UNIVERSITY OF CAPE COAST

ASSESSMENT OF RESIDUAL CHLORINE AND ITS DECAY IN STORED WATER FROM COMMUNITIES IN CAPE COAST METROPOLIS, GHANA

BY

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DECLARATION

Candidate's Declaration

I hereby declare that this thesis is the result of my own original research and that no part of it has been presented for another degree in this university or elsewhere.

Candidate's Signature ………………………… Date ……………………

Name: Obed Fred Ohenekena Ohene-kwayisi

Supervisor's Declaration

I hereby declare that the preparation and presentation of the thesis were supervised in accordance with the guidelines on supervision of thesis laid down by the University of Cape Coast.

Supervisor's Signature……………………….. Date…………………

Mr. J. K. Tuffour

ABSTRACT

Residual chlorine in tap water has been of great concern worldwide especially in developed countries, as disinfected water at the water treatment plant may be polluted again when the water is being transported. The residual chlorine content in tap water samples distributed through pipeline by the Ghana water company limited Brimsu Headworks, to the populace of Cape Coast Metropolis was assessed for residual chlorine in eight weeks. This study ascertained the residual chlorine content of the tap water and its safety level for human use; the similarity in the residual chlorine contents. Samples were collected weekly from eleven suburbs and the residual chlorine analysed by spectrophotometric method using diethyl-p-phenylenediamine (DPD) regent. Two sets of distinct residual chlorine concentrations were observed; with means (mean ± CV) 0.199±1.833 ppm for samples from Abura, Pedu, Brafoyaw, Duakor, University of Cape Coast Lec Village; and 0.317±1.208 ppm for samples from Elmina, UCC Campus, Kotokoraba, Kwaprow, Amamoma and Akotokyir. The highest residual chlorine content was found at Amamoma, and the lowest at Pedu. Even though the tap water was from the same source, it had varying levels of residual chlorine. One-way ANOVA revealed that there was statistically significant difference in residual chlorine levels in tap water at each community ($p = 0.00 < \alpha = 0.05$) and ($F_{crit} = 1.876 < F_{statistic} = 1946.976$). The pH ranged from 6.50-7.20, and showed no significant difference. The was no significant correlation between the pH and the residual chlorine content. A hierarchical cluster analysis showed 50 % similarity for Akotokyir and Kotokoraba, Abura and Elmina, 58%; Brafoyaw and UCC had similar levels of 65%. No sample had similarity level above 70 %. The residual chlorine decay in stored tap water kept in different storage conditions over the 8 days revealed that, for water stored in a room, the level of residual chlorine reduced by 65.38% for tap water stored in covered container and 64.23% for tap water kept in uncovered container. For tap water kept outdoor, residual chlorine reduced by 65.02% for tap water kept in uncovered container and 63.6% for tap water in a covered container. All the tap water sampled had residual chlorine within the 0.2- 0.5 ppm guideline set by World Health Organization (WHO). The free chlorine and bacterial should be assessed concurrently.

KEY WORDS

Chlorine decay

Hypochlorous acid

N, N diethyl -p- phenylenediamine

Residual Chlorine

Tap water

Water disinfection

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DEDICATION

To my mother: Madam Ruth Jemima Aidoo and Siblings

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LIST OF ABBREVIATION

RC	Residual Chlorine
WQI	Water Quality Index
DPD	N, N-diethyl-p-phenylenediamine
HI	Hazard Index
PCA	Principal Component
DO	Dissolved Oxygen
COD	Chemical Oxygen Demand

CHAPTER ONE

INTRODUCTION

Background to the Study

For life and human health, water is a necessary resource, as well as for economic development; food security, poverty alleviation, long-term and environmental sustainability (Karakuş & Yıldız, 2020). Water is a basic natural resource, on which both plants and animals depend for survival. Spring, waterfalls, rivers, and tertiary irrigation systems are all sources of surface water (Wimbaningrum et al., 2015).The bioavailability of nutrients for plant growth and production of essential minerals in animals is made possible as a result of water, serving as a media of transmission.

Unfortunately, human activities such as application of toxic chemicals for mining, disposal of untreated dye effluent from industrial waste into streams and rivers, and the use of excess weedicides and herbicides which contains heavy metals, resulting in the contamination of the surface water. Excess metals are however leached into the underground water (Jounaid et al., 2021; Rizk et al., 2022; Yi et al., 2020). Mostly the degree of contamination is beyond reclamation. Human practices have contributed immensely to the contamination of some fresh water available for both plant and animal consumption. The degree of pollution of fresh water has led to the limited clean water, which is shared between plant and animal. This has resulted in increasing water scarcity, due to lack of appropriate technology and robust method for water treatment (Nations, n.d.; van Vliet et al., 2021; Zhang et al., 2021).

The unavailability of funds to purchase modern machinery, materials and training of personnel to manage and secure the few fresh water remaining has worsen fresh water crisis. Agriculture, the major consumer of fresh water, has been impacted greatly due to lack of resources for water treatment. Willingness by farmers to use any water for crop cultivation has led to increasing agriculture in peri-urban, and urban areas use of wastewater in Ghana (Ochoa-Noriega et al., 2020). Researchers in Ghana are paying close attention to the study of clean and safe drinking water, since only approximately 30% of Ghana's populace have access to clean, pipe-borne water that is safe to drink. The remaining 70% of Ghanaians rely on rivers, boreholes, streams, rainwater, and other alternative sources of water (Obeng et al., 2010). According to the Ghana Living Standards Survey Round 4 (GLSS 4), which is cited in the National Water Policy (1998), 40% of urban families depend on their neighbors and merchants for their water source. According to the Policy, "with the rapid spread of new housing projects, frequently ahead of utility services, more and more urban inhabitants will depend on vendors and tanker services, at costs well above utility rates" (Obeng et al., 2010; Peprah & Opoku, 2018).

Providing individuals with appropriate supplies of safe quality and large quantity of clean water, via pipelines and storage tanks made of various materials between water sources and customers, is essential for ensuring compliance with drinking water standards as well as for the health of consumers (Belcaid et al., 2023).

Chlorine disinfection protects both life and property, by removing a broad spectrum of pathogenic organism. This stops the regrowth of harmful bacteria, and viruses in water facilities. This makes water safe, and economical for human consumption (Cheswick et al., 2020; Jefri et al., 2022; Lindmark et al., 2022).

Water disinfection, typically the final phase in water cleaning procedure, aids in the prevention of sickness and a number of diseases. However, while technology is being developed for applying typical disinfectants (ozone, chlorine, and chlorine dioxide, Chloramine) disinfection by-products, might react with lingering organic molecules. The water contains bromide and iodide, resulting in cancer-causing and genotoxic chemicals (Black, 1984; Nshemereirwe et al., 2022; Vainoris et al., 2019; Wilson et al., 2019). It is expedient to control the residual chemicals in the water after treatment to avert adverse health effects. The method of disinfecting drinking water that is most frequently employed is chlorination. Therefore, monitoring the level of chlorine is crucial for maintaining the water quality (Kasik et al., 2008; Wilson et al., 2019; Xue et al., 2020).

Systems for both potable and non-potable water apply chlorine disinfection processes. It is legally required in each case to know the level of free chlorine at the end of the distribution networks. Hypochlorous acid ($HOCl$) and hypochlorite ion (OCl^{-}), which are both forms of chlorine, combined to form residual chlorine. Generally, residual chlorine in drinking water is a mixture of $HOCl$ and OCl^{-} (Seymour et al., 2020). Maximum residual chlorine concentrations in treated water range from 0.08 to 0.8 ppm, depending on the legislation and purpose. This range relates to free chlorine, or the total chlorine in the form of $HClO$ and ClO^{-} anions as well as chlorine molecules dissolved in water. The temperature and pH affect the actual ratio of all these chlorine types (Kasik et al., 2008; Tabatabaei et al., 2021). The acceptable level of residual free chlorine in home water saved for later use is 0.2 ppm (Abuzerr et al., 2020; Wilson et al., 2019; Yimer et al., 2022). The World Health (Schwenke et al., 2019) Organization claims that about (2.0 - 4.0) ppm chlorine respectively, can be found in clear and turbid water respectively. Germany's Potable Water Ordinance states that following disinfection, the free chlorine concentration in drinking water should even be regulated between (0.1 - 0.3) ppm (Schwenke et al., 2019). A swimming pool for recreation facility has a free chlorine content of 1.5 – 2 ppm. Excessive free chlorine concentrations may either result in serious health conditions or negatively impact human health (Yen et al., 2020).

Chlorine is mostly added in salt or gaseous form at the last phase of a process used to treat water, and is added to potable water during disinfection operations, it hydrolyzes in the water to produce hypochlorous acids and hypochlorite ions.

$$NaOCl + H_2O \rightleftharpoons HOCl + NaOH \quad (1)$$

$$HOCl \rightleftharpoons ClO^- + H^+ \quad (2)$$

Equation (1): shows (Sodium hypochrite) added to water in salt form, and equation (2) shows further dissociation of hypochlorous acids during water disinfection. The pH affects the quantity of each of the two species, HOCl and ClO^-. HOCl is the dominating species at pH 5.5, while ClO^- is the main species at pH > 8.5. The remaining chemical that is present as chlorine gas (Cl_2), hypochlorous acid (HOCI), and the hypochlorite anion is referred to as free chlorine. Chlorine exists in water bodies, resulting from excessive sodium hypochlorite use during water treatment (Pathiratne et al., 2008).

Monitoring water quality is an essential tool for achieving long-term clean water development. It gives important data for managing water. Natural and man-made processes influence the quality of surface water in a given region (Yıldız & Karakuş, 2020).

Water's hydro-chemical qualities influence its residential, industrial, and irrigating-related applications. The chemistry and quality of water are greatly influenced by the interaction of water with the lithologic units it flows through. Programmes to monitor water quality are critical for the protection of clean water supplies (Karakuş & Yıldız, 2020).

Free Chlorine Concentration in Tap and Well Water Quality Worldwide

Despite widespread misconceptions to the contrary, several anthropogenic activities contaminate groundwater supplies. Groundwater is thought to have good microbiological and physicochemical qualities. According to (Li et al., 2021), groundwater pollution results from the industrialization and urbanization processes that have progressed over time, without taking into account the effects on the environment. This eventually causes the water's physical, chemical, and biological properties to deteriorate. Groundwater resources in Ghana are gradually coming under greater threat from contamination due to industrial expansion, agriculture, and mining (Annan et al., 2022).

Twenty liters or more of water per person per day must be accessible from a source within one km of the user's residence was the standard used by (Cairncross & Valdmanis, 2003) to determine availability of water. Public connections and the house or communal water sources can both provide access to a better water supply. About 46.5 percent of people access water provided through pipes, compared to 29.1 percent that utilize protected wells or boreholes. About 9.4 percent moreover use bottled or sachet water. Approximately 10.6% of households rely on surface water sources such rivers, streams, dams, canals, and ponds for drinking water. Less than one percent (0.7%) rely on rainwater, while one percent (1.1%) rely on tanker/vendor services according to a survey by Obeng et al., (2010). These data (Obeng et al., 2010) show improved access to potable water supply to the Ghanaian populace.

Approximately 42 percent of the populace in sub-Saharan Africa still lacks access to better water. Since seawater makes up more than 97 percent of the world's water supply, it cannot be used for most agricultural or drinking purposes (Wilson et al., 2019). For the public to receive high-quality water, water distribution infrastructure is essential. In the distribution system, little is known about how pollutants, particles, and disinfectants flow. In assessing water quality in the distribution network, chlorine residuals in drinking water have long been acknowledged as a great indicator of contamination. There is no ongoing independent monitoring programme in Ghana to evaluate the quality of the water at the treatment facilities and the distribution network according to earlier research by Karikari and Ampofo (2013).

The best way to disinfect sources of drinking water is to utilize chlorine, due to the effectiveness and readily available chlorine products. However, research has shown that trihalomethanes (THM) are formed when chlorine interacts with different chemical compounds. It is recognized that exposure to high concentrations of chloroforms over extended periods of time can result in cancer (Freese & Nozaic, 2004; Wyczarska-Kokot et al., 2020).

which is most frequently created during chlorination. Depending on contact duration and proximity to the treatment plant, users may be exposed to (DBPs) that form in the distribution system when utilizing Chlorine (Gile, 2016; Jeffrey et al., 2022a).

Residual Chlorine Levels in Tap Water Worldwide

According to a study done in Andean, maintaining a residual chlorine levels of 0.87 mg/L in the distribution tank met the Ecuadorian standard (0.3 mg/L) residual chlorine level in drinking water at the pH of 7.24, but was less than 0.5 mg/L value for the current COVID-19 epidemic, as advised by the WHO (García-Ávila et al., 2021). Another study conducted at Alexandria Governorate in Egypt, indicated that for a total of 288 measurements made in tap water at individual homes after it had gone through storage tanks, only 73.6 percent of the measurements met the 0.35 mg/L free residual chlorine limit set by the Egyptian drinking water standard (Abdullah, 2014). In Ghana, a study conducted by Karikari and Ampofo on drinking water quality from the Accra-Tema Metropolis' distribution systems, which derive their water source from the Kpong and Weija treatment plants, indicated that the residual chlorine level found in the drinking water ranged between (0.13 and 1.35 mg /L). At the treatment facilities, there were high levels of residual chlorine, but the levels reduced as the water flows farther away from the plants (Karikari & Ampofo, 2013).

Due to differences in the distances between metropolises' respective storage facilities, and the installation of new water pipelines in some metropolises, while older rusty pipe tubes are used by others. Each metropolis has varying residual chlorine concentrations in the treated water. These differences result in greater residual chlorine levels at the treatment plant, but reduced residual chlorine levels, continue as the treated water flows along the pipelines to the end users (Karikari & Ampofo, 2013; Qaiser et al., 2014)

Statement of the problem

The presence of bacteria, fluorides, irons, magnesium and other chemicals constituents does not conform to national standards. Also, another key issues was the reduction of microbial contaminant, which requires the application of chlorine (Ministry of Water Resource works and Housing, 2015).

Potable water from Accra-Tema Metropolis was found to be contaminated by fecal coliforms. At pH between 6.8 and 7.4, the chlorine residues varied between 0.13 and 1.35 mg/L. A lot of residual chlorine was found in water at treatment facilities, which were above WHO limits. The residual chlorine concentration dropped as the water flowed further away from the facility (Karikari & Ampofo, 2013).

Two studies conducted in Tamale, also indicated a free chlorine content in tap water that ranged from (0.065 – 0.568) ppm and 0.0 ppm with pH ranged from 7.005 -7.598 (Fitzpatrick, 2008; Hansen, 2014). According to the level of residual chlorine in water, low chlorine consumption levels almost always have no negative effects on health. However, prolonged exposure to high chlorine levels can cause major health problems, such as an increased risk of cancer and infertility problems.

The world health organization recommends 0.2 – 0.5 ppm residual chlorine in tap water (WHO, 2011) yet very little research has been done Thus far since 2015, to assess the free chlorine in tap water in Ghana and specifically in Cape Coast metropolis. Therefore, the aim of this research is to investigate drinking water quality by assessing the residual chlorine levels in tap water, in selected communities within the Cape Coast metropolis in Central Region of Ghana, and to evaluate the associated health risks. This study may have its own implications for corrective action from water supply authorities, policy and decision makers as well as consumers.

Research Objectives

Main Objective

Assess the residual chlorine levels in potable water sources based on residual chlorine concentrations, the associated potential hazards and propose remedial options.

Specific Objectives

1. Assess the free chlorine concentrations in tap water from Cape Coast Metropolis.
2. To compare the free chlorine levels in tap water from eleven localities (Nine from Cape Coast and two from its environs: Elmina and Brafoyaw)
3. Determine the relation between the residual chlorine and the pH of the tap water.
4. Study residual chlorine decay in tap water.

Significance of the Study

Provide data on free chlorine levels in tap water to argument existing findings on the quality of tap water in the Cape Coast Metropolis.

Provide knowledge on the residual chlorine concentration level at the end-user, the associated health risk and to suggest the necessary remedial measures where necessary.

Delimitations of the study

The scope of the study was focused on assessment of residual chlorine in tap water in eleven communities. The study of the chlorine decay along the transmission pipelines was not done, because the locations for the mappings of the transmission's pipelines could not be obtained from Ghana Water Company Limited. Sampling within the selected communities was limited to few sites. Sample analysis was done in the laboratory.

Limitations of the Study

1. Due to the cost of reagent, time constraints and unavailability of desired equipment for on-site measurement, twenty samples were collected from each locality within five weeks, and the sampling was done at few sites in the communities.
2. Using N, N diethyl-1,4-phenylenediamine (DPD) colorimetric method for residual and combined chlorine levels, were to be assessed at the sampling sites, including on-site measurement of the pH of tap water. However, due to unavailability of portable equipment, measurements were done in the laboratory.

Organization of the study

Five chapters made up this research project. Chapter one: thus introduction, highlighted the background information on importance of water, and the major sources of surface water supply in Cape Coast. It further posits the significance of providing quality potable water by chlorine treatment, to the people of Cape Coast Metropolis. The objectives, delimitation, limitation and organization of the study were detailed.

Chapter two, literature review: presents research works conducted on water treatment by Chlorination method and the levels of free chlorine in the water. Chapter three, methodology: the materials and procedure used to analyze residual chlorine level in potable water, and chlorine decay in stored potable water were stated. It further stated the approach used in processing the data. Chapter four, presents the results and discussion of the study. Chapter five, presents the summary, conclusion and recommendations that would aid policy makers in decision making.

CHAPTER TWO

LITERATURE REVIEW

Introduction

In this chapter, the various research works on sources of water and water purification, in literature were reviewed. Particular attention was devoted to literature on water disinfection by chlorine method, some methods for testing the residual chlorine level in water were also highlighted, since it was the central theme for this dissertation.

Water Treatment

The tradition of water purification and distribution can be improved, sustained in the Ghanaian setting. Specifically, in the Cape Coast metropolis where potable water scarcity is predominant, alternative water source can be exploited by recommending these measures:

- acquiring, managing, and controlling water to make it accessible to humans
- the many types of water usage
- controlling natural water resources and managing restrictions
- Knowledge, know-how, myths, and symbols relating to water
- The cultural landscape of water
- Health, water quality, and related representations

Water treatment residual (WTR), is a recycled material that can be utilized as bioretention filter medium to remove important pollutants from stormwater runoff, particularly phosphorus. In the future, WTR may be modified creatively and used to remove pathogens from stormwater runoff to produce clean water for human consumption (Xu et al., 2020).

Research indicates that, the percentage of Ghanaians who have access to improved sources of drinking water is reported to be 79 percent, although this figure does not account for the quality of the water that is drunk. Statistics place the availability of purified piped water delivered directly to households or public standpipes at 95%. But because the supply of purified piped water is frequently interrupted, sometimes for long time, many homes mostly depend on wells, boreholes, springs, and surface sources water for consumption. Just one in five families (19%) have access to properly regulated water sources, according to a more recent study report (Appiah-Effah et al., 2021).

For infection control and hygiene purposes, health care facilities (HCF) must have a consistent supply of safe water. The fundamental framework for access to water, sanitation, and hygiene must be improved in low-income nations, especially in Sub-Saharan Africa. In order to maintain a consistent water distribution, intermittent water supply, whether it comes from a networked or unconnected source, demands water storage in containers. This adds an extra danger of recontamination; hence water disinfection during storage is needed. To keep the water quality at the sites of use at a lower cost, post-treatment chlorination is required (Huttinger et al., 2015).

Purification Capacity of Products in Water Treatment

Despite the fact that several distribution systems later suffer an increase in bacterial counts as water move away from the point of treatment, raw water treatment reduces the number of microorganisms present. One factor contributing to the reduction in water quality is the regrowth of bacteria in biofilms that build on interior surfaces. In order to evaluate the rate and capacity of purification, a literature review was conducted because each water treatment product has a unique purpose and capacity to treat water. Each water treatment product is represented by a graphic that lists the various contaminants that it may remove from water, along with the percentage of each substance that is removed, based on laboratory data. Among the substances taken into account in the evaluation are bacteria, viruses, protozoa, and fungi or algae, additionally, there is a section that describes the decline of various chemical and physical impurities (Israr et al., 2017).

Types of Water Disinfection Methods

Reverse osmosis, distillation, microfiltration, membrane ultrafiltration, and filtration are a few methods for treating water that minimize the concentration of contaminants conveyed or created in the distribution of potable water (Wicaksono et al., 2020). For wastewater remediation, several traditional treatment approaches are available, including biological, chemical processing: flocculation, activated charcoal, filtration, and ion exchange resins (Ameta et al., 2018).

Chlorine and chloramine are the two main disinfectants used in potable water treatment. Either chlorine or chloramines are used in most localities. For operational purposes or at different seasons of the year, some chloramines and chlorine are alternately applied in municipalities as additional disinfectants. Chlorine dioxide, is less frequently applied in water treatment. To eliminate viruses, germs, and parasites from potable water, chlorine is added as disinfectant. The quantity of free chlorine in potable water can be moderated using a variety of measures. A minimal level of chlorine in potable water does not negatively impact human health, when the water is consumed. Hence can help prevent epidemics related to water (CDC, 2020b).

Ozone Water Treatment

Advanced oxidation processes (AOPs) are advised as a solution to aid in the remediation of disinfection byproducts because they are typically resistant to oxidation, mostly because of the presence of halogen compounds. The oxidation potential of ozone is greater than those of hypochlorous acid, chlorine, and chlorine dioxide, and monochloramine, demonstrating that it has the strongest oxidizing capability among these disinfectants (Beltrán et al., 2021).

For a long time, huge water production plants were the only places that use ozone water treatment because it was believed to be expensive. Since this information enables evaluation of the potential for utilizing this technology in small water treatment plants, the issue of the prices of ozone water treatment is of utmost importance. Based on water production and cost data from 2017, the calculations were made. The hydraulic load of the building was 58.7%, and the unit costs were 0.77, 0.59, and 0.53 EUR/m-^{3}, respectively. The costs of pumping the treated water into the network compensating tank were also included in the electricity bills for the unit.

Two ozone generators with an 80 g capacity and four TOPAZ oxygen generators of ozone per hour, with a measurement device for online round up the basic technological line's water ozonation equipment was applied for water treatment. The process's variable parameters include the ozone dose, contact time, and residual ozone control. Ozone's rising popularity is a result of its effectiveness against a variety of water-borne contaminants. Ozone treatment is frequently required because the quality of withdrawn water falls short of what is needed for drinking water. A rising number of facilities that use this extremely efficient technique to obtain the greatest water quality possible attest to its effectiveness. Additionally, more and more attention is being paid to the safety of drinking water due to the great concern for health (Pawełek & Bergel, 2019). However, new methods of treating water have been researched in recent years in an effort to improve their capacity for doing so and get around the drawbacks of chlorination and other established technologies like ozone and ultra violet C (UV C) radiation. In recent years, it has been shown that the Fenton and photo-Fenton processes are effective alternatives for disinfecting water (Polo-López et al., 2019). Other metals, such as cobalt and copper, are utilized in reduced oxidation state processes known as Fenton-like reactions. There are numerous kinds of Fenton processes, including Fenton, electro-Fenton, electro-photo-Fenton, sono-Fenton, sono-photo-Fenton, and sono-electro-Fenton, as well as hybrid Fenton and Fenton type processes (Ameta et al., 2018).

Reaction equation for Fenton process

$$Fe^{2+} + H_2O_2 \rightarrow Fe^{3+} + {}^{\bullet}OH + OH^{-} \quad (1)$$

$${}^{\bullet}OH + H_2O_2 \rightarrow HO^{\bullet}_2 + H_2O \quad (2)$$

$$Fe^{2+} + {}^{\bullet}OH \rightarrow Fe^{3+} + OH^{-} \quad (3)$$

$$Fe^{3+} + HO^{\bullet}_2 \rightarrow Fe^{2+} + O_2 + H^{+} \quad (4)$$

$${}^{\bullet}OH + {}^{\bullet}OH \rightarrow H_2O_2 \quad (5)$$

Organic pollutant + ${}^{\bullet}OH$ $\rightarrow$ Degraded products (Ameta et al., 2018)

Solar Disinfection Water Treatment

Numerous studies have demonstrated the efficiency of solar disinfection in removing microorganisms and lowering diarrheal morbidity, however this is only true for waters with low turbidity. In addition to safe water storage and domestic water treatment, previous research has shown that solar disinfection is crucial for reducing diarrhea.

The stated findings, however, indicated that there were diverse results and that a thorough investigation and meta-analysis had not been carried out to examine the evidence of the relative effectiveness of the solar disinfection water, a strategy for minimizing diarrhea. One of the tried-and-true methods for treating home water that are now being pushed by numerous organizations is solar water disinfection. The technique uses single-use transparent plastic or glass containers that are heated by the sun and UV rays to kill germs (Soboksa et al., 2020).

Oxidation-Filtration Treatment

The maximum allowable concentration of oil products, phenols, and nitrogen compounds are many times greater in the surface waters closer to most chemical industries. This doubles the already high amount of oil products in the surface water in some local districts. One important source of water supply is groundwater. Surface water sources are becoming more and more polluted. When selecting a water treatment system, the type of iron in the water is most important. organic materials, silicon compounds, iron ions, and manganese substances with humic origin are all present in higher concentrations in groundwater. Having trouble getting clean, high-quality drinking water that meets with sanitary standards and regulations for water consumption, determine the contaminants that contribute to the emergence of colloidal particles. Iron undergoes oxidation to produce a minimally soluble iron (III) hydroxide of a conventional colloid with well-known features. Additionally, these humic-derived organic molecules support stable ironcontaining colloid systems, and further removed by filtration (Shiyan et al., 2022). Recovering wastewater for use in indirect potable reuse (IPR) produces drinkable water, instead of straight potable reuse (DPR), use an interim environmental buffer, which either lacks a buffer or simply provides a small amount of dilution or storage time. Environmental protection measures which may be a lake, river, or groundwater aquifer, is thought to offer extra protection by dilution or elimination by filtration (for aquifers), photolysis (for surface waters), or biological deterioration (Jeffrey et al., 2022a).

Generally speaking, pathogens and dissolved organic and inorganic materials are the two categories of pollutants in drinking water that are of concern. The so-called pollutants of emerging concern have drawn the most attention, a collective name for organic and inorganic species that are present at low concentrations (also known as micropollutants) but may yet constitute a serious chronic health risk. Despite the concern over significant contaminants like PFAS (perfluoroalkyl/polyfluoroalkyl substances), DBPs (disinfection byproducts), and sporadic industrial pollutants, the vast majority of contaminant of emerging concern (CECs) do not pose any known risks to human health at the levels found in waste water treatment plant effluent, and even less so after purification (Jeffrey et al., 2022b).

According to an overview among the world's installations devoted to wastewater reuse for potable water supply, they are primarily based in the US. Several stations have also been developed in Australia, Singapore, and Southern Africa. It is unknown whether any indirect source of potable water is provided by China's numerous water reuse facilities. But numerous studies have shown that de facto reuse of sewage from municipalities as a source of potable water poses a significantly higher danger to health than planned reuse, either directly or indirectly (Jeffrey et al., 2022a).

Electrochemical Water Treatment Method

Lowering salt discharge and improving water reclamation can be accomplished by integrating desalination membrane operations. According to numerous research, combining membrane desalination and nano filtration increases effectiveness and economic viability in terms of energy consumption and flow (Aliyu et al., 2018). With increased water stress, not just in traditional desert regions but also in development regions due to conflicting uses, it is becoming more crucial to increase water availability through reuse and desalination. Since electrochemical methods frequently do not need chemicals to be added, and are characterized by large electron yields, they meet two of the Clark's criteria for green chemical processing, among other fulfillment in chemistry. In electrochemistry, the use of current as an agent can be used to control the mobility of ions, oxidation and reduction reactions, and the surroundings of ions. This makes it a desirable technique for getting rid of charged organisms.

The electrocoagulation (ECo) method is a widely used electrochemical technique that is frequently used in the treatment of water, including removing all organic and inorganic material contaminants as well as other unwelcome water components from drinking water, service water, and wastewater. Dissolved metal ions or colloids are removed from drinking water, service water, and wastewater through precipitation, reduction, charge neutralization, or adsorption. This method is very expensive since electricity is needed for the water purification process (Simon et al., 2018).

Ultraviolet (UV) Radiation for Water Treatment

When determining whether intake of water is safe, combined use of chlorine and ultraviolet light as chemical and physical disinfectants, respectively, is complimentary and crucial. A thorough analysis of the process effectiveness and financial viability revealed that, viruses were eliminated using the UF + UV (ultrafiltration + ultraviolet radiation) method to a level that allowed for the reuse of water for agricultural use at a cheap cost (Ritt et al., 2021; Takeuchi & Tanaka, 2020). High degrees of disinfection of all pathogens can be achieved using UV irradiation in water treatment. Development of regulated disinfection byproducts can be reduced or completely avoided. A few possible locations for UV irradiation in distribution systems that are envisioned are UV boosters in the distribution network, UV in the tanks' inlets or outputs, and UV in the tanks themselves; Light Emission Diodes (LEDs) spaced along pipe walls; small point of use or entry treatment systems for homes, buildings, or taps; or submersible swimming or rolling UV LED drones to reach problematic pipes and provide a "shock" treatment or provide sterilization after main breaks or repairs. In recent years, UV Light Emitting Diodes (UV-LEDs) have become a new source of UV radiation. UV-LEDS are probably a great source of UV for water disinfection systems since they are compact, run at low power and voltage, and can be rapidly turned on and off (Keshavarzfathy & Taghipour, 2019; Linden et al., 2019).

High efficiency against protozoa that are resistant to chlorine, no additional disinfection byproducts, and compatibility with adding UV to secondary disinfection methods already in place for improved protection are all advantages of UV applications in water. The use of UV-compatible pipe materials, the installation of dispersed LEDs, the control of waste heat from the LED's back surface, and the potential presence of opportunistic microorganism regrowth are just a few examples of potential difficulties and research needs that are discussed. The relatively inert regulatory climate in some nations makes it difficult to build frameworks for the assessment and acceptance of UV technology in distribution systems that demand a chemical secondary disinfectant. Little is known about behavior of biofilms in pipes when exposed to UV light, including any possible gains that might be lost, the possibility of fouling LED emission surfaces and monitoring sites, and the availability of a distributed power network to power the LEDs. The primary barriers to their wider usage currently include the use of synthetic waters in laboratory experiments rather than actual waters, high capital and operating expenses, and little to no experience with full-scale plant management (particularly for UV-based combination processes) (Collivignarelli et al., 2021; Linden et al., 2019).

For the purpose of enhancing energy efficiencies, research on light-emitting diode UV (LED-UV) technology has recently received more attention (Sholtes and Linden, 2019;Yu et al., 2020). Failure in the case of LED lights has been linked to a large drop in optical power from the original value as a result of a corresponding decline in the silicon encapsulation or semiconductor device (Arques-Orobon et al., 2020). Despite the advancements in LED technology, they have not yet been used to disinfect water on a large scale. Since adeno-viruses are known to be the most resistant to UV radiation, the recommended UV dosage to achieve the goal of inactivation is often based on quantity of viruses. Higher average fluence rates are seen for UV-LEDs with all radiation profiles when they are located closer to the observer (Jeffrey et al., 2022b; Kheyrandish et al., 2018).

One of the most effective approaches to solve this current challenge is UV disinfection, despite the fact that research on its effectiveness in degrading antibiotic resistance genes (ARGs) is still in its infancy. However, the method significant energy requirements make it necessarily expensive. Additionally, UV photolysis only would not effectively damage ARGs because DNA damage depends on UV fluence, which is often higher for causing DNA damage than cell structure, water matrix, and microbiological inactivation. In what are known as advanced oxidation procedures (AOPs), oxidants like hydrogen peroxide (H_2O_2) and chlorine (Cl_2) can be used to improve the process for actual wastewaters. Trihalomethanes (THMs), Haloacetic acids, and chlorate content in the treated wastewater considerably increased in all waste-water treatment plants (WWTPs) whether chlorine was used alone or in combination with UV. Disinfection By Products (DBPs) fully disappeared when the same chemicals were converted to per-acetic acid (PAA) or PAA/UV (Albolafio et al., 2022; Umar, 2022).

Table 2.0 shows the efficacy of the chemical disinfectants; hypochlorous acid, chloramine and chlorine dioxide used in water disinfection.

Table 1: Characteristics of mostly Applied Chemical Disinfectants and Oxidants

Residual Chlorine	Chloramines (HOCl and OCl¯)	Chlorine dioxide (ClO2) (mostly NH_2Cl)
Stable Residual?	Yes	Yes
Chemical byproducts brominated Formed: halogenated	Chlorinated, brominated Limited iodinated: trihalomethane haloaceticacid,haloacetonitriles	Less chlorinated, byproducts than chlorine
Efficacy for:		
Bacteria Excellent	Excellent	Good
Protozoa Good	Fair to poor	Poor
Viruses Excellent	Excellent	Fair

Source: (Bond et al., 2020)

Importance of Assessment of Water Quality

The pertinent goal for assessing water quality would probably fall under one of the categories mentioned below. One can choose the most pertinent objective for a program by using the table below, which presents a hierarchy of objectives.(*How to Design a Water Quality Testing Programme in Four Steps*, n.d.)

Table 2; shows the aims of water quality test.

Table 2: Objectives of Implementation of Water Quality Test

i.	Improve access to safe water services
ii.	Rehabilitate contaminated hand dug wells
iii.	Check the water quality for human consumption
iv.	Test every hand dug well

Source: (*How to Design a Water Quality Testing Programme in Four Steps*, n.d.)

Chlorine for Water Treatment

Drinking water quality can be increased and diarrheal disease decreased with the use of domestic water treatment and storage, which consist of filters and durables like chlorine. Despite the fact that HWTS products are healthy, demand is still low. According to estimates, 33% of families in nations without regular provision of safe water, treat their own potable water. However, utilization is minimal in rural areas, among lower income earners , and in locations with worse quality (Ritter et al., 2020). To maintain a sufficient amount of free chlorine over time without going beyond the limits for chlorine residual and disinfection byproducts, as outlined by (Ranieri & Świetlik, 2010). Chlorination is reported to have caused significant reduction in the number of infections linked to contaminated drinking water in industrialized countries, which had positive effects on social growth and welfare (Polo-López et al., 2019; Ritter et al., 2020).

Disinfection Reagents and Its End Product in Drinking Water Purification

Due to its low solubility in water, liquid chlorine cannot be used to sterilize water properly and also poses a risk to workers and causes pipe corrosion. Instead, chlorine gas is used. Due to minimal cost, simplicity of application, high efficacy, and ability to keep its efficacy in disinfecting water until it gets to the customer. When chlorine is introduced to water, some of it is consumed as a result of compounds that may be present in the water; the remaining chlorine is termed as residual chlorine (Hameed et al., 2018).

The following chemical reactions take place when chlorine is applied to water: (Collivignarelli et al., 2018; Khawaga et al., 2021)

$$Cl_2 + H_2O \rightleftharpoons HOCl + H^+ + Cl^- \quad \text{(i)}$$

$$HOCl \rightleftharpoons H^+ + OCl^- \quad \text{(ii)}$$

For pH values higher than pH 3.0, the total chlorine concentration is lower than 1,000 mg/liter; very little molecular chlorine (Cl_2) is present. The created hypochlorous acid (HOCl) further ionizes to create hypochlorite ion (OCl^-) and hydrogen ion (H^+) (Equation ii). The breakdown of hypochlorous acid is mostly reliant on pH and, to a much lesser extent, temperature, with almost 100% of the acid present at pH 5 and almost 100% of the hypochlorite ion present at pH 10.

Inorganic Chloramines Used for Potable Water Disinfection

Any ammonia (NH_3) in the water would react with chlorine during the chlorination process to create inorganic chloramines, which are used to disinfect water to give a combined available chlorine residue. Ammonia is occasionally purposefully added to chlorinated public water supplies. Additionally, organic amines and chlorine will react. It is termed "combined accessible chlorine" (Khawaga et al., 2021), which include the organic chloramines that are created. In comparison to hypochlorous acid and hypochlorite ion, inorganic chloramines are more stable, but they are less effective oxidizing and disinfecting agents. They consequently create a residue in water that last longer.

The reaction of amine with chlorine is illustrated below;

$$NH_3 + HOCl \rightleftharpoons NH_2Cl + H_2O \quad \text{(iii)}$$

$$NH_2Cl + HOCl \rightleftharpoons NHCl_2 + H_2O \quad \text{(iv)}$$

$$NHCl_2 + HOCl \rightleftharpoons NCl_3 + H_2O \quad \text{(v)}$$

$$2\,NH_2Cl + HOCl \rightleftharpoons N_2 + 3\,HCl + H_2O \quad \text{(vi)}$$

(Black, 1984; Collivignarelli et al., 2018; Khawaga et al., 2021; Pathiratne et al., 2008)

According to research done by Krishan and others (2023), "breakpoint chlorination and re-chlorination" results in a rise in chlorine demand with each subsequent application. In order to improve some of the standard control measures used by utilities, it becomes necessary to use fresh findings (Khawaga et al., 2021; Stefán et al., 2019).

Chlorine Demand

Chlorine may be added to surface and underground water to kill pathogenic discharges (Bond et al., 2020; Desye et al., 2021; Freese & Nozaic, 2004; Habashi, 2019; Hameed et al., 2018). The additional chlorine may form chlorine-produced oxidants (CPO) as a result of a reaction with water molecules. When free chlorine-containing substances (such as gaseous chlorine or hypochlorite) are added to water, the sum of all free and combined oxidative species is created. It has been used on municipal water systems since 1908 and is an efficient and cost-effective method of disinfection. Due to the toxicity of residual chlorine and the possibility for chlorinated effluents to produce damaging chlorine-produced oxidants, its adoption for cleaning untreated water has been regarded with skepticism (Collivignarelli et al., 2018; Freese & Nozaic, 2004). Hypochlorous acid (HOCl) and the hypochlorite ion (OCl^-), often known as free chlorine, are present in the solution when chlorine is introduced to fresh water (Bond et al., 2020; Khawaga et al., 2021). This will produce a variety of chloramines, sometimes known as combined chlorine, if ammonia is present. Total chlorine is made up of combined and residual chlorine. Hypobromous acid (HOBr), hypobromous ion (OBr^-), and bromo-amines are all disinfectants that are produced when bromide, which is abundant in ocean water, is added to water (Taterka et al., 2020). Either first-order or second-order kinetics are included in the majority of models described in the literature to depict chlorine degradation in bulk water. The overall first-order kinetic equation for the decrease in chlorine content of water was stated as; $C_t = C_o\, exp\,(-kt)$ (Warton et al., 2006).

C_o is the starting chlorine concentration, C_t is the chlorine concentration at time t, and k is the first-order decay constant. First-order models exclude other species that the chlorine is reacting with and instead depend only on the concentration of chlorine. Several models have employed first-order kinetics to represent chlorine degradation in bulk water, neglecting reactions with pipe wall materials and following the quick early reactions of chlorine with inorganic species (Belcaid et al., 2023; Lytle & Liggett, 2016; Wang et al., 2019), created a parallel first-order with two kinetic factors, one reflecting rapid decay and the other slower decay, both occurring at the same time, in a model that may be more accurate in describing the genuine chlorine demand. The model employs two distinct decay constants (k), and a coefficient, x, that shows the proportion of chlorine that reacts via each of the two mechanisms:

$C_t = C_o\,[x\, exp\,(-k_1 t) + (1-x)\, exp\,(-k_2 t)]$

Using a dosing experiment, immediate need was satisfied by dosing receiving water with three doses of chlorine at various slack tide stages and measuring the resulting concentration after ten seconds. The "immediate demand" was calculated as the difference between the dose (as determined by measurement in the control blank) and the resulting chlorine concentration.

For the data, an exponential fit was found. As a starting point for the second component of the model, the immediate demand model was utilized. The second component of the model determined the concentration at a given time based on the chorine demand and dilution. The Chlorine Produced Oxidants still present in the plume at each time (t) after discharges are found by repeatedly solving Equation (a). It should be noted that by multiplying the duration by the incoming water's velocity, the distance may be calculated.

$$C_t = \frac{C_{t-1} - X_{k\,t}}{D_t / D_{t-1}} \qquad \text{(a)}$$

C_t; Concentration of Chlorine product oxidant at specific time (t) C_{t-1}; Concentration of Chlorine product oxidant remaining in the treated water at time interval (t-1) ppm

D_t; Dilution at time (t)

D_{t-1} is the dilution at time (t-1)

D_t / D_{t-1} is the ratio of dilution used to account for dilution of the chlorine product oxidant at time t and t-1 respectively (Taterka et al., 2020). Traditional approaches to estimating chlorine demand (HOCl) due to dissolved organic matter (DOM) rely on bulk water quality measures and disregard structural characteristics of certain compounds that may better signal reactivity toward the disinfectant (Luilo & Cabaniss, 2010). Designing effective therapy requires an understanding of chlorination in the context of disruptive and difficult operation. limiting the input of ammonia to water system, provide backup systems to maintain adequate aeration, or using extra anti-bacterial techniques that do not raise chlorine demand can all help reduce the dangers of increased chlorine demand on microbiological safety, which do not depend on keeping residual chlorine (Ziemba et al., 2021). But most often limiting ammonia into water systems cannot be efficiently controlled because of the abundant nitrogen in the soil and atmosphere, hence the necessity to maintain residual chlorine content in the treated water for effective disinfection and protection of the distribution network from algae and bacteria contamination.

It was required to gather chlorinated water from the many sources supplying the network of distribution pipelines in order to estimate the kinetics of chlorine depletion without affecting the pollutant that had already formed on the internal surface of the pipelines. The water kinetics for each source were established in a lab in order to estimate the rate of reduction in chlorine in a climate-controlled system. The following factors may affect accurate measurements: Before sampling, the first three elements were taken into account: the operator, the technology, and the medium being tested: whether the water is from mains service? Some have experienced persistent degradation resulting in coming into contact with the distribution materials (Belcaid et al., 2023; Zhao et al., 2018).

Water Treatment Using Chlorine (Chemical Water Disinfection)

Traditionally, salt (NaCl) dissolved in water is electrolyzed to make chlorate, which is then reduced to produce chlorine dioxide. In addition to chlorine gas, bleaching powder, high test hypochlorite (HTH), pills, granules, and liquid bleach are all examples of substances that contain chlorine (Habashi, 2019). As a more effective disinfectant that does not produce the hazardous chlorinated organic compounds, chlorine dioxide has substituted chlorine in many products. The application of high purity chlorine dioxide and contact with humus soil components will not result in the production of trihalomethanes (THMs), and halo acetic acids (HAA) (Wang et al., 2018). Chlorine dioxide can be more efficient than chlorine at higher pH levels, giving water a better taste, fewer byproducts, and a better odor (Chlorite is the main by-product from use of chlorine dioxide) (Khawaga et al., 2021).The pathogens bacteria, viruses, fungi, algae, and protozoa can all be removed from water by adding chlorine dioxide. Laboratory experiments have demonstrated that chlorine dioxide concentrations of (0, 1) ppm, for 5-minute contact times are effective for inactivating microorganisms (Israr et al., 2017).

Potable water utilities with source rich in bromine (Br_2) or iodine (I_2), water treatment facilities, benefits from both chlorination and chloramination. In addition to effectively disinfecting surfaces and oxidizing iodine all the way to IO_3 to prevent the development of iodine disinfection byproduct (I-DBPs), chlorine can also oxidize bromine to HOBr / BrO^- (Zhu & Zhang, 2016). Another research shows that three mycobacterial species were easier to control with chlorine than with the other two disinfectants. Legionella pneumophila, serogroup 1 (Sg1) were successfully managed with chloramine. To fully know the impact on the identification and content of the five pathogens in drinking water, the disinfection type and total chlorine residual (TCR) was examined. The result indicated that three mycobacterial species were easier to control with chlorine than with the other two disinfectants (Donohue et al., 2019).

Since they are a more stable secondary disinfectant, chloramines are used as a measure of control to limit microbial development as part of a strategy to keep the water in drinking systems for distributing fountains clean (Feretti et al., 2020). Chlorine dioxide, free chlorine, and monochloramine were graded from most to least effective at inactivating N. europaea.

Monochloramine was substantially less effective than the other two. Monochloramine must not be added often during water treatment and ammonia oxidizing bacterium (AOB). Pathogens can be inactivated using powerful disinfectants like free chlorine and chlorine dioxide, however there is a risk of nitrification in the potable water supply system, when monochloramine was used for disinfection (Zhang et al., 2021). High chloramine content and pH can cause the formation of hydrazine, a chemical that poses a health risk. Through investigations on laboratory animals, hydrazine has been linked to both carcinogenic and mutagenesis effects, and it is categorized as a potential carcinogen limit of 10 ng/L in potable water, by (Najm & Guo, 2007). Research shows that hydrazine is the end product of the reaction of chloramine with ammonia, that synthesis is favored at elevated pH levels (Allard et al., 2020). Another research indicated that there were no records of genotoxic, cancer-causing, reproductive, or developmental impacts. Chloramine toxicological data is insufficient to suggest occupational exposure limits depending on health (OELs) (Wastensson & Eriksson, 2020). Therefore, the application of chlorine gas or chlorine dioxide in water treatment is the most efficient and safest method.

The Effect of Chlorine on Pathogens in Drinking Water

Effect of Chlorine on Legionella pneumophila

The best practices for decreasing bacterial contamination in water have not yet been identified for long-term success (Huo et al., 2021; Marchesi et al., 2016; McCuin et al., 2022). The chlorine residuals that were employed were comparable to quantities that could be found in the distribution networks of sizable public drinkable water sources. It was thought about how different pH levels, temperatures, and chlorine concentrations would affect the environment. Both environmental and clinical strains of Legionella were tested in great numbers. At pH of 7.2 in distribution systems, free chlorine is typically employed at low concentrations (0.2– 0.5 ppm) for disinfection to maintain water quality or at greater concentrations as a disinfection process known as hyperchlorination. The effectiveness of the chlorine disinfection, directly correlated with the relationship found on the various microorganisms in the water systems. Five strains of Legionella spp., two environmental isolates and three from culture collections, were subjected to two amounts of free chlorine normally present in drinking water. Both the concentrations of the microorganisms in the absence of chlorine and the free chlorine concentration were studied for the experimental times chosen, according to previous controls done on the water matrix. L. pneumophila sg. ATCC 33152 had the highest resistance levels at 0.2 ppm and 0.5 ppm. The inactivation of the two L. pneumophila sg. 1 strain at 0.2 ppm exposure as compared to the three other strains investigated. After 24 minutes of treatment, L. pneumophila sg.7 ATCC 33823, L. pneumophila sg.8, and L. long beach and ATCC 33462 all had a decreased cultivability, although L. pneumophila sg.1 strain experienced a roughly decreased reduction (Cervero-Aragó et al., 2015; Subbaram et al., 2017). Compared to less than one minute for Escherichia coli, a 99 percent kill of L. pneumophila was reached after 40 minutes. Water consumption patterns and water-saving fixtures may produce stagnation, which increases the risk of infection by L. pneumophila from biofilms (Huang et al., 2020; Martin et al., 2020).

Testing of free Chlorine

The DPD (diethyl-paraphenylene diamine) indicator test with a comparator is the most popular test. The quickest and simplest way to measure chlorine residual is with this test (Habashi, 2019). The amount of free chlorine (sometimes referred to as chlorine residual, free chlorine residual, and residual chlorine) in drinking water implies;

(i) Initially, enough chlorine was added to the water to render the bacteria and some viruses that cause diarrheal illness inactive.

(ii) During storage, the water is shielded from pollution again. Since the absence of the majority of disease-causing organisms is correlated with the presence of free chlorine in drinking water, this factor serves as a gauge for the water's potability (CDC, 2020a).

Most of the time, a customer's indicator of water safety is the aesthetic features of their tap water. Taste and odor (T&O) in particular are powerful predictors of tap water quality among those variables. Customers may reject tap water that has an odd flavor or smell and turn to alternative sources of water, which may be more expensive or riskier than the tap water they initially rejected.

The disinfection method utilized in most water treatment facilities is usually what gives chlorine off-flavor. Despite the fact that chlorine off-flavor has been identified as a factor in people rejecting tap water, the water is safe and protected from contamination by pathogen (Doria et al., 2009). Many nations have rules about how much free residual chlorine should be kept in the water that consumers consume (Pestana et al., 2019). Actually, the taste of chlorine is considered an indicator of high-quality water by the legislation.

Various values, ranging from 0.20 to 0.65 mg/L, are suggested in literature as the threshold for free chlorine perception (Piriou et al., 2015). Standard for Ecuador (0.3 mg/L) for residual chlorine in drinking water distribution network (DWDN) (García-Ávila et al., 2021). In Australia, the National Standard stipulates that the water scheme's chlorine levels must not exceed 5 mg/L, which is in line with the WHO's suggested guideline limits (WHO). All ages, including infants over six months and the elderly can safely drink the public water supply (Martino, 2019). On the basis of the WHO infrastructure recommendation (0.2–0.5 mg/L Free Chlorine Residue), passive chlorination had the lowest percentage of households serviced with an appropriate chlorine residual (Lindmark et al., 2022). The recommended level of residual chlorine under Peruvian laws is 0.5 mg/L. Although bacterial regrowth has been noted at the recommended Free Residual Chlorine (FRC) levels within this range, the recommended FRC concentrations of 0.2–0.5 mg/L are still suggested to safeguard the water against regrowth and recontamination during storage and usage. Drinking water greater than 0.2 mg/L of free chlorine was recommended at Haiti. According to Mexican drinking water laws, FRC ranges between 0.2 to 1.5 mg/L. In India (recommended FRC level is 2.0 mg/L). The Brazilian law's recommended free chlorine concentration (0.5 mg/L) which is higher than the FRC of 0.3 mg/L for urban areas in Colombia (Nielsen et al., 2022).

Testing for free chlorine is advised in two situations by the Safe Water System (SWS) Program;

i) Before a water distribution begins, dose testing should be done in study locations.

Dosage testing's objective is to ascertain the amount of chlorine (sodium hypochlorite solution) added to drinking water in order to maintain the presence of free chlorine during the typical duration of water storage in a household.

ii) To test water that has been held in homes in order to monitor and evaluate the quality for compliance with chlorination.

While a residual free chlorine level of 0.5 mg/L will be sufficient to preserve water quality throughout the distribution network, it is most likely insufficient to do so when water is kept in a bucket or jerry can within a home for a full 24 hours.

For dose testing, it has been suggested that; (CDC, 2020b; Felix et al., 2022)

(a) There shouldn't be more than 2.0 mg/L of free chlorine present at 30 minutes after adding sodium hypochlorite (this ensures the water does not have an unpleasant taste or odor).

(b) A minimum of 0.2 mg/L of free chlorine should be present 24 hours after adding sodium hypochlorite to water storage containers used by households (this ensures microbiologically safe water). Chlorination's purpose is to supply the water source with the necessary amount of chlorine. Any chlorine that is present in excess of what is required to satisfy the demand after it has been met remains as a residual after the need has been met (CDC, 2020a; Habashi, 2019).

In underdeveloped nations, there are three primary techniques for determining the presence of free chlorine in drinking water:

i) Pool test kits

ii) Color-wheel test kits

iii) Digital colorimeters

All three techniques rely on a color change to indicate the presence of chlorine and a measurement of the intensity of that color to quantify the amount of chlorine.

Pool Test Kits

This method of testing makes use of a liquid chemical called OTO (orthotolidine), which becomes yellow in the presence of total chlorine. About, 1-5 drops of the solution should be added to a tube of water; watch for a change in color. A technique for determining the overall chlorine content of swimming pool water, measures chloramines and free chlorine content in the pool water (CDC, 2020a; Murray & Lantagne, 2015; Suppes et al., 2023).

Color-Wheel Test Kits

Chemical DPD (N,N diethyl-p-phenylenediamine), as a powder or tablet turns pink when chlorine is present in the water. To visually correlate the color to a free or total chlorine reading, the field worker employs a color wheel. The test kit has a range of 0 to 3.5 mg/L, or 0 to 3.5 ppm, for measuring total and/or free chlorine using various chemicals in the kit (parts per million) (CDC, 2020a).

Digital colorimeters

The most precise method for measuring free chlorine and/or total chlorine residual in the field is with digital colorimeters in underdeveloped nations. These colorimeters operate in the following way:

i) Mixing DPD tablets or powder into a vial of test water until the color turns pink;

ii) Inserting the vial into a device that emits a wavelength of light to measure the intensity of the color shift, then automatically calculates and digitally displays the color intensity (the free and/or total chlorine residual). The meter's range is 0 to 4 mg/L, which is equivalent to 0 to 4 ppm (parts per million) (CDC, 2020a).

iii) When the N, N-diethyl-para-phenylenediamine (DPD) reagent and water samples were combined in this experiment, the free chlorine in the water sample oxidized the DPD amine and created two oxidation products. The main oxidation product at pH values close to neutral was a semi-quinoid cationic substance known as a Wurster dye (magenta colored).

iv) The pink hue observed in the DPD colorimetric test could be attributed to this free radical species' relative stability. Higher oxidant concentrations favored the development of the unstable colorless imine, which caused the colored solution to appear "faded" over time (George et al., 2022).

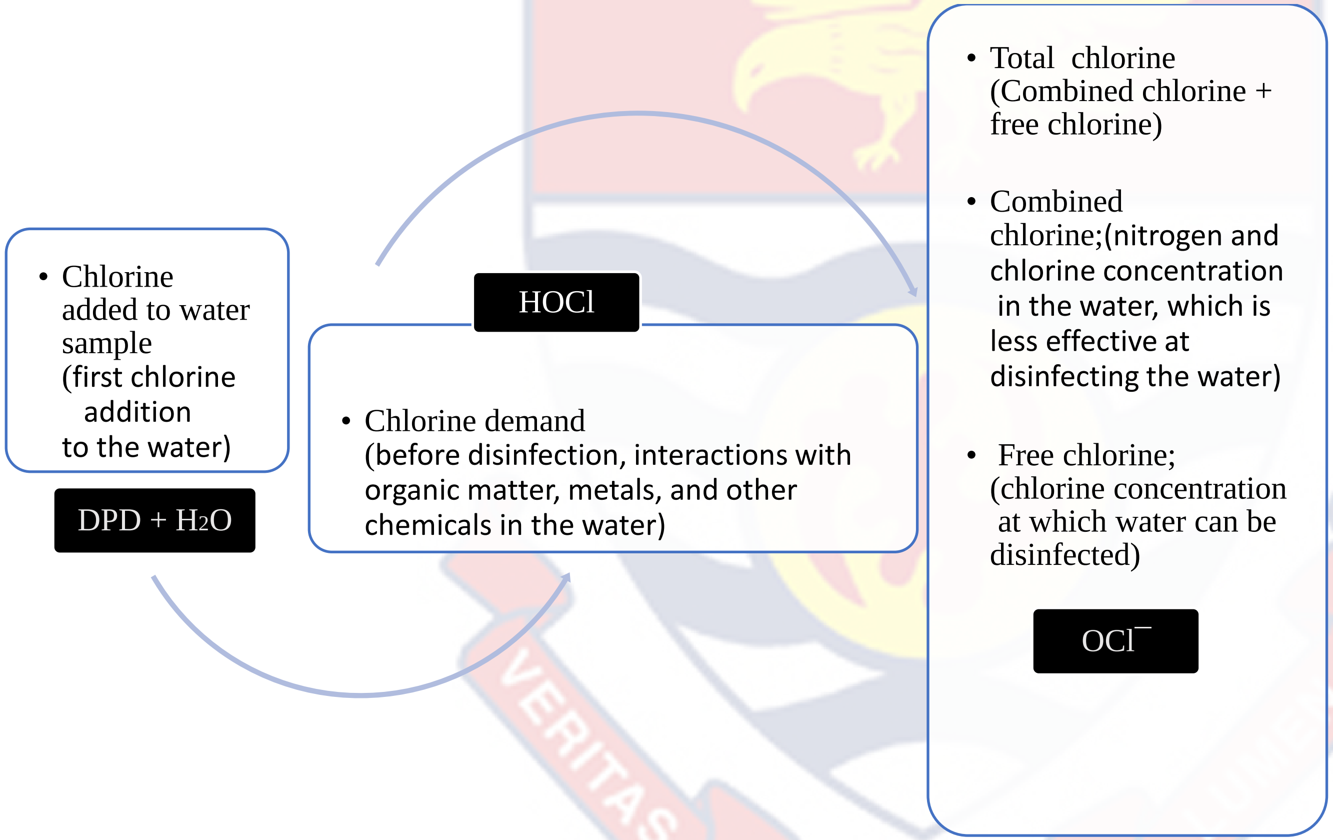

Figure 1: Chlorine Disinfection in Water Flow Chart (CDC, 2020a)

Water Treatment using Chlorine

Use of chlorine is not advised:

i) when the availability of chlorine compounds on a consistent basis is uncertain.

ii) where chlorine might interact with other chemicals in the water to produce unfavorable or hazardous byproducts.

iii) in an effort to eradicate viruses or cysts.

iv) when meticulous monitoring cannot be performed (Habashi, 2019).

Physicochemical Parameters that Influence Chlorine Disinfection in Water Treatment

pH (power of Hydrogen)

In assessing how corrosive water is, pH is crucial. The more acidic the pH, the more corrosive the water is. Electrical conductivity and total alkalinity had a positive correlation with pH. An increased pH values indicate that changes in physicochemical conditions are more likely to disrupt the balance of carbon dioxide, carbonate, and bicarbonate (Patil et al., 2015). This metric shows how the water's acids and alkalis are balanced. The pH values should be between 5 and 8. Any water treatment facility that wants to operate at peak efficiency and keep track of changes in water quality must monitor pH, extreme pH values might be a sign of unintentional spills, treatment failure, or improperly cured cement pipelines (Israr et al., 2017).

Chemical Oxygen Demand (COD)

Another indicator of organic material contamination in water is COD, which is expressed in mg/L. It is needed for the chemical oxidation of the organic material in water, and it measures the amount of dissolved oxygen needed (Patil et al., 2015). A lower COD level shows that there is less oxidizable organic matter in the sample, which will also result in lower amounts of dissolved oxygen (DO) (Dhungana, 2019).

Dissolved Oxygen (DO)

DO provide information on the quantity of free or non-compound oxygen contained in water. Aquatic animals and microorganisms deplete DO through chemical oxidation and respiration, particularly during the breakdown of plant biomass and other organic materials. DO is derived from the atmosphere and are produced by aquatic plants during photosynthesis. Higher temperatures, salt, and other environmental factors reduce the amount of oxygen that dissolves in water, which might fluctuate daily and seasonally (Dhungana, 2019).

Chlorination at Breakpoint

Breakpoint chlorination, which is the process of varying the chlorine to ammonia molar ratio (Cl/N), causes changes in the total chlorine residual and chlorine species (Stefán et al., 2019). When wastewater effluent and reclaimed water are chlorinated, breakpoint chlorination occurs when the ammonia nitrogen content is roughly 0.5-1 mg/L and the chlorine dosage is roughly 1-10 mg/L. In the breakpoint chlorination process, some intriguing oxidation reactions have been noticed, such as the oxidation of ammonia and the generation of disinfection byproducts (DBPs). The chloramines concentration reaches its highest under circumneutral conditions and at Cl/N 1.0; (the breakpoint), at Cl/N 1.5 to 1.7 ammonia is oxidized to nitrogen and nitrate, and the total chlorine residual reaches its minimum (Devi & Dalai, 2021). It destroys a common micro-pollutant that is resistant to chlorine in an amazing way, Since the pH had an impact on the formation and decomposition rates of chloramines, the elimination rate is maximum at pH 7.0 and lower in acidic and basic solutions (pH 5.5 and pH 9.5, respectively) (Khawaga et al., 2021; Wang et al., 2018).

A study on some drinking water treatment facilities that used breakpoint chlorination had their by-products of chlorination studied. Haloacetic acids, haloacetonitriles, and trihalomethanes were found in order of increasing concentration (14.7 g/L to 143 g/L) (Stefán et al., 2019). Since the source water from deep aquifers contains a disproportionately high amount of ammonium ions, it is essential to both cleanse the water and simultaneously remove the ammonium ions to stop the production of nitrite. The breakpoint chlorination method, which produces more organic and inorganic byproducts than disinfection because it requires around ten times as much chlorine, is employed for these objectives. As reported in the literature, breakpoint chlorination speeds up the breakdown of chloramines at greater chlorine to ammonia ratios as a result of auto-decomposition and redox processes (Devi & Dalai, 2021; Stefán et al., 2019).

Because chloramine is more stable and produces fewer disinfection byproducts (DBPs) than chlorine, it has become a popular option in many industrialized nations, including the USA, Australia, and several European nations. Due to its lower reactivity with organic matter, iodide, and bromide in the water, trihalomethanes (THMs) and haloacetic acids (HAAs) are formed less frequently. In the water distribution system (WDS), chloramine is employed as a secondary disinfectant. Nitrification, however, is a significant issue with the chlor-amination since it speeds up the degradation of chloramines (Karthik et al., 2020). Given the foregoing, it may be concluded that breakpoint chlorination may be a different method of removing ammonia from drinking water (*Removal of Ammonia from River Water Using Breakpoint Chlorination*, 2020).

Quantity of Chlorine needed for water treatment

Depending on the use, different amounts of chlorine are required to treat water. From 1.0 to 4.0 mg/L is considered a typical range for disinfection of drinking water (CDC, 2020b). As a general guideline, combine non-scented National Science Foundation (NSF) approved household bleach (5.25 percent chlorine) in the reservoir to shock chlorinate and disinfect a storage tank (Connell, 2019). The most affordable chlorine source is chlorine gas, which is often used in concentrations of 1 to 16 mg/L to treat water (Moreira & Bondelind, 2017). Commonly, final treated waters get chlorine doses in the range of 0.2-2.0 mg/L of free chlorine, resulting in a residual of approximately 0.02-0.3 mg/L at the consumer's tap (Wu & Dorea, 2020).

A typical chlorine decay curve (FCR versus time) comprises two phases: the quick decay phase often occurs within the first 30 minutes of chlorine dosing, and the gradual decay phase follows (Wu & Dorea, 2020).

Utilizing Principal Component Analysis, comparison of the chlorine content in potable water at various sites and waterway

Using a statistical method called principal component analysis (PCA), one can examine correlations between sets of samples with various variables, such as different sample sites concentration results for each sample, to see if sample profiles are similar to one another (Metcalf & Casey, 2016; Saba & Boehm, 2011). In eleven sample sites, a field sampling effort was carried out where possible source areas were sampled. The purpose of the source sampling was to identify the chlorine content in the distribution lines on all the sites that have a conduit to the canal that contain Chlorinated water. It should be noted that for site characterization purposes during earlier investigations, twenty samples were taken from all locations. A total of 220 tap water samples from various pipe stand were gathered for this study. A subset of three samples representing source samples each was chosen for the current study from the data and tested for chlorine content using Anderson, Bowman and Kennedy-Parker method (Anderson et al., n.d.).

These samples were representative of source water samples from the various distribution pipelines. Presented in this research are the findings from these samples. PCA was used to examine the association between the chlorine content and the results. In several researches, the PCA-based correlation matrix has been used to investigate the similarity in sample from different places due to sampling being done at different locations of distinct environmental parameters.

PCA has benefits and drawbacks. The benefits include: (a) because all variables are theoretically equally important, hence there is no response variable; (b) It lessens the number of variables that need to be further considered. Principal components have the following drawbacks: (a) they are more difficult to interpret than the original variables than new variables; (b) PCA is an exploratory analysis that involves personal interpretation, though interpreting the variables in the factorial space follows certain guidelines; (c) the quantity of components to be preserved must be carefully chosen to avoid excluding crucial (information found in the original variables is relevant for a particular aim; (d) Categorical variables cannot be included in classical PCA;

only numerical covariates may be used, no categorical covariates. One can find references there as well as comprehensive descriptions of the PCA technique (Bossew et al., n.d.).

Chapter Summary

The sources of water for human consumption were reviewed. In addition, various researches works on water treatment methods were also considered in this chapter. Moreover, attention was focused on chlorine reagents used in water disinfection; the approach for testing residual chlorine level was also highlighted. Literature on some statistical methods that would be used for data processing in this study was also considered.

Breakpoint chlorination, residual chlorine levels in water worldwide was reviewed. The quantity of chlorine applied for effective disinfection of potable water was highlighted. Physicochemical parameters; such as dissolved oxygen, pH, and chemical oxygen demand for ascertaining water quality was reviewed at the later part of this chapter.

Disinfection byproduct resulting from application of chlorine reagent for water disinfection was also reviewed. The concluding paragraph covered statistical analysis used for the residual chlorine level source at the study area.

CHAPTER THREE

METHODOLOGY

Introduction

In this chapter, demography of the study areas was looked at, the major water source supplied to the populace of Cape Coast Metropolis was also considered. It further posits the approach utilized to measure the residual chlorine level in water, the instruments applied and the reagents used were also highlighted.

The Ghana Water Company Limited's (GWCL) Brimsu treatment plant, serves as the principal source of tap water supply to the indigenes. The headworks, feeds other communities in the region, it is a surface water impoundment (the Kakum River) with a 4 million gallons (18,000 m^3) per daily capability of treatment facility. In line with the GWCL, only 60% of the inhabitants of the Cape Coast Metropolis receive daily water from the Headworks, somewhat more than the country's average of 54.5% for city dwellers. Majority of less privileged populace, who can neither afford either sachet or bottled water, directly drink the tap water treated by GWCL without further purification. As a result, the WHO stresses: "the appearance, taste, and odor of drinking-water should be acceptable to the consumer" (Obeng et al., 2010).

In line with the discourse on tap water quality, this chapter highlights the procedure used to ascertain whether the tap water provided by GWCL meet the minimal standards for safety and acceptability as per the WHO recommendations, for residual chlorine level in tap water at the end-user pipe-stand.

The map of Cape Coast Metropolis was shown at Figure 2. It captures most of the localities studied. The eleven localities studied were; Abura, Amamoma, Akotokyere, Brafoyaw, Duakor, Elmina, Kotokoraba, Kwaprow, Pedu, UCC, UCC Lect.

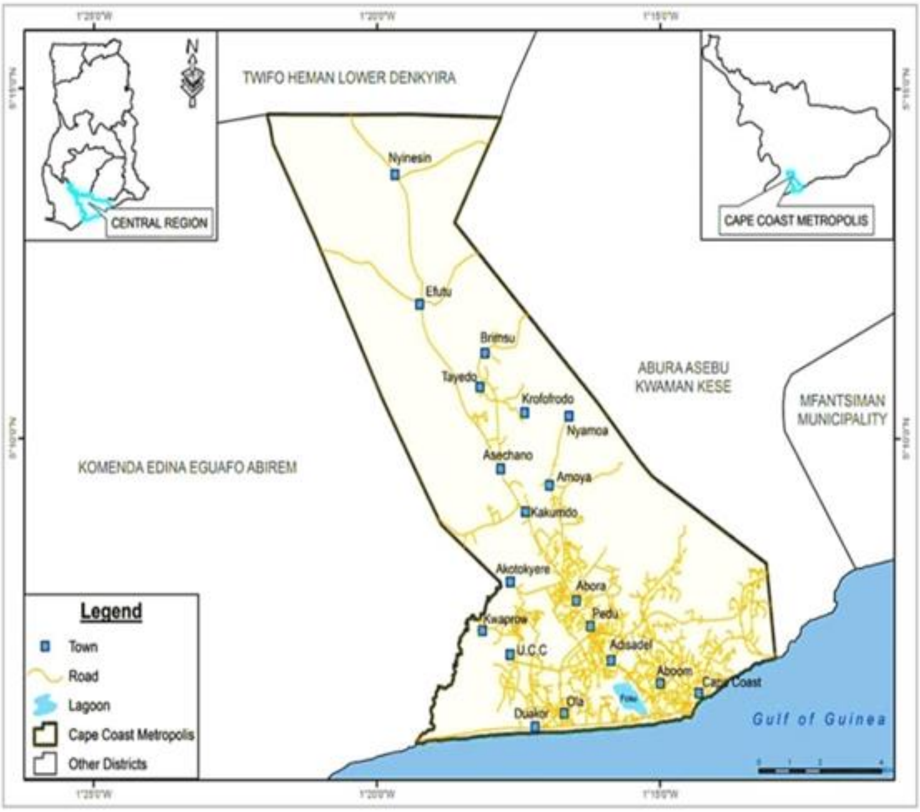

Figure 2: Map of Cape Coast Metropolis showing Study Area (Source: Department of Geography and Regional Planning, University of Cape Coast, Ghana, 2017).

Sample Collection

Tap water samples were taken from eleven (Abura, Akotokyir, Amamoma, Brafoyaw, Duakor, Elmina, Kwaprow, Kotokoraba, Pedu, UCC, UCC Lect Village) selected communities located at Cape Coast Metropolis, situated at the Central region of the Republic of Ghana. A total of 220 composite tap water samples were collected, made up of 20 samples each from the eleven different communities in Central region on the 14th December 2022

– 24th January 2023. At each site three composite tap water samples were collected with a 500-milliliter polyethylene bottles. Each bottle was rinsed several times with portion of the tap water to be sampled, before fetching the samples to the brim directly from the tap. The samples were labelled with unique site identification code and placed in a box. It was immediately transported to the Laboratory (Desye et al., 2021).

Sample Preparation and Absorbance Measurement

From each of 500 mL tap water sample, 10 mL tap water sample was measured using 10 mL measuring cylinder into a polyethylene container, one sachet of milwaukee MI 526 – 100 Free chlorine reagents: N, N-diethyl-para-phenylenediamine (DPD) was added to it. The sample was agitated for 3 minutes; it was poured into the glass cuvette. Triplicate analysis was done, and the absorbance for each sample taken at a wavelength range of 500-550 nm using T 70 UV-Vis Spectrometer, pH of the samples was measured using JENWAY 3510 at a temperature of 28.0 °C within 24 hours' period. This procedure was repeated twice. In all 220 tap water samples were analyzed.

Chlorine Decay Study

Tap water samples (six bottles) were collected directly from the tap at UCC using a 500-milliliter polyethylene bottles. Each bottle was rinsed several times with portion of the tap water to be sampled, before fetching the samples to the brim directly and transported to the laboratory for analysis. Residual chlorine content of the tap water samples was measured at the first day of sampling, using Colorimetric method. One sachet of milwaukee MI 526 – 100 free chlorine reagents: N, N-diethyl-para-phenylenediamine (DPD) was added to it. The sample was agitated for 3 minutes; it was poured into the glass cuvette. Triplicate analysis was done, and the absorbance for each sample taken at a wavelength range of 500-550 nm using T 70 UV-Vis Spectrometer. Three out of the six bottles were kept outdoor and exposed to sunlight, one bottle out of the three outdoor samples was left uncovered while the remaining two were covered. The remaining three bottles were kept indoors, one bottle out of the three was covered while other two bottles were left uncovered. Daily measurement of absorbance for residual chlorine level in the samples continued for eight days.

Principal Component Analysis (PCA)

In this work, principal component of ambient and surface biophysical characteristic that affected the water samples from the various locations was employed. The first and second PCs of the ambient and surface biophysical elements impacting chlorinated water samples are represented by PC 1 and PC 2 in relation to sites with most similar and less similar chlorine concentration respectively (Mijani et al., 2020; Saba & Boehm, 2011)

A calibration curve used for extrapolating the levels of residual chlorine was shown in Figure 3.

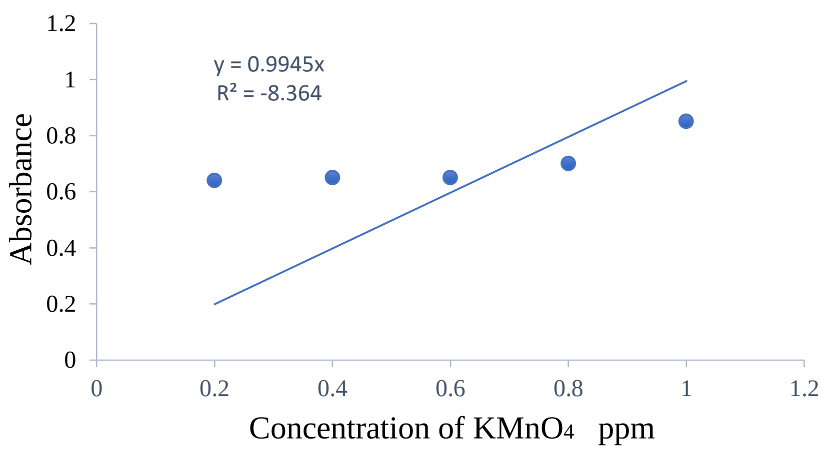

Figure 3: Calibration Curve for KMnO4 Standardization

Chapter Summary

At the introductory part of chapter three, the demography of Cape Coast metropolis was reviewed. The sampling collection approach used was also highlighted; further elaboration on sample preparation, and absorbance measurement was covered.

The analytical method utilized for sample analysis, (ie: spectrometric method) was highlighted. Residual chlorine (RC) decay study was captured; moreover, the calibration curve for extrapolating the RC levels from the obtained absorbance was covered.

Statistical analysis (principal component analysis) applied was reviewed at concluding paragraph.

CHAPTER FOUR

RESULTS AND DISCUSSION

Introduction

This chapter provides inference and empirical evidence to support the research findings. It also highlights the precautionary measures taken to ensure the integrity, and significance of the results.

Quality Control/Assurance

Taps sampled were wiped with alcohol to prevent any bacteria contamination. Amber Bottles used for sampling were washed with diluted nitric acid, thereafter, rinsed with portion of the tap water before filled to the brim and capped. The spectrometer used for sample analysis was calibrated, and blank samples were also runed. After, the prepared samples were analyzed in triplicate measurement and averaged.

Analysis of variance (ANOVA) is a statistical technique that is frequently used to compare the means of more than two parameters while taking one variable into account separately (ud Din & Hayat, 2021). The One-way ANOVA findings (at 95%) were used to determine whether there were any differences that were statistically significant between the measured tap water parameter in the eleven communities. The mean values of the RC measured at the various sampling locations inside the Cape Coast Metropolis were compared to determine whether there were statistically significant differences.

Chlorine Profile in the Study Areas

The results of the analyses of the free chlorine (RC) content in potable water samples collected from distribution pipelines to various communities at the Cape Coast Metropolis are shown in Table 4. The Table is made up of results from sampling eleven (11) Communities. A sum of 220 tap water samples was analyzed. The concentration (mean) of RC content in tap water at the end-user ranged from 0.201 to 0.317 ppm.

The standard error values of the means ranged (from 0.001 to 0.003) were quite small, indicating how far the measured values varied from the actual population mean. Additionally, it suggests that there was very little variation between the measured and true values of the RC, which is consistent with a normal distribution.

According to (Demir, 2022; Hatem et al., 2022), acceptable values for skewness and kurtosis, range between -2 and +2 and -7 to +7 respectively, are needed to demonstrate a normal univariate distribution. For the purpose of this study, demonstrating a normal univariate distribution, values for skewness and kurtosis were between -0.961 and +0.198, and -1.388 to +1.591, respectively, are deemed acceptable. Hence this data is normally distributed.

The mean±CV of the residual chlorine in mg/L were Amamoma: 0.317±1.208 > Kotokoraba: 0.301±1.240 > Akotokyir and Kwaprow: 0.300±0.754 and 0.300±0.801 respectively > UCC: 0.299±1.290 > Elmina: 0.293±4.051 > UCCL: 0.213±1.368 > Brafoyaw: 0.203±2.332 > Duakor: 0.202±1.765 > Abura: 0.201±2.336 and Pedu: 0.199±1.833. The highest residual chlorine content was found at Amamoma, and the lowest at Pedu. There was variation in the residual chlorine levels over the period, as revealed by coefficient of variation (CV%) which ranged from 4.051 as highest and 0.754 as least. However, the variations were minimal, as shown on (Table 3). This variation could be due to decay of residual chlorine through interaction with the biofilm, the material composition of the pipeline and organic matter in the pipeline. These have been observed to contribute significantly to chlorine decay. (Nono et al., 2019).

Table 3: Free Chlorine Concentration in Tap Water at Cape Coast Metropolis

Chlorine concentration /ppm													
Sample ID	Abu	Ped	Dua	Elm	Kwa	Ako	Kot	Ucc	Ama	Bra	Ucc L	Mean	Stdev
S1	0.192	0.195	0.207	0.269	0.300	0.300	0.300	0.296	0.321	0.197	0.210	0.253	0.050
S2	0.195	0.197	0.204	0.271	0.301	0.301	0.297	0.294	0.318	0.200	0.211	0.254	0.049
S3	0.192	0.196	0.205	0.273	0.298	0.297	0.296	0.298	0.317	0.196	0.208	0.253	0.049
S4	0.202	0.194	0.203	0.280	0.303	0.301	0.307	0.302	0.322	0.203	0.212	0.257	0.051
S5	0.197	0.198	0.207	0.299	0.299	0.297	0.296	0.297	0.314	0.206	0.213	0.257	0.048
S6	0.203	0.195	0.208	0.301	0.303	0.299	0.304	0.300	0.319	0.201	0.215	0.259	0.050
S7	0.206	0.192	0.198	0.283	0.301	0.297	0.297	0.298	0.322	0.205	0.215	0.256	0.049
S8	0.198	0.198	0.200	0.300	0.298	0.301	0.303	0.295	0.316	0.207	0.213	0.257	0.050
S9	0.195	0.194	0.202	0.304	0.303	0.302	0.307	0.300	0.308	0.194	0.208	0.256	0.053
S10	0.201	0.200	0.204	0.275	0.299	0.300	0.298	0.302	0.311	0.196	0.212	0.254	0.048
S11	0.204	0.198	0.202	0.302	0.296	0.302	0.302	0.296	0.320	0.207	0.212	0.258	0.050
S12	0.202	0.201	0.197	0.303	0.301	0.298	0.306	0.304	0.314	0.210	0.214	0.259	0.050
S13	0.198	0.203	0.198	0.293	0.298	0.296	0.296	0.300	0.318	0.205	0.213	0.256	0.049
S14	0.203	0.200	0.200	0.302	0.299	0.304	0.301	0.302	0.312	0.203	0.207	0.257	0.050
S15	0.206	0.203	0.201	0.304	0.296	0.301	0.302	0.306	0.317	0.197	0.210	0.258	0.050
S16	0.206	0.203	0.197	0.297	0.302	0.297	0.298	0.293	0.319	0.204	0.213	0.257	0.049
S17	0.205	0.204	0.204	0.300	0.296	0.299	0.304	0.304	0.320	0.207	0.217	0.260	0.049
S18	0.202	0.197	0.208	0.299	0.303	0.303	0.306	0.297	0.323	0.202	0.218	0.260	0.050
S19	0.205	0.202	0.206	0.298	0.301	0.297	0.304	0.294	0.317	0.207	0.215	0.259	0.048
S20	0.208	0.205	0.198	0.296	0.297	0.299	0.299	0.292	0.313	0.211	0.217	0.258	0.046

Mean	0.201	0.199	0.202	0.293	0.300	0.300	0.301	0.299	0.317	0.203	0.213	0.257	0.049
Stdev	0.005	0.004	0.004	0.012	0.002	0.002	0.004	0.004	0.004	0.005	0.003	0.004	0.003
CV%	2.336	1.833	1.765	4.051	0.801	0.754	1.240	1.290	1.208	2.332	1.368	1.725	0.893
Sm	0.001	0.001	0.001	0.003	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Min	0.192	0.192	0.197	0.269	0.296	0.296	0.296	0.292	0.308	0.194	0.207	0.249	0.049
Max	0.208	0.205	0.208	0.304	0.303	0.304	0.307	0.306	0.323	0.211	0.218	0.263	0.049
Kurtosis	-0.699	-0.977	-1.269	-0.727	-1.328	-0.881	-1.388	-0.993	-0.189	-0.841	-0.529	-0.347	1.591
Skewness	-0.596	0.005	-0.017	-0.961	0.014	0.198	0.119	0.182	-0.555	-0.287	-0.285	-0.647	-0.037

(Source: Field Data; Ohene-kwayisi, 2023)

The level of RC in the potable water studied were within the acceptable levels recommended by WHO (0.2- 0.5 ppm) (Bishankha et al., 2013). Cross contamination through distribution pipelines may be the explanation for the lower amount of free chlorine in tap water at the end-user pipe stand (Al-Mansori et al., 2020; Desye et al., 2021). In the event that cast iron pipelines is used, according to a study by (Zhao et al., 2011; Zhong et al., 2017), regardless of the water's pH and oxygen content. Iron ions (Fe^{2+}) consume a large amount of the free chlorine in the form of hypochlorous acid (HOCl) (Belcaid et al., 2023).

The RC concentration in potable water from the distribution pipelines at the various sampling sites ranged from 0.19 to 0.32 ppm, which conform to the permissible residual chlorine limit in drinking water slated by Center for Disease Control (CDC) and Safe Water Systems(SWS) and world health organization (WHO) (Allard et al., 2020; Connell, 2019; Devianti & Yulianti, 2018). This means that, tap water consumed in Cape Coast Metropolis have RC level far below the permissible limit, might contain microorganisms like; bacteria, fungi etc. that would be detrimental to the consumer's health.

Trends in Free Chlorine Concentration

Generally, the RC concentration in potable water was found to be most prevalent at Amamoma = 0.317 ppm, and Pedu = 0.199 ppm had the least. Within the communities the trend of the residual chlorine distribution was Amamoma > Kotokoraba > Akotokyir and Kwaprow > UCC > Elmina > UCCL > Brafoyaw > Duakor > Abura > Pedu.

Figures 4, shows the trend of RC concentration in tap water samples from the selected communities at Cape Coast Metropolis. There were two set of closely related RC levels (Fig 5 and 6). The levels of RC for the set with lower RC ranged from 0.199±1.833 to 0.213± 1.368 ppm, for Pedu, Abura, Duakor, Brafoyaw and UCC Lect., and 0.293±4.051 to 0.317±1.208 ppm, for Elmina, UCC, Kotokoraba, Kwaprow,Amamoma and Akotokyir. which illustrates samples with distinct residual chlorine content at the various sampling dates.

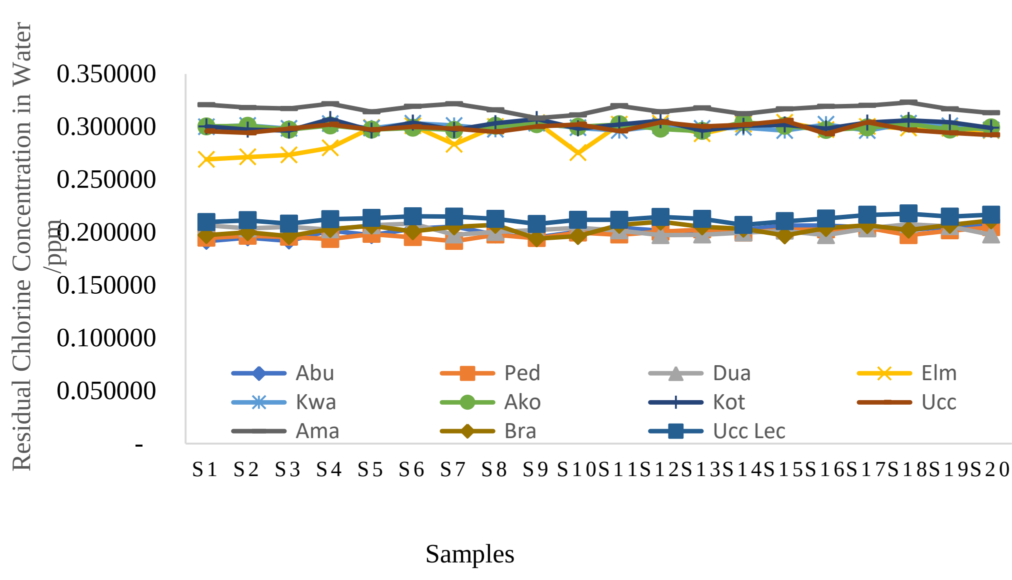

Figure 4: Trend of Variation of Residual Chlorine Concentration in Water Samples at Study Site

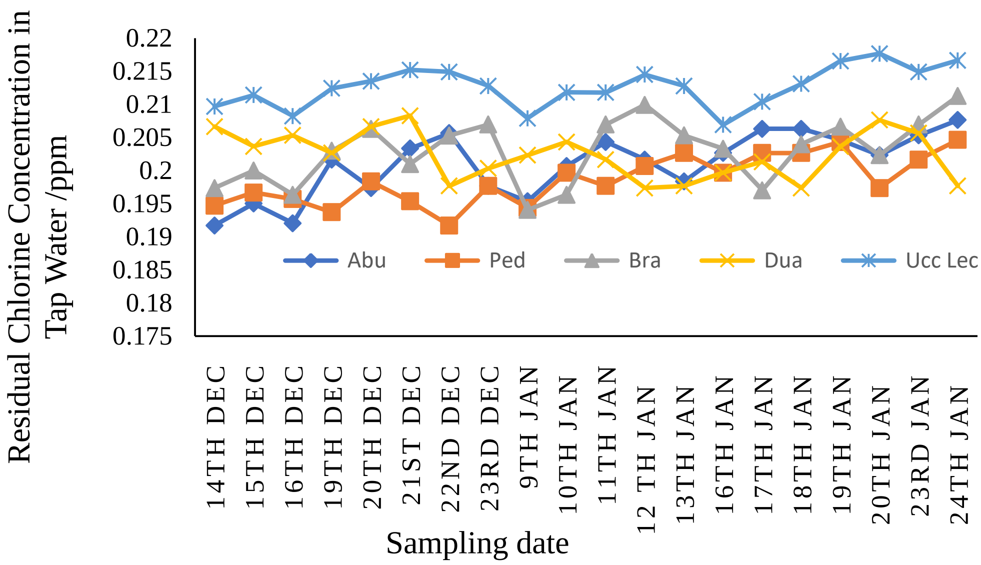

Figure 5: Trend of Variation of Residual Chlorine Concentration in Tap Water at Abu, Pedu, Brafoyaw and UCC Lecture Village

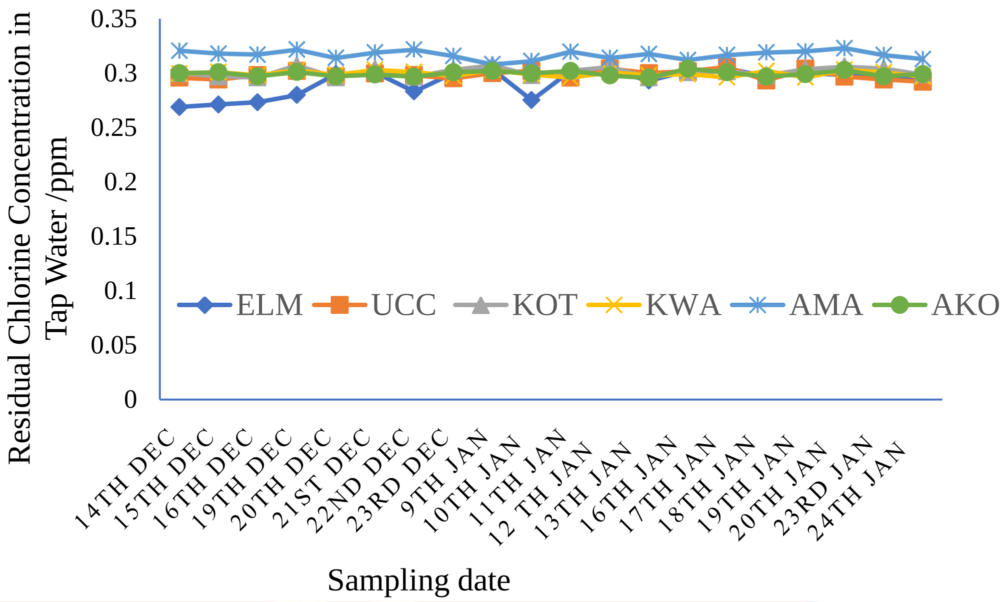

Figure 6: Trend of Variation of Residual Chlorine Concentration in Tap Water at Elmina, UCC, Kotokoraba, Kwaprow,Amamoma and Akotokyir

The Figure 7, shows bar chart for the eleven communities that had similar residual chlorine levels. On the chart; Abura, Pedu, Duakor and Brafoyaw showed similar levels. UCC Lect., showed distinct residual chlorine level from the initially stated communities. Elmina, Kwaprow, Akotokyir, Kotokoraba and UCC also showed some level of similarity. Hence one-way anova was performed on the residual chlorine levels to identify the communities that might show much similarity. The anova results is showed

Tables 4,5 and 6.

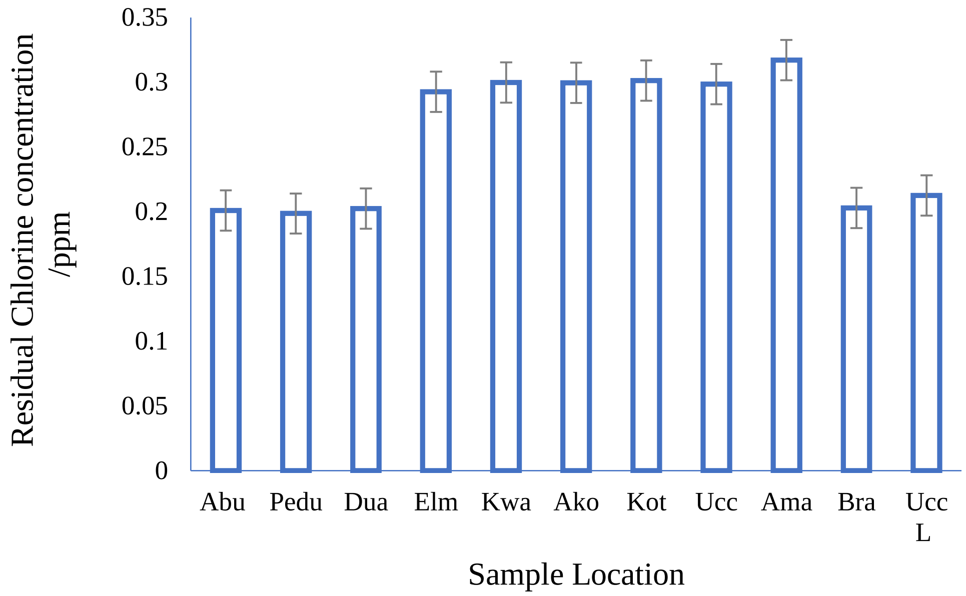

Figure 7: Residual Chlorine Concentration in Tap Water at Cape Coast Metropolis

Anova Analysis for Variation in Residual Chlorine Levels

Table 4: Anova Single Factor Result for Residual Chlorine Concentration in Tap Water at Cape Coast Metropolis

SUMMARY

Groups	Count	Sum	Average	Variance
Abu	20	4.020	0.201	2.321 E-05
Ped	20	4.020	0.201	2.321 E-05
Dua	20	4.047	0.202	1.342 E-05
Elm	20	5.851	0.293	14.785 E-05
Kwa	20	5.994	0.300	6.072 E-06
Ako	20	5.991	0.300	5.376 E-06
Kot	20	6.024	0.301	1.468 E-05
Ucc	20	5.971	0.299	1.560 E-05
Ama	20	6.340	0.317	1.545 E-05
Bra	20	4.060	0.203	2.360 E-05
Ucc Lec	20	4.253	0.213	8.911 E-06

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.526	10	0.053	1946.976	0.000	1.876
Within Groups	0.006	209	2.703 E-05			
Total	0.53					

(Source: Field Data; Ohene-kwayisi, 2023)

Table 5: Summary Results for Residual Chlorine Concentration in Tap Water from Abura, Pedu and Duakor, Brafoyaw, UCC Lect Village

SUMMARY						
Groups	Count	Sum	Average	Variance		
Abu	20	4.019	0.201	2.321 E-05		
Ped	20	3.972	0.198	1.395 E-05		
Dua	20	4.047	0.202	1.342 E-05		
Bra	20	4.060	0.203	2.360 E-05		
Ucc Lec	20	4.253	0.213	8.911 E-06		
Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.002	4	5.777 E-04	34.765	0.00	2.467
Within Groups	0.001	95	1.662 E-05			
Total	0.004	99				

(Source: Field Data; Ohene-kwayisi, 2023)

Table 6: Summary Results for Residual Chlorine Concentration in Tap Water at Elmima, Kwaprow, Akotokyir, Kotokoraba, UCC, Amamoma

SUMMARY						
Groups	Count	Sum	Average	Variance		
Elm	20	5.851	0.293	1.478 E-04		
Kwa	20	5.994	0.300	6.072 E-06		
Ako	20	5.991	0.300	5.376 E-06		
Kot	20	6.024	0.301	1.468 E-05		
Ucc	20	5.971	0.299	1.560 E-05		
Ama	20	6.340	0.317	1.545 E-05		
Source of Variation	SS	df	MS	F	P-value	Fcrit
Between Groups	0.007	5.000	0.001	39.316	0.000	2.294
Within Groups	0.004	114.000	0.000			
Total	0.011	119.000				

(Source: Field Data; Ohene-kwayisi, 2023)

When describing a continuous response in terms of a single factor made up of two or more levels, the phrases Single Factor Analysis of Variance, Single Factor ANOVA, One Way Analysis of Variance, (One Way ANOVA) is used (Hayes, 2020).

There is statistically significant difference in the mean values if the P-value, which measures significance, is less than or equal to α (0.05 level). For this study, One-way ANOVA revealed that there was statistically significance difference in RC levels from the communities ($p = 0.00 < \alpha = 0.05$) and ($F_{crit} = 1.876 < F_{statistic} = 1946.976$) as shown on Table 4; ($p = 0.000 < \alpha = 0.05$) and ($F_{crit} = 2.467 < F_{statistic} = 34.765$) as shown on Table 5; ($p = 0.000 < \alpha = 0.05$) and ($F_{crit} = 2.294 < F_{statistic} = 39.316$) as shown on Table 6 (Desye et al., 2021; Jurgens et al., 2019; Wenning et al., 2023). At 95 % confidence level, the residual chlorine (RC) levels in the tap water that flows through the pipelines had no appreciable influence on the material composition of the pipelines. Even though the water is from the same source, it had varying effects of RC in the water. (Abura ≠ Pedu≠ Duakor ≠ Elmina ≠ Kwaprow ≠ Akotokyir ≠ Kotokoraba ≠ UCC≠ Amamoma ≠ Brafoyaw ≠ UCC as shown on Tables 4,5 and 6.

Residual chlorine measured in the 220 water samples collected from 11 communities in the Cape Coast metropolis, indicated that while the city's water supply is of good quality, the quality could be harmed by the water supply's aging distribution system. From the results, it was noted that the residual chlorine (RC) levels were all lower than they should have been, using Anova: single factor (Gallo et al., 2023). Regular operating procedure, prior to being detected in the district hydraulic portion of the distribution network, might be useful to display the drinking water quality, in particular the chlorine concentration, during periods of high and low demand. Due to the high chlorine consumption by the ferrous ions (Fe^{2+}), which results in substantial susceptibility among consumers, it was suggested that a low content of free chlorine in the cast iron pipes was based on the experimental results. In the case of cast iron pipes, according to a study by (Zhao et al., 2011; Zhong et al.,2017) and regardless of the water's pH and oxygen content. Iron ions (Fe^{2+}) consume a large amount of the free chlorine in the form of hypochlorous acid (HOCI) (Belcaid et al., 2023).

Information on how closely the RC levels is related to one another is provided by linear correlation (r or R) of RC from two sites. In order to show how closely two linked variables are related to one another, linear correlation analysis is a useful tool for investigating the association between those variables by conducting a correlation analysis. With the requirement that the variables under examination have a normal distribution, interval or ratio variable should be taken into account as it measures the degree of linear correlation of variables, for extremely significant correlation $-0.70 \geq R > -1.00$, $+0.70 \leq R < +1.00$; remarkably significant high correlation $-0.50 \geq R > -0.70$, $+0.50 \leq R < +0.70$; medium or fair Correlation $-0.35 \geq R > -0.50$, $+0.35 \leq R < +0.50$; weak correlation: $-0.20 > R > -0.35$, $+0.20 < R < +0.35$; Very Low or Negligible Correlation: $-0.20 \geq R \leq +0.20$, for negative and positive correlation respectively. Not at all correlated $R= 0$, (Senthilnathan, 2019). The RC in tap water samples from two different locations were compared to show how the RC content were related to one another in terms of the RC content in the water sample.

Table 7: Correlation of Residual Chlorine Concentration at Cape Coast Metropolis

	Abu	Ped	Dua	Elm	Kwa	Ako	Kot	Ucc	Ama	Bra	Ucc L
Abu	1.00										
Ped	1.00	1.00									
Dua	-0.38	-0.38	1.00								
Elm	0.54	0.54	-0.23	1.00							
Kwa	-0.10	-0.10	0.22	-0.12	1.00						
Ako	-0.04	-0.04	0.18	0.14	0.05	1.00					
Kot	0.19	0.19	0.18	0.45	0.37	0.50	1.00				
Ucc	0.08	0.08	-0.03	0.18	-0.10	0.14	0.31	1.00			
Ama	0.15	0.15	0.20	-0.25	0.15	-0.12	0.03	-0.15	1.00		
Bra	0.52	0.52	-0.44	0.43	-0.25	-0.28	0.03	-0.25	0.15	1.00	
Ucc L	0.55	0.55	0.03	0.25	0.08	-0.34	0.16	-0.19	0.42	0.64	1.00

(Source: Field Data; Ohene-kwayisi, 2023)

Regression and correlation (Table 7) analysis indicated an extremely strong positive linear correlation between RC content in water samples from Abura and Pedu: ($r = 1.00$; $p < 0.05$) and within samples from different sites at each community. Brafoyaw and UCCL showed a high positive correlation R= 0.64, Abura and Pedu with UCCL also showed a medium positive linear correlation of R = 0.55. Followed by Abura and Pedu with Elmina with R = 0.54. Both Abura and Pedu correlated positively with Brafoyaw samples; R = 0.52. Akotokyir and Kotokoraba, R = 0.50. The complex correlation value that results when two localities had exactly the same level is non-zero, whereas samples with different level were near to zero or zero (Geitner et al., 2019).

The correlation coefficient (R^2) is a metric used to assess how significantly two variables are related. Most often, the linear correlation coefficient is employed to examine the strength of the relationship between two variables, the degree of multicollinearity, and the presence of mediating or moderating factors. The R^2 tells us how accurate the explained value of the dependent variable is in relation to the independent variable. Or, how much of the variation in the dependent variable can be accounted for by the variation in the dependent variable (Senthilnathan, 2019).

By comparing the concentration value of one locality against the other, the coefficient of determination R^2 can be used to determine how similar any two localities content are. When the R^2 number is 1.0, the localities are a perfect match, and when it is 0.0, there is no link between them. The degree of similarity between two localities in this instance was evaluated according to the following criteria: R^2 for a fingerprint match was 0.9 or higher R^2 ranges from 0.8 to 0.89 for very comparable fingerprints. The R^2 for similar fingerprints ranges from 0.7 to 0.79. If R^2 is 0.6 to 0.69 for a hazy association, then R^2 is zero (0) for distinct fingerprints. Whether, the sample profiles are normalized or not has no effect on the R^2 value between the two samples (Saba & Boehm, 2011).

In general, the prevalence of residual chlorine in tap water was found in the order: Amamoma, Kotokoraba,> Akotokyir and Kwaprow > UCC > Elmina > UCCL > Brafoyaw > Duakor > Abura and Pedu. Regression analysis indicated an extremely strong positive linear correlation between Abura and Pedu with a Coefficient of Determination $R^2 = 1.00$ (CI = 95%), and within samples from different sites at each community. This signify a fingerprint match, R^2 higher than 0.9, as shown on Table 8, these observations suggest that there might be a common distribution pipeline that supply tap water to Abura and Pedu localities and each locality might have one pipeline that distribute the tap water to different sites within the locality. Since the $R^2 = 0$

for the following Locations: Abura with Akotokyir, Pedu with Akotokyir, Kwaprow with Akotokyir, Kotokoraba with Amamoma, Kotokoraba with Brafoyaw and Duakor with UCCL, it suggests that there is no significant relationship between the RC concentration in tap water from these areas. Hence distinct pipelines might distribute tap water to these areas since R^2 is zero (0) for distinct fingerprints (Saba & Boehm, 2011).

Table 8: Correlation Coefficient (R^2) of Residual Chlorine concentration at Cape Coast Metropolis

	Abu	Ped	Dua	Elm	Kwa	Ako	Kot	Ucc	Ama	Bra	Ucc L
Abu	1.00										
Ped	1.00	1.00									
Dua	0.14	0.14	1.00								
Elm	0.29	0.29	0.05	1.00							
Kwa	0.01	0.01	0.05	0.01	1.00						
Ako	0.00	0.00	0.03	0.02	0.00	1.00					
Kot	0.04	0.04	0.03	0.20	0.13	0.25	1.00				
Ucc	0.01	0.01	0.00	0.03	0.01	0.02	0.10	1.00			
Ama	0.02	0.02	0.04	0.06	0.02	0.01	0.00	0.02	1.00		
Bra	0.27	0.27	0.19	0.18	0.06	0.08	0.00	0.06	0.02	1.00	
Ucc L	0.30	0.30	0.00	0.06	0.01	0.11	0.03	0.04	0.18	0.41	1.00

(Source: Field Data; Ohene-kwayisi, 2023)

Cluster Analysis

A hierarchical cluster analysis was done on the RC concentration between the localities, and also between the various sampling sites with Ward's method and their concentrations measured for similarity. Localities having strong correlation formed cluster. Figure 8; shows dendrogram for cluster analysis, similarity test conducted on free chlorine in potable water samples from various sample locations. In all, two main groups of clusters were obtained for the localities at ten (10 %) similarity, consisting of (Abura, Elmina, Pedu, Brafoyaw and UCC Lec) as first group and (Duakor, Kwaprow, Amamoma, Akotokyir, Kotokoraba and UCC) as the second group.

There were three groups of clusters at 20% similarity, consisted of (Abura, Elmina, Pedu, Brafoyaw and UCC Lec) as first group, (Duakor, Kwaprow, Amamoma) as the second group and (Akotokyir, Kotokoraba and UCC) as the third group. For 40% similarity, there were six groups, consisted of (Abura, Elmina, Pedu, Brafoyaw and UCC Lec) as first group, Duakor as second group, Kwaprow as third group, Amamoma as fourth group, (Akotokyir and Kotokoraba) as fifth group and UCC as sixth group. For 50% similarity, three cluster were obtained: Abura, Elmina, Pedu; Akotokyir & Kotokoraba, and Brafoyaw & UCC. All the others were distinct. (Figure 8) Samples that showed above 50% similarity includes Akotokyir and Kotokoraba, formed a group at 52%. Abura and Elmina showed 58% similarity, Surprisingly Brafoyaw and UCC L samples had similar levels of 65%. No sample had similarity level found at 70 %. This indicated that in all locality's similarity the concentration of free chlorine content in the potable water, were distinct and dissimilar as illustrated by figure 8.

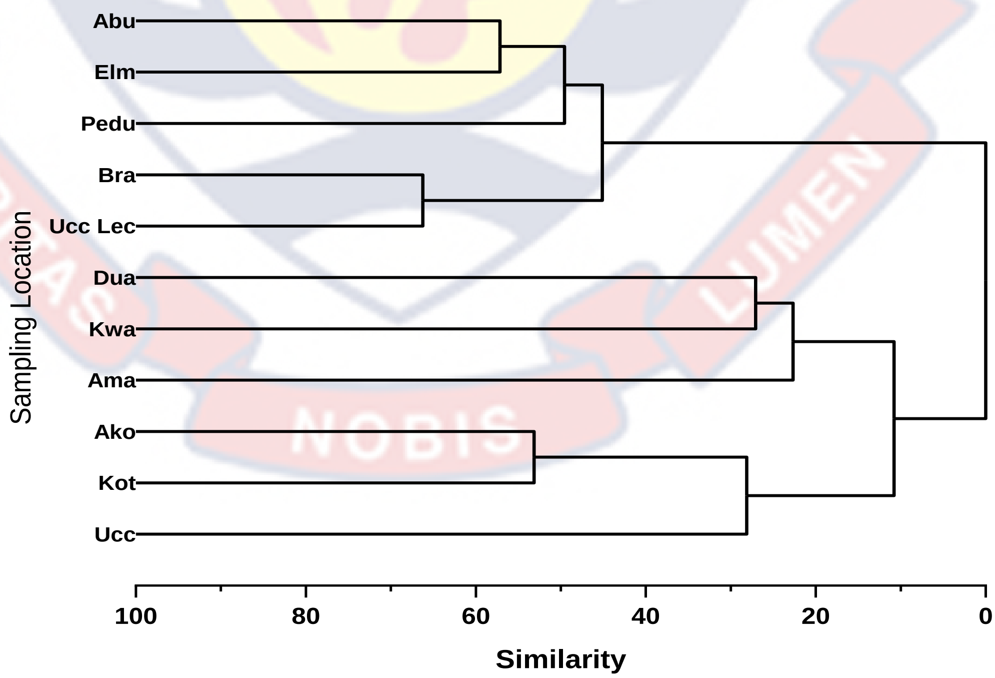

Figure 8: Dendrogram for Similarity Test for Residual Chlorine Content in Tap Water at Cape Coast Metropolis

The samples across the localities on different days, over the period of study showed a higher level of similarity of RC content in the tap water. Sample points one and two (S1 and S2) showed about 92% similarity, followed by sample six, eight, eleven, and eighteen (S8 & S11) and (S6 & S18) at 90% similarity. Samples (S13 & S17) and (S16:S20) also had similarity level of 88%. For samples below 85% similarity, S14 and S15 were the only samples. In all there were three groups of cluster samples with similar RC conentration as shown by figure 9. The clustered samples which show similar residual chlorine distribution might have had similar interaction in the distribution pipelines, that supply tap water to these sampling point within the locality.

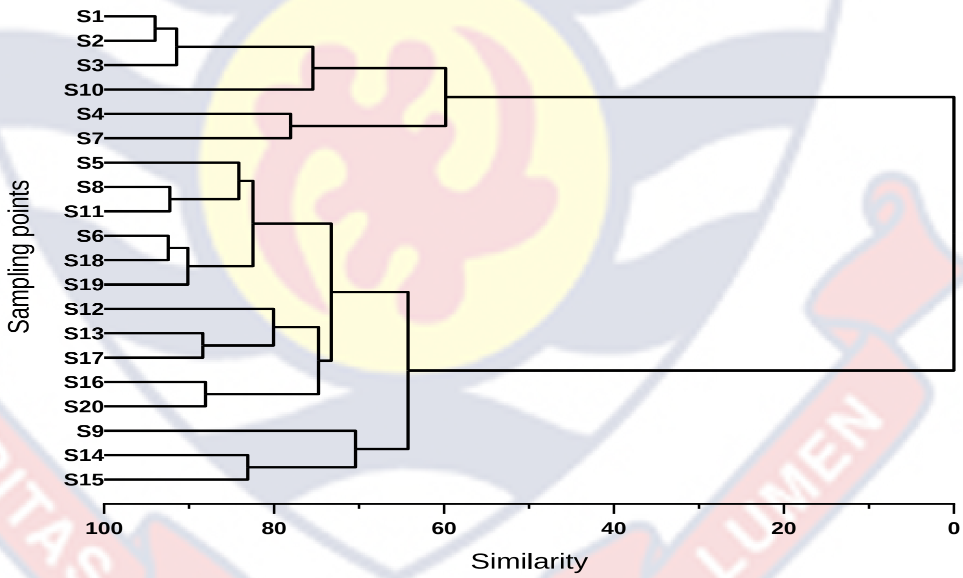

Figure 9: Dendrogram for Similarity Test for Residual Chlorine Content in Tap Water at Sampling point

The Figure 10, shows overall results of free chlorine (RC) concentration in potable water samples sampled at sites S1-S20. In general, the bar chart shows the levels of RC for all the samples at each site for all the eleven locations

(Abura, Pedu, Duakor, Elmina, Kwaprow, Akotokyir, UCC, Amamoma, Brafoyaw and UCC Lec).

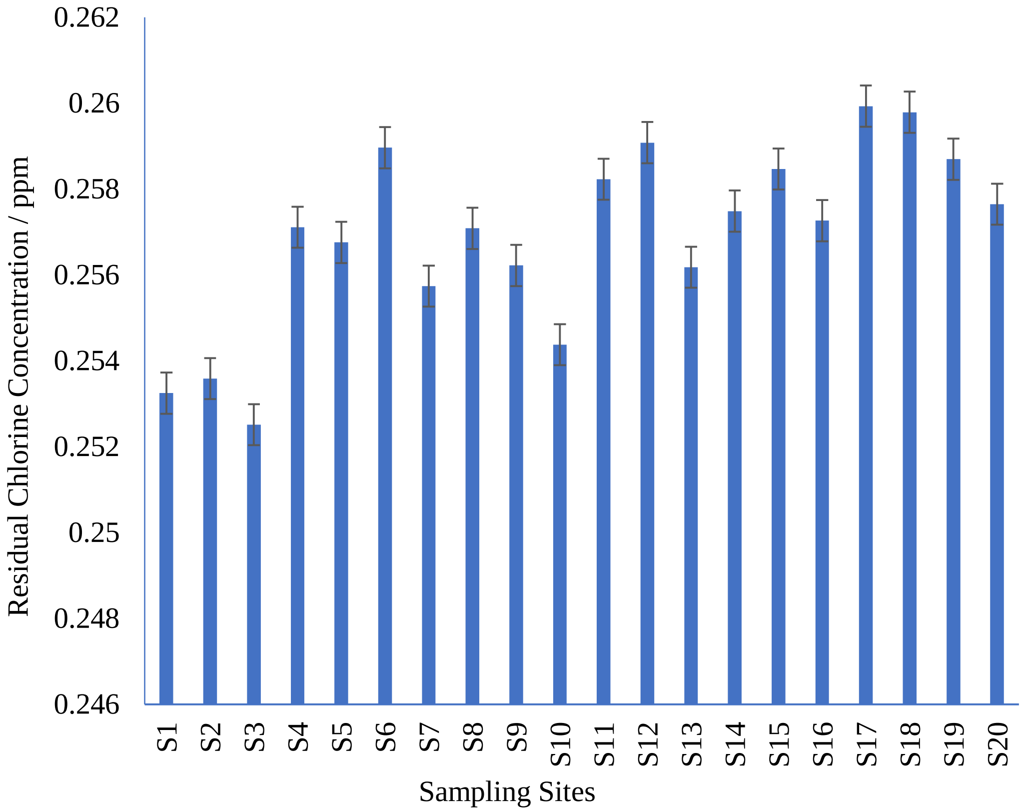

Figure 10: Residual Chorine Concentration in Tap Water at Sampling sites

The level of free chlorine concentration in the samples at the individual sites was found to be S17= 0.259932 >S18 = 0.259791 > S12= 0.259081 > S6 = 0.258965 > S15= 0.258468 > S11= 0.258231 > S20= 0.257649 > S14= 0.257487 > S16 = 0.257267 > S4= 0.257113 > S8= 0.257086 > S5= 0.256760 > S9 = 0.256222 > S13= 0.256181 > S7= 0.255741 > S10 = 0.254377 > S2= 0.253586 > S10 = 0.254377 > S2= 0.253586 >S1= 0.253249 > S3= 0.252513 S17 had the highest with the lowest being S3, as shown on the chart. This means for the overall samples, site 17 had much of free chlorine relative to all the other sites with the least RC at S3.The amount of free chlorine detected in tap water sources was found to be in the acceptable range recommended by

World Health Organization (0.2–0.5 mg/L) (Abuzerr et al., 2020; Desye et al., 2021; Khadse et al., 2016).

Coefficient of Determination (R^2)

The coefficient of determination R^2, for the various sample locations were determined by regression of residual chlorine in tap water from one location to the other. It was evident that one sample location (Abura) when graphed against the second (Pedu) sample had an R^2 value of 0.9995, which indicates a strong positive correlation between the tap water samples from these locations as shown in Figure 11. When the R^2 number is 1.0 for compared profiles, this indicates that profiles are a perfect match, and when it is 0.0, there is no link between the compared profiles. The degree of similarity between two sample profiles in this instance was evaluated according to the following criteria: R^2 of 0.9 or more indicates a fingerprinting match. If R^2 ranges from 0.8 to 0.89 for very comparable fingerprints. The R^2 is 0.7 to 0.79 for similar fingerprints. The R^2 for a hazy association is between 0.6 and 0.69. The R^2 is less than 0 for fingerprints that are clearly distinct (Saba & Boehm, 2011).

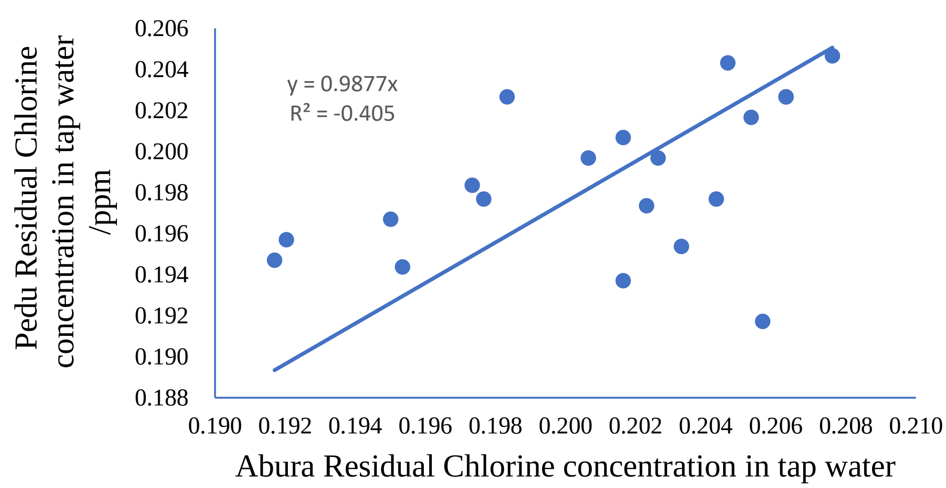

Figure 11: Correlation of Residual Chlorine Content for Abura and Pedu Tap Water Samples

Principal Component Analysis

By examining relationships between Residual Chlorine (RC) in tap water samples from various communities, the residual chlorine concentration in samples for each community was analyzed by Principal component analysis (PCA). Principal component analysis is a statistical technique that may be used to check if sample profiles are similar to one another. A graph with the residual chlorine samples plotted on the horizontal and vertical axes shows the results in PCA. The graphed output of PCA is a scores plot. Which shows the RC concentration profile, each sample is assigned a distinct position in the PCA scores plot (Ben Salem & Ben Abdelaziz, 2021; Fatima et al., 2022; Islam Khan et al., 2022; Jankowska et al., 2017; Krishan et al., 2023; Saba & Boehm, 2011).

The biplot shows both Principal Component (PC) scores of samples (similarities between samples), and loadings of Communities (vectors) on the normalized data. The vector shows the influence or strength of residual chlorine in the samples at each community (Achour et al., 2022; Firat et al., 2023). It also describes the primary variance orthogonally to the principal components and gives scoring plots (eigen values) on the horizontal and vertical axes. Each PC has a single dimension, with a value of zero at its midpoint. The direction that a particular variable in the PC is moving in on a single dimension vector as indicated by the sign (positive or negative). Smaller values of the residual chlorine (RC) play a relatively minor impact in explaining the variation caused by the PC, whereas bigger values play a much larger part in doing so. No variation on the PC is accounted for by the community with score of 0 (Torres-Bejarano et al., 2023)

The principal components Analysis of Residual Chlorine (RC) observed in 2D and 3D for the tap water samples studied are shown (Figure 12,13 and 14) respectively. The PCA community loadings plot provides a clearer explanation of why the samples are similar to one another. The primary principal component (PC1, depicted on the horizontal axis) of the scores plot, captured the majority of the variability (35.57 percent of the variability) present, 18.57 percent of the variability in PC 2, as shown by Figures 12. A 15.06 percent of the variability in PC 3 was identified, illustrated by Figure 13. If the score values of samples taken from two different locations match up, then the residual chlorine concentration profiles of these two locations are identical. The separations between samples (shown by red points) reveal their similarity. Distances among samples reflect their similarities; the closer the samples point the more similar their RC profile. The angles between the communities reflect their correlation.

Communities' relationships with one another are also shown in loading plots (angles between community vectors). The cosine of the angle formed by the corresponding vectors and the estimated correlation of two communities is related. Perpendicular vectors (angle 90°) show a lack of correlation between the residual chlorine concentration in tap water from communities they represent, while small angles less than 90° (those pointing in the same direction) indicate positive correlation between communities. Large angles closer to 180° (with arrows or vectors pointing in the opposite directions) suggest negative correlation.

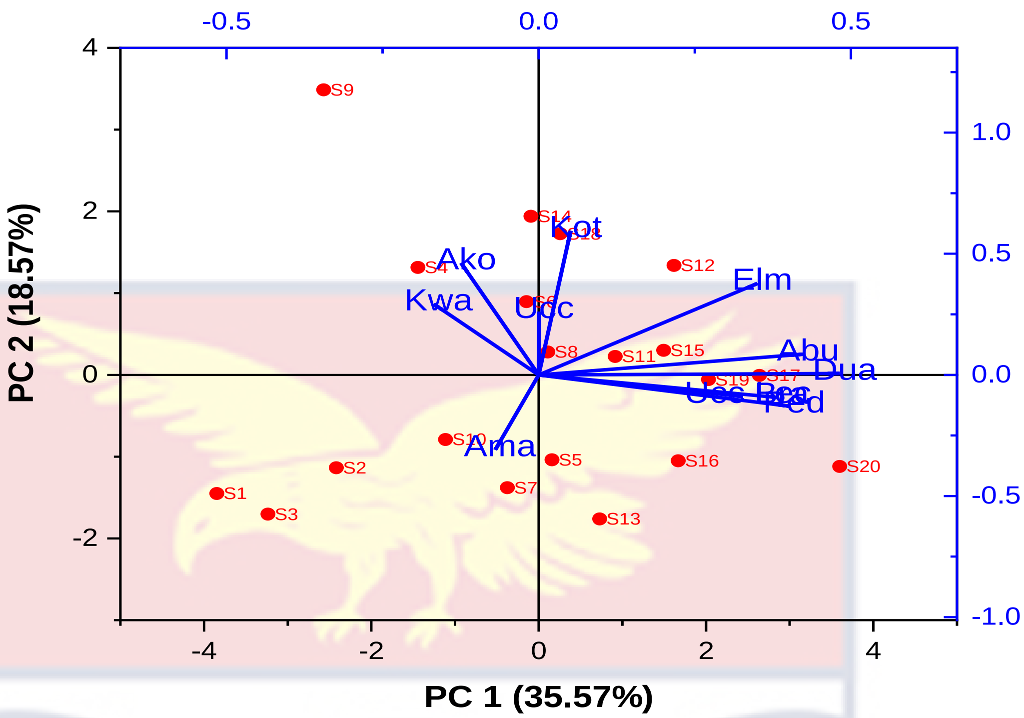

Figure 12: Biplot of Principal Component Analysis (PC1:PC2) of Residual Chlorine Concentration in Tap Water Samples collected from Cape Coast Metropolis

In general, Akotokyir and Kwaprow had similar RC concentration, and were positively correlated in PC1. Elmina and Abura had similar RC, were positively correlated in PC1 and PC2. Brafoyaw, Abura and Pedu samples were similar, and positively correlated, showed much influence in PC2. UCC and Duakor had distinct samples from all the other communities, were negatively correlated. UCC had no influence in PC 1, likewise, Duakor in PC 2. Amamoma showed distinct negative correlation, with much influence in PC1. Kotokoraba, Amamoma had much influence in PC1, but were negatively correlated.

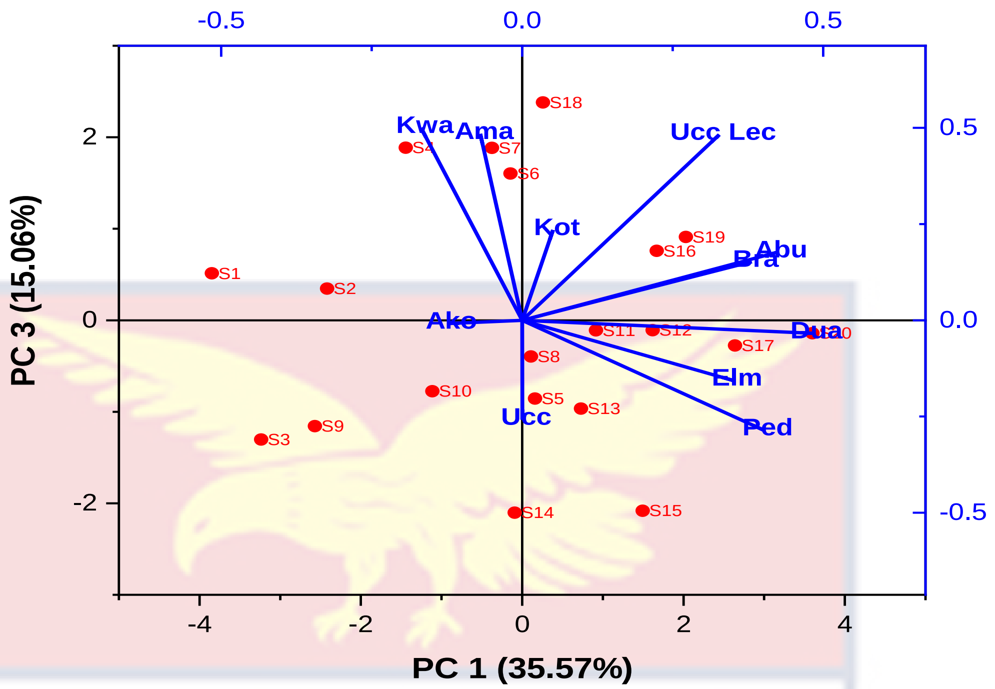

Figure 13: Biplot of Principal component analysis (PC1:PC3) of Residual Chlorine concentration in tap water samples collected from Cape Coast Metropolis

In Figure 13, Kwaprow and Amamoma had much influence in PC1, with strong positive correlation. Akotokyir, showed no influence in PC 3; likewise, UCC in PC1. Kotokoraba, showed strong positive influence than UCC Lec in PC1. Abura and Brafoyaw showed extremely strong influence in PC3, with a positive correlation. Duakor, showed exceptional influence in PC 3, followed by Elmina and Pedu respectively.

Generally, the score plot show that samples; S1, S2, S3 are separated and distant from samples; S16, S20. This implies they belong to different clusters whiles, those that are closer have relatively higher similarity and belong to the same cluster. S1, S2, S3: S8, S11: S6, S18, S19 are similar.

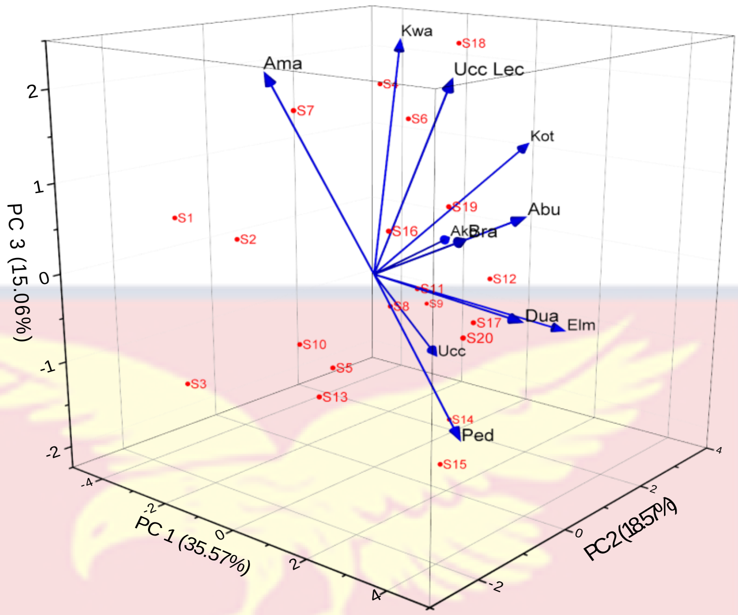

Figure 14: Three dimension score plot of Principal component analysis (PC1:PC2:PC3) of Residual Chlorine Concentration in Tap Water Samples collected from Cape Coast Metropolis

Figure 14, shows the three dimension (3D) score plot and loadings of the Principal Components Analysis of residual chlorine (RC) content in tap water samples for the eleven communities studied.

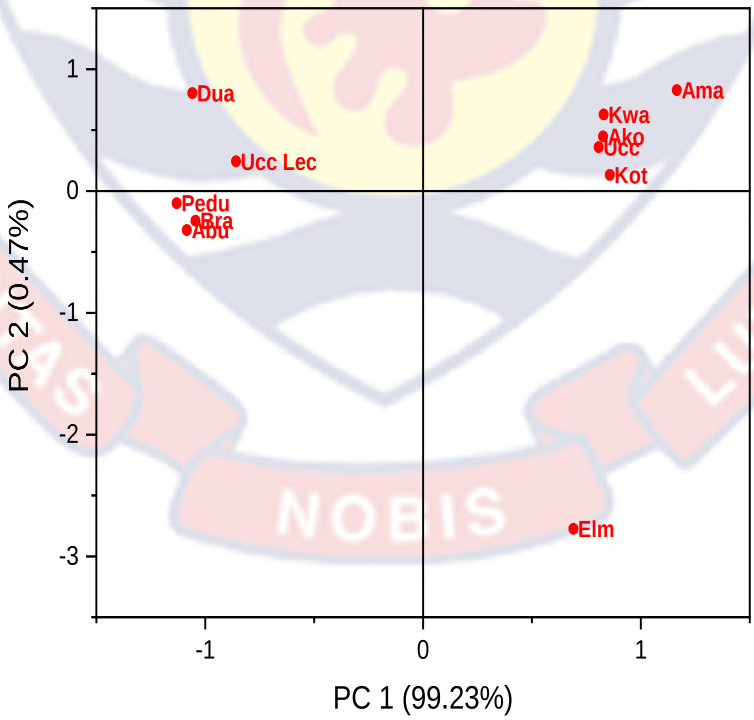

Figure 15: Biplot of Principal component analysis (PC1:PC2) of Residual Chlorine concentration in tap water samples collected from Cape Coast Metropolis and its environ

Generally, the score plot shows that there were three clusters of communities with distinct residual chlorine levels. Amamoma, Kwaprow, UCC and Kotokoraba as first cluster; Abura, Brafoyaw, Pedu, Duakor, UCC Lec, as second cluster and Elmina as third cluster. With a significant separation on the main Principal Component one (PC1= 99.23%) and less significant separation on PC 2 = 0.47%. Even though there were three distinct clusters, each cluster's tap water sample RC level differed from each, this means that there were different residual chlorine concentration levels at each locality as shown by Figure 15.

Pearson correlation coefficient (PCC) and coefficient of divergence (COD), are the two main methods for comparing and contrasting sample water sources from any two places. For instance, the PCC is used to evaluate the chlorine content of any two water samples, whereas the COD evaluates the degree of fluctuation of chlorine discovered concurrently on a specific day in two sampling sites. Lower COD values (0.2) suggest that the sources of chlorine in the two regions are comparable, but larger PCC values (>0.7) suggest that the chlorine concentrations in the two regions do not change over time.

The environment affects behavior and transportation, climatic factors may change the chemical processes that take place in water (Gómez-Martínez et al., 2021; Karimi et al., 2022). This, in turn, may change the chemical concentrations in the water. It was believed that unexplained sources and ideal weather conditions were the optimal conditions to observe the lowest and greatest PCC values for sampling locations in all months (Johnson et al., 2022; Olaoye et al., 2021).

For the sample sites and Locations residual chlorine tap water data set, principal component analysis (PCA), cluster analysis (CA), were used to assess the pattern and relations in the residual chlorine concentration in the tap water samples from the several localities and also reach a rudimentary understanding of their potential connection. All additional tests were run at the level of 0.05; regression and correlation were run at 0.05 and 0.01 confidence levels.

Effect of pH on Residual Chlorine Concentration in Tap Water

The pH of the tap water samples was determined during the study period (Table 9). The relationship between the pH and the residual chlorine content, and the similarity between the pH's at any two sampling locations and between the samples on the different sampling days were also assessed.

Table 9: pH's of Tap Water Samples at Sampling Communities (Cape Coast and its environs)

pH	Abu	Pedu	Dua	Elm	Kwa	Ako	Kot	UCC	Ama	Bra	UCCL
S1	6.90	6.80	7.10	6.80	6.90	7.20	6.90	6.80	7.10	6.80	6.50
S2	6.80	6.40	6.80	7.20	6.80	6.80	6.70	7.20	6.90	6.90	6.70
S3	6.70	6.60	6.90	6.90	7.20	7.10	7.10	7.10	7.30	7.20	6.70
S4	6.80	6.50	7.20	7.10	6.70	6.90	6.80	6.90	6.90	7.30	6.40
S5	6.60	6.80	7.10	6.80	7.10	6.80	6.70	7.30	6.90	6.90	6.70
S6	6.90	6.40	7.20	6.90	6.80	7.30	6.90	6.80	7.30	7.10	6.90
S7	6.40	6.60	6.90	6.70	6.90	6.90	7.20	7.20	6.90	6.90	6.50
S8	6.80	6.80	7.20	6.90	6.70	6.60	7.10	7.40	7.20	7.30	6.70
S9	6.60	7.20	6.90	6.80	6.90	7.20	6.90	6.90	6.90	6.80	6.50
S10	6.90	6.90	7.10	7.10	7.20	6.90	7.10	6.70	7.10	6.90	6.60
S11	6.70	6.70	6.80	7.30	7.10	7.10	6.80	6.90	6.90	6.90	6.40
S12	6.80	7.10	7.20	6.90	6.80	6.70	6.70	6.80	6.80	7.50	6.50
S13	6.40	6.90	6.90	7.20	6.60	6.90	6.90	7.30	7.20	6.90	6.40
S14	6.80	6.50	7.30	7.10	7.10	6.60	7.10	6.70	6.80	7.20	6.70
S15	6.90	6.80	6.80	6.90	6.80	7.20	6.90	7.20	6.70	6.90	6.80
S16	6.30	6.50	7.10	6.70	6.90	6.90	7.20	6.80	6.90	6.90	6.50
S17	6.40	7.10	6.90	6.90	7.10	7.30	6.90	6.90	7.10	6.90	6.60
S18	6.80	6.60	7.20	7.10	6.90	6.90	7.10	7.30	6.50	7.20	6.80
S19	6.40	6.90	6.80	6.90	7.20	7.10	6.90	6.70	7.30	6.90	6.60
S20	6.70	6.50	7.10	7.20	7.10	7.30	7.20	6.60	6.90	6.90	6.80
Mean	6.90	6.80	7.10	6.80	6.90	7.20	6.90	6.80	7.10	6.80	6.50
Stdev	0.20	0.24	0.17	0.18	0.19	0.23	0.17	0.25	0.21	0.20	0.15
Min	6.30	6.40	6.80	6.70	6.60	6.60	6.70	6.60	6.50	6.80	6.40
Max	6.90	7.20	7.30	7.30	7.20	7.30	7.20	7.40	7.30	7.50	6.90
CV	2.88	3.51	2.37	2.62	2.68	3.13	2.46	3.66	3.02	2.91	2.30

(Source: Field Data; Ohene-kwayisi, 2023)

The pH ranged from 6.50-7.20, the mean pH of the water samples from eight out eleven communities were below pH = 7.0 and lies within the permissible limits for drinking water (WHO,2007, US EPA, Health Canada, New Zealand Ministry of Health, Singapore's National Water, Germany Federal Ministry of Health, Iceland EPA, UAE EPA, Australia Medical Research Council)(Karim et al., 2020). However, where the water is used in swimming pools, the pH has to be maintained between 7.2 and 7.8. Even though the water is from the same source, it showed variation in pH levels. This could be due to the effect of the pipe linings (Xu et al., 2021).

The observed pH is within the range of most drinking water (Obeng et al., 2010). Obeng et., 2010 reported (pH = 6.51- 6.71) for treated water from the same source (Brimsu Headworks) and Kakari et., 2013 reported (pH = 6.8-7.4) for treated water from Kpong and Weija treatment plants that supplies water to Accra-Tema Metropolis. Another study conducted by Hansen (2014) in Tamale showed that 42% of the tap water samples analyzed had pH ranged from 7.005- 7.598. The pH of the water samples in this study was comparable to levels found in Tamale and Accra (Hansen, 2014; Karikari & Ampofo, 2013). However, (WHO, 2017) recommend a pH range of 6.5 to 8.5, which is ideal pH for a water system, this varies based on the individual features of a system (Hansen, 2014). Based on the WHO pH limit, the water samples studied is safe for human use.

Relation between pH and Residual Chlorine Concentration in tap water

The relation between pH and Residual chlorine was assessed using the bivariate analysis (Pearson Correlation) that measures the strength of association between two variables. The regression and correlation analysis of residual chlorine on pH for the various sites are shown (Figure 16 - 26).

For Abura, Duakor, Elmina, Kwaprow, Akotokyir, and Kotokoraba, a slight decrease in residual chlorine concentration with increasing pH was observed for figure 16 - 22.

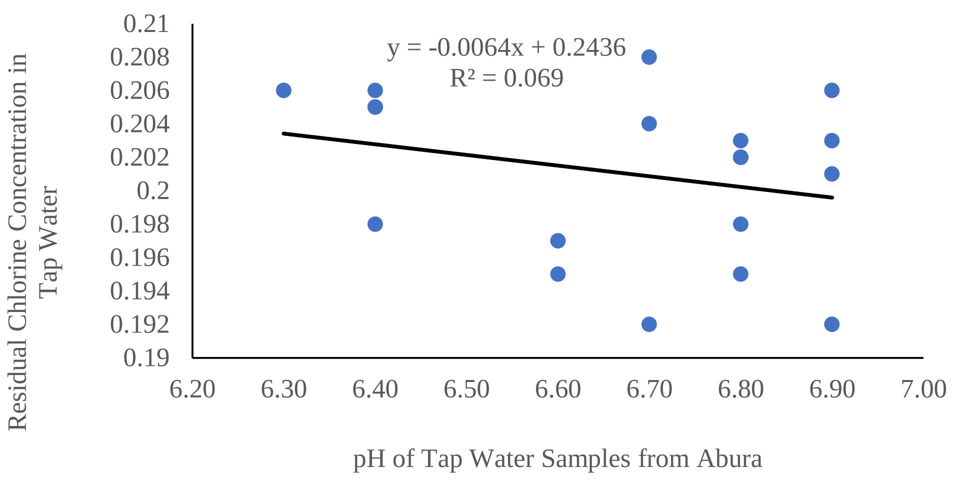

Figure 16: Graph of pH and Residual Chlorine Concentration of Tap Water Sample from Abura

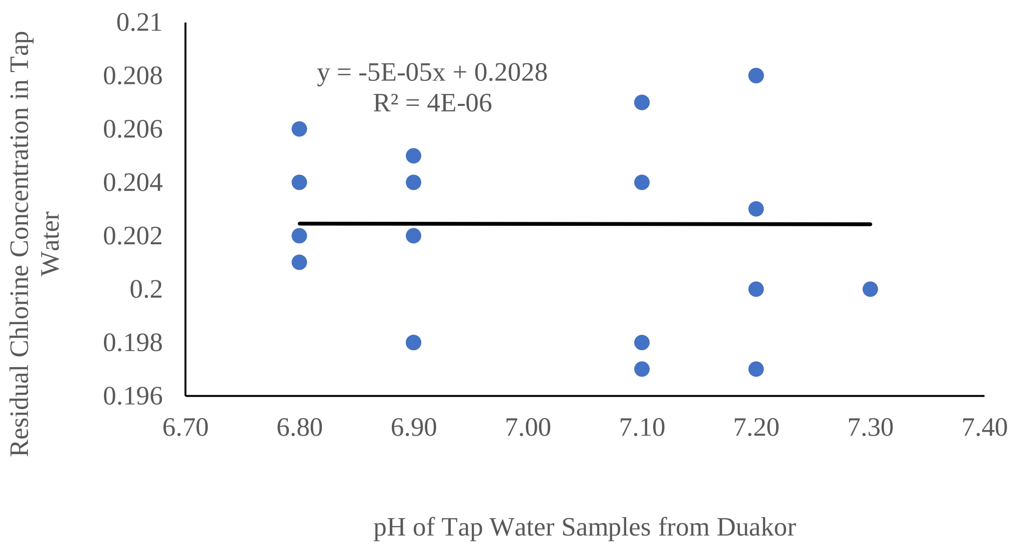

Figure 17: Graph of pH and Residual Chlorine Concentration of Tap Water Sample from Duakor

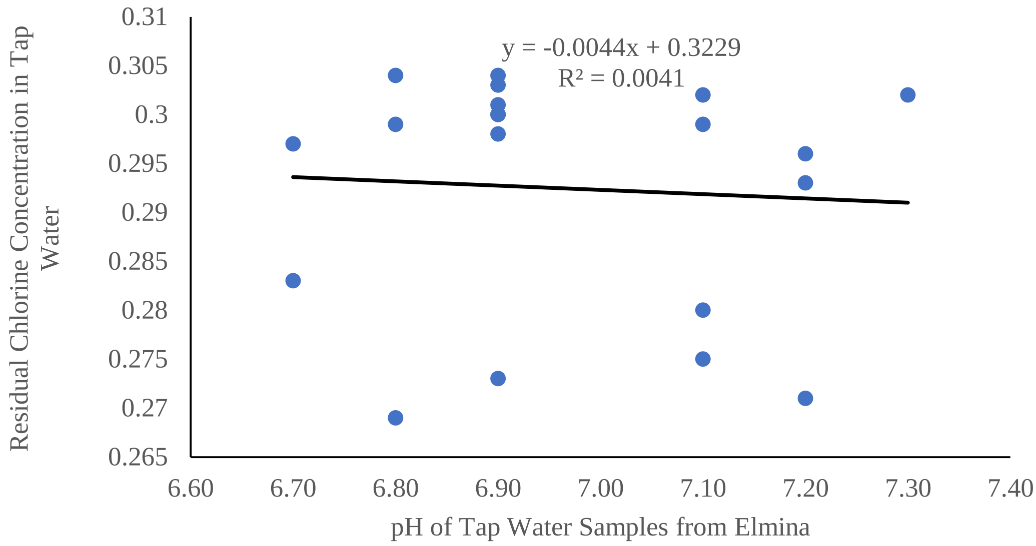

Figure 18: Graph of pH and Residual Chlorine Concentration of Tap Water Sample from Elmina

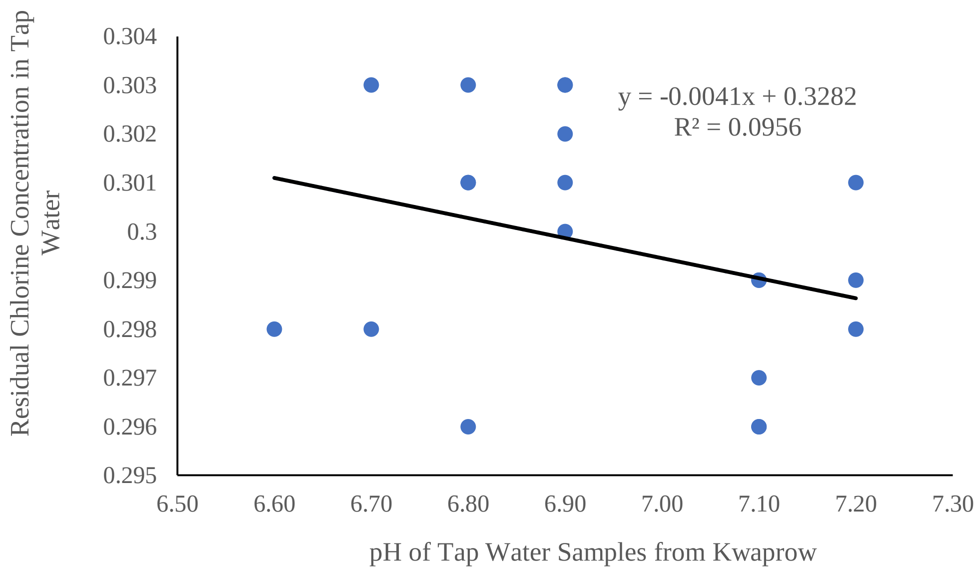

Figure 19: Graph of pH and Residual Chlorine Concentration of Tap Water Sample from Kwaprow

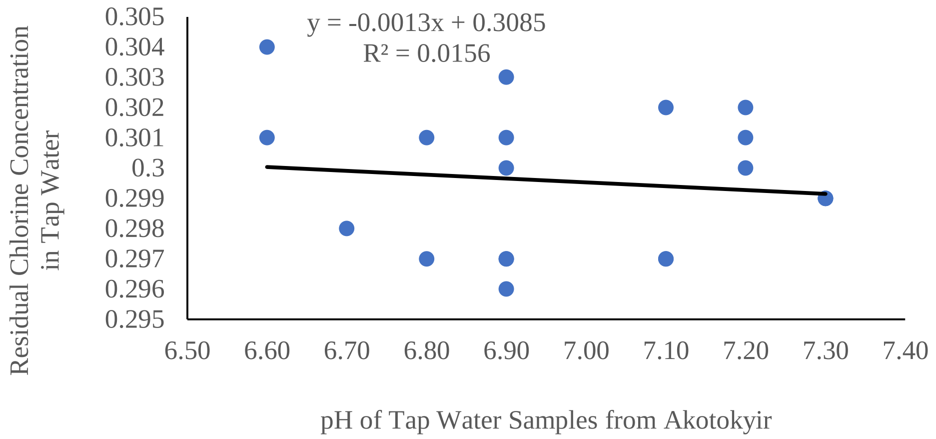

Figure 20: Graph of pH and Residual Chlorine Concentration of Tap Water Sample from Akotokyir

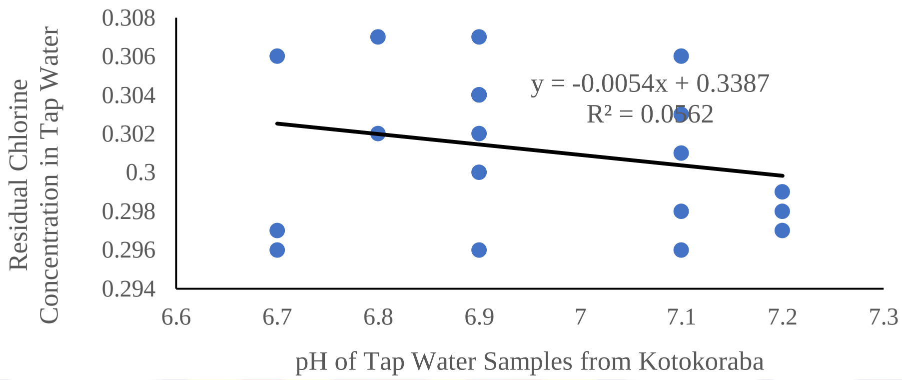

Figure 21: Graph of pH and Residual Chlorine Concentration of Tap Water Sample from Kotokoraba

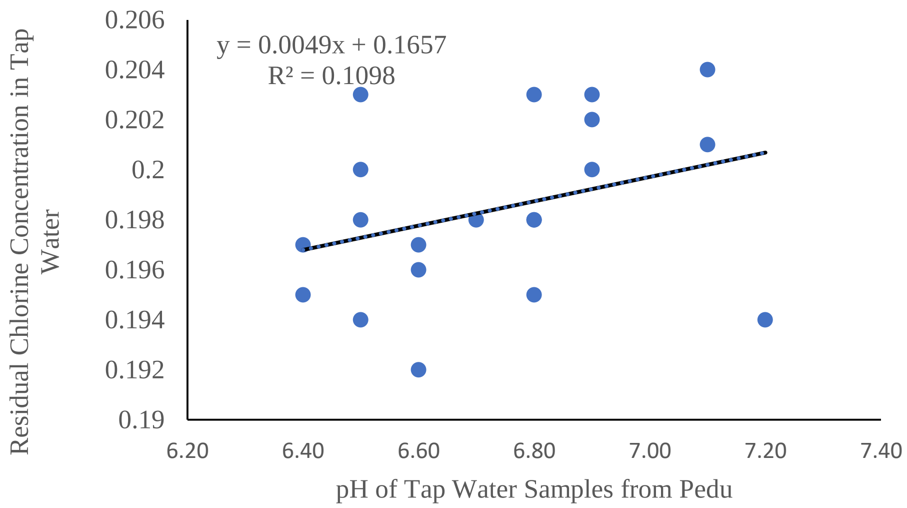

Figure 22: Graph of pH and Residual Chlorine Concentration of Tap Water Sample from Pedu

However, increased residual chlorine concentration with increasing pH was observed for Pedu, UCC, Amamoma, Brafoyaw and UCC L, as shown on figure 23-26. As pH increases, the disinfection ability of residual chlorine decreases.

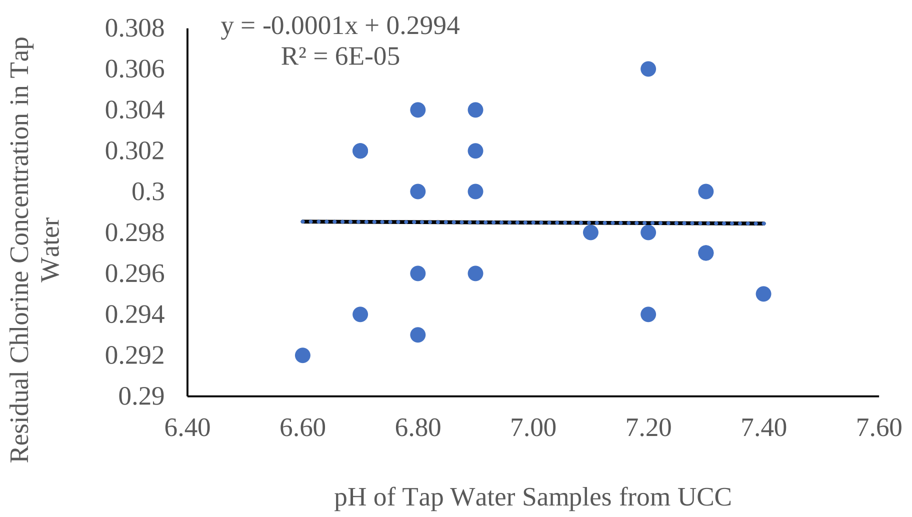

Figure 23: Graph of pH and Residual Chlorine Concentration of Tap Water Sample from UCC

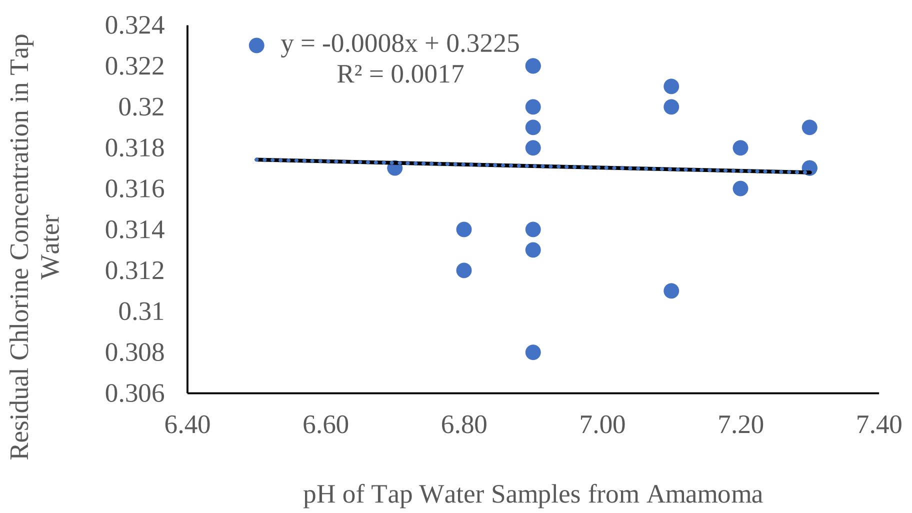

Figure 24: Graph of pH and Residual Chlorine Concentration of Tap Water Sample from Amamoma

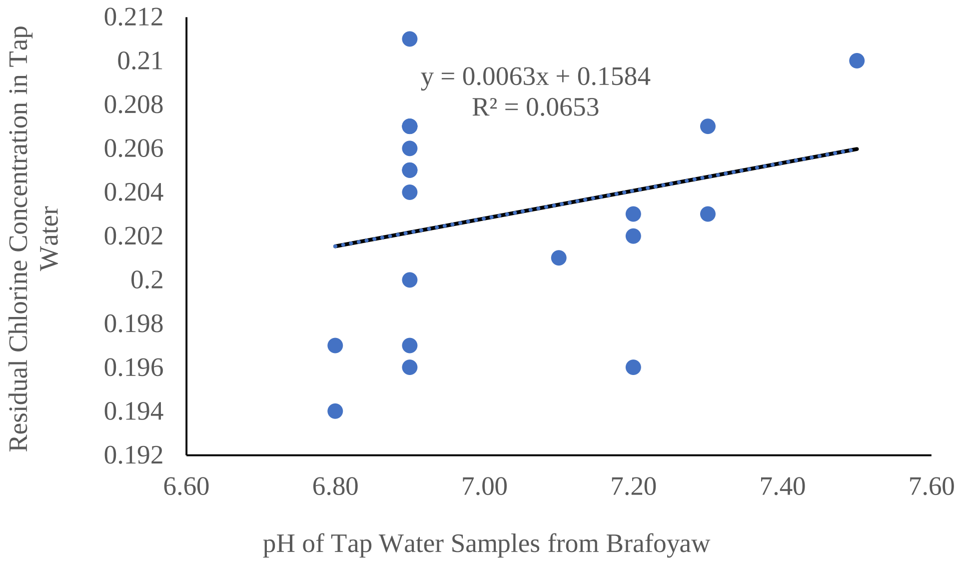

Figure 25: Graph of pH and Residual Chlorine Concentration of Tap Water Sample from Brafoyaw

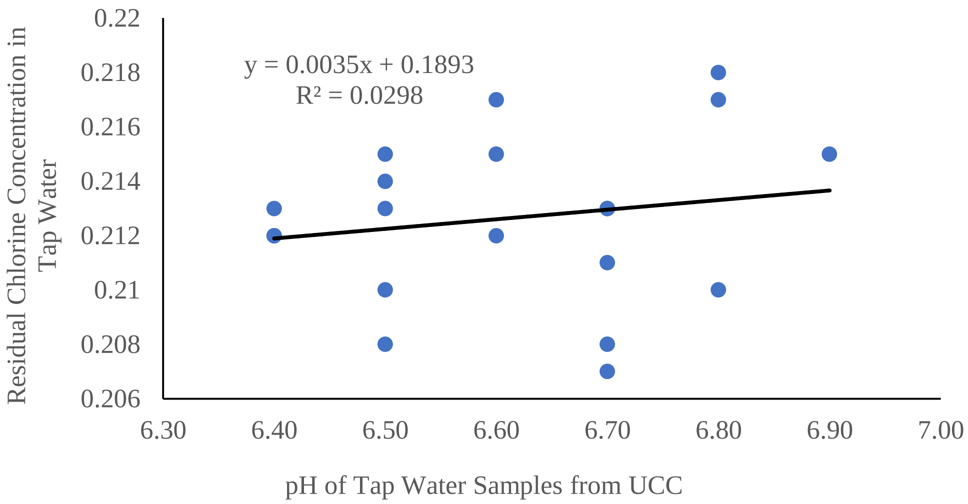

Figure 26: Graph of pH and Residual Chlorine Concentration of Tap Water Sample from UCC Lec

Residual Chlorine Decay

This study ascertained the residual chlorine concentration level that remains in tap water samples stored in covered and uncovered containers over a period of eight days (Figure 27).

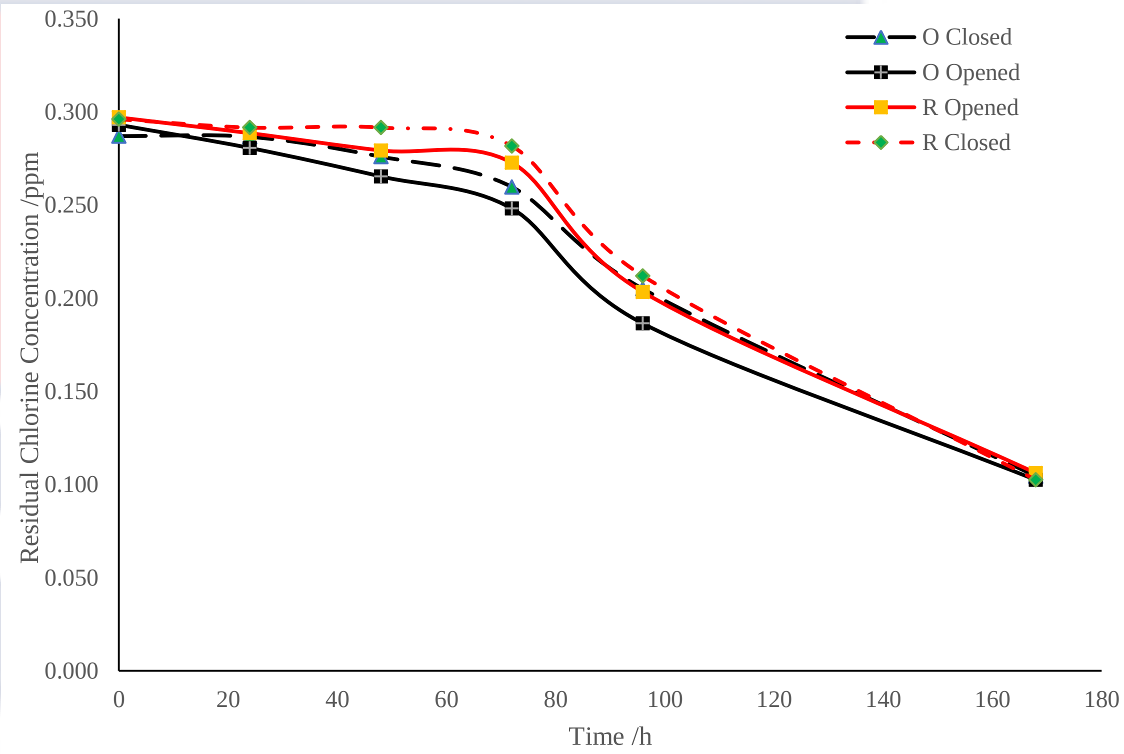

Figure 27: Trend in Decay of Residual Chlorine Concentration in Stored Tap Water

The effect of the mode of storage (opened or covered and at outdoor and indoor) were of principal focus in this study. It was recognized that the rate of residual chlorine decay depended on the mode of storage. Exposure to the atmosphere and the temperature affected the residual chlorine concentration in the tap water (Figure 27). The residual chlorine concentration reduced gradually over the first three days. Then decayed steeply after the third day. Generally, the residual chlorine in water stored in containers without lids showed larger decrease in the residual chlorine compared to those with lids. Also, water stored outdoor showed greater decrease in the residual chlorine content than those stored indoors. The residual chlorine concentrations on the eight-day were about the same level.

The variation in the residual chlorine content was reported as percentage decay over the period (Figure 28). It revealed that in three days (72 hours) the water stored outdoor (30°C) in

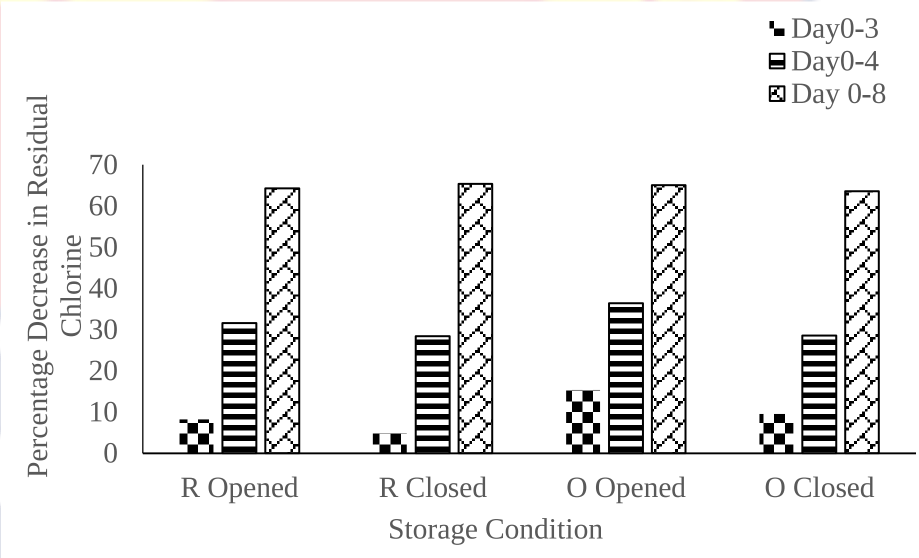

Figure 28: Decrease of Residual Chlorine in tap water with Storage Conditions

Open containers had the largest drops in the residual chlorine content (15.33%) compared to one stored indoors (25°C) which recorded 8.21% decreased (Figure 28 and Table 10). This is probably because the rate of decay was higher for water stored outdoor (30°C) than the one stored indoor at 25°C.

Table 10: Percentage Decrease in Residual Chlorine

Period	R Opened	R Closed	O Opened	O Closed
Day0-3	8.2054	4.870	15.329	9.514
Day0-4	31.545	28.400	36.383	28.582
Day 0-8	64.265	65.377	65.022	63.598

(Source: Field Data, Ohene-kwayisi, 2023)

This observation suggest that increased temperature affected the rate of decay of chlorine in the water. The reason for this difference is that the way chlorine reacts with water depends on the specific circumstances of each zone, including temperature, the amount of organic matter present in the water, how well the distribution system is functioning. According to the amount of organic matter in the water, the chlorine degradation increases (expressed by dissolved organic carbon). More organic matter means that degradation happens more quickly, this agrees with those reported in literature (García-Ávila et al., 2020).

Table 11: Average Rate of Residual Chlorine Decay

	Rate of decay ug/h			
	R Opened	R Closed	O Opened	O Closed
Day 0-3	0.34	0.20	0.62	0.38
Day 3-4	2.89	2.90	2.57	2.28
Day 4-8	1.35	1.52	1.17	1.40
Day 3-8	1.73	1.87	1.52	1.62
Day 0-8	1.14	1.15	1.13	1.09

(Source: Field Data, Ohene-kwayisi, 2023)

The total percentage residual chlorine decay after the third, fourth and eight-day ranged respectively from 4.87 -15.33 %, 28.40 – 36.38 % and 63.60 – 65.38 % (Figure 28 and Table 10).

On the third- and fourth-day, water stored outdoor and exposed to the atmosphere recorded the highest decrease in residual chlorine concentration: whilst those stored indoors and covered recorded the least (Table 10). However, on the eight-day water stored indoor and covered recorded the highest decrease in residual chlorine 65.37 %; followed by outdoor opened 65.38 %; then indoor opened 64.26% and the least 63.60 % for water stored outdoor in a covered container.

Health Implication of Residual Chlorine in tap water system

To suppress infectious bacteria, chemical treatments such as chlorine is utilized (Adefisoye & Olaniran, 2022). Few research focuses on how fungi that are significant to hygiene and the mycotoxins produce, spread across tap water distribution systems that are both burdened by aging infrastructure and ancillary distribution networks that lack high-pressure water delivery systems. (Mhlongo et al., 2020). However, as disinfection byproduct (DBP) concentrations in tap water are often only examined less often, less is known about their levels than in the effluent from drinking water treatment plant (DWTPs) (Pang et al., 2022; Zhou et al., 2023).

Even though drinking water distribution systems include residual chlorine, the bacteria are a refractory human pathogen that can develop biofilms on pipe walls and pose health hazards (Lin et al., 2017). Because the planktonic cells in biofilms produced by *Vibrio cholerae, Pseudomonas aeruginosa* and *Staphylococcus spp., etc. and* bacterial pathogens such as *Legionella pneumophila* and *Mycobacterium avium*, amoeba-infecting bacteria such as *Chlamydia*-related organisms (Reduced Chlorine in Drinking Water Distribution Systems Impacts Bacterial Biodiversity in Biofilms - PMC, 2018), have the ability to leak into drinking water, under certain circumstances: such as leakage from waste tanks and effluent from septic leach fields into drinking water sources, resulting in microorganism present in the water that pose a threat to human health. Since the majority of the bacteria in drinking water distribution systems (DWDSs) are found at the pipe wall, strategies that attempt to stop or interfere with the initial adhesion and subsequent biofilm formation are a significant advancement in the control of drinking water quality. Bacterial biofilms seen in typical drinking water were observed, along with how they responded to various chlorination doses: (Atik et al., 2021; Chowdhury, 2012; Valdivia-Garcia et al., 2019).

Klebsiella H1 from Jiulong River, *Pseudomonas C5* from Xinglin River, *Flavobacterium GS3* from biofilms attached to the granular activated carbon, and *Sphingomonas Z22* from laboratory tap water, all four bacteria produced single biofilms that were vulnerable to sodium hypochlorite. Biomass and cultivability increased at high disinfectant doses after a 30-minute disinfection period, but decreased with increasing disinfectant concentration**.** Analysis using flow cytometry revealed that as disinfectant doses (Sodium hypochlorite) were raised, the number of clusters increased and their sizes reduced. Under heavy disinfectant treatment, about 0.5–1 mg/L of residual chlorine appeared to be sufficient for drinking water treatment while disinfection depleted. Knowing the effectiveness of disinfectants (chlorine) and how extracellular polymeric substances (EPS) affects biofilm resistance will therefore be useful knowledge for determining the minimum disinfectant level in tap water. Residual chlorine concentrations in drinking water distribution systems need to be kept below recommended levels in order to reduce the possibility of producing dangerous disinfection byproducts (EPA, 2015; Leonard et al., 2022; Lin et al., 2017).

The provision of safe drinking water is impacted by biofilm resistance to high chlorine concentrations. These microbes, which can spread from drinking water sources to people, exhibited drug resistance. As a result, it is advised that periodical evaluations of biofilm formation in drinking water samples be conducted (Bhasin et al., 2023).

Ideally, drinking water should be clear, colorless and well aerated with no unpalatable taste or odor. It should contain no suspended particle, harmful chemical substance or pathogenic micro-organisms. Chlorination is used as one of the final treatments in order to kill any possible remaining parasites, bacteria, and viruses by the application of chlorine reagent. Since some cysts, like cryptosporidium, are immune to chlorine treatment, it is ineffective against them (Reed, 2011).

For 1.0 ppm chlorine disinfection at a pH of 7.5, the following bacteria can be eliminated within the following periods: E. coli 0157:H7 (Bacterium) less than 1 minutes; Hapatitis A (virus) approximately 16 minutes; Giardia (Parasite) approximately 45 minutes; and Crytosporidium (Parasite) approximately 15,300 minutes (CDC Control Disease Center and Prevention, 2021; Cullom et al., 2020). Comparing the residual chlorine concentration level (1.0 ppm), needed to eliminate these bacteria from drinking water, it is shown from the chlorine decay studies (Figure 28), that the level of residual chlorine in stored tap water is not enough to kill these bacteria. Hence the water must be further treated: by boiling to eliminate these bacteria before consuming.

Chlorination disinfects the water, protecting it from germs that lurk in the pipelines as the water travels through communities to homes and workplaces. However, chlorine can be harmful to human health, often harmful byproduct can emerge when chlorine- treated water enters and flow through the water distribution pipelines.

The health risk associated with chlorine consumption can differ in severity, depending on the level of contamination. In most cases, low levels of chlorine consumed will pose no adverse health effect from this contamination.

However, long-term consumption of high levels of chlorine possess serious health issues and an increase in cancer risk, infertility issues (*Pizzorno, 2018*).

Chapter Summary

This section of the thesis explicitly presented the research findings, and drew inferences on the results. The chapter initially posits the quality control/quality assurance measures took to ensure the integrity of the results. It further looked at the chlorine profile at the study areas. Also, two distinct trends in residual chlorine (RC) levels in the water studied were graphically presented on a line graph (ie; lower levels ranged from 0.19 ppm to higher level 0.317 ppm).

One-way analysis of variance (ANOVA) was conducted on the residual chlorine data to ascertain significant variation in the residual chlorine levels in water at the study areas. The results showed significant variation ($p < 0.00$).

Correlation analysis was applied on the residual chlorine levels, to ascertain the relationship in the RC levels in water at the study areas. In assessing the similarity in the RC levels at the study sites, the RC data cluster analysis was utilized.

For source characterization, principal component analysis was applied on the RC level data to identify the source relationship of RC at the study sites. The effect of pH on RC level in the water was ascertained, and the findings were graphically presented.

At the end of the chapter, the findings of RC decay study were graphically presented. The concluding paragraph looked at the health implication of the residual chlorine levels in the water consumed.

CHAPTER FIVE

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

Overview

This chapter consists of the summary, conclusion and some recommendations on the residual chlorine level in water studied. It briefly presents the significance and the implication of the research findings, and proposes areas that should be considered in future studies.

Summary

The residual chlorine levels in tap water samples treated (Chlorinated) and distributed through pipeline by the Ghana water company limited Brimsu Headworks, to the populace of Cape Coast Metropolis and it environ was assessed. There were two set of distinct residual chlorine concentration 0.199±1.833 ppm and 0.317±1.208 ppm as lowest and highest levels respectively with a pH range of 6.50-7.20. The mean concentration of Residual Chlorine (RC) in tap water measured in part per million (ppm) were; Amamoma: 0.317±1.208 > Kotokoraba: 0.301±1.240 > Akotokyir and Kwaprow: 0.300±0.754 and 0.300±0.801 respectively > UCC: 0.299±1.290 > Elmina: 0.293±4.051 > UCCL: 0.213±1.368 > Brafoyaw: 0.203±2.332 > Duakor: 0.202±1.765 > Abura: 0.201±2.336 and Pedu: 0.199±1.833. The highest residual chlorine content was found at Amamoma, and the lowest at Pedu. The pH ranged from 6.50-7.20, the mean pH of the water samples from eight out eleven communities were below pH = 7.0 and lies within the permissible limits for drinking water

The One-way ANOVA findings (at 95%) were used to determine whether there were any differences that were statistically significant between the measured tap water residual chlorine concentration in the eleven communities. The mean values of the RC measured at the various sampling locations inside the Cape Coast Metropolis were compared to determine whether there were statistically significant differences.

As shown in Table 4; ($p = 0.000 < \alpha = 0.05$). Even though the tap water was from the same source, it had varying effects of RC in the water. (Abura ≠ Pedu≠ Duakor ≠ Elmina ≠ Kwaprow ≠ Akotokyir ≠ Kotokoraba ≠ UCC≠ Amamoma ≠ Brafoyaw ≠ UCC.

Overall, almost all the communities had RC level in tap water within the guideline set by World Health Organization (WHO), Safe Water Systems (SWS) and Center for Disease Control (CDC) permissible RC level (0.2- 0.5 ppm of RC).

A hierarchical cluster analysis was performed on the residual chlorine concentration between the eleven communities, and also between the various sampling sites with Ward's method and their concentrations measured for similarity. Samples that showed above 50 % similarity includes Akotokyir and Kotokoraba, formed a group at 52 %. Abura and Elmina showed 58% similarity, Surprisingly Brafoyaw and UCC L samples had similar levels of 65%. No sample had similarity level found at 70 %.

For the study of residual chlorine decay in stored tap water kept in different storage conditions, the level of residual chlorine reduced by 65.377% for tap water stored in covered container kept in a room, 65.022% for tap water kept in uncovered container outdoor, 64.265% for tap water kept in uncovered container in a room and 63.598% for tap water in a covered container kept outdoor, over the 8 days.

Chlorination disinfects the water, protecting it from germs that lurk in the pipelines as the water travels through communities to homes and workplaces. However, chlorine can be harmful to human health, often harmful byproduct can emerge when chlorine- treated water enters and flow through the water distribution pipelines.

The health risk associated with chlorine consumption can differ in severity, depending on the level of contamination. In most cases, low levels of chlorine consumed would pose no adverse health effect from this contamination. However, long-term consumption of high levels of chlorine possess serious health issues and an increase in cancer risk, infertility issues (*Environmental Toxins and Infertility* - *Joseph Pizzorno 2018*,).

Conclusion

The residual chlorine levels in tap water supplied by Ghana water company limited Brimsu Headworks to Cape Coast and neighboring communities were all within the permissible limit set by World Health Organization, Safe water System. Hence the water is safe for drinking with respect to residual chlorine.

The pH of the water had no significant effect on the residual chlorine levels in the tap water.

Recommendations

1. There should be further studies on chlorine monitoring, with associated microbial contamination levels in tap water, particularly cryptosporidium.
2. Periodic assessment of the residual chlorine (RC) level in tap water should be conducted, and to assure consumers of the safety of the water.

3. Old pipelines made of material that react with residual chlorine should be replaced with polyvinyl Chloride, to reduce the amount of chlorine residual consumed after water disinfection and distribution.

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APPENDICES

APPENDIX A

Residual Chlorine Result for Tap Water at Abura

	Absorbance			Concentration /ppm			Mean C	
Sample ID	A1	A2	A3	C1	C2	C3	Av C	STDEV
S1	0.192	0.193	0.193	0.191	0.192	0.192	0.192	0.00047
S2	0.195	0.198	0.195	0.194	0.197	0.194	0.195	0.00141
S3	0.191	0.194	0.194	0.190	0.193	0.193	0.192	0.00141
S4	0.202	0.203	0.203	0.201	0.202	0.202	0.202	0.00047
S5	0.198	0.199	0.198	0.197	0.198	0.197	0.197	0.00047
S6	0.204	0.205	0.204	0.203	0.204	0.203	0.203	0.00047
S7	0.206	0.207	0.207	0.205	0.206	0.206	0.206	0.00047
S8	0.199	0.198	0.199	0.198	0.197	0.198	0.198	0.00047
S9	0.196	0.197	0.196	0.195	0.196	0.195	0.195	0.00047
S10	0.201	0.202	0.202	0.200	0.201	0.201	0.201	0.00047
S11	0.205	0.206	0.205	0.204	0.205	0.204	0.204	0.00047
S12	0.202	0.203	0.203	0.201	0.202	0.202	0.202	0.00047
S13	0.199	0.200	0.199	0.198	0.199	0.198	0.198	0.00047
S14	0.204	0.203	0.204	0.203	0.202	0.203	0.203	0.00047
S15	0.208	0.207	0.207	0.207	0.206	0.206	0.206	0.00047
S16	0.206	0.208	0.208	0.205	0.207	0.207	0.206	0.00094
S17	0.205	0.206	0.206	0.204	0.205	0.205	0.205	0.00047
S18	0.203	0.204	0.203	0.202	0.203	0.202	0.202	0.00047
S19	0.206	0.207	0.206	0.205	0.206	0.205	0.205	0.00047
S20	0.208	0.209	0.209	0.207	0.208	0.208	0.208	0.00047

APPENDIX B

Residual Chlorine Result for Tap Water at Pedu

	Absorbance			Concentration / ppm			Mean C	
Sample ID	A1	A2	A3	C1	C2	C3	Av C	STDEV
S1	0.196	0.195	0.196	0.195	0.194	0.195	0.195	0.00047
S2	0.198	0.197	0.198	0.197	0.196	0.197	0.197	0.00047
S3	0.197	0.196	0.197	0.196	0.195	0.196	0.196	0.00047
S4	0.195	0.194	0.195	0.194	0.193	0.194	0.194	0.00047
S5	0.199	0.199	0.200	0.198	0.198	0.199	0.198	0.00047
S6	0.196	0.197	0.196	0.195	0.196	0.195	0.195	0.00047
S7	0.193	0.192	0.193	0.192	0.191	0.192	0.192	0.00047
S8	0.199	0.199	0.198	0.198	0.198	0.197	0.198	0.00047
S9	0.195	0.196	0.195	0.194	0.195	0.194	0.194	0.00047
S10	0.201	0.201	0.200	0.200	0.200	0.199	0.200	0.00047
S11	0.199	0.198	0.199	0.198	0.197	0.198	0.198	0.00047
S12	0.202	0.202	0.201	0.201	0.201	0.200	0.201	0.00047
S13	0.204	0.203	0.204	0.203	0.202	0.203	0.203	0.00047
S14	0.201	0.201	0.200	0.200	0.200	0.199	0.200	0.00047
S15	0.204	0.203	0.204	0.203	0.202	0.203	0.203	0.00047
S16	0.203	0.204	0.204	0.202	0.203	0.203	0.203	0.00047
S17	0.205	0.206	0.205	0.204	0.205	0.204	0.204	0.00047
S18	0.199	0.198	0.198	0.198	0.197	0.197	0.197	0.00047
S19	0.203	0.203	0.202	0.202	0.202	0.201	0.202	0.00047
S20	0.206	0.205	0.206	0.205	0.204	0.205	0.205	0.00047

APPENDIX C

Residual Chlorine Result for Tap Water at Akotokyir

	Absorbance			Concentration /ppm			Mean C	
Sample ID	A1	A2	A3	C1	C2	C3	Av C	STDEV
S1	0.302	0.301	0.302	0.300	0.299	0.300	0.300	0.00047
S2	0.301	0.303	0.303	0.299	0.301	0.301	0.301	0.00094
S3	0.298	0.299	0.299	0.297	0.298	0.298	0.297	0.00047
S4	0.303	0.302	0.303	0.301	0.300	0.301	0.301	0.00047
S5	0.299	0.298	0.299	0.298	0.297	0.298	0.297	0.00047
S6	0.301	0.300	0.300	0.299	0.299	0.299	0.299	0.00047
S7	0.298	0.299	0.298	0.297	0.298	0.297	0.297	0.00047
S8	0.302	0.303	0.302	0.300	0.301	0.300	0.301	0.00047
S9	0.304	0.303	0.304	0.302	0.301	0.302	0.302	0.00047
S10	0.301	0.302	0.301	0.299	0.300	0.299	0.300	0.00047
S11	0.304	0.304	0.303	0.302	0.302	0.301	0.302	0.00047
S12	0.299	0.300	0.299	0.298	0.299	0.298	0.298	0.00047
S13	0.297	0.298	0.297	0.296	0.297	0.296	0.296	0.00047
S14	0.306	0.306	0.305	0.304	0.304	0.303	0.304	0.00047
S15	0.301	0.303	0.303	0.299	0.301	0.301	0.301	0.00094
S16	0.297	0.299	0.299	0.296	0.298	0.298	0.297	0.00094
S17	0.300	0.301	0.301	0.299	0.299	0.299	0.299	0.00047
S18	0.304	0.305	0.304	0.302	0.303	0.302	0.303	0.00047
S19	0.298	0.299	0.299	0.297	0.298	0.298	0.297	0.00047
S20	0.301	0.300	0.301	0.299	0.299	0.299	0.299	0.00047

APPENDIX D

Residual Chlorine Result for Tap Water at Amamoma

	Absorbance			Concentration/ppm			Mean C	
Sample ID	A1	A2	A3	C1	C2	C3	Av C	STDEV
S1	0.322	0.323	0.322	0.320	0.321	0.320	0.321	0.00047
S2	0.319	0.32	0.32	0.317	0.318	0.318	0.318	0.00047
S3	0.318	0.319	0.319	0.316	0.317	0.317	0.317	0.00047
S4	0.324	0.322	0.324	0.322	0.320	0.322	0.322	0.00094
S5	0.315	0.316	0.316	0.313	0.314	0.314	0.314	0.00047
S6	0.321	0.321	0.32	0.319	0.319	0.318	0.319	0.00047
S7	0.324	0.323	0.323	0.322	0.321	0.321	0.322	0.00047
S8	0.317	0.318	0.317	0.315	0.316	0.315	0.316	0.00047
S9	0.309	0.311	0.309	0.307	0.309	0.307	0.308	0.00094
S10	0.312	0.313	0.313	0.310	0.311	0.311	0.311	0.00047
S11	0.321	0.322	0.321	0.319	0.320	0.319	0.320	0.00047
S12	0.315	0.316	0.316	0.313	0.314	0.314	0.314	0.00047
S13	0.319	0.32	0.319	0.317	0.318	0.317	0.318	0.00047
S14	0.314	0.313	0.314	0.312	0.311	0.312	0.312	0.00047
S15	0.317	0.319	0.319	0.315	0.317	0.317	0.317	0.00094
S15	0.321	0.321	0.320	0.319	0.319	0.318	0.319	0.00047
S16	0.322	0.321	0.322	0.320	0.319	0.320	0.320	0.00047
S17	0.325	0.324	0.325	0.323	0.322	0.323	0.323	0.00047
S18	0.319	0.318	0.318	0.317	0.316	0.316	0.317	0.00047
S19	0.314	0.315	0.315	0.312	0.313	0.313	0.313	0.00047
S20	0.317	0.316	0.317	0.315	0.314	0.315	0.315	0.00047

APPENDIX E

Residual Chlorine Result for Tap Water at Brafoyaw

	Absorbance			Concentration/ppm			Mean C	
Sample ID	A1	A2	A3	C1	C2	C3	Av C	STDEV
S1	0.199	0.198	0.199	0.198	0.197	0.197	0.197	0.00047
S2	0.201	0.202	0.202	0.200	0.201	0.199	0.200	0.00081
S3	0.198	0.197	0.198	0.197	0.196	0.196	0.196	0.00047
S4	0.204	0.205	0.205	0.203	0.204	0.202	0.203	0.00082
S5	0.208	0.207	0.208	0.207	0.206	0.206	0.206	0.00048
S6	0.203	0.201	0.201	0.202	0.200	0.201	0.201	0.00081
S7	0.207	0.206	0.207	0.206	0.205	0.205	0.205	0.00048
S8	0.209	0.207	0.209	0.208	0.206	0.207	0.207	0.00081
S9	0.195	0.196	0.196	0.194	0.195	0.193	0.194	0.00080
S10	0.198	0.197	0.198	0.197	0.196	0.196	0.196	0.00047
S11	0.208	0.209	0.209	0.207	0.208	0.206	0.207	0.00083
S12	0.211	0.212	0.211	0.210	0.211	0.209	0.210	0.00083
S13	0.206	0.208	0.206	0.205	0.207	0.204	0.205	0.00125
S14	0.205	0.204	0.205	0.204	0.203	0.203	0.203	0.00048
S15	0.198	0.199	0.199	0.197	0.198	0.196	0.197	0.00081
S16	0.205	0.206	0.206	0.204	0.205	0.203	0.204	0.00082
S17	0.208	0.208	0.207	0.207	0.207	0.206	0.207	0.00049
S18	0.204	0.203	0.204	0.203	0.202	0.202	0.202	0.00047
S19	0.209	0.207	0.209	0.208	0.206	0.207	0.207	0.00081
S20	0.212	0.214	0.214	0.211	0.213	0.210	0.211	0.00126

APPENDIX F

Residual Chlorine Result for Tap Water at Duakor

	Absorbance			Concentration/ppm			Mean C	
Sample ID	A1	A2	A3	C1	C2	C3	Av C	STDEV
S1	0.208	0.208	0.207	0.207	0.207	0.206	0.207	0.00047
S2	0.205	0.204	0.205	0.204	0.203	0.204	0.204	0.00047
S3	0.206	0.206	0.207	0.205	0.205	0.206	0.205	0.00047
S4	0.204	0.203	0.204	0.203	0.202	0.203	0.203	0.00047
S5	0.207	0.208	0.208	0.206	0.207	0.207	0.207	0.00047
S6	0.209	0.209	0.210	0.208	0.208	0.209	0.208	0.00047
S7	0.199	0.198	0.199	0.198	0.197	0.198	0.198	0.00047
S8	0.201	0.201	0.202	0.200	0.200	0.201	0.200	0.00047
S9	0.203	0.204	0.203	0.202	0.203	0.202	0.202	0.00047
S10	0.205	0.205	0.206	0.204	0.204	0.205	0.204	0.00047
S11	0.202	0.203	0.203	0.201	0.202	0.202	0.202	0.00047
S12	0.198	0.199	0.198	0.197	0.198	0.197	0.197	0.00047
S13	0.199	0.198	0.199	0.198	0.197	0.198	0.198	0.00047
S14	0.200	0.201	0.201	0.199	0.200	0.200	0.200	0.00047
S15	0.202	0.202	0.203	0.201	0.201	0.202	0.201	0.00047
S16	0.198	0.199	0.198	0.197	0.198	0.197	0.197	0.00047
S17	0.205	0.205	0.204	0.204	0.204	0.203	0.204	0.00047
S18	0.209	0.208	0.209	0.208	0.207	0.208	0.208	0.00047
S19	0.206	0.207	0.207	0.205	0.206	0.206	0.206	0.00047
S20	0.199	0.199	0.198	0.198	0.198	0.197	0.198	0.00047

APPENDIX G

Residual Chlorine Result for Tap Water at Elmina

	Absorbance			Concentration/ppm			Mean C	
Sample ID	A1	A2	A3	C1	C2	C3	Av C	STDEV
S1	0.269	0.271	0.271	0.268	0.270	0.270	0.269	0.00094
S2	0.272	0.274	0.272	0.271	0.273	0.271	0.271	0.00094
S3	0.275	0.274	0.275	0.274	0.273	0.274	0.273	0.00047
S4	0.281	0.282	0.281	0.280	0.281	0.280	0.280	0.00047
S5	0.301	0.300	0.301	0.299	0.299	0.299	0.299	0.00047
S6	0.303	0.302	0.302	0.301	0.300	0.300	0.301	0.00047
S7	0.284	0.285	0.285	0.283	0.284	0.284	0.283	0.00047
S8	0.301	0.302	0.302	0.299	0.300	0.300	0.300	0.00047
S9	0.305	0.306	0.305	0.303	0.304	0.303	0.304	0.00047
S10	0.276	0.278	0.276	0.275	0.277	0.275	0.275	0.00094
S11	0.304	0.303	0.304	0.302	0.301	0.302	0.302	0.00047
S12	0.305	0.304	0.305	0.303	0.302	0.303	0.303	0.00047
S13	0.295	0.294	0.295	0.294	0.293	0.294	0.293	0.00047
S14	0.303	0.304	0.304	0.301	0.302	0.302	0.302	0.00047
S15	0.306	0.305	0.306	0.304	0.303	0.304	0.304	0.00047
S16	0.299	0.298	0.299	0.298	0.297	0.298	0.297	0.00047
S17	0.302	0.301	0.302	0.300	0.299	0.300	0.300	0.00047
S18	0.298	0.301	0.301	0.297	0.299	0.299	0.299	0.00141
S19	0.299	0.301	0.299	0.298	0.299	0.298	0.298	0.00094
S20	0.298	0.297	0.298	0.297	0.296	0.297	0.296	0.00047

APPENDIX H

Residual Chlorine Result for Tap Water at Kotokoraba

	Absorbance			Concentration /ppm			Mean C	
Sample ID	A1	A2	A3	C1	C2	C3	Av C	STDEV
S1	0.302	0.301	0.302	0.300	0.299	0.300	0.300	0.00047
S2	0.299	0.298	0.299	0.298	0.297	0.298	0.297	0.00047
S3	0.297	0.299	0.297	0.296	0.298	0.296	0.296	0.00094
S4	0.308	0.309	0.309	0.306	0.307	0.307	0.307	0.00047
S5	0.297	0.298	0.298	0.296	0.297	0.297	0.296	0.00047
S6	0.306	0.305	0.305	0.304	0.303	0.303	0.304	0.00047
S7	0.298	0.299	0.298	0.297	0.298	0.297	0.297	0.00047
S8	0.305	0.304	0.305	0.303	0.302	0.303	0.303	0.00047
S9	0.308	0.309	0.309	0.306	0.307	0.307	0.307	0.00047
S10	0.299	0.299	0.301	0.298	0.298	0.299	0.298	0.00094
S11	0.304	0.303	0.304	0.302	0.301	0.302	0.302	0.00047
S12	0.307	0.308	0.307	0.305	0.306	0.305	0.306	0.00047
S13	0.297	0.299	0.297	0.296	0.298	0.296	0.296	0.00094
S14	0.301	0.303	0.303	0.299	0.301	0.301	0.301	0.00094
S15	0.304	0.302	0.304	0.302	0.300	0.302	0.302	0.00094
S16	0.299	0.301	0.299	0.298	0.299	0.298	0.298	0.00094
S17	0.305	0.306	0.305	0.303	0.304	0.303	0.304	0.00047
S18	0.307	0.308	0.308	0.305	0.306	0.306	0.306	0.00047
S19	0.306	0.305	0.306	0.304	0.303	0.304	0.304	0.00047
S20	0.299	0.301	0.301	0.298	0.299	0.299	0.299	0.00094

APPENDIX I

Residual Chlorine Result for Tap Water at Kwaprow

	Absorbance			Concentration /ppm			Mean C	
Sample ID	A1	A2	A3	C1	C2	C3	Av C	STDEV
S1	0.301	0.301	0.302	0.299	0.299	0.300	0.300	0.00047
S2	0.303	0.302	0.303	0.301	0.300	0.301	0.301	0.00047
S3	0.299	0.301	0.299	0.298	0.299	0.298	0.298	0.00094
S4	0.305	0.303	0.305	0.303	0.301	0.303	0.303	0.00094
S5	0.298	0.301	0.301	0.297	0.299	0.299	0.299	0.00141
S6	0.304	0.305	0.305	0.302	0.303	0.303	0.303	0.00047
S7	0.302	0.304	0.302	0.300	0.302	0.300	0.301	0.00094
S8	0.298	0.301	0.298	0.297	0.299	0.297	0.298	0.00141
S9	0.305	0.305	0.304	0.303	0.303	0.302	0.303	0.00047
S10	0.299	0.301	0.301	0.298	0.299	0.299	0.299	0.00094
S11	0.297	0.299	0.297	0.296	0.298	0.296	0.296	0.00094
S12	0.303	0.301	0.303	0.301	0.299	0.301	0.301	0.00094
S13	0.301	0.299	0.299	0.299	0.298	0.298	0.298	0.00094
S14	0.301	0.300	0.301	0.299	0.299	0.299	0.299	0.00047
S15	0.297	0.299	0.297	0.296	0.298	0.296	0.296	0.00094
S16	0.304	0.303	0.304	0.302	0.301	0.302	0.302	0.00047
S17	0.298	0.297	0.298	0.297	0.296	0.297	0.296	0.00047
S18	0.305	0.304	0.305	0.303	0.302	0.303	0.303	0.00047
S19	0.301	0.303	0.303	0.299	0.301	0.301	0.301	0.00094
S20	0.298	0.299	0.298	0.297	0.298	0.297	0.297	0.00047

APPENDIX J

Residual Chlorine Result for Tap Water at UCC

	Absorbance			Concentration/ppm			Mean C	
Sample ID	A1	A2	A3	C1	C2	C3	Av C	STDEV
S1	0.297	0.297	0.298	0.296	0.296	0.297	0.296	0.000469
S2	0.296	0.295	0.296	0.295	0.294	0.295	0.294	0.000469
S3	0.301	0.299	0.299	0.299	0.298	0.298	0.298	0.000938
S4	0.304	0.303	0.304	0.302	0.301	0.302	0.302	0.000469
S5	0.298	0.300	0.298	0.297	0.299	0.297	0.297	0.000938
S6	0.301	0.302	0.301	0.299	0.300	0.299	0.300	0.000469
S7	0.299	0.300	0.300	0.298	0.299	0.299	0.298	0.000469
S8	0.297	0.296	0.297	0.296	0.295	0.296	0.295	0.000469
S9	0.301	0.302	0.302	0.299	0.300	0.300	0.300	0.000469
S10	0.304	0.303	0.304	0.302	0.301	0.302	0.302	0.000469
S11	0.298	0.297	0.297	0.297	0.296	0.296	0.296	0.000469
S12	0.306	0.305	0.306	0.304	0.303	0.304	0.304	0.000469
S13	0.303	0.301	0.301	0.301	0.299	0.299	0.300	0.000938
S14	0.304	0.302	0.304	0.302	0.300	0.302	0.302	0.000938
S15	0.308	0.307	0.307	0.306	0.305	0.305	0.306	0.000469
S16	0.295	0.294	0.295	0.294	0.293	0.294	0.293	0.000469
S17	0.306	0.305	0.306	0.304	0.303	0.304	0.304	0.000469
S18	0.299	0.298	0.298	0.298	0.297	0.297	0.297	0.000469
S19	0.296	0.296	0.295	0.295	0.295	0.294	0.294	0.000469
S20	0.294	0.293	0.294	0.293	0.292	0.293	0.292	0.000469

APPENDIX K

Residual Chlorine Result for Tap Water at UCC L

	Absorbance			Concentration/ ppm			Mean C	
Samples ID	A1	A2	A3	C1	C2	C3	Av C	STDEV
S1	0.301	0.302	0.301	0.299	0.030	0.299	0.210	0.12702
S2	0.304	0.304	0.303	0.302	0.030	0.301	0.211	0.12810
S3	0.299	0.298	0.299	0.298	0.030	0.298	0.208	0.12627
S4	0.305	0.304	0.305	0.303	0.030	0.303	0.212	0.12880
S5	0.306	0.307	0.307	0.304	0.031	0.305	0.213	0.12936
S6	0.309	0.308	0.309	0.307	0.031	0.307	0.215	0.13049
S7	0.308	0.309	0.309	0.306	0.031	0.307	0.215	0.13021
S8	0.305	0.305	0.306	0.303	0.030	0.304	0.213	0.12899
S9	0.298	0.298	0.299	0.297	0.030	0.298	0.208	0.12603
S10	0.304	0.306	0.304	0.302	0.030	0.302	0.212	0.12824
S11	0.303	0.305	0.305	0.301	0.030	0.303	0.212	0.12829
S12	0.308	0.307	0.308	0.306	0.031	0.306	0.214	0.13007
S13	0.306	0.305	0.305	0.304	0.030	0.303	0.213	0.12899
S14	0.297	0.298	0.297	0.296	0.030	0.296	0.207	0.12533
S15	0.301	0.303	0.303	0.299	0.030	0.301	0.210	0.12744
S16	0.306	0.305	0.306	0.304	0.030	0.304	0.213	0.12922
S17	0.311	0.309	0.311	0.309	0.031	0.309	0.217	0.13138
S18	0.313	0.312	0.312	0.311	0.031	0.310	0.218	0.13194
S19	0.308	0.309	0.309	0.306	0.031	0.307	0.215	0.13021
S20	0.311	0.312	0.311	0.309	0.031	0.309	0.217	0.13124