

**A SURVEY OF DISINFECTION BY-PRODUCTS IN
TAP WATER FROM SELECTED AREAS IN NAIROBI
COUNTY AND THIKA SUB-COUNTY, KENYA**

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**A Survey of Disinfection By-products in Tap Water from Selected
Areas in Nairobi County and Thika Sub-County, Kenya**

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**A Thesis Submitted in Partial Fulfilment for the Degree of Master
of Science in Chemistry in the Jomo Kenyatta
University of Agriculture and Technology**

2015

DECLARATION

This thesis is my original work and has not been presented for a degree in any other University

Signature.....Date.....

Veronica Osoro

This thesis has been submitted for examination with our approval as university supervisors.

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DEDICATION

This thesis is dedicated to my husband and my children.

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NOMENCLATURE

Abbreviation Meaning

AFD African Development Bank

C Concentration

CUEA Catholic University of Eastern Africa

DBP Disinfection By-product

DOC Dissolved Organic Carbon

ECD Electron Capture Detector

EPA Environmental Policy Agency

GC Gas Chromatography

GV Guideline value

HAAs Haloacetic acids

KEBS Kenya Bureau of Standards

KU Kenyatta University

MAC Maximum Allowable Concentration

MS Mass Spectrometer

NAWASCO	Nairobi Water and Sewarage Company
NOM	Natural Organic Matter
SD	Standard Deviation
SPI	Septum Programmable Injector
TCU	True Color Units
TDS	Total Dissolved Solids
THMS	Trihalomethanes
TOC	Total Organic Carbon
TSS	Total Suspended Solids
TU	Turbidity Units
UNICEF	United Nations Children's Fund
UoN	University of Nairobi
USEPA	United States Environmental Protection Agency
UVA	Ultra Violet Absorption
WHO	World Health Organization

ABSTRACT

Over 1.1 billion people in the world lack access to potable water. Diarrheal and other waterborne diseases cause an estimated 2.2 million deaths per year. To curb these diseases, chlorination is a proven water treatment method. Concerns have been raised about the potential long term health effects of formation of disinfection by-products to users of chlorinated water. These by-products have limits of which they should not exceed. This study investigated the production of trihalomethanes (THMs) in chlorinated tap water from selected areas in Nairobi County and Thika Sub-County, Kenya. Water samples were directly collected from the taps, and taken to KEBS for analysis of THMs using Gas Chromatography-Electron Capture Detector. Data obtained was subjected to Microsoft Excel and analysis of variance. Water samples from Kawangware Estate, Technical University College of Kenya and Hurlingham had some significant amount of chloroform; $7.4\mu\text{g/L}$ with SD of 1.0, 5.3 ± 3.0 and 15 ± 4.0 ($\mu\text{g/L}$) respectively. Water samples from Technical University College of Kenya, Karura Forest, Catholic University of Eastern Africa, Kawangware Estate and Hurlingham showed traces of dibromochloromethane as follows: 6.5, 5.6, 3.7, 5.3, 7.1 ($\mu\text{g/L}$) respectively with SD ranging from 0.1 to 1.1. The study investigated how pH, Temp, Turbidity and DOC affects the formation of THMs in chlorinated water. The results showed that THMs concentration was high in samples with high values of pH, Temp, DOC and Turbidity. A narrow range of turbidity (4.5–4.9 NTU) and DOC (1.0–2.3 $\mu\text{g/L}$) was recorded. SD for turbidity in water samples ranged from 0.03-0.07 and 0.04-0.26 for DOC. The data presented herein clearly show that chlorination of filtered waters does not lead to THMs concentrations above the WHO guideline values. Therefore, proper chlorine disinfection in municipal and borehole water in Kenya is recommended.

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background Information

Clean drinking water is essential to humans and other life forms. Access to safe drinking water has improved steadily and substantially over the last few decades in almost every part of the world (Björn and Lomborg, 2001). However, some observers have estimated that by 2025 more than half of the world population will be facing water-based vulnerability (Kulshreshtha, 1998). Water plays an important role in the world economy, as it functions as a solvent for a wide variety of chemical substances and facilitates industrial cooling and transportation. Approximately 70% of freshwater is consumed in agriculture (Kulshreshtha, 1998).

According to a 2008 World Health Organization report, 1.1 billion people lack access to clean drinking water supply, 88% of the 4 billion annual cases of diarrheal disease are attributed to unsafe water and inadequate sanitation and hygiene, while 1.8 million people die from diarrheal diseases each year. In addition, waterborne diarrheal diseases lead to decreased food intake and nutrient absorption, malnutrition, reduced resistance to infection (Baquiet *al.*, 1993), and impaired physical growth and cognitive development (Guerrant *et al.*, 1999). WHO estimates that 94% of these diarrheal cases are preventable through modifications of the

environment, including access to safe water (Björn and Lomborg, 2001). Chlorination was first used for disinfection of public water supplies in the early 1900s, and it is one factor that contributed to dramatic reductions in waterborne diseases in cities in the United States (Cutler and Miller, 2005).

1.1.1 Public Water Supply

Water supply is the provision of water by public utilities, commercial organizations, community endeavors or by individuals, usually via a system of pumps and pipes (Nickson *et al.*, 2003). The source of water supplied is likely to originate from groundwater, reservoirs, lakes, rivers, canals, surface water, atmospheric generated water, rainwater and desalinated seawater (Björn and Lomborg, 2001).

1.1.2 Water Treatment

Drinking water sources are subject to contamination and require appropriate treatment to remove disease-causing agents (Lindsten, 1984). Public drinking water systems use various methods of water treatment as in (Fig 1.1) to provide safe drinking water for their communities.

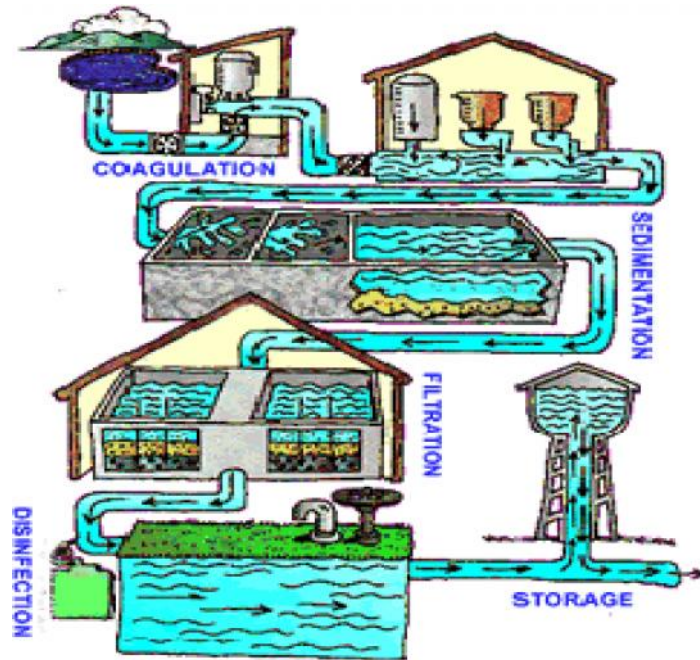


Fig 1.1 Schematic diagram for water purification and treatment (Source: USEPA, 1998)

1.1.3 Coagulation and Flocculation

Coagulation and flocculation are often the first steps in water treatment. Chemicals with a positive charge are added to the water. The positive charge of these chemicals neutralizes the negative charge of dirt and other dissolved particles in the water. When this occurs, the particles bind with the chemicals and form larger particles, called floc (Lindsten, 1984).

1.1.4 Sedimentation and Filtration

During sedimentation, floc settles to the bottom of the water supply, due to its weight. This settling process is called sedimentation. Sedimentation and flocculation are meant to remove Natural Organic Matter (NOM), (USEPA, 1998) and therefore should be carefully done.

Once the floc has settled to the bottom of the water supply, the clear water on top passes through filters of varying compositions (sand, gravel, and charcoal) and pore sizes, in order to remove dissolved particles, such as dust, parasites, bacteria, viruses, and chemicals (Nickson *et al.*, 2003).

1.1.5 Disinfection

After the water has been filtered, a disinfectant (for example, chlorine, chloramine) may be added in order to kill any remaining parasites, bacteria, and viruses, and to protect the water from germs before it is piped to homes and businesses (Lindsten, 1984).

1.1.6 Drinking Water Quality Standards

Drinking water quality standards describes the quality parameters set for drinking water. Despite the truism that every human on this planet needs drinking water to survive and that water may contain many harmful constituents, there are no universally recognized and accepted international standards for drinking water (UNICEF, 2010).

Where drinking water quality standards do exist, most are expressed as guidelines (Table 1.1 and 1.2) or targets rather than requirements (WHO, 1998).

Table 1.1: WHO Maximum Guidelines for Organic Metals

Group	Substance	Formula	Health based guideline by the WHO
Chlorinated alkanes	Carbon tetrachloride	CCl ₄	2 µg/l
	Dichloromethane	C H ₂ Cl ₂	20 µg/l
	1,1-Dichloroethane	C ₂ H ₄ Cl ₂	No guideline
	1,2-Dichloroethane	Cl CH ₂ CH ₂ Cl	30 µg/l
	1,1,1-Trichloroethane	CH ₃ C Cl ₃	2000 µg/l
Chlorinated ethenes	1,1-Dichloroethene	C ₂ H ₂ Cl ₂	30 µg/l
	1,2-Dichloroethene	C ₂ H ₂ Cl ₂	50 µg/l
	Trichloroethene	C ₂ H Cl ₃	70 µg/l
	Tetrachloroethene	C ₂ Cl ₄	40 µg/l
Aromatic hydrocarbons	Benzene	C ₆ H ₆	10 µg/l
	Toluene	C ₇ H ₈	700 µg/l
	Xylenes	C ₈ H ₁₀	500 µg/l
	Ethylbenzene	C ₈ H ₁₀	300 µg/l
	Styrene	C ₈ H ₈	20 µg/l
	Polynuclear Aromatic Hydrocarbons (PAHs)	C ₂ H ₃ N ₁ O ₅ P ₁₃	0.7 µg/l

Source: WHO, 1998

Table 1.2: WHO Maximum Guideline Standards for Disinfectant By-Products

Group	Substance	Formula	Health based guideline by the WHO	
Disinfectants	Chloramines	$\text{NH}_n\text{Cl}^{(3-n)}$, where $n = 0, 1 \text{ or } 2$	3 mg/l	
	Chlorine	Cl_2	5 mg/l	
Disinfectant by-products	Bromate	Br O_3^-	25 $\mu\text{g/l}$	
	Chlorate	Cl O_3^-	No guideline	
	Chlorite	Cl O_2^-	200 $\mu\text{g/l}$	
	Formaldehyde	HCHO	900 $\mu\text{g/l}$	
	Trihalomethanes	Bromoform	C H Br_3	100 $\mu\text{g/l}$
		Dibromochloromethane	$\text{CH Br}_2\text{Cl}$	100 $\mu\text{g/l}$
		Bromodichloromethane	CH Br Cl_2	60 $\mu\text{g/l}$
		Chloroform	CH Cl_3	300 $\mu\text{g/l}$
	Chlorinated acetic acids	Monochloroacetic acid	$\text{C}_2\text{H}_3\text{Cl O}_2$	No guideline
		Dichloroacetic acid	$\text{C}_2\text{H}_2\text{Cl}_2\text{O}_2$	50 $\mu\text{g/l}$
		Trichloroacetic acid	$\text{C}_2\text{HCl}_3\text{O}_2$	100 $\mu\text{g/l}$
		Trichloroacetonitrile	$\text{C}_2\text{Cl}_3\text{N}$	1 $\mu\text{g/l}$
	Bromide	Br^-	0.5 mg/l	

Source: WHO, 1998

1.2 Drinking Water Disinfection Technologies

1.2.1 Chlorine Dioxide Disinfection

Chlorine dioxide is a faster-acting disinfectant than elemental chlorine. It is relatively rarely used, because in some circumstances it may create excessive amounts of chlorite, which is a by-product (Baker *et al.*, 2002). Chlorine dioxide is supplied as an aqueous solution and added to water to avoid gas handling problems (Andriamirado *et al.*, 2007)

1.2.2 Chloramine Disinfection

The use of chloramine is becoming more common as a disinfectant (Baker *et al.*, 2002). Although chloramine is not as strong an oxidant, it does provide a longer-lasting residual than free chlorine and it will not form THMs or haloacetic acids. It is possible to convert chlorine to chloramine by adding ammonia to the water after addition of chlorine. The chlorine and ammonia react to form chloramine. Water distribution systems disinfected with chloramines may experience nitrification, as ammonia is a nutrient for bacterial growth, with nitrates being generated as a by-product (Singer and Philip, 1995).

1.2.3 Ozone Disinfection

Ozone is an unstable molecule which readily gives up one atom of oxygen providing a powerful oxidizing agent which is toxic to most waterborne organisms (Lindsten, 1984). It is a very strong, broad spectrum disinfectant that is widely used in Europe. It is an effective method to

inactivate harmful protozoa that form cysts. It also works well against almost all other pathogens. Ozone is made by passing oxygen through ultraviolet light or a "cold" electrical discharge (Reckhow and Singer, 1990). Some of the advantages of ozone include the production of fewer dangerous by-products and the absence of taste and odour problems (in comparison to chlorination). Another advantage of ozone is that it leaves no residual disinfectant in the water. The U.S. Food and Drug Administration has accepted ozone as being safe; and it is applied as an anti-microbiological agent for the treatment, storage, and processing of foods. However, although fewer by-products are formed by ozonation, it has been discovered that ozone reacts with bromide ions in water to produce concentrations of the suspected carcinogen bromate (USEPA, 1998).

1.2.4 Ultraviolet Disinfection

Ultraviolet light (UV) is very effective at inactivating cysts, in low turbidity water (Rook, 1978; White, 1999). UV light's disinfection effectiveness decreases as turbidity increases, a result of the absorption, scattering, and shadowing caused by the suspended solids. The main disadvantage to the use of UV radiation is that, like ozone treatment, it leaves no residual disinfectant in the water; therefore, it is sometimes necessary to add a residual disinfectant after the primary disinfection process. This is often done through the addition of chloramines, discussed above as a primary disinfectant. When used in this manner, chloramines provide an effective residual disinfectant with very few of the negative effects of chlorination (Lindsten, 1984).

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Disinfection By-Products

Disinfection byproducts are formed when disinfectants used in water treatment plants react with bromide and/or natural organic matter (i.e., decaying vegetation) present in the source water. Different disinfectants produce different types or amounts of disinfection byproducts. Disinfection byproducts for which regulations have been established have been identified in drinking water, including trihalomethanes, haloacetic acids, bromate, and chlorite (Baker *et al.*, 2002) .

2.1.1 Trihalomethanes (THMs)

Trihalomethanes (THM) are a group of four chemicals that are formed along with other disinfection byproducts. When chlorine as a disinfectant is used to control microbial contaminants in drinking water, it reacts with naturally occurring organic and inorganic matter in water to form THMs (Lindstorm, 1997). The trihalomethanes are chloroform, bromodichloromethane, dibromochloromethane, and bromoform. USEPA has published the Stage 1 Disinfectants/Disinfection Byproducts Rule to regulate total trihalomethanes (TTHM) at a maximum allowable annual average level of 80 parts per billion (USEPA, 1998)

2.1.2 Haloacetic Acids (HAAs)

Haloacetic Acids (HAAs) are a group of chemicals that are formed along with other disinfection byproducts when chlorine or other disinfectants used to control microbial contaminants in drinking water react with naturally occurring organic and inorganic matter in water (Delgado, 2010). The regulated haloacetic acids are: monochloroacetic acid, dichloroacetic acid, trichloroacetic acid, monobromoacetic acid, and dibromoacetic acid. USEPA has published the Stage 1 Disinfectants/Disinfection Byproducts Rule to regulate HAAs at a maximum allowable annual average level of 60 parts per billion (USEPA, 1998)

2.1.3 Bromate

Bromate is a chemical that is formed when ozone used to disinfect drinking water reacts with naturally occurring bromide found in source water (Morris et al., 1992). EPA has established the Stage 1 Disinfectants/Disinfection Byproducts Rule to regulate bromate at annual average of 10 parts per billion in drinking water (EPA, 1998).

2.1.4 Chlorite

Chlorite is a byproduct formed when chlorine dioxide is used to disinfect water (Baker *et al.*, 2002). EPA has published the Stage 1 Disinfectants/Disinfection Byproducts Rule to regulate chlorite at a monthly average level of 1 part per million (EPA, 1998).

2.2 Environmental and Public Health Effects of Consumption of DBPs

Disinfectants in drinking-water do not raise health concerns themselves at the levels used but some of their by-products do (Reckhow and Singer, 1990). Potential human health effects would depend on both the concentration of disinfectant by-products and the length and timing of exposure (Reckhow and Singer, 1990).

Some studies in human populations seem to indicate that chlorinated and chloraminated drinking-water may cause cancers of the bladder, colon and rectum (Reckhow and Singer, 1990).

2.2.1 Composition of Source Water Contaminants

Most source water contaminants include organic particulates or Natural Organic Matter (NOM) (Farewell *et al.*, 1988). They are particulate or dissolved matter resulting from degradation of plant and animal materials. NOM affects color and turbidity since it includes suspended materials, colloidal solids and settleable solids (Christam and Ghassemi, 1966). Humic acids which are the main THM precursors are found in this category (Philip; Singer, 1990). Inorganic particulates which include mineral matter resulting from weathering, erosion or runoff in the catchment such as silts, clays, are contaminants. Bacteria and viruses are other contaminants.

NOM, a complex mixture of organic compounds resulting from the degradation of vegetative matter in the catchment and compounds resulting from the growth and decomposition of algae and weeds, is mainly made of

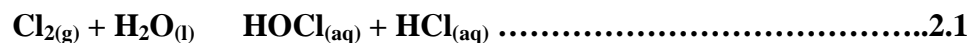
humic substances namely humic acids with molecular weights between hundreds and tens of thousands (Philip and Singer, 1990). The majority of NOM exists as dissolved compounds and is often measured as Dissolved Organic Carbon (DOC). It is commonly accepted that some NOM compounds, notably those with light absorbing chemical structures such as aromatic rings, are the most likely to react to form Disinfectant By-Products (Shunji *et al.*, 1998)

2.2.2 Measurement and Characterization of NOM

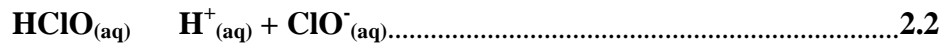
The total concentration of NOM is usually measured as total organic carbon (TOC) or dissolved organic carbon (DOC) with a filter of 0.45µm. All dissolved and / colloidal organic compounds are usually detected (Farewell *et al.*, 1988). The species most likely to react with chlorine to form DBPs are thought to be those that absorb visible and/or UV light at certain wavelengths and more specifically colored compounds with C=C double bond (Shunji *et al.*, 1998).

2.2.3 Chlorination

When chlorine is added to water, it reacts to form a pH dependent equilibrium mixture of chlorine, hypochlorous acid and hydrochloric acid (Fair *et al.*, 1948) as shown in equation 2.1 below:

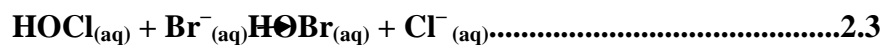


Depending on the pH, hypochlorous acid partly dissociates into hydrogen and hypochlorite ions as shown in equation 2.2 below:



In acidic solution, the major species are Cl₂ and HOCl while in alkaline solution, effectively only ClO⁻ is present. Very small concentrations of ClO₂⁻, ClO₃⁻, ClO₄⁻ are also found (Shunji *et al.*, 1998).

Another reaction that occurs in waters containing bromide ion and hypochlorite is the production of hypobromous acid as shown in equation 2.3:



This reaction is irreversible, and the product hypobromous acid is a better halogenating agent than hypochlorous acid and interferes with common analytical procedures for free chlorine (Mel *et al.*, 1993).

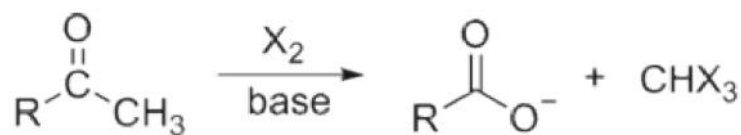
Chlorine reacts with humic substances (dissolved organic matter) present in most water supplies, forming a variety of halogenated DBPs as shown in 2.4 below:



Hypochlorous acid and methyl ketone groups (acetyl groups) react in humic acids to form trihalomethanes (Rook, 1974).

This chemical reaction where a haloform (CHX₃, where X is a halogen) is produced by the exhaustive halogenation of a methyl ketone (a molecule containing the R-CO-CH₃ group) in the presence of a base is called a haloform reaction (Bunce and Manahan, 1984). R can represent an alkyl or

an aryl. The reaction (equation 2.5) can be used to produce chloroform (CHCl₃), bromoform (CHBr₃), or iodoform (CHI₃).



R = H, alkyl, aryl

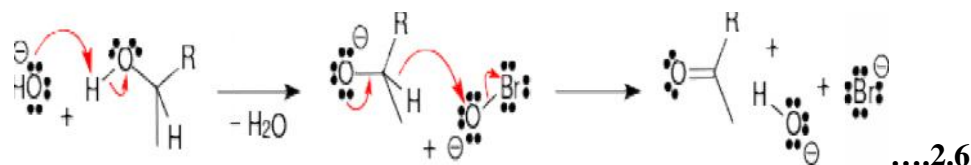
X = Cl, Br, I

.....2.5

Substrates that successfully undergo the haloform reaction are methyl ketones and secondary alcohol oxidizable to methyl ketones, such as isopropanol. The only primary alcohol and aldehyde to undergo this reaction are ethanol and ethanal, respectively. 1,3-Diketones such as acetylacetone also give the haloform reaction. -ketoacids such as acetoacetic acid will also give the test upon heating. The halogen used may be chlorine, bromine, or iodine (Bunce and Manahan, 1984).

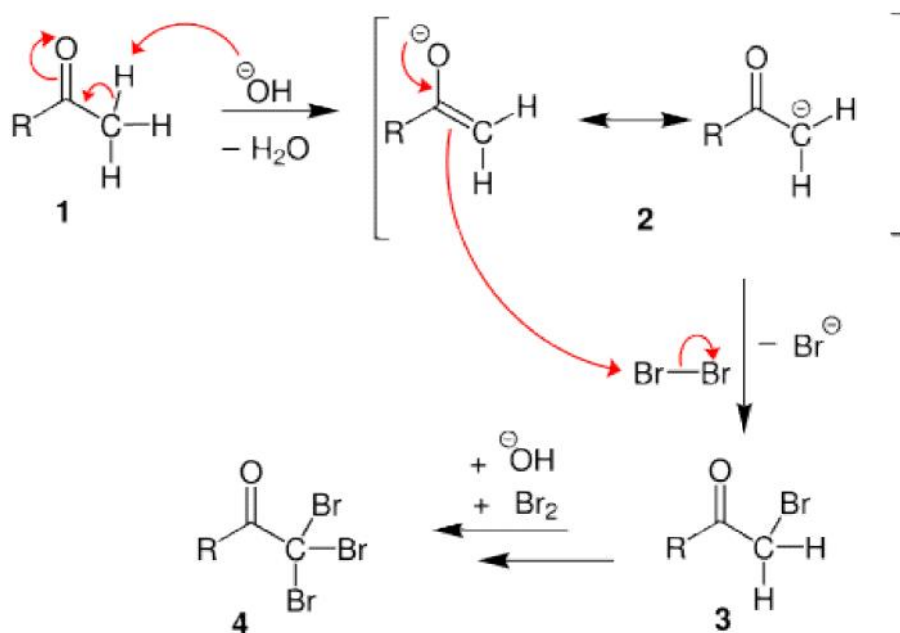
2.2.4 Mechanism

The alcohol is first oxidized to a ketone by the hypohalite as shown in the chemical mechanism 2.6 below.



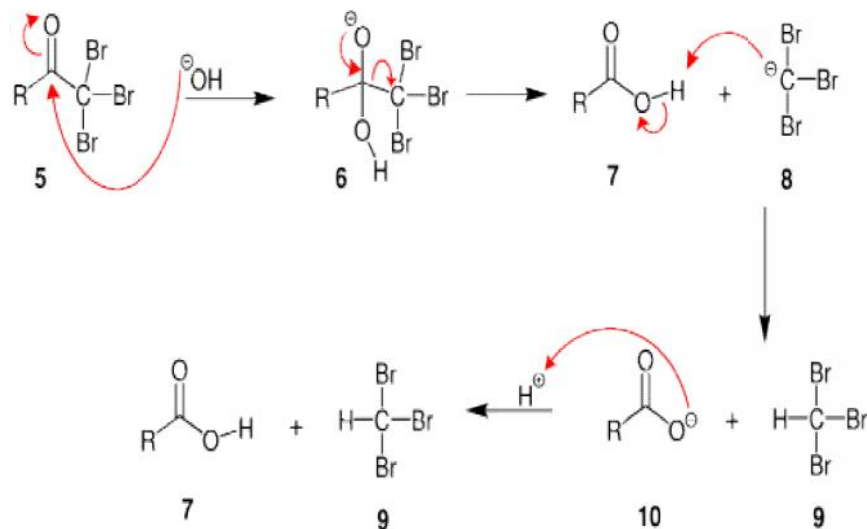
If a methyl ketone is present, it reacts with the hypohalite in a three-step process:

- Under basic conditions, the ketone undergoes keto-enol tautomerization as presented in mechanisms (1 and 2) below. The enolate undergoes electrophilic attack by the hypohalite (containing a halogen with a +1 charge as in mechanisms (3 and 4) below.



- When the position has been exhaustively halogenated as in 4 above, the molecule undergoes a nucleophilic acyl substitution mechanism (5) by hydroxide, with CX_3 being the leaving group stabilized by three electron-withdrawing groups as presented in mechanisms (6,7 and 8)

3. In the third step the CX_3^- anion abstracts a proton from either the solvent or the carboxylic acid formed in the previous step, and forms the haloform(8)



Although humic substances are the likely major source of trihalomethanes, other organic carbon substances can also be trihalomethane precursors. For example, with some alkenes, chlorine adds to an activated double bond, the byproduct of which may be oxidized to methyl ketones, and may then undergo the haloform reaction. Similarly, meta-hydroxy phenolic compounds and cyclohexanes containing a methylene group flanked by two carbonyls can yield trihalomethanes (Bunce and Manahan, 1984). Many of the compounds produced as a result of chlorination of organic carbon compounds are probable carcinogens to humans or have been shown to be mutagenic (Singer and Reckhow, 1990 ; Health Canada, 1997).

2.2.5 Trihalomethanes

THMs have the general formula CHX_3 (Table 2.1) where X can be Cl or Br. Studies show that hypochlorous acid and hypobromous acid react with naturally occurring organic material to create four compounds with potential human health effects (Rook, 1974). Subsequent research established that THMs caused the development of tumors in animal models (IARC, 1999).

Table 2.1: Characteristics of Common Trihalomethanes

Trihalomethane	Prevalence	Health Effects
Chloroform (CHCl_3)	High	Carcinogenic
Bromodichloromethane (CHBrCl_2)	Moderate	Carcinogenic, Genotoxic
Dibromochloromethane (CHBr_2Cl)	Moderate	Carcinogenic, Genotoxic
Bromoform (CHBr_3)	Moderate	Carcinogenic, Genotoxic

Richardson *et al.*, 2007

Chloroform, bromoform, bromodichloromethane, and chlorodibromomethane are majorly addressed in guidelines and regulations (USEPA, 1998). Chloroform generally dominates because the three brominated compounds form only in the presence of naturally occurring bromide (Richardson *et al.*, 2007).

A summary of the prevalence, possible health effects of the four THMs is provided in Table 2.3

2.2.6 Regulation of THMs

Guidelines for Canadian Drinking Water Quality recommend a maximum acceptable concentration of 100µg/L (Table 2.2) for total THMs. In the United States, THMs are regulated by the USEPA Stage 1 Disinfectants and Disinfection Byproducts Rule (USEPA, 2002; WHO, 2008).

Table 2.2: THMs Guidelines and Regulations

Disinfection By-Product	Guidelines for Canadian Drinking Water Quality	US Environmental Protection Agency Regulations	World Health Organization Guidelines	European Union Standard
Total THMs	100µg/L	80µg/L	–	100µg/L
CHCl ₃	–	–	300µg/L	–
CHBrCl ₂	–	–	60µg/L	–
CHBr ₂ Cl	–	–	100µg/L	–
CHBr ₃	–	–	100µg/L	–

USEPA, 2002; WHO, 2008

WHO also proposes the use of an additive toxicity guideline value, using the fractionation equation that the sum of the four THMs' actual concentration (C) divided by their guideline value (GV) should not be greater than one (WHO, 2004) as shown in equation 2.7 below.

$$\frac{C_{\text{Chloroform}}}{GV_{\text{Chloroform}}} + \frac{C_{\text{BDCM}}}{GV_{\text{BDCM}}} + \frac{C_{\text{DBCM}}}{GV_{\text{DBCM}}} + \frac{C_{\text{Bromoform}}}{GV_{\text{Bromoform}}} = 1 \dots\dots\dots(2.7)$$

2.3 Study Area, Nairobi County and Thika Sub-county, Kenya

Nairobi occupies an area of about 700 km² at the south-eastern end of Kenya’s agricultural heartland. At 1,600 to 1,850 m above sea level, it enjoys tolerable temperatures all year round (Mitullah, 2003). The Nairobi, Ngong, and Mathare rivers traverse numerous neighborhoods and the indigenous Karura forest still spreads over parts of northern Nairobi.

The bulk of water supply for Nairobi comes from Thika (Ngethu) and Sasumua dam. Over time, water supply for the city has failed to meet demand. The current estimated water demand for Nairobi is 650 000 m³/day compared to the production of 482,940m³ /day (WRMA, 2010). The difference between production and demand has been widening over time due to population growth, inadequacy of the carrying capacity of the distribution network and climate shocks(Mitullah, 2003). Most residents in Nairobi County get their portable water from Nairobi Water and Sewarage Company (NAWASCO). Jomo Kenyatta University of Agriculture and Technology (main campus) uses their own treated borehole water.

2.3.1 Sasumua Dam

Sasumua Dam (Fig 2.1) is one of Athi Water Sewarage Board assets.



Fig 2.1 Sasumua Dam (Source: NAWASCO, 2011)

The dam is located on the Sasumua stream, tributary of Chania near Njabini Township on the South end of the Aberdare Mountain (Pagiola and Stefano, 2007).

2.3.2 Sasumua Treatment Plant

Sasumua treatment plant (Fig 2.2) is composed of three phases; Phase 1 is sedimentation where Alum is used as a coagulant sedimentation (Pagiola and Stefano, 2007).



Fig 2.2 Sasumua Treatment Plant (Source: NAWASCO, 2007.)

This is followed by Phase 2 and 3 which include rapid gravity and filtration. Disinfection is by chlorination and pH adjustment by the

addition of soda ash. After treatment water is conveyed to Nairobi by means of a long buried steel pipeline (Joseph andKaranja, 2011).

2.3.3 Thika Dam (Ndakaini)

Thika dam (fig 2.3) is owned by Athi and operated by the Nairobi City Water & Sewerage Company.



Fig 2.3Thika Dam (Source: NAWASCO, 2011)

Water from the dam is conveyed through a system of tunnels running from the dam, tapping Kiama River and Kimakia River and diverting the flows to Chania River at the Mwagu Outfall. Water is tapped from Chania River at Mwagu and conveyed via a tunnel to the Mataara chamber from where it's conveyed by steel pipelines to Ngethu water production plant by gravity (Joseph andKaranja, 2011).

2.3.4 Ngethu Water Treatment Plant

At Ngethu water treatment plant (fig 2.4), water flows through intake tunnels into a distribution chamber in the plant's raw water building.

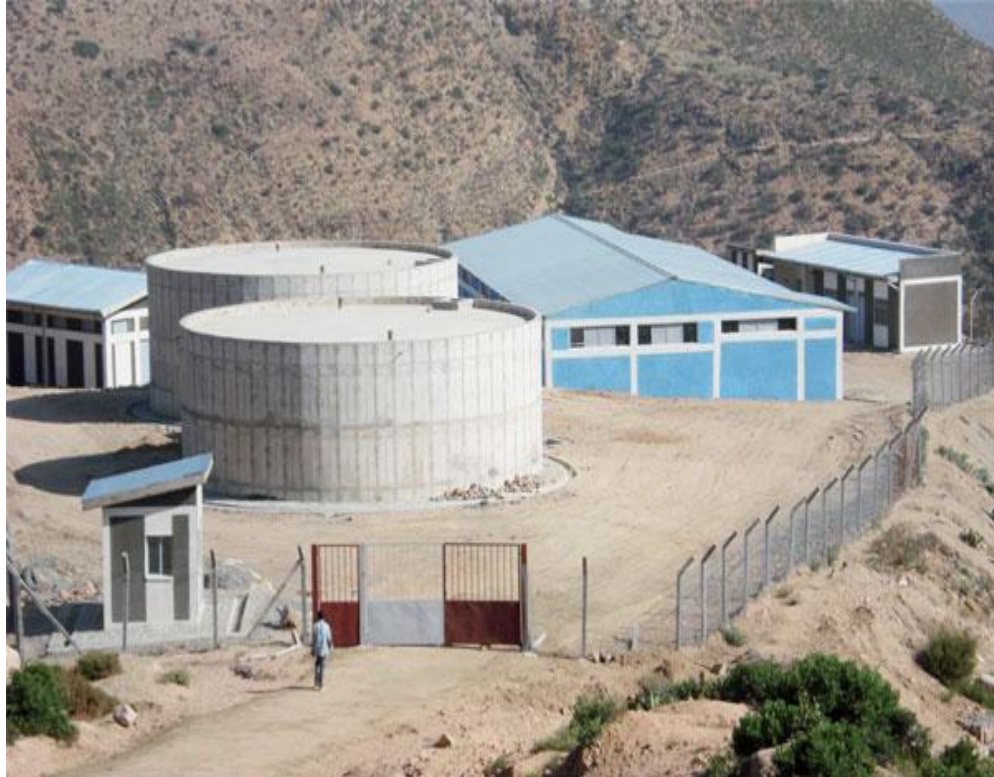


Fig 2.4 Ngethu Treatment Plant (Source: NAWASCO, 2011)

Vertical pumps draw the water through a series of traveling screens, which prevent large debris, such as fish and seaweed, from entering the system. It is then pumped to the main treatment plant to begin the treatment process (AFD, 1998).

2.3.5 Treatment Steps at Ngethu and Sasumua Plants

2.3.6 Abstraction

Water is abstracted from the source and carried through a pipe known as the intake pipe which takes the water to the treatment works (Joseph andKaranja, 2011).

2.3.7 Screening

At the mouth of the intake pipe, there are a series of screens whose purpose is to prevent suspended particles from entering the system and finding their way into the pumps (Farewell *et al.*, 1988). Thereafter, water enters into a tank called a sump from where it is pumped to the next stage clarification and filtration.

2.3.8 Clarification and Filtration

Most surface waters contain settleable impurities, which settle out by gravity when the water is allowed to be still (Christam andGhassemi, 1966). Surface water also contains suspended impurities e.g. clay particles and algae, which normally remain in suspension and cannot be removed by settling but rather by filtration (Nickson*et al.*, 2003). Moreover it contains dissolved impurities which comprise various mineral compounds in solution e.g. manganese and iron (Kemper *et al.*, 2004).

The clarification process which mainly removes second category of particles involves Coagulation and Flocculation (Lindsten, 1984). A

chemical known as a coagulant such as Aluminium Sulphate (or Alum) is mixed in the water. The Alum distorts the properties of the suspended particles that prevent them from settling and causes them to come together (coagulate) to form larger particles called flocs through the flocculation process.

As the flocs become bigger and heavier they begin to settle to the bottom of the clarifier from where they are removed. Water leaving the clarification stage is clear but not yet safe for drinking because the addition of alum leaves it slightly acidic and still contains micro – organisms.

Water moves to the next stage of treatment known as filtration. Filtration involves causing the water to fall by gravity through graded sand media to remove any suspended particles that may have passed the clarification stage (Nickson *et al.*, 2003).

2.3.9 Disinfection

This stage of treatment follows filtration and its main purpose is to kill all harmful micro- organisms that could be in the water. Through disinfection the colour and smell of the water is also improved. The process involves mixing of water with a saturated solution of a chlorine compound e.g. sodium hypochlorite. The applied chlorine dose ensures that not only are the germs in the water at the time of application killed, but also those from subsequent contamination of water during distribution and storage will also be killed (Lindsten, 1984). This explains why on

some occasions, water, especially that from kitchen taps which is directly connected to supply pipes has a characteristic smell of chlorine.

After disinfection the water is allowed to settle in a tank known as the Clearwell for a specific period of time, during which the chlorine does its intended work (AFD, 1998). In the Clearwell, Soda Ash is added. This is the final stage of water treatment.

Water is then pumped to reservoirs which are usually located at a high point from which it is distributed to the public.

2.4 Borehole Water

Borehole water is a private water supply which is not provided by a water company. Most private supplies are situated in the more remote, rural parts of the country. The supply may serve just one property or several properties through a network of pipes (Duppont and Hayman, 2001).

Rainwater permeates rocks and collects as ground water in natural, underground reservoirs called aquifers. It can take months or even years for the water to reach aquifers from the surface. To abstract this water, boreholes are sunk as far as 120 metres into the rocks. Water is pumped to the surface, treated and distributed to consumers. Borehole water often has low total suspended solids (TSS), low bacteriological and organic content but has high total dissolved solids (TDS), temporary hardness and possible iron, manganese and nitrite contamination (Kemper *et al.*, 2005).

2.4.1 Treatment Process of Borehole Water in JKUAT

Once water has been pumped to the surface, it passes through a series of screens whose purpose is to prevent suspended particles from entering the system and finding their way into the pumps (Nickson *et al.*, 2003). This is followed by addition of synthetic Magnesium Oxide to neutralize water. Thereafter, water passes through a system which provides automatic backwashing depth filters for the removal of iron and manganese, then to vessels containing Sodium ions for water softening (Mwango *et al.*, 2004).

After the process above, water undergoes filtration and disinfection as explained in (page 22) (AFD, 1998).

2.5 Statement of the Problem

Chlorine has been used to disinfect water for almost a century due to its ability to kill bacteria and viruses in water (Cutler and Miller, 2005). The use of chlorine as a disinfectant has been an effective contribution to public health, eliminating plagues such as cholera and typhoid, and reducing the incidence of intestinal illness and other health problems caused by waterborne pathogens such as cryptosporidium (Cutler and Miller, 2005). The benefits of disinfection, however, do not come without adverse effects. Depending on the disinfection procedure used (chlorination) and the chemical composition of the water prior to disinfection, many different organic chemical disinfection by-products can form in drinking water (Baker *et al.*, 2002). Trihalomethanes (THMs) are by-products of chlorine disinfection. The THMs (chloroform, bromodichloromethane, dibromochloromethane, and bromoform) are formed when free chlorine combines with organic matter, like decaying vegetation commonly found in lakes and reservoirs (Richardson *et al.*, 2007). THMs are carcinogenic in large quantities, for they are thought to contribute to 9% of the cancer of the bladder and 18% of the cancer of the rectum (Singer and Philip, 1995). This study is meant to verify if the samples from the study area contain THMs within the recommended WHO levels (WHO, 2008).

2.6 Justification

Chlorination of drinking water prevents the spread of waterborne infections and has been a common practice for almost a century (Fair *et*

al., 1948). Chlorine has greatly reduced the prevalence of waterborne diseases as it is effective against almost all bacteria and viruses, as well as amoeba (Cutler and Miller, 2005). However, consumption of chlorinated drinking water has been associated with urinary and gastrointestinal tract cancers in human epidemiology studies (Koivusalo *et al.*, 1994). Disinfection by-products arise from the reaction between natural organic material in the water and chlorine (Baker *et al.*, 2003). Trihalomethanes (THMs), which are disinfectant by-products are carcinogenic in large quantities (Singer and Philip, 1995). They are regulated by the United States Environmental Protection Agency (USEPA, 1998). The formation of THMs can be minimized by effective removal of as many organics from the water as possible prior to addition of chlorine (Lindsten, 1984)

2.7 Hypothesis

Tap water of selected areas in Nairobi County and Thika Sub-county, Kenya, does not contain significant harmful levels on treatment with chlorine powder (sodium hypochlorite).

2.8 Objectives

2.8.1 General Objective

The general objective of the current project is:

To investigate the presence and levels of THMs in tap water of selected areas in Nairobi County and Thika Sub-county, Kenya.

2.8.2 Specific Objectives

The specific objectives of the current project are:

1. To determine pH, Colour, Turbidity, Temperature and Total Organic Carbon (TOC) in tap water samples from selected areas in Nairobi County and Thika Sub-county, Kenya.
2. To determine the concentration of the various THMs in tap water samples from selected areas in Nairobi County and Thika Sub-county, Kenya.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Experimental Design

This study was conducted in 2012 in areas surrounding Nairobi County and Thika Sub-county, Kenya. Tap water which is used for drinking by the local communities in Nairobi and its environs was investigated for the presence of THMs. Tap water was collected into 500mL plastic bottles, which were obtained from JKUAT GK lab. Since the water samples to be analysed were already chlorinated, therefore, no more chlorination was needed. Each water sample was tested for THMs and the physical properties (pH, Color, Turbidity, TOC and Temperature).

3.2 Sample Collection

Water samples were collected from Nairobi and its environs, to test for THMs. Water samples were collected into 500mL plastic bottles from Kawangware Estate (Nairobi West), Hurlingham, (Nairobi West), Chiromo Campus (University of Nairobi), Catholic University of East Africa (Karen, Nairobi), Kenyatta University (Main Campus), Starehe Boys Centre (Nairobi East), Karura Forest (Kiambu), Kimathi Estate (Nairobi East), Jomo Kenyatta University of Agriculture and Technology (Thika Sub-County), Technical University College (Nairobi), hence a total of 10 samples. Samples were collected directly from the tap into the plastic bottles after allowing it to flow for one min; the bottle was filled to

the brim and closed. The samples were refrigerated at 4°C prior to analysis. Analysis was done 6 days after sample collection at Kenya Bureau of Standards (KEBS) water quality labs in Nairobi, Kenya.

3.3 Determination of Turbidity

Samples were allowed to come to room temperature before analysis. Each sample was thoroughly shaken to disperse the solids and the air bubbles were given time to disappear. 5mls from each sample was poured into the turbidimeter tube and the turbidity was read directly from the instrument scale (Arnold, 1999).

3.3.1 Preparation and Measurement of DOC in Samples

The DOC samples were prepared by placing the sample in 50 mL head-space free vials and acidified below a pH of 2 with phosphoric acid (90% purity) to allow all bicarbonate and carbonate ions to be converted to carbon dioxide. DOC samples were then filtered through a 0.45 µm filter paper (Cole-Parmer® Nylon Membranes) before placing it in the vial for measurement.

Measurements were performed using a TOC-V CPH analyzer with a Shimadzu ASI-V autosampler and catalytically aided combustion oxidation using Non-Dispersive Infrared Detector (NDIR) having a detection limit of 0.08 mg/L (Shimadzu Corporation, Kyoto, Japan). Operating conditions for DOC measurements were; injector volume 50 µL; oven temperature 680°C; carrier gas flow 150 mL/min; potassium hydrogen phthalate standards 0-10 mg/L (Arnold, 1999).

3.3.2 Measurement of Colour

Color was measured using visual comparison with platinum-cobalt standards. One unit of color is that produced by 1 mg/L platinum in the form of the chloroplatinate ion. The ratio of cobalt to platinum was varied to match the color in the samples (Christman and Ghassemi, 1966).

3.3.3 Temperature and pH

Temperature and pH were measured using an Accumet Excel XL50. The temperature probe was calibrated using a mercury thermometer while pH probes were calibrated using standard buffer solutions from Fisher Scientific (APHA, 1992).

3.4 GC-ECD System Performance Calibration

Before each GC-ECD system run, performance and calibration were verified for all analytes.

Hexane (95% purity) was injected at the beginning of each run to ensure the system is free from contaminants or interfering peaks. The GC oven temp was set to 280°C, the injector at 280°C, and the ECD at 380°C for about half an hour. The septum was changed prior to every analytical GC run. This was done by cooling the heated zones of the column oven to 40°C (Hodgeson *et al.*, 1988).

3.4.1 Preparation and Analysis of THMs Calibration Standards

About 5ml of acetone (95% purity) was placed into 10 mL volumetric flask. The sealed bottle of the commercial mix (2000 μ L of the THMs; Supelco #4-8045) was opened and 100 μ L added to the volumetric flask. Acetone was added to the flask to fill it to the mark. The solution was labeled and transferred to a separate heavy-walled flask (Supelco #3-3293) and stored in the freezer compartment of refrigerator prior to analysis (Hodgeson *et al.*, 1988).

Calibration standards were analyzed using SPI/Gas Chromatography–Electron Capture Detector (SPI/GC-ECD) on a TraceMS (ThermoFisher, Austin, TX) attached to a Trace 2000 gas chromatograph equipped with a split/splitless injector (1177; split) and operated in the splitless mode with a split ratio of 100 (Hodgeson *et al.*, 1988)

3.4.2 Trihalomethane Analysis

Since water samples had been removed from refrigerated storage and allowed to equilibrate to room temperature, therefore, from each water sample, 10 μ L of water was removed using a pre-cleaned gas-tight syringe and transferred into a Septum Programmable Injector (SPI) headspace vial and the SPI vial immediately crimp-sealed using Teflon-lined septum (Hodgeson *et al.*, 1988).

Water samples were analyzed using SPI/Gas Chromatography–Electron Capture Detector (SPI/GC-ECD) on a TraceMS (ThermoFisher, Austin, TX) attached to a Trace 2000 gas chromatograph equipped with a

split/splitless injector (1177; split) and operated in the splitless mode with a split ratio of 100 (Hodgeson *et al.*, 1988)

Because of the volatility of the THMs, rapid screening of THMs was achieved by direct injection (injection temperature; 250°C) of the water sample into a capillary column (450-type phase, 30m x 0.32mm, internal diameter 1.8 µm, Varian Equipment) connected to ECD. For THMs, this technique produced a short turn-around time with an analysis time of less than eight minutes (Reding *et al.*, 1989).

The SPI was cooled for injection and then heated rapidly to provide a sharp injection band. Water was unretained, and the initial column temperature was held just above its boiling point to ensure its quick elution (Engewald, 1999). The column oven was then programmed to readily elute the VOCs and any other higher boiling organics. Injections were made into a pre-column of uncoated silica (4m x 0.52mm internal diameter) to retain the salts and prevent column contamination. Automated sampling was done using a Varian auto sampler (8400 Varian Chromatography Systems). The carrier gas was nitrogen with a constant column flow of 2mL/min. Delay between injections was one minute and cleaning between injections was done using acetone (Hodgeson *et al.*, 1988).

The penetration depth for both the sample and solvent was 90%. The draw up speed was 5.0µL/sec. The detector used nitrogen as its make up gas with a flow of 44mL/min. The set point temperature for the detector was

50°C, and the cell contact potential was 400mV. The procedure was repeated thrice for the standards and each water sample.

3.4.3 Determination and Quantification of THMs

The XcaliburQuan software (ThermoFisher) was used for peak integration, calibration, and quantification. Peaks were integrated with the Integrated Collaborative Information Systems integrator and confirmed by visual inspection. Relative response factors were calculated on the basis of the relative peak areas of analyte quantitation ion and labeled analog ion. Trihalomethanes were quantified by comparing the ratios of analyte peak areas with labeled analog areas for both water samples and freshly prepared calibration standards. The calibration range was 0.05, 0.10, 0.15, 0.20, 0.25, 0.30 mg/L for all the analytes(Hodgeson *et al.*, 1988).

3.5 Data Analysis

The results were tabulated and Microsoft Office Excel was used to calculate standard deviation and draw graphs. Microsoft Office Excel was also used to calculate standard deviation of y ($S_{y/x}$), a measure of random error of y -values and the standard deviations of the slope (S_b). The values for lower detection limit (y_{LOD}) were also calculated. Data was presented in form of tables and line graphs using Microsoft Office Excel.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Results on the Water Quality Parameters

Results of the water quality testing are presented in (table 4.1). A narrow range of turbidity (4.50–4.90NTU) and DOC (1.00–2.30 µg/L) was obtained.

Table 4.1 Water Quality Parameters

N= 10 in all the samples

Water samples (ID)	pH	Temp°C	Turbidity (NTU)	Colour (TCU)	DOC (µg/L)
Chiromo Campus	6.9	23.1	4.60±0.04	1	1.00±0.17
CUEA	7.0	23.6	4.80±0.03	2	1.4±0.04
Kawangware Estate	7.2	23.9	4.80±0.03	3	2.00±0.16
Kenyatta University (Main Campus)	6.9	23.2	4.60±0.04	1	1.10±0.14
Starehe Boys Centre	6.8	23.0	4.60±0.04	1	1.20±0.10
Karura Forest	7.0	23.5	4.80±0.03	2	1.80±0.10
Kimathi Estate	6.9	23.1	4.50±0.07	1	1.10±0.17
JKUAT (Main Campus)	6.9	23.0	4.70±0.03	1	1.10±0.17
Technical University College of Kenya	7.1	23.9	4.80±0.03	3	2.10±0.20
Hurlingham	7.2	24.0	4.90±0.06	4	2.30±0.26

Standard Deviation for turbidity in water samples ranged from 0.03 to 0.07, while for DOC, the range was from 0.04 to 0.26. Source water temperatures were normal ranging from 23.0–24.0°C with Hurlingham recording the highest.

The lowest and highest turbidity values were recorded in Kimathi Estate and Hurlingham (4.50 and 4.90 TU) respectively. The suspended particles absorb heat from the sunlight, making turbid waters become warmer, and so reducing the concentration of oxygen in the water because oxygen dissolves better in colder water (Shunji *et al.*, 1998). Higher turbidity also reduces the amount of light penetrating the water, which reduces photosynthesis and the production of dissolved Oxygen (USEPA, 1991).

Colour and UVA_{254} were low, an indication that the NOM in the water samples collected had less significant C=C double bond. Turbidity in water is directly related with color (Shunji *et al.*, 1998). This was the case in water sample from Hurlingham.

The lowest and highest DOC values were recorded in Chiromo Campus and Hurlingham (1.00 and 2.30 $\mu\text{g/L}$) respectively. Temperature, color and turbidity are directly related to DOC (Shunji *et al.*, 1998).

The values for pH ranged from 6.8 to 7.2 with Kawangware and Hurlingham recording the highest. WHO has established a maximum recommended pH (8.5) value for chlorination of water, this is because chlorine is less effective at inactivating microorganisms at higher pH values (WHO, 1996).

4.1.1 KEBS and WHO Standards for Physical Water Quality Parameters

The physical water quality parameters from the samples also fell within both KEBS (KEBS, 1985) and WHO Standards (WHO, 1996) as presented in tables 4.2 and 4.3 respectively.

Table 4.2: KEBS Water Quality Parameters

Substance	Unit	Drinking Water	Bottled Water
Colour	TCU	10	10
Taste and Odour	-	Acceptable by consumer	Acceptable by consumer
Turbidity	NTU	5	1
pH	-	6.5-8.5	6.5-8.5

(Source: KEBS, 1985)

Table 4.3: WHO Standards Water Quality Parameters

Substance	Unit	Drinking Water
Colour	TCU	10
Taste and Odour	-	Acceptable by consumer
Turbidity	NTU	5
pH	-	6.5-8.5

(Source: WHO, 1996)

Turbidity range for the samples was 4.5-4.9 NTU compared to 5NTU in both KEBS and WHO requirements. Color and pH were also within the requirement; Color ranged between 1-4 TCU and pH 6.8-7.2 for the

samples, compared to 10TCU and pH range of 6.5-8.5 in both KEBS and WHO requirements.

4.2 Results of the THMs Standards

With the use of the above mentioned methods, the chromatogram (fig 4.1) of GC standards was obtained.

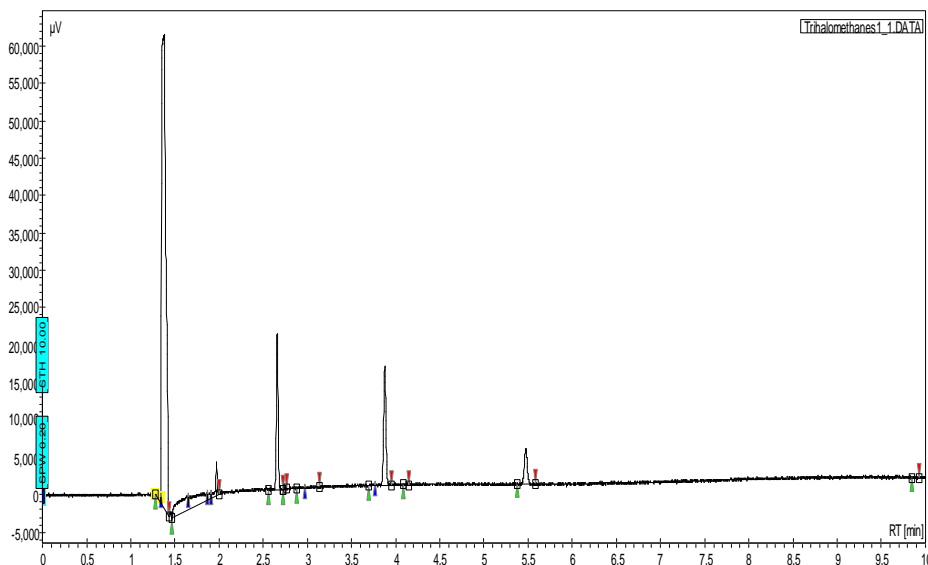


Fig 4.1 Chromatogram of THM Standards

The chromatogram of the unknown peaks was compared with a spectrum from a standard solution of pure reference. The reference confirmed that a signal that appeared at minute 1.97 matched with CHCl_3 . For CHClBr_2 , CHCl_2Br and CHBr_3 the detector detected a response at 2.66, 3.88 and 5.47 retention time(s) respectively. Concentration of 0.05, 0.15 and $0.20\mu\text{g/L}$ for chloroform, peak areas of 107.4, 171.6 and $204.6\mu\text{V/min}$ were depicted respectively. For CHClBr_2 , concentration of 0.05, 0.20 and $0.30\mu\text{g/L}$ depicted peak areas of 458.9, 1747.4 and $2941.7\mu\text{V/min}$ respectively (Table 3.1).

CHCl₂Br, with concentration of 0.10, 0.15 and 0.20 μg/L depicted peak areas of 465.1, 509.4 and 724.2 μV/min respectively. Finally, CHBr₃, with concentration of 0.05, 0.15 and 0.25 μg/L depicted peak areas of 202.3, 607.4 and 972.0 μV/min respectively. Chloroform and bromodichloromethane are extremely volatile relative to the other two constituents of THMs and are ultimately transferred to air as a result of their volatility. Their boiling points contributes to their volatility with CHCl₃ having a boiling point of 62°C, while CHClBr₂, CHCl₂Br and CHBr₃ boil at 119°C, 90°C and 149°C respectively (Leavens *et al.*, 2007). From the peak areas, calibration graphs (Fig 3.2 to 3.5) for the THM standards were drawn using Microsoft Excel to get correlation (R²) values. These values (R²) were 0.9970, 0.9940, 0.9630, 0.9990) for CHCl₃, CHClBr₂, CHCl₂Br and CHBr₃ respectively.

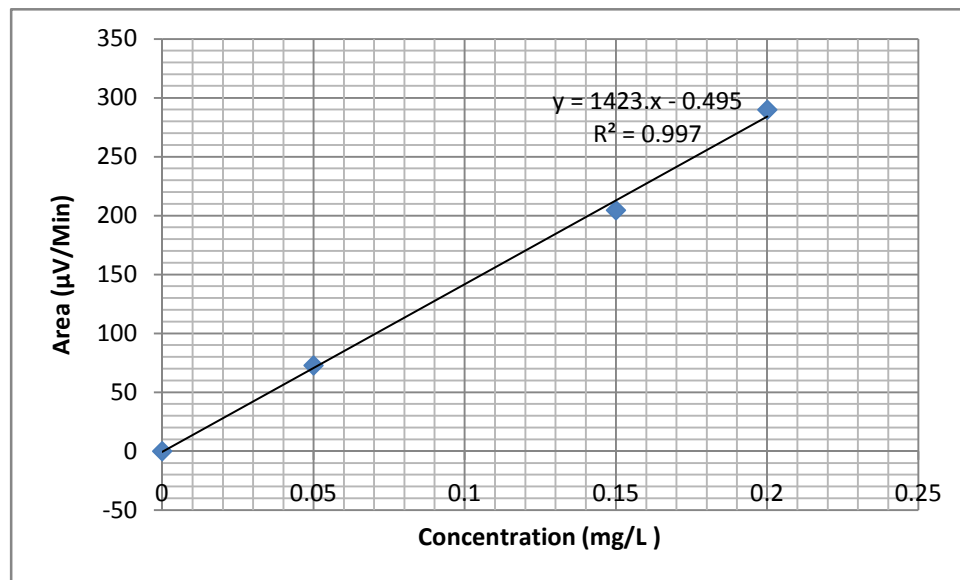


Fig 4.2: Calibration Graph for Chloroform

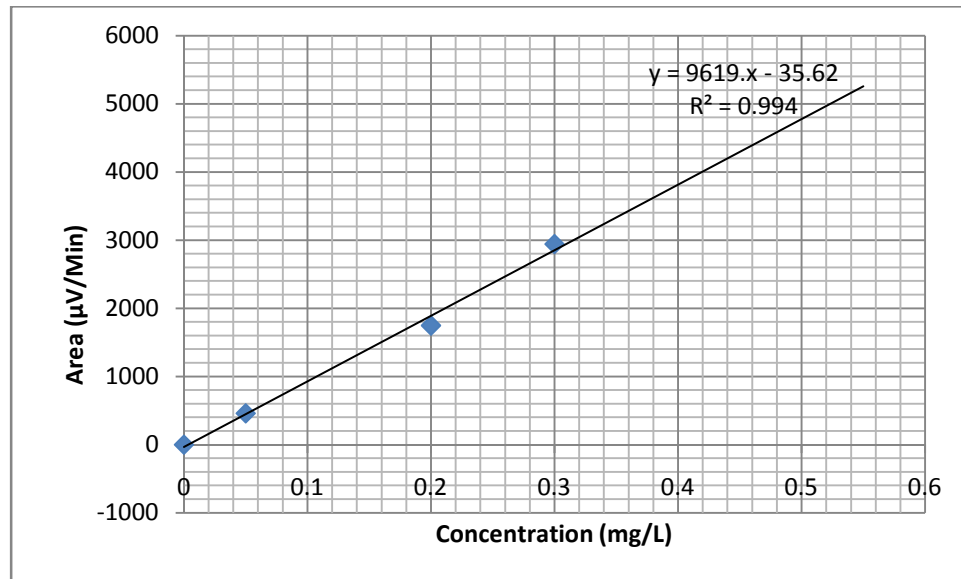


Fig 4.3: Calibration Graph for Dibromochloromethane

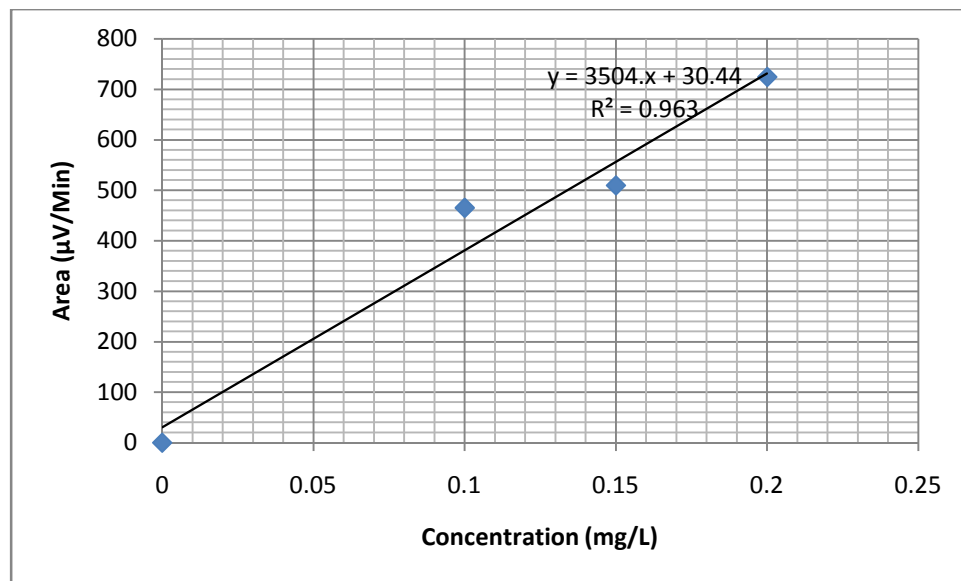


Fig 4.4: Calibration Graph for Bromodichloromethane

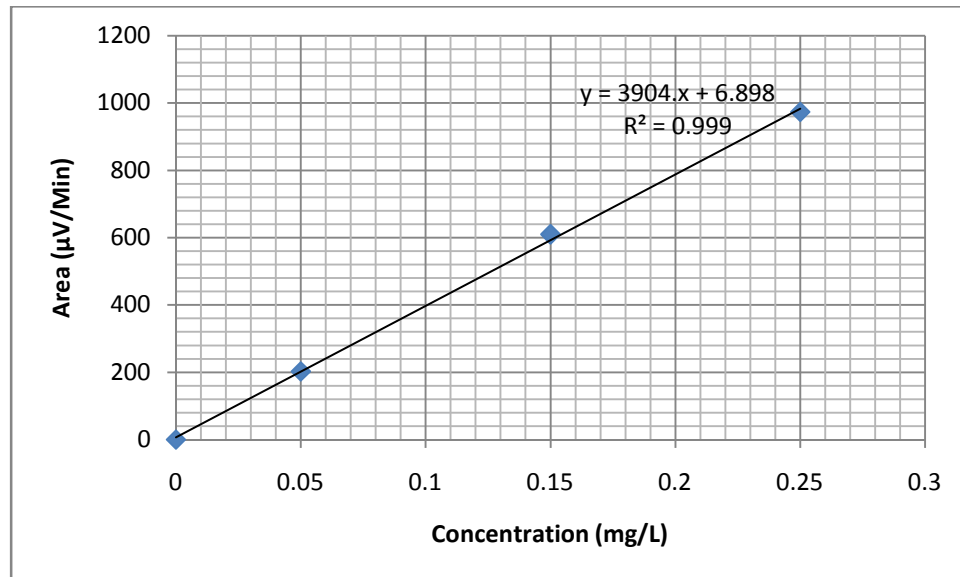


Fig 4.5: Calibration Graph for Bromoform

The calibration graph, ($y=1423x-0.495$) for chloroform, ($y=9619x-35.60$) for dibromochloromethane, ($y=3504x+30.44$) for bromodichloromethane and ($y=3904x+6.898$) for bromoform, were used in determining the Standard Deviation of the THMs.

4.2.1 Determining LODs of the THMs Standards

Values of Limit of Detection (LODs) were determined using regression equations and the results presented in (Table 4.4).

Table 4.4: Values for Limit of Detection for y (y_{LoD})

Standards	$S_{y/x}$ (μ V/Min)	S_b (V/g/Min/L)	(y- intercept)	y_{LoD} (μ g/L))
CHCl ₃	0.01	0.05	0.07	0.21
CHClBr ₂	0.12	0.51	0.53	2.06
CHCl ₂ Br	0.07	0.48	0.47	1.72
CHBr ₃	0.02	0.08	0.20	0.43

The lowest and highest values of y ($S_{y/x}$) were 0.01 and 0.12 μ V/Min for chloroform and dibromochloromethane respectively. This was the same for S_b values which were 0.05 and 0.51 V/g/Min/L. The y-intercept values were slightly above zero, ranging from 0.07to0.53.

4.3 Results of the Concentration of THMs in Samples

Calibration graphs, ($y=1423x-0.495$) for chloroform, ($y=9619x-35.60$) for dibromochloromethane, ($y=3504x+30.44$) for bromodichloromethane and ($y=3904x+6.898$) for bromoform, were used to calculate the concentration (x) of THMS in the analytes and results were presented in Table 4.5 below.

Table 4.5: Results of the Concentration of THMs in Samples

Sample ID	THMs Concentration ($\mu\text{g/L}$)				
		CHCl_3	CHClBr_2	CHCl_2Br	CHBr_3
Blank		-	-	-	-
Chiromo Campus		<0.21	<2.06	<1.76	<0.43
C.U.E.A Karen		<0.21	3.7 ± 1.1	<1.76	<0.43
Kawangware Estate		7.4 ± 1.0	6.1 ± 0.2	<1.76	<0.43
K.U(Main Campus)		<0.21	<2.06	<1.76	<0.43
Starehe Boys Centre		<0.21	<2.06	<1.76	<0.43
Karura forest		<0.21	5.6 ± 0.1	<1.76	<0.43
Kimathi Estate		<0.21	<2.06	<1.76	<0.43
J.K.U.A.T(Main Campus)		<0.21	<2.06	<1.76	<0.43
Kenya Polytechnic		5.3 ± 3.0	6.5 ± 0.4	<1.76	<0.43
Hurlingham		15.0 ± 4.0	7.1 ± 0.7	<1.76	<0.43

N=5 in all the samples. Water samples from four locations, Kimathi Estate (Nairobi East), Chiromo Campus (University of Nairobi), Jomo Kenyatta University of Agriculture and Technology (Main Campus) and Starehe Boys Centre, did not show any traces of THMs. All the analytes tested were <LoD for bromodichloromethane and bromoform.

Water samples from Kawangware Estate, Technical University College of Kenya and Hurlingham both from Nairobi West had some significant amount of chloroform; $7.4\mu\text{g/L} \pm 1.0$, 5.3 ± 3.0 and 15.0 ± 4.0 ($\mu\text{g/L}$) respectively. Water samples from Technical University College of Kenya, Karura Forest, Catholic University of Eastern Africa, Kawangware Estate and Hurlingham showed traces of dibromochloromethane. This included; 6.5, 5.6, 3.7, 5.3, 7.1 ($\mu\text{g/L}$) respectively with Standard Deviation ranging from 0.1 to 1.1.

Chloroform and bromodichloromethane are extremely volatile relative to the other two constituents of THMs and are ultimately transferred to air as a result of their volatility (Leavens *et al.*, 2007). Bromide concentration in water can result in brominated THMs (Richardson *et al.*, 2007). The presence of dibromochloromethane in a few samples is an indication of bromide ions in water.

Chlorine doses and consequently THM formation are typically more significant in disinfection due to the higher chlorine doses required to verify disinfection efficacy. This is also true where chlorine demand remains in incompletely treated water in a situation of excessive remaining

DOC in water (IARC, 1999). The THMs which were realized in this study is an indication that there was a significant amount of DOC that remained. This can be contributed due to the fact that Sedimentation and flocculation were not perfectly carried out (Pagiola and Stefano, 2007). Where organic matter has not been adequately removed or organic sediments exist in reservoirs and pipelines, booster chlorination facilities can result in increased THM formation (IARC, 1999).

WHO proposes the use of an additive toxicity guideline value (GV), using the fractionation equation (equation 4.1) that the sum of the four THMs' actual concentration (C) divided by their guideline value (GV) should not be greater than one (WHO 2004).

$$\frac{C_{\text{chloroform}}}{GV} + \frac{C_{\text{dibromochloromethane}}}{GV} + \frac{C_{\text{bromodichloromethane}}}{GV} + \frac{C_{\text{bromoform}}}{GV} = 1 \quad (4.1)$$

Since no sample showed any trace for both bromodichloromethane and bromoform, values for chloroform (0.028) and dibromochloromethane (0.029) were used to verify this guideline value. From the calculation a value of, 0.0006 was realized which is $\ll 1$.

Therefore, no samples exceeded the WHO guideline values for chloroform and dibromochloromethane detected in the samples (WHO, 2008).

THMs concentration increases significantly with the increasing turbidity due to the presence of suspended particulates (WHO, 2004). Sources of turbidity include; soil erosion, waste discharge, urban runoff and eroding stream banks (Christam; Ghassemi, 1966). The suspended particles absorb

heat from the sunlight, making turbid waters become warmer, and so reducing the concentration of oxygen in the water because oxygen dissolves better in colder water (Shunji *et al.*, 1998). Higher turbidity also reduces the amount of light penetrating the water, which reduces photosynthesis and the production of dissolved Oxygen (USEPA, 1991). Sample from Hurlingham had the highest turbidity of 4.9TU and consequently the highest concentration of chloroform and dibromochloromethane (15.0 and 7.1($\mu\text{g/L}$)) respectively.

Studies show that the concentration of THMs increases with increase in Temperatures (Kavanough *et al.*, 1980). This is due to the fact that, high temperatures increase the reaction rate between chlorine and TOC content. When temperatures increase, reactions take place faster, causing a higher chlorine concentration to be required for a proper disinfection. This causes more halogenic disinfection byproducts to form (Cincinnati and Simmon, 1981).

When pH values are high, more hypochlorite ions are formed, causing the effectivity of chlorine disinfection to decrease. The lower the pH, the higher non- ionized Hypochlorite ions is found, thus increasing its reaction rate with the humic matter (Cincinnati and Simmon, 1981). However, THM yields depend rather on the last step of the THM reaction pathway, which is base-catalyzed as with the haloform reaction (Bunce and Manahan, 1984). The samples had a pH range from (6.8 to 7.2) with Hurlingham recording the highest while Starehe boys Center recording the lowest value.

DOC is the most widely measure of NOM in water (Farewell *et al.*, 1988). High chlorine doses will form greater concentrations of DBPs as long as the water is not limited by the amount of Natural Organic Matter. In naturally occurring water, this organic matter usually consists of humic substances (Philip and Singer, 1995). Although fulvic acid accounts for over 90% of the aqueous humic in many water sources, studies found that relative contributions to the formation of THMs by the humic fraction is greater than that of the fulvic fraction since the former substances react more readily with chlorine (Philip and Singer, 1995).

CHAPTER FIVE

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

1. A narrow range of turbidity (4.5–4.9 TU) and DOC (1.0–2.3 $\mu\text{g/L}$) was recorded. The lowest and highest turbidity values were recorded in Kimathi Estate and Hurlingham respectively. Standard Deviation for turbidity in water samples ranged from 0.03 to 0.07, while for DOC, the range was from 0.04 to 0.26. Water samples from Hurlingham had the highest DOC value of 2.3 $\mu\text{g/L}$ compared to sample from Chiromo with the lowest value of 1.0 $\mu\text{g/L}$.
2. Source water temperatures were normal ranging from 23.0–24.0°C. Colour and UVA_{254} were low, an indication that the NOM in the water samples collected had less significant C=C double bond (Shunji *et al.*, 1998).
3. Water sample from Hurlingham had the highest turbidity of 4.9 TU and consequently the highest concentration of chloroform and dibromochloromethane (15.0 and 7.1 (ng/L)) respectively.
4. The THMs which included CHCl_3 showed a signal at retention time (min) 1.97, while CHClBr_2 , CHCl_2Br and CHBr_3 showed their signals at 2.66, 3.88 and 5.47 retention time(s) respectively. Calibration graphs for the THMs Standards had correlation (R^2) values of 0.9970, 0.9940, 0.9630, 0.9990) for CHCl_3 , CHClBr_2 , CHCl_2Br and CHBr_3 respectively. The regression equations obtained in the calibration graphs, ($y=1423x-0.495$) for

Chloroform, ($y=9619x-35.60$) for dibromochloromethane, ($y=3504x+30.44$) for bromodichloromethane and ($y=3904x+6.898$) for bromoform, were used to calculate the concentration (x) of THMS in the analytes.

5. Water samples from Kawangware Estate, Technical University College of Kenya and Hurlingham both from Nairobi West had some significant amount of chloroform; $7.4\mu\text{g/L}$ with SD 1.0, 5.3 ± 3.0 and 15.0 ± 4.0 ($\mu\text{g/L}$) respectively. Water samples from Technical University College of Kenya, Karura Forest, Catholic University of Eastern Africa, Kawangware Estate and Hurlingham showed traces of dibromochloromethane. This included; 6.5, 5.6, 3.7, 5.3, 7.1 ($\mu\text{g/L}$) respectively with Standard Deviation ranging from 0.1 to 1.1.
6. The data presented herein clearly show that chlorination of filtered waters does not lead to THMs concentrations that exceed the WHO guideline values (WHO, 2008).

5.2 Recommendations

1. Water samples should be tested more often so as to be sure that the water used for drinking is free from THMs. More research should be done in areas which recorded some significant amount of THMs. They include water samples from CUEA, Kawangware, Hurlingham, Karura Forest and Technical University College of Kenya.
2. Since the water samples tested meet the WHO requirements for THMs, chlorine disinfection should be used to disinfect drinking water in Kenya.
3. This study can also be done in Umoja Estate, near Jeska Supermarket, Nairobi. Residents complain of sewage smell in their tap water which they receive only during the weekend. There is a possibility of having clean water pipes laid side by side with sewage pipes posing a risk of wastewater sipping to the clean water pipes and in turn carried to their taps during the weekend.
4. Analysis of HAAs on chlorinated tap water should be done in future.

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APPENDICES

Appendix 1: Concept paper