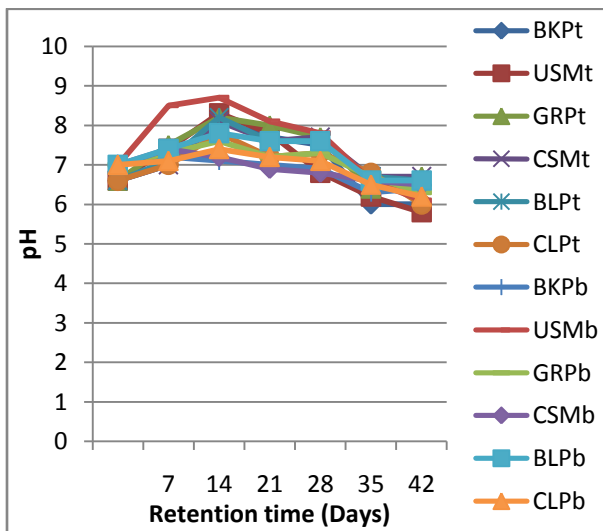


Figure A.6: Variation pattern of pH of water during research period.

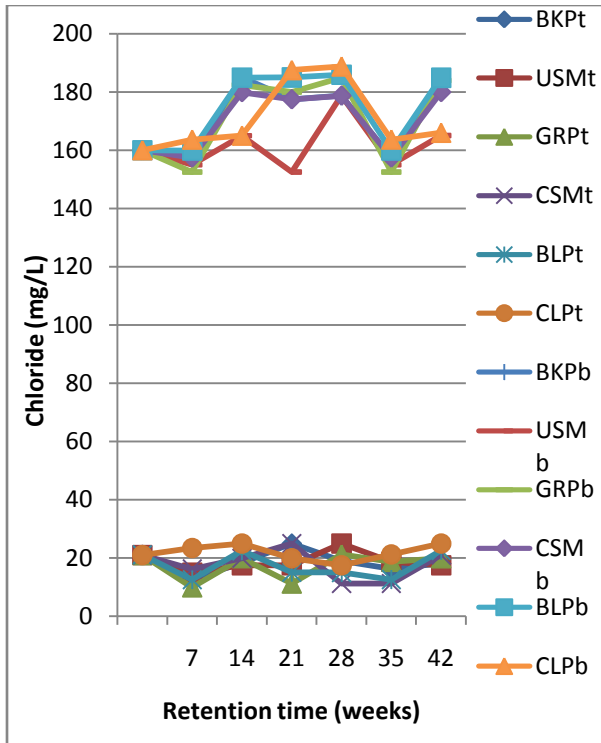


Figure A.7: Variation pattern of Chloride ions in water during research period.

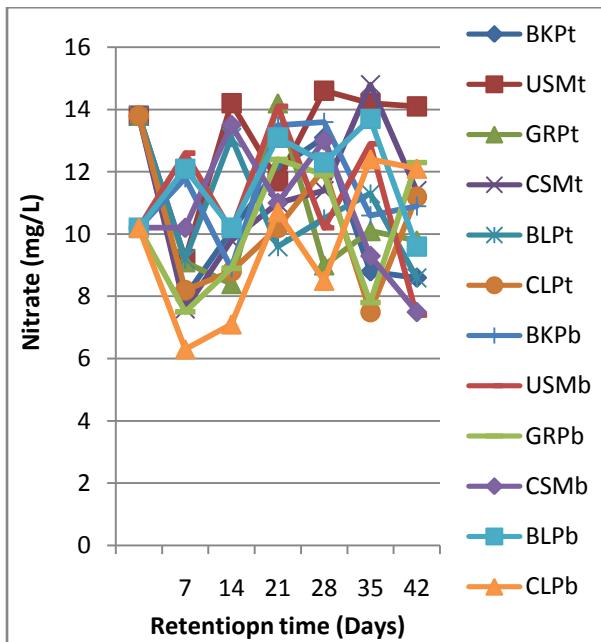


Figure A.8: Variation pattern of nitrate in water during research period.

**Legend:**

BKP<sub>b</sub> = Borehole water stored in a black plastic tank,

BKPt = Tap water stored in a black plastic tank,

BLP<sub>b</sub> = Borehole water stored in a blue plastic tank,

BLPt = Tap water stored in a blue plastic tank,

CLP<sub>b</sub> = Borehole water stored in a clay pot,

CLPt = Tap water stored in a clay pot,

CSM<sub>b</sub> = Borehole water stored in a coated steel metal tank,

CSMt = Tap water stored in a coated steel metal tank,

GRP<sub>b</sub> = Borehole water stored in a green plastic tank,

GRPt = Tap water stored in a green plastic tank,

USM<sub>b</sub> = Borehole water stored in an uncoated steel metal tank,

USMt = Tap water stored in an uncoated steel metal tank.

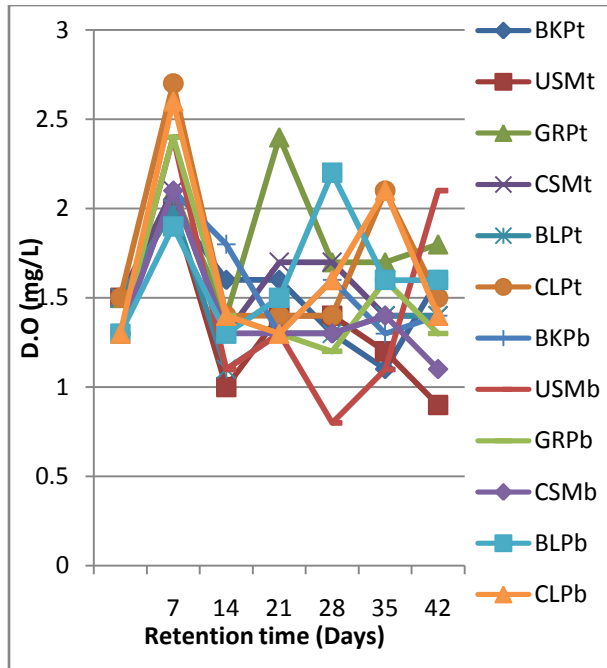


Figure A.9: Variation pattern of D.O in water during research period.

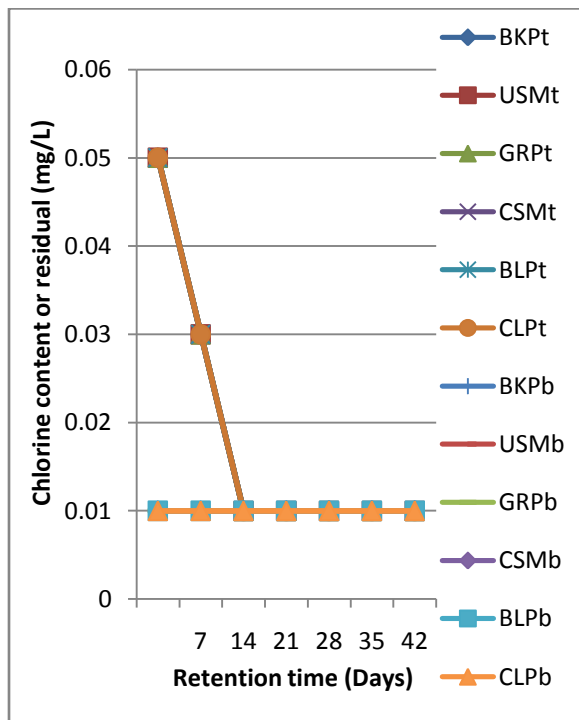


Figure A.10: Variation pattern of Chlorine (residual) in water during research period.

**Legend:**

BKP<sub>b</sub> = Borehole water stored in a black plastic tank,

BKPt = Tap water stored in a black plastic tank,

BLP<sub>b</sub> = Borehole water stored in a blue plastic tank,

BLPt = Tap water stored in a blue plastic tank,

CLP<sub>b</sub> = Borehole water stored in a clay pot,

CLPt = Tap water stored in a clay pot,

CSM<sub>b</sub> = Borehole water stored in a coated steel metal tank,

CSMt = Tap water stored in a coated steel metal tank,

D.O = Dissolved Oxygen,

GRP<sub>b</sub> = Borehole water stored in a green plastic tank,

GRPt = Tap water stored in a green plastic tank,

USM<sub>b</sub> = Borehole water stored in an uncoated steel metal tank,

USMt = Tap water stored in an uncoated steel metal tank.

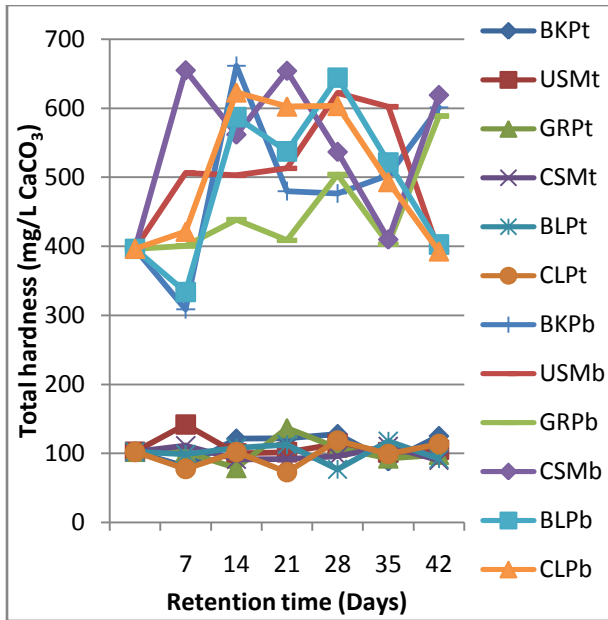


Figure A.11: Variation pattern of total hardness in water during research period.

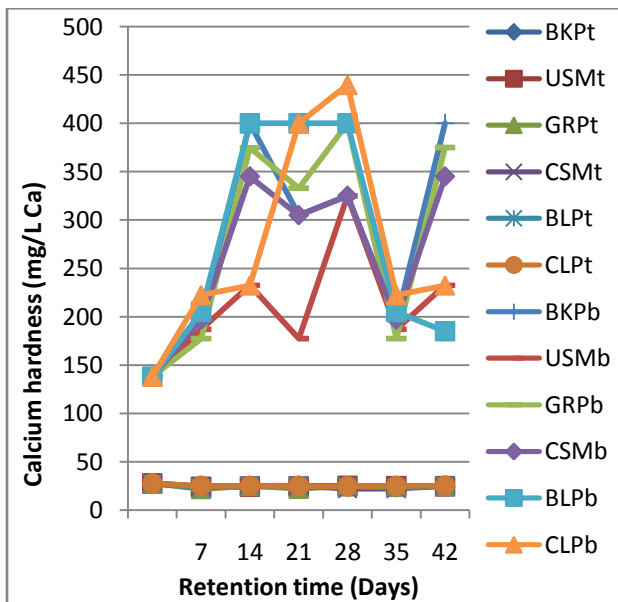


Figure A.12: Variation pattern of Calcium hardness in water during research period.

**Legend:**

BKP<sub>b</sub> = Borehole water stored in a black plastic tank,

BKPt = Tap water stored in a black plastic tank,

BLP<sub>b</sub> = Borehole water stored in a blue plastic tank,

BLPt = Tap water stored in a blue plastic tank,

CLP<sub>b</sub> = Borehole water stored in a clay pot,

CLPt = Tap water stored in a clay pot,

CSM<sub>b</sub> = Borehole water stored in a coated steel metal tank,

CSMt = Tap water stored in a coated steel metal tank,

GRP<sub>b</sub> = Borehole water stored in a green plastic tank,

GRPt = Tap water stored in a green plastic tank,

USM<sub>b</sub> = Borehole water stored in an uncoated steel metal tank,

USMt = Tap water stored in an uncoated steel metal tank.

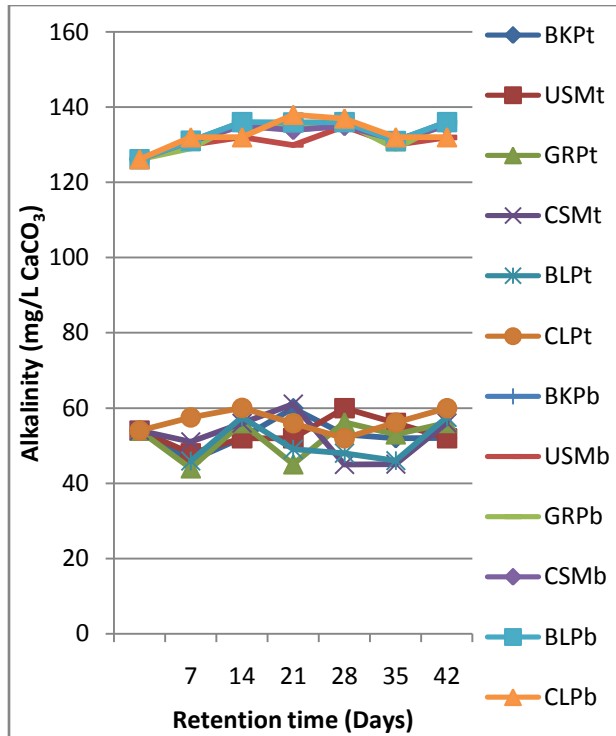


Figure A.13: Variation pattern of Alkalinity in water during research period.

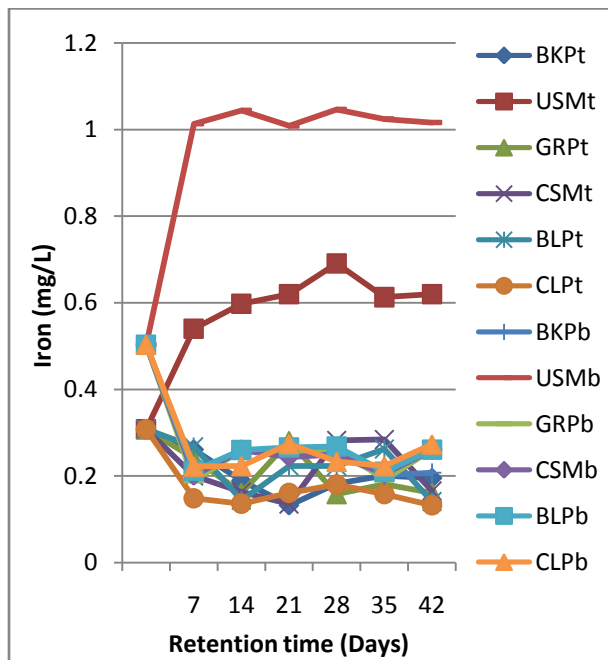


Figure A.14: Variation pattern of Iron in water during research period.

**Legend:**

BKP<sub>b</sub> = Borehole water stored in a black plastic tank,

BKPt = Tap water stored in a black plastic tank,

BLP<sub>b</sub> = Borehole water stored in a blue plastic tank,

BLPt = Tap water stored in a blue plastic tank,

CLP<sub>b</sub> = Borehole water stored in a clay pot,

CLPt = Tap water stored in a clay pot,

CSM<sub>b</sub> = Borehole water stored in a coated steel metal tank,

CSMt = Tap water stored in a coated steel metal tank,

GRP<sub>b</sub> = Borehole water stored in a green plastic tank,

GRPt = Tap water stored in a green plastic tank,

USM<sub>b</sub> = Borehole water stored in an uncoated steel metal tank,

USMt = Tap water stored in an uncoated steel metal tank.

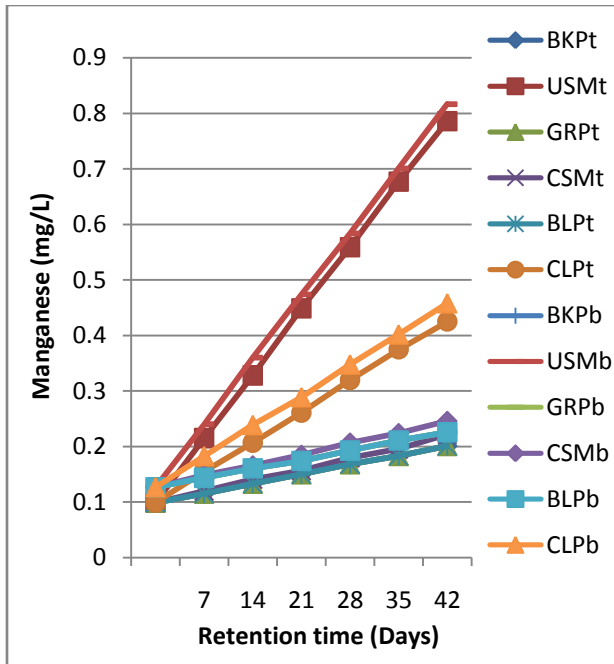


Figure A.15: Variation pattern of Manganese in water during research period.

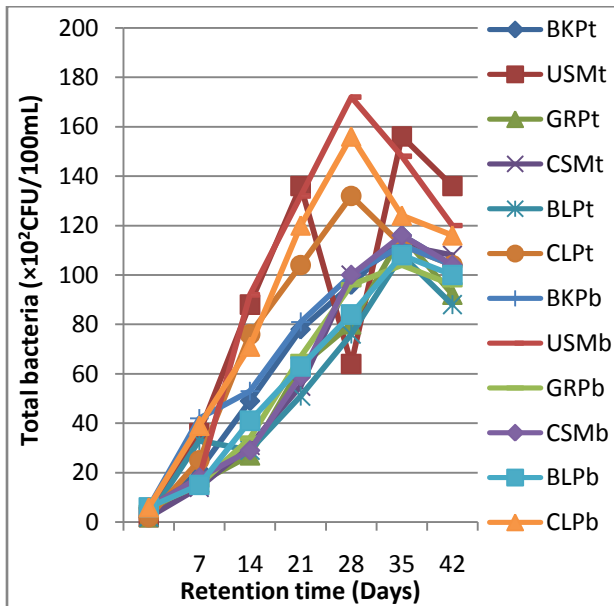


Figure A.16: Variation pattern of Total Heterotrophic Bacteria (THB) in water during research period.

**Legend:**

BKP<sub>b</sub> = Borehole water stored in a black plastic tank,

BKPt = Tap water stored in a black plastic tank,

BLP<sub>b</sub> = Borehole water stored in a blue plastic tank,

BLPt = Tap water stored in a blue plastic tank,

CLP<sub>b</sub> = Borehole water stored in a clay pot,

CLPt = Tap water stored in a clay pot,

CSM<sub>b</sub> = Borehole water stored in a coated steel metal tank,

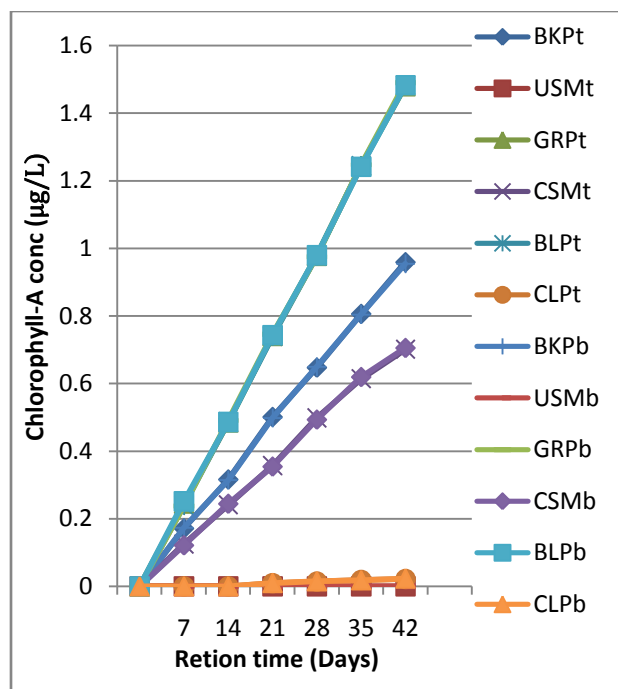
CSMt = Tap water stored in a coated steel metal tank,

GRP<sub>b</sub> = Borehole water stored in a green plastic tank,

GRPt = Tap water stored in a green plastic tank,

USM<sub>b</sub> = Borehole water stored in an uncoated steel metal tank,

USMt = Tap water stored in an uncoated steel metal tank.



CSMt = Tap water stored in a coated steel metal tank,

GRP<sub>b</sub> = Borehole water stored in a green plastic tank,

GRPt = Tap water stored in a green plastic tank,

USM<sub>b</sub> = Borehole water stored in an uncoated steel metal tank,

USMt = Tap water stored in an uncoated steel metal tank.

Figure A.17: Variation pattern of chlorophyll-A in water during research period.

**Legend:**

BKP<sub>b</sub> = Borehole water stored in a black plastic tank,

BKPt = Tap water stored in a black plastic tank,

BLP<sub>b</sub> = Borehole water stored in a blue plastic tank,

BLPt = Tap water stored in a blue plastic tank,

CLP<sub>b</sub> = Borehole water stored in a clay pot,

CLPt = Tap water stored in a clay pot,

CSM<sub>b</sub> = Borehole water stored in a coated steel metal tank,



## APPENDIX B: RELATIONSHIP BETWEEN MANGANESE (Mn) CONCENTRATION AND RETENTION TIME

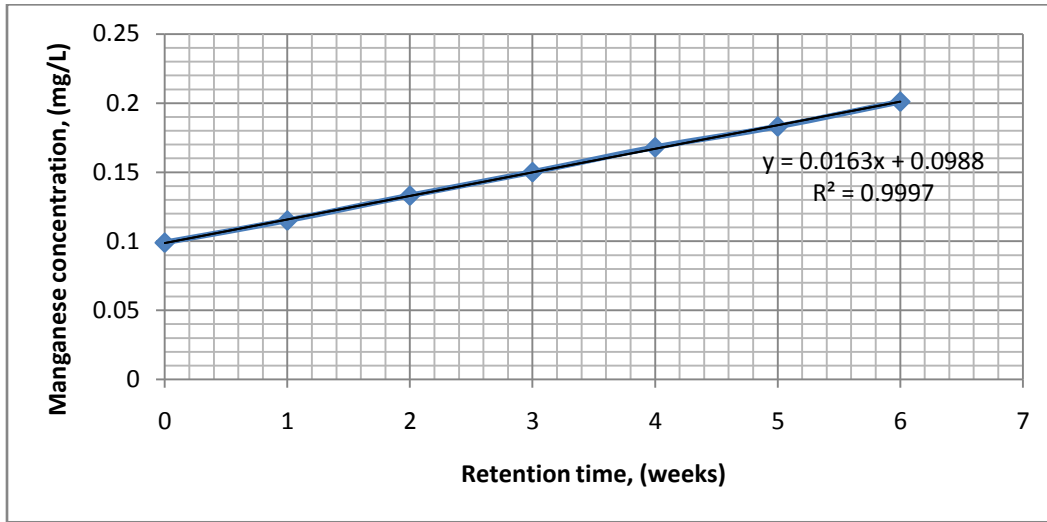


Figure B.1: Relationship between Mn concentration and retention time in tap water stored in plastic tanks.

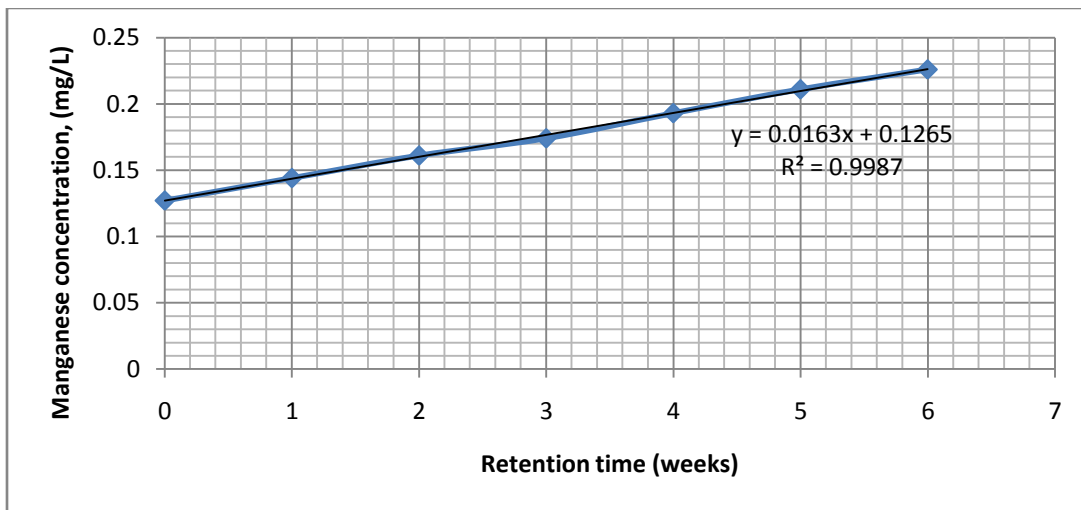


Figure B.2: Relationship between Mn concentration and retention time in borehole water stored in plastic tanks.

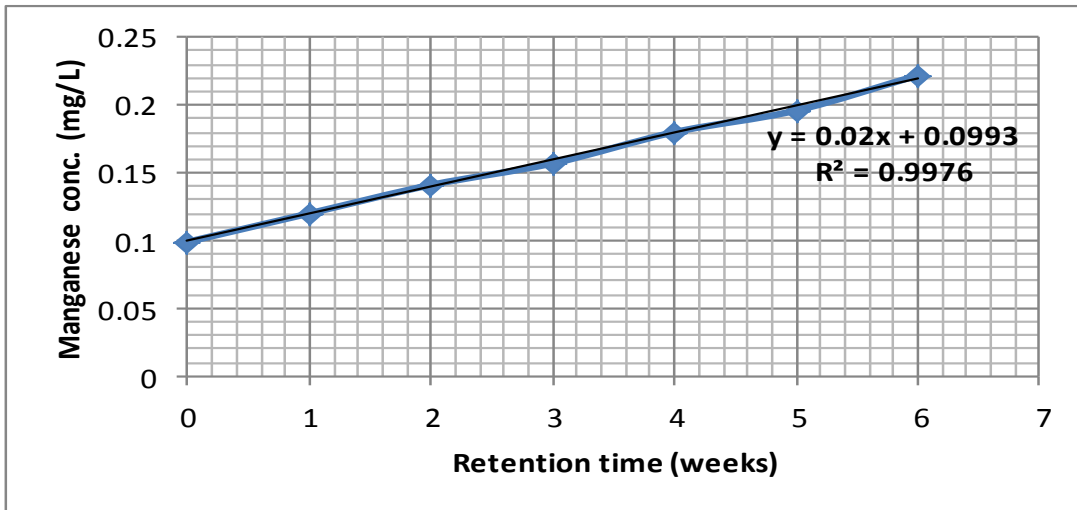


Figure B.3: Relationship between manganese concentration and retention time in tap water stored in a coated steel metal tank.

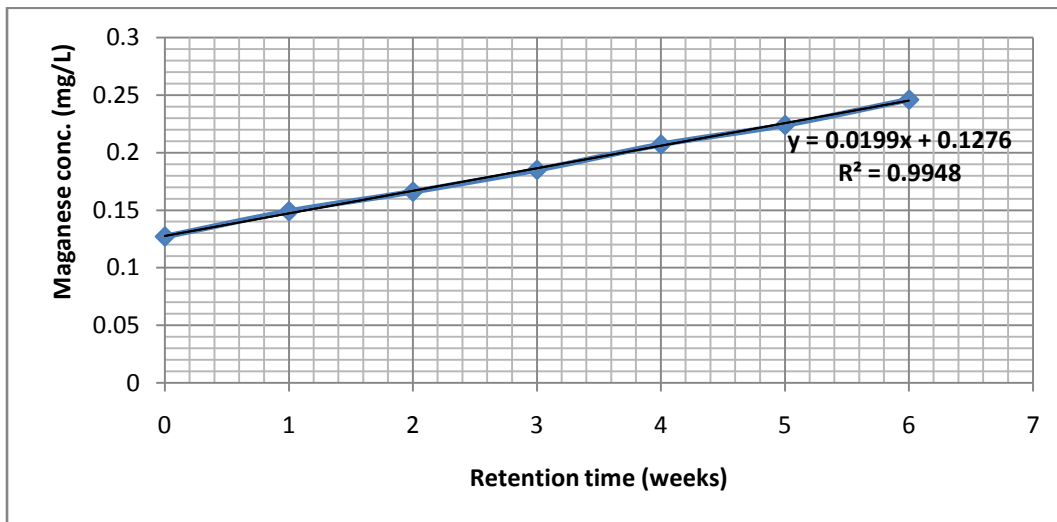


Figure B.4: Relationship between manganese concentration and retention time in borehole water stored in a coated steel metal tank.

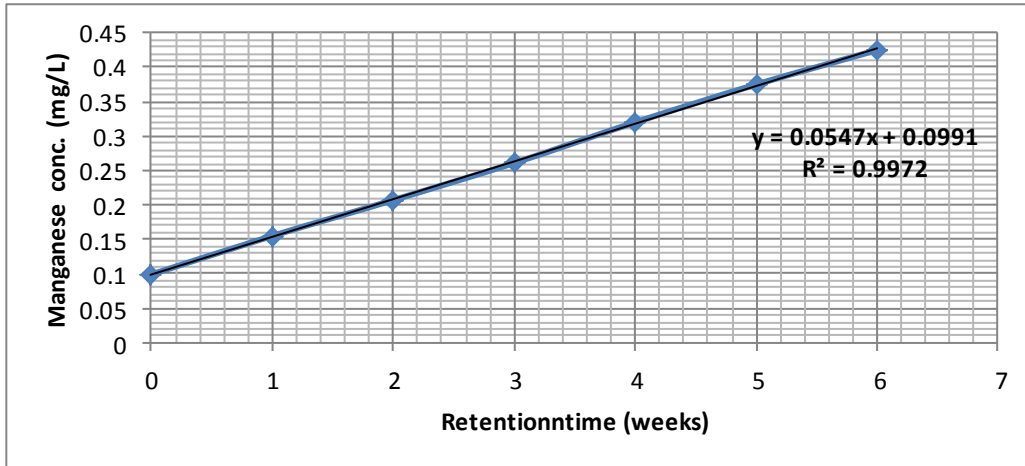


Figure B.5: Relationship between manganese concentration and retention time in tap water stored in an uncoated steel metal tank.

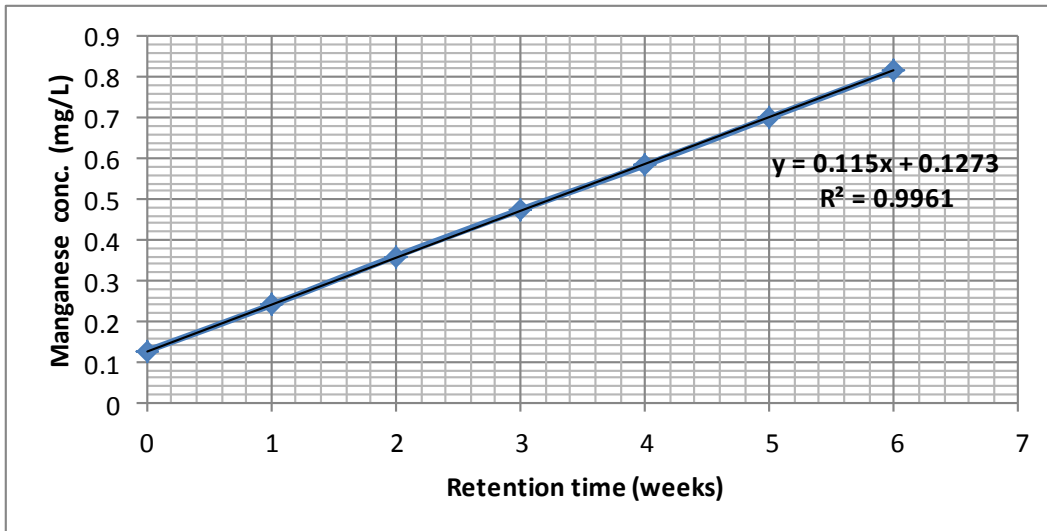


Figure B.6: Relationship between manganese concentration and retention time in borehole water stored in an uncoated steel metal tank.

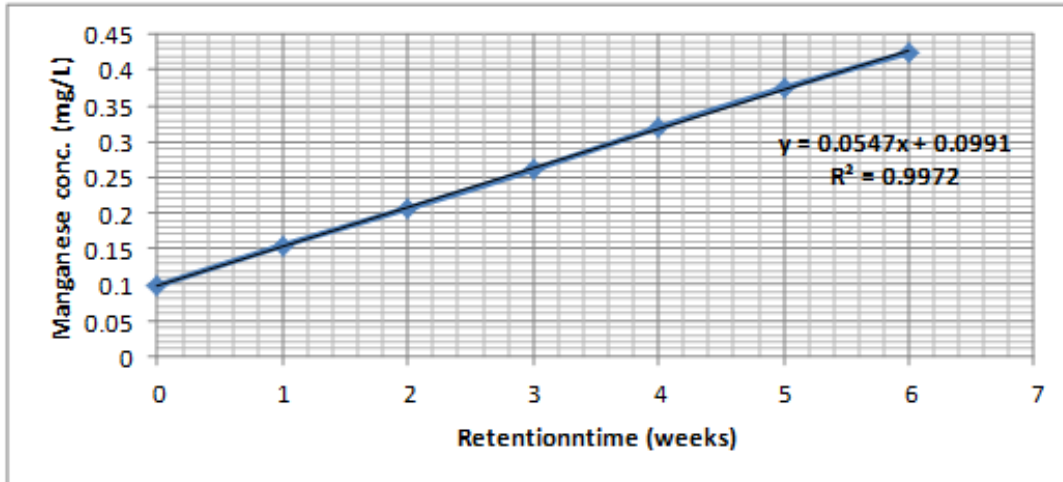


Figure B.7: Relationship between manganese concentration and retention time in tap water stored in a clay pot.

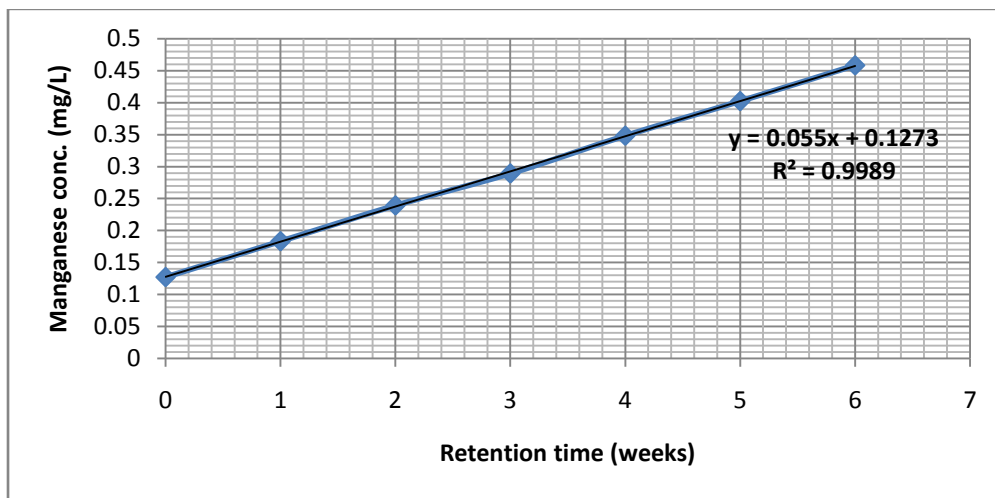


Figure B.8: Relationship between manganese concentration and retention time in borehole water stored in a clay pot.

**APPENDIX C: RELATIONSHIP BETWEEN CHLOROPHYLL-A CONCENTRATION AND RETENTION TIME**

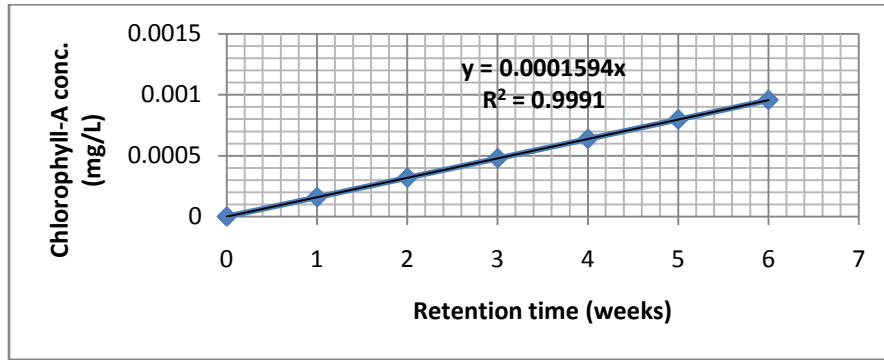


Figure C.1: Relationship between chlorophyll-A concentration and retention time for water stored in black plastic tanks.

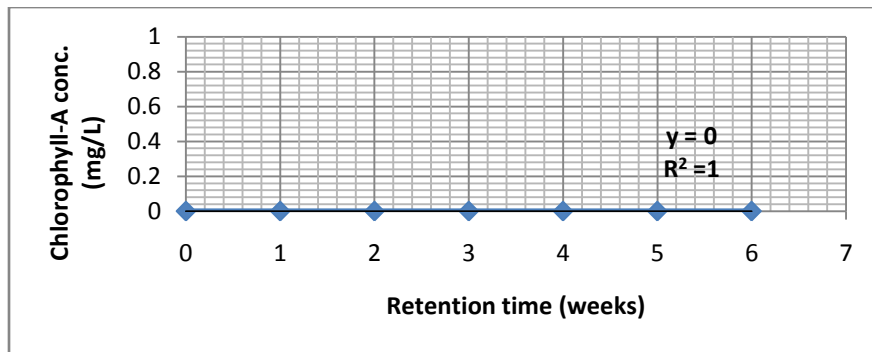


Figure C.2: Relationship between chlorophyll-A concentration and retention time for water stored in uncoated steel metal tanks.

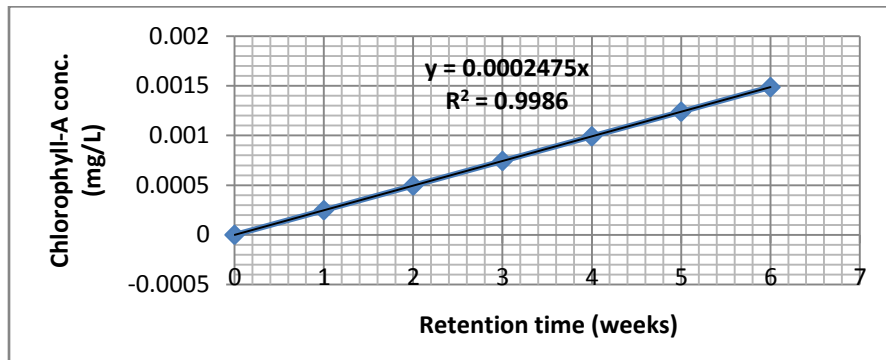


Figure C.3: Relationship between chlorophyll-A concentration and retention time for water stored in green plastic tanks.

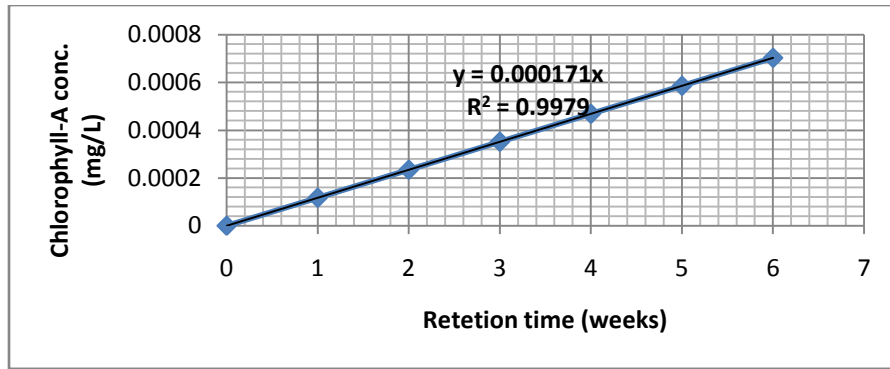


Figure C.4: Relationship between chlorophyll-A concentration and retention time for water stored in coated steel metal tanks.

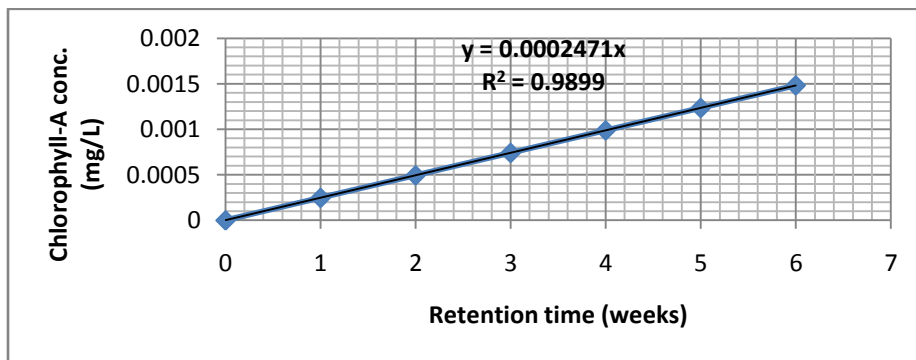


Figure C.5: Relationship between chlorophyll-A concentration and retention time for water stored in blue plastic tanks.

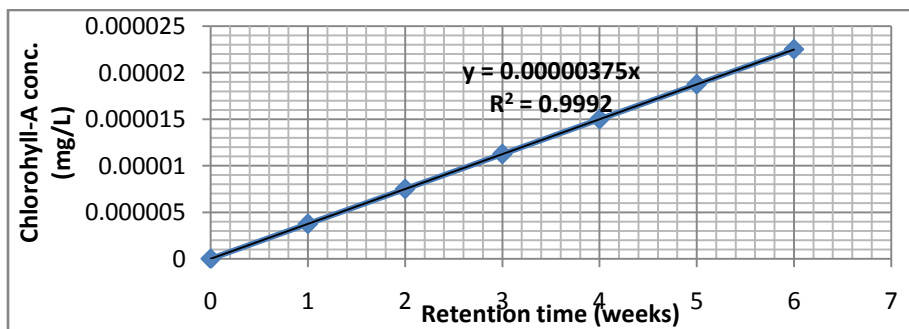


Figure C.6: Relationship between chlorophyll-A concentration and retention time for water stored in clay pots.

**APPENDIX D: RESULTS FROM STATISTICAL ANALYSIS SYSTEM (SAS) 9.2**

**Whole Model**

**Summary of Fit**

RSquare	0.999497
RSquare Adj	0.999476
Root Mean Square Error	6.681887
Mean of Response	399.52
Observations (or Sum Wgts)	74

**Analysis of Variance**

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	3	6212079.1	2070693	46378.58
Error	70	3125.3	45	Prob > F
C. Total	73	6215204.5		<.0001*

**Parameter Estimates**

Term	Estimate	Std Error	t Ratio	Prob> t
Intercept	84.493854	13.93127	6.07	<.0001*
X1	-0.986756	0.322608	-3.06	0.0031*
X2	-0.109506	0.021794	-5.02	<.0001*
X3	4.4685849	0.197211	22.66	<.0001*

**Step History**

Step	Parameter	Action	"Sig Prob"	Seq SS	RSquare	Cp	p	AICc	BIC	
1	X1	Entered	0.0000	6169004	0.9926	964.78	2	692.66	699.229	○
2	X2	Entered	0.0000	20151.91	0.9958	515.43	3	652.493	661.13	○
3	X3	Entered	0.0000	22923.25	0.9995	4	4	497.884	508.522	⊙

**APPENDIX E: MAXIMUM RETENTION PERIODS FOR STORING TAP WATER OR BOREHOLE WATER IN STORAGE CONTAINERS**

Table E.1: Maximum retention period for storing tap water in a black plastic tank.

Parameters that are health threat or toxic	Permissible limit set by W.H.O Standard	Time required to reach permissible limit	Minimum time interval required to reach a permissible limit	Maximum retention period
Nitrate	50mg/L	PNR	4 weeks	≤ 4 weeks (3 weeks is suggested for safety purpose)
Manganese	0.2mg/L	5 weeks		
Total bacteria	10 <sup>4</sup> CFU/100mL	4 weeks		
Chlorophyll-A	5.0×10 <sup>-2</sup> mg/L	PNR		

PNR = Permissible limit not reached during retention period.

Table E.2: Maximum retention period for storing tap water in an uncoated steel metal tank.

Parameters that are health threat or toxic	Permissible limit set by W.H.O Standard	Time required to reach permissible limit	Minimum time interval required to reach a permissible limit	Maximum retention period
Nitrate	50mg/L	PNR	Less than a week	It is suggested that water should not be stored for safety purpose
Manganese	0.2mg/L	Less than a week		
Total bacteria	10 <sup>4</sup> CFU/100mL	2 weeks		
Chlorophyll-A	5.0×10 <sup>-2</sup> mg/L	PNR		

PNR = Permissible limit not reached during retention period.

Table E.3: Maximum retention period for storing tap water in a green plastic tank.

Parameters that are health threat or toxic	Permissible limit set by W.H.O Standard	Time required to reach permissible limit	Minimum time interval required to reach a permissible limit	Maximum retention period
Nitrate	50mg/L	PNR	4 weeks	≤ 4 weeks
Manganese	0.2mg/L	5 weeks		( <b>3 weeks</b> is suggested for safety purpose)
Total bacteria	10 <sup>4</sup> CFU/100mL	4 weeks		
Chlorophyll-A	5.0×10 <sup>-2</sup> mg/L	PNR		

PNR = Permissible limit not reached during retention period.

Table E.4: Maximum retention period for storing tap water in a coated steel metal tank.

Parameters that are health threat or toxic	Permissible limit set by W.H.O Standard	Time required to reach permissible limit	Minimum time interval required to reach a permissible limit	Maximum retention period
Nitrate	50mg/L	PNR	4 weeks	≤ 4 weeks
Manganese	0.2mg/L	5 weeks		( <b>3 weeks</b> is suggested for safety purpose)
Total bacteria	10 <sup>4</sup> CFU/100mL	4 weeks		
Chlorophyll-A	5.0×10 <sup>-2</sup> mg/L	PNR		

PNR = Permissible limit not reached during retention period.

Table E.5: Maximum retention period for storing tap water in a blue plastic tank.

Parameters that are health threat or toxic	Permissible limit set by W.H.O Standard	Time required to reach permissible limit	Minimum time interval required to reach a permissible limit	Maximum retention period
Nitrate	50mg/L	PNR	4 weeks	≤ 4 weeks
Manganese	0.2mg/L	5 weeks		( <b>3 weeks</b> is suggested for safety purpose)
Total bacteria	10 <sup>4</sup> CFU/100mL	4 weeks		
Chlorophyll-A	5.0×10 <sup>-2</sup> mg/L	PNR		

PNR = Permissible limit not reached during retention period.

Table E.6: Maximum retention period for storing tap water in a clay pot.

Parameters that are health threat or toxic	Permissible limit set by W.H.O Standard	Time required to reach permissible limit	Minimum time interval required to reach a permissible limit	Maximum retention period
Nitrate	50mg/L	PNR	1 week	≤ 1 week
Manganese	0.2mg/L	1 week		( <b>6 days</b> is suggested for safety purpose)
Total bacteria	10 <sup>4</sup> CFU/100mL	3 weeks		
Chlorophyll-A	5.0×10 <sup>-2</sup> mg/L	PNR		

PNR = Permissible limit not reached during retention period.

Table E.7: Maximum retention period for storing borehole water in a black plastic tank.

Parameters that are health threat or toxic	Permissible limit set by W.H.O Standard	Time required to reach permissible limit	Minimum time interval required to reach a permissible limit	Maximum retention period
Nitrate	50mg/L	PNR	4 weeks	≤ 4 weeks
Manganese	0.2mg/L	4 weeks		( <b>3 weeks</b> is suggested for safety purpose)
Total bacteria	10 <sup>4</sup> CFU/100mL	4 weeks		
Chlorophyll-A	5.0×10 <sup>-2</sup> mg/L	PNR		

PNR = Permissible limit not reached during retention period.

Table E.8: Maximum retention period for storing borehole water in an uncoated steel metal tank.

Parameters that are health threat or toxic	Permissible limit set by W.H.O Standard	Time required to reach permissible limit	Minimum time interval required to reach a permissible limit	Maximum retention period
Nitrate	50mg/L	PNR	Less than a week	It is suggested that water should not be stored for safety purpose
Manganese	0.2mg/L	Less than a week		
Total bacteria	10 <sup>4</sup> CFU/100mL	2 weeks		
Chlorophyll-A	5.0×10 <sup>-2</sup> mg/L	PRN		

PNR = Permissible limit not reached during retention period.

Table E.9: Maximum retention period for storing borehole water in a green plastic tank.

Parameters that are health threat or toxic	Permissible limit set by W.H.O Standard	Time required to reach permissible limit	Minimum time interval required to reach a permissible limit	Maximum retention period
Nitrate	50mg/L	PNR	4 weeks	≤ 4 weeks
Manganese	0.2mg/L	4 weeks		( <b>3 weeks</b> is suggested for safety purpose)
Total bacteria	10 <sup>4</sup> CFU/100mL	4 weeks		
Chlorophyll-A	5.0×10 <sup>-2</sup> mg/L	PNR		

PNR = Permissible limit not reached during retention period.

Table E.10: Maximum retention period for storing borehole water in coated steel metal tank.

Parameters that are health threat or toxic	Permissible limit set by W.H.O Standard	Time required to reach permissible limit	Minimum time interval required to reach a permissible limit	Maximum retention period
Nitrate	50mg/L	PNR	3 weeks	≤ 3 weeks
Manganese	0.2mg/L	3 weeks		( <b>2 weeks</b> is suggested for safety purpose)
Total bacteria	10 <sup>4</sup> CFU/100mL	4 weeks		
Chlorophyll-A	5.0×10 <sup>-2</sup> mg/L	PNR		

PNR = Permissible limit not reached during retention period.

Table E.11: Maximum retention period for storing borehole water in a blue plastic tank.

Parameters that are health threat or toxic	Permissible limit set by W.H.O Standard	Time required to reach permissible limit	Minimum time interval required to reach a permissible limit	Maximum retention period
Nitrate	50mg/L	PNR	4 weeks	≤ 4 weeks
Manganese	0.2mg/L	4 weeks		( <b>3 weeks</b> is suggested for safety purpose)
Total bacteria	10 <sup>4</sup> CFU/100mL	4 weeks		
Chlorophyll-A	5.0×10 <sup>-2</sup> mg/L	PNR		

PNR = Permissible limit not reached during retention period.

Table E.12: Maximum retention period for storing borehole water in a clay pot.

Parameters that are health threat or toxic	Permissible limit set by W.H.O Standard	Time required to reach permissible limit	Minimum time interval required to reach a permissible limit	Maximum retention period
Nitrate	50mg/L	PNR	1 week	≤ 1 week
Manganese	0.2mg/L	1 week		( <b>6 days</b> is suggested for safety purpose)
Total bacteria	10 <sup>4</sup> CFU/100mL	2 weeks		
Chlorophyll-A	5.0×10 <sup>-2</sup> mg/L	PNR		

PNR = Permissible limit not reached during retention period.