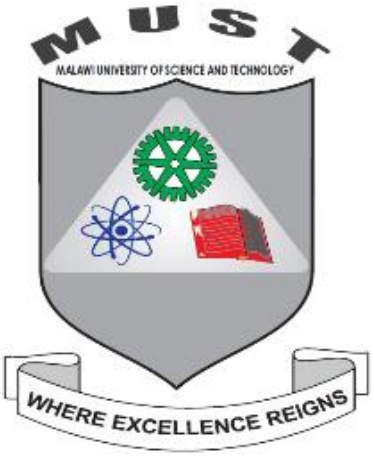


DEVELOPMENT OF TRIHALOMETHANES FORMATION TOOL FOR OPERATIONAL MANAGEMENT OF WATER SUPPLY SYSTEM: CASE OF THYOLO WATER SUPPLY SCHEME

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Dissertation submitted to Ndata School of Climate and Earth Sciences of the Malawi University of Science and Technology in partial fulfillment of the requirements for the Bachelor of Science degree in Water Quality and Management.

JULY, 2021

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Development of trihalomethanes formation tool for the operational management of water supply system: a case of thyolo water supply scheme

ABSTRACT

Disinfection is a very significant water treatment process for drinking water safety, as it inactivates pathogens from drinking water. Chlorination is the most widely used method for disinfection of drinking water, but there are concerns about the formation of by-products, such as trihalomethanes (THMs), since chronic exposure to them may pose risks to human health. For these reasons regulations fix maximum acceptable THMs levels throughout distribution networks, so it is very important to be able to correctly reproduce their formation. Research has provided many predictive models for the formation of DBPs based on various water quality parameters and following different methodologies, many models for predicting THMs formation have been developed, both based on empirical relationships and kinetics involved during chlorine reaction. The study aimed at developing an operational management tool for the formation of DBPs in drinking water supply systems in Thyolo. Such management tools are helpful to the water utility managers during decision making, for example, setting a disinfectant dose, contact time, adjustment of pH, temperature, etc., to reduce the formation of DBPs and at the same time maintain the required disinfectant residual. Primary data from the water supply scheme was collected using grab sampling. Parameters such as PH temperature (°c), ORP, EC, TDs, were measured using the multi-parameter on-site to determine the water quality of the scheme. The residual chlorine (mg/L Cl2), TSS (mg/l) turbidity (NTU), and fecal coliform were measures in the laboratory using photometer and membrane filter technique respectively. Laboratory, experiments were carried out to assess possible effects of DBPs drivers (PH and temperature) that result in the formation of THM upon chlorination, after the experiments it was found that pH and temperature have an effect on residual chlorine which reacts with natural organisms to form THMs. a regression equation of RC = -3.2302 + 0.34923TURBIDITY -0.28699TSS + 0.035095 TEMP + 0.008081 TDs + 0.11475 PH + 0.011009 FC was developed as a management tool to monitor free residual chlorine concentration in the distribution systems.

ACKNOWLEDGEMENTS

Firstly I would like to thank the Almighty God for being with me and guiding me throughout the four years of study at Malawi University of Science and Technology, including the time I was conducting my research. Despite many obstacles, it has been successful.

I would also like to pass my sincere gratitude to my family that rendered their efforts towards the successful completion of my research. Mr. C. Makocha, Mrs. Ina Makocha and Mr. E Mvula.

My extended gratitude should also go to Mr. H. Yapuwa my supervisor, for his tireless effort towards the successful completion of my research paper.

Lastly, it is my profound privilege to express my sincere thanks and deep sense of gratitude to the whole class of 2021 water quality and management, for the cooperation and academic knowledge well shared, throughout my study period at MUST.

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ACRONYMS/ABBREVIATIONS

BWB: Blantyre Water Board

DBP: Disinfectant by Products

FC: Fecal Coliform

FRC: Free Residual Chlorine

MBS: Malawi Bureau of Standard

MUST: Malawi University of Science and Technology

NTU: Nephelometric Turbidity Unit

ORP: Oxidation-Reduction Potential

THMs: Trihalomethanes

WDN: Water Distribution Network

WHO: World Health Organization

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1. INTRODUCTION

For centuries, communities developed around water sources such as rivers where a source of drinking water was readily available. 'Good water was defined as water that was clear, pleasant to the taste, and free from odor. It was not until the discovery that water could be a major vehicle of disease in the middle of the 19th century that attitudes towards drinking water began to change (Richardson *et al.*, 2007).

Following the use of continuous application of chemical disinfectants, starting in the early 1900s in Europe and the USA, outbreaks of diseases attributable to waterborne pathogens, such as typhoid and cholera, dramatically declined in developed countries. Chlorine became the most widely adopted and revered disinfectant for water treatment worldwide, because of its potency, relative ease of use, lasting residual, and cost-effectiveness (Freese *et al.*, 2004).

Its reputation as the 'disinfectant of choice' remained untarnished until 1974, when evidence published separately by Rook (1974) and Bellar *et al.* (1974) showed chloroform in drinking water resulted from the reaction between chlorine and natural organic matter. Since that time, extensive research has shown a variety of halogenated disinfection by-products to be formed through the use of chlorine, including trihalomethanes (THMs), haloacetic acids (HAAs), halo aldehydes, halo ketones, haloacetonitriles, chloropicrin, and chlorophenols (Nikolaou *et al.*, 1999; Richardson *et al.*, 2007). Of the more than 300 disinfection by-products that have been reported from the use of chlorine disinfection, THMs have received the most attention (both scientifically and regulatory) due to their widespread occurrence and the reported health concerns. This being the case many studies have been done to investigate the formation of trihalomethanes and how they can be monitored and managed, these studies were in develop countries where models were introduced to predict the THMS formations in their water supply systems. Looking at developing countries the issue of THMS is still not discovered because once the water has been treated and chlorinated it's potable for drinking water without looking at the disinfection by-products formed after it is chlorinated. This is why

this study is undertaken aiming at exposing the information gap existing in developing countries especially in Malawi since no study has been conducted to predict, monitor, and manage the formation of trihalomethanes in our water systems.

The use of chlorine in Malawi started following its effectiveness in the US, Canada, and other countries. However, in 1970 chlorination came into scrutiny when disinfection by-products were discovered in chlorinated water. (Gopal et al 2006; Hua, et al 2008). The formation of these by-products in chlorinated water depends on several factors including water temperature, pH, chlorine dose, contact time of residue chlorine, natural organic matter (NOM) present in the water source (Gopal, et al., 2006; Baribeau, *et al.*, 2002). Although in most cases chlorination is associated with the carcinogenic disinfection by-products, it is still possible to produce water that is free from the by-products of chlorination when the chemical precursors are absent or removed before chlorination.

1.1. Problem statement

The research addressed the literature gap on the formation of trihalomethanes in drinking water distribution networks. This is so because there was no scientifically proven data or literature before in Malawi that addressed this lack of literature on the topic at hand and with the growing cases of carcinogen cases in Malawi which were reported high starting from 2010 till now (kelias. P Msyamboza 2012). These disinfectants by-products cause cancer in public health, this made the project essential. Since the investigation taken by the project helped in improving if these disinfectant by-products in drinking water are contributing to the rising case of cancer in the country. Therefore as this is the case the availability of the literature in this paper will be useful as it will be possible to come up with the management and operational plans for the water utility companies in other districts of Malawi to help safeguard public health from the impacts of disinfection by-products.

1.2. Research Objective

To develop a tool for the management of trihalomethanes formation in the water supply system.

1.2.1. Specific Objectives

• To determine the water quality status of the Thyolo water supply Scheme.
• To investigate the drivers of trihalomethanes formation in drinking water.
• To develop an assessment system tool for the management of trihalomethanes in the water supply system.

1.3. Research Question

- What is the water status of the water supply system?
- Does the system operational parameter influence the formation THMs?
- How useful can a mathematical model be in the management of THMs in water supply systems?

1.4. Significance of the Study

- The study will help to fill the information gap that exists in our water boards in Malawi since there is a lack of information in our water board systems on disinfection by-products formed in our water supply systems after it has been treated and chlorinated. This will notify them on how to regulate and monitor the formation of trihalomethanes in water systems by developing tools that will manage this task.
- To serve as references to all who will handle similar projects in the future after the paper will be published.

2. CHAPTER 2 LITERATURE REVIEW

2.1. Treatment processes

2.1.1. Sedimentation

Primary sedimentation tanks or clarifiers are designed to achieve 50% to 70% removal of suspended solids and 25% to 40% removal of BOD. The BOD removed is associated with the organic fraction of the suspended solids. Sedimentation is a process that involves the removal of suspended solids from a water body by settling them out. The size of the solid particles plays a major role in the efficiency of sedimentation. Larger particles settle out quickly, whereas smaller particles may remain suspended for longer periods and eventually settle out (APHA, 2005).

2.1.2. Screening

Raw wastewater contains a significant amount of suspended and floating materials. These include rags, weeds, twigs, organic matter, and a variety of solids. The solids can damage pumps and mechanical equipment and interfere with the flow in pipes and channels. Screening devices are placed ahead of pumps to remove the larger materials from the wastewater stream. The removed debris, called *screenings*, is usually disposed of in landfills or by incineration. Different types of screens are available depending on wastewater characteristics and site requirements (Spellman 2009).

2.1.3. Flocculation

This refers to settling observed in a suspension with particles that coalesce or flocculate as they come in contact with other particles. This results in increasing the size, shape, and mass of the particles, thus increasing the settling rate. The trickling filter is one of the earliest types of attached growth processes that were used. It has been used for secondary treatment since the early 1900s (Metcalf and Eddy, 2003). The term *trickling filter* is misleading, as most of the physical processes involved in filtration are absent in

this process. Instead, sorption and subsequent degradation of organic matter are used for substrate removal (Peavy et al., 1985)

2.1.4. Coagulation

The main function of coagulation is to destabilize suspended particles by neutralizing the negative charge and aggregate destabilized particles into flocs, which are removed by sedimentation and/or filtration. Coagulation can reduce the NOM level by different pathways. (Gregor et al. 1997). It was indicated that the doses of coagulants required are determined by the content of NOM rather than by the turbidity. Primarily due to the negative charge carried by NOM, there is a stoichiometric relationship between the required dose of coagulant and the TOC concentration in the water to be treated. After coagulation, the dominance of lower molecular weight materials increases considerably (Omelia et al. 1999).

2.1.5. Filtration

Filtration is used when the regulatory limit for effluent TSS is less than or equal to 10mg/L (Davis, 2011). filtration aims at removing particulate matter from water by forcing the water to pass through porous media. On the contrary, some researchers have found that lower molecular weight matter is more amendable than higher molecular weight matter due to the size exclusion effect. Therefore the adsorption NOM is mainly controlled by the molecular size distribution of NOM and pore size distribution of carbon. Background NOM reduces the adsorption of trace level contaminants.

2.2. Disinfection

Disinfection in potable water treatment may be defined as the reduction of pathogenic organisms to prevent waterborne diseases (Haas, 1999). Many techniques of disinfection are practiced, some more common than others, including the use of chlorine, potassium permanganate, ultraviolet light, and ozone (Freese et al, 2004; Sadiq & Rodriguez, 2004; Warton et al., 2006).

2.2.1. Different Disinfection Techniques

2.2.1.1. Chlorination

Chlorine is the most widely used primary disinfectant and is also often used to provide residual disinfection in the distribution system. Chlorine is the most used disinfectant due to its advantages such as being easy to use and well the cost of chlorine is cheap compared with other disinfectants. Monitoring the level of chlorine in drinking water entering a distribution system is normally considered to be a high priority because the monitoring is used as an indicator that disinfection has taken place. Residual concentrations of chlorine of about 0.6 mg/l or more may cause problems of acceptability for some consumers based on taste. This practice, termed simple or marginal chlorination, predominantly consisted of adding chlorine or chlorine affiliates to water, commonly after filtration. Since that time the endorsement and prevalent application of free residual chlorine evolved as a result of developments in our knowledge of chlorination chemistry and the biocidal capabilities of various forms of chlorine (Akin et al., 1982; USEPA, 1999). The role of chlorine as the 'disinfectant of choice' remained unchallenged until 1974, when independent research by Rook (1974) and Bellar et al. (1974) determined the presence of chloroform in chlorinated drinking water. This chloroform was present due to the reaction of residual chlorine with natural organic matter in the presence of high pH and temperature. Since then DBPs have been actively investigated, with significant research effort being directed towards increasing our understanding of DBP formation, occurrence, and health effects.

2.2.1.2. UV disinfectants

Disinfectants such as ultraviolet provide viable alternatives to chlorine. However, ultraviolet has disadvantages, in terms of its disinfectant abilities, residual effect, cost, and hard to use. Also, in comparison to chlorine, which has been much more widely studied, there is little information about the DBPs that these alternative disinfectants produce. Thus, it is not known if the DBPs from alternative disinfectants are safer or more hazardous than those formed by chlorine (Richardson et al., 2000).

2.2.1.3. Ozone water disinfectants

In general, an ozonation system includes passing dry, clean air through a high voltage electric discharge. Raw water pass through a venturi throat which creates a vacuum and pulls the ozone gas into the water or the air is then bubbled up through the water being treated. Since the ozone will react with metals to create insoluble metal oxides, post filtration is required (Lesolle, D. 2012). Ozone Advantages to ozone water treatment include the minimization of inorganic, organic, and microbiological problems and taste and odor problems. Furthermore, no additional chemicals are added to the water. Meanwhile, disadvantages include a lack of germicidal or disinfection residual to inhibit or prevent growth. Furthermore, the system may require pre-treatment for hardness reduction.

2.3. Trihalomethanes formation

Trihalomethanes (THMs) are halogen-substituted single-carbon compounds with the general formula CHX_3, where X represents a halogen, which may be fluorine, chlorine, bromine, or iodine, or combinations thereof. The THMs most commonly present in drinking water are chloroform (CHCL3), bromodichloromethane, or dichlorobromomethane ($CHBrCl_2$) (BDCM), dibromochloromethane or chloro-dibromomethane ($CHClBr_2$) (DBCM), and bromoform ($CHBr_3$).THMs were discovered in 1974 by Rook J. in the Netherlands and Bellar *et al.* in the USA. THMs form as a result of replacing three hydrogen atoms in methane with halogen elements. The reaction of free chlorine with certain organic compounds in wastewater leads to DBP formation, including THMs. In drinking water, chloroform is always with the highest concentration and is often represented by more than 90% of the total concentration of THMs.

The distribution of each species of THM will vary according to the water source, the treatment processes, and conditions operated at the water treatment works, and the nature of the distribution system. The key factors that can influence THM formation are pH, organic matter, and temperature, free residual chlorine, chlorine dosage, and retention time.

2.3.1. Natural organic matter

NOM is a prerequisite to THM formation (Kitis et al., 2001; Parsons et al., 2004). Natural organic matter (NOM) is ubiquitous in surface and groundwater sources and usually exists at concentrations between 2-10 mg/l (Bolto et al., 2002), although much higher levels are sometimes found depending on the watershed characteristics (Garcia, 2005). For most waters, in particular, water in distribution systems, the reactions of chlorine with organic matter make up the majority of the chlorine demand (Clark & Bouton, 1998). A relationship between organic matter concentration and chlorine decay would therefore be expected.

2.3.2. pH

In general, a high pH results in a higher level of THMs. Several authors, such as Morris and Baum (1978), Stevens et al. (1976), Fleischacker and Randtke (1983), Reckhow and Singer (1985) have observed that the chlorination of most organic compounds led to larger amounts of chloroform at higher pH values. Stevens et al. (1989) evaluated the effects of pH and reaction time on DBP formation. They observed that the formation of THM increased with an increase in pH especially the range from 5 to 9.4.

2.3.3. Retention time

The chemical stability of DBPs and their concentration varies in the water as the retention time increases in the water supply system. Due to biodegrading effect, long retention times, and availability of free chlorine before exhaustion, the concentration of THMs increases but in some cases the HAAs values decrease to zero for long-distance occupants in the water supply system but it does not have any effect on the THMs (Reckhow & Singer, 2011). The concentration of THMs increases as the reaction time of the NOM and disinfectant increases (Xie, 2004). The level of THMs increases from the water distribution system to the first consumer but reduces towards the last consumer. Stevens et al. (1989) observed that the formation of THM increased with time especially over the first 48 hours.

2.3.4. Free Residual chlorine

Residual chlorine is directly proportional to DBP formation (Xie, 2004). The concentration of THMs increases as the dose of disinfectants increases (Reckhow and Singer, 2011). Minor changes in disinfectant in the water distribution system do not have any major impact on the formation of DBPs in the system. A study reveals that when the residual chlorine is reduced to 0.3 mg/L in the system, the formation of DBPs is also relatively low (Reckhow and Singer, 2011). Chlorine concentration also decreases because of corrosion, biofilm, and scaling in the pipelines (Rossman, 2006; Al-Jasser, 2007).

2.3.5. Temperature

Although there have been relatively few studies that have investigated how temperature implicitly affects DBP formation, it is widely acknowledged that an increase in temperature increases DBP formation (Kavanaugh et al., 1980; Krasner et al., 1989; Rodriguez & Serodes, 2001; Kim et al., 2002; Toroz & Uyak, 2005). Higher temperatures will generally increase the rate of reaction. Consequently, THM formation increases through the larger doses of chlorine required. Higher temperatures also mean a higher rate of hydrolysis (where water molecules split into hydrogen and hydroxide ions), which leads to a faster break up of aromatic bonds, allowing further halogenation and a higher formation of DBPs (Garcia et al., 2005).

2.3.6. Chlorine Dosage

It is generally accepted that the THM formation increases with increasing chlorine dose (Adin *et al.*, 1991). However, it appears that chlorine residuals way above chlorine demand have little impact on increasing the rate of THM formation (Trussell & Umphres, 1978; Fleischacker & Randtke, 1983). THM formation increases with increasing chlorine dosage up to a point where the reaction is no longer chlorine limited. Beyond this point, the reaction is likely to be TOC limited. Carlson & Hardy (1998) demonstrated that with a chlorine: TOC ratio of less than 1, chlorine had the greatest effect on THM formation. Above this ratio, it was found that there was little change in amounts of THM formed.

2.4. Assessment of Treated Water in Public Water Supply

In the literature many models for predicting THMs formation have been developed, both based on empirical relationships and kinetics involved during chlorine reactions. In this work, the use of some of these models and their reliability in real situations is investigated through the application to the Aurunci-Valcanneto Water Supply System in Southern Lazio (Italy). The comparison of the performances of 18 selected literature empirical models furnishes interesting observations, indicating that the formula developed using field data, results in being more suitable for reproducing THMs formation for the presented case study. Other considerations are also offered from the comparison with the results obtained using a simple first order kinetic model, calibrated using measured data. (Angelo Leopardi March 2012)Many water quality assessment studies have been done in Malawi conducted in so many districts of Malawi; In 2007 M.Mkandawire assessed the physical, chemical, and biological study of drinking water. A case study at Chiradzulu and Mulanje. In this study physicochemical parameters were measures such as pH, temperature, TDs, and Turbidity. Biological parameter such as fecal coliform was a measure to see its contamination in drinking water. LBM Kosamu 2013 assessed the physical changes in drinking water quality during distribution. A case study of Area 25, based on the laboratory assessment that was done, found out that the water in the area was safe for consumption concerning residual chlorine, manganese, pH, Zinc, turbidity, lead, and fecal coliform as the levels met the WHO and MBS standards for drinking water quality. No research has been done on the formation of disinfectants by-products hence less knowledge when it comes to Trihalomethanes formation in water supply systems. However, there are still gaps regarding the quality water being treated using these treatment methods for instance chlorination. Chlorination becomes a problem once the residual chlorine reacts with natural organic matters to form disinfection by-products that are harmful to human health. This is why management tools are to be developed to regulate and monitor the formations of these DBPs.

3. METHODOLOGY

3.1. Study Area

Figure 1 Map of Thyolo District in the appendix

The study took place at the Mpeni water treatment plant in the Thyolo district. Thyolo district is located in the southern region of Malawi on the shire highlands. It borders Mulanje to the east, Blantyre to the north, and Nsanje to the south. The climate is dry and with savanna type of vegetation. Generally, the area terrain is sloppily surrounded by mountains and rivers/streams. The soil is roamed clay and some parts are rocky (Maoulidi 2012). This plant distributes water to not less than five thousand customers around Thyolo district. Mpeni water treatment plant uses a conventional method of treating water. Conventional Method treatment plants use a combination of coagulation, sedimentation, filtration, and disinfection to provide clean, safe drinking water to the public



Figure 2: Sedimentation Tank at Mpeni Water Treatment plant

The sedimentation tank is the point where the raw water abstracted from the Mpeni river has to undergo the coagulation and flocculation processes where alga floc is added to the raw water to form coagulants. due to the high density of the floc formed they sink in the sedimentation tank. Thereby reducing the turbidity levels of the water. The

sedimentation tank has two tanks with a volume of 350m3 each makes up a total of 700 cubic meters. After the sedimentation process, the water goes into the filtration tank.



Figure 3: Filtration Tank at Mpeni Water Treatment Plant

A filtration tank is where the remaining silts and floc that failed to settle out in the sedimentation tank are removed through the filtration method. The filtration tank at the Mpeni water treatment plant consists of grave sand at the bottom, coarse sand at the middle, and fine sand at the top of the tank to enhance water clarity before disinfection. The filtration tanks work at the same time at the plant. When the filtration process takes place the water goes into the disinfection tank. The disinfection tank is where the addition of a disinfectant takes place. The Mpeni water treatment plant uses chlorine for disinfection. The disinfection aims at killing the bacteria that are harmful to human health. The plant produces 850 cubic meters of treated water per day.

3.2. Sampling

Sampling was done using the method of grab sampling, where the samples were collected once but in duplicates. Statistical selection of sampling points was used in the selection of sampling points for data collection. The sampling points were chosen based on their distance to the plant to see the effects of contact time with the formation THMs. This study used a quantitative design, where experiments were conducted to obtain values.

3.3. Materials

Materials used for this study were as follows; a multi-probe meter, hydro test photometer, GPS meter, Turbidity Tube instrument, polyethylene bottles, plastic bucket, and sample collection box.

3.4. Data collection

Sampling was done in May 2021. Water samples were collected from selected points along with the Thyolo water treatment scheme. . A total of 30 samples were collected, two bottles of samples at each point starting from the treatment plant to the furthest point of the distribution network. Ten samples were collected of raw water. Bottles containing water samples were all labelled starting from the raw water samples, treated water, and eight consumer samples collected at every household. Water samples required for microbial analysis were also collected in grass bottles of 1L and 500 ml that were sterilized by autoclaving them at a temperature of 121°C for 15 minutes in an oven. The glass bottles were preserved in ice at 4°C. Water samples were collected to measure pH, turbidity, electrical conductivity (EC), total dissolved solids (TDS), oxidation-reduction potential (ORP), free residual chlorine, temperature, fecal coliform, and total coliform. As such, the data for this study was sourced in-situ water quality parameter testing and laboratory analysis. All analytical methods and procedures that were followed during data collection have been described in detail in the Standard Methods for the Examination of Water and Wastewater on part 1000 section 1060 B about the

collection of data and section 1060 C about sample storage and preservation (APHA et al, 1999).

3.5. Determination of Physico-chemical

3.5.1. Temperature, Turbidity. PH, EC, TDs, ORP and DO

To obtain quantitative information on the physical and chemical water quality variables of raw and treated water, a multi-probe Aqua meter was used. Values of pH, electrical conductivity, total dissolved solids, oxidation-reduction potential, salinity, and temperature were recorded in-situ by immersing a multi-probe Aqua meter into the water in a plastic bucket. The readings were recorded on paper after two minutes when the meter has stabilized. In situ data was required to aid the interpretation of other water quality results that were analyzed in the lab and as well as achieving objective number one about knowing the status of the water supply scheme. Standard analytical methods were used for the determinations of all the parameters on part 1000 section 1060 B that have details on collection of samples (APHA, 2001), and a Practical Guide to the Design and Implementation of Freshwater Quality Studies and Monitoring Programmes was also used to provide standard methods for sampling physico-chemical parameters (Bartram & Balance 1996).

3.5.2. Residual Chlorine

Free residual chlorine was determined through the DPD method in which 10 ml samples were reacted with DPD number 1 and quantifies using an HT 1000 spectrophotometer.

3.5.3. Microbiological Parameters Analysis

The membrane filter (MF) method was used for bacteriological analysis. To determine the presence or absence of total coliforms and fecal coliforms in water, the MF method was used (APHA et al. 1999). With this method, a water sample was passed through the membrane. This helps keep bacteria on the membrane filter. After filtration, the membrane filter containing bacteria cells was placed on a media. It was then incubated at 35°C for total coliforms for 24hours and 44°C for fecal coliforms for 18hours. After incubation, colonies were counted with a colony counter.

3.5.4. Determining the pH and temperature influence on residual chlorine

Two treatments of drivers of THMs were set in the laboratory. These drivers were PH and temperature; the treatments had three setups each as shown in table 1 and three beakers (making a total of nine beakers per treatment) were set for assurance of results at each setup. Raw water samples from the scheme were used for both experiments. 1mg/l concertation of chlorine was used and a constant chlorine dose was also used in the treatments. Contact times of 0, 0.5, 1, 8, and 24 hours were also used in the treatments. The ranges of pH and temperature were chosen so that they included the values used at the facility (Table 1)

Table 1: show lab setup

PARAMETERS	SETUP 1	SETUP 2	SETUP 3
TEMPERATURE(°C)	8	18	28
PH	5	8.7	10

Reagent grade sodium hypochlorite of 60% strength was used as a chlorine source. The pH was adjusted by the addition of HCl to reach a pH of 5 and NaOH was used to adjust the pH of 10. A constant temperature was maintained using thermostats (LAUDA, M40). 1000 ml of raw water was used for each setup and results of COD, EC, TDS, fecal coliform, free residual chlorine, TSS, Turbidity were obtained starting from 0 hours up 24 hours test. For the determination of TSS, Turbidity, and free residual chlorine, samples were extracted using glass vials with a lined septum cap and analyzed immediately on a photometer. The same procedure was used for temperature treatment.

3.6. Data Analysis

Data were analyzed using Microsoft Excel statistical package to calculate mean, standard deviation, and standard error. The results were compared with the Malawi Bureau of Standards (MBS) and World Health Organization (WHO) water quality guidelines. The THMs formation during chlorination carried out at different operating conditions was

analyzed by multifactorial analysis of variance (ANOVA) using the program Minitab version 71.10.

Furthermore, the results of this study were presented in tables by arranging water quality variables data in rows and different sampling points in columns, data presented in images and graphs were used to compare water quality variables at various sampling points in the treatment distribution system. Lastly, standard methods acquired for determining water samples used the international system of units (SI). The concentration units for chemical and physical results were expressed in mass units/L mostly in milligrams per liter (mg/L), Nephelometric Turbidity Unit (NTU), Degree Celsius (symbol: °C), Parts per thousands (ppt), and micro Siemens per centimeter (µS/cm). All the details on units were derived from section 1050: Expression of results (APHA, 2001).

4. CHAPTER 4: RESULTS AND DISCUSSION

4.1. PROFILING THE WATER STATUS OF THE WATER SUPPLY SYSTEM

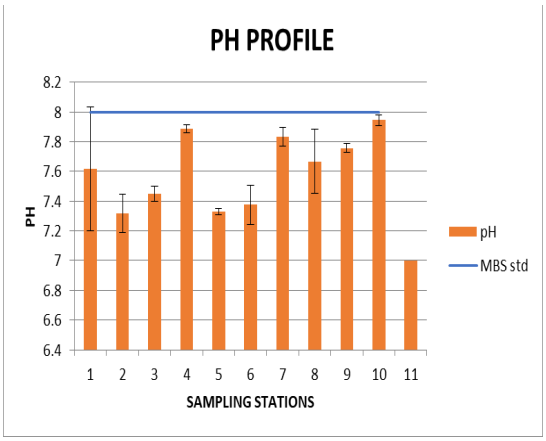
A summary of the results is presented in the table below after calculating the mean for each sampling station value since they measured three times to obtain data that was accurate. These results were used to plot graphs of the parameters which also compare each of the parameters with the acceptable levels as stipulated by the World Health Organisation (WHO, 2011) and Malawi Bureau of Standards (Malawi Bureau of Standards, 2012).

Table 2: Data of physico-chemical parameters

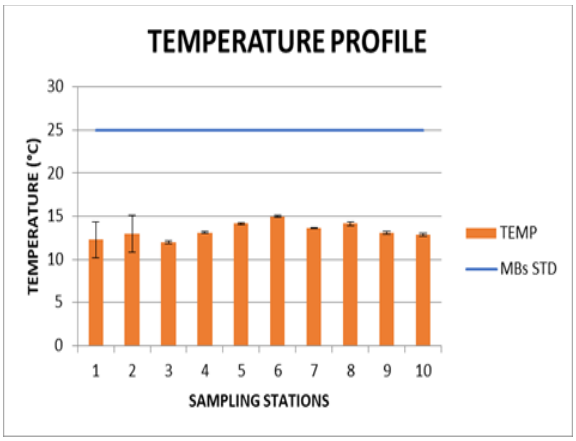
	PARAMETERS								
Sampling Station	PH	TEMP (°c)	FRC(mg/	ORP (REDOX	FC(#/100 ml	EC(uS/c)	TDs (mg/L)	TSS (mg/l)	Turbidit (NTU)
Raw water	7.61	12.27	0.17	25.85	250	97.25	62.5	21	18.5
Treated water	7.32	12.99	0.075	0.33	0	102.66	66.33	1.5	0
Consumer 1	7.45	11.97	1.81	-31.15	0	99.5	64.5	2.5	0
Consumer 2	7.89	13.11	1.3	32.04	0	102.67	66	0	0.5
Consumer 3	7.33	14.13	1.38	-30.67	0	100.67	65	0	0
Consumer 4	7.37	14.99	1.715	-29.2	0	99.67	65	2	3
Consumer 5	7.83	13.66	1.525	31.23	0	102	64.33	0	0
Consumer 6	7.67	14.17	0.12	64.53	0	100.67	66	0	0
Consumer 7	7.77	13.06	0.1	102.8	0	88.33	65.33	0	0
Consumer 8	7.94	12.86	0.12	25.767	0	102.33	66	0	0

Figure 4: Graphs Showing the Status of the Plant

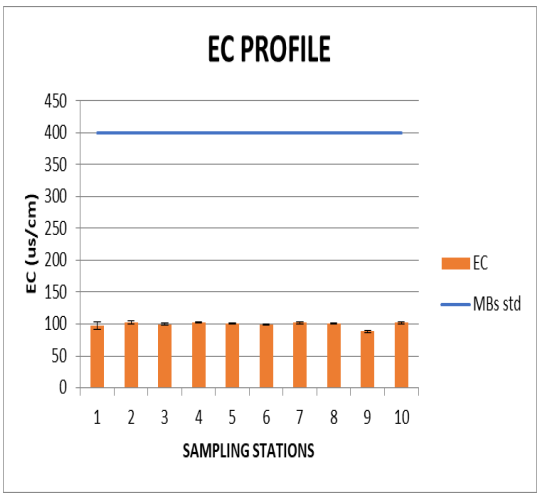
4.2. GRAPHS SHOWING THE STATUS OF THE WATER SUPPLY



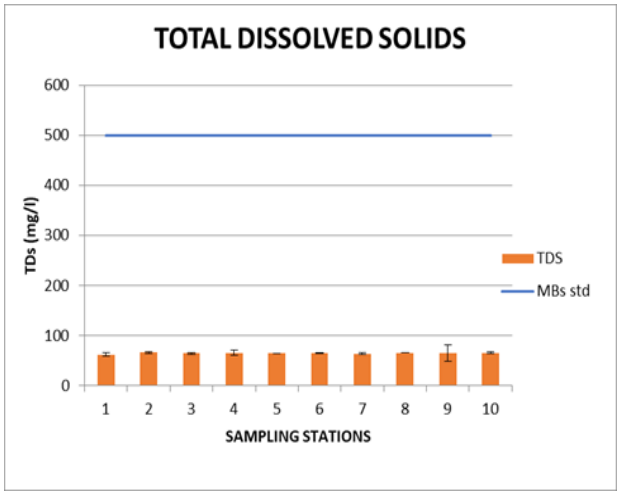
A. Graph of pH vs sampling stations



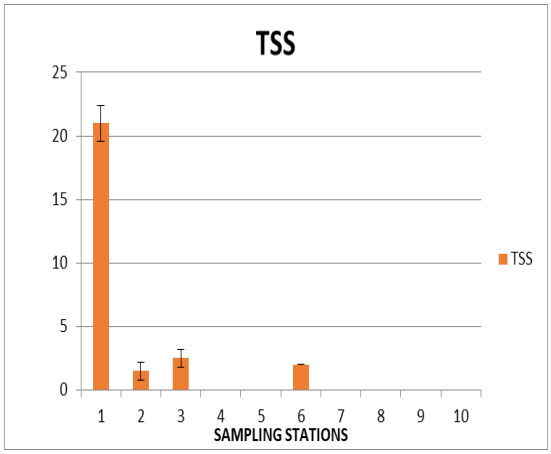
B. Graph of temperature vs sampling stations



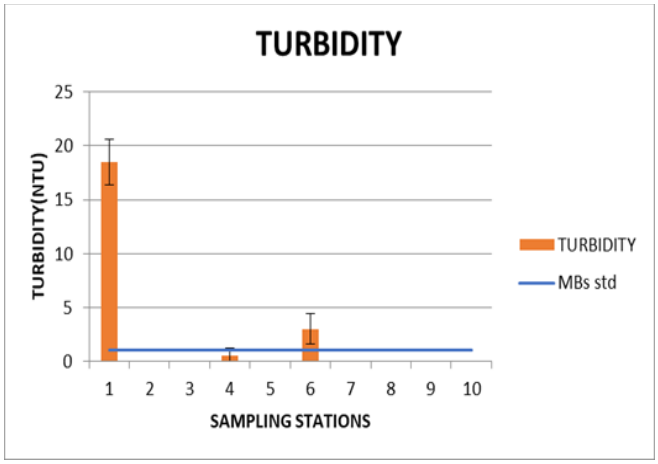
C. graph of EC vs sampling stations



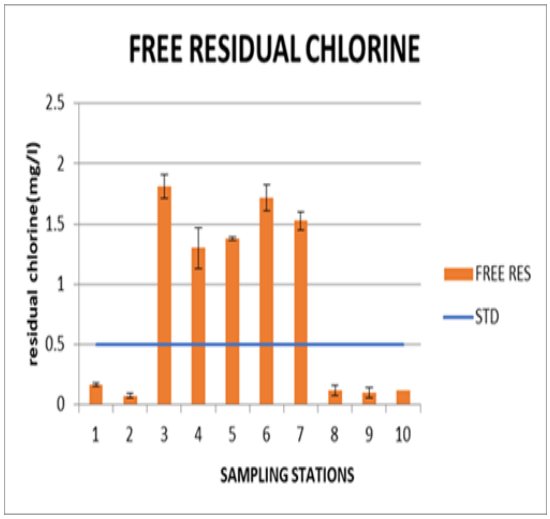
D. Graph of TDs vs sampling stations



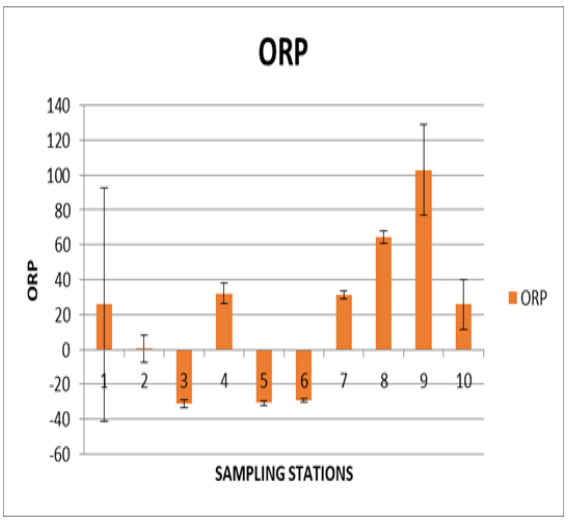
E. Graph of TSS vs sampling stations



F. Graph of turbidity vs sampling stations



H. Graph of FRC vs sampling stations



I. Graph of ORP vs sampling stations

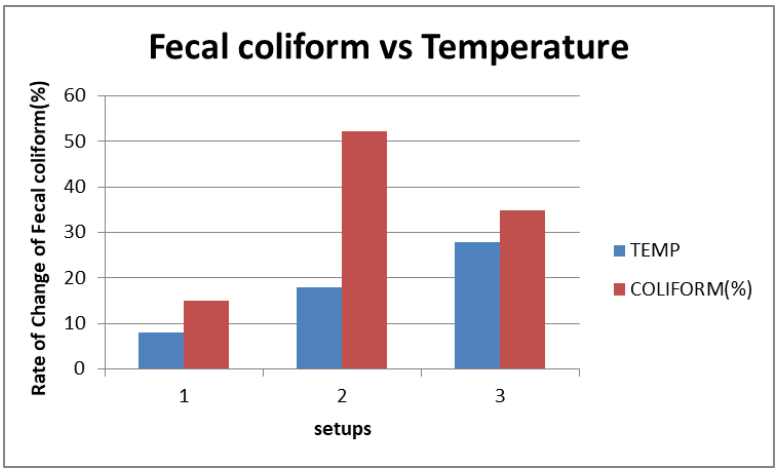
The water pH (Graph A) ranged from a mean of 7 to 8 in the distribution system. This is within the WHO guidelines and Malawi bureau of standards of drinking water quality. However, the levels from the treatment point to the consumer showed a significant difference ($\alpha = 0.003$). This might be attributed to the leaching of salts from the distribution pipes (Schock, 1999; Agatemor and Okolo, 2007). Water Temperature (Graph B) of the Thyolo water supply scheme was found to be 10°c-15°c which according to the Malawi bureau of standards are within range since the required standards are

25°c. EC and TDs levels (Graphs C and D) were not exceeded or they were aligned with WHO guidelines and MBS standards in all cases. Turbidity levels (Graph F) did show a significant variation between the raw water and consumer 4 the values ranging from 18.5 ± 0.075 to 3.00 ± 0.155 NTU since at the stage of raw water the water was not yet treated and at consumer 4 shows that there is pollution along with the distribution system. Pollution could be in the form of soil particles, organic matter, and even heavy metal entry into the distribution system causing the color of the water to significantly change along with the distribution system. When water is not turbid, it is not evidenced enough to rule out any microbial or chemical contamination but the aesthetic quality is acceptable to most consumers (APHA 2005). The ORP values (Graph I) that were measured substantially declined at points 3, 5, and 6, meaning that the levels of oxygen present in the water were low; this was due to the increase in pH at these stations. According to Weiner (2007), when the ORP value is high, there is lots of oxygen present in the water. This means that bacteria that decompose dead tissue and contaminants can work more efficiently. In general, the higher the ORP value, the healthier the water is. ORP is measured in addition to dissolved oxygen because ORP can provide scientists with additional information on the water quality and degree of pollution (Weiner 2007). Residual chlorine levels (Graph H) showed decreasing concentration with increasing distance from the treatment point. The concentration ranged from 1.81 ± 0.083 to 0.1 ± 0.083 mg/L at the treatment point and furthest, consumer, respectively. The presence of free chlorine (also known as residual chlorine, chlorine residual, and free chlorine residual) in drinking water indicates that a sufficient amount of chlorine was added initially to the water to inactive bacteria and some viruses that cause diarrheal disease (Xie 2005). This is also true for the Thyolo water supply scheme as the water dispersed to the stations near the plant had some concentration of residual chlorine. The residual chlorine concentrations in stations 3,4,5,6 and 7 were manifested to be higher than the recommended standard of 0.5mg/l whereas stations 8, 9, and 10 had a residual concentration of less than 0.5mg/l. this is true to the fact that stations, 3,4,5,6, and 7 were very near to the utility whereas stations 8, 9, and 10 were far away from the utility, thus the distance for water to reach these stations were long which increase time for the degradation of the residual chlorine. This trend is normal and could be attributed to the

fact that chlorine is still effective or being used in the distribution system. The mean levels of chlorine reaching the farthest consumer tap are at minimum levels, five times less than at the treatment point but still meet the acceptable WHO and MBS standards. There was no variation in the bacteriological quality of water (Table 7) between the treatment point (no colonies/ml) and consumer point (no colonies/ml). This signifies that there was no fecal contamination between the treatment point and consumer point to cause any risk of water-borne diseases. The WHO and MBS standards for drinking water standard require that there should be no fecal coliforms in drinking water and that if any are found, an intervention should be instigated to resolve the problem

Figure 5: Graphs Showing Temperature relationship with the rate of change of FC and FRC

4.3. GRAPHS SHOWING RATE OF CHANGE OF PARAMETERS



4.3.1. FIGURE: Rate of change of fecal coliform with Temperature

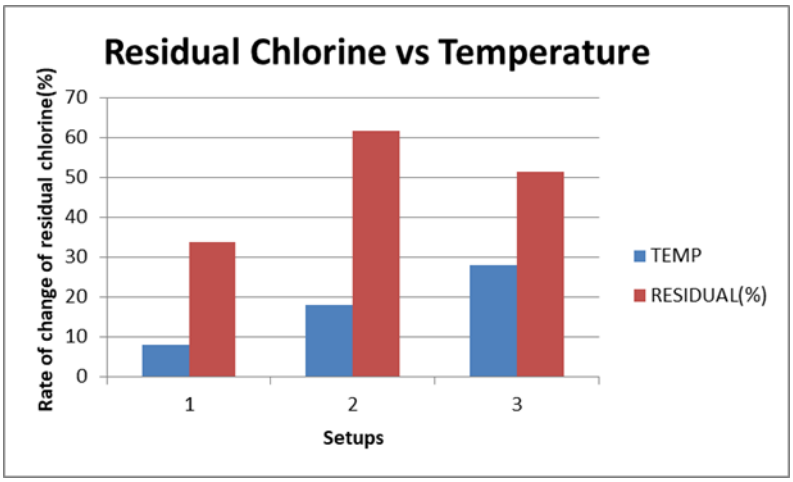


Figure 4.2.2 Graph of residual chlorine with temperature

Base on the graphs of temperature with the rate of change in fecal coliform and residual chlorine it shows that as the temperature was increasing so was the rate of change of the two parameters. The products are relatively stable, their formation increases with the temperature. As shown in Fig 4.2.1, a strong relationship was observed between residual chlorine and water temperature. At the studied water temperature range 8-28 1C), the variation in the change of residual chlorine was small in the cold water (water temperature of <15) in comparison to the higher temperature (water temperature of >15). Other studies indicate that THM formation has a critical temperature (Tc) of 18.9 1C. Therefore the higher THMs formation is expected at a temperature above the Tc value. This has been manifested in the graph of residual chlorine, when the temperature was at 18c the rate of residual chlorine increased implying that more residual chlorine was reacting with the natural organic matter in the experiment to form trihalomethanes.

Figure 6: Graphs showing the relationship of pH with the rate of change of FC and FRC

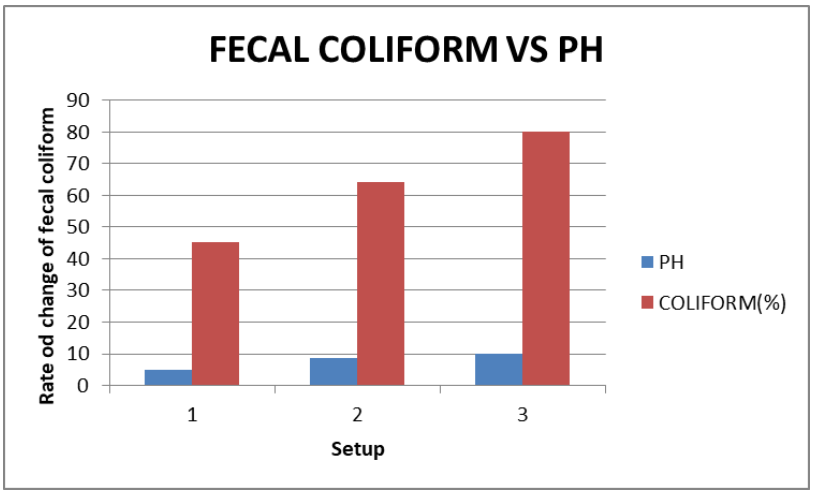


Figure 4.2.4 Graph of the rate of change of fecal coliform with temperature

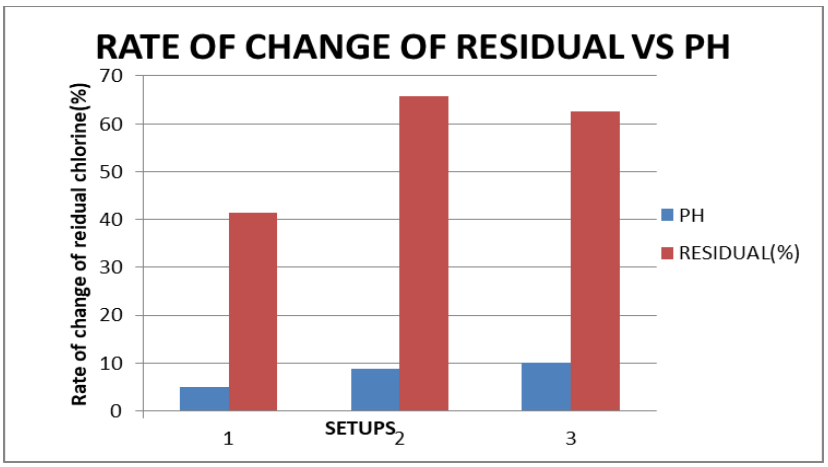


Figure 4.2.5 Graph of the rate of change of residual chlorine with pH

Base on the graphs of the rate of change of residual chlorine and fecal coliform with pH, it was discovered temperature ranging from the 8.7 above favors the formation of trihalomethanes. This is due to the case that as pH increases the rate of reaction in the water also increases thereby influencing the reaction of residual chlorine with natural organic matter to form trihalomethanes. since fecal coliform is a very important biological indicator of water contamination and pollution, which implies that in the fecal coliform there is the presence of natural organic matter that are the major drivers of trihalomethanes and also looking at the graph of the rate of change of fecal coliform with pH it shows or indicates that when pH increase so does the rate of fecal coliform. Hence concluding that high pH influences the formation of trihalomethanes.

Table 3: ANOVA Tables

4.4. ANOVA TABLES

4.4.1. ANOVA SHOWING PH RELATIONSHIP WITH RESIDUAL CHLORINE

Anova: Two-Factor Without Replication						
SUMMARY	*Count*	*Sum*	*Average*	*Variance*		
0.38	2	0.87	0.435	0.02205		
0.27	2	0.6	0.3	0.005		
0.03	2	0.03	0.015	0.00005		
0.84	3	0.6	0.2	0.0259		
0.76	3	0.9	0.3	0.0721		
ANOVA						
ɔurce of Variatio	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	0.1839	2	0.09195	15.19835	0.006173	19
Columns	0.015	1	0.015	2.479339	0.025602	18.51282
Error	0.0121	2	0.00605			
Total	0.211	5				

4.4.2. ANOVA SHOWING TEMPERATURE RELATIONSHIP WITH RESIDUAL CHLORINE

Anova: Two-Factor Without Replication

SUMMARY	*Count*	*Sum*	*Average*	*Variance*
0.63	2	0.79	0.395	0.00245
0.45	2	0.56	0.28	0.005
0.27	2	0.17	0.085	0.00405
0.87	3	0.72	0.24	0.0133
0.54	3	0.8	0.266667	0.041033

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	0.098233	2	0.049117	9.415335	0.009601	19
Columns	0.001067	1	0.001067	0.204473	0.006954	18.51282
Error	0.010433	2	0.005217			
Total	0.109733	5				

For protection against microbes, the addition of free residual chlorine to water is done (Bull et al., 2009). This also affects the DBP concentration. It has been found that the least concentration of THMs was present when the free residual chlorine (FRC) was present in moderation, that is, 0.2–0.5 mg/L. This range of the FRC is the one that has been prescribed by WHO (2011) and has been proven effective because of the same. Contrarily, THMs were reported in high concentrations in water containing high amounts of FRC. Since FRC acts as a precursor for the formation of DBP, high levels of FRC serve as an optimal condition resulting in a high concentration of THMs (Singer, 1994; Richardson et al., 2015). Based on the experiment done in the laboratory the levels of FRC keep on decreasing at different time intervals till the levels were very low, thus meaning that the FRC was reacting with organic matter in the water to form the THMs. This was witnessed in both treatments; firstly in the treatment of pH as the pH was increasing the FRC was decreasing with long contact time. the same changes happened with temperature treatment, when the temperature was increasing the FRC levels in the treatment was decreasing and according to the p-value that was obtained after doing Anova data analysis of these treatments the p-value for both cases was less

than 0.05 (>0.05) which in this case the null hypothesis has to be, since this meanings that temperature and pH have an influence on the FRC as a factor of THMs formation.

4.5. DEVELOPMENT OF THMS FORMATION MANAGEMENT TOOL WATER

The treatment plant water quality parameters of fecal coliform, PH, temperature, turbidity, and TSS were used in the development of the tool because they have a relationship or link with residual chlorine. The Minitab 17 tool pack was used to come up with the fit regression model and therefore a regression equation was developed, which in this case is the tool developed for the management of THMs formation in the distribution networks.

Table 4: Correlation Table

4.5.1. CORRELATION TABLE

	TURBIDITY	*TSS*	*FREE CHLORINE*	*TEMP*	*TDS*	*EC*	*PH*	*F COLIFORM*
TURBIDITY	1							
TSS	0.431852	1						
FREE CHLORINE	-0.42639	-0.13059	1					
TEMP	-0.33850	0.064874	0.635610761	1				
TDS	-0.02746	0.254219	0.338316605	0.53414	1			
EC	-0.02746	0.254219	0.338316605	0.53414	1	1		
PH	0.457940	0.584020	0.943390496	0.616766	0.255220	0.25522	1	
F COLIFORM	-0.47508	0.242470	0.784590216	0.395546	0.113403	0.113403	0.59113	1

To develop management and operational tool correlation analysis was used, the parameters that had a strong relationship with other parameters and also from the correlation analysis the same parameters were weighted depending on the strong relationship it has with the other parameters to develop monitoring rules. These multiple relationships were for all the parameters that are the physical, chemical, and biological parameters, and it was observed that temperature, pH, and fecal coliform have a strong relationship with residual chlorine. Whereas electrical conductivity, total dissolved solids, had a strong correlation with temperature and this is important because these parameters display the connection or an effect they have on each other thus they are included in the

development of the tool that will help monitor the formation of trihalomethanes in the water. Therefore the equation, shown below portrays how the concentration of chlorine in mg/l and how it will be monitored or managed in the water distribution network.

4.5.2. Trihalomethanes Management Tool

RC = -3.2302 + 0.34923TURBIDITY -0.28699TSS + 0.035095 TEMP + 0.008081 TDs + 0.11475 PH + 0.011009 FC.

RC = Residual chlorine (mg/l)

FC = Fecal Coliform (counts/100ml)

TDs = Total Dissolved Solids

TEMP = Temperature (°C)

TSS = Total suspended solids (mg/l)

This tool will help in the management and monitoring of the THMs formation by optimizing the amount of residual chlorine concentration in the distribution networks. Since the THMs are formed due to the reaction of residual chlorine and the presence of organic matter in the systems. Due to the lack of an instrument to measure trihalomethanes concentration directly residual chlorine was used to monitor their formation in water. This tool can be used by water utility companies to control the formation of disinfectant by-products in the water distribution networks. The developed tool was an excel based tool where the user has to measure all the parameters involved in the equation and by making sure that the resulting value of residual chlorine does not exceed the WHO guidelines or the MBS standards for drinking water. The tool development was based on water quality parameter analysis, correlation data analysis with the P values selected at 0.5, which was accompanied by multiple regression analysis of selected parameters from the correlation data analysis. Hence an equation was successfully developed which will guide the monitoring of chlorine dosing at each point of re-disinfection, and safeguard public health.

5. CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

5.1. CONCLUSION

Base on the data collected and has been indicated in the result section.it is discovered that A trend in the following variables EC, TDs, Turbidly, PH, fecal coliform, and Temperature versus the WHO and MBS standards, displayed that their values were in with the WHO and MBS standards, which concludes that the plant is functioning efficiently in removing some organic matter and contaminants. This means that the treated water quality at station 2 to the distribution network is good. The results of the investigation indicate that PH and temperature affect the residual chlorine concentration which is a factor of THMs formation. In addition, the residual chlorine concentration of the water supply scheme was found to be above the required limits established by MBs and WHO which is 0.5mg/l. This shows that THMs formation can occur in the distribution networks of the scheme since the formation of THMs is given by two main precursors such as residual chlorine and organic matter; these are not the only variables that participate in this process. Factors such as contact time, TOC (<0.20mg/l), temperature (<17°C on average), pH (between 6.5 and 8) and raw water source has also a significant influence on THMs. Thus why there is a need for the management tool of these THMs formations to monitor and control the drivers that result in the influence of the THMs.

5.2. RECOMMENDATIONS

It is recommended to carry out studies on the formation of other possible disinfection by-products given the environmental conditions. Considering that quality parameters such as temperature, pH, turbidity, presence of TOC as well as the chlorine dose and contact time of chlorine with water cause a direct effect on the formation of trihalomethanes, it is necessary to perform a deeper analysis of the impacts of these. This study was developed in the semi-urban of Thyolo, but it is known that the conditions of typical areas can greatly affect the results obtained in this study because in many of these areas there are not adequate infrastructures for water treatment and the use of chlorine in disinfection is poorly controlled. Considering the effects that temperature and pH

have, studies in rural areas with temperatures and pH higher than the scope of this study are also necessary.

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7. APPENDIX

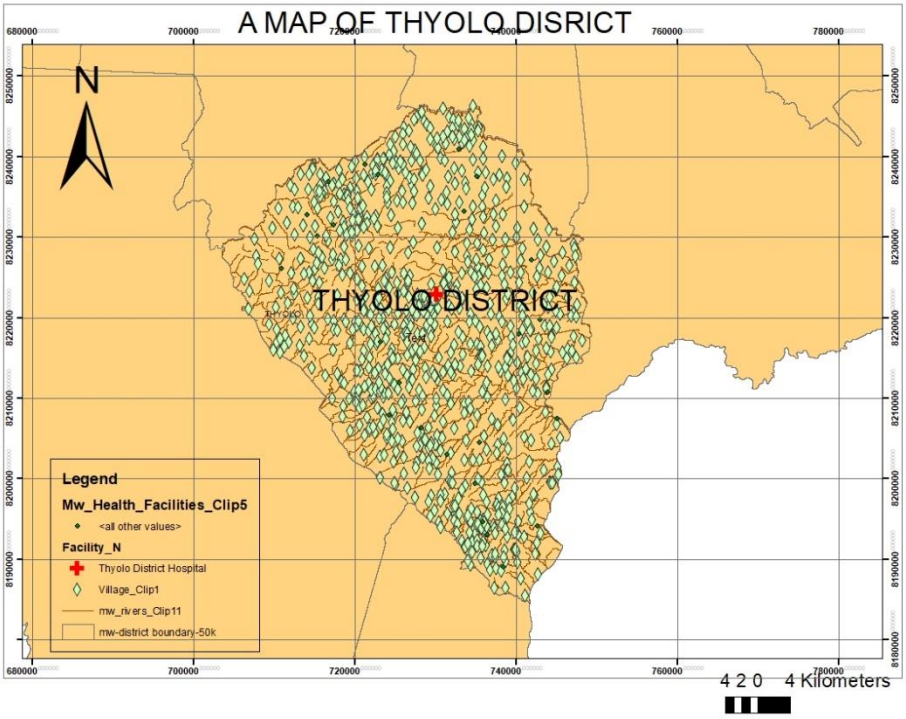


Figure 1 Map of Thyolo District