STUDIES OF DISINFECTION BY-PRODUCTS AND HEAVY METALS IN AHMADU BELLO UNIVERSITY DRINKING WATER SUPPLIES AND OPERATIONS OF SOME TREATMENT PLANTS

BY

SHAIBU-IMODAGBE, EGBENYA MUSAH
B.Sc.(Hons) SOIL SCIENCE (IBADAN), M.Sc. POLLUTION AND ENVIRONMENTAL CONTROL (MANCHESTER)
(Ph.D/ENG/16449/1998 – 1999)

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

AUGUST 2011

STUDIES OF DISINFECTION BY-PRODUCTS AND HEAVY METALS IN AHMADU BELLO UNIVERSITY DRINKING WATER SUPPLIES AND OPERATIONS OF SOME TREATMENT PLANTS

BY

SHAIBU-IMODAGBE, EGBENYA MUSAH
B.Sc.(Hons) SOIL SCIENCE (Ibadan), M.Sc. POLLUTION AND ENVIRONMENTAL CONTROL (Manchester)
(Ph.D/ENG/16449/1998 – 1999)

A THESIS SUBMITTED TO THE SCHOOL OF POSTGRADUATE STUDIES, AHMADU BELLO UNIVERSITY, ZARIA

IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF DOCTOR OF PHILOSOPHY IN WATER RESOURCES AND ENVIRONMENTAL ENGINEERING

DEPARTMENT OF WATER RESOURCES AND ENVIRONMENTAL ENGINEERING, FACULTY OF ENGINEERING,

AHMADU BELLO UNIVERSITY, ZARIA

AUGUST 2011

DECLARATION

I declare that the work in the thesis entitled "STUDIES OF DISINFECTION BY-PRODUCTS AND HEAVY METALS IN AHMADU BELLO UNIVERSITY DRINKING WATER SUPPLIES AND OPERATIONS OF SOME TREATMENT PLANTS" has been performed by me in the Department of Water Resources and Environmental Engineering under the supervision of Prof. OKUOFU, Charles Amen (Major supervisor). The information derived from literature has been duly acknowledged in the text and a list of references provided. No part of this thesis was previously presented for another degree or diploma at any university.

_____ _____

SHAIBU-IMODAGBE, EGBENYA MUSAH DATE

CERTIFICATION

This thesis entitled "STUDIES OF DISINFECTION BY-PRODUCTS AND HEAVY METALS IN AHMADU BELLO UNIVERSITY DRINKING WATER SUPPLIES AND OPERATIONS OF SOME TREATMENT PLANTS" by Shaibu-Imodagbe, Egbenya Musah meets the regulations governing the award of the degree of Doctor of Philosophy (PhD) of Ahmadu Bello University, and is approved for its contribution to knowledge and literary presentation.

Prof. C. A. Okuofu Chairman, Supervisory Committee	_____ Signature	_____ Date
Dr A. Ismail Member, Supervisory Committee	_____ Signature	_____ Date,
Dr J. A. Otun Member, Supervisory Committee	_____ Signature	_____ Date,
Dr D. B. Adie Head of Department of WREE	_____ Signature	_____ Date,
Prof A. A. Joshua Dean, School of Postgraduate Studies	_____ Signature	_____ Date,

ACKNOWLEDGEMENT

My gratitude goes to the Almighty Allah for sparing my life till today and for granting me the opportunity and grace to complete this work, Alhamdulilah! My gratitude also goes to my team of supervisors headed by Prof. Charles A. Okuofu. I am indeed overwhelmingly grateful to Prof. Okuofu for he was a source of encouragement at periods when hopes seemed to fade. Sir, I am also highly indebted to you for your numerous counsels and very useful suggestions regarding this work. May Almighty God reward you abundantly. To my colleagues, friends and members of the supervisory team Dr. Abubakar Ismail, Dr Johnson A. Otun and Dr Donatus B. Adie I am grateful for your encouragement and contributions to get this work completed. To my other friends and colleagues in the Department of Water Resources and Environmental Engineering, I thank you all for your assistance. This piece of work is my little contribution towards guiding the activities of the department towards topical issues of the day as they affect our time. I look forward to more challenging involvement of other members of the department in the study area in years to come.

As this study span the period of years it had taken to complete, so have more people been involved in assisting in its completion. My immense gratitude also goes to Dr Unyimadu, John Paul and Dr Williams Akan of Physical and Analytical Chemistry Department of Nigerian Institute of Oceanography and Marine Research, Victoria Island and Chemistry Department, Covenant University, Otta, Ogun State respectively for granting me access to the analytical Gas Chromatography equipment without which the study would not have succeeded. I will also like to express my appreciation to Mr Ibrahim Attah Isah, an instrumentation and analytical specialist at NAFDAC regional

laboratory Lagos for being always there to assist with GC calibration. I am really grateful to you all. I am most sincerely grateful to my brothers and friends Mr Jibril Odogba and Mr Femi Akindele and his host of colleagues of the USEPA who worked tirelessly to procure a GC for this work in its early stage. Femi I owe this work to you. Your encouragement all the way including the financial and moral support cannot be forgotten. My brother and friend Jibril, your support in cash and kind drove this work to its completion. Thank you both immensely for being there for me.

To my wonderful wife, children and family, I cannot say how joyful it is for me that this work has finally been completed. Your wonderful patience and endurance paid off. Thank you immensely for being there always. May Allah continue to bless you and guide you aright. To Madam Fausat Mubo Popoola your words of encouragement and support were a great asset to this work. May Allah reward you abundantly, Ameen. To all my other colleagues, Hajiya H. Omenesa, Mallam Aliyu Sa'id, Mallam M. A. Shehu, Hajiya Jamila Abdullahi and Mallam U. D. Idris among others, thank you for all your support and encouragement. May Allah reward you all and may your moments of completion of your various works arrive very soon, Thank you all.

My appreciation also goes to the Ahmadu Bello University Zaria and Carnegie Foundations for granting me some financial assistance towards undertaking the research.

ABSTRACT

This study had a broad objective of determining the quality of drinking water produced by Ahmadu Bello University (ABU) water treatment plant. Its samples were chemically analysed for general chemical properties, heavy metals and Disinfection By-Products (DBPs) content in accordance with standard analytical methods and USEPA methods 551.1 and 552.2 for the DBPs. Structured questionnaire survey was adopted to evaluate the operating code of practice of the ABU water works and nine others. 80% of the surveyed water works were found to be of the single train, one injection point, and one disinfection segment treatment plants. All the water works have both preliminary and main water treatment processes including screening, flocculation, sedimentation and disinfection processes. World Health Organization (WHO) operating code of practice is used by 90% of the treatment plants but in varied forms. Treatment plants declaring disinfecting water always were 70% though some reports indicate otherwise while irregular supply prevented those not always disinfecting. Operators of 60% of treatment plants claimed uninterrupted water distribution but irregular water distribution was reported. 80% of the treatment plants had no fully functional service laboratories. Staff were found inadequate, with low capacity building and have limited professional competence in potable water delivery. Treated water assessed parameters were pH 7.2, conductivity 96.3µS/cm @ 25^0C, total dissolved solids 63.75 mg/l, total organic carbon 2.3 mg/l, nitrate 1.00 mg/l, phosphate 0.12 mg/l, chloride 0.57 mg/l and sulphate 36.17 mg/l. Zinc and lead were the only heavy metals detected, in concentrations of 0.04 and 0.035 mg/l respectively. Thirty-six DBPs including nine of the regulated eleven were found in the study. Observed total regulated Trihalomethanes were 0.0107 and 0.0093 mg/l, total regulated Halo-

acetic acids 0.52580 and 0.23774 mg/l, total halo-Acetonitriles 0.0269 and 0.0096 mg/l, total other-DBPs 0.1012 and 0.0409 mg/l and total chlorinated solvents 0.1440 and 0.1306 mg/l (for household and boiled household water respectively) which did not conform to Nigerian, USEPA, EU and WHO standards because the concentrations of lead, total THM_4, 1,1,2-Trichloroethane and total HAAs exceeded these standards' maximum permissible levels. Longitudinally, this investigation showed DBP formation is a consequence of disinfection after which the DBPs were first detected and in higher concentrations. First morning urine showed higher DBP concentrations than boiled drinking water triggering public health consequence beginning with increased excretion by the kidneys to maintain the homeostatic status of the body coupled with incidences of cancer, diseases of the kidney, liver, the reproductive systems and damage to the central nervous system. Statistically, observed concentrations were found to be significantly different between DBP groups ($F = 3.5115^*$) or highly significantly different among the groups ($F = 4.8582^{**}$) and HAAs ($F = 4.93^{**}$). Person's correlation coefficients (r) ranged from over 0.5 to 0.98 in over 85% of the analytes indicating a strong combination effects likely varying from additive to synergistic impacts in the body.

TABLE OF CONTENTS

	Description	*Page*
	Inside page	i
	Declaration	ii
	Certification	iii
	Acknowledgement	iv
	Abstract	v
	Table of Content	ix
	List of Figures	xii
	List of Tables	xiv
	Appendix	xv
	Abbreviations	xvi
	Definitions	xvii
	CHAPTER ONE	1
1.0	INTRODUCTION	1
1.1	Water resources and Transformation in the Environment	1
1.2	Water as a Life Support	2
1.3	Water Quality	3
1.4	Water Treatment.	5
1.5	Problem Statement	7
1.6	Justification	8
1.7	Objectives of the Study	9
	1.7.1 Specific Objectives of the study	9
1.8	Scope of the Study	10

	Description	*Page*
	CHAPTER TWO	11
2.0	LITERATURE REVIEW	11
2.1	Access to Potable Water	11
2.2	Wholesomeness of Drinking Water	12
2.3	Emergence of Disinfection By-Products in Drinking Water	12
2.4	Water Treatment and Disease Emergence	16
2.5	Health Effects of Disinfection By-Products	21
2.6	Water Quality of the Kubanni Reservoir	25
	CHAPTER THREE	27
3.0	MATERIALS AND METHODS	27
3.1	Administration of Study Questionnaire	27
3.2	Sampling	29
	3.2.1 Sample Collection	29
	3.2.2 Sample Preservation	30
3.3	Analyses of Samples	31
	3.3.1 Abridged USEPA and Standard Methods Analytical methods	32
	3.3.2 Gas Chromatography System	36
	3.3.3 Analytical Standards	37
3.4	Ahmadu Bello University Water Treatment Plant	37
	CHAPTER FOUR	41
4.0	RESULTS AND DISCUSSIONS	41
4.1	Questionnaire Analysis	41

	Description	*Page*
	4.1.1 Development of the Surveyed Water treatment Plants	41
	4.1.2 Common Facilities and Processes Available in Treatment the Plants	43
	4.1.3 Intake and Production units of the Treatment plants	48
	4.1.4 Size and Operation of the Distribution Systems	52
	4.1.5 Laboratory Services and Disinfection Process	56
4.2	General Chemical Properties of the Ahmadu Bello University treated drinking water	46
	4.2.1 General Chemical Properties of ABU treated Drinking Water	62
	4.2.2 Concentration of Heavy Metals in ABU treated Drinking water	67
4.3	Disinfection by-Products in A. B. U. treated water samples	51
	4.3.1 Halo-alkanes	71
	4.3.2 Acetonitriles	88
	4.3.3 Other Disinfection By-Products	91
	4.3.4 Chlorinated Solvents	98
4.4	Halo-Acetic Acids	105
	4.4.1 Monobromoacetic acid	117
	4.4.2 Dichloroacetic acid	117
	4.4.3 Trichloroacetic acid	118
	4.4.4 Dibromoacetic acid	119
	4.4.5 Bromochloroacetic acid, Bromodichloroacetic acid and Chlorodibromoacetic acid	122
	4.4.6 Tribromoacetic acid	123
	4.4.7 2,3-Dibromopropionic acid	123
	4.4.8 Dalapon (2,2-Dichloropropionic acid)	124

	Description	*Page*
	CHAPTER FIVE	129
6.0	SUMMARY, CONCLUSION AND RECOMMENDATIONS	129
6.1	Summary	129
6.2	Conclusion	134
6.3	Recommendations	136
	REFERENCES	139
	APPENDIX	145
	Study Questionnaire Administered to the Surveyed Water Treatment Plants	145

LIST OF TABLES

	Description	*Page*
Table 4.1	Development of the Surveyed Water Treatment plants	42
Table 4.2	Component Facilities and Processes of the Surveyed Treatment Plants	44
Table 4.3	Intake and Production Units of he Surveyed Water treatment Plants	50
Table 4.4	Size and Operations of the Distribution Systems	54
Table 4.5	Laboratory Services and Disinfection Process	57
Table 4.6	Mean Values of General Chemical Properties of Conventionally Treated water from the A. B. U. Water Treatment plant	65
Table 4.7	Mean Concentration of Heavy Metals in the Conventionally Treated Water from A. B. U. Water Treatment plant	68
Table 4.8	National and International Drinking Water Quality Standards	72
Table 4.9(a)	Mean Levels of Halo-alkanes, and Acetonitriles, in Drinking Water supplies from the A. B. U. Water works and Resulting Urine	57
Table 4.9(b)	Mean Levels of *other* DBPs and Chlorinated Solvents in Drinking Water supplies from the A. B. U. Water works and Resulting Urine	83
Table 4.10	Total Mean Levels of THMs, Acetonitriles *other* DBPs and Chlorinated Solvents obtained from Treated Drinking Waters and Urine Samples	94
Table 4.11	Analysis of Variance (ANOVA) Table of obtained Mean Levels of THMs, Acetonitriles, *other* DBPs and Chlorinated Solvents	104
Table 4.12	Total Levels of Haloacetic acids in Sampled Drinking Water from the A. B. U. Water Treatment Plant and First Morning Urine Samples	115
Table 4.13	Table of Observed Means of Halo-acetic acids in Sampled ABU Treated Drinking Water and Urine Samples	115
Table 4.14	ANOVA Table of the Observed levels of Haloacetic acids in the drinking water and Urine Samples	126
Table 4.15	Table of Correlations	127

LIST OF FIGURES

	Description	*Page*
Fig. 3.1	Schematic Diagram of ABU Drinking Water Treatment Plant and Distribution System showing Sampling Points	28
Fig. 4.1	Gas Chromatograms of THMs, Acetonitriles, *Other* DBPs and Chlorinated Solvents in A.B.U. treated water after chlorination	77
Fig. 4.2	Gas Chromatograms of THMs, Acetonitriles, *Other* DBPs and Chlorinated Solvents in A. B. U. treated water in the Booster station	78
Fig. 4.3	Gas Chromatograms of THMs, Acetonitriles, *Other* DBPs and Chlorinated Solvents in Household A.B.U. treated water	79
Fig. 4.4	Gas Chromatograms of THMs, Acetonitriles, *Other* DBPs and Chlorinated Solvents in Household Boiled A.B.U. treated water.	80
Fig.4.5(a)	Gas Chromatograms of THMs, Acetonitriles, *Other* DBPs and Chlorinated Solvents in First Morning Urine (FMU) samples of some Area 'E' No. 20 Household occupants	81
Fig. 4.5(b)	Gas Chromatograms of THMs, Acetonitriles, *Other* DBPs and Chlorinated Solvents in First Morning Urine (FMU) samples of some Area 'E' No. 20 Household occupants	82
Fig. 4.6	Gas Chromatogram of Haloacetic acids in A. B. U. treated water samples after Chlorination	107
Fig. 4.7	Gas Chromatogram of Haloacetic acids in A. B. U. treated water samples from the Booster station	108
Fig. 4.8	Gas Chromatogram of Haloacetic acids in Household A. B. U. treated water samples (Area 'E' House No. 20)	109
Fig. 4.9	Gas Chromatogram of Haloacetic acids in Household Boiled A. B. U. treated water samples	110
Fig. 4.10	Gas Chromatogram of Haloacetic acids in Dad's First Morning Urine (FMU) samples from the Household level (Area 'E' House No. 20)	111
Fig. 4.11	Gas Chromatogram of Haloacetic acids in Mom's First Morning Urine (FMU) samples from the Household level (Area 'E' House No. 20)	112

	Description	*Page*
Fig. 4.12	Gas Chromatogram of Haloacetic acids in Son's First Morning Urine (FMU) samples from the Household level (Area 'E' House No. 20)	113

APPENDIX

	Description	*Page*
Appedndix I:	Questionnaire for Water Treatment Plants on Code Of Practice	138

ABBREVIATIONS

ABU	-	Ahmadu Bello University
ANOVA	-	Analysis of Variance (table)
CDBPs	-	Chlorine or Chlorinated Disinfection By-Products
DBP	-	Disinfection By-Product
DBPs	-	Disinfection By-Products
Df/df	-	Degree(s) of freedom
EU	-	European Union
F	-	Fisher's F (value) in F – Test
FMU	-	First Morning Urine
HAA(s)	-	Haloacetic acid(s)
MCL(s)	-	Maximum Contaminant Level(s)
MCLG(s)	-	Maximum Contaminant Level Goal(s)
oDBPs	-	Other Disinfection By-Products
r	-	Correlation (Spearman's) coefficient
THAAs	-	Total haloacetic acids
THM(s)	-	Trihalomethane(s)
$TTHAA_5$	-	Total of five priority/regulated haloacetic acids
$TTHM_4$	-	Total of four priority/regulated halomethanes
TTHMs	-	Total tri-halomethanes
US	-	The United States of America
USEPA	-	United States of America Environmental Protection Agency
WHO	-	World Health Organization
ACGIH TLV	-	American Conference of Governmental and Industrial Hygienists' threshold limit value expressed as a time-weighted average; the concentration of a substance to which most workers can be exposed without adverse effects.

DEFINITIONS

Bioaccumulation: The gradual build-up of materials which exist in the environment that are consumed by man. The build-up may occur in the tissues or organs of the body, where they can be easily absorbed and re-used or metabolised.

Carcinogen: A substance which induces cancer in a living organism.

Disinfection By-Products: Potentially harmful chemical products formed from the reaction between the disinfectant(s) used in the water treatment process and materials found in the treated water which normally do not pose any serious risk to health

Disinfection: The use of chemical(s) (disinfectant(s)) in the drinking water treatment process to kill or remove most or all causative agents (microorganisms) of infectious water borne diseases such that the ultimately treated drinking water is wholly safe from such infectious diseases.

Excretion: The process of the body getting rid of metabolic wastes and other substances toxic to the body when they are in large quantities. It is a way by which the body maintains suitable concentration of solutes and amount of water in the body fluids.

Genotoxicity: This is a measure of the ability of a substance to damage the genetic materials of an organism. The Ames Salmonella mutagenicity assay is used for genotoxicity testing because it is capable of detecting point mutations within a short time.

Heavy metals: Loosely defined group of metals mostly transition metals that exhibit metallic properties. Many definitions have been proposed, some based on density, atomic weight, atomic number, some chemical properties or toxicity. Heavy metals occur naturally in the ecosystem with large variations in concentrations

Homeostasis: The tendency for the internal environment of the body to be maintained constant. Mostly referring the internal body fluids with respect to their ionic balance.

Maximum Contaminant Level Goal(s): As contained in the United States of American Safe Drinking Water Act, (1974) and its subsequent amendments, This is the maximum level(s) of a contaminant(s) in drinking water at which no known or anticipated adverse effects on health effects of persons would occur, and which allows for an adequate margin of safety. MCLGs are non enforceable public health goals

Maximum Contaminant Level(s): According to the SDWA and its amendments It is maximum permissible level of a contaminant in drinking water which is delivered to any user of a public water system. The MCLs are enforceable

standards. The margin of safety in MCLGs ensure that exceeding the MCL slightly does not pose significant risk to public health.

Maximum Permitted Levels: This is the highest amount of contaminant allowed in treated drinking water under the Nigerian National Drinking Water Standards.

Mutagenicity: This is a measure of the ability of an organism to change in its characteristics by the alteration of its hereditary materials.

Water quality: This is a measure of the physical, chemical and biological characteristics of water relative to the needs of one more biological species including human needs or purposes. Relative to these human needs are the acceptability of the water on the basis of the defining qualities or characteristics.

CHAPTER 1

INTRODUCTION

Drinking water is a fundamental requirement of the human body that cannot be replaced. Good quality drinking (potable) water is primarily sourced from rainfall or from surface water sources such as streams, rivers, springs, and lakes. Where these surface waters do not exist or where they exist in quantities that cannot adequately support the dependent populations, ground water resources are exploited in the form of wells and boreholes to provide this vital body requirement necessary for the survival of the dependent populations. As a result water has and continues to be the centre of ancient and present day civilizations.

1.1 Water Sources and Transformation in the Environment

Globally, water occupies about 75% of the earth's surface. Freshwater (surface water) resources are limited to less than 30% of the earth's hydrosphere, making potable water still more limiting (Michael, 1987; Schoeny, 2010). Rainfall is the primary source of water. Before present day developments and in some rural areas in developing countries, rain water is still relatively very clean and it is directly abstracted for drinking and used for other domestic purposes without any significant consequence. Rainwater flows into streams, rivulets, rivers and lakes which are referred to as surface water sources. Also, under heavy and sustained rainfall, rainwater ponds on the ground and slowly infiltrates and percolates through layers of porous strata until it reaches impervious stratum where it forms pools to become ground water (Microsoft Encarta 2007). Globally, all sources of water are inter-related in a continuous circulation known as the hydrological cycle in which surface water, ground water, seas and oceans

are influenced by meteorological interactions like evaporation, transpiration and edaphic movements (infiltration and percolation). The water environment - including the oceans, rivers, streams, groundwater, all seas and adjacent coastal areas - forms an integrated whole that is an essential component of the global life-support system. Recent climatic changes have resulted in extreme conditions of floods, landslides and droughts, which have in some regions become disastrous in their consequences (UNU, 2001).

1.2 Water as a Life Support and other Uses

Water is very vital to all living things, plants and animals alike. It is a precondition for human, animal and plant life as well as an indispensable economic resource. Water also plays a fundamental role in climate regulation (WISE, 2011). From the point of view of use, water is a renewable but finite resource already stressed by the demands of today's global population. With increasing global population of over 6 billion people, the stress becomes alarmingly increasing. Water is needed by the populace for food preparation, drinking, washing, bathing, swimming and for agricultural production in irrigation schemes and industries for production processes and to cool production machineries. It is evident therefore that water is one of the most basic and critical components of human life. Such water is mostly of the freshwater resources which are essential components of the earth's hydrosphere and an indispensable part of the terrestrial ecosystems.

Potable water becomes still more limiting because of rapid eco forest destruction and aggravated pollution of water resources in many world regions, widespread water scarcity, global climate change, and the progressive encroachment of incompatible human activities on the world's hydrosphere (Microsoft Encarta 2001; UNU, 2001).

Also, it is now very obvious that while many surface water bodies are becoming over tapped demanding inter basin transfer of water, groundwater resources are also being over pumped in many parts of the world leading to landslides and faults. Inadequate water supplies are threatening human health, agricultural production, environmental quality and regional stability in many regions of the world. In addition to this, there is increasing pollution of freshwater bodies by anthropogenic activities (Michael, 1987; Marr and Cresser, 1987; Postel, 2000; Microsoft Encarta 2001; Porter, 2002). As a result, a range of water crises in water quality and quantity, have been triggered, and as such water must be collected and distributed with increasing care. It is against this background that chapter 18 of Agenda 21 of the Rio De Janeiro Conference on climate change in 1992 set a high priority on the protection of water resources from depletion, pollution and degradation, through climate change and the sophisticated practices of man that produce complex wastes which mostly end up in water bodies (Porter, 2002).

1.3 Water Quality

Due to high level of industrialization in many cities and towns worldwide, recently, rainwater has become generally laden with gaseous contaminants such as sulphur oxides, nitrogen and carbon oxides and hydrocarbon particulates (from vehicular emissions) among others. As a result, rainwater nowadays is so acidic and loaded with other contaminants that it is unsuitable for natural and anthropogenic uses like drinking and is capable of causing injury and damage to the body physiology of man if consumed in that form. Even amenities are not spared of the resulting high degrees of degradation (through corrosion) due to this contaminated rain water. Surface waters experience pollution from influx of sewage, particulates, domestic, agricultural and industrial wastes including microbes, groundwater usually in its course dissolves soluble minerals and organic materials as it percolates into the ground. Depending on

the level of these contaminants entering the surface and sometimes ground water, Marr and Cresser, (1987), identified four categories of rivers and streams as Classes I - IV which are in the order of increasing contamination (pollution). While class I rivers/streams are very mildly polluted and do not constitute any risk to any living organism in it, and use of the water, class IV rivers/streams are so grossly polluted that they can hardly be of any use to living resources except after remediation. These pollutants do not only make water impure but also modify its properties including its capacity to spread diseases. Most importantly, the microbial contaminants of drinking water sources have continued to pose the greatest of health challenges in view of water borne diseases which have been identified to be among the five causes of morbidity and mortality in developing countries like Nigeria (Reiff, 1995). Furthermore Snyder and Merson (1982) had noted that in developing countries, 875 million annual cases of diarrhoeal are reported with 4.6 million deaths. Furthermore, Reiff, (1995) reported that between 1st January 1991 and 30th December 1993, in developing countries, there were more than 950,000 cases of cholera with more than 9,000 deaths. With this picture, disinfection in public water supply is the most important step in drinking water treatment. It is considered by many as one of the public health triumphs of the 20th century especially among developing countries which have considered it as their main barrier against the transmission of water borne diseases. Even when it became known that products of disinfection are implicated in disease occurrence, the developing countries strategized that microbial safety take precedence over associated health risk of Disinfection By-Products (Reiff, 1995; Schoeny 2010). Many water treatment techniques have evolved over the years resulting in different quality drinking waters

Because treated drinking water quality does vary widely from source to source, the Standards Organization of Nigeria, EEC, Canadian Department of the Environment and

the U.S. Public Health Service and Drinking Water Division of the USEPA have established certain standards for drinking water. Similar water quality standards have been established by many states and by the World Health Organization. In drinking water supply, these standards set the maximum concentration of contaminant chemical compounds and bacteria that can be safely allowed in treated drinking water,(Microsoft Encarta, 2001)..

1.4 Water Treatment

It is evident that most surface water sources contain biological and chemical contaminants, a situation that is exacerbated by the universal solvency of water which allows it to dissolve most things to some extent. The knowledge that these contaminants could be injurious to health dates back into history. This has made it expedient to treat water from surface sources and sometimes ground sources before use for drinking purposes. Efforts were made, even in the pre-historic times to rid drinking water of these contaminants leading to the introduction of various treatment strategies like the use of hot metals and solar energy to heat water to rid it of contaminants. Later measures included boiling and filtration with linen to kill the disease causing microorganisms and to remove the suspended materials respectively (USEPA, 1990b). For large community water supply schemes, these methods have been modified by the use of screening methods to remove floating objects in the water. Also, flocculating and precipitating agents are now mixed with the water to remove suspended organic matter. Next is the addition of slaked or hydrated lime to remove the excessive hardness of the water (if any). The aeration process removes the undesirable tastes that may be present in the water.

Subsequently, the water undergoing treatment is subjected to the disinfection process which results in the destruction of disease causing organisms in drinking water sources. There is primary disinfection and secondary disinfection. While primary disinfection refers to part of the treatment process that provides the necessary inactivation of *Gardia* cysts, bacteria, and viruses in source water, secondary disinfection refers to maintenance of disinfection residual which prevents the regrowth of microorganisms in the water distribution system. Of the methods of disinfection, chlorine gas is the most common, than the use of ultraviolet radiation, chlorine dioxide, calcium and sodium hypochlorite as well as ozone.

Under certain conditions, chlorine can combine with remaining organic materials such as humus, fulvic acids and amides in water to produce potentially harmful by-products generally referred to as disinfection by-products – DBPs among which are trihalomethanes (THMs),. THMs have been implicated in liver and kidney defects, which have been observed in rats, mice and dogs as well as decreased immune system functions in mice, when fed with water containing THMs (USEPA, 1990c).

Complex chemical reactions occur when chlorine is added to water especially if the water contains dissolved organic matter but these reactions are not always obvious. Chlorine odour or taste in finished water is sometimes as a result of too little chlorine in water rather than too much. Chlorine reacts with any substance that exerts a chlorine demand -Impurities that increase chlorine demand include natural organic materials, sulphides, ferrous iron and nitrites (Microsoft Encarta, 2007; USEPA, 1990b). Chlorine can also combine with ammonia and other nitrogenous compounds called *combined available chlorine residual.* The unreacted chlorine that remains in the water after any combined residual is formed is called *available chlorine residual.* The free chlorine is

more active than the combined available chlorine, but free chlorine is not available unless the chlorine demand of raw water is satisfied. When chlorine dosage exceeds the *break point,* that is, the point at which chlorine demand is satisfied additional chlorine will result in free available chlorine residual. The chlorine dosage needed to produce a free residual varies with the quality of the raw water source (USEPA, 1990b).

1.5 Problem Statement

Unsanitary conditions prevalent in our environment have been found (Clark, et al, 2001; Craun and Calderon, 1998; 2001) to be strongly linked to the incidences of water borne diseases. Even in most developed economies where the purification systems operate at very high levels of efficiency, there are occasional outbreaks of biological contaminants in drinking water supplies as in the outbreak of c*ryptosporidiosis* in Milwaukee, in the U.S. A. (USEPA, 1997a; 1999). Apart from the contaminant micro-organisms, the process of conventionally treating drinking water generate products which react with themselves and other constituents (which on their own do not pose hazards to human health) after the routine processing in the treatment works, to produce materials which have health implications. These products include Disinfection By-Products (DBPs) such as Trihalomethanes (THMs), which include chloroform, bromodichloromethane, bromoform, dibromochloromethane; Haloacetic Acids (HAAs) such as mono-, di-, and Trichloroacetic Acids and mono-, di- and Tri-Bromoacetic Acids; and Haloketones based on the use of chlorine as a disinfectant. In addition, volatile organic compounds (VOCs) like chlorinated solvents are likely products of disinfection are produced. Among these are, Trichloroethylene, Carbon tetrachloride, Vinyl chloride, 1, 2-Dichloroethane, Benzene, 1,1-Dichloroethylene and 1,1,1-Trichloroethane. Disinfectants and their residual fractions such as chlorine, hypochlorous acid, and hypochloric acid are also sources of worry when chlorine is

used as a disinfectant as in most of our treatment works (Stevens, *et al* 1989; USEPA, 1990b). Some metals are generated in the water stream obtained after purification such as metallic lead, Iron, Zinc, Copper and Chromium are among the undesirables in drinking water as are anionic products like Sulphates, Nitrates, fluorides and chlorides. While these may not necessarily constitute primary contaminants in the water source they are considered to be secondary contaminants because some are present after purifying water. Some of the products are known to have carcinogenic and mutagenic effects (Stevens, *et al* 1989; USEPA, 1990b; 1990c; 2011a; 2011b) and are therefore likely to be injurious to health. The continued occurrence of water borne diseases demonstrates that contamination of drinking water with pathogenic bacteria, viruses and parasites still poses a serious health risk when treatment is inadequate or when contamination occurs in the distribution system (USEPA, 1997).

There is no proper regulatory body monitoring Nigeria's drinking water quality although it is part of the wide and loose mandate of the Water Quality Department of the Federal Ministry of Water Resources and the State Water Agencies. This creates a dearth of relevant information on the status of the drinking water in the country. As a result, there is the lack of proper supervision of the water treatment works to ensure compliance with the code of practice in the industry.

1.6 Justification

Chlorine is capable of combining with dissolved organic matter in water. In the disinfection process in potable water treatment, chlorination is one of the cheapest means of destroying biological contaminants. Considering that our raw water sources are prone to exposure to several organic contaminants from waste disposal and other sources among others into water bodies, significant proportions of some of these

organics remain in the ultimately treated water to combine with chlorine and other compounds used for disinfection. As a result, our conventionally treated water contain these disinfection by-products like chlorine disinfection by-products such as trihalomethanes, other haloalkanes, acetonitriles, chlorinated solvents and haloacetic acids. These products are known to have serious health implication. The study would also provide empirical information on the levels of contamination that remain in conventionally treated water under Nigerian environmental conditions. Such will constitute a basis for advocacy for an appropriate agency of government to supervise water treatment. It would also form the basis for the update of existing legal standards enacted by the Standards Organization of Nigeria (SON, 2007) for drinking water quality to ensure appropriate protection of persons from exposure to health hazards through the consumption of treated drinking water containing chlorination by-products.

1.7 Objective of the Study

The general objective of this study is to determine the quality of drinking water from the Ahmadu Bello University Water Treatment plant under the operating code of practice in Nigerian water treatment plants especially in relation to the general chemical properties, the presence or otherwise of Disinfection By-Products, and heavy metals.

1.7.1 Specific Objectives

The specific objectives of this study are:

(i) Assessing the operating code of practice at the A. B. U. Water treatment plant to ascertain its conformity with the practices in selected municipal water treatment plants in Northern Nigeria such as Zaria, Kaduna, Kano, Gusau, Katsina, Minna, Sokoto, Birnin Kebbi and Jos (Shen)

(ii) Determining the General Chemical properties and the heavy metal content of the treated drinking water from the Ahmadu Bello University water treatment plant.

(iii) Determining the types and levels of disinfection by-products present in the treated water.

(iv) Examining the public health implications of the presence of the by-products of disinfection.

1.8 Scope of the Study

The study concentrates on the Ahmadu Bello University Drinking Water Treatment plant for detailed assessment of the chemical properties of its conventionally treated drinking water especially in relation to the occurrence and levels of Disinfection By-Products in the treated water consumed by the university populace. The evaluation of the operating code of practice however covers other nine selected municipal drinking water treatment works in Northern Nigeria to provide information on the levels of uniformity of the drinking water treatment processes. This study is limited to the drinking water produced by the Ahmadu Bello University water treatment plant only. Comparison to other water treatment plants in Northern Nigeria is only for the assessment of the similarity or otherwise of the water treatment processes. This study did not intend to extrapolate the results of analyses of the ABU water treatment to these plants in terms of their water quality and levels of DBPs. This study is not in any position to medically diagnose and examine the types of diseases associated with DBPs other than the potential health effects associated with long time exposure already documented in literature.

CHAPER 2

LITERATURE REVIEW

2.1 Access to Potable Water

The United Nations Committee on Economic, Cultural and Social Rights in 2002, on behalf of the United Nations took the unprecedented step of agreeing on a General Comment on water as a human right by declaring that water is fundamental for life and health, and that the human right to water is indispensable for leading a healthy life in human dignity as it is a prerequisite to the realization to all human rights. By this, therefore, safe and secure drinking water is a human right as declared for the first time on the 4th of December 2002 that water should be treated as a social and cultural good, and not primarily as an economic commodity (ENS, 2002). Immediately 147 countries ratified this convention and as such accepted that they have a constant continuing duty to progressively ensure that everyone has access to safe and secure drinking water and sanitation facilities equitably and without discrimination. But, by the 5th Annual Water for the Poor Act 2009 report, released by the US States' Department late 2010, only 17.2% of Nigerians have access to pipe borne water in the country that is the 6th largest producer of crude oil in the world (Nwokeoma, 2011). Since water naturally and anthropogenically contains contaminants, various treatment processes have been devised to purify water including coagulation, flocculation, sedimentation, filtration disinfection and residual disinfection (USEPA, 1990b; Vrijenhoek, *et al,* 1998). Meanwhile, some 1.1 billion people lack access to safe drinking water and as the global population climbs up from 6 to 8 billion people, 38 per cent (3 billion people) will live in water stressed countries (Postel 2000).

2.2 Wholesomeness of Drinking Water

The recharge of surface water usually abstracted for drinking washes solutes in the dissolved and partially dissolved forms into the receiving surface water sources. Nitrates are among the first of these contaminants to be washed into the water because of high mobility of nitrate nitrogen. Subsequently, nitrates and particulates rich in essential nutrients like phosphates which are partially soluble are washed into the surface waters likewise. So nutrients as contaminants, enter into surface waters to cause eutrophication (Tisdale and Nelson, 1993; Mason, 2002). The United States of America had been among countries in the forefront of ensuring the delivery of safe water to its populace, a situation that had seen the enactment of various laws to ensure compliance in the supply of wholesome potable water. Among such legislation is the Safe Drinking Water Act (SDWA) of 1974 with its 1986 and 1996 amendments and the Surface Water Treatment Rule which came into effect in December 1990 (Cox, 1997; Clark and Thurnau, 2001). They further acknowledged that in compliance with SDWA, one would require to identify the trend in compliance with the Total Trihalomethanes (TTHM) Rule, nitrate rule, coliform rule and number of violation of the Maximum Contaminant Levels (MCL) rules of treatment works. According to the United States Environmental Protection Agency (USEPA, 1999), the number of community treatment works in violation of the SWTR increased from 10 in 1991 to 1,500 (amounting to 14% of community treatment systems) in 1994 and reduced to less than 1000 in 1998. In that report, (USEPA, 1999), observed that affected populations ranged from 140,000 in 1991 to 26 million in 1994, which decreased to 18 million in 1998.

2.3 Emergence of Disinfection By-Products in Drinking Water

According to Wigle (1998), chlorine was discovered in 1774 but was first used in the disinfection process by Semmelweis at a maternity ward of a Vienna hospital in 1864 to

clean hands to prevent perpetual fever. He further noted that it was first continuously used in the United States of America (USA) in 1904 for water supply to New Jersey and at a site that served the Chicago stockyards to control sickness in livestock caused by sewage contaminated water. His observation included the fact that chlorination has been the main method of disinfecting water in the United States, Canada and many other countries for many decades and it has proved to be very effective against most water borne disease pathogens. Chlorine pellet feed and the gas feed are the cheapest form of disinfecting water for drinking purpose with average total and operating costs of $0.26 and $0.23 per 3,785 litres respectively computed at capital cost annualised at 10 per cent interest over 20 years plus operation and maintenance costs with average flow assumed at 50 per cent of designed flow (USEPA, 1990b) as against $0.33, $0.49 and $0.53 for hypochlorous solution. But among the factors which are important to successful chlorination are the concentration of free chlorine, the contact time, the temperature, pH and turbidity levels (USEPA, 1990b). In view of these, chlorination process has been identified as one of the greatest public health achievement of the twentieth century and provides the greatest safeguard to the menace of water borne diseases (Keiff, 1995; Schoeny, 2010). Despite this economic advantage over other disinfectants, the use of chlorine has the added advantage of a variety of possible application points. It is also appropriate as a primary and secondary disinfectant but it produces halogenated by-products which are harmful potentially, conflict with corrosion and controls pH levels when used as a secondary disinfectant (USEPA, 1990a).

Clark and Thurnau (2001) reported that while chlorine has wide ranging successes in the control of bacteria and viruses, even in its residual levels in the distribution systems, it has limited control of parasites like *Cryptosporidium spp*. They reported that ozone however is most generally effective as a disinfectant but is beset with the difficulty of

maintaining a residual in the distribution system due to its high reactivity. Clark and Thurnau (2001) also identified that the TTHM rule and Nitrate rule recognized that disinfectants form total trihalomethanes when natural organic matter in water reacts with the disinfectants and that these disinfectants by-products (DBPs) have potential chronic health effects.

According to Fox and Lytle, (1996) and Okun *et al*, (1997); treatment plants which meet all the Surface Water Treatment Rule (SWTR) requirements of the Safe Drinking Water Act (SDWA) are still vulnerable to the microbial breakthrough as was experienced in the Cryptosporidiosis outbreak in Milwaukee in 1993 due to the inadequacies of chlorine. Hence, Source Water Protection as recognized by the 1996 amendment to the SDWA was identified as one very vital method of controlling DBPs and microbial contaminants (Borst, *et al*, 2001).

Surface water as earlier reported is usually loaded with organic debris and their decomposition intermediate products. These act as precursors for the formation of Trihalomethanes (THMs) one of the halogenated by-products. Vrijenhoek *et al* (1998) however, further observed that a modification of coagulation process - called enhanced coagulation removes the organic matter and its decomposition intermediates which acts as a precursor to THMs and removes suspended particles that cause turbidity including the THMs precursors using salt coagulants (alum at doses of 20 - 60 mg/L) or adjusts the pH (to 5.5) of the source water or both. LeChevallier, (1999) noted that the cost of chlorine and its efficacy, which dramatically decreased water related diseases had led to its widespread use in water treatment in the US but creates concerns as a result of disinfection by-products and the chlorinous tastes and odours. Rather than this causing the elimination of secondary disinfections in drinking water treatment LeChevallier,

(1999) further made a case for its continued use as it helps to limit regrowth of microorganisms and inactivates microorganisms that may enter the system through contamination. He therefore suggested that in the meantime a balance be maintained between the dual objective of effective disinfection and aesthetic water quality. He reported that from European perspectives some countries are legally required to disinfect their surface and ground water supplies to minimize biofilm formation and the occurrence of animalcules (protozoans) to prevent recontamination. Others are to indicate where contaminations had occurred while others do not need to disinfect or maintain a disinfectant residual in order to avoid the formation of disinfection by-products or simply because the distribution system is well maintained. His report further indicated that other countries maintain a balance between these two for drinking water. However, the then 15 member EU community are guided by the 1980 Approved Drinking Water Directive that was implemented in 1985. This Directive does not strictly mandate water supplies to be disinfected but it does set microbial, physical and chemical standards that must be met in water produced for human consumption (Hydes, 1999). Furthermore, this new Directive sets mandatory standards for *Escherichia coli* and *Entercocci* and non-mandatory parameters for *Clostridium perfrigens,* total coliforms, and total bacteria. In addition, Hydes (1999) reported that the EU also established mandatory limits for DBPs as well as required its member states to ensure that their water suppliers meet the requirement to keep clean, safe drinking water flowing. While existing surface water treatment guidance manual can over predict the disinfection dosages required for a utility to inactivate pathogens because of conservative assumptions regarding contact basin hydraulics, disinfectant concentrations and the rate at which pathogens are inactivated, some revolutionary design framework known as the Integrated Disinfection Design Framework (IDDF) can now more accurately predict

pathogen disinfection and the formation of disinfection by-products because it incorporates the water utility particular conditions into the calculation of disinfection effectiveness (Bellamy, 2000).

2.4 Water Treatment and Disease Emergence

On the effect of spent filter backwash recycle on *Cryptosporidium oocytes,* turbidity and particles removal Cornwell *et al*, (2001) concluded that conventional treatment may be adequate for the removal of *Cryptosporidium* introduced to raw water from recycle but the removal of solids from the spent filter backwash may be warranted. Thus, an understanding of the ability of conventional sedimentation and filtration processes to handle the increased particle and cyst loading that occur when spent filter backwash recycle is used, enables utilities to determine the level of recycle necessary within their treatment systems. Craun and Calderon (2001) reported that distribution system contamination has resulted in a significant number of water borne disease outbreak in the United States due to chemical and microbial contamination from cross connections and back siphonage. They reported that these are due to lack of adequate water pressure throughout the distribution system, presence of old and leaky water mains, inadequately monitored and maintained residual disinfectant level, lack of cross connection control programme, inadequate routine inspection of storage facilities and low corrosion control efforts. Also, Jakubovics, (1998) and Le Chevallier (2000) had observed that such loss in pressure in the distribution mains and contamination through distribution failures encourages the growth of biofilms, which are collections of organic, and inorganic, living and dead materials collected on a surface like pipe surfaces. They include bacteria among the varieties of microorganism content and can trap viruses and parasites like cryptosporidium in the biofilms. According to them, these biofilms undergo many transformations like decomposition of the dead remains, and propagation of diseases by

the component bacteria that are pathogenic. Earlier, Craun *et al* (1998) had observed that even though outbreak of *cryptosporidiosis* can occur if *oocysts* are present in a water supply, the presence of *oocysts* does not mean an outbreak will occur. This underscores the author's suggestion that the role of protective immunity - which may be acquired through low level sporadic exposure to *cryptosporidium parvum* in drinking water - be considered in assessing water borne *cryptosporidiosis* risk. Antherholt *et al,* (1998) had noted that as with other faecally derived microbes, rainfall appears to increase concentrations of *Gardia* and *Cryptosporidium* through its effects on the amount of particulate matter in the water. They further reported that there may be a link between *Cryptosporidium* and *Gardia* concentrations' peak and when, for instance, turbidity reaches its highest level. Tracking indicators of microbiological quality such as heterotrophic plate counts, coliform enumerations, total direct counts, and fixed bacterial biomass during five time periods both before and after the distribution system was supplied with nanofiltered water, showed that nanofiltration offered several benefits such as enabling the application of chlorine at lower concentrations, and improvement of bio-stability of the treated water in the distribution system, (Laurent, 1999). An American Water Works Association (AWWA) Committee Report (1999) on Emerging Pathogens, observed that four bacteria have gained increased importance in the cause of water related diseases even though they have not been well known by water treatment plants managers. Of these four bacteria, *Mycobacterium avium* complex, (MAC), *Helicobacter pylori,* pathogenic *Escherichia coli* and *Camylobacter jejuni,* MAC is given the highest priority because it is widely distributed and it can cause serious illness, resist disinfection and regrow in biofilms in the distribution system. On the other hand, *H. pylori* was ranked of moderate concern, since it is common in humans and causes illness. Like the bacteria, the. committee also reviewed emerging pathogens - Viruses, protozoa, and algal

toxins as being among the six important pathogens documented in water. The caliciviruses, particularly Norwalk virus, entero viruses, and hepatitis virus and the protozoans *Cylospora microsporodia* and *Taxoplasma gondii* and cyanobacteria toxins among which none has been found to be considered as of great concern, while Norwalk virus and other caliciviruses, *Cyclospora, microsporidia* and algal toxins are rated of moderate concern (AWWA, 1999a,b). These are further emphasizing the need for disinfection in the treatment process.

As more stringent regulatory controls come into force with more information becoming available on the health impact of the various chemicals present in drinking water sources the maximum contaminant levels (MCLs) for each contaminant will always be reviewed on the downward side compelling water treatment managers and owners to incorporate additional processes to remove more of each contaminant. Arsenic and nitrate which are among the most known devastating child's health drinking water contaminants can be routinely removed below Maximum Contaminant Levels (MCL) of *2mg/L* and 10 mg(N)/L respectively using sulphate selective resins - a process which is also considered to be a least cost alternative at many treatment plants (Ghurye *et al*, 1999). This is because the two birds (arsenic and nitrates) can be efficiently removed with one stone (ion exchange).

Schoeny (2010) noted that disinfection is one of the major triumphs of the 20th century in public health worldwide and for more than 30 years it has been known that chlorination as a disinfection process produce several products which produce cancer in animals. But Lipscomb (2000), while acknowledging that the goal of extrapolating toxicity dose response data to predict adverse effects on human health is to use the best available data on toxicity in the risk assessment, noted further that this is made complicated by the

many factors including human exposure to low concentrations of these chemicals in treated drinking water. Also is the question of whether these critical effects will manifest in humans or not. According to USEPA (1990c), the acute toxicity of chlorine in amounts in drinking water appears to be relatively low, but additional chronic data are inconclusive on issues concerning chlorine's carcinogenicity or cardiovascular toxicity. Of the THMs, Chloroform has been most documented in toxicity. It has been implicated in the carcinogenicity in rats and mice. The National Cancer Institute in the US reported increased incidence of kidney tumours in male and female rats and mice on exposure to chloroform in drinking water (USEPA, 1990c). Lipscomb (2000) however noted further that while epidemiological evidence exist linking DBPs with potential health outcomes of concern such as cancer, reproductive and development effects, weak moderate association has been identified between low birth rate and consumption of chlorinated water, between spontaneous abortions and bromodichloromethane exposure and between neural tube defects and exposure to THMs. He noted further that due to uncertainty and scarcity of human data, information on reproductive and human development toxicity and carcinogenicity data from peer reviewed animal studies were used to estimate health effects.

According to Clarke and Thurnau (2001), chloroform was the first of the disinfection by-products to be discovered by Rook, in 1974 and Bellar and Lichtenberg also in 1974 almost simultaneously from the interaction between disinfectant chlorine and natural organic matter in water. By 1989, over 500 disinfection by-products had been discovered through bench scale studies of the chlorination of natural water and humic spiked water using extraction capillary column chromatography with mass special analytical procedures (Steven *et al*, 1989; USEPA, 2011b). Of these, only eleven are regulated under the Safe Drinking Water Act of (1974) as modified up to 1986.

According to Owens (2001), these amendments were ambitious, establishing standards setting deadlines and requiring promulgation of enforceable maximum contaminant levels (MCLs) and non-enforceable maximum contaminant level goals (MCLGs) for 85 contaminants in 3 years, 9 within 12 months and at least 40 more within 24 months. On a comparison of the types and magnitude of disinfection by-products under different disinfection conditions, Goslan *et al* (2009) reported that treatment plants using chloramine find it easier to meet the EU THM regulatory limit of 100 microgram /l than those using the chlorine disinfectant because of the volume of these DBPs when using chlorine. Similar works by Bougeard *et al* (2010) also observed that monochloroamination resulted in lower concentration of DBPs except 1,1-dichloropropanone and noticed that the concentration of THMs correlated well with HAAs that were formed. Furthermore, they noted that with more bromine in the treated water, so will there be more brominated DBPs and the impact of bromine resulted in speciation of the DBPs as earlier reported in literature (Bougeard *et al* (2010)). In a study of occurrence of new DBPs Krasner, *et al* (2006), noted that in addition to the regulated DBPs, more than 50 others were being studied and rated as high priority for potential toxicity. They noted that THMs and haloacetic acids (HAAs) represent the groups of halogenated DBPs formed on a weight basis, while haloacetaldehydes were the third most formed DBP class. They further noted that pre-ozonation increased the formation of THMs while bromine encouraged the speciation and formation of brominated DBPs like the brominated furanones and others which are seldom analysed such as brominated ketones, acetaldehydes, nitromethanes, and acetamides. Later, Krasner (2009) noted that the frontier of recent emerging DBPs is expanding to include iodinated trihalomethanes and acids, haloacetonitriles, halonitromethanes, haloacetaldehydes, and nitrosamines. He further noted that these may be more toxic than

the regulated ones such as the chlorine and bromine containing THMs and haloacetic acids. He reported that these new DBPs are formed when source water is impacted by treated wastewater, algae and iodide fractions. While noting that alternative disinfectants to chlorine such as chloroamines, chlorine dioxide, ozone and ultraviolet rays may minimize the formation of some of the regulated DBPs, these disinfectants may increase the formation of these emerging disinfection by-products. He further noted that, with treatment plant optimization in different DBP scenarios with limited successes in the control of these DBPs, biofiltration may significantly reduce the formation potential of these by-products. Using gas chromatography/mass spectrometry (GC/MS) Richardson *et al* (2003) had earlier noted that under high bromine concentration (2 mg/l) using chlorine and chloramine as disinfectants, elevated bromine content in the source water caused a significant shift in the speciation to bromine containing DBPs, bromoform, and dibromoacetic acid in dominant proportions than few observed chlorinated DBPs. Iodo-trihalomethanes were also identified as well as brominated carboxylic acids and the first time discovered halogenated pyrrole as a DBP. Their obtained results showed fulvic acid being responsible for THMs, haloacetic acids and aldehydes but humic acid was directly responsible for the formation of 2,3,5-tribromopyrrole.

2.5 Health Effects of Disinfection By-Products

With respect to the health effects of disinfection by-products (DBPs), especially chlorinated disinfection by-products, in detailed analyses on first morning urine samples Wigle, (1998) observed that the potent oxidising power of chlorine is responsible for the increased mutagenicity of chlorinated water due to the reaction of chlorine disinfectant with humic substances released from the breakdown of organic materials. He further noted that though many chlorinated DBPs have been discovered, only very few have been subjected to carcinogenicity bioassay tests. Among these few are the regulated four

member THMs (chloroform, bromoform dibromochloromethane and bromodichloromethane) that have been found to cause kidney and liver tumours in rats and mice when fed straight and with corn oil. He again noted that in addition to these bioassays using experimental animals, epidemiological results had been most consistent in showing an association between exposure to THMs and bladder cancer, while conflicting results had been obtained between THMs and colon and rectum cancers. The USEPA (1999) however, had recognised that a causal relationship between chlorinated surface waters and bladder cancer had not been demonstrated conclusively by epidemiological investigations, but concluded that potential causal relationship had been supported by the weight of evidence from toxicological and epidemiological studies. Based on the cancer epidemiology database, USEPA (1999) noted that bladder cancer studies provide better evidence of association of exposure to the chlorinated water and bladder cancer than other types of cancer. Conclusively USEPA (1999) noted that evidence from available epidemiological and toxicological studies show that chlorinated waters continue to support a hazard concern and require a prudent public health regulatory approach. Accordingly USEPA (2011b) concluded that the health effects of people drinking total of the four regulated THMs in excess of the maximum contaminant limit for many years run the risk of liver, kidney or central nervous systems problems and also run the increased risk of cancer, while those consuming drinking water containing the five regulated haloacetic acids in excess of the maximum contaminant levels for many years may have increased risk of cancer.

In urinalysis, the kidneys are known to excrete contaminants from the body in order to maintain the homeostatic balance of the blood stream and other body fluids. Increased levels of contaminants in the urine have been traced to either of four conditions – hormonal imbalance, a higher than normal urine formation, a likely malfunctioning

kidney due to diseases like inflammation and a higher than normal concentration of the contaminant in the body and body fluids (MedlinePlus, 2011; Tutorvista, 2011; NKUDIC, 2011).

Comparing human risk assessment of the four regulated THMs and two of the HAAs using animal studies and epidemiological studies from 15 different countries worldwide, Hamidin *et al* (2008), showed that risk assessment using probabilistic approach from animal data showed no overlap between highest human exposure dose and the lowest human equivalent dose. However with epidemiological data, there was a positive overlap between the highest exposure dose and the lifetime average daily doses for trichloromethane, bromodichloromethane, dichloroacetic acid and trichloroacetic acid. They concluded that this suggests that there are possible adverse health risks as a small increased incidence of cancers in males and development effects in infants. However, they reported further that epidemiological data may affect these overall results because they contain several risk factors and exposure classifications.

The newly discovered DBP, 2,3,5-tribromopyrrole was tested by Richardson *et al*, (2003) for mammalian cytotoxicity, and genotoxicity earlier and found to be 4.5x more cytotoxic than MX, 8x more cytotoxic than dibromoacetic acid and 16x more cytotoxic than potassium bromate respectively. It was also found to induce acute genomic damage having a genotoxic potency of 299 microM similar to MX. Later on, Richardson *et al* (2007) reviewed the occurrence, genotoxicity and carcinogenicity of 85 DBPs including the 11 regulated ones and the 74 emerging DBPs and identified three categories of these DBPs. Category 1 contained eight DBPs which include bromodichloromethane, dichloroacetic acid, dibromoacetic acid and bromate, formaldehyde, acetaldehyde, MX, and N-nitrosodimethylamine are characterised by having all toxicologic characteristics of

human carcinogens, while category two contains twenty nine DBPs that are genotoxic and members include chloral hydrate and chloroacetaldehyde that are rodent carcinogen. Category three contains the remaining 14 DBPs with little or no toxicological data available on them. They reported that a recent epidemiological study found that much of the risk for bladder cancer associated with drinking water was associated with three factors, THM levels, showering/swimming (that is dermal/inhalation exposure and genotype (having the GSTT1-1 gene). Accordingly Chowdry and Husain (2011) noted that 14 – 16% of bladder cancers (a chronic effect) in Ontario Canada are attributable to drinking waters containing relatively high levels of chlorinated by-products, while also documenting the fact that acute effects range from cardiac anomalies, still birth, miscarriage and pre-term delivery. In the same vein while highlighting the various chronic effects of ingesting water disinfected among human populations, Schoeny (2010), noted that the gene – environment interaction in DBP studies in swimming pool water exposures and GSTZ1 (glutathione S-transferase zeta – 1) rs1046428 polymorphism in swimmers were missing one or both copies of GSTT1 appeared to be particularly susceptible to bladder cancer when exposed to relatively high levels of THMs in water. Her review also identified bathers in chlorinated pool in Barcelona had increased frequency of micronuclei in peripheral blood cells – a marker of DNA damage and evidence of systemic exposure to mutagens due to association with brominated THMs in the water. She concluded that in the pool balancing act one must weigh the immediate hazards that might result from exposure to microbial pathogens if adequate disinfection levels are not maintained against potential long term hazards associated with exposure to DBPs. While proposing a source reduction approach through pollution prevention and precursor removal she noted it to be rather challenging for swimming pools as the swimmers themselves are the largest source of nitrogenous substrates and

substantial source of organic matter necessary for DBP formation. She concluded by advocating the use of all tools available including advanced analytical methods, genomic end points and engineering approaches to guarantee the delivery of all water that is safe for drinking, bathing and swimming. Earlier, Teuchler, *et al* (2000) had noted that health risks from the ubiquitous exposure to mixtures of DBPs are of concern because existing epidemiological and toxicological studies suggest the existence of systemic or carcinogenic effects. They stressed that preliminary results suggest that dose additivity is a reasonable risk assessment assumption for DBPs.

2.6 Water Quality of the Kubanni Reservoir

In their work on the status of the Kubanni reservoir between 2002 and 2004, Adakole and Abulode (2009) noted that the concentration of some heavy metals (chromium, cadmium and lead) in the reservoir water and sediment of the Kubanni reservoir were above the WHO recommended limits, with mean values of 1.22 ± 0.05, 1.26 ± 0.05, 0.02 ± 0.01 and 0.86 ± 0.04 mg/l for lead, cobalt, cadmium, and chromium respectively. However, Tukura *et al* (2007) observed numerous ranges of values for some of these heavy metals which showed seasonal variations. In the rainy season, the metals showed the following range of values 0.003 – 0.03 mg/kg dry weight for cadmium, 0.20 – 2.50 for chromium, 0.70 – 2.45 for copper, 0.47 – 3.71 for lead and 0.70 – 3.70 mg/kg for zinc. In the dry seasons observed ranges were 1 – 19 mg/kg for cadmium, 0.33 – 8.53 for chromium, 0.00 – 1.41 for copper, 1.70 - 4.00 for lead and 0.03 – 3.49 mg/kg. Also, Tukura *et al* (2011) in analysing for concentrations of trace metals bound to carbonates, iron (Fe) and Manganese (Mn) oxides and organic matter using Atomic Absorption Spectrophotometer, observed that there is also seasonal influence in the correlation between any two (trace metals and binding sites). They observed that Fe/Mn oxides provided more binding sites for trace metals in the dry season (with 1.97 mg/kg in the

dry season as against 1.64 mg/kg in the rainy season). They also observed from correlation analyses that Cr correlated with Fe/Mn oxides (r=0.7971) in the rainy season, as Cr and Zn with carbonates (r=0.8925), Cu and Zn with organic matter (r=0.8314) and Pb and Zn with organic matter (r=0.7626) in the dry season. These indicate that while iron and manganese oxides are responsible for chromium pollution in the rainy season, organic matter is responsible for lead, zinc and copper pollution in the dry season as well as for zinc and some chromium from carbonates in the sediments. These, they attributed to the fact that Fe/Mn oxides and organic matter are more accessible to trace metals than other sediment matrices and hence generate these metal pollutants in the Kubanni reservoir. While studying the levels of some heavy metals in freshwater crab (*Cardisoma guahumi*) from the Kubanni reservoir using Energy Dispersive X-Ray Fluorescence (EDXFR), Abolude *et al* (2009) found the levels of some of these heavy metals to be higher than the WHO recommended safe levels. Among these values were manganese (2400 ± 1125 to 2910 ± 1130 ppm), iron (1390 ± 95 to 2900 ± 467), lead (238 ±16), zinc (304 ± 0.5 to 498 ± 58), arsenic (160 ± 10), Rubidium (75.6 ± 31.1), strontium (380 ± 46 to 1610 ± 57), vanadium (7710 ± 212) niobium (29.3 ± 5) and zirconium (30.5 ± 4). With lead and iron levels well above the permissible limits in the WHO standards they concluded that the crab (*C. guahum*) could be used as a bio-indicator.

CHAPER 3

MATERIALS AND METHODS

This study had many facets. There was an initial assessment of the Ahmadu Bello University (A. B. U.) water treatment plant to determine its level of conformity with common code of practices within the water treatment industry in Nigeria. As a result a structured questionnaire (Appendix I) was administered to some municipal water treatment plant facilities as well as the operators of the A. B. U. water treatment plant in 2004. Subsequently, the study concentrated on the water generated from the A. B. U. water treatment plant. Samples were taken for detailed chemical analyses including the measurement of concentrations for disinfection by-products in the treated drinking water.

3.1 Administration of the Study Questionnaire

Operators of selected municipal drinking water treatment plants were administered the designed structured questionnaire soliciting information about the operating code of practice in their drinking water treatment plants. These water treatment plants are located in Zaria, Katsina, Gusau, Sokoto, Birnin Kebbi, Jos, (Shen) Minna, Kaduna, Kano (Challawa Gorge (Kano)) and the Ahmadu Bello University. Among information sought are the date of initial commissioning of each treatment works, improvements undertaken including rehabilitation and expansion, the year carried out, the component treatment processes in terms of primary and main treatment processes, the amount of treated water produced, the availability and functionality of service laboratories, the disinfectant and quantities used, the frequency of use of disinfectant, the treated water distribution network and the general plant layout. This survey was to assess the degree to which the operations of the A.B.U water works are in conformity with those of the other selected water works

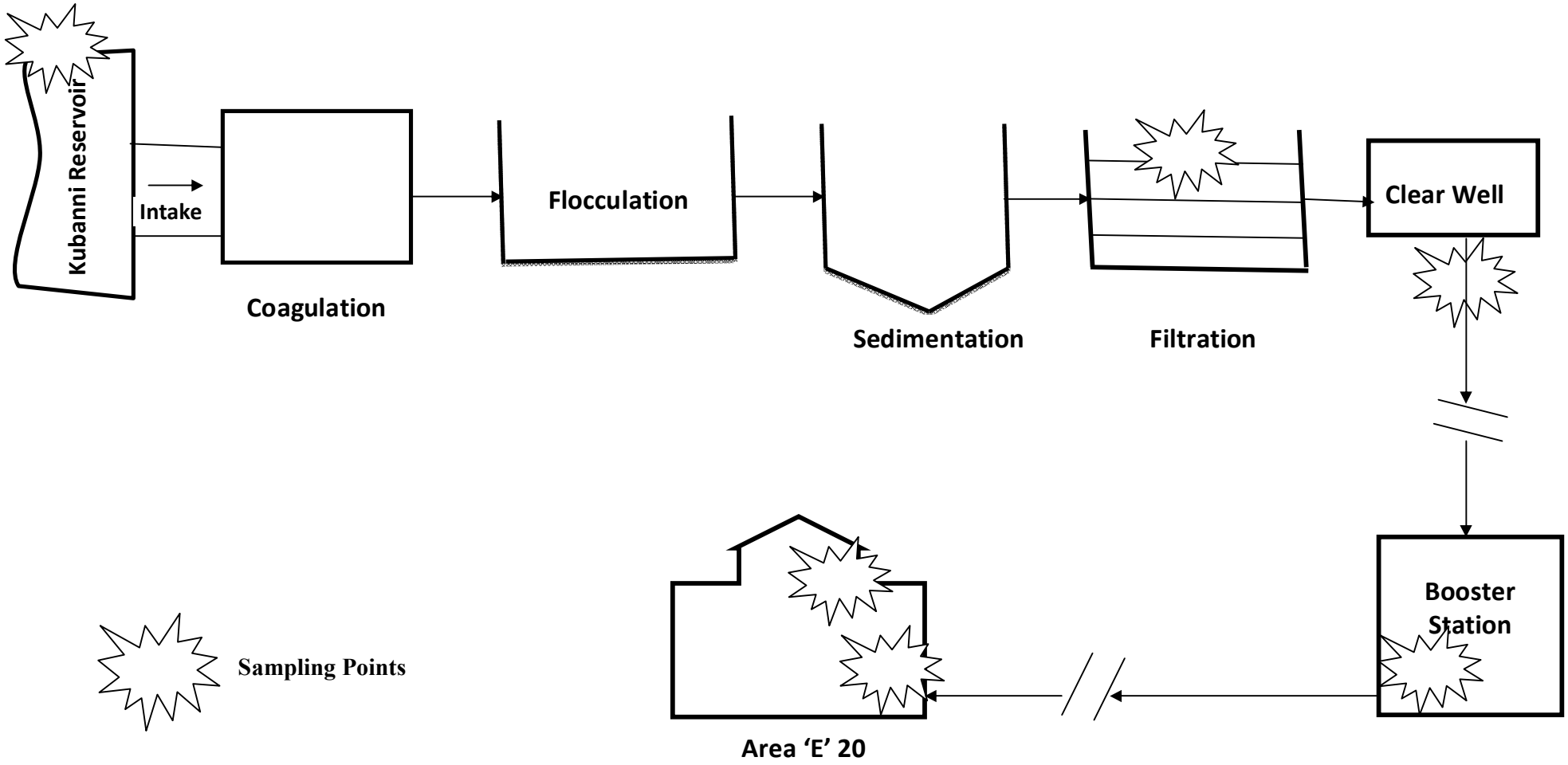


Fig 3.1 Schematic diagram of A.B.U. Drinking Water Treatment Plant and Distribution System Showing the Sampling points (Not Drawn to scale)

3.2 Sampling

3.2.1 Sample Collection

Water samples were collected longitudinally along the treatment and distribution processes from the Ahmadu Bello University drinking water treatment plant from the raw water intake at the reservoir, after sedimentation in the sedimentation tanks, after chlorination, in the booster station and at household level (Area E, House No. 20). Also, boiled water samples were collected at household level; (Area E, House No. 20) (see Fig.3.1 above). The sample collection was in accordance with the outlined procedure in the United States Environmental Protection Agency (USEPA, 1995) Methods 551.1 and 525.2.

Ten sets of samples were collected during the study with each set consisting of samples from nine different sampling points as outlined above. At each sampling point, samples were collected in duplicates. Apart from conforming with the procedures outlined in the USEPA (1995) methods stated above, samples were collected to ensure representativeness, none degradation while in transit and adequacy for full range of analyses anticipated. A total of 252 samples were obtained in the study. Only 108 samples which were collected in six sampling set were finally used in the results assessment. This was due to the fact that the first four sets of samples were done with different de-chlorinating agents (ammonium chloride for THMs, Acetonitriles, chlorinated solvents and other DBPs and sodium sulphite for chloral hydrate and HAAs). Only 72 samples with ammonium chloride could be analysed because pentane was the only available extractant. The results obtained from these 72 samples showed no trend and were inconsistent (among duplicates) and hence had to be discarded. The purity of the pentane as a DBP extractant could not be ascertained and it was suspected to be responsible for the variation in the results. Since chloral hydrate and the haloacetic acids

require MTBE, the solvent had to be sourced. It was only after its procurement that subsequent sampling was undertaken using only ammonium chloride as the de-chlorinating agent and MTBE as extracting solvent for all the 108 samples of subsequent six sets of sampling. Four out of the six sampling were undertaken in the rainy season months while only two sampling sets were carried out in the dry season months. There was no specific regularity of sampling as the availability of a functioning Gas chromatograph was the deciding factor of when to sample.

3.2.2 Sample Preservation

In accordance with these methods, collected samples were taken in 60mls glass vials containing 1gm of ammonium chloride or sodium sulphite and phosphate buffer mixture as the de-chlorinating agents so that the water samples did not top over to spill the de-chlorinating agent. These de-chlorinating agents like ammonium chloride are used to convert the free chlorine to monochloroamine thereby preventing further reaction between free chlorine and other organic fractions to form other DBPs after sampling. Ammonium chloride was the de-chlorinating agent when Methyl *tert* Butyl Ether (MTBE) was used in the extraction of THMs and HAAs while sodium sulphite was used as the de-chlorinating agent in the samples to be analysed for chloral hydrate and haloacetic acids. MTBE is a highly carcinogenic and very restricted solvent which was very difficult to procure. When it was not available, pentane was used as a substitute extracting solvent for the DBPs except chloral hydrate and haloacetic acids. Inconsistent and wide ranging concentration levels of the analytes were obtained with this substitute extracting solvent hence it was discontinued until MTBE was procured. After the addition of the de-chlorinating agent mixtures, samples were immediately stored in ice filled cooler jugs to keep them as close as possible to -4^0C before analyses. The samples were initially analysed at the Physical and Analytical Chemistry Department of the

Institute of Oceanography and Marine Research, Victoria Island, Lagos until their gas chromatography (GC) broke down. Thereafter subsequent GC analyses were undertaken at the Central Instrumentation Laboratories unit of Covenant University, Otta, Ogun State. These laboratories are located about 1,500 km from Zaria where analyses were carried out using gas chromatography with electron capture detection capability.

Samples of the first morning urine were taken from some male and female volunteers of Area E House No. 20, A.B.U. Zaria to determine their content of disinfection by-products as suggested by Wigle, (1998).

3.3 Analyses of Samples

The water samples were subjected to some general chemical analyses and heavy metals content as well as detailed DBP analyses for disinfection by-products. The general chemical analyses were conducted in accordance with procedures in Standard Methods for the Examination of Water and Waste Waters 20th Edition (APHA, 1998). For example, Total Dissolved Solids (TDS) was measured by method 24540 of the Standard Methods using glass fibre filter. Residual chlorine was determined by the iodometric method II of the standard method 4500 using sodium thiosulphate and salinity was determined by the electrical conductivity method (method 2520 of the standard methods). The heavy metals in the water samples were also determined in accordance with Standard Methods for the Examination of Water and Wastewaters (APHA, 1998) using a Perkins Elmer Atomic Absorption Spectrophotometer. These general chemical analyses for the drinking water quality and heavy metals content were done at the Physical and Analytical Chemistry Department of Nigerian Institute of Oceanography and Marine Research, Victoria Island, Lagos. Initially, the Disinfection By-Products analyses were initiated at this analytical laboratory until 2008 when the Gas Chromatography broke

down. Subsequently, the Disinfection By-Products analyses for Trihalomethanes (THMs), Haloacetic acids (HAAs), Acetonitrils and chlorinated solvents were undertaken at the Central Instrumentation Laboratory (CIL) of Chemistry Department of Covenant University in Otta, Ogun State. These analyses were conducted in accordance with the standard methods and the United States Environmental Protection Agency (USEPA, 1995) – Methods 551.1 and 552.2. Method 551.1 involved extraction of the THMs, Acetonitrils and chlorinated solvents in the samples with MTBE. The extract was then injected into a calibrated Gas Chromatograph with electron capture detection (ECD) capability. The respective masses of each analyte were computed from the injection chromatogram using the installed ChemStation software for data analyses and reporting. Method 552.2 on the other hand extracts the Haloacetic acids which are injected into the gas chromatograph for determination after methylation and derivatization of the various fractions of the Haloacetic acids. Computations to determine their masses were carried out as previously stated above.

3.3.1 Abridged USEPA and Standard Methods Analytical Methods used

(a). Extraction and Determination of Tri-Halomethanes (THMs), Acetonitriles, other DBPs and Chlorinated Solvents

(i) Remove sample vials from the fridge and allow to equilibrate to room temperature.

(ii) Remove the caps to the sampling vials. Remove 10 (40) mls volume of the sample. Check the pH of the sample using the removed sample. If the pH is not within the range of 4.5 and 5.5, the sampling must be repeated.

(iii) Inject 50(20)µL of decafluorobiphenyl - the surrogate standard for the fortification of the analyte in the sample solution. Mix slowly and carefully inverting the sample vial two times with minimal sample agitation.

(iv) Proceed with sample extraction with MTBE. Add 3 (1.2)ml MTBE with a type A TD transfer or automatic dispensing pipette.

(v) Add 10g Sodium chloride (NaCl) or 20 (8)g Sodium sulphate (Na_2SO_4) that has been muffled in a furnace to the sample vial. Recap and extract the Na_2SO_4/MTBE/sample mixture by vigorously and consistently shaking the vial by hand for 4 minutes. Invert the vial and allow the water and MTBE phases to separate (approx. 2 minutes). If a series of samples are being extracted, the sample should be recapped, agitated, and placed in a horizontal position with the un-dissolved Na_2SO_4 distributed along the length of the vial. If the vial is left in a vertical position, the salt will solidify at the bottom and will not dissolve during sample extraction.

(vi) Using a disposable Pasteur pipette, transfer a portion of the solvent phase from the 60 ml vial to an auto sampler vial. Be careful not to take the water phase especially unto the bottom of the auto sampler vial. If some water phase appears at the bottom of the auto sampler vial, the bottom water layer can be discarded by a Pasteur pipette.

(vii) For sample analysis, set the GC (with Electron Capture Detection (ECD) capability) at operating conditions as described in the USEPA (1995) manual in methods 551.1 sections 6.9.2.1 and 6.9.2.2. Inject 2 (1) µL of the sample extract into the GC. Record the resulting peak response. For optimum performance and precision, an auto sampler for sample injection and a data system (hence the ChemStation software) for signal processing are strongly recommended.

(b). Extraction and Determination of Halo-Acetic Acids (HAAs)

This methodology uses sample extraction, methylation/derivatization and Gas Chromatography using the Electron Capture Detection (ECD) Approach.

Sample Extraction

(i) Remove the samples from storage and allow them to equilibrate to room temperature.

(ii) Place 40 (20) ml of the water sample into a pre-cleaned 60 ml sampling vial with a Teflon lined screw cap.

(iii) Add 20 (10) µL of surrogate standard (10.0 µg/mL 2,3-dibromopropionic acid in MTBE as in section 7.5.2 of US EPA Method 552.2. Ensure that when adding the surrogate or analyte standard in MTBE, be sure that the needle of the syringe is well below the level of the water. After injection cap the sample and invert once. This ensures that the standard solution is mixed well with the water.

(iv) Adjust the pH to less than 0.5 by adding 2 (1) ml of Concentrated sulphuric acid. Cap and shake and check the pH or narrow range pH paper.

(v) Quickly add approximately 2 (1) gm of copper II sulphate pentahydrate and shake until dissolved to give aqueous and organic phases.

(vi) Quickly add 16 (8) gm of muffled sodium sulphate and shake for 3 to 5 minutes until almost all is dissolved. This is to increase the ionic strength of the analyte as such drive the haloacetic acids into the organic phase. The addition of the copper and sodium sulphates are done quickly so that the heat generated from the addition of the acid will help dissolve the salts.

(vii) Add 4 (2) ml MTBE and place on the mechanical shaker for 30 minutes or hand shaken for two minutes if performed vigorously.

(viii) Allow the phases to develop in approximately 5 minutes.

Methylation and Derivatization

(i) Using a Pasteur pipette, transfer about 3 (1.5) ml of the upper MTBE layer to a 15 ml graduated centrifuge tube.

(ii) Add 1 (0.5) ml of 10% concentrated Sulphuric acid in methanol prepared by adding 5 ml to 20 – 30 ml of methanol in -a 50 ml volumetric flask in a cooling bath. Dilute to 50 ml with methanol.

(viii) Cap the centrifuge tubes and place on a heating block or sand bath at 50^0C for two (2) hours. The vials must fit snugly into the heating bath to ensure proper heat transfer to ensure the attainment of the methylation process.

(ix) Remove the tubes from the heating block or sand bath and allow them to cool before removing the caps.

(x) Add 4 (2) mls of saturated sodium bicarbonate solution in 1 ml increments. Exercise caution when adding the solution because the evolution of carbon dioxide (CO_2) in this neutralization is rather rapid.

(xi) Shake each centrifuge for 2 minutes as the neutralization moves to completion, it is important to continue to exercise caution by venting frequently to release the evolved CO_2.

(xii) Transfer exactly 1.0 ml of the upper MTBE layer to an auto sampler vial. A duplicate vial should be filled using the excess extract.

(xiii) Add 10 µL of internal standard to the vial to be analysed (25 µg/ml 1,2,3-trichloropropane in MTBE per section 7.5.1 of US EPA 552.2)

(xiv) Analyse the sample as soon as possible. The sample extract may be stored up to 7 days if kept at 4^0C or less or up 14 days if kept at -10^0C or less.

Keep the extract away from light in amber glass vials with Teflon-lined caps.

(xv) Inject 2 (1)µL of the sample extract into the GC with ECD capability after detailed calibration. Record the resulting peak responses in the concentration, area or height units.

3.3.2 Gas Chromatography System

In the detailed laboratory analyses for the selected Disinfection By-Products, an Agilent Gas Chromatograph (GC) Model 19091-413 was used. Its configuration is described by the code 192.168.0.29. The equipment was installed with ChemStation software for operation, data analyses and reporting. The GC has two capillary columns. Column 1 is a special analysis column described by Agilent part no. 19091V-413 with a maximum temperature of 260^0C. It has a maximum length of 30m and a diameter of 320µm and a film thickness of 1.6µm. Both its inlet and outlets are inserted in the front inlet and front detector of the GC respectively. Column 2 on the other hand is a type HP 5.5% Phenyl Methyl Siloxan capillary column described by Agilent part no. 19091J-413 with a maximum temperature of 325^0C. It has a maximum length of 30m and a diameter of 320 µm and a film thickness of 0.25µm. Like the Column 1, it is oven heated and it is not inventorized. Its inlet is at the back inlet and the outlet is at the back detector. The GC uses Helium (He) as the carrier gas and Nitrogen as the makeup gas. The He inlets at the back and front inlets are inserted into one injection port. The GC has a tray injector type that is operated manually in place of the auto sampler. Although the equipment has both the split and splitless inlets, it uses the splitless inlet at a heater temp of 250 ^{0}C at a pressure of 8.9456 psi (61.68 kPa) and a flow rate of 20mL/min. The GC has a standard septum purge flow mode and a flow rate of 3 mL/min. The gas served delivers after 2 minutes in a splitless mode at 20 ml/min. It uses a micro Electron Capture Detection that

is heated over 300^0C, having a makeup flow of Nitrogen at 40mL/minute. The oven temperature is set on with an equilibrium time of 1 minute and a run time of 14.5 minutes for the oven to peak at 120^0C, at a pressure of 12 psi (8.74 kPa) and a peak flow rate of 2 mL/min (i.e.40 cm/sec). No valves are installed in the equipment.

3.3.3 Analytical Standards

For the Gas Chromatography to work adequately, analytical standards are needed to calibrate it. Three grades of standards are required. These are analytes standards, surrogates standards and internal standards samples. Commercial samples of these standards were obtained from Ultra Scientific Analytical Solutions, North Kingston, RI 02852-7723 USA. Most of the standards, if not all were in 1 ml glass ampoules. Most of the chemicals are controlled chemicals because of their highly contaminating effects on the environment. As a result several undertakings were required before their importation was approved. The standard or adequacy of the supplied chemicals was assured under an accompanying CERTIFICATE OF QUALITY ASSURANCE duly signed by the chief Analytical Director of the company.

3.4 Ahmadu Bello University Water Treatment Plant

The Ahmadu Bello University water supply system obtains its raw water from the Kubanni reservoir created from a dam across the River Kubanni. The reservoir has a catchment area of 57 km^2 (22 square miles) and a width of 122 meters and a mean depth of 6 meters (Adakole, *et al*, 2011). With the dam construction, an all year round raw water supply to the water treatment plant supplying the A.B.U. community with drinking water is guaranteed.

According to the Ahmadu Bello University Water Resources and Supply Committee report, (Anon, 2004), the water treatment plant was established in 1970 when it was

apparent that municipal water treatment plant in Zaria could not adequately meet the water demand of the Ahmadu Bello University community. This fact was further buttressed by the fact that existing water yield of the few bore holes could not meet the water demand of the fast expanding university community. This comprised the increasing students' populace, the university academic and support staff and their dependant family populace. The nearby Samaru Community was somehow dependent on the university water supply as it became evident after the water works commissioning when regular incidences of power outages resulted in disrupted water supply to the Samaru community from the Zaria municipal works.

The water treatment works was designed to supply 13.64 million litres of potable water per day. Its source of raw water is the impounded reservoir called Kubanni manmade lake. The design of Ahmadu Bello University Water Supply Scheme was done in two phases, i.e., Phase-I and Phase-II. At commissioning in 1981, the Ahmadu Bello University water treatment plant in its phase I stage of development was to supply about 4.8 million litres (1.2 million gallons) of potable water per day, to a total population of 22,000 people (these include; students, residents and non-resident senior and junior staff including their families and other dependent relatives).

Apart from the dam, the water treatment plant include water intake structures, water treatment works, a booster station, main pressure pipelines and several small sized over-head tanks distributed over the ABU main campus. The construction of the impounded reservoir (dam), which is the main raw water source, the intake structures, the raw water pumps house, and the construction of the entire treatment plant including the installation of pumps were completed in 1981. Full operation however, started in January, 1982, initially with three pumps at intake, 1,500m^3 clear water well, three pumps at high lift, 3

numbers of Sand-gravity filters, 4 numbers of Bottom Hooper type sedimentation tanks (later in 1990, one number was added to make a total of five tanks).

The booster station was commissioned in 1985, for the purpose of increasing pressure to convey treated water to high-pressure zones. It was established in between Dan-Fodio Hall and Area BZ Staff Quarters. The station started initially with two pumps of similar capacities and one underground reinforced concrete tank of about $110m^3$ capacity. Presently, the station was expanded to house, 2 additional pumps all of similar capacities and an additional steel surface tank of $117m^3$ capacity.

The distribution mains include pressure pipelines ranging from 350mm diameter to 75mm diameter which distribute treated water from the treatment plant to all the low-pressure zones, these are:

(a) Academic Areas including students' hostels
(b) Area 'A_I' and 'A_{II}' Staff Quarters
(c) Area III Staff Quarters
(d) Parts of Area BZ Staff Quarters
(e) A separate line to booster station tanks

On the other hand, the booster station pumps and distributes treated water to all the high-pressure zones located in upper Area BZ, Areas, 'C', 'E', 'F' and 'G'.

During the design stage, it was proposed that by 1995, the Ahmadu Bello University water supply plant would be in Phase-II to supply the full designed capacity of 13.6 million litres of treated water per day to an approximate population of about 72,000 people, by up-grading the facilities installed in Phase-I. Unfortunately, since its commissioning in 1981, the Ahmadu Bello University water supply plant is still in its Phase-I state, while the entire campus population has increased tremendously. This means that the supply currently is grossly inadequate and water supply is generally

unreliable especially in students' hostel like Dan Fodio and residential areas on higher elevations such as Upper Area BZ, Areas C, E, F and G. The water treatment plant is very poorly served with electricity, which in most instances compounds its problem. It is however, worth noting that some rehabilitation and replacement of parts and stocking of vital components like the service laboratory has taken place in the last couple of years. There is also a replacement of the two aged stand by generators with one higher capacity generating set.

The results of tests conducted on water samples outlined above in earlier sections of this chapter are presented in chapter four.

CHAPER 4

RESULTS AND DISCUSSIONS

4.1 Questionnaire Analysis

4.1.1 Development of the Surveyed Water Treatment Plants

Tables 4.1 to 4.5 analysed most of the information from the survey questionnaire administered to the water treatment plants in parts of Nigeria. From Table 4.1 it is seen that the sampled water treatment plants were established and commissioned at various stages of Nigeria's development. Two of the treatment plants were commissioned before-independence at Kaduna North and Sokoto. This is not unexpected as the former was the regional capital of Northern Region of Nigeria, while the latter is the historical seat of the caliphate that was very important even before the advent of the colonial administration. The next three water treatment plants were in the provincial capitals of Zaria, Katsina and Kano. Two of them later metamorphosed into state capitals, while Zaria became one of the largest cities of the emergent Kaduna state. Subsequently, three of the water treatment plants were commissioned between 1979 and 1986 at Minna, Birnin Kebbi, and the Ahmadu Bello University, Zaria, while two were commissioned between 1986 and 1999 at Gusau and the Jos Extension plant at Shen (Jos). In all these locations, the establishment of the water treatment plants was primarily aimed at supplying potable water to the people of these cities.

Table 4.1: Development of the Surveyed Water Treatment Plants

S/No.	Description	Observation
a.	Year of Commissioning	
	(i) Pre-Independence	20%
	(ii) Between 1960 and 1979	30%
	(iii)Between 1979 and 1986	30%
	(iv)Between 1986 and 1999	20%
b.	Additional works since commissioning	
	Had additional works	100%
c.	Nature of additional works	
	(i) Rehabilitation	10%
	(ii) Expansion	30%
	(iii)Both Expansion and Rehabilitation	60%
d.	Period of most recent works	
	(i) Less than 5 years ago	30%
	(ii) Between 5 and 10 years ago	40%
	(iii)Between 10 and 15 years ago	10%
	(iv)Between 15 and 20 years ago	20%

From Table 4.1 also, it is observed that all the water treatment plants had undergone some form of additional works since commissioning. The works were either rehabilitation of existing facilities as was the case in the Second Challawa Gorge (Kano) water treatment plant or expansion as was the case with Gusau, Minna and Shen (Jos) water treatment plants. At the Birnin Kebbi, Sokoto, Katsina, Zaria, Kaduna and ABU water treatment plants both rehabilitation and expansion have either already been undertaken or are on-going as is the case with the Ahmadu Bello University treatment plant. On how recent these works were undertaken; 40% of the treatment plants (located at Katsina, Birnin Kebbi, Challawa Gorge – Kano and Kaduna North) had done renovation between 5 and 10 years ago. These were followed by 30% of the plants (at

Minna, ABU and Jos) whose renovations were done less than 5 years ago. It was only in Zaria water works (accounting for 10% of the treatment plants) had done renovations between 11 and 15 years ago which was least in the survey. This shows that the upgrade of these plants is relatively recent as most were upgraded in or under a decade. This is a reasonable period to upgrade in response to population growth in our cities.

4.1.2 Common Facilities and Processes Available in the Treatment Plants

Table 4.2 shows some of the facilities in the treatment plants. Regarding the preliminary water treatment processes, the treatment plant in Sokoto, Gusau, Birnin Kebbi, Minna, Shen (Jos), ABU, Zaria and Kaduna (80%) have screening devices to remove floating objects before the water is passed into the plant for treatment. However, 20% of the water treatment plants reported that they do not have screening devices. These plants are those in Challawa Gorge (Kano) and Katsina. It is likely that those plants without screening devices are fed by raw water that is free of floating matter hence do not require screens to separate these materials from the water abstracted.

From Table 4.2, the survey also showed that 40% of the treatment plants surveyed have preliminary chemical treatment to remove algae and other aquatic plants that could disturb their treatment processes. These are Kano (Challawa Gorge), Minna, Shen (Jos), and Gusau plants, where the growth of aquatic plants has constituted a menace to their operations. The rest, 50% do not have to chemically treat for aquatic plants as they do not constitute a problem in their water treatment. There was no response from the Sokoto water treatment plant probably because the reporting officer had no full understanding of the question asked. When the plant was inspected, there were serious cases of aquatic plant growth at the reservoir.

Table 4.2: Component Facilities and Processes of the Surveyed Water Treatment Plants

S/No.	Description	Observation
a.	Available Preliminary water Treatment options	
	(i) Screening to remove floating matter	
	- Available	80%
	- Not available	20%
	(ii) Chemical treatment to remove algae and aquatic nuisance	
	- Available	40%
	- Not available	50%
	- No Response	10%
	(iii) Pre-sedimentation to remove mud and other colloids	
	- Available	60%
	- Not available	40%
	(iv) Micro-straining to remove algae, aquatic plants and small debris	
	- Available	50%
	- Not Available	50%
b.	Main treatment Processes	
	(i) Chemical feed and Rapid mix	
	- Available	90%
	- No Response	10%
	(ii) Coagulation/flocculation to convert non settleable to settleable particles	
	- Available	100%
	(iii) Sedimentation to remove settleable particles	
	- Available	100%

Table 4.2 cont'd

S/No.	Description	Observation
b Cont'd	(iv) Filtration to remove bio-contaminants and solid matter	
	- Available	100%
	(v) Softening to remove hardness causing chemicals	
	- Available	80%
	- Not Available	20%
	(vi) Using Granulated Activated Carbon (GAC) to remove colouring, radionuclides, organic chemicals like pesticides, THMs and solvents	100%
	- Not Available	
	(vii) Aeration and Oxidation to remove VOCs, H_2S, radon, dissolved gases, oxides of Fe, Al and Mn	
	- Available	90%
	- Not Available	10%
	(viii) Corrosion control to prevent scaling and corrosion	
	- Available	30%
	- Not Available	70%
	(ix) Reverse Osmosis and Electrodialysis to remove nearly all inorganic contaminants	
	- Not Available	100%
	(x) Ion exchange Process to remove inorganic contaminants and hardness chemicals	
	- Not Available	100%
	(xi) Activated Alumina to remove inorganic contaminants	
	- Available	20%
	- Not Available	80%
	(xii) Neutralization with lime to increase pH of the water	
	- Available	100%

On the availability of pre-sedimentation facilitiesy to remove large settleable solids like coarse sand and gravelly particles, 60% of the water treatment plants responded in the affirmative while 40% reported that the facility is absent in their treatment plants. Among those reporting the presence, are the treatment plants at Gusau, Sokoto, Shen (Jos), Zaria and Kaduna. This is not surprising because the raw water sources are either directly from upland areas or traverse upland terrains where gritty fractions are eroded. It is also because in most of these treatment plants with high load of sand and gritty fractions, the raw water is directly abstracted from flowing rivers. The plants without the facility are Challawa Gorge (Kano), ABU, Birnin Kebbi and Katsina, where the raw water is abstracted from manmade reservoirs, which allow the gritty fraction to settle.

Fifty per cent of the water treatment plants micro-straining devices to separate algal and other aquatic plants from the abstracted water. The other 50% of the respondents reported that such devices are not present in their plants. This trend is similar to the observations of chemical control for the algal and other aquatic plants. It is likely that the treatment plants with algal and other aquatic plants menace would require either chemical treatment or straining devices to remove the aquatic plants while those that do not have the problem do not need the facilities.

As part of the survey, the responding plant managers were requested to supply information about their main treatment methods. Ninety per cent of the respondents confirmed that their treatment plants are equipped with chemical feed and rapid mix facilities that enable them absorb and thoroughly mix water treatment chemicals adequately for effective chemical combination with the treated water. All the plants except the Gusau plant confirmed the availability of such facilities. The case of Gusau may have arisen due to the ignorance of the reporting officer. This is because most, if not

all the water treatment plants are conventional one-disinfection segment water treatment plants where adequate chemical feed and mixing are ensured for sedimentation and filtration to be efficient.

All the water treatment plants reported having coagulation and flocculation as the main method of treating water after the coagulating agent; usually ferrous aluminium sulphate (alum) has been thoroughly mixed with the water. This is the reason while the earlier response about the Gusau treatment plant may not necessarily express the true situation at the plant.

After using the alum, all the water treatment plants use sedimentation to remove or separate settleable particles from the water being treated. The separation also acts as a preliminary stage for removing biocontaminants which support microbial growth.

All the water treatment plants except those in Zaria and Kaduna use softening process in their water treatment process. But direct physical inspection of their facilities showed that none of them had separate facilities for softening other than the combined liming and coagulation. This is responsible for the response.

All the water treatment plants disinfect water to get rid of micro-organisms which could be disease vectors. In addition, the disinfection process also sterilizes other biocontaminants and other solid matter which may breed disease vectors.

All the treatment plants do not use Granulated Activated Carbon (GAC) in their treatment process. This is not surprising as they are conventional one-disinfection segment water treatment plants, with simple designs. Similarly, innovative treatment processes like reverse osmosis, electrodialysis, ion exchange are absent from all the surveyed treatment plants.

All the water treatment plants were provided with one form of aerators or the other especially pre-aeration by spraying the water before it is mixed with chemicals in the rapid mix chambers. It is possible that the response from Challawa Gorge (Kano) water treatment plant was due to misunderstanding of the question.

Thirty per cent of the respondents (Gusau, Birnin Kebbi and ABU) reported the availability of corrosion control facilities in their treatment plants while the remaining seventy per cent do not have. However, site visits revealed that these plants reporting unavailability of corrosion control facilities had liming units. Again their response is probably borne out of ignorance or a misunderstanding of the question or yet still probably due to their degree of technical competence.

While all the water treatment plants are reported to have liming facilities, 20% (Challawa Gorge (Kano) and Birnin Kebbi) are reported to have activated alumina units to remove inorganic contaminants. The inspection of these two plants did not however confirm this. It is most probable that the operators may have confused this process involving activated alumina with alum coagulating. This is another indication that operators of the water treatment plants may not have sufficient knowledge of present day treatment processes and their relevance in the delivery of potable water.

4.1.3 Intake and Production units of the Treatment Plants

Table 4.3 is a summary of responses in respect of the sizes of their intake and production units. Twenty per cent of the water treatment works (Gusau and Birnin Kebbi) are reported to have catchment areas of between 5 and 10 hectares, while Katsina water works has a catchment of between 15 and 30 hectares. Sokoto, Minna Shen (Jos), Challawa Gorge (Kano), Zaria and Kaduna treatment works have catchment areas in

excess of 30 hectares. In most of these areas the size of the catchment is influenced principally by the nature of the terrain and their hydrological characteristics.

Only a fraction of the catchment area is protected in half (50%) of the treatment works, but 30% had full protection of their catchment area while 20% had none of their catchment area protected. This shows the level of vulnerability of the source waters to human activities and contamination. Full protection is practiced in Birnin Kebbi, Gusau and Minna which are either emerging new state capitals (Birnn Kebbi and Gusau) or second generation state capital (Minna), where development control and environmental health inspection and control have not yet collapsed.

Many (40%) of the treatment works have agriculture as the sole land use practice in their catchment area. This was followed by urbanization and established residences (20%) while other land use practices not listed in the questionnaire accounted for 20% of the responses. Combined agriculture, urbanization and residences together with mining activities for building materials were least, (10%). This trend corresponds with the age and degree of urbanization of the various cities. While agriculture is the dominant land use within the catchments in Katsina, Minna, Challawa Gorge (Kano) and Birnin Kebbi, urbanization and building of residences were the combined land use practices in Shen (Jos) and Gusau towns and the combination of agriculture, urbanization with residences were reported to be common within the catchment in Sokoto water works. In the ABU water works catchment, agriculture and mining for building materials are the common land use practices.

Table 4.3 Intake and Production Units of the Surveyed Water Treatment plants

S/No.	Description	Observation
a.	Size of the catchment area	
	- Between 5 and 10 ha	20%
	- Between 10 and 15 ha	0%
	- Between 15 and 30 ha	10%
	- Over 30 ha	70%
b.	Protection of catchment area	
	- All of the catchment area	30%
	- A fraction of the catchment area	50%
	- None of it	20%
c.	Human Activities within the catchment area	
	- Agricultural Use	40%
	- Urbanization/Residential use	20%
	- Agricultural, Urbanization/Residential combined	10%
	- Urbanization/Residential and Mining combined	10%
	- None of the above	20%
d.	Initially designed daily capacity of the Treatment plant	
	- Between 4 and 6 million litres per day	30%
	- Between 12 and 20 million litres per day	20%
	- Between 20 and 28 million litres per day	10%
	- Over 40 million litres per day	40%
e.	Present operating daily capacity of the Treatment plant	
	- Less than 4 million litres per day	10%
	- Between 4 and 6 million litres per day	10%
	- Between 6 and 12 million litres per day	10%
	- Between 12 and 20 million litres per day	10%
	- Between 28 and 40 million litres per day	40%
	- Over 40 million litres per day	20%
f.	Raw surface water supplemented with ground water for treatment	
	- Yes	60%
	- No	40%

On the initial designed capacity of the water treatment plants, many of them (40%) were designed to have capacities greater than 40 million litres per day. Those with capacities ranging between 4 and 6 million litres per day that were 30% of water treatment plants; and those with capacities of 12 to 20 million litres were 20% of the plants. There were those treatment plants with capacities of 20 and 28 million litres per day but were the least. The designed capacities were in relation to the approximate population served by the water treatment plants. As a result it is not surprising that the Ahmadu Bello University treatment plant was designed to have the least capacity followed by those in more recent state capitals like Gusau and Birnin Kebbi, while Kaduna, Kano, Sokoto and Shen (Jos) that are large cities and sometimes capital cities of colonial and early independence periods, are among the high capacity water treatment plants.

Presently, most of the water treatment plants were found to be operating within the range of their earlier designed capacities or even at capacities lower than the initially designed. This is despite the expansion and rehabilitation undertaken in subsequent years. As a result, many of the treatment plants (40%) are producing between 28 and 40 million litres per day. Among the treatment plants in this category are those at Minna, Shen (Jos), Zaria and Kaduna. Zaria is operating within its range of designed capacity while Kaduna, Minna and Shen (Jos) are operating at lower than their designed capacities. Against this background these cities are either increasing in size due to their new found status of new state capitals as in Gusau, Katsina, and Jos or as old state capitals like Minna and Kano or older state or even a former regional capital like Kaduna, or due to a resulting population increase as a result of population migration from the rural areas to these old and emerging conurbations. This condition is probably due to the fact that as part of the infrastructural facilities in these urban areas, they are easily made ineffective by the population influx which creates a demand imbalance over supply of potable water.

Also, budgetary provisions are not made to adequately cope with the demands for improved service delivery. An assessment of the treatment plants revealed that staffing is also a problem that may be responsible for the low production output of the plants. As such, basic maintenance services could not be undertaken to effectively maintain the plants to meet and cope with even marginal increases in demand. Across the plants, it was observed that there is a preponderance of artisans over skilled technologists, water engineers and scientists that can adequately operate, maintain and manage a water treatment plant. The few engineers are engaged in administrative assignments at the Water Board covering entire states. The situation became worsened by the devaluation of the Naira in 1986, which made the procurement of vital machineries and spare parts too expensive for the budgetary allocations to adequately cope with.

Survey results also show that 60%of the treatment plants supplement their treated water supply with ground water supply. Among the treatment plants practicing this, are those in Birnin Kebbi, Gusau, Sokoto, Challawa Gorge (Kano) ABU and Kaduna. However, cities like Shen (Jos), Katsina, and Minna are among those cities that rely only on treated surface water for potable supply. This is probably due to the fact that the underlying geology and hydrogeology of Northern Nigeria do not support evenly distributed ground water across the region. As a result, while economic abstraction of ground water is very easy in some areas like Sokoto and Gusau, it is not a feasible option to augment surface water sources in areas like Shen (Jos) (Federal Republic of Nigeria, 1965).

4.1.4 Size and Operation of the Distribution Systems

Table 4.4 evaluates information about the production capacities of the treatment plants and the operations of the distribution systems. Some of the treatment plants (30%) reported that they have a distribution network covering an area of between 10 and 20

km^2. Another 30% have distribution networks of over 50 km^2, while others were equally split between network coverage of between 5 and 10 km^2 and between 20 and 50 km^2. The ABU treatment plant had the least distribution coverage followed by Zaria, while, Shen (Jos) and Kaduna Challawa Gorge (Kano) are among those with the largest range of coverage of over 50 km^2. This pattern of distribution network coverage is not surprising because the trend is similar to that of population and size of the cities and community served.

Many (40%) treatment works reported that they produce and distribute water regularly throughout their entire network 24 hours, 7 days a week. During the field visit however, this was found not to be correct. Some (30%) of the treatment plants produce water during the day and night but distribute in rotation at select periods of the day. Others produce during the day and distribute in rotation during the day only. These treatment plants were represented by 10% and were least in number. It may be the intention of all the treatment plants to provide uninterrupted water supply throughout their networks, but it is hardly practicable within the operating conditions these treatment plants find themselves. Most, if not all, lack adequate spare parts, while budgetary provisions are relatively inadequate. Also the manpower position cannot support adequate operation and maintenance as well as the occasional incidences of misappropriation of the very scarce funds allocated.

Table 4.4: Size and Operation of the Distribution Systems

S/No.	Description	Observation
a.	Spread/coverage of the Distribution Network	
	- Between 5 and 10 km^2	20%
	- Between 10 and 20 km^2	30%
	- Between 20 and 50 km2	0%
	- Over 50 km^2	50%
b.	Operation in the Distribution Network	
	- Produce water and distribute water over entire network 24 hourly	40%
	- Produce water during daytime and distribute water over entire network at night only	20%
	- Produce water during the daytime and distribute in rotation throughout the day	10%
	- Produce water during the day and night and distribute in rotation over the network at select periods in a day	30%
c.	Frequency of Distribution failures	
	- Frequent	10%
	- Sometimes	90%
d.	Frequency of attention to distribution failures	
	- Promptly	80%
	- Regularly	10%
	- No Response	10%
e.	Health Risk Associated with your treated water	
	- Microbial (Yes) 30% (No) 60% (No Response) 10%	
	- Fluoride (Yes) - 0% (No) 80% (No Response) 20%	
	- Barium (Yes) 0% (No) 80% (No Response) 20%	
	- Nitrate (Yes) 30% (NO) 60% (No Response) 10%	
	- Radionuclides (Yes) 0% (No) 100%	
	- Arsenic (Yes) 0% (No) 100%	
	- Volatile Organic Carbon (Yes) 0% (No)100%	

On the reliability of the distribution network, a vast majority (90%) of the respondents reported that distribution failures do sometimes occur; while 10% reported that distribution failures are frequent in their distribution networks. This is not surprising as the topography, operation of the distribution system and ages of the networks all have significant influences on the reliability of the distribution networks. Nonetheless, 80% reported that the network failures are promptly attended to while 10% reported that the failures are regularly attended to and 10% did not response. It was noted that cities where failures are promptly attended to, are those where the degree of surveillance is high and sometimes have emergency response groups that attend to such failures. This was the case in cities like Kano where the facilities of the old WRECA (Water Resources Engineering Construction Agency) are still in place. In other cases, the people are well mobilized to report distribution failures promptly for immediate attention. This is the case of Kaduna metropolis.

Water treatment plant operators were asked about risks associated with their water. Many (60%) reported that there is no risk of microbial infection by consuming their treated water, but 30% reported that there are chances that there are chances of microbial contamination of the water they produce. This is because of possible contamination in their distribution network due to occasional pipe breakages in their networks. This is the experience in Zaria, Sokoto, Katsina; while ABU, Kaduna, Challawa Gorge (Kano), Minna, Shen (Jos) Gusau, and Birnin Kebbi did not respond to the question.

With regards to fluoride risk in the treated water, no respondent reported the likelihood of fluoride in their treated water but 80% of the respondents were categorical that their water was safe from fluoride poisoning and 20% did not respond.

While 60% of the treatment plants had no risk of nitrate poisoning from their treated water, 30% of the treatment plants located in Sokoto, Gusau, and Birnin Kebbi reported the likelihood of nitrate poisoning from their treated water. These nitrate prone treatment are located in catchment areas that are mostly within agricultural lands from which water sources are enriched with nitrates from agriculturally applied fertilizers. Such large dose of nitrates cannot be effectively removed in the conventional treatment of such raw water. Only Challawa Gorge (Kano) (10%) treatment plant did not respond to the question. All the treatment plants did not see the likelihood of radionuclides risk in their treated water. Similarly there is no risk of arsenic and volatile organic carbon poisoning in the treated water from all the treatment plants.

4.1.5 Laboratory Services and Disinfection Process

Most of the treatment plants (90%) use chlorine as the disinfecting agent in the treatment process. The staff of most of the treatment plants complained of the difficulty in handling chlorine gas. As a result most of the plants use commercial hypochlorite as a source of chlorine to disinfect their water. The Shen (Jos) water treatment plant uses a combination of chlorine and ammonia to produce chloroamine as the disinfecting agent in their water treatment.

The sampled water treatment plants use various proportions of disinfectant in their treatment process in conformity with WHO International Standards for Drinking Water treatment. From this survey, 30% of the respondents use between 1 and 5 mg/l and another 30% also use between 5 and 10 mg/l. This was followed by 20% of the respondents who did not respond to the question. The least respondents (10%) use between 10 and 15 mg/l of disinfectant while another 10% of the respondents use over 15 mg/l of disinfectant.

Table 4.5: Laboratory Services and Disinfection Process

S/No.	Description	Observation
a.	Disinfectant in use in the Treatment Plant	
	- Chlorine	90%
	- Chlorine with ammonia	10%
b.	Rate of Disinfectant in use in the Treatment Process	
	- 1 mg – 5 mg/l	30%
	- 5 mg – 10 mg/l	30%
	- 10 mg – 15 mg/l	10%
	- Over 15 mg/l	10%
	- No Response	20%
c.	Availability of Service Laboratory	
	- Available	100%
d.	Functionality of the Service Laboratory	
	- Functional and used for all daily services in the treatment process	50%
	- Partly functional. Only used for some analyses	50%
e.	Routine analyses undertaken in the Service laboratory	
	- Turbidity (Yes) 90% (No) 10%	
	- pH (Yes) 100%	
	- Residual Chlorine (Yes) 70% (No) 30%	
	- Heavy metals (Yes) 10% (No) 90%	
	- Microbial (*E. coli, Gardia, Cryptosporidium*) (No) 100%	
	- Dissolved Organic Matter (DOM) (No) 80% (No Response) 20%	
	- Filamentous algae (No) 100%	
f.	Stock Level of Disinfectant	
	- Always maintain a steady stock for regular use	70%
	- Buy to use always, cannot maintain a stock in store	20%
	- Sometimes run out of stock due to inflationary trend	10%

Table 4.5 cont'd

S/No.	Description	Observation
g.	Water Treatment without use of disinfectant	
	- No Never	70%
	- Yes sometimes	30%
h.	Frequency of treating water without disinfectant	
	- Sometimes	10%
	- Only on a few occasions during the dry seasons due to lack of funds	20%
i.	Provision for disinfection residual	
	- Yes	80%
	- No	20%
j.	Level of disinfection residual	
	- Less than 1 mg/l	30%
	- Between 1 and 5 mg/l	30%
	- Between 5 and 10 mg/l	10%
	- Over 10 mg/l	10%
	- No response	20%
k.	Number of Treatment Trains, Injection points and Disinfection segments in Treatment plants	
	- Conventional plant with ONE disinfection segment	80%
	- Treatment plant with TWO disinfection segments	10%
	- Treatment plant with ONE injection point and multiple disinfection segments	10%
l.	Budget allocation to the Treatment plant	
	- Dwindling despite inflation	10%
	- Improving despite increasing demands on resources of government	70%
	- Internally generate money, so no financial problems	10%
	- No Response	10%

It is possible that the high proportion of no response may have arisen due to doubts about the computations of the various levels of disinfectant applied. It was also observed that most of the water treatment plants had no functioning service laboratories and hence the difficulties of accurate measurement of disinfectant used. The lack of adequate manpower may also have compounded this problem. Although many respondents claimed to be following international standards, it was observed from some of the responses that even when the same standards were in use different doses were applied. For example, all the treatment plants reported to be following the WHO standards except the Shen – Jos using the EU standards. However, they use different rates in the rainy season ranging from 1-5 mg/l for Katsina, Zaria and Challawa Gorge to 5-10 mg/l for Sokoto and ABU and 10 – 15 mg.l for Minna. In the dry season, there is also a disparity in the doses used (under the same standards) with Sokoto, Katsina, Challawa Gorge, ABU, Zaria and Kaduna using the same dose (1-5 mg/l) while Minna uses different dose of 5-10 mg/l. Despite these, the different treatment plants use different doses in the dry and wet/raining seasons, with lower doses in use in the dry season. Closely related to this is the fact that 70% of the responding treatment plants reported maintaining a steady stock of disinfectant in Gusau, Sokoto, Katsina, Minna, Shen (Jos) Challawa Gorge (Kano), and Ahmadu Bello University water works while Zaria and Kaduna reported buying to use as they cannot maintain stock in store; and Birnin Kebbi noted sometimes it runs out of stock. Interestingly, it is these treatment plants, (Birnin Kebbi, Zaria and Kaduna) that reported treating water without disinfectant on some occasions in the dry season due to budgetary constraints. While this may be the hard truth which the management of the plants especially in Zaria and Kaduna will strongly contest and even deny, they are real life situations which may even exist in other plants, because there is no agency or body to regularly monitor the practices of water treatment plants creating

ample room for sharp practices to occur at the expense of good quality water. Closely related to this, is the usual administrative bottleneck in the release of funds to public utilities leading to low efficiency, poor service delivery, corruption, and ineptitude/incompetence.

All the responding treatment plants reported that they had service laboratories in their water works. However, observations were that provisions were made for the laboratories in many of the plants but the laboratories were not functional. As at the survey period in 2004, only Challawa Gorge (Kano), Minna and Shen (Jos) had partially operational laboratories while Sokoto, Gusau, Birnin Kebbi Katsina, and ABU did not. It could be remarked that many situations may have changed now as Minna had installed a High Performance Liquid Chromatography in its laboratory for more detailed analysis of its produced water while ABU has procured many component to enhance its analytical capability.

A majority of the treatment plants (90%) were capable of carrying out turbidity tests on the water undergoing treatment, except Gusau. All the plants could measure pH. Majority (70%) could measure residual chlorine, although there were no facilities in the laboratories to indicate so except in Minna and Challawa Gorge (Kano). Heavy metal determination is one notable area where all the plants facilities or expertise even in Challawa where they claimed to have. That a plant has a qualified chemcist does not necessarily mean he/she can analyse water for metals. Therefore the reported 10% capability is therefore misleading. The water treatment plants confessed their inability to undertake microbiological analyses of water. While 80% were very clear that they could not undertake assessment of dissolved organic matter, 20% did not respond. Also, all the respondents reported that they were estimating filamentous algae in their treatment

systems but this was not evident. These responses are indicative of the various risks which the treated water from the plants can pose to the consumers. It is obvious, that microbial contamination is likely when some treatment plants are not adequately funded to ensure that there is disinfectant in stock all year round. Closely related to this is the inability to ensure that adequate residual disinfectant is provided to ensure safety of water throughout its conveyance in the distribution network. This is despite the fact that 80% of the respondents reported that they provide for disinfectant residual of various proportions. Good as this may seem but the inability to measure this item makes it doubtful how the proportion could be ensured; once again, these are highlighting the spurious extent of some of the responses. Inability to measure heavy metals in the treated water can also make the risk of their poisoning very rife.

Most of the treatment plants (80%) are conventional plants having one injection point and one disinfection segment, while 10% of the respondents (Minna treatment plant) has two injection points and two disinfection segments; and 10% (Shen (Jos)) treatment plant has one injection point but multiple disinfection segments. This trend confirms the fact that majority of the water treatment plants in this part of the country had been designed as simple conventional water treatment plant aimed at treating less complex raw water. The two variations may have probably been aimed at ensuring more sterilized water.

Majority (70%)of the water treatment plants had increased finances despite increasing demands on government resources, while the remaining 30% equally reported among three other options of dwindling allocation despite inflation (10%), internally generating revenue as such do not face financial problems (10%) and no response (10%). It is hardly possible that funds for water treatment works are adequate as it is very evident that potable water supply is seriously inadequate that there is hardly any of the cities that

has uninterrupted water supply for 24 hours of the day and 7 days of the week. It is strongly suspected that these responses are made to satisfy the political leadership of each of these states.

4.2 Quality of Ahmadu Bello University Treated Drinking Water

Water samples from the Ahmadu Bello University drinking water treatment plant were collected and subjected to detailed general chemical analyses, to determine the general quality of its treated drinking water and the types and concentrations of disinfection by-products. This was after the administration of the study questionnaire to it and other water treatment plants in Nigeria. This was aimed at ascertaining the level of uniformity of their water treatment operations. From the analysis of the questionnaires it is evident that the operations are generally similar and relatively uniform, aimed at producing clean water for the populace.

4.2.1 General Chemical Properties of ABU Treated Drinking Water

Samples of the treated drinking water from the Ahmadu Bello University Water treatment plant were subjected to general chemical analyses to determine their pH, Total Dissolved Solids, Salinity, Total Organic carbon, Residual Chlorine, Conductivity, Nitrates, Phosphates, Chlorides and Sulphates content. Subsequently the results of these analyses were compared with national and international standards. The results of these analyses are presented in Table 4.6.

4.2.1.1 pH

From the results, the average pH of the treated drinking water was between 6.7 and 8.0, with the lowest values found in the water sample from the house in Area 'E' quarters. The highest value of 8.0 was recorded at the booster station. This is probably due to the fact that the combination of liming agents used and the disinfectant (calcium

hypochlorite) could have completely equalized at the booster station. However the low pH value at the house in Area 'E' may have arisen because of the formation of biofilms due to intermittent flow in the distribution system and distribution failures. These biofilms are organic and inorganic, living or dead capable of undergoing decomposition to create intermediate products (Jakubovics, 1998;; LeChevallier, 2000). The processes of and the formation of these products has tendency to acidify the medium and produced decomposition particulates. In the boiling process at house level these particulates are dissolved to neutralize the acidity created during conveyance in the distribution system thereby resulting in neutral pH for the boiled water. However, the observed mean pH values are all well within Nigerian standards as well as the international drinking water pH range of values (6.5 – 8.5 for SON (2007) and USEPA (2011a) standards).

4.2.1.2 Dissolved Solids

The Total Dissolved Solids were between 50.50 and 70 mg/l, as against the 500 mg/l as the maximum contaminant level required by the Nigerian drinking water standards (SON, 2007) and the USEPA (2011a) standards. This shows that the observed dissolved solids concentrations in the ABU treated water are well within the acceptable limits. The higher concentrations noticed after boiling the household water may be due to heat induced dissolution of some solutes that may have still remained in the water after filtration, thereby increasing the proportion of dissolved solids.

4.2.1.3 Conductivity

The mean conductivity of the water samples ranged from 66 micro Siemens to 131.00 micro Siemens per cm at 25 ^{0}C compared to 1000 micro Siemens per cm at 25^{0}C as the permitted maximum by the Nigerian Water quality standards. It is evident that these values are considerably low in comparison with the critical limit of 4 milli Siemens per

centimetre for waters of high salt content with a possibility of inducing salinity. The higher value at chlorination stage could be as a result of the calcium hypochlorite used as disinfectant and higher chloride content in the chlorinated water sample. Despite this, the values are still considerably low. Therefore, the ABU treated water is within acceptable limits of local and international standards (SON, USEPA and WHO standards).

4.2.1.4 Salinity

The salinity measurements were undertaken but values were consistently not detectable. The method used which involves electrical conductivity for measuring salinity is the recommended method in the standard methods for the examination of water and wastewater 20th edition (APHA, 1998). Salinity in the water is minimal, thereby positively contributing to high water quality.

4.2.1.5 Residual Chlorine

Residual chlorine was also below detectable limit in most of the determinations. This is a dangerous development because residual chlorine is necessary to safeguard water in the distribution network against contamination after the disinfection in the treatment plant, especially when pipe breakages occur in the distribution network. It is suspected that the absence of a functional service laboratory further compounded this problem.

4.2.1.6 Total Organic Carbon

The average Total Organic Carbon (TOC) content measured ranged from 2.2 to 6.65 mg/l with the highest values recorded in the raw water; while the least values were recorded for boiled household water. There was a gradual decline in the concentrations as raw water was progressively treated along the treatment line. It reduced to 2.25 mg in the chlorinated water and increased in the booster station to 2.40 mg/l.

Table 4.6: Mean Values of General Chemical Properties of Conventionally Treated Drinking Water from the A.B.U. Water Treatment Plant

Parameter	Raw Water	Sedimentation water	Chlorinated water	Booster Station water sample	House Level water (Area E)	Area E Boiled water sample
pH	7.8	7.6	7.8	8.0	6.7	7.0
Total Dissolved solids (TDS mg/l)	50.50	50.50	51.50	55.00	66.00	70.00
Salinity (%)	0.00	0.00	0.00	0.00	0.00	0.00
Total Organic Carbon (TOC mg/l)	6.65	4.4	2.25	2.40	2.30	2.20
Residual Chlorine (mg/l)	0.00	0.00	0.00	0.00	0.00	0.00
Conductivity (μS/cm @ 25^0C)	83.50	102.50	131.00	121.00	102.00	66.00
Nitrates (mg/l)	3.00	2.40	0.80	0.80	1.40	0.80
Phosphate (mg/l)	0.30	0.15	0.25	0.15	0.10	0.10
Chloride (mg/l)	12.30	0.80	12.65	0.50	0.50	0.70
Sulphate (mg/l)	40.00	23.00	22.50	24.50	42.00	42.00

This is due to the formation of biofilms in the storage tanks at the booster station since it is not always filled with water. Subsequently, the concentration drops towards household level due to biofilms involvement in depleting residual disinfectant (Jakubovics, 1998; LeChevallier, 2000). The observed low value in the boiled water could be traced to the breakdown of the TOC during boiling. Generally, these concentrations are well within acceptable levels in the Nigerian and International standards and the trend in concentrations are consistent with normal trend in which raw water (with 8 mg/l) is usually higher in concentrations than treated water (with 2 mg/l).

4.2.1.7 Sulphate Concentration

Sulphate concentration was from 23.00 mg/l in the sedimentation water sample to 42.00 mg/l for household level in Area 'E'20. The higher values in the household sample could be attributable to either biofilms created in the distribution network for the same reasons as earlier adduced (Jakubovics, 1989; LeChevallier, 2000). These values are considerably lower than the range of proportions in the national drinking water standards (100 mg/l) as well as those of the international standards for drinking water with maximum concentration of 250 mg/l (USEPA and EU) and 500 mg/l (WHO) as in Table 4.8.

4.2.1.8 Nitrate Concentration

Average nitrate concentration was from 0.80 mg/l to 3.00 mg/l. The highest concentration was obtained from raw water while the least concentration of 0.80 mg/l was obtained in the samples after chlorination, booster station, and household water after boiling. The highest value for the raw water is consistent with the high mobility of the nitrogen in the environment. The decrease in the sample after sedimentation could be traced to the flocculation process while the slight increase at the household level sample is probably either due to biofilms created because the distribution network is not always filled with water (because of the periodical distribution of water) or external inflow into the distribution network as a result of distribution failures

(Tisdale and Nelson, 1993; Mason, 2002). Despite this, the average values of nitrates in the treated water samples are considerably lower than the range of values in national drinking water standards (50 mg/l) and those of international standards (10 mg/l MCL and MCLG for the USEPA, 50 mg/l for the WHO and EU standards) (Table 4.8).

4.2.1.9 Phosphate Concentration

Average phosphate values for the water decreased down the treatment line to the household after boiling. The concentrations ranged from 0.30 mg/l in the raw water to 0.10 mg/l in the household water and boiled household water sample. This is probably due to the influence of biofilms that grow on the pipe surfaces due to intermittent water supply as reported earlier (Jakubovics, 1998; LeChevallier, 2000).

4.2.2 Concentration of Heavy Metals in ABU Treated Drinking Water

Table 4.7 shows the mean concentrations of heavy metals in the treated water from the Ahmadu Bello University water works. Among the six heavy metals determined, only two were detected in the treated water at various sampling points; while a third was only detected at one of the sampling points. Others were not detected in any of the samples. Chromium was not detectable in the raw water, nor was it detected in any of the samples undergoing treatment or at the household level sample. Similarly, Cadmium and manganese were not detectable in any of the samples.

4.2.2.1 Iron Concentration

Iron on the other hand was detected only in the raw water sample but was not detected in the treated samples. or the samples at the household level. This study showed that the iron in the raw water was removed during the treatment process at sedimentation after flocculation (USEPA, 1990a).

Table 4.7: Mean Heavy Metal Concentration in the Conventionally Treated Drinking Water from the A.B.U. Water Treatment Plant

Parameter (mg/l)	Raw Water	Sedimentation water	Chlorinated water	Booster Station water sample	House Level water (Area E)	Area E Boiled water sample
Chromium (Cr)	ND	ND	ND	ND	ND	ND
Lead (Pb)	0.040	0.040	0.035	0.035	0.035	0.01
Zinc (Zn)	0.010	0.035	0.025	0.030	0.050	0.030
Cadmium (Cd)	ND	ND	ND	ND	ND	ND
Iron (Fe)	3.45	ND	ND	ND	ND	ND
Manganese (Mn)	ND	ND	ND	ND	ND	ND

ND = Not Detected

The level of iron in the raw water is traceable to eroded particulates from the weathering products of aluminosilicates to form sesquioxides (Al_2O_3, and Fe_2O_3) (Tisdale, 1993). This had been removed in the treatment process and as such poses no danger to the drinking humans. The not detectable levels means the prevailing concentration is significantly lower than the levels that the equipment can detect and these are far below the Maximum Contaminant Levels expressed by national (0.3 mg/l) and international standards (USEPA, 0.30 mg/l and EU limit of 0.20 mg/l). When drinking water contains appreciable quantities of iron, the iron imparts taste to the water which consumers normally object to.

4.2.2.2 Lead Concentration

The detectable heavy metals in the treatment process were iron, lead and zinc. Average Lead concentrations were from 0.01 to 0.04 mg/l. The higher values were obtained in the raw water samples and samples after sedimentation. The values decreased to 0.035 mg/l in the samples after chlorination and this level was maintained on to the household level samples. This observation indicates that there is a significant loading of lead into the raw water source. It is most likely that drainage water from Samaru is significantly loaded with effluent from mechanical workshops and automotive battery sheds that are rich in lead wastes from de-commissioned automotive batteries close to the channel flowing into the Kubanni reservoir.. It is also likely that these concentrations are increased by dry and wet deposition of lead particulates from exhaust fumes of automobiles plying the main highway from Zaria to Funtua and even from vehicular traffic in Samaru village. These values are significantly higher than total lead concentrations permitted in national (0.01 mg/l) and in international standards [below detectable limit - USEPA (MCLG) 0.01 mg/l (WHO) and 0.01 mg/l (EU)]. There is a serious risk of kidney and nervous system damage among consumers of the water treated at the ABU water treatment plant (Table 4.8; USEPA, 2003; USEPA 2011). The trend is probably indicating a relatively low removal of the lead fractions during the treatment process, especially

in the sedimentation stage. Therefore, inflow from Samaru village need to be diverted and treated to remove lead before discharge into the Kubanni Lake as against the present practice of direct discharge into the lake.

4.2.2.3 Zinc Concentration

The average concentration of zinc recorded for the different samples ranged from 0.01 mg/l in the raw water to 0.05 mg/l for household water. This concentration at the household could be due to biofilms formation in the distribution network as a result of intermittent flow and sometimes inflow of contaminated water into the distribution mains during distribution network failures (Jakubovics, 1998; LeChevallier, 2000). Zinc is common and naturally occurring in air, soil and water. A trace element, a micronutrient and an essential element, it is a mineral of exceptional biological and public health importance. Its deficiency causes growth retardation in children, delayed sexual maturity, susceptibility to infection, diarrhoea, birth defects and contribute to death of 800,000 children worldwide. Too little of the element causes loss of appetite, decreased sense of taste and smell, slow wound healing and skin sores. Too much however stomach cramps, skin irritations, vomiting, nausea, and anaemia. Very high levels can cause damage to the pancreas and disturb protein metabolism. It is strongly liable to bio-accumulation. Even though a trace element, it occurs readily is soils and available to plants as a micronutrient it is highly needed for the successful growth of crops. From the soil, it dissolves in soil solution and subsequently washes into the surface waters. Anthropogenically, zinc is added to the environment through waste generation and handling, resulting in increased levels to induce toxicity effects listed above as effects of excess doses (Tisdale, 1993; Lenntech, 2011). Despite these, however, the observed levels of zinc are far lower than the national maximum permitted level of 3.0 mg/l and also lower than the international drinking water standard value of 5.0 mg/l (USEPA MCL). Therefore the treated water is safe with respect to zinc concentration.

4.3 Disinfection By-Products of the Halo-alkanes, Acetonitriles *other* Disinfection By-Products and Chlorinated Solvents in ABU treated Drinking water

Figures 4.1 to 4.3 below show the chromatograms of the water samples from the ABU water treatment plant and supply to households. Figure 4.4 is of the chromatograms of household boiled water, while Figures 4.5 (a) and (b) contain the chromatograms of FMU samples from household volunteers. Table 4.9(a) and (b) show the mean concentrations of halo-alkanes, acetonitriles and chlorinated solvents as determined in the Ahmadu Bello University treated and distributed drinking water. These include nine of the eleven regulated DBPs and the rest are part of the emerging DBPs (USEPA, 1995). From the table it is observed that various ranges of concentrations were obtained for the categories of analytes listed.

4.3.1 Halo-alkanes

4.3.1.1 Trichloromethane (chloroform)

From Table 4.9(a), mean values of Trichloromethane (Chloroform) content in the water was from below detectable limit to 0.0049mg/l. (4.9µg/l). The raw water and the water after sedimentation had concentrations that were below detection. Higher values were observed in the first morning urine (FMU) samples of the volunteer occupants of A.B.U House number E 20 that were between 0.0033 and 0.0105 mg/l. The concentration in the urine of the family head was found to be considerably higher than those of the other occupants. The average mean urine concentration was 0.00773 mg/l, 258% higher than the boiled water concentration of 0.0030 mg/l. These concentrations are far lower than the requirements of international standards. The WHO, EU and national drinking water standards, did not set a requirement for this particular compound. It is only the USEPA that had set individual maximum contaminant level goal (MCLG) for this compound at 0.07 mg/l. From this perspective, it is revealed that the ABU treated water is safe from the contamination with trichloromethane (Chloroform)

.

Table 4.8: National and International Drinking Water Quality Standards, (SON, 2007; USEPA, 2011a; WISE, 2011)

Contaminant	Potential Health Effects from Long time Exposure above the MCL from ingestion of water	Nigerian National Drinking Water Standards (Max. Permitted Levels (mg/L))	USEPA		WHO		EU	
			MCL (mg/L)	MCLG (mg/L)	MCL (mg/L)	MCLG (mg/L)	MCL (mg/L)	MCLG (mg/L)
Bromodichloromethane	Cancer, Liver, Kidney, Reproductive effects		See TTHMs	Zero				
Bromoform	Cancer, Nervous system, Liver, Kidney effects		See TTHMs	Zero				
Dibromochloromethane	Nervous System, Liver, Kidney, Reproductive effects		See TTHMs	0.06				
Chloroform	Cancer, Liver, Kidney, Reproductive effects		See TTHMs	0.07 OR 70 ppb				
Total Trihalomethanes (TTHMs)	Increased Risk of Cancer, Liver, Kidney or Central Nervous system problems	0.001	0.080	N/A			0.10	
Dichloromethane					0.02			
Dichloroacetic acid	Cancer and other effects			Zero				
Trichloroacetic acid	Possibly cancer and Reproductive effects		See HAA_5	0.02				
Monochloroacetic acid	Increased risk of Cancer		0.06	0.07				
Haloacetic acids (HAA5)	Increased risk of Cancer		0.060	N/A				
Carbon tetrachloride	Cancer		0.005	Zero	0.002			
1,2-Dichloroethane	Cancer		0.005	Zero	0.030		0.003	
1,1-Dichloroethane					-			

Table 4.8 cont'd

Contaminant	Potential Health Effects from Long time Exposure above the MCL from ingestion of water	Nigerian National Drinking Water Standards (Max. Permitted Levels (mg/L))	USEPA		WHO		EU	
			MCL (mg/L)	MCLG (mg/L)	MCL (mg/L)	MCLG (mg/L)	MCL (mg/L)	MCLG (mg/L)
1,1-Dichloroethylene	Cancer		0.007	0.007				
1,1,1-Trichloroethane	Cancer		0.2	Zero	2.00			
1,1,2-Trichloroethane	Cancer		0.005	Zero				
Trichloroethylene	Cancer		0.005	Zero				
1,1-Dichloroethene					0.03			
Trichloroethene					0.07			
1,2-Dichloroethene					0.05			
Tetrachloroethene					0.04			
1,2-Dibromo-3-chloropropane					0.001			
1,2-Dichloropropane					-			
1,3-Dichloropropane					0.020			
Aluminum			0.05 to 0.02				0.20	
Chloride		250	250				250	
Colour			15 colour units		-		Acceptable to consumers	
Copper	Gastrointestinal irritation	1.00	1.00		2.00		2.0	
Lead	Kidneys, Nervous System damage	0.01	TT+	Zero	0.01		0.01	
Flouride		1.50	2.00		1.50		1.50	
Iron		0.30	0.30		-		0.20	
Manganese		0.20	0.05				0.05	
pH		6.5 – 8.5	6.5 – 8.5		-			

Table 4.8 cont'd

Contaminant	Potential Health Effects from Long time Exposure above the MCL from ingestion of water	Nigerian National Drinking Water Standards (Max. Permitted Levels (mg/L))	USEPA		WHO		EU	
			MCL (mg/L)	MCLG (mg/L)	MCL (mg/L)	MCLG (mg/L)	MCL (mg/L)	MCLG (mg/L)
Sulphate		100	250		500		250	
TDS		500	500		-			
Zinc		3.0	5.00					
Cadmium	Kidney effects	0.003	0.005	0.005	0.03		0.005	
Chromium (total)	Liver, Kidney, Circulatory disorders	0.05	0.10	0.10	0.05		0.05	
Nitrate	Methaemoglobulinemia	50	10	10	50		50	
Nitrite	Methaemoglobulinemia	0.2	1	1	50		0.50	
Ammonium					0.20		0.50	

The American Conference of Government industrial Hygienists set threshold limit value (TLV) of 10 mg/l for the compound (ACGIH, 1994-1995) which is significantly higher than of the determined values. Therefore, there is no serious risk of the cancer, liver and kidney diseases and central nervous system problems usually associated with the analyte. The FMU samples are considerably higher by over 250% than the individual water concentrations especially the boiled household water for drinking. This is an indication of increased excretory activities of the kidneys to maintain the homeostatic status of the body fluids as well as the concentration of these contaminants which may have accumulated earlier in the body systems of the volunteers ((MedlinePlus, 2011; Tutorvista, 2011; NKUDIC, 2011). In view of the fact that TLVs are not only dependent on the concentration of the contaminants alone it is dependent on the susceptibility of the body to the emergent disease, such earlier bioaccumulation will ultimately tip beyond the threshold limit and subsequently result in the emergence of serious diseases which an overworked kidney may experience (ACGIH, 1994-1995).

4.3.1.2 Tribromomethane

Tribromomethane (Bromoform) concentrations in the treated waters were from below detection limits in the raw water and sedimentation water sample to 0.0078 mg/l in the booster station. The concentration (0.0067 mg/l) in the water after chlorination increased to 0.0078 mg/l in the booster station probably due to the reaction between remaining disinfectant or residual disinfectant with some of the dissolved organic matter from biofilms formed due to partial filling of the booster tanks.

From the booster station, the bromoform concentration decreased to 0.0040 mg/l at household level which subsequently decreased to 0.0038 in the boiled household drinking water. With the first morning urine samples, concentrations ranging from 0.0036mg/l to

0.0054 mg/l with an average value of 0.00467 mg/l, shows that urine samples have bromoform concentrations higher (123%) than the boiled water concentration. Despite fact that the boiled water concentration ((0.0038 mg/l).was higher than that of the family head volunteer (0.0035 mg/l), the average urine concentration (0.0044 mg/l) was still higher than the concentration of the house level boiled drinking water indicating increased excretory activities of the kidneys. This increased excretion by the kidneys could be due to either a hormonal imbalance, or a higher than normal urine formation. It could also be due to a malfunctioning kidney because of diseases like inflammation or because of higher proportion of the bromoform and its fractions from the boiled water in the blood due to previous bioaccumulation of the compound (MedlinePlus, 2011; Tutorvista, 2011; NKUDIC, 2011). As in the case of the chloroform, the national standards did not provide a maximum permissible level for the compound as are with the WHO and the EU standards. Only the USEPA standards set the maximum contaminant level goal for the compound to be below detectable limit. The national and EU standards set a maximum contaminant level for a group of halo-methanes which include the compound. The presence of bromoform in drinking water increases the risk of disease occurrence irrespective of the fact that its concentration is low. It is against this background that the USEPA set a targets objective of below detectable limit as its maximum contaminant level goal (MCLG) in treated drinking water. This is because Bromoform is one of the priority halo methanes (and hence regulated) as it had been found to induce cancer in experimental animals, cause reproductive abnormalities and cause injury to the nervous system. The risk of these health effects have been duly acknowledged (Table 4.8; USEPA, 2011(a); WISE, 2011) among humans especially in the incidences of cancer. This is the risk posed by bromoform in ABU treated drinking water.

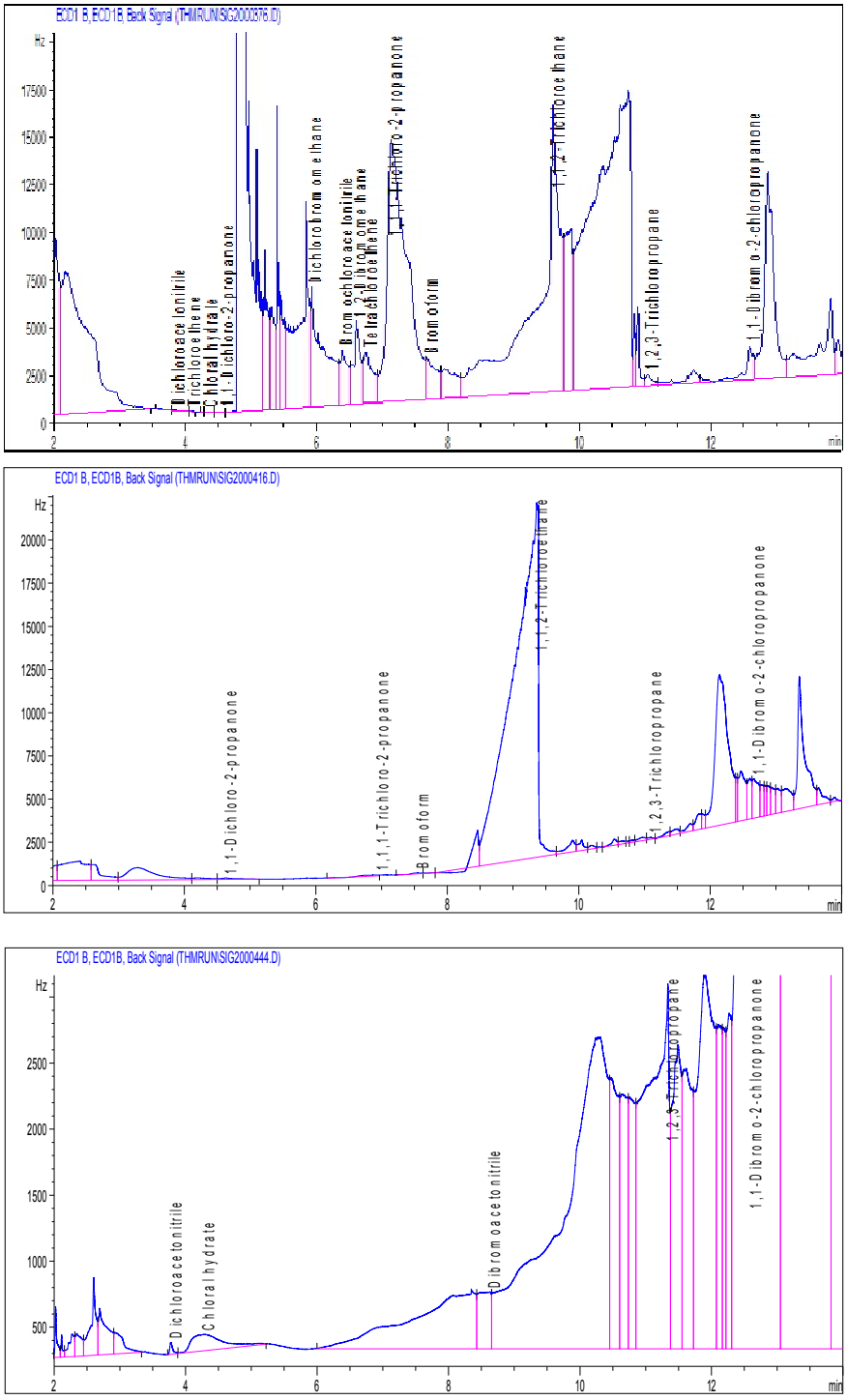


Fig 4.1: Some Gas Chromatograms of THMs, Acetonitriles, other DBPs and Chlorinated solvents in treated water from ABU water treatment plant after chlorination

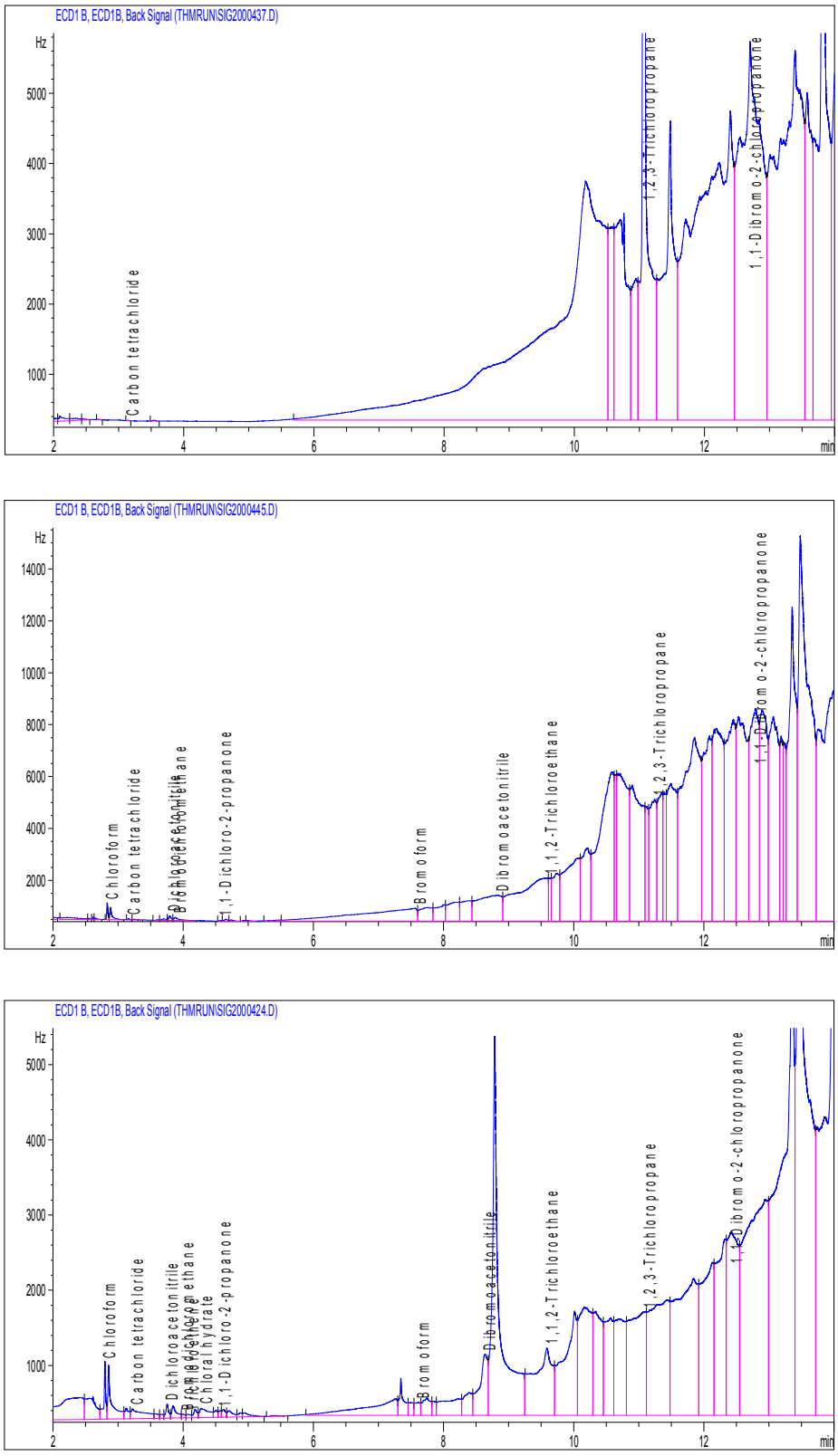


Fig4.2: Some Gas Chromatograms of THMs, Acetonitriles, other DBPs and Chlorinated solvents in treated water from ABU water treatment plant in the Booster Station

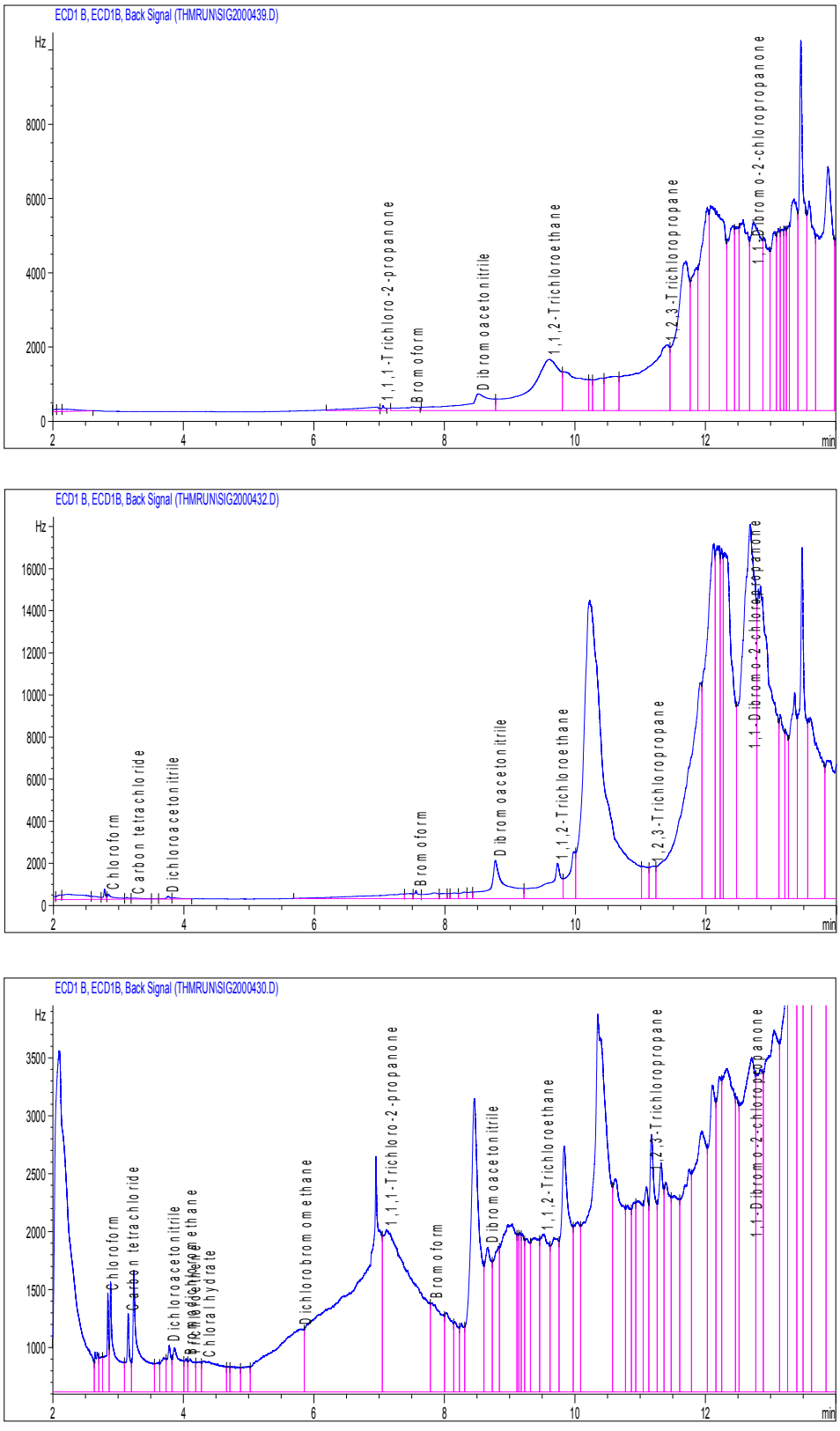


Fig4.3: Some Gas Chromatograms of THMs, Acetonitriles, other DBPs and Chlorinated solvents in treated water from ABU water treatment plant at Household level

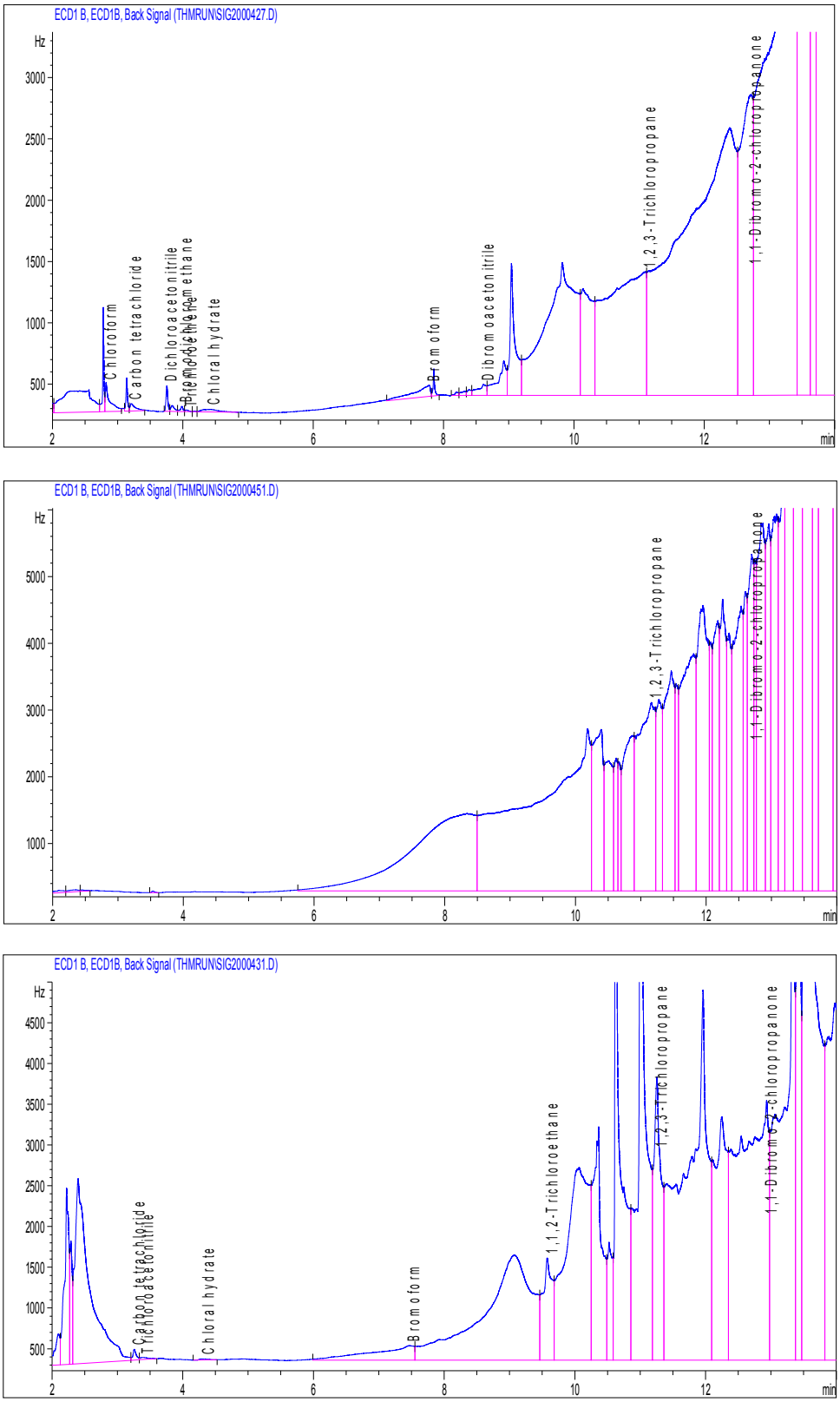


Fig4.4: Some Gas Chromatograms of THMs, Acetonitriles, Other DBPs and Chlorinated solvents in Boiled water from ABU water treatment plant at Household level

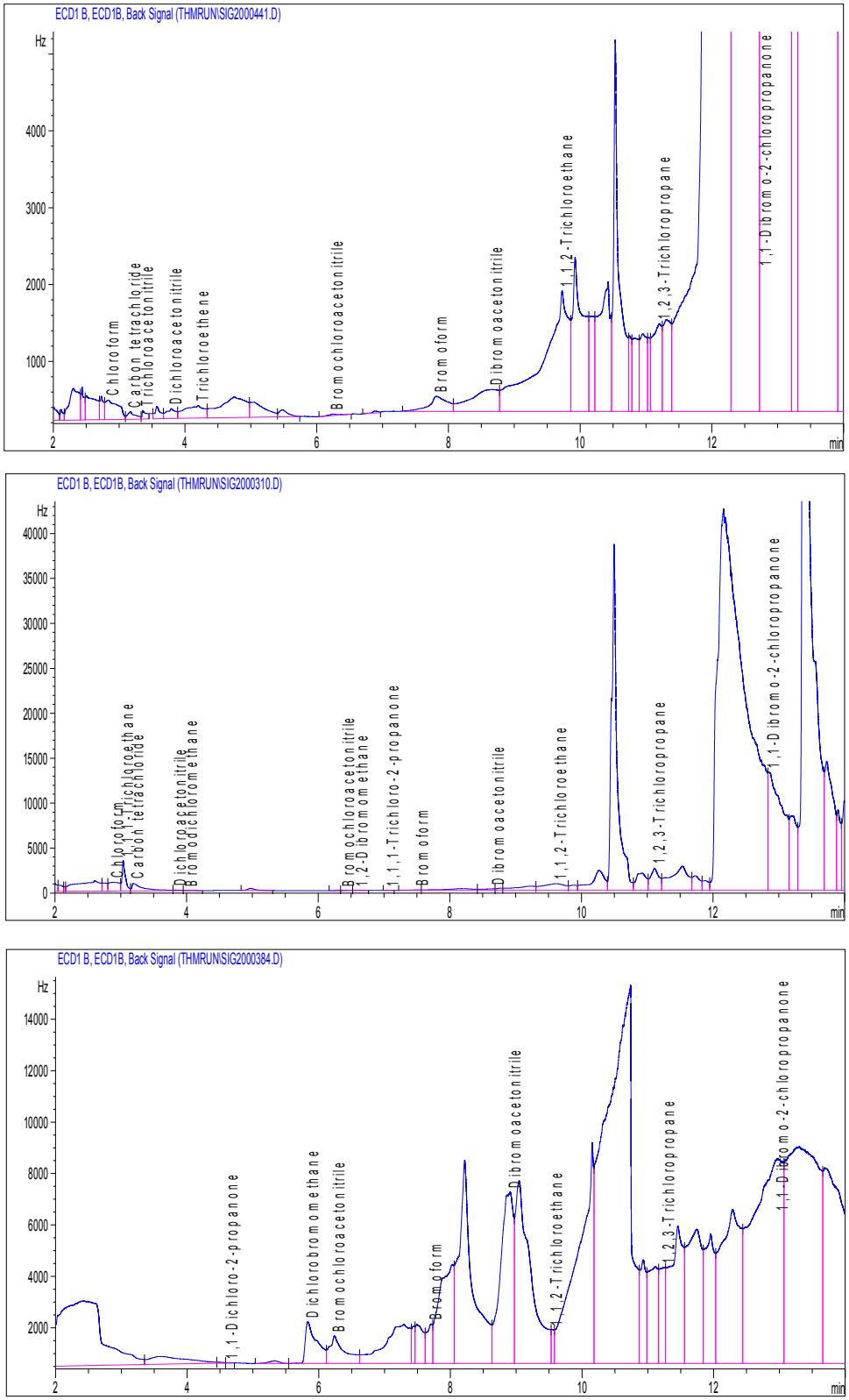


Fig4.5(a): Some Gas Chromatograms of THMs, Acetonitriles, other DBPs and Chlorinated solvents in some First Morning Urine (FMU) Samples of some Area 'E' No. 20 Household occupants

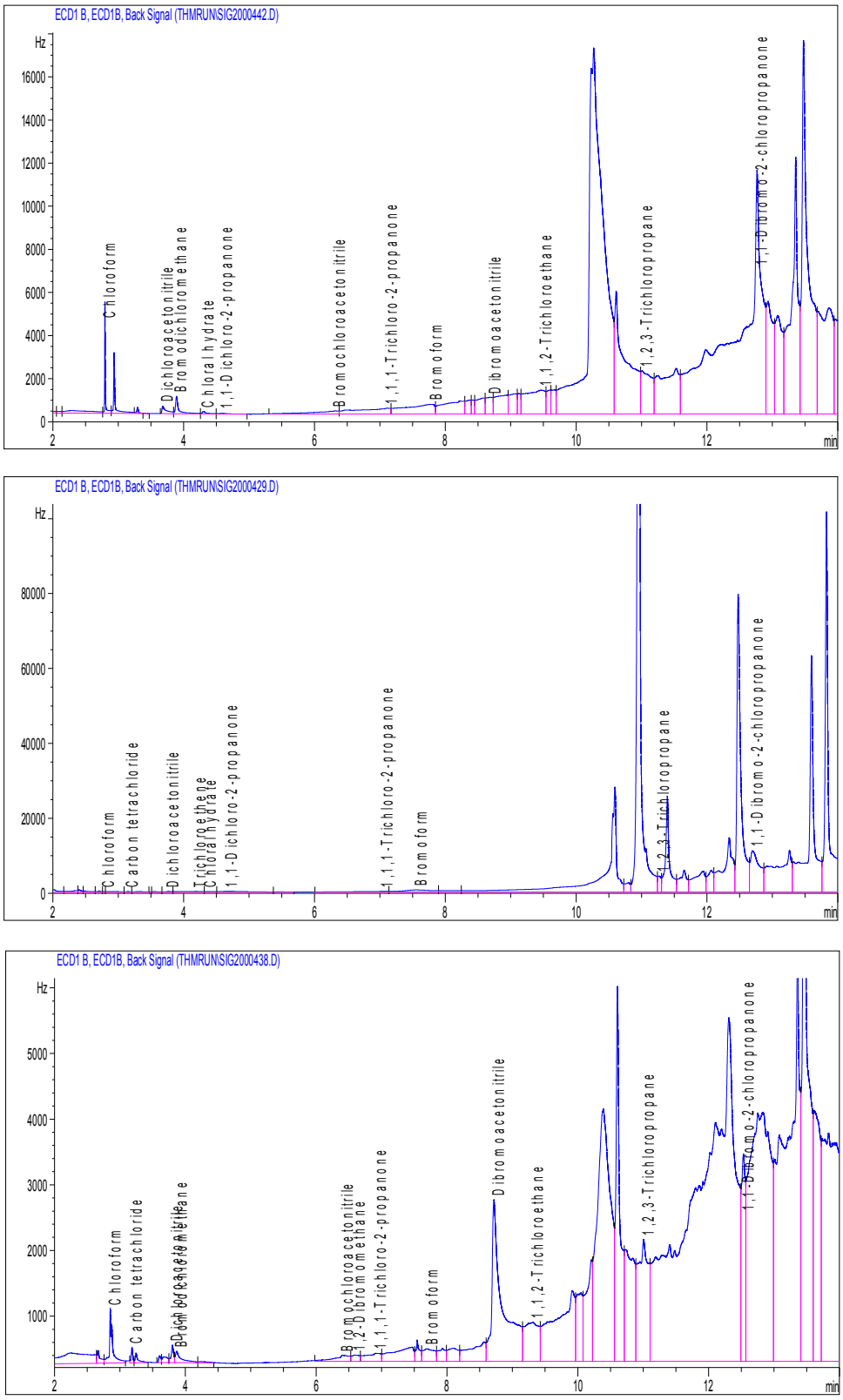


Fig4.5(b): Some Gas Chromatograms of THMs, Acetonitriles, other DBPs and Chlorinated solvents in some First Morning Urine (FMU) Samples of some Area 'E' No. 20 Household occupants

Table 4.9(a) Mean Levels of Halo-alkanes, Acetonitriles in Drinking Water Samples from ABU Water works and the Resulting Urine Samples.

	Raw Water	Water after Sedimentation	Water after chlorination	Booster Station	Household water	Boiled water	Dad's FMU	Mom's FMU	Son's FMU
Tri Halo Methanes (THMs) (mg/L)									
Trichloromethane (Chloroform)	0.00	0.00	0.00	0.0027	0.0038	0.0030	0.0105	0.0049	0.0033
Tribromomethane (Brmomform)	0.00	0.00	0.0067	0.0078	0.0040	0.0038	0.0036	0.0054	0.0050
Dibromochloromethane	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bromodichloromethane	0.00	0.00	0.00	0.0026	0.0029	0.0025	0.0026	0.0037	0.0029
Sub Total TTHM$_4$	***0.00***	***0.00***	***0.0067***	***0.0131***	***0.0107***	***0.0093***	***0.0167***	***0.014***	***0.0112***
Dichlorobromomethane	0.00	0.00	0.4322	0.00	0.0997	0.00	0.00	0.0691	0.00
1,2-Dibromomethane	0.00	0.00	0.0535	0.00	0.00	0.00	0.0027	0.00	0.0042
Total Halo Methanes (TTHMs)	**0.00**	**0.00**	**0.4924**	**0.0131**	**0.1104**	**0.0093**	**0.0194**	**0.0831**	**0.0154**
Haloacetonitriles (mg/L)									
Bromochloroacetonitrile	0.00	0.00	0.0139	0.00	0.00	0.00	0.0024	0.0052	0.0030
Dibromoacetonitrile	0.00	0.00	0.0106	0.0241	0.0247	0.0049	0.0102	0.0368	0.0222
Dichloroacetonitrile	0.00	0.00	0.0009	0.0013	0.0022	0.0012	0.0018	0.0063	0.0019
Trichloroacetonitrile	0.00	0.00	0.00	0.00	0.00	0.0035	0.0036	0.00	0.00
Total Acetonitriles	**0.00**	**0.00**	**0.0254**	**0.0254**	**0.0269**	**0.0096**	**0.0180**	**0.0483**	**0.0271**

FMU – Refers to First Morning Urine sample

4.3.1.3 Dibromochloromethane

Dibromochloromethane was not detected in the ABU treated drinking water during this study. It does not therefore pose any health risk to anyone drinking the water.

4.3.1.4 *Bromodichloromethane*

Bromodichloromethane fractions were detected in the treated water from the booster station onwards. The raw water and the water after sedimentation had below detectable concentrations. Subsequently, these concentrations increased to 0.0026 mg/l in the booster station, to 0.0037 mg/l in the urine samples of the volunteer mother in Area 'E' 20. The increase in the concentration from the booster station to the household level could be due to the increase in acidity (from pH 8-0 to 6.7). However, the proportion observed at household level also decreased when boiled, most probably due to thermal dissociation during the boiling process. That is also probably due to the effect of heating of the water during boiling which tend to vaporize fractions of the halo-methane. The first morning urine samples showed concentrations that were higher than the concentration in the boiled water at household level. Specifically, the average of the FMU samples' mean concentration (0.0031 mg/l) is considerably higher than the boiled water sample mean concentration, indicating increased excretion by the kidneys. This increased excretion by the kidneys could be due to either a hormonal imbalance, or a higher than normal urine formation. It could also be due to a malfunctioning kidney because of diseases like inflammation or because of higher proportion of the Bromodichloromethane and its fractions from the boiled water in the blood due to previous bioaccumulation of the compound (MedlinePlus, 2011; Tutorvista, 2011; NKUDIC, 2011). This biological phenomenon is capable of many health implications such as increases in the incidences of cancer, damage to the reproductive organs, kidney and liver as well as nervous system disruption.

4.3.1.5 Dichlorobromomethane

The concentrations of dichlorobromomethane in the samples varied from below detectable limit to 0.4322 mg/l. Two of the sampled waters and one urine sample recorded concentrations of the analyte greater than below detectable limit. These are the water sample after chlorination which recorded the highest concentration of Dichlorobromomethane at 0.4322 mg/l; the urine sample with 0.0691 mg/l; and the household water which had 0997 mg/l. The observed high concentration of the dichlorobromomethane in the chlorinated sample is due to the fact that the added chlorinated disinfectant, on contact with the dissolved organic matter, reacts to form maximum proportions of this and other disinfection by-products. It is from here that the quantities detected at other sampling points are derived, after compensating for losses due to the flow pattern and friction (USEPA, 2011(A); Goslan, *et al* 2009). In view of this, the household levels are lower than the levels immediately after the chlorination. It is noted that during the boiling of the household water, there were losses of dichlorobromomethane but somehow, the compound reappeared in the urine sample despite its absence in the boiled water. This could be traced to the likelihood of speciation of the compound with its nearest halo-alkane neighbours (Bougeard *et al* 2010), causing it to emerge in the urine samples. As a result, the low level in the urine sample is either indicative of the low level of transmutation and speciation in the body system or could indicate alternative source of absorption by the body other than ingestion through drinking water. The national standards did not include it among the compounds the existing standards determined the maximum permissible level in drinking water. Although not generally considered as one of the priority and regulated halo-methanes grouped in the various international standards, it is still necessary that more research is conducted on it to ascertain the level of impact it has on the body

metabolism and the likelihood or otherwise of its involvement in causing the diseases noted for the halomethanes.

4.3.1.4 1,2-Dibromomethane

The concentrations of 1,2-Dibromomethane in the sampled water were found to vary from below detection to 0.0535 mg/l, for the sampled waters while the urine samples ranged between 0.027 and 0.0042 mg/l with average concentration of 0.00345 mg/l. While most of the water samples had concentrations that were below detection it was the water after chlorination that had higher concentration (0.0535 mg/l). Subsequently, the water samples did not contain any more of the compound. It is likely that the compound is unstable and had undergone dissociation due to the high volatility of halo-alkanes, rendering it to be below detection. Its occurrence in the urine is a likely pointer to speciation, which may have arisen as a result of re-composition of the ingested components in the body (Bougeard *et al*, 2010). 1,2-Dibromomethane and dichlorobromomethane have not received as much attention like the regulated halo-alkanes and as such they are not usually included in the various standards. More studies need to be conducted to ascertain their level of involvement in inducing diseases and the types of diseases they are involved in. this will enable the determination of their maximum permissible levels to be included in the national standards.

4.3.1.5 Total Regulated Halo-Alkanes

From the study, the total mean concentrations of the regulated halo-methanes (chloroform, bromoform, Dibromochloromethane and bromodichloromethane) are in the range from 0.0067 mg/l in the water sample after chlorination to 0.0131 mg/l in the booster station sample and from 0.0107 mg/l in the household level sample to 0.0093

mg/l in the boiled water sample. The increase in the booster station sample over the sample after chlorination could be due to development of biofilms leading to higher total organic carbon (TOC) in the booster station, (2.40 as against 2.25 mg/l). Since dissolved organic matter is a precursor to the formation of chlorinated disinfection by-products, the increased fraction of TOC could have reacted with whatever disinfectant fractions that were present to form higher concentration of the disinfection by-products (Jakubovics, 1998; LeChevallier, 2000). The increased TOC could have arisen because of the formation biofilms in the booster station tanks due to fluctuations in the water level in the tanks. The decreasing level at the house level concentration is probably due to losses in the distribution as a result of frictional losses and flow characteristics (Stevens et al 1989; USEPA, 1997). The concentrations of these regulated THMs in the FMU samples ranged from 0.0112 to 0.0167 mg/l. The average of these mean sample concentrations is 0.01397 mg/l in the urine samples. When compared to the concentration of the boiled water sample, the urine samples are 150% higher than boiled water samples in these regulated halo-methanes. This indicates high excretory activities of the kidneys which could be due to either a hormonal imbalance, or a higher than normal urine formation. It could also be due to a malfunctioning kidney because of diseases like inflammation or because of higher proportion of the regulated Trihalomethanes and their fractions from ingested boiled water in the blood due to previous bioaccumulation of these compounds (MedlinePlus, 2011; Tutorvista, 2011; NKUDIC, 2011). It may also likely indicate other sources of ingestion of the Trihalomethanes apart from drinking the treated and boiled water source. On the possibility of bioaccumulation of the Trihalomethanes and due to the increased excretory activities of the kidneys, these have implication for the human health in injury and diseases to the overworked kidney and risks of cancer, disruption to the nervous system and liver damage

which these compounds have been known for (USEPA, 2011(A)). When compared to international standards the concentration of the total four Trihalomethanes ($TTHM_4$ – the 4 regulated halomethanes) are considerably lower than the maximum contaminant levels for the sum of the concentrations in the USEPA (0.080 mg/l) and EU (0.10 mg/l) but higher than the national standard level of 0.001 mg/l. However, due to likely bio-accumulation, increased excretion of these substances by homeostasis in human tissues as indicated in the urine samples results. The adopted maximum contaminant level goal of the USEPA for these regulated halo-methanes (below detectable limit) should be the ultimate objective. This notwithstanding, the higher than national standards maximum permitted concentration of 0.001mg/l is a source of worry to consumers of ABU treated water and should be a concern for the ABU water treatment plant operators.

4.3.2 Acetonitriles

In this study, four acetonitriles were analysed for in the water samples collected. These are Bromochloroactonitrile, Dibromoacetonitrile, Dichloroacetonitrile and Trichloroacetonitrile. These four are an important group of disinfection by-products in the conventional treatment of drinking water (USEPA, 1995).

4.3.2.1 Bromochloroacetonitrile

Mean concentrations of Bromochloroacetonitrile were from below detection to 0.0139 mg/l in the water samples while the urine samples had between 0.0024 mg/l and 0.0052 mg/l. The observed concentration in the water sample after chlorination was lost in the distribution network up to the household. The emergence of the compound in the urine samples probably indicates a possibility of speciation and re-composition of the components of the decomposition to give lower fractions than was determined in the water sample after chlorination (Bougeard *et al*, 2010). Unlike the halo-alkanes and

halo-acetic acids, these acetonitriles are not included in the national standards and the various international standards in terms of their regulation, which would warrant setting their maximum contaminant levels or maximum contaminant level goals or maximum permissible levels. This could be due to the fact that not enough information had been obtained about them. As a result, their capacity to accumulate in biological tissues, their long term and short term effects in the body should be studied in details.

4.3.2.2 Dibromoacetonitrile

Dibromoacetonitrile concentrations range from below detectable limit in the raw water and water at sedimentation to 0.0247 mg/l for the sampled waters. On the other hand, the urine samples had values ranging from 0.0102 mg/l to 0.0368 mg/l. While the water samples showed increased concentration from the chlorination stage to household, level, the boiled water concentration was lower in dibromoacetonitrile concentration. This could be due to the combined influence of increasing total organic carbon (2.25 to 2.30 to 2.40 mg/l) chlorination towards the household level. This increase in TOC is traceable to biofilms development in the booster station and the distribution mains due to intermittent water supply (Jakubovics, 1998; LeChevallier, 2000) and changes in the reaction of the distribution system which became slightly acidic (pH 6.7) in as distribution progress to the household level (USEPA, 1997). It is probably due to the dissociation of the compound on boiling. The higher urine concentrations indicate increased excretion by the kidneys, due either to a possible hormonal imbalance, or a higher than normal urine formation, or a likely malfunctioning kidney as a result of diseases like inflammation among others. It could also be due to higher concentration of the dibromoacetonitrile in the blood stream from previous bioaccumulation. (MedlinePlus, 2011; Tutorvista, 2011; NKUDIC, 2011).

This has a likelihood of causing a biological injury or damage to the body in the form of a disease occurrence.

4.3.2.3 Dichloroacetonitrile

Dichloroacetonitrile had mean concentrations in the various water samples ranging from below detectable limit to 0.0022 mg/l. The urine concentrations range from 0.0018 to 0.0063 mg/l. A close observation shows that the concentrations of the dichloroacetonitrile in the water increased progressively from the raw and sedimentation to the household level where the concentration was 0.0022 mg/l. The boiled water had a lower concentration than the household water (0.0012 compared to 0.0022 mg/l). The reason for the lower mean value for the boiled water sample is probably due to the effect of boiling (resulting in evaporation, dissociation or decomposition of compound). The mean concentration in the urine samples (0.03333 mg/l) is considerably higher than in the boiled water sample of 0.0012 mg/l. This could have arisen from a previous bioaccumulation of the compound from the water consumed or another source of absorption of the compound by the body. Physiologically the body responds to this elevated level by inducing increased excretion by the kidneys. The increased excretory activities of the kidneys may likely cause the kidneys to be over worked in order to maintain the homeostatic status of the blood stream and body fluids which can result in injury and damage to the kidney and the body (MedlinePlus, 2011; Tutorvista, 2011; NKUDIC, 2011; USEPA, 2011(A)). A review of national and international standards shows no limits set for the compound probably due to its limited study and available information. It is therefore pertinent that more studies be focussed on dichloroacetonitrile as well as other acetonitriles to provide more detailed information about their potential health impacts.

4.3.2.4 Trichloroacetonitrile

From the table of results, traces of Trichloroacetonitrile were noticed in the boiled water sample and from some urine samples while majority of the other samples did not show significant levels of the compound. The reasons for this observation cannot be immediately explained.

4.3.2.5 Total Acetonitriles

These are the sum of mean concentrations of the analysed four acetonitriles. Their concentrations were found to vary between below detection and 0.0269 mg/l for water samples, while the urine samples were between 0.0180 and 0.0483 mg/l. The total mean concentrations for the water increased up to the household level probably due to increasing total organic carbon (from 2.25 to 2.40 mg/l) and increasing level of acidity (pH 7.8 to 6.7). But, concentration of acetonitriles in boiled water was lower than that of household water due to heat induced dissociation or decomposition in boiling the water. In comparison to boiled water, urine concentration of total acetonitriles (0.03113 mg/l).was over 324% higher than that of boiled water. This indicates increased excretion by the kidneys of acetonitriles. This will most likely create injury and damage in the form of diseases in the consuming human populace (MedlinePlus, 2011; Tutorvista, 2011; NKUDIC, 2011; USEPA, 2011(A)). Hence the need for increased attention to be focused on these group of by-products of water treatment.

4.3.3 Other Disinfection By-Products (oDBPs)

These *other* disinfection by-products include chloral hydrate, chloropicrin, 1,1-Dichloro-2-propanone, 1,1,1-Trichloro-2-propanone and 1,1-Dibromo-2-chloropropanone, which are also produced in the course of disinfection in the drinking water treatment process (USEPA, 1995). These occurred in various concentrations in the treated water as well as

the first morning urine. Individually, the mean concentrations are presented in Table 4.9(b).

4.3.3.1 Chloral Hydrate

Chloral hydrate is scientifically is trichloroacetaldehyde monohydrate and occurred in concentrations between below detection and 0.0042 mg/l at household levels; and in first morning urine between 0.0030 and 0.0032 mg/l. The raw water and the water after sedimentation had concentrations that were below detectable limits. The first instance of significant concentrations of the chloral hydrate was observed after chlorination with an average concentration of 0.0033 mg/l. This concentration decreased to an average of 0.0031 mg/l in the booster station water due frictional losses and increased turbulences which caused increased volatility of the compound. The concentration then increased to 0.0042 mg/l in the household level due to acidity of the medium. The boiled water sample however, recorded a lower average concentration due to evaporation losses and high volatility of the chloral hydrate. The average concentration in the first morning urine samples (0.0031 mg/l) was higher than the boiled water average concentration (0.0029 mg/l) by a factor of 107%. This shows that chloral hydrate like other chlorinated disinfection by-products is biologically excreted by the kidneys to maintain homeostatic status of the blood stream and other body fluids. This increased excretory action of the kidneys is sometimes related to prior bioaccumulation of these compounds in the body issues thereby requiring excretion. Such bioaccumulation induces chronic toxicity condition which is liable to cause injury and damage including increased risks of cancer and damage to the nervous system, liver and kidneys (MedlinePlus, 2011; Tutorvista, 2011; NKUDIC, 2011; USEPA, 2011(a)). It is also possible that there are other sources of the compound in the body other than the drinking water source.

Table 4.9(b): Mean Levels of *other* DBPs and Chlorinated Solvents in Drinking water Samples from ABU Water works and the Resulting Urine Samples.

	Raw Water	Water after Sedimentation	Water after chlorination	Booster Station	Household water	Boiled water	Dad's FMU	Mom's FMU	Son's FMU
Other DBPs (mg/L)									
Choral Hydrate (Trichloroacetaldehyde monohydrate)	0.00	0.00	0.0033	0.0031	0.0042	0.0029	0.00	0.0030	0.0032
Chloropicrin (Trichloro (nitro) methane)	0.00	0.00	0.0023	0.00	0.00	0.00	0.00	0.00	0.00
1,1-Dichloro-2-propanone	0.00	0.00	0.0017	0.0017	0.00	0.0017	0.00	0.0026	0.0039
1,1,1-Trichloro-2-propanone	0.00	0.00	0.0555	0.00	0.0115	0.00	0.0026	0.0061	0.0040
1,1-Dibromo-2-chloropropanone	0.00	0.00	0.1513	0.0469	0.0855	0.0363	0.1527	0.1247	0.0380
Total *other* DBPs	**0.00**	**0.00**	**0.2141**	**0.0517**	**0.1012**	**0.0409**	**0.1553**	**0.1364**	**0.0491**
Chlorinated Solvents (mg/L)									
Carbon Tetrachloride	0.00	0.00	0.00	0.0027	0.0029	0.0027	0.0033	0.0146	0.0026
1,2-Dibromoethane	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Tetrachloroethylene	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1,1,1-Trichloroethane	0.00	0.00	0.00	0.00	0.00	0.00	0.0030	0.00	0.00
1,1,2-Trichloroethane	0.00	0.00	0.2270	0.0174	0.0110	0.0055	0.0087	0.0052	0.0059
Trichloroethylene	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1,2,3-Trichloropropane	0.00	0.00	0.1900	0.1499	0.1263	0.1186	0.0828	0.0829	0.0874
1,1,2-Trichloroethene	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 4.9(b) Cont'd.

	Raw Water	Water after Sedimentation	Water after chlorination	Booster Station	Household water	Boiled water	Dad's FMU	Mom's FMU	Son's FMU
Trichloroethene	0.00	0.00	0.0208	0.0048	0.0038	0.0038	0.0043	0.0047	0.0050
Tetrachloroethene	0.00	0.00	0.0113	0.00	0.00	0.00	0.00	0.00	0.00
Total Chlorinated Solvents	**0.00**	**0.00**	**0.4490**	**0.1748**	**0.1440**	**0.1306**	**0.0934**	**0.1074**	**0.1009**

FMU = First Morning Urine sample; DBP = Disinfection By-Products.

Table 4.10: Total Mean levels of Trihalomethanes, Acetonitriles, *other* Disinfection By-Products (*o*DBPs), and Chlorinated Solvents obtained from Treated Drinking Water and Urine samples

	Raw Water	Water after Sedimentation	Water after Chlorination	Booster Station sample	Household level sample	Boiled Water Sample	Dad's FMU	Mom's FMU	Son's FMU
Trihalomethanes	0	0	0.4924	0.0131	0.1104	0.0093	0.0194	0.0831	0.0154
Acetonitriles	0	0	0.0254	0.0254	0.0269	0.0096	0.018	0.0483	0.0271
Other DBPs	0	0	0.2141	0.0517	0.1012	0.0409	0.1553	0.1364	0.0491
Chlorinated Solvents	0	0	0.392	0.2139	0.1368	0.1553	0.1112	0.1074	0.1009

FMU = First Morning Urine

As with other disinfection by-products which are not regulated, more studies are required to determine the impact of chloral hydrate on the body system. Such will enable the determination of the maximum permissible levels under the national and international standards.

4.3.3.2 Chloropicrin

Chloropicrin (Trichloro (nitro) methane) was identified at concentrations of below detectable limit in the raw water and water sample after sedimentation, to 0.0023 mg/l in the water sample after chlorination. Subsequently the substance was not found at any other sampling point. This is one example of one disinfection by-product that is safely broken down in the treatment process in operation at the Ahmadu Bello University water treatment plant.

4.3.3.3 1,1-Dichloro-2-propanone

The mean concentration for 1,1-Dichloro-2-propanone in the raw and sedimentation water samples had below detectable limit of the compound and a maximum concentration of 0.0017 mg/l in the chlorinated water, booster station and boiled household water. Concentration of the household water however was also below detection, making the trend in concentration rather complex. On one hand this trend may indicate a compound that is relatively stable and resistant to degradation even though its formation process is likely to be relatively slow. The concentration in the urine samples are higher values than the boiled water sample and indeed their average mean value was found to be greater than the boiled water sample by a factor of over 190%. If really this compound is resistant it will definitely create a very dangerous health human impact in people and animals consuming the water treated by the ABU water works. This is because the body metabolism will not adequately break it down

and hence the relative rate of bio-accumulation will be higher than other less resistant compounds. Therefore its capacity to cause diseases through injury and damage in body tissues could be on a magnified scale (MedlinePlus, 2011; Tutorvista, 2011; NKUDIC, 2011; USEPA, 2011(a)). Therefore more detailed study of the compound need to be vigorously pursued.

4.3.3.4 1,1,1-Trichloro-2-propanone

From Table 4.9(b), mean concentrations for 1,1,1-Trichloro-2-propanone were below detection in the raw water and water after sedimentation. However, mean concentration of 0.0555 mg/l was obtained after disinfection. Subsequently, the booster station concentration for 1,1,1-Trichloro-2-propanone was again found to be below detection limits. Again, the boiled water showed non detectable concentration even though the concentration in the household water was 0.0115 mg/l. Again, the trend of occurrence of the concentrations is rather complicated and cannot be readily explained. The urine samples showed appreciable concentrations in contrast to the water samples, however.

4.3.3.5 1,1-Dibromo-2-chloropropanone

The mean concentration of 1,1-Dibromo-2-chloropropanone, in the sampled water ranged from below detection to 0.1513 mg/l in the sampled waters while the urine samples had concentrations of between 0.0380 mg/l and 0.1527 mg/l. It is strongly suspected that the concentration of this DBP was below detection in the raw water and water sample after sedimentation because the disinfection had not taken place to facilitate the formation of the 1,1-Dibromo-2chloropropanone. The subsequent water sample, taken after chlorination, recorded the first significant concentration (0.1523 mg/l) of the DBP in the drinking water treatment process at the ABU water works. The

concentration reduced in the booster station (0.0469 mg/l) probably due to frictional losses and turbulent flow resulting in increased volatility of the compound as the water is distributed to the booster station after chlorination. The concentration increased in to the household level (0.0855 mg/l) probably due to the acidity of the medium (pH 6.7 from 8). Measured mean concentrations of the urine samples ranged from 0.0380 to 0.1527 mg/l with an average concentration of 0.1051 mg/l which was higher than the boiled water concentration by a factor of 290%. Again this is indicative of the excretory activities undertaken by the kidneys, the magnitude of which is on the increase with the magnitude of disinfection by-products. The increase in the kidney activities is unsafe for the body as it may cause injury and damage in the form of disease occurrence (MedlinePlus, 2011; Tutorvista, 2011; NKUDIC, 2011; USEPA, 2011(a)).

4.3.3.6 Total oDBPs

From Table 4.9(b), the measured mean concentrations of other Disinfection by-Products were summed up. These concentrations were highest in the water after chlorination (0.2141 mg/l). This concentration decreased to 0.0409 mg/l at the boiled water in house number 20 in Area 'E' quarters. The urine samples were considerably higher in concentration than the water samples with a range of mean values from 0.0491 to 0.1553 mg/l. The average of the mean urine sample concentrations (0.1136 mg/l) on computation is over 277% higher than the concentration of the boiled water sample. Again this is indicate of increased excretion by the kidneys, caused by either a possible hormonal imbalance, or a higher than normal urine formation, or a likely malfunctioning kidney due to diseases like inflammation among others as well as higher proportion of the disinfection by-products in the blood due to previous bioaccumulation of the compounds and their fractions from the boiled water, (MedlinePlus, 2011; Tutorvista, 2011; NKUDIC, 2011) which is dangerous for the human health.

4.3.4 Chlorinated solvents

Table 4.9(b) shows the mean concentration of commonly known chlorinated solvents formed during the disinfection process in drinking water treatment (USEPA, 1995). Four of these chlorinated solvents were not detected in the treated water by the ABU water works. They are 1,2-Dibromoethane, Tetrachloroethylene, Trichloroethylene and 1,1,2-Trichloroethene. Others like carbon tetrachloride, 1,1,1-trichloroethane, 1,1,2-Trichloroethane, Trichloroethene, and Tetrachloroethene either had traces or were found in some of the sampled waters.

4.3.4.1 Carbon Tetrachloride

Mean concentrations of carbon tetrachloride ranged from below detectable limit to 0.0029 mg/l in the sampled waters while urine concentrations varied between 0.0026 and 0.0146 mg/l. The highest mean concentration of 0.0029 in the water samples was obtained in the water at household level, followed by 0.0027 for both the booster station water and the boiled water. The concentration of the water sample after chlorination surprisingly showed concentrations that were below detection of carbon tetrachloride while subsequent samples indicated some quantities of the analyte. This may be due to the fact that the formation process of carbon tetrachloride may not have completed within the chlorination chamber and hence not detected there until in the booster station where it manifested. It may also be that increased turbulence during the flow from the chlorination chamber to the booster station may have aided the completion of the formation process the compound. The acidic nature of the household medium may have been responsible for more of the analyte to form there than the booster station. Lower levels in the household boiled water again may be due to the effect of heat from the boiling process which may have aided the volatility of the compound. The urine samples in comparison were reasonably higher in concentration

of the compound than the water samples. The average mean urine sample concentration of carbon tetrachloride was 0.0068 mg/l which is a factor of 253% higher than the boiled water concentration of the chlorinated solvent. This is also indicative of increased excretion (MedlinePlus, 2011; Tutorvista, 2011; NKUDIC, 2011; USEPA, 2011(a)). Being one of the regulated contaminants, the USEPA and WHO had set limits for it in drinking water. While the USEPA set a maximum contaminant level of 0.005 mg/l and a maximum contaminant level goal of below detectable limit, the WHO set a limit of 0.002 mg/l because the compound is implicated in the formation of cancer. The national standard has no level set for it in the Nigerian Drinking Water Standards (SON, 2007; USEPA, 2011(a); WISE 2011). From these results the ABU treated water is USEPA compliant but WHO noncompliant. It is in this regards that the likely degree of prior bioaccumulation before excretion in the urine samples' results is worrisome, as the amount excreted in the urine are far higher than the USEPA and WHO maximum levels of safety. The American Conference of Government Industrial Hygienists (1994-1995) has a threshold limit value of 5 mg/l for carbon tetrachloride detectable by any of the analytical methods for its level of significance due its carcinogenicity.

4.3.4.2 1,1,1-Trichloroethane

1,1,1-Trichloroethane is one chlorinated solvent which was not detected in any of the water samples but somehow, some traces of it were noticed in one of the urine samples. The concentration of 0.0121 mg/l was obtained in one of the four replicates giving a mean concentration of 0.0030 mg/l. The reason for this occurrence is not immediately foreseen in this study; it is likely that another source other than the water may have given rise to it.

4.3.4.3 1,1,2-Trichloroethane

Table 4.9(b) also shows the mean concentrations of 1,1,2-Trichloroethane in the water and urine samples. The mean concentrations ranged below detectable limits to 0.2270 mg/l for the waters and from 0.0052 mg/l to 0.0087 mg/l for urine. The highest concentration in the water was observed in the water sample after chlorination which had 0.2270 mg/l. This is because this is the expected instance of maximum production of the solvent analyte when the reaction between the disinfectant chloride ion combines with the DBP precursor like dissolved organic matter occurs. This concentration gradually decreases along the distribution network due to frictional losses and high volatility encountered as a result of the turbulent flow. This is why water samples at household level had the least concentration of the chlorinated solvent among the sampled waters. However, when water was boiled, the concentration DBP in the boiled water was again lower than the household water concentration due likely to increased volatility of the chlorinated solvents by boiling. This justifies how 0.0056 mg/l for boiled water compared with 0.0110 mg/l for the household water sample. The calculated average urine concentration of 0.0066 mg/l. is higher in the boiled water with 0.0056 mg/l by a factor of over 117%. This higher than boiled water content of the chlorinated solvent content in the urine arose due to excretion of the compound from the blood stream (and the body fluids). As earlier mentioned, this increased excretion of chemical substance by the kidneys is a likely consequence of either hormonal imbalance in the body, or damage or injury to the kidney in the form of inflammation of the kidney for example, or production of unusually large amounts of urine or increased levels of the chlorinated solvent in the body (due to previous bioaccumulation). Since there is no known or suspected kidney ailment among the volunteers and since there is no significant difference in the quantity of urine produced

as FMU, it is more likely that the increased levels excreted may have been due to the previous bioaccumulation (MedlinePlus, 2011; Tutorvista, 2011; NKUDIC, 2011; USEPA, 2011(a)). This likelihood has a likely negative consequence of disease occurrence. The USEPA set a maximum contaminant level of 0.005 mg/l for the compound, while the WHO limit is 2.00 mg/l. The USEPA identified the compound as potentially responsible for liver, kidney or immune system problems in humans and as such set a public health goal of 0.003 mg/l. The national drinking water standards do not have any permissible limit set for this compound. In comparison with these available standards, the ABU water works treated water (for all its sampled water at various stages of production) including the boiled water stage are not USEPA compliant in terms of the chlorinated solvent 1,1,2-Trichloroethane so compared, but WHO compliant in its regards. But in view of the danger water containing the chlorinated solvent poses to human health (causing liver, kidney or immune system problems), the more stringent USEPA should be better adhered to. The seriousness of the risk to health is responsible for the USEPA to set a maximum contaminant level goal of below detectable limit as a target restriction SON, 2007; USEPA, 2011(b); WISE, 2011).

4.3.4.4 1,2,3-Trichloropropane

Mean concentration for the chlorinated solvent 1,2,3-Trichloropropane are also presented in the Table 4.9(b) ranging from below detectable limit in the raw and sedimentation water to 0.1900 mg/l in the water after chlorination. From here the concentration gradually reduces along the distribution line until the household level where a mean concentration of 0.1263 mg/l was observed. After boiling, the concentration reduced to 0.1186 mg/l due to the effect of boiling in causing the evaporation or decomposition of most compounds. The concentration of the urine

samples ranged from 0.0828 to 0.0874 mg/l with an average of 0.0844 mg/l. This lower concentration of the chlorinated solvent in urine samples than the boiled water indicates strongly bioaccumulation of the compound as the difference between boiled water concentrations with the average mean urine level must have been absorbed or accumulated in the body tissues. This has a tendency of bio accumulating to subsequently cause chronic toxicity. Such a condition may likely create some injuries and damage in the form of diseases. Close examination shows that this chlorinated solvent is not among the regulated pollutants the USEPA. Similarly the Nigerian drinking water, WHO and the EU standards did not regulate this compound. Despite these, the chlorinated solvent 1,2,3-Trichloropropane needs to be studied in details to determine its effects at various doses on the body metabolism (MedlinePlus, 2011; Tutorvista, 2011; NKUDIC, 2011; USEPA, 2011(a)).

4.3.4.5 Trichloroethene

In the table (Table 4.9(b)) the mean concentrations for trichloroethene are presented for both the water and urine samples. The waters have a range of mean values of below detectable limit in the raw and sedimentation water samples, to 0.0208 mg/l in the water after chlorination. Meanwhile, the water from the booster station had a mean concentration of 0.0048 mg/l. The household level recorded a mean value of 0.0038 mg/l that was the same concentration after boiling the water. The urine samples were somewhat of higher concentration than most of these. This was probably due to the relative resistance of the chlorinated solvent being determined. The urine mean values ranged from 0.0043 to 0.0050 mg/l with an average value of 0.0047 mg/l. The value was lower than the average mean of urine sample concentrations of 0.0047 mg/l by a factor of 123%. This is indicating high excretion of the chlorinated solvent trichloroethene from the body tissues, as a result of similar situations described earlier

above. The remotely possible prior bioaccumulation could lead to disease occurrence in the body of consumers of the treated water (MedlinePlus, 2011; Tutorvista, 2011; NKUDIC, 2011; USEPA, 2011(a)). In comparison to national and international standards, only the WHO had set a limit for the compound at 0.07 mg/l. In view of the lower levels of the chlorinated solvent in the household water and in boiled water (with 0.0038 mg/l), the ABU treated water quality complies with the WHO standards for this chlorinated solvent.

4.3.4.6 Tetrachloroethene

Tetrachloroethene was observed in the water sample after chlorination with a mean concentration of 0.0113 mg/l, but disappeared from water in the distribution system. So, it was not detected from the booster station to the household levels and the urine samples. This is most probably due to the volatility and relative instability of the chlorinated disinfection by-products (USEPA, 1995).

The total chlorinated solvents in the sampled waters showed concentrations whose mean values ranged from below detectable limit to 0.449 mg/l after chlorination. Subsequently mean concentration decreased progressively due to turbulent flow and high volatility to 0.1748 mg/l in the booster station, then to 0.1440 mg/l in the household water (USEPA, 1995). When the household water was boiled the boiling action caused the chlorinated solvents to either evaporate or dissociate and lower mean concentration level obtained for the boiled water sample as 0.1306 mg/l. The concentrations in the urine samples were 130% lower than the concentration in the boiled water with average urine concentration of 0.1006 mg/l. The trend of the urine and boiled water mean concentration values for these chlorinated solvents indicates bioaccumulation of some fractions of the chlorinated solvent in the body tissues indicating a likely chronic toxicity problem of subsequent disease occurrence.

Table 4.11: Analysis of Variance (ANOVA) Table of obtained Mean Levels of Trihalomethanes, Acetonitriles, Other DBPs and Chlorinated Solvents

Sources of Variation	*Df*	*Sum of Squares (SS)*	*Mean Squares (MS)*	$F_{calculated}$	$F_{tabulated}$	
					α=0.05	*α=0.01*
Total	35	0.417808				
Treatment (Levels/conc.)	8	0.221230	0.02765375	4.8582**	2.36	3.36
Block (Types/analytes)	3	0.059965	0.01998833	3.5115*	3.01	4.72
Error	24	0.136613	0.00569221			

df – Degrees of freedom, α – Probability function,(1% and 5% levels) F – Fisher's F function. * - Significance at 5% probability level, ** - Significant at 5% and 1% Probability levels.

The results obtained in Tables 4.9(a) and (b) were subjected to statistical analysis to determine the nature of the differences among the mean concentrations between sampling stations and among the various categories of chlorinated disinfection by-products as analysed and presented in the tables. Using a Completely Randomised Block Design, and Analysis of Variance, for the various mean concentrations as the treatments, the calculated F was found to be 4.8582** which when compared to the tabulated F value at 5% and 1% probabilities (2.36 and 3.36 respectively) showed that the differences between the mean concentrations at different sampling stations (as treatments) were highly significant. On the other hand the differences between the various groups of analytes (Tri-halomethanes, Haloacetonitriles, *other* Disinfection By-Products and Chlorinated solvents) constituted the blocks. The analysis of variance of the differences between these groups' totals of determined mean concentrations were found to have a calculated F value of 3.5115* which when compared with the tabulated F values at probability level at 5% and 1% (3.01 and 4.72 respectively) showed that these differences among the types or groups of compounds determined were only significant, at 5% probability only (see Table 4.11 below for the ANOVA table).

4.4 Halo-Acetic acids

Haloacetic acids are the next important group of compounds which are formed in the course of disinfecting water undergoing treatment. Figures 4.6 to 4.8 give the chromatograms of haloacetic acids in the drinking water samples while figures 4.10 to 4.12 show the chromatograms of these acids in the first morning urine samples of volunteers at house Number 20 Area 'E' quarters of Ahmadu Bello University, Zaria. Also, Table 4.12 shows the various total concentration of the halo-acetic acids as measured replicates during this study while Table 4.13 has the means of the observed levels during the sampling periods.

Like the halo-alkanes and others, these measurements were done on samples obtained from nine stations including three urine samples. In the table eleven halo-acids were measured among which were nine Haloacetic acids and two halo propionic acids. Only five of these acids are currently regulated by only the USEPA. The national standard (The Nigerian Drinking Water Standards) however has no provisions for this group of disinfection by-products in drinking water. As with the halo-alkanes, and other groups earlier determined, the halo acetic acids had concentrations between below detectable limits onwards, with most of the highest observed concentrations occurring in the water after chlorination.

4.4.1 Monochloroacetic acid

Monochloroacetic acid for one had a range of mean concentration values from below detectable limit to 0.13854 mg/l for the sampled waters with the highest mean concentration recorded for the water sample after chlorination. The urine concentrations, on the other hand ranged from below detectable limits to 0.03782 mg/l. From the chlorinated water the observed concentration decreased to the booster station and subsequently to the household water which had 0.09706 mg/l of the acid. This decrease is most probably due to the friction and turbulence which enhances increased volatility of the compound in the distribution system. When the water at household level was boiled the mean concentration of the monochloroacetic acid content in the boiled water decreased to 0.08829 mg/l probably due to volatility and evaporation losses and or thermal dissociation of the compound during the boiling process. The average mean concentration of the acid in the urine samples was 0.01261 mg/l. This was considerably lower than the proportions in the boiled water sample. This is indicative of bioaccumulation as the difference between these is the accumulated fractions retained by the body. The build-up of the monochloroacetic acid in this manner has a tendency to result in chronic toxicity in the form of diseases as well as injury and damage to the body tissues subsequently (USEPA, 2011(a); USEPA, 2011(b); WISE, 2011).

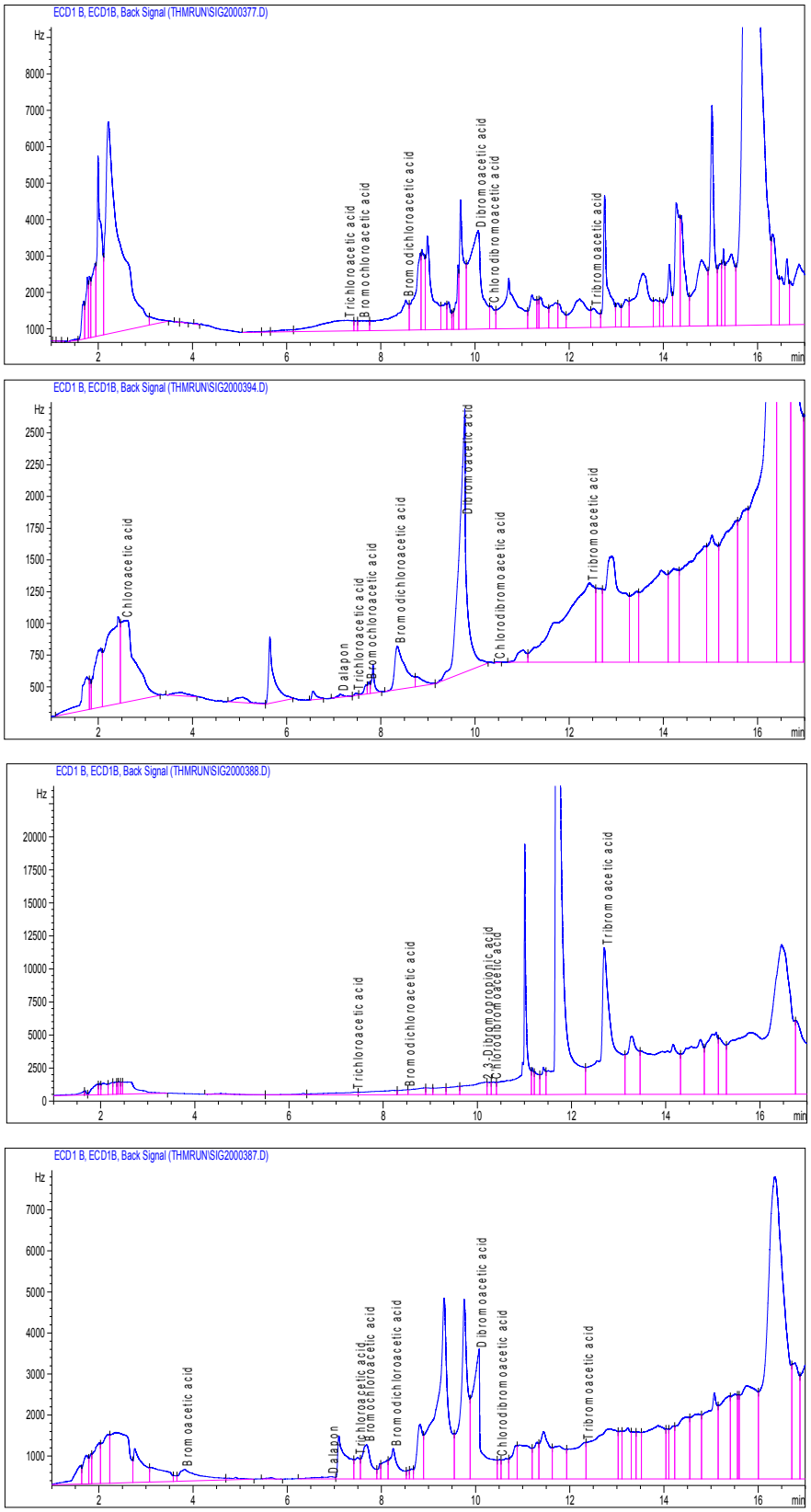


Fig. 4.6: Gas Chromatograms of Halo Acetic Acids in A.B.U. treated water samples after Chlorination.

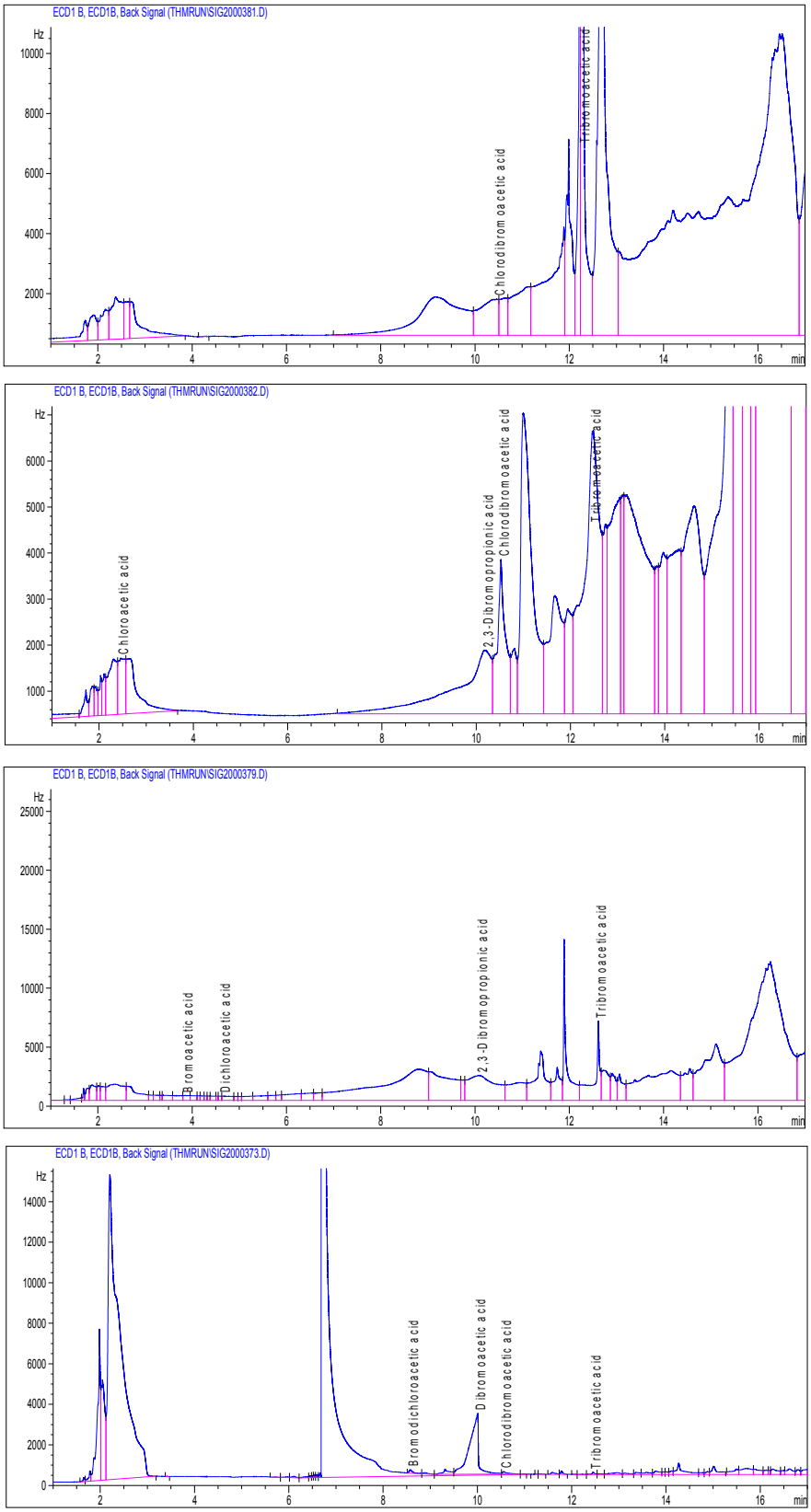


Fig. 4.7: Gas Chromatograms of Halo Acetic Acids in A.B.U. treated water samples from the Booster Station.

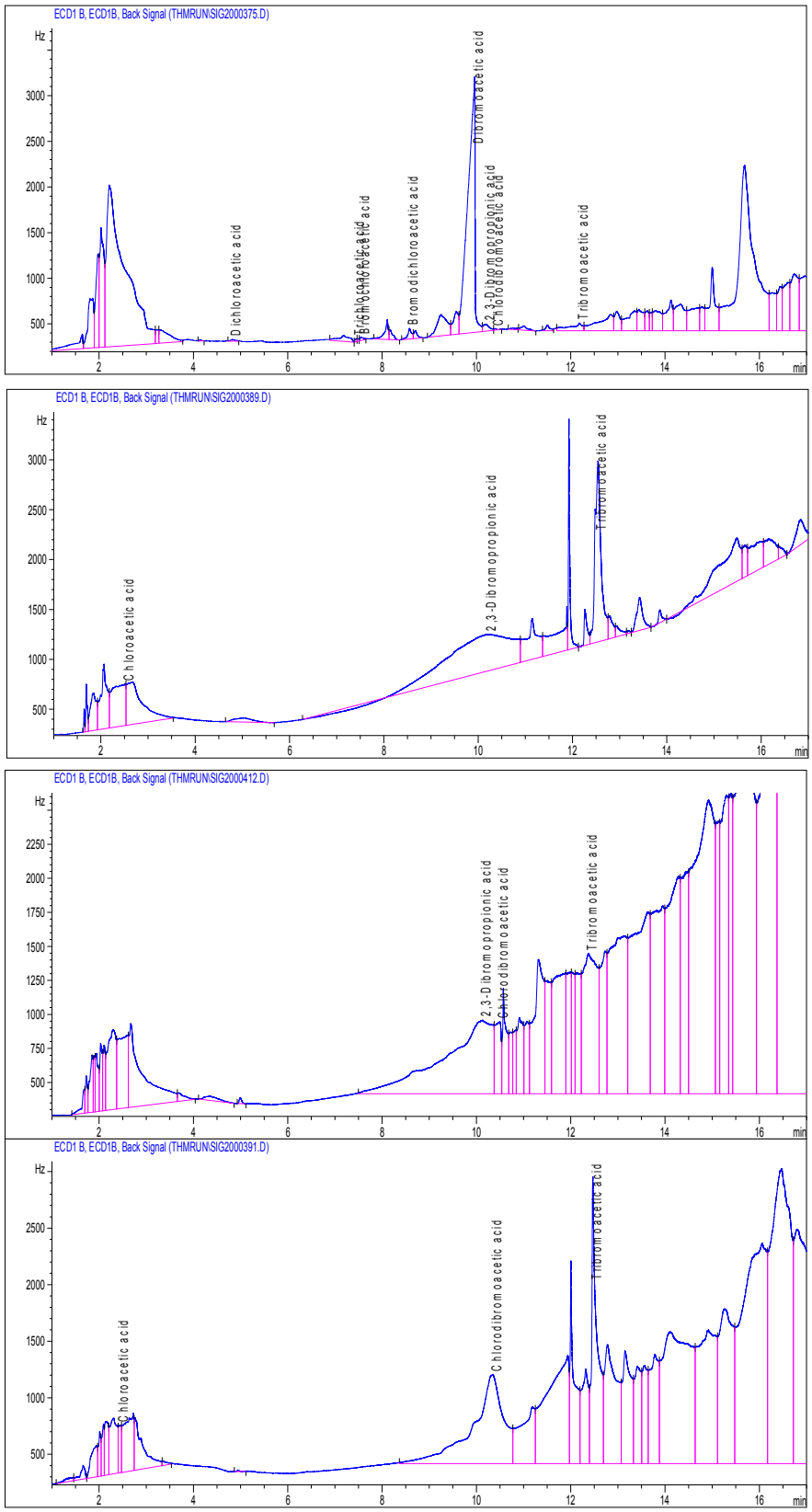


Fig. 4.8: Gas Chromatograms of Halo Acetic Acids in A.B.U. treated water samples from Household Level (Area E 20).

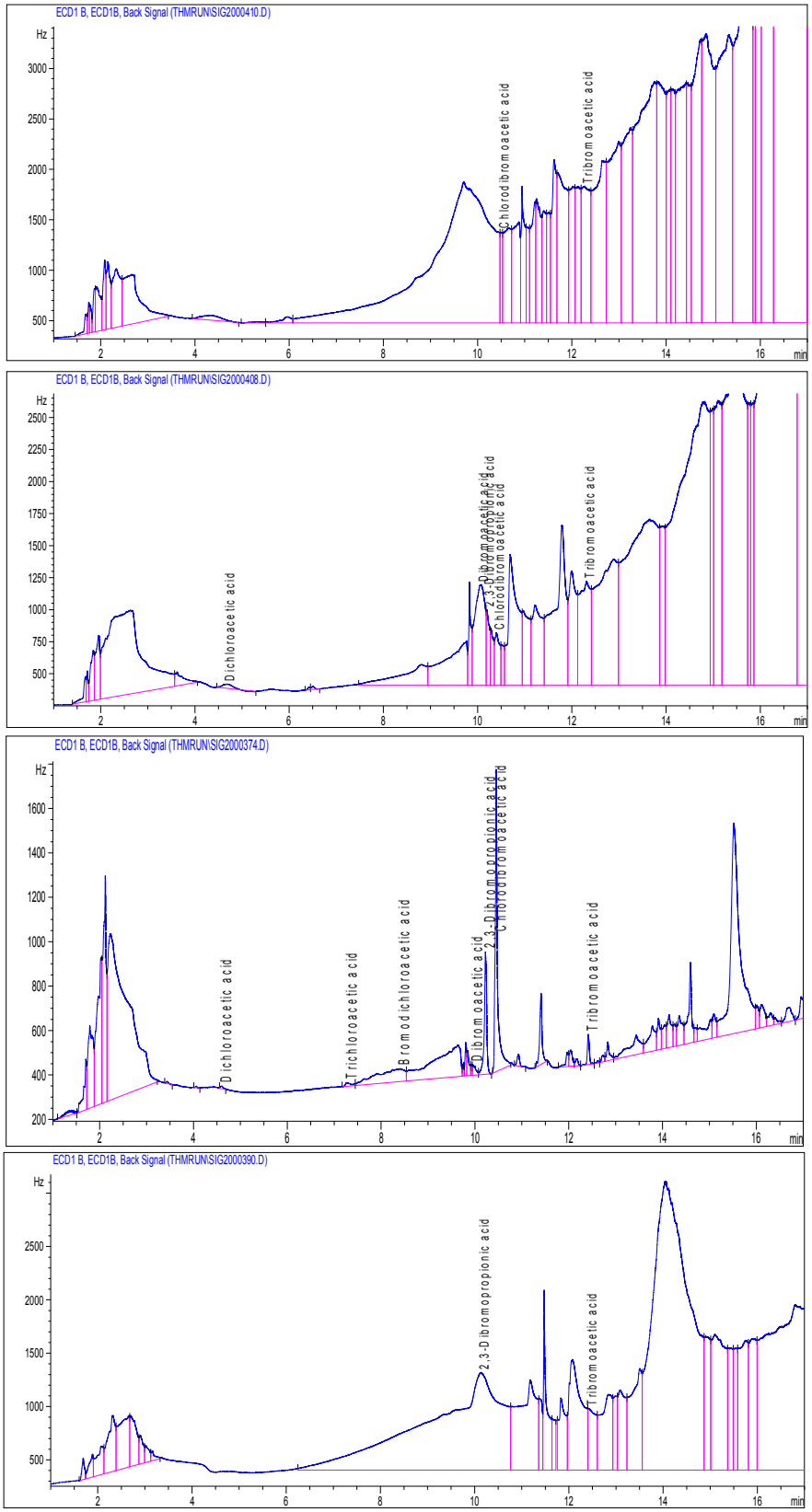


Fig. 4.9: Gas Chromatograms of Halo Acetic Acids in A.B.U. treated Boiled water samples from Household Level (Area E 20).

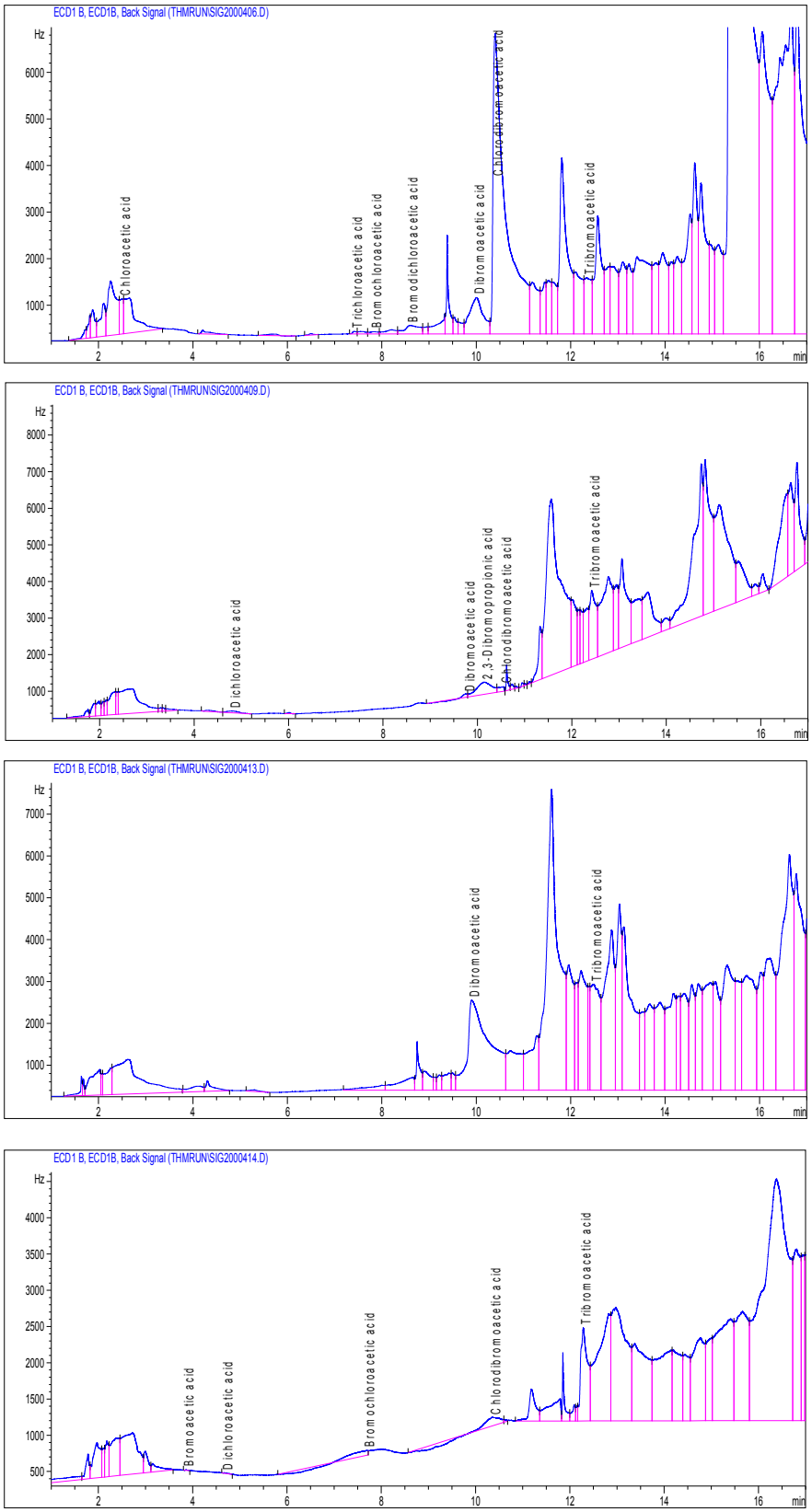


Fig. 4.10: Gas Chromatograms of Halo Acetic Acids in Dad's First Morning Urine (FMU) samples from Household Level (Area E 20).

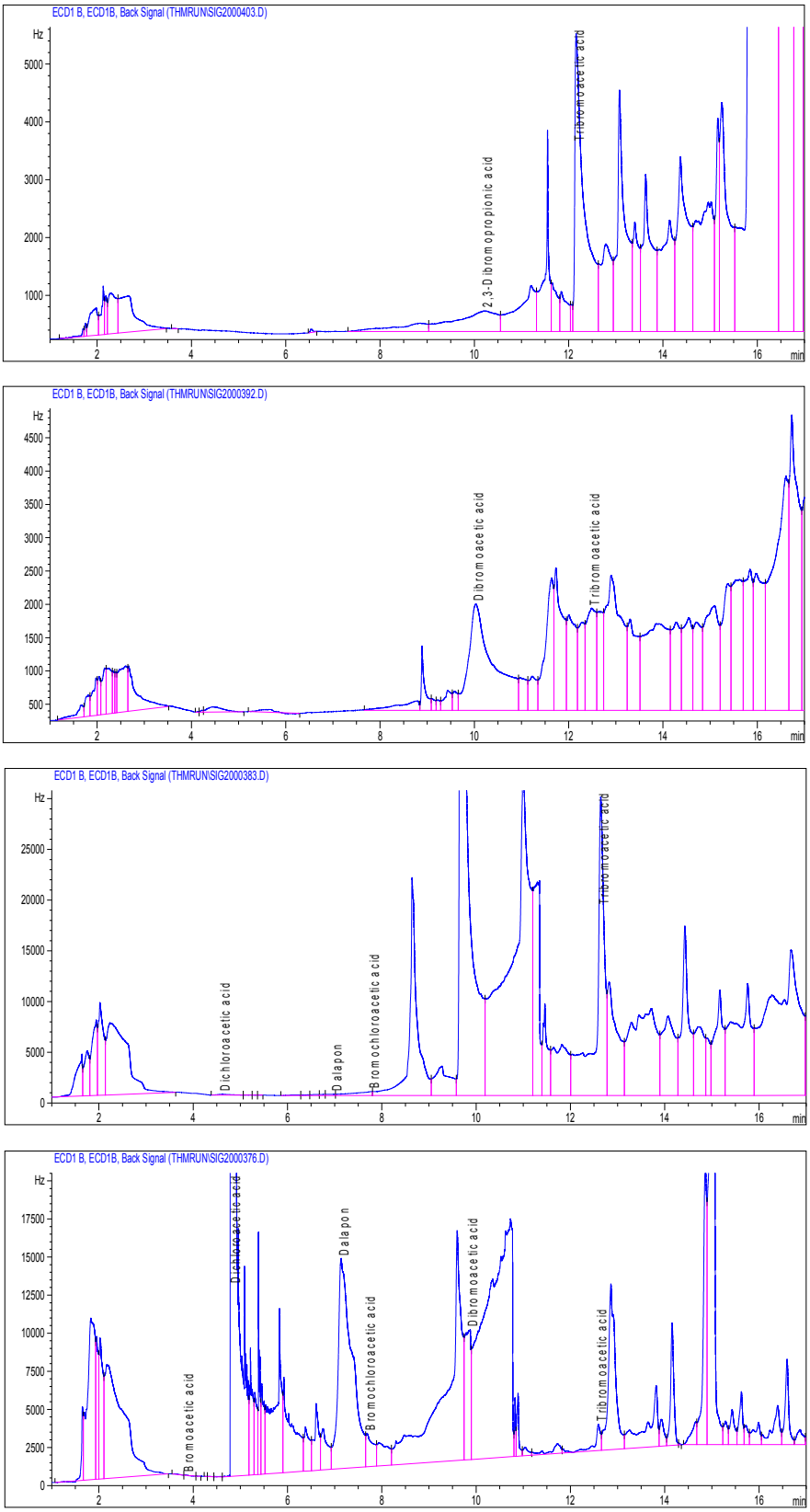


Fig. 4.11: Gas Chromatograms of Halo Acetic Acids in Mom's First Morning Urine (FMU) samples from Household Level (Area E 20).

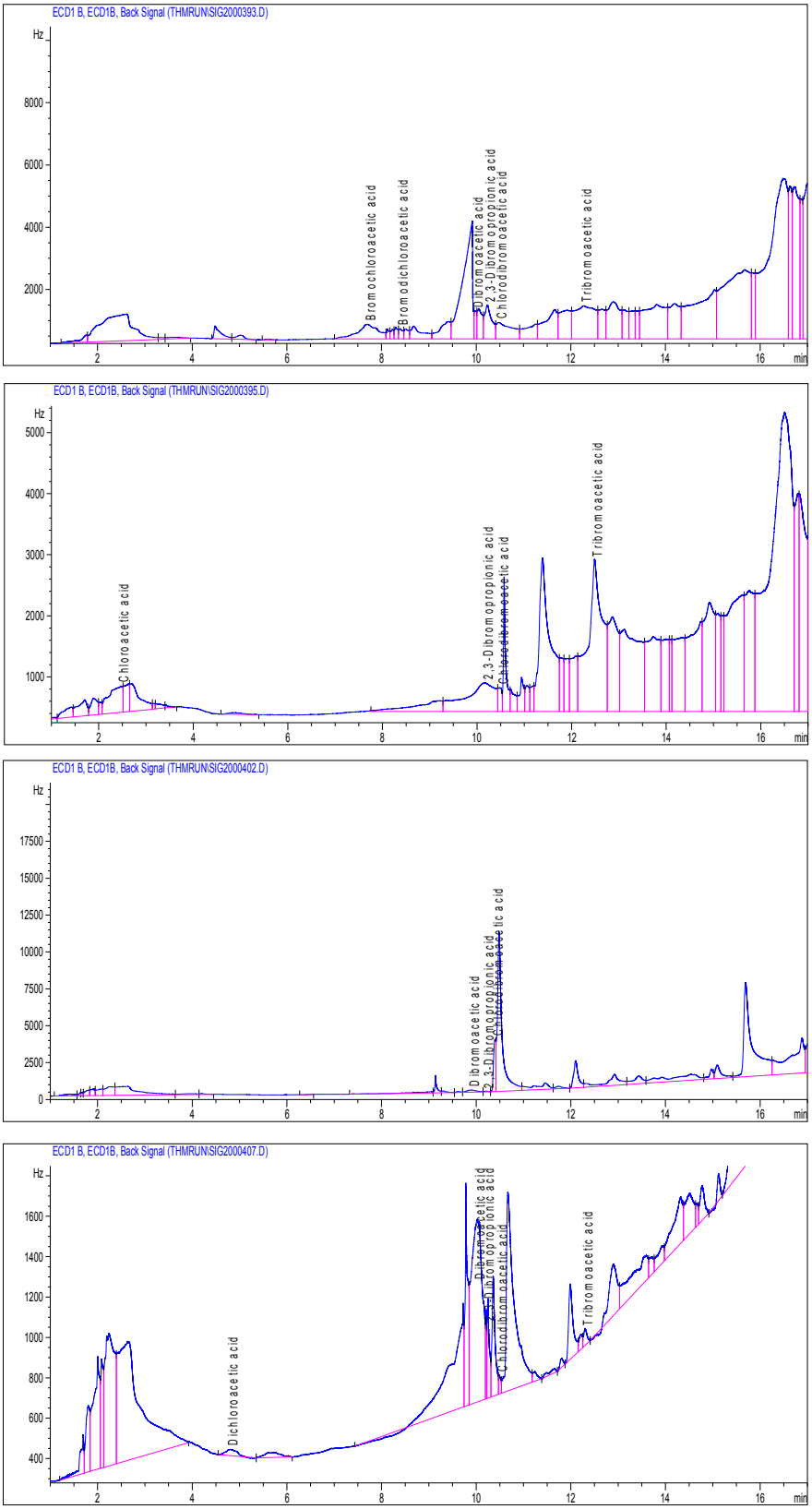


Fig. 4.12: Gas Chromatograms of Halo Acetic Acids in Son's First Morning Urine (FMU) samples from Household Level (Area E 20).

Table 4.12 Total Levels of Haloacetic acids in Sampled Drinking Water from the Ahmadu Bello University Water Treatment Plant and First Morning Urine Samples.

	Levels of Measured Halo Acetic acids (HAAs) (mg/L)			
Sampled Site	I	II	III	IV
Raw Water sample	0	0	0	0
Water from Sedimentation tank	0	0	0	0
Water Sample after chlorination	1.996328	1.509945	1.258462	1.075918
Water Sample from the Booster Station	1.199087	1.951844	0.558677	0.345555
Water sample from Household tap (Area E)	0.247102	0.278485	0.507471	0.385824
Boiled Household Tap water sample (Area E)	0.150072	0.154997	0.216619	0.173566
Dad's First Morning Urine sample	0.133650	0.168957	1.138997	0.820448
Mom's First Morning Urine sample	0.612069	0.626980	3.161786	3.156393
Child's First Morning Urine sample	0.0710792	0.118481	0.833984	0.590151

Table 4 13: Table of Observed Means of Halo-Acetic Acids' Levels in Sampled A.B.U. Treated Drinking Water and Urine Samples

	Raw water	Sedimentation water sample	Chlorinated water sample	Booster station water sample	Household level water sample	Boiled household water	Dad's FMU sample	Mom's FMU	Child's FMU
Monochloroacetic acid (MCAA)	0.00	0.00	0.13854	0.12532	0.09706	0.08829	0.03782	0.00	0.00
Monobromoacetic acid (MBAA)	0.00	0.00	0.00954	0.00517	0.00152	0.00	0.01504	0.00	0.00
Dichloroacetic acid (DCAA)	0.00	0.00	0.39352	0.00325	0.00118	0.00053	0.00134	0.00	0.00071
Trichloroacetic acid (TCAA)	0.00	0.00	1.07592	0.38582	0.34556	0.17357	0.82045	3.15639	0.59015
Dibromoacetic acid (DBAA)	0.00	0.00	0.21484	0.07383	0.04087	0.02470	0.16589	0.24931	0.00
Sub Total ($THAA_5$)	**0.00**	**0.00**	**1.83236**	**0.59339**	**0.48619**	**0.28709**	**1.04054**	**3.4057**	**0.59086**
Bromochloroacetic acid (BCAA)	0.00	0.00	0.04255	0.03353	0.00848	0.00747	0.00811	0.00	0.00
Bromodichloroacetic acid (BDAA)	0.00	0.00	0.48421	0.11250	0.05537	0.03097	0.051214	0.02303	0.00
Chlorodibromoacetic acid (CDAA)	0.00	0.00	0.13595	0.08250	0.04703	0.00761	0.01316	0.02780	0.00

Table 4.13 cont'd.

	Raw water	Sedimentation water sample	Chlorinated water sample	Booster station water sample	Household level water sample	Boiled household water	Dad's FMU sample	Mom's FMU	Child's FMU
Tribromoacetic acid (TBAA)	0.00	0.00	0.70331	0.54065	0.12188	0.07551	0.16127	0.98467	0.17993
2,3-Dibromopropionic acid (2,3-DBPA)	0.00	0.00	0.04814	0.03100	0.02193	0.00779	0.00204	0.00626	0.00928
Dalapon (2,2-Dichloropropionic acid)	0.00	0.00	0.00464	0.00	0.00	0.00	0.00	0.17290	0.00

HAAs – Halo acetic acids; FMU – First Morning Urine sample

4.4.2 Monobromoacetic acid

Table 4.13 also contains information about monobromoacetic acid in the waters and the urine samples. The mean concentration in the water samples ranged from below detectable limits to 0.00954 mg/l while a trace of the compound was found in one of the urine samples despite the fact that on boiling the household water for drinking, the mean concentration of the monobromoacetic acid in the boiled water became below detectable limit. Despite this, a sample of the urine showed some trace of the acid in it with a mean concentration of 0.01504 mg/l. While the reason for this observation could be not immediately perceived from the point of the drinking water, it is most likely that sources other than the chlorinated disinfected treated water may be additional avenues by which the monobromoacetic is absorbed into the body before its excretion in the urine sample. This has the likely implication of adding more stress on the kidneys in its excretory activities (MedlinePlus, 2011; Tutorvista, 2011; NKUDIC, 2011; USEPA, 2011(a)).

4.4.3 Dichloroacetic acid

Dichloroacetic acid mean concentrations recorded in this study varied from below detection for the raw and sedimentation water samples to 0.39352 mg/l in the water sample after chlorination. Other water samples recorded concentrations lower than this while the urine samples varied between below detectable limit and 0.00134 mg/l. The highest concentration value was recorded in the sample after chlorination expectedly. Flow characteristics within the distribution system, like detention time, nature of flow and frictional losses and volatility of the compound are likely factors responsible for the decreasing level of the analyte beyond the chlorination stage to the booster station to the household level as observed USEPA, 1995). The household level concentration of 0.00118 mg/l further reduced to 0.00053 mg/l after boiling the water reaching the

household. This is most likely due to either volatility of the acid and evaporation losses or dissociation or decomposition of the acid as a result of increased temperature during boiling or all of them. In comparison, the urine samples recorded higher levels of the compound than the boiled water sample (with average mean value of 0.001025 mg/l) by a factor of over 193%. This is definitely due to increased excretory action of the kidneys either due to increased urination, or damage to the kidney like inflammation or due to higher content of the acid in the body and the blood stream due to previous accumulation in the body. This could also be due to hormonal imbalance or the fact that other sources of intake of the acid other than the boiled drinking water may have increased the blood level. This obvious higher concentration in the blood stream is most likely to cause a chronic toxic effect in the body in the form of damage to the kidney and of increased incidence of cancer in the body, which these compounds are known for (MedlinePlus, 2011; Tutorvista, 2011; NKUDIC, 2011; USEPA, 2011(a)).

4.4.4 Trichloroacetic acid

In Table 4.13 it is also that the observed mean concentrations for trichloroacetic acid ranged from below detectable limits to 1.07592 mg/l in the water sample after chlorination. Other water samples recorded reduced levels than the water sample after chlorination, with values of 0.38582, 0.34556, and 0.17357 mg/l respectively for the booster station, household level and boiled water samples. The urine samples on the other hand had between 0.59015 mg/l and 3.15639 mg/l with and average mean concentration of trichloroacetic acid of 1.52233 mg/l. This is higher than in the boiled water levels by a factor of over 850%. A careful observation of the mean concentration of trichloroacetic acid showed that it had recorded the highest concentrations in the urine samples than water samples. This development, like other instances where analyte levels in the urine exceeded the boiled water concentrations, there are risks of

the chances of chronic toxicity effects in terms of likely damage to the kidneys, liver, nervous system among others (USEPA, 2011; WISE, 2011). This situation could have arisen due to hormonal imbalance in the body that can cause this increased excretion. The increased levels in the urine over that of the boiled water may also point to other sources of intake of the acid other than the boiled drinking water. It could again also point to probable speciation of the disinfection by-products as had been reported in some literature to cause higher body concentration (bioaccumulation) from which the increased excretion had occurred. This higher concentration in the body could cause a chronic toxic effect in the body in the form of damage to the kidney and of increased incidence of cancer in the body as well as diseases of the central nervous system and the liver (MedlinePlus, 2011; Tutorvista, 2011; NKUDIC, 2011; USEPA, 2011(a)).

4.4.5 Dibromoacetic acid

Dibromoacetic acid on the other hand had mean detected concentration levels ranging from below detection to 0.21484 mg/l for the water samples while the urine samples ranged from below detection to 0.24931 mg/l. It is suspected that the decreasing trend in the concentrations from the water sample after chlorination towards the household level could be attributable to the flow characteristics in the distribution network where frictional losses and nature of flow could have resulted in lower concentrations. The higher than boiled water mean concentration of the dibromoacetic acid in the urine samples could be as a result of hormonal imbalance in the body leading to higher excretion by the kidneys of the substance into the urine, or other intake of the compound apart from drinking water source or bio-accumulation leading to increased levels in the blood stream prompting increased excretion in the urine. It is also possible that there is more urine formation or even the chances of compound speciation leading

to more of the dibromoacetic acids from other compounds in the body tissues after ingesting the drinking water as reported in the literature, (MedlinePlus, 2011; Tutorvista, 2011; NKUDIC, 2011). Like in all other analytes with higher concentrations over the ingested boiled water concentrations, this higher concentration in the body is most likely to cause a chronic toxic effect in the form of damage to the kidney and of increased incidence of cancer in the body.

The toxicity testing of these various haloacetic acids have not been elaborately investigated at national level (which is why these are not included in the national drinking water standards) except as undertaken by the United States Environmental Protection Agency (USEPA, 1990 a,b&c, 1995, 1997, 1999, 2011a&b). They have been implicated in the increased incidences of cancer in the body and damage to the kidneys. As a result, a maximum contaminant level of 0.060 mg/l and a maximum contaminant level goal of below detectable limit were set for this group of chlorinated disinfection by-products. This has been the basis of assessing the water treatment in relation to these acids as disinfection by-products globally. This study therefore summed the concentrations of these five regulated acetic acids determined in ABU treated drinking water and found that their concentrations ranged from below detection limits to 1.83236 mg/l for the sampled waters while the urine samples ranged from 0.59086 to 3.4057 mg/l. Since the national standards have no provisions for this group of DBPs, comparison with international standards therefore the only option. The ABU treated water was as such found to be USEPA noncompliant as its levels of total regulated haloacetic acids far exceed not only the MCL (0.060 mg/l for the combined five regulated acids) but also the MCLG of below detectable limit. Like most, if not all the individual acids, the decreasing mean levels in the water after chlorination to the household level is a likely function of flow characteristics (in terms frictional losses

and nature of flow). The obviously higher values for the urine samples is likely due to the increased excretion by the kidneys, or hormonal imbalance or increased availability of the acids in the blood stream due to earlier bioaccumulation or probably due to more urine formation and or compound speciation or combination of some of these factors. The resultant implication of this is that this higher concentration in the body is most likely to cause a chronic toxic effect in the form of damage to the kidney and of increased incidence of cancer in the body. The Nigerian Drinking water standards does not have set limits for haloacetic acids in drinking and as such national standard in respect to haloacetic acids as disinfection by-products does not exist for comparison. Therefore, these values can only be assessed in comparison to the USEPA standards. It can be deduced that these mean values are above the USEPA maximum contaminant level and as such makes the water unsafe for human consumption. As at the 1994-1995, the American Conference of Government Hygienists had not set the recommendations for the threshold limit values for this group of compounds or the individual acids. Since only the USEPA standard is available and its limits are exceeded, this implies that the ABU treated water is USEPA noncompliant and may be significantly health impairing with respect to the (haloacetic acids (HAA) content. Therefore more studies should be undertaken on it while also management of the treatment plant must vigorously pursue measures to minimize the levels of haloacetic acids produced in the water.

Apart from the regulated haloacetic acids (halo5 acids), other acids identified in the ABU treated water included bromochloroacetic acid, bromodichloroacetic acid, chlorodibromoacetic acid, tribromoacetic acid, 2,3-Dibromopropionic acid and Dalapon (2,2-Dichloropropionic acid) See Table 4.13.

4.4.6 Bromochloroacetic acid, Bromodichloroacetic acid and Chlorodibromoacetic acid

Bromochloroacetic acid, bromodichloroacetic acid and chlorodibromoacetic acid have range of mean values from below detectable limits to 0.04255, 0.48421 and 0.13595 mg/l respectively. These were mean values for the water samples while their urine samples had mean values ranging from below detectable limits to 0.0081 for bromochloroacetic acid (average 0.0027), below detection to 0.051214 for bromodichloroacetic acid (average 0.02475) and below detection to 0.01316 for chlorodibromoacetic acid (average 0.01365) mg/l. In comparison to the boiled water, these mean concentrations of 0.00747, 0.03097 and 0.00761 mg/l it showed that among the three compounds, only chlorodibromoacetic acid showed lower urine mean concentrations than the boiled water mean concentration of the acid. It therefore means that while the urine samples for the bromochloroacetic and bromodichloroacetic acids exhibited bioaccumulation in the tissues due to lower levels excreted from the urine against average urine samples, the chlorodibromoacetic acid is definitely higher than the drinking water proportion as a result of increased excretory activities of the kidneys which may either be due to the fact more chlorodibromoacetic acid may have been ingested through other sources other than the drinking water or may have arisen due to more urine formation or could have been possible due to a possible hormonal imbalance in the body or as a result of problems of the kidney like inflammation which may prevent adequate balancing of the compound in the blood stream and the urine. In either of these cases there are serious adverse implications for human health as bioaccumulation and increased excretion can lead to chronic toxicity conditions and an overworked and possibly inflamed and damaged kidney respectively and an increased risk of cancer.

4.4.7 Tribromoacetic acid

Like the chlorodibromoacetic, acid, the tribromoacetic acid had a higher average urine concentration than the boiled water concentration of this acid. This has the same implication as the other compounds that similarly have higher than boiled water concentrations in their urine samples. The decreasing trend in the mean values of the acids in the samples as water is conveyed from the chlorination stage towards household levels is also similar to other cases of analysed acids and is attributable to the same reason of frictional losses, turbulent flow and increased volatility of the disinfection by-products.

4.4.8 2,3-Dibromopropionic acid

2,3-Dibromopropionic acid was also determined in the water and the urine samples. Mean values of the analyte in the water samples varied from below detectable limits to 0.04814 mg/l while the urine samples had mean values ranging from 0.00204 mg/l to 0.00928 mg/l. The various water samples showed decreasing mean levels from the chlorinated water sample with 0.04814 mg/l to the household level water sample with 0.02193 mg/l due to flow characteristics in terms frictional loses, nature of flow among others in the distribution network. The boiled water sample mean level was also lower than the mean level of the compound at household level (0.00779 compared to 0.02193 mg/l). This is also likely due to thermal dissociation in the boiling process which produced lower mean concentration value for the boiled water. The urine samples had an average mean value of 0.00586 mg/l for the 2,3-dibromopropionic acid. This shows that some proportions of the acid could have been accumulated within the tissues while the remainder is excreted in the urine. Therefore bioaccumulation is highly probable for this halo acid with a likely possibility of chronic toxicity to possibly cause injury

and damage to the body in the form of diseases later (MedlinePlus, 2011; Tutorvista, 2011; NKUDIC, 2011; USEPA, 2011(a)).

4.4.9 Dalapon (2,2-Dichloropropionic acid)

Dalapon, although a herbicide is a halo acid. Its IUPAC nomenclature is 2,2-Dichloropropionic acid. In this study, traces of it were observed in the water sample after chlorination and subsequently disappeared from the other sampled waters, but traces of it occurred again in one of the urine samples. The decreasing change in the proportion after chlorination to household level could be attributable to flow characteristics in the distribution system. It is also possible that transmutation may have occurred causing the compound to disappeared completely throughout the gathering and distribution network of the treated water (Bougeard *et al*, 2010). However, the re-occurrence in one of the urine samples could likely be due to other sources other than the treated water as the River Kubanni and its tributaries had been extensively cropped in earlier times by resident staff of the Ahmadu Bello University many of whom were using various pesticides including herbicides like Dalapon. It is also possible that residues of this may have been ingested from common food materials still grown in the Kubanni basin upstream and downstream of the reservoir. It is also possible that close resemblances of the compound were able to undergo speciation within the body tissues to form the compound in the body that is excreted in one of the urine samples. The implication of this is that despite the long period of official ban among ABU resident staffs from agricultural activities in the Kubanni basin, residues of agricultural pesticides are still occurring within the environment. Therefore this ban must be strengthened with adequate monitoring of basic foods including drinking water for these potent chemicals which have strong possibilities of inducing chronic to acute toxicities in the human body.

4.4.10 Statistical Analysis

Results of statistical analysis of these changes in the measured levels of the halo acids in this experiment are presented in Table 4.14. These results gave an F (calculated) value of 4.93** which indicate significance at 5% and 1% probabilities. This show that the measured levels of concentration of the halo acids varied highly significantly from the various sampling points and indeed with the urine samples. Therefore this study was sensitive enough to identify these changes among the sampled waters at different stages of production and distribution and also with the urine samples' concentrations.

Table 4.15 shows the values of correlation coefficients (r)the various analytes of this study. The values indicate that most of the analysed groups of compounds correlated well with each other except between the four of the regulated halomethanes and the analysed total halomethanes with a correlation coefficient (r) of -0.047 where there was a very low inverse correlation. Also a relatively weak correlation (more scattered relationship) between total halomethanes and chlorinated solvents (0.217) and between halo acetonitriles and four of the regulated halomethanes (0.297) were obtained in the study.

Table 4.14: ANOVA Table of the observed levels of HAAs in the Drinking Water and Urine Samples

Sources of Variation	df	Sum of Squares	Mean Squares	$F_{Calculated}$	$F_{Tabulated}$	
					p=0.05	p=0.01
Total	35	23.55121	0.6729			
Treatment (Levels/conc.)	8	13.97977	1.74747125	4.93**	2.31	3.26
Error	27	9.57144	0.3544978			

df – Degrees of freedom, α – Probability function,(1% and 5% levels) F – Fisher's F function. * - Significance at 5% probability level, ** - Significant at 5% and 1% Probability levels.

Table 4.15: Table of Correlations

	Total Haloacetic acids	Total Trihalomethanes	Five Regulated Haloacetic acids	Four Regulated Trihalomethanes	Halo Acetonitriles	*Other* DBPs	Chlorinated Solvents
Total Haloacetic acids	1.000	0.451	0.980**	0.556*	0.832**	0.753**	0.539*
Total Trihalomethanes		1.000	0.481	-0.047	0.724**	0.530*	0.217
Five Regulated Haloacetic acids			1.000	0.437	0.836**	0.711**	0.394
Four Regulated Trihalomethanes				1.000	0.297	0.760**	0.915**
Halo Acetonitriles					1.000	0.617**	0.400
Other DBPs						1.000	0.762**
Chlorinated solvents							1.000

* Significant at 5% probability level
** Significant at both 5% and 1% probability levels
DBPs: Disinfection By-Products.

Apart from these trends, the rest of the correlations showed relatively positively strong to positively strong and perfectly strong positive correlations among the rest of the analytes in the study with correlation coefficients ranging from 0.394 to 0.832 and also 0.980 between total haloacetic acids and haloacetonitriles (0.832) and between total haloacetic acids and five regulated haloacetic acids (0.980) as had been observed by Bougeard *et al*, (2010). Many of these values for correlations among the analysed DBPs were found to either be significant or highly significant. These positive and strongly correlated figures imply that the each of the correlating analyte has a strong positive relationship or association with the component analyte. That is, high concentration levels (mean levels) of one of the analytes are associated with high concentration levels (mean levels) of the other analyte in the relationship. The implication of this is the likelihood that these disinfection by-products are likely to occur together when and wherever one occurs in the production and distribution system. While this creates additional source of concern to consumers of the treated water and treatment plant managers, it is additional source of worry as there exist a strong indication of a combination effect of these disinfection by-products in the form of additive and synergistic effects of the DBPs in their health implications (Teuschler, *et al* 2000). This further adds to the status of priority contaminants and establishes urgent need for their control.

CHAPTER FIVE

5.0 SUMMARY, CONCLUSION AND RECOMMENDATIONS

5.1 Summary

During the field survey of some water treatment plants in Nigeria, it was observed that the level of staffing in these treatment works was grossly inadequate. None of the plants had the compliment of a qualified water treatment plant manager, a chemist, a water engineer, a microbiologist, and a faults/maintenance officer. In addition, two technologists/foremen would be necessary to supervise the array of technicians including plumbers, welders, pump and plant operators. At best, majority of the water treatment plants have a water engineer and a technologist, technicians and operators each. This leaves much to be desired in terms of the knowhow of water treatment, technics and their reasons for water treatment (capacity building). Also from the survey, it was evident that most (80%) of the water treatment plants are designed and built as conventional one disinfection segment single injection treatment trains. Very few of the treatment plants were of the one treatment train with one injection point and multiple disinfection segments (10%) and a treatment train with two disinfection segments (10%). All the surveyed plants had undergone rehabilitation and expansion in view of the increasing population served. They have both preliminary and main water treatment processes. There was some level of inaccuracy in some of the information provided during the survey and some of these anomalies were found from site inspections and benefitting communities. While most of the treatment plants reported having functional service laboratories, observations show that none of the treatment plants had fully operational service laboratories. At best these laboratories can be partly functional doing basic tests like pH. Majority of the surveyed water treatment plants reported never treating water without disinfectant, but some

acknowledged treating without disinfectant even though inhabitants served complained of foul odours in the treated water sometimes in the rainy seasons. Most of the plants reported not experiencing budgetary constraints when it is obvious that consumables and spares cannot be procured to allow for uninterrupted water supply to all areas in the distribution network. Their response could probably have been made to placate their political mentors. None of the treatment plants was found able to serve uninterrupted water supply to all communities within the distribution network 24 hours a day and 7 days of the week. It was observed that the operation of the treatment works is far less than professional in nature as opportunities existed for sharp practices; for example, instances arise where disinfectants are not stocked. This will make water to be treated without disinfectants. Despite the fact that most if not all water treatment plants reported using the WHO code of practice responses from them showed many varied applications. This calls for strict supervision. It was observed that there is no agency whether of government or otherwise that is mandated to inspect the operations of the water treatment plants in terms of the quality of water they produce, even though wholesome potable water has been adopted as a human right by the United Nations Human Rights Commission.

In terms of general chemical analysis of the various water samples, ten parameters were determined. These include pH, Total dissolved solids, salinity, Total organic carbon, residual chlorine, conductivity, nitrates, phosphates, chlorides and sulphates. The range of mean values for the pH was from 6.7 in the household level to 8.0 in the booster station. The average mean pH of the treated water was computed to be 7.5, indicating a neutral pH value for the treated drinking water. This is within acceptable limits in the national and international standards. The total dissolved solids ranged from 50.5 to 70 mg/l with a mean average of 57.25 mg/l. The salinity mean values were consistently zero. The mean total organic carbon was found vary from 2.20 mg/l for the treated water that had been boiled to

6.65 mg/l for the raw water giving an average mean value of 3.37 mg/l. The measured residual chlorine was very low (below detectable limit) in all the water samples. The mean conductivity values ranged from 66.0 mg/ for the boiled water at household level to 131.00 mg/l at the chlorinated water giving an average mean conductivity of 101 mg/l. Mean nitrate levels ranged from 0.80 mg/l in boiled drinking water and chlorinated water to 3.00 mg/l in the raw sample. These gave an average mean concentration of 1.4 mg/l. Phosphate mean levels ranged from 0.1 mg/l in the boiled drinking water to 0.30 mg/l in the raw water sample, giving an average mean concentration of 0.175 mg/l. The chloride content ranged from 0.50 to 12.30 mg/l. This gives average mean value of 4.575 mg/l while sulphate mean values ranged from 22.5 mg/l to 42.00 mg/l with an average mean value of 32.5 mg/l. Comparing these values with the Nigerian Drinking water standards and international standards on water quality it was found that most of the values are well within those of Nigerian (SON), USEPA and WHO standards. The ABU treated water is therefore USEPA and WHO complaint. However, the very low values for the residual chlorine is a source of concern as it leaves the distribution system vulnerable to infection since there is no residual disinfectant to sterilize the system against re-infection when failures occur in the distribution system.

In terms of heavy metals, only two were detectable in the treated drinking water while the third (Iron) was only detected in the raw water sample not in the treated water samples. While lead gave mean values ranging from 0.01 to 0.040 mg/l with an average mean value of 0.0325 mg/l, zinc had a mean range of values of 0.01 mg/l to 0.05 mg/l with an average mean value of 0.03 mg/l. Against a national maximum permissible limit of 0.01 mg/l and 3 mg/l for lead and zinc respectively, the treated drinking water is only partially compliant (compliant with zinc and iron but noncompliant with respect to lead) in terms of heavy metal content. Also, with these values (against international standards) the ABU treated

water is USEPA compliant with respect to zinc and iron but noncompliant with respect to lead which may have been eroded from the automotive battery sheds and mechanical garages in Samaru village, whose drainage empty into the Kubanni reservoir. Also, the lead may have been dry and wet deposited from vehicular fumes and washed into the reservoir during rainfall.

The analyses for chlorination disinfection by-products in the ABU treated water identified Trihalomethanes, acetonitriles, other disinfection by-products, chlorinated solvents and haloacetic acids. The obtained mean values were compared with national and international standards notably the USEPA primary (priority) standards. Total mean values of the total regulated (four) halomethanes were found to vary from below detectable limit to 0.0131 mg/l for the water samples while the urine samples had between 0.0140 mg/l and 0.1120 mg/l for the four regulated halomethanes of Trichloromethane, Tribromomethane, dibromochloromethane and bromodichloromethane. In comparison with the national standards (SON) total halomethanes has a maximum permissible level of 0.001 mg/l while the USEPA maximum contaminant level for these four halomethanes was previously set at 0.10 mg/l and later reviewed to 0.08 mg/l from 31st December 2003, the sampled waters are not complying with the Nigerian national standards while it is within the compliance range with the USEPA. It is also in the compliance with the EU standard of 0.1 mg/l. Therefore the ABU treated water is USEPA and EU compliant with regards to the total Trihalomethanes but noncompliant with national standards on Trihalomethanes. In this study however the six determined Trihalomethanes had total mean values ranging from below detectable limit to 0.4924 mg/l for the water samples while the urine samples had mean values ranging from 0.0154 mg/l to 0.0831 mg/l. Even though these six Trihalomethanes did not correlate very well with four regulated Trihalomethanes (r=-0.047), they showed lower mean values for the sampled waters than the urine samples.

The total acetonitriles mean values in the sampled waters ranged from below detectable limit to 0.0269 mg/l, while the urine samples were of the range of 0.018 mg/l to 0.0483 mg/l. For the other disinfection by-products, total mean values for the sampled waters were of the range of below detectable limit to 0.2141 mg/l while their proportions in the urine samples were of the range of 0.0491 mg/l to 0.1553 mg/l. The chlorinated solvents on the other hand, had total mean values for the sampled waters ranging from below detectable limit to 0.4490 mg/l. However, the regulated chlorinated solvents, 1,1,2-Trichloroethane exceeded the MCL allowed by the USEPA standard of 0.005 mg/l with 0.0110 mg/l. The urine samples on their own had total mean values of these chlorinated solvents ranging from 0.0934 mg/l to 0.1074 mg/l. These are not regulated under the national standards for drinking water in Nigeria. But of the determined eleven haloacetic acids, five are the common (likely priority) ones which are regulated under the USEPA standards and the national standards do not regulate these too like the acetonitriles. The total mean values for these five halo-acids for the sampled waters ranged from below detectable limit to 1.83236 mg/l, while the urine samples' total mean values ranged from 0.59086 mg/l to 3.4057 mg/l with an average mean value of 1.6790 mg/l. However, the total mean values of the eleven measured halo-acids in the sampled waters varied between below detectable limit and 3.2516 mg/l while the urine samples had total mean values ranging from 0.78007 mg/l to 4.62036 mg/l.

These ranges of values and the resultant changes in the measured levels between the sampling points and the changes among the measured parameters were subjected to statistical analyses. Analysis of variance (ANOVA) of these changes showed that the differences between the levels of the analytes were highly significantly different (with F calculated as 4.8582** for the THMs, Acetonitriles, other DBPs and Chlorinated solvents

as well as 4.93** for the Haloacetic acids) while the ANOVA for the differences among the totals for the groups of analytes (THMs, Acetonitriles, other DBPs, and chlorinated solvents) were only significantly different with calculated F value of 3.5115*. Statistically, correlation analyses using Person's correlation coefficient showed relatively strong positive to strong positive and perfectly strong positive correlations among majority of the analytes many of which were significant (5%) to highly significant (5% and 1% probabilities) in the study with correlation coefficient (r) values ranging from 0.394 to 0.832 and also 0.980 between total haloacetic acids and halo-acetonitriles (0.832) and between total haloacetic acids and five common haloacetic acids (0.980) as in literature (Teuschler, *et al* 2000). These positive strongly correlated figures imply that the each of the correlating analyte has a strong positive relationship or association with the component analyte with a possibility of associative effects like additive and even synergistic toxicity.

5.2 Conclusion

From the results of this study, it is evident that the while operators of water treatment plants in parts of Northern Nigeria claim to process drinking water according to a commonly defined code of practices, their operations varied widely. It was also evident that most of these treatment plants had service laboratories which were not fully functioning and some of these treatment plants do skip disinfection in their treatment process for drinking water. The manpower position of the treatment plants was found to be relatively inadequate and hardly do these treatment plants provide uninterrupted and wholly satisfactory service of potable water delivery in their distribution network all the time despite the fact that drinking water has since 2004 been a basic human right. These clearly establish the need for a statutory body to supervise and monitor the quality of drinking water and its supply in Nigeria.

Also, it is evident that chlorine is the main disinfectant in use in ABU water treatment plant. It is the main source of the chlorination by-products in the ABU treated water samples for the halo-alkanes, acetonitriles, *other* disinfection by-products, chlorinated solvents and the haloacetic acids that have been observed in the drinking water treated by the plant. This is because all water samples before the chlorination stage (raw water, and water sample from sedimentation tanks) consistently gave values of below detectable limit for the analytes. Subsequently, highly significant reduction of the concentrations of the various analytes after the chlorination stage occur within the treatment and distribution system resulting in stepwise reduction from the sample after chlorination to the booster station and to the household levels for most of the determined disinfection by-products. This is probably due to distribution losses or decomposition or breakdown of the compounds due to volatility of the compounds, flow characteristics (in terms of frictional losses, and flow pattern among others) for the THMs, acetonitriles, *other* DBPs, chlorinated solvents and haloacetic acids many of which are not regulated.

In majority of cases, the urine samples were significantly higher in the measured concentrations of the disinfection by-products than the boiled water concentration of these analytes. It is possible that these situations may have arisen due to increased excretory activities of the kidneys due to abnormally high levels of these contaminants (analytes) in the blood stream due to prior bioaccumulation or due to hormonal imbalance, or yet still due to a disease of the kidney like inflammation or due to more urine production. Since there is no history or report of kidney problems among the household members providing the urine samples, and since the volume of the urine did not significantly change, it is more likely that the increased urine levels may have been due to increased excretory activities of the kidneys precipitated by the abnormal increases of these analytes in the body by prior bioaccumulation (MedlinePlus, 2011; Tutorvista, 2011; NKUDIC, 2011; USEPA, 2011(a)). The

bioaccumulation has a tendency to cause chronic toxicity condition that may manifest in the form of diseases of the liver, reproductive system and kidney as well as increase in cancer cases and damage to the nervous system which these compounds are noted for in subsequent years. This is a source of serious concern because the mean concentration levels of these DBPs are higher than the maximum permissible levels in the national standards for drinking water, where these exist in the standards. Therefore while the compliance of the ABU treated water with the USEPA standards for the halo-alkanes is noteworthy, it is a serious concern that the treated water is seriously noncompliant in terms of its lead content, haloacetic acids' and some chlorinated solvents like 1,1,2-trichloroethane concentration in the treated water. The very high statistical correlation values for these disinfection by-products further aggravates the implications of their presence in the drinking water as not only their concentrations but also their presence in different types has a tendency for combination effects on the health of individuals which may be additive or even synergistic in nature as had been indicted in literature (Teuschler, *et al* 2000). This is why more detailed study should be undertaken at national and international levels of the health impacts of most of the DBPs and their degree and implications of their interactions and when confirmed drastic measures must be taken to enhance their control of these drinking water contaminants beginning with more stringent control standards put in place nationally and internationally..

5.3 Recommendations

In view of the fact that this is one of the pioneer studies of the disinfection by-products in conventionally treated drinking water in this part of the world it is hereby recommended that:

i. More work be undertaken to test the consistency of these results, their trend and implications.

ii. The Ahmadu Bello University sets up a multidisciplinary team of researchers from the Water Resources and Environmental Engineering, the Microbiology and

Chemistry Departments to investigate the occurrence of these products in its treated drinking water and undertake investigations into the balance between optimum microbial control and disinfectant use in the control of disinfection by-products in conventionally treated drinking water.

iii. The automotive battery workers (auto electricians) in Samaru should be identified and educated about the likely havoc the waste from their de-commissioned batteries can cause.

iv. Their de-commissioned batteries and wastes should be centrally collected, the lead plates recovered and recycled under the supervision of the university health services.

v. More sponsorship of specific research activities on drinking water quality to ascertain the optimum residual disinfectant level and minimum DBPs formation and optimum microbial control with minimum DBPs formation nationwide.

vi. Use is made of these results as a preliminary basis for advocacy for a supervisory agency within the Federal Ministry of Water Resources to monitor the quality of treated drinking water nationwide on a continuous basis in other to safeguard the populace, with the strong representation of the various ministries of health.

vii. Nigeria's signatory to the declaration of wholesome drinking water as a basic human right, is strongly advocated rather than the present system of it being considered as a privilege to be withdrawn at the slightest opportunity of budgetary adjustments or change.

viii. Since ABU water supply service laboratory has now been significantly improved upon, routine analyses be stepped up to ascertain the level of efficiency of calcium hypochlorite as an appropriate disinfectant, ability to produce disinfection residual in the distribution network and amount of as well as conditions of generating disinfection by products.

ix. Sponsorship of more research into the various risks attendant to the consumption of individual disinfection by-products (which are now known to be over 500) and their various combinations. Such risk assessment studies must also detail the potential health effects of exposure and the public health implications of the various levels (above the MCLs) as well as the MCLGs.

x. Detailed epidemiological studies of the current health status of consumers of this treated water are undertaken to determine if any of the potential health effects are already manifest in the ABU community.

xi. More vigorous studies are undertaken on the nature and operations of various water treatment plants.

xii. An appropriate supervisory body for all water treatment plants is set up nationwide with full statutory powers to ensure full compliance with the ethics of professional water treatment for distribution to the people.

xiii. Drinking water treatment is professionalised to ensure adequate water treatment using appropriate legal and administrative instruments.

xiv. A comprehensive review of the existing drinking water standards in Nigeria (SON 2007) is undertaken to adequately include all possible contaminants in drinking water, all of which would have been tested for full range of effects with their Threshold limit values (TLV) and the maximum safe levels determined and recorded in details.

REFERENCES

Abolude, D. S., Davies O. A. and Avong, D. W. (2009): Level of Heavy Metals in freshwater Crab (*Cardisoma guahumi*) obtained from Ahmadu Bello University Reservoir, Zaria Nigeria. International Journal of Animal and Veterinary Advances 1(2): 54-58.

Adakole, A.J. and Abulodi, D. S. (2011): Pollutional Status of Kubanni lake through Metal Contaminations in Water and Sediments Columns. http://wldb.ilec.or.jp/data/ilec/WLC13_Papers/S!&/s17-1.pdf 16/6/2011

American Conference of Government Industrial Hygienists (1994): Threshold Limit Values for Chemical Substances and Physical Agents and Biological Exposure Indices; Technical Affairs Office, KemperWoods Centre, 1330 Kemper Meadow, Drive, Cincinnati OH 45240

Anon, (2004): Committee Report on Water Resources and Supply in Ahmadu Bello University, Submission to the Vice Chancellor, Ahmadu Bello University, Zaria, May 2004

American Public Health Association APHA (1998): Standard Methods for the Examination of Water and waste water, 20th edition. American Water Works Association, Water Environment Federation, Washington, D.C.

Antherholt T. B. *et al* (1998): Effect of Rainfall on *Gardia* and *Crypto;* Journal of American Water Works Association September, 1998: Vol. 90:9, 66 - 80.

AWWA, (1999a): Committee Report: Emerging Pathogens - Bacteria; Microbiological Contaminants Research Committee, AWWA Research Division; Journal of American Water Works Association September, 1999, Vol. 91:9, 101 - 109.

AWWA, (1999b): Committee Report:- Emerging Pathogens - Viruses, Protozoa, and Algal Toxins; Microbiological Contaminants Research Committee, AWWA Research Division; Journal of American Water Works Association September, 1999, Vol. 91:9, 110- 121.

Bellamy W., K. Carlson, D. Pier, J. Ducoste, M. Carlson, (2000): Determining Disinfection Needs; Journal of American Water Works Association, May 2000, Vol. 92;.5; 44-52.

Bellar, T. A. and Lichtenberg, J. T. (1974). Determining volatile organics at microgram-per-liter level by gas chromatography. Journal of the American Water Works Association, 66, 739-744.

Borst, M., Krudner, M., O'Shea, M. L. Perdek, J. M., Reasoner, D. and Royer, M. D. (2001). Source Water Protection: Its Role in Controlling Disinfection By-Products (DBPs) and Microbial Contaminants in Drinking Water, edited by Clark, R. M. and Boutin B. K. EPA/600/R-01/110 December, 4-2.

Bougeard, C. M. Goslan, E. H., Jefferson, B. and Parsons, S. A (2010). Comparison of the disinfection by-products formation potential of treated water exposed to chlorine and monochloramine. Water Research Vol.44:3, 729 – 740.

Chowdry, S. and Husain, T. (2011). Human health risk from trihalomethanes in drinking water evaluation with fuzzy aggregation. http://library.witpress.com/pages/PaperInfo.asp?PaperID=15804 26/01/2011.

Clark, R. M. and Thurnau, R. C. (2001). Control of Microbes and DBPs in Drinking Water: An Overview Controlling Disinfection By-Products and Microbial Contamination in Drinking Water edited by Clark, R. M. and Boutin B. K. EPA/600/R-01/110 December, 1-5 to 1-12.

Cornwell, D. A. and M. J. MacPhee, (2001): Effects of Spent Filter Backwash recycle on Cryptosporidium Removal; Journal of American Water Works Association April, 2001, Vol. 93:4, 153-162.

Cox, W. E. (1997). Evolution of the Safe Drinking Water Act: A search for effective quality assurance strategies and workable concepts of Federalism. William and Mary Environmental Law and Policy Review, 21, 69-164.

Craun, G. F., Frost, F. and Calderon, R. L. (1998): Water borne Outbreaks of Cryptosporidiosis; Journal of American Water Works Association September, 1998 Vol. 90:9, 81-91.

Craun, G. F. and R. L. Calderon, (2001): Waterborne Disease Outbreaks Caused by Distribution System Deficiencies; Journal of American Water Works Association September, 2001 Vol. 93:9, 64 - 75.

Environment News Service – ENS (2002): Water for Health declared a Human Right; in Safe and Secure Drinking Water is a Human Right – A United Nations Committee declared, 4th December, 2002, Geneva Switzerland; Environment News Service, December, 4, 2002.

Federal Republic of Nigeria (1965): The Distribution and Chemical Quality of Groundwater in Northern Nigeria. Geological Survey of Nigeria. Federal Government of Nigeria, 1965.

Fox, K. R. and Lytle, D. A. (1996). Milwaukee's crypto outbreak investigation and recommendations. Journal of American Water Works Association, 88(9), 87-94.

Ghurye, G. L., D. A. Clifford and A. R. Tripp, (1999): Combine Arsenic an Nitrate Removal by Ion Exchange in Journal of American Water Works Association, Vol. 91:10, 85-96 October, 1999

Goslan, E. H. Krasner, S. W. Bower, M. Rocks, S. A. Holmes, P. Levy, L. S. Parsons, S. A. (2009). A comparison of disinfection by-products found in chlorinated and chloraminated drinking waters in Scotland. Water Res. 43(18):5698 – 4706.

Hamidin N., Yu Q. J. and Connel, D. W. (2008). Human health risk assessment of chlorinated disinfection by-products in drinking water using a probabilistic approach. Water Res. 2008 Jul:42(13):3263-74 Epub 2008 Mar 6.

Hydes O**.,** (1999): European Regulation on Residual Disinfection; in Journal of American Water Works Association, Vol. 91:1, 70-74 January, 1999

Jakubovics, N. S. (1998): Biofilms in Potable Water Distribution Network. Ph.D Thesis, University of Warwick, University of Warwick Publications, http://webcast.warwick.ac.uk/36980/ accessed 13/10/2011

Krasner, S. W. (2009). The formation and control of emerging disinfection by-products of health concern. Philos Transact A Math Phys Eng Sci 2009 Oct 13:367(1904):4077-95.

Krasner, S. W., Weinberg, H. S. Richardson, S. D. , Pastor, S. J., Chinn, R. Sclimenti, M. J., Onstad, G. D. and Thruston, A. D. Jnr. (2006). Occurrence of a new generation of disinfection by-products. Environ Sci Technol 2006 Dec 1:40(23):7175-85.

Laurent P., P Servais, D. Gatel,.P. Bonne and J. Cavard; (1999): Microbiological Quality before and After Nanofiltration; Journal of American Water Works Association, October, 1999; Vol. 91:10, 62-72.

LeChevallier, M. W. (1999): The Case for Maintaining a Disinfectant residual; in Journal of American Water Works Association, Vol. 91:1, 86-94 January, 1999.

LeChevallier, M. W. (2000): Biofilms in drinking Water Distribution Systems: Significance and Control in Identifying Future Drinking Water Contaminants. The National Academy Press.

Lenntech (2011): Chemical Properties of Zinc: Health Effects and Environmental Effects of Zinc. http://www.lenntech.com/periodic/elements/zn. htm accessed 15/10/2011

Lin, Y. E., J. E. Stout, and V. L. Yu (1998): *Legionella* in Water Distribution Systems; Journal of American Water Works Association September, 1998 Vol. 90:9, 112-121.

Lipscomb, J. (2000). Overview of toxicity/carcinogenicity: Animal Data for use in Quantitative use in risk assessment. Research Report - Conducting a Risk Assessment of Mixtures of DBPs for drinking water treatment system; edited by Hertzberg, R. C. Lipscomb, J. C., Murphy P. A., Rice, G. E. and Teuschler, L. K. (Project Leader) National centre for environmental assessment Cincinnati, OH 45268. EPA/600/R-03/040 Sept. 2000.

Marr I. L. and M. S. Cresser (1987): Environmental Chemical Analysis; Publishers; International Textbook Company, New York, U. S. A.

Mason, C. F. (2002): Biology of Freshwater Pollution. Prentice Hall publishers, 387 pp

MedlinePlus (2011). Chloride – urine – Trusted health information for you. A publication of US National Library of Medicine and National Institute of Health. http://www.nlm.nih.gov/medlineplus/ency/article/003601.htm 15/03/2011.

Michael, A. M. (1987): Irrigation: Theory and Practice, Reprint; Published by Vikas Publishing House, PVT Ltd., 576 Marjid Road Jangpura, New Delhi - 110014

Microsoft Encarta, (2001): Water Supply and Water Works; Microsoft Encarta Online Encyclopaedia 2001, http: // Encarta.msn.com © 1997 - 2001 Microsoft Corporation. All rights Reserved.

Microsoft Encarta, (2007): Water Supply and Water Works; Microsoft Encarta Online Encyclopaedia 2007, http://Encarta.msn.com © 1993 - 2006 Microsoft Corporation. All rights Reserved.

New Mexico Environment Department (2001): Drinking Water Quality In National Drinking Water Clearing House, State of New Mexico, US.

NKUDIC, (2011). Your Urinary System and how it Works. A Publication of the National Institute of Diabetes and Digestive and Kidney Diseases, National Institute of Health. http://kidney.niddk.nih.gov/kudiseases/pubs/yoururinary 14/03/2011

Nwokeoma, J. (2011): Ministerial list :Why Jonathan needs a Good Cabinet. Punch Newspaper, 1/6/2011. www.punchontheweb.com/Article.aspx?theartic=Art201106014383457

Okun, D. A., Craun, G. F. Edzwald, J. K. Gilbert, J. B. and Rose, J. B. (1997). New York City: To filter or not to filter? Journal of American Water Works Association , 89(3), 62-74

Owens, J. (2001). A Review of federal drinking water regulations in the United States of America in Controlling Disinfection By-Products and microbial contaminants in drinking water, pp2-1 to 2-14. EPA/600/R-01/110 December 2001.

Pollard, S. J., D. 0. Harrop, P CrowcroftS. H. Mallett, S. R. Jeffries and P. J. Young, (1995): Risk Assessment for Environmental Management: Approaches and Applications, In Journal of Chartered Institute of Water and Environmental Management, Vol. 9:6, 621 -628.

Postel S. L. (2000): Water and World Population Growth; Journal of American Water Works Association, April, 2000; Vol. 92:4, 131-138

Potter N. N. (1987): Food Science; First Indian Edition by CBS Publishers and Distributors, 485, Jain Bhawan Bhola Nath Nagar Shahdara, Delhi-110032 (India).

Porter, H. (2002): Acid rain Environment Pollution – SMILE Programme Chemistry Index. http://mypages.iit.edu/-smile/cheminde.html 2/6/2002

Reiff, F. M. (1995). Balancing the chemical and microbial risks in the disinfection of drinking water supplies in developing countries. Proceedings of the Rome Symposium (September 1994) on Assessing and managing health risks from drinking water contamination; Approaches and Applications pp 23 – 30.

Richardson, S. D., Thryston, A. D. Jr., Rav-Acha, C., Groisman, L., Popilevsky, I., Juraev, O., Glezer, V., McKague, A. B., Plewa, M. J. and Wagner, E. D(2003). Trivromopyrrole, brominated acids and other disinfection by-products produced by disinfection of drinking water rich in bromide. Environ Sci Tecnol, 2003 Sep 1:37(17):3782-93.

Richardson, S. D., Plewa, M. J., Wagner, E. D., Schoeny, R. and Demarini, D. M.(2007). Occurrence, genotoxicity and carcinogenicity of regulated and emerging disinfection by-products in drinking water, a review and roadmap for research. Mutat Res. 2007 Nov-Dec638(1-3):178-242. Epub 2007 Se 12

Schoeny, R. (2010). Disinfection by-products: A Question of Balance. Environ. Health Perspect 118:a466-a467. Doi:10.1289/ehp.1003053 Nov. 2010.

Standards Organisation of Nigeria (SON) 2007: Nigerian Standard for Drinking Water Quality. Nigerian Industrial Standard NIS 554: 2007. ICS 13.060.20.

Stevens, A. A., Moore, L. A. and Miltner, R. J. (1989). Formation and control of non-trihalomethane disinfection by-products. Journal of American Water Works Association, 81(8), 54-60.

Snyder, J. D. and Merson, M. H. (1982): The Magnitude of the Global problem of Acute Diarrhoeal disease: A Review of Active Surveillance data. Bull. World Health Organization 60, 605-613

Teuschler, L. K., Gennings. C.,Stiteler, W. M,. Hertzberg, R., Colman, J. T., Thiyagarajah, A., Lipscomb, J. C., Hartley, W. R. and Simmons J. E. (2000). A multiple-purpose design approach to the evaluation of risks from complex mixtures of disinfection by-products (DBPs). Drug and Chemical Toxicology 23(1)307-321, (2000).

Tisdale, S. L. and Nelson, W. B. (1993): Soil Fertility and Fertilizers. 4th edition. Macmillan Publishers, (New York and Toronto) 634 pp.

Tukura, B. W., Kagbu, J. A. and Gimba, C. E. (2007): Effects of pH, Total Organic Carbon (TOC) on the Disitirbution of Trace Metals in Kubanni Dam Sediments, Zaria, Nigeria. Science World Journal, Vol. 2 (No3) 1-6

Tukura, B. W., Kagbu, J. A. and Gimba, C. E. (2011): Correlation Analyses of Organically Bound Trace Metals and Sediment in Kubanni Dam, Zaria, Nigeria. J. Environ. Sci Technol., 4: 437 – 441

Tutorvista, (2011). Osmoregulation Animation in Human. http://www.tutorvista.com/biology/osmoregulation-animation-in-human 20/03/2011.

United Nations Conference for Environmental Development (1992). "Agenda 21". Programmes of Action for Sustainable Development. UNCED, 1992.

United Nations University, International Network on Water, Environment and Health, (2001): Global Water Crisis in UNU/INWEH Me Master University, 1280 Main Street, West Hamilton, Ontario L8S 4L8 Canada.

USEPA (1990a): Technologies for Upgrading Existing or Designing New Drinking Water Treatment Facilities; In Technology Transfer, Series;EPA/625/4-89/023 of March 1990, from the Office of Drinking Water United States Environmental Protection Agency

USEPA, (1990b): Environmental Pollution Control Alternatives: Drinking Water Treatment for Small Communities EPA/625/5-90/025, U.S. Environmental Protection Agency Office of Technology Transfer and Regulatory Support, Washington, D. C. U. S. A.

USEPA, (1990c): Seminar Publication: Risk Assessment, management and Communication of Drinking Water Contamination, EPA/625/4-89/024 of June 1990 from the Office of Research and Development Washington, D. C. US, EPA, USA.

USEPA, (1995): Methods for the Determination of Organic Compounds in Drinking Water. Supplement III. EPA/600/R-95/131, Office of Research and Development, Washington DC 20460, August.

USEPA, (1997): Research Plan for Microbial pathogens and Disinfection By-Products in drinking water. EPA 600-R-97-122, Office of Research and Development, Washington D.C. December.

USEPA, (1999): Microbial and Disinfection By-product Rules Simultaneous Compliance Guidance Manual. EPA 815-R-99-015.

USEPA, (2003): National Drinking Water Standards; Consumer Confidence Reports – Building Public Trust. Drinking Water Pocket Guide #1 EPA 816-K-03-003 June 2003

USEPA (2011a). Basic information about disinfection by-products in drinking water: Total Trihalomethanes, Haloacetic acids, bromate and chlorite. http://water.epa.gov/drink/contaminants/basicinfomation/disinfection byproducts.cfn 13/02/2011.

USEPA (2011b). Executive Summary. http://www.epa.gov/athens/publications/reports/DBP/sec003_exec_summary.pdf. 26/01/2011

Vrijenhoek, E. M., Childress, A. E., Elimelech, M., Tanaka, T. S., Beuhler, M. D. (1998): Removing particles and THM precursors by enhanced Coagulation; Journal of American Water Works Association, April, 1998.

Watts, S. (1987): Drancunculiasis in Africa in 1986: Its Geographic extent, incidence and at risk population. Am. J. trop. Medicine and Hygiene 37, 119-125.

Wigle, D. T. (1998). Safe drinking water: a public health challenge. Chronic Dis Can 19:103-107.

WISE, (2011). Drinking Water Directive: The Drinking Water Directive (DWD), Council Directive 98/83/EC. The European 13/02/Commission. http://ec.europa.eu/environment/water/water-drink/index_en.html 13/02/2011

APPENDIX I

Dear Sir,

QUESTIONNAIRE FOR WATER TREATMENT PLANT PROCESSES.

I am a postgraduate student of the Ahmadu Bello University, Zaria. I am undertaking a research on the quality of water produced from conventional water treatment plants. In this study focus is on the available treatment plant processes, the type of disinfectant in use, the capacity of the treatment plant and the presence or otherwise of a service laboratory within the treatment plant. These and other information being requested are for academic research purposes only. Your cooperation is highly solicited; thank you.

1. When was your water treatment plant first commissioned?
   a). Pre-Independence b). Between 1960 and 1979 c). Between 1979 and 1986
   d). Between 1986 and 1999 e). After 1999.

2. Has there been any additional works done therein since then?
   a) Yes b) No

3. If answer to 2 above is Yes, what is the nature of the additional works done
   a) Rehabilitation b) Expansion c) Both

4. When was the most recent work done at the water treatment plant
   a). Less than 5 years ago
   b). Between 5 and 10 years ago
   c). Between 11 and 15 years ago
   d). Between 16 and 20 years ago
   e). over 20 years ago.

5. At the moment, what are the available water treatment processes within your treatment plant?
   PRELIMINARY TREATMENT PROCESSES
   a). Screening to remove most floating matter Yes/No
   b).Chemical treatment to remove algae and other aquatic nuisance
   Yes/No
   c). Pre-sedimentation to remove gravel, sand and other gritty materials
   Yes/No
   d). Micro- straining to remove algae, aquatic plants and small debris.
   Yes/No

   MAIN TREATMENT PROCESSES
   a). Chemical feed and Rapid mix to water Yes/No
   b). Coagulation/flocculation to convert non settleable to settleable particles
   Yes/No
   c). Sedimentation to remove settleable particles Yes/No
   d). Softening to remove hardness causing chemicals Yes/No

e). Filtration to remove biocontaminants and solid matter which cause turbidity Yes/No

f). Disinfection to kill disease causing microorganisms Yes/No

g).Adsorption with Granulated Activated Carbon (GAC) to remove colouring, radio nuclides, organic chemicals such as pesticides, solvents and Tri halo Alkanes Yes/No

h). Aeration to remove VOCs, H_2S, radon, dissolved gases, oxides of iron Aluminum and manganese Yes/No

i). Corrosion Control to prevent scaling and corrosion Yes/No

j). Reverse Osmosis and Electrodialysis to remove nearly all inorganic contaminants Yes/No

k). Ion exchange to remove some inorganic contaminants, including hardness causing chemicals Yes/No

l). Activated Alumina to remove inorganic contaminants Yes/No

m).Oxidation filtration to remove some inorganic contaminants e.g. iron, manganese and radium Yes/No.

n). Neutralization with lime to increase the pH of the treated water Yes/No

6. What is the approximate size of your catchment?
   a). Less than 1 ha
   b). Between 1 and 5 ha
   c). Between 5 and 10 ha
   d). Between 10 and 15 ha
   e). Between 15 and 30 ha
   f). Over 30 ha

7. How much of these are is protected (like fencing) and policed
   a). All of the catchment area
   b). A fraction of it
   c). None of it

8. What is the dominant Human Activity(ies) in the raw water catchment? You may choose more than one if they so exist.
   a). Agriculture
   b). Urbanization/Residential
   c). Industrial
   d). Mining

9. What is the initial designed capacity of your water treatment plant
   a). Less than 1 million gallons of treated water daily
   b). Between 1 and 1.5million gallons of treated water daily
   c). Between 1.5 and 3million gallons of treated water daily
   d). Between 3 and 5 million gallons of treated water daily
   e). Between 5 and 7 million gallons of treated water daily
   f). Between 7 and 10 million gallons of treated water daily
   g). Over 10 million gallons of treated water daily

10. After rehabilitation and expansion what is the new capacity of the water treatment plant?

a). Less than 1 million gallons of treated water daily
b). Between 1 and 1.5million gallons of treated water daily
c). Between 1.5 and 3million gallons of treated water daily
d). Between 3 and 5 million gallons of treated water daily
e). Between 5 and 7 million gallons of treated water daily
f). Between 7 and 10 million gallons of treated water daily
g). Over 10 million gallons of treated water daily

11. What is the present operating capacity of the water treatment plant?
a). Less than 1 million gallons of treated water daily
b). Between 1 and 1.5million gallons of treated water daily
c). Between 1.5 and 3million gallons of treated water daily
d). Between 3 and 5 million gallons of treated water daily
e). Between 5 and 7 million gallons of treated water daily
f). Between 7 and 10 million gallons of treated water daily
g). Over 10 million gallons of treated water daily

12. Does your treatment plant supplement its raw water supply with ground water? Yes/No

13. If you do have ground water supply to supplement or to solely supply urban water needs please indicate if this category of water is subjected to disinfection.
a). No need for disinfection
b). There is disinfection like in the surface water treatment.

14. What is the present disinfecting agent in use in the treatment process?
a). Chlorine
b). Chlorine plus ammonia
c). Ozone
d).

15. Have you had cause to change your disinfecting agent? Yes/No

16. If yes, why?
……
..

17. Also if Yes, what was/were the disinfecting agent(s) you had earlier used? (you may choose more than one as the case may be)
a). Chlorine
b). Chlorine plus ammonia
c). Ozone
d).

18. What is your average daily quantity of the disinfecting agent in use?
a). In the Rainy Season _____
b). In the dry season _____
in treating raw water for safe use.

19. Is there a "portable" side laboratory within the treatment plant? Yes/No

20. If Yes, what analyses are you capable of undertaking routinely in your daily operations

a). Turbidity Yes/No
b). pH Yes/No
c). Residual Chlorine levels Yes/No
d). Heavy metals Yes/No
e). *E. coli* Yes/No
f). *Gardia sp.* Yes/No
g). *Cryptosporodium sp.* Yes/No
h). Organic matter content Yes/No
i). Filamentous Algal growth at sedimentation tanks Yes/No

21. If Yes what is its state of functionality?

a). Functional – used daily for all necessary analysis of treated water
b). Partly functional – can only do some analyses and cannot be used every day.
c). Not functional – exists but cannot be put to use due to lack of qualified personnel or lack of equipment or lack of money to buy necessary chemicals
d). Does not even exist at all in the treatment plant. Has to seek the assistance of ministry of health to do some of the tests on some cases when disease outbreaks are feared.
e). Does not exist in the treatment plant and do not bother about water analyses.

22. What is your budget like over the past 5 – 10 years

a). Consistent with the needs of the water treatment plant in meeting the operating cost of paying staff salaries, cost of treatment chemicals and analyses and capital cost of replacement spare parts, expansion of tanks, building and distribution channels and overall plant maintenance.
b). Dwindling despite inflationary trends
c). Improving, despite increasing costs of items in recent times over inflationary trend

23. What is your stock level of Disinfectants?

a). Always maintain a steady stock of disinfectant - in store for regular use.
b). buy to use always, cannot afford to maintain a stock in store
c). Sometimes run out of stock because of budgetary constraints and supply difficulties.

24. Do you sometimes treat your water without or with les than normal quantities of the disinfectant applied?

a). Yes
b). No- Never.

25. If yes, indicate frequency or regularity of such practice.

a). Very Frequently
b). Sometimes
c). Only on few cases during the dry season as a result of lack of funds or when we have supply problems.
d). Does not. Disinfectant is always in use.

26. Do you always use residual disinfectant? Yes/No

27. If Yes, what proportion of total use is the residual?
    a). Less than 1%
    b). Between 1 and 5%
    c). Between 5 and 10%
    d).Over 10%
    e). 0%

28. Is your choice of residual disinfectant guided by any code of practice? Yes/No

29. If Yes, please name the code of practice…….

30. Do you have a disinfection profile of your treatment plant i.e. a relationship between the disinfection residual in your treated water and the control of common pathogenic microbes like *Gardia or Cryptosporidium spp*
    Yes/ No.

31. How frequently do you backwash your filters?
    a). Very frequently
    b). Frequently as stipulated in the operating code of practice
    c). Sometimes
    d). Rarely

32. What is the approximate spread of your distribution network?
    a). Less than 5km
    b). Between 5 and 10 km
    c). Between 10 and 20 km
    d). Between 20 and 50 km
    e). Between 50 and 100km
    f). Over 100 km.

33. How does your water treatment and distribution run?
    a). Operate and distribute water 24 hourly over the entire distribution network
    b). Operate only on daily (daytime) basis only continuously over the entire distribution network
    c). Operate on daytime basis, in rotation, over distribution system
    d). Operate on daytime basis in rotation and over select periods in areas within the distribution network
    e). Operate day and night in rotation and over select periods in areas within distribution system

34. How regular are failures in your distribution network?
    a). Very frequent
    b). Frequent
    c). Sometimes
    d). Hardly

35. What are the common traceable dangers or risks associated with your treated water

a). Microbial Yes/No
b). Flouride Yes/No
c). Barium Yes/No
d). Nitrate Yes/No
e). Radionuclides Yes/No
f). Arsenic Yes/No
g). Organics Yes/No
h). None of these

36. Are you aware of Disinfection Bye Products (DBPs)? Yes/No

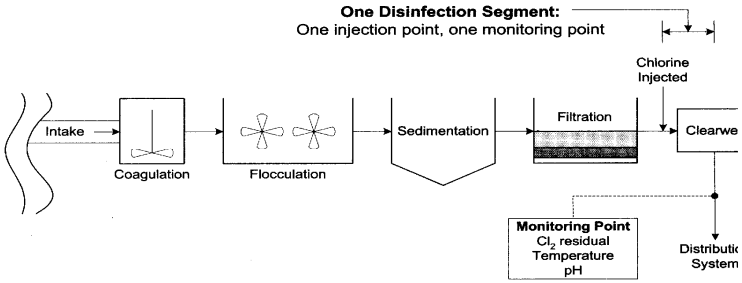
37. Are you aware that they are implicated in health problems Yes/No

38. Do you foresee them as a source of health risk in your treated water? Yes/No

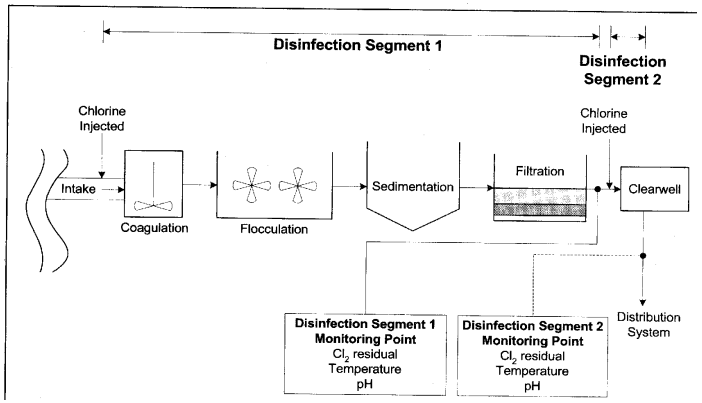
39. Does your raw water show distinct seasonal variation in characteristics such as colour, turbidity, taste and probably hardness? Yes/No

40. Are you aware of any deliberate discharge of treated sewage (sewage effluent) or effluent from septic tank into your raw water Yes/No

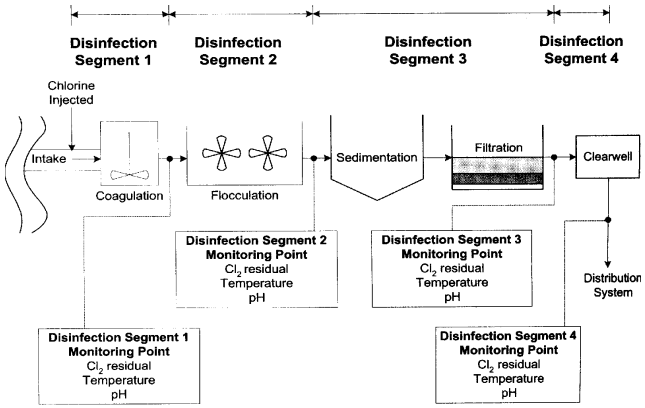
41. Which of these diagrams schematically represents your treatment plant layout?



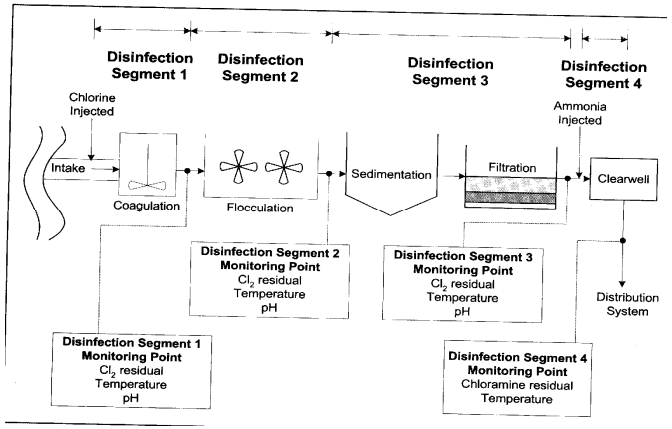
a). A Treatment Plant Schematic showing a conventional plant with *One Disinfection Segment*



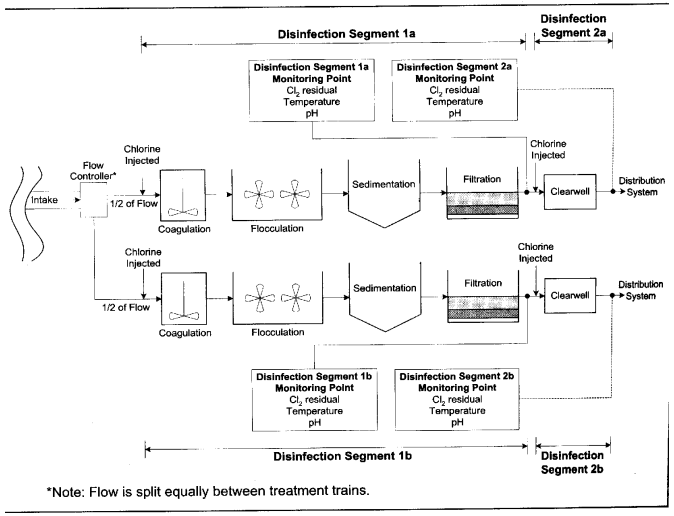
b). A Treatment Plant Schematic with t*wo Disinfection Segments*



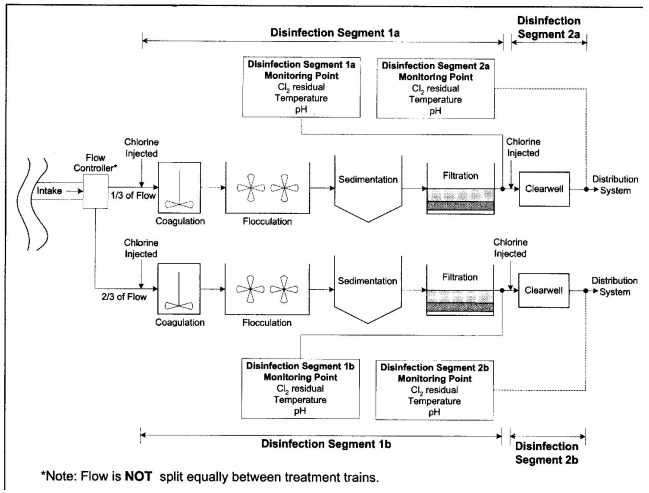
c). Treatment Plant Schematic Showing *one Injection point with Multiple Disinfection Segments*



d). A Treatment Plant Schematic with t*wo identical Treatment Trains and two injection points having Multiple Disinfection Segments*



e). Treatment Plant Schematic with *Multiple Identical Treatment Trains and Multiple Injection Points with Multiple Disinfection Segments*



f). Treatment Plant Schematic with *Multiple Treatment Trains and Multiple Disinfection Segments*. Note Flow is not split equally between the Trains