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Assessing the Impact of Temperature on Microbial Population in Selected Drinking Water Sources in the Kenema City

Bintu Sabur Janneh
BSC Hons Environmental Management and Quality Control, Master in Public Health
Lecturer in The Public Health Department, Faculty of Health Sc Iences and Disaster Management at The Eastern Technical University of Sierra Leone

ABSTRACT

Public and environmental health protection requires safe drinking water, which means that it must be free of pathogenic bacteria. Among the pathogens spread in water sources, enteric pathogens are the ones most frequently encountered. As a consequence, sources of faecal pollution in waters devoted to human activity must be strictly controlled. In developing countries, 2.6 billion people lack access to basic sanitation and 1.1 billion do not have access to improved water sources. This combination leads to 1.6 million deaths each year from preventable diarrheal diseases, 90 % of which are among children less than 5 years of age. (WHO, 2004). The drinking water quality with respect to bacteriological examination by quantitative determination of total coliform and faecal coliform count and presence or absence for *E.* coli were done for twenty-five (25) hand dug drinking water well samples from Kenema City where cases of cholera and diarrhoea were found to be maximum.

Microbiological water quality parameters were analysed for using the growth media method. Results from water analysis from all the samples collected from the 25 hand dug wells showed that some of the hand dug drinking water sources in the study area were contaminated with *E.*coli, faecal coliform and non-faecal coliform. The higher concentration of microbiological indicators in some of the water sources in this study area have demonstrated the presence of pathogenic organisms which constitute a threat to anyone consuming or in contact with these waters. The majority of the drinking water sources is polluted. Regular quality control mechanisms need to be in place to ensure safety of drinking water**.**

INTRODUCTION

In developing countries, 2.6 billion people lack access to basic sanitation and 1.1 billion do not have access to improved water sources. This combination leads to 1.6 million deaths each year from preventable diarrheal diseases, 90 % of which are among children less than 5 years of age. (WHO, 2004). Public and environmental health protection requires safe drinking water, which means that it must be free of pathogenic bacteria. Among the pathogens spread in water sources, enteric pathogens are the ones most frequently encountered. As a consequence, sources of faecal pollution in waters devoted to human activity must be strictly controlled. Coliform bacteria are the standard used for bacterial quality in drinking water. Coliform bacteria is not a single bacteria species, rather it is a grouping of several different bacterial species. The presence of coliform bacteria in water sources indicates that sewage or some type of surface water is entering and contaminating the water supply. Along with coliform bacteria, other disease causing organisms may be present, and these can cause diseases such as dysentery, typhoid and hepatitis. A water source contaminated with coliform bacteria requires immediate attention. Coliform bacteria are often used as indicator of sanitary quality of foods and water. These organisms are normally found in the aquatic environment and on vegetation. The presence of coliform bacteria in drinking water indicates that the water was not properly treated to eliminate pathogens, or that it got contaminated somewhere in the distribution system. Escherichia coli, a member of the coliform group can ferment lactose at 44^{o}C as well. The origin of Escherichia coli is almost exclusively of faecal origin, thus, if it is found in water or food, it indicates faecal contamination, and an imminent health danger, as other faecal pathogens such as viruses or parasites may be also present. The majority of test for bacteria depend on using three indicator bacterial types. They are the total coliform group, the faecal coliform group, and *E.* coli

Most coliforms are present in large numbers among the intestinal flora of humans and other warm-blooded animals, and are thus found in faecal wastes. As a consequence, coliforms, detected in higher concentrations than pathogenic bacteria, are used as an index of the potential presence of entero-pathogens in water environments. The use of the coliform group, and more specifically *E.* coli, as an indicator of microbiological water quality dates from their first isolation from faeces at the end of the 19th century. Coliforms are also routinely found in diversified natural environments, as some of them are of telluric origin, but drinking water is not a natural environment for them. It is well established that life in any form cannot continue to exist without water; hence water is one of the essential elements for supporting life on earth. It is considered to be the most abundant elements on the planet and therefore has many applications. Amongst the various uses of water, drinking purpose is a crucial one and therefore such water needs proper treatment before consumption. Water that is used for drinking purposes should not contain pollutants or contaminants as it may lead to disease conditions and other potential hazard conditions. Although drinking water coverage has increased worldwide, access to reliable water quality is still a challenge. Poor water quality bears the risk to transport and spread diseases related to water. The problem may not be limited to untreated surface water but may also arise from improved water sources with poor water quality. Another study also states that about 1.8 billion people get water from a sources that are already contaminated with faeces, which can cause cholera, typhoid and many other acute and chronic diseases (Bain *et.al.,* 2014; Jessoe, 2013; Sobsey *et.al.,* 2008).

One of the most common adverse health impact related to poor water quality is diarrhoea. Over 780 million people now lack access to an improved water source World Health Organisation (WHO, 2012) and several studies has estimate the number of people who rely on microbiologically or chemically unsafe water to be 1.8 billion, or about 28%of the global population (Onda K, LoBuglio J., *et.al.,* 2012). Unsafe drinking water is a leading cause of some preventable disease, with the burden borne primarily by children in low and middle-income countries World Health Organisation (WHO, 2012). Pathogen transmitted in drinking water account for an unknown but presumed significant percentage of the estimated 4 billion cases and 1.9 million deaths from diarrhoea diseases each year World Health Organisation (WHO, 2005; Blakely T, Hales S., *et.al.,* 2005). According to World Health Organisation (WHO) and United Nation International Children Emergency Fund (UNICEF) monitoring data from 2004. Access to safe drinking water plays an important role in human life related to health. Recently, the United Nations (UN) stated that safe and clean drinking water is a human right. Therefore, the UN declared "Water for life" program in the period from 2005-2015 and became one of the pillars of the millennium development goals that was achieved by 2015 was halving the number of people without proper access to safe drinking water and basic sanitation (Bloomfield, 2012; WHO, 2011).Furthermore, in developing countries, 17% of all deaths of children below 5 years of age are due to diarrhoea (usually following ingestion of poor quality drinking water) (Prüss A., *et.al.,* 2001) (Clasen, T., Schmidt, W.P., Rabie T *et.al.,* 2007).

Diarrhoeal diseases in 2000 contributed 3% and 400,000 child death to the global disease burden and estimated around one and half million death of children under five years old (Prüss-Üstün *et.al.,* 2008; WHO, 2000). A study from Nicaragua also stated that children from homes with low water availability had a 34% higher rate of diarrhoea. Research showed that 75% of children who get diarrhoea in Dhaka World Health Organisation (WHO, 2007). Bangladesh had an enteric pathogen in their faeces which strengthened the hypothesis that water-borne pathogens are a common cause of diarrhoea (Ashbolt, 2004; Gorter *et.al.,* 1998). A better understanding of the level of microbial water contamination can help us to develop protection program for drinking water systems. Interventions may include measures to improve the water treatment process at household level (St. Laurent and Mazumder, 2014). Ideally, the assessment needs to be done only at the source or piped water system intake, the assessment can also be done at the household level because the result at source may not reflect the water quality that is consume (Wright *et.al.,* 2004).

Water in general is not completely pure because it may contain some form of chemical, physical and biological species that may render it impure. Therefore, we can consider water used for drinking as pure when the presence of any of the above categories of species does not present any significant potential health issue when ingested. Unwanted and/or excessive bacterial growth in drinking water distribution systems can cause deterioration of microbial water quality during storage and transport. Firstly, a number of hygienically relevant opportunistic pathogens, such as Pseudomonas aeruginosa, Legionella pneumophila, Mycobacteria, Aeromonas hydrophila, Klebsiella pneumoniae, and Campylobacter have the capacity to grow at low nutrient concentrations in drinking water distribution systems and/or in households (Szewzyk *et.al.*, 2000; Flemming *et.al.*, 2002; Vital *et.al.,* 2008, 2012; Wang *et.al.,* 2013). In addition to bacterial species, certain protozoa have pathogenic properties (e.g. Acanthamoeba, Cryptosporidium, Giardia lamblia), or act as hosts for pathogenic bacteria such as Legionella pneumophila (Bichai *et. al.,* 2008; Thomas and Ashbolt, 2011; Wang *et. al.,* 2013), while enteric viruses were recognized to cause water-born gastrointestinal or other viral illness (e.g., noroviruses, Hepatitis A virus) (Wingender and Flemming, 2011).

Temperature is one of the most important ecological and physical factor which has a profound influence on both the living and non-living components of the environment, thereby affecting organisms and the functioning of an ecosystem. Although temperature generally influences the overall quality of water (physico-chemical and biological characteristics), the WHO guideline values recommended in water temperatures should be kept outside the range of 25-50^{0}C and a rise in surface water temperatures has been observed since the 1960's in Europe, North America, and Asia (0.2–2)^{0}C, mainly due to atmospheric warming caused by increases in greenhouse gas emissions from anthropogenic activities (Bates *et. al.,* 2008). Surface water temperature is largely dependent on the ambient air temperature and discharge volume. The research work will look at the various drinking water sources (both ground water and surface waters) in five sections in Kenema District and relate how microbial quality influences the anticipated microorganisms in the drinking water supply sources in these water sources from the sections indicated. These sections include Konduboteihun, Lekpeteiy, Lambayama, Nyandayama and Simbeck.

Statement of problem

Sierra Leone is one of the poorest countries in the world. The country is still struggling to provide clean and safe water to its citizen and this has led to the occurrence of outbreaks like typhoid, cholera etc. when microbes influence on water in a particular locality is well established, proper actions can be taken to contain whatever pathogenic microorganisms are in such waters. But the effect of temperature on microorganisms in drinking water has not been sufficiently investigated in the sections this study will be carried out. Hence the gap is expected to be filled to some extent when the research has been carried out in full. Understanding the risk and providing an appropriate treatment technology are important because unsafe drinking water quality is directly related to health issues including premature fatalities caused primarily by microbial contamination prevalent in developing countries (WHO, 2011, Prüss-Ustün *et. al.,* 2014). Poor microbial quality of drinking water is linked to various health conditions, most typically manifesting as diarrhoea, vomiting and gastroenteritis (Chanlett, 1992; American Society for Microbiology, 2002). Diarrhoeal disease has been documented to account for 4.3% of the total global disease burden, in which 88% of cases is caused by poor quality drinking water, poor hygiene and inadequate sanitation. The link between microbial drinking water quality and human health has been questioned. Whilst some studies, such as those by, (Payment *et.al.*, 1991, Payment *et. al.*, 1993, Pinfold *et.al.*, 1991), (Quick, 1997 and Chidavaenzi *et.al.* 1998), have shown that good microbial quality of drinking water is related to a reduction in health outcomes, other studies by (Esrey *et.al.*, 1985, Esrey *et.al.*, 1991 and Payment *et.al.,* 1993) suggest that a reduction in health outcomes is more likely to be achieved through the provision of good quality and quantity of water in conjunction with proper hygiene practices and good sanitation, rather than through the provision of microbially safe drinking water alone.

In general, water supply implementation projects in Kenema consist of three steps: a preparation phase, a construction phase, and a post-construction phase. There are sub-steps that are part of each step. One of the vital parts in the preparation phase is measuring the quality of the water source. Afterwards, the construction phase can be done and water can be distributed. In the third phase, monitoring system and evaluation is done to ensure the project is working well or it needs more improvement. Even though the national coverage has increased significantly, the water quality is still bad due to ineffective drinking water system program and bad economic situation in Kenema (Shrestha *et.al.*, 2003). Although developing countries are commonly highlighted for their populations having low coverage for access to safe water, developed countries including the United States continue to have issues as well. For example, Flint, Michigan underwent a water crisis recently due to lead contamination of the water caused by a switch to a more corrosive water that was compounded by long water residence times, old age of water distribution piping, and poorest average neighbourhood housing condition that resulted in harmful blood lead levels measured in its inhabitants before the intervention took place (Sadler *et.al.,* 2015).

Objective of the study

Broad Objective

The main objective of this study is to assess the effect of temperature on the microbial population of drinking water supply sources in the study area.

Specific Objectives:

1. To identify the various water supply sources for hand dug drinking wells in the study area
2. To determine the categories of microbial population and their abundance in the drinking water supply sources in the study area.
3. To suggest possible intervention to improve water quality in the study area from the results of the microbial testing.

Significant of the study

An understanding on the microbial population and its diversity in drinking water significantly contributes in determining the actions to be taken in reducing or eliminating such populations. This will help provide clean drinking water in the sections that will be surveyed and hence reduce the incidences of water related diseases. In addition, findings in the study will provide an essential reference material on those working on water issues as well as those that may want to conduct research on water issues.

Research questions

- What are the categories and microbial population in the hand dug well drinking water supply sources in the study area?
- What are the purposes of the water supply sources for hand dug well in the study area?
- What are the specific effects of microbial population on the hand dug well drinking water supply sources in the study area?

Research hypothesis

- “The perception of the water quality is not dependent on the educational level of the people.”
- “Does the bacteriological contaminants in water lead to water related disease”

LITERATURE REVIEW

Introduction

The United Nations (UN) set a goal in their Millennium Declaration to reduce the amount of people without safe drinking water by half in the year 2015 (UN, 2000). Safe drinking water for human consumption should be free from pathogens such as bacteria, viruses and protozoan parasites, meet the standard guidelines for taste, odour, appearance and chemical concentrations, and must be available in adequate quantities for domestic purposes (Kirkwood, 1998). However, inadequate sanitation and persistent faecal contamination of water sources is responsible for a large percentage of people in both developed and developing countries not having access to microbiologically safe drinking water and suffering from diarrhoeal diseases (WHO, 2002; WHO, 2002). Diarrhoeal diseases are responsible for approximately 2.5 million deaths annually in developing countries, affecting children younger than five years, especially those in areas devoid of access to potable water supply and sanitation (Kosek *et. al*., 2003; Obi *et. al*., 2003; Lin *et. al*., 2004; Obi *et. al*., 2004). Political upheaval, high numbers of refugees in some developing countries, and the global appearances of squatter camps and shanty rural towns, which lack proper sanitation and water connections, have contributed to conditions which disease causing microorganisms can replicate and thrive (Leclerc *et. al*., 2002; Sobsey, 2002; Theron and Cloete, 2002). The people most susceptible to waterborne diseases include young children, the elderly, people suffering from malnutrition, pregnant woman, immunocompromised individuals, people suffering from chemical dependencies and persons predisposed to other illnesses like diabetes (Sobsey *et. al.,* 1993; Gerba *et. al*., 1996; Grabow, 1996; Leclerc *et. al*., 2002; Theron and Cloete, 2002). Furthermore, an increasing number of people are becoming susceptible to infections with specific pathogens due to the indiscriminate use of antimicrobial drugs, which have led to the selection of antibiotic resistant bacteria and drug resistant protozoa (WHO, 2002; NRC, 2004).

In developing countries, many people are living in rural communities and have to collect their drinking water some distances away from the household and transport it back in various types of containers (Sobsey, 2002). Microbiological contamination of the water may occur between the collection point and the point-of-use in the household due to unhygienic practices causing the water to become a health risk (Sobsey, 2002; Gundry *et. al*., 2004; Moyo *et. al*., 2004). To improve and protect the microbiological quality and to reduce the potential health risk of water to these households, intervention strategies is needed that is easy to use, effective, affordable, functional and sustainable (CDC, 2001; Sobsey, 2002). Many different water collection and storage systems have been developed and evaluated in the laboratory and under field conditions (Sobsey, 2002). In addition, a variety of physical and chemical treatment methods to improve the microbiological quality of water are available (Sobsey, 2002). The aim of this study was to improve the microbiological quality of drinking water in rural households by the implementation of intervention strategies which include the use of traditional storage containers as well as the CDC safe storage container, with or without the addition of a sodium hypochlorite solution at the point-of-use.

Faecal contamination and disease outcome

Pathogenic organisms such as viruses, bacteria, protozoa and helminth eggs are often found in faeces of humans and animals (Ashbolt, 2004) and may contaminate drinking water sources causing several infectious diseases (WHO, 2011). Table 1 provides examples of disease outbreaks that occurred as a result of failure in supply systems.

Indicator organisms of faecal contamination

Direct pathogen monitoring is impractical because pathogens occur generally in small numbers and their detection by routine techniques may be impossible. In addition, detecting pathogenic organisms is often time consuming, costly and poses health risks. As a result, indicator organisms are chosen over pathogenic microorganisms (Leclerc, 2001). Indicator organisms, particularly bacterial indicators, are widely used to assess contamination of water sources by human and animal excreta. *E.* coli, total coliform and thermotolerant coliform bacteria have been used extensively as indicators of faecal contamination to monitor drinking water quality. When compared to detection of pathogenic organisms, detection and enumeration of bacterial indicators remains in the forefront of microbial water quality monitoring. However, using indicator organisms has several drawbacks. For instance, they might respond differently to the physico-chemical characteristics of water. Moreover, pathogens can exist in water even in absence of indicator organisms (JMP, 2012).

Total coliform bacteria

Total coliforms are organisms that are generally found in the environment. The group encompasses coliforms that originate from human and animal faeces along with those coliforms that naturally exist in soil. Coliform bacteria can grow at 37oC in the presence of bile salt, also they are characterized by their ability to utilize lactose and produce gas and acid (Horan, 2003). In many instances coliform bacteria are used to assess the quality of water supplies treated with chlorine, as they are sensitive to chlorination and their presence indicates the occurrence of contamination (JMP, 2012). However, because of their presence in the environment this group of organisms are not considered as useful indicator of faecal contamination (WHO, 2011).

Thermotolerant coliform bacteria

Thermotolerant coliforms comprise coliforms that are able to ferment lactose at 44.5 °C. The group contains bacteria like *E.* coli and Klebsiella pneumoniae. The detection of thermotolerant coliforms indicates contamination of water sources with faecal material (Bitton, 2005). Several studies show that faecal coliforms are not potent indicators of faecal contamination as a result of the presence of species that are found in nature like Klebsiella (Alonso *et. al*., 1999; Ashbolt *et. al.,* 2001; Leclerc *et. al*., 2001). So, their presence can be used as a secondary indicator to assess the effectiveness of water treatment plants and they are generally easy to detect (WHO, 1997).

Escherichia coli (E. coli)

E. coli is a species of thermotolerant coliform distinguished by producing endole from tryptophan, and it also possess β-galactosidase and β-glucuronidase enzymes. *E.* coli is predominantly found in the gastrointestinal tract of warm-blooded animals (Krieg & Holt, 1984). Nevertheless, some findings show that E. coli can also be found, multiply and persist in the environment especially in tropical soils, climates and waters rich with organic matter (Jimenez *et. al*., 1989; JMP, 2012). The majority of *E.* coli strains are non-pathogenic, even though some serotypes, like *E.* coli 0157:H7, can cause serious illnesses (Wilson *et. al*., 2011). The use of *E.* coli as an indicator organism of water quality dates back to the late of 18th century. However, the procedures were not suitable for periodic detection of *E.* coli. Due to this surrogates for *E.* coli like coliforms were used to detect faecal contamination (Edberg *et. al*., 2000). Multiple tube fermentation and membrane filter methods are most commonly used techniques to detect indicator organisms of faecal contamination in water. After the enzymes β-glucuronidase and β-galactosidase were identified the sensitivity of multiple tube fermentation and membrane filter techniques increased (Annie, 2002). The detection of *E.* coli shows recent faecal contamination of water sources as the bacteria is sensitive to environmental factors due to this the indicator bacteria is widely used to monitor the quality of water. The detection of *E.* coli in water samples does not prove that pathogenic organisms are present, instead it shows a risk of faecal contamination, and therefore the possible presence of pathogenic microorganisms of faecal origin (Brüssow *et. al.,* 2004). As a result, the detection and enumeration of E. coli is broadly used to monitor water samples for faecal contamination and (Atlas *et. al*., 1993). 2.4. Other indicator organisms

Faecal Streptococcus

This group comprises numerous species of Enterococcus bacteria among which Enterococcus faecalis and Enterococcus faecium appear in large numbers. They are resistant to salt and to action of chlorination. Due to this they tend to live longer than coliform bacteria in water sources. They have limited application in routine water quality monitoring because of their lower abundance in faeces and the long detection (JMP, 2012).

Clostridium perfringens

The spores formed by Clostridium perfringens persist in the environment for a long period of time. This bacterium can stay dormant in soils and biofilms for several years and is therefore unsuitable at indicating recent faecal contamination. Another limitation is that the cost of analysis to detect Clostridium perfringens is relatively higher than other indicator organisms due to anaerobic nature of the bacteria it should be incubated in anaerobic condition (Edberg *et. al.,* 2000).

Microbial drinking water quality

The primary concern about microbial drinking water quality is the possible outbreak of pathogens, and the resulting risks for human health. Although water treatment plants apply various disinfection strategies, occasional microbial water quality failure still happens even in developed countries, where water quality is commonly high. For instance, a population of around 57500 people were affected during an outbreak of Cryptosporidium in Yorkshire, UK in 2014 (Drinking water inspectorate, 2014). A total of 42 water-associated outbreaks were reported in USA from 2013 to 2014 and Legionella accounted for 57% of the events (Katharine *et. al.,* 2017). Water treatment failure is commonly attributed to large scale outbreaks, such as inadequate or interrupted treatment of water (Craun *et. al.,* 2010). However, as biofilm is a good shelter for microorganisms (Costerton *et. al.,* 1995), its existence increases the survival and growth opportunity of pathogens with low-level concentrations.

Regarding the non-pathogenic microorganisms either within or released from biofilms, water quality and drinking water distribution system (DWDS) operation might be affected by degrading aesthetics and reducing disinfection efficiency. According to industry reports (Customer Council for Water, 2014), the leading water quality problem related to aesthetics as given by customers is discoloration. Discoloration is associated with the mobilisation of accumulated materials from DWDS as reflected by the increasing turbidity (Vreeburg and Boxall 2007). This event often occurs with the change of hydraulic regimes (Husband *et. al*., 2008) and the particulate accumulations within discoloured water is found to have a relationship with biomass (Gauthier *et. al.,* 1999), thereby making discoloration as a possible water safety issues. In addition, though the mechanisms of accumulations of discoloration materials have not been fully investigated, biological interactions were thought to be one of the material sources (Kirmeyer 2000). Except influencing water quality as an entire structure, some specific microbial groups within biofilm (i.e. nitrifying bacteria) could affect water quality through bio-chemical reactions. Nitrification is a process often observed within DWDS using chloramine as disinfectant, where nitrifying bacteria including ammonia oxidizing bacteria (AOB) and nitrite oxidizing bacteria (NOB) could utilize free ammonia as nutrient and produce nitrite/nitrate (Grady *et. al.,* 2011). This process will bring series of water quality problems and a fast decay of disinfectant residual is one of the major consequences (Cunliffe 1991; Odell *et. al.,* 1996*;* Sathasivan *et.al.,* 2008). A low-level disinfectant residual will result in an increased chance of pathogen outbreak, and simultaneously promote the development of biofilm which could make DWDS management to be difficult. To address this phenomenon, studies have focused on investigating the nitrifying community (Regan *et. al.,* 2002; Regan *et. al*., 2003) and the physio-chemical factors relating to the process (Cunliffe 1991; Fleming *et. al.,* 2005, 2008). On the other hand, water utilities usually respond by increasing disinfectant residual, combined with system flushing (Seidel *et. al*., 2005). However, the efficiency of such strategies remains limited.

Ultimately, reducing microbial water quality failures and increasing drinking water distribution system (DWDS) operation efficiency are of significant importance; and to do so requires further understanding of the processes and interactions involving biofilm characteristics and microorganisms within it. Consequently, research evaluating both operational effects on biofilm and microbial community at a molecular level is needed. This, could give insight into biofilm characteristics, and thereby provide feasible management suggestions for water utilities.

Removal of Human Infectious Disease Pathogens

Bacteria, Parasites and Viruses Disinfection, which is the removal of pathogenic (i.e., disease-causing)

Microorganisms, is an important and desirable outcome of wastewater treatment processes. WSPs are well known to efficiently and effectively remove different types of pathogenic microorganisms, such as faecal enterococci, Cryptosporidium, Giardia, helminth eggs (for example, Taenia, Ascaris, and Trichuris) (Davis-Colley *et. al*., 2000; Anceno *et. al*., 2007; Reinoso and Bécares 2008; Tyagi *et. al*., 2008). Their high efficiencies of removing pathogens and relatively low costs are two of the main reasons that make

WSPs very popular in the developing world (Davis-Colley *et. al*., 2000). There are three main types of pathogens that are present in wastewaters (Davis-Colley *et. al*., 2000). These are bacteria, viruses, and parasites including protozoan parasites and worm parasites. Bacterial pathogens include bacteria such as Salmonella, Shigella, Vibrio cholera, pathogenic strains of *E*. coli and several bacteria that cause zoonotic (harboured by domestic or wild animals) diseases. Campylobacter spp. is one of those bacteria that cause zoonotic diseases. Studies have indicated that Campylobacter spp. including the common human-pathogenic C. Jejuni, are effectively removed in WSPs (Davis-Colley *et. al*., 2000). C. Jejuni is one of the most important causes of waterborne gastroenteritis in the developed world (Davis-Colley *et. al*., 2000). Oragui and other researchers (1986) indicated that Campylobacter spp. were completely removed in deep WSPs in northeast Brazil. One year later, Pearson and other researchers (1987) indicated that C. Jejuni along with Salmonella spp. was removed more rapidly than *E*. coli in a WSP system. Bacterial diseases cause many thousands of people to die every year, especially in the developing world where public health engineering is not well established. Therefore, WSPs play a key role in reducing the incidence of bacterial diseases and avoiding epidemic outbreaks (Mara 2001). The enteric viruses cause waterborne enteric diseases in both developed and developing worlds. There are at least 140 types of waterborne enteric viruses reported including Hepatitis A virus and rotavirus (Davies-Colley *et. al*., 2000). For people who have healthy immune systems, viral diseases do not have lethal effects, but some viral diseases, such as hepatitis A can have life-long effects. Some viruses are resistant to standard disinfectants, such as chlorine. However, they can be efficiently removed in wastewater stabilization ponds WSPs by sunlight, adsorption/sedimentation of solids and increased pH levels (Davies Colley *et. al.,* 2000). Protozoan parasites including Giardia and Cryptosporidium have been reported to cause public health concerns (Bitton 1999; Robertson *et. al*., 1999). Those parasites can cause diarrhoea, abdominal pain, and nausea. Even though the symptoms are rarely fatal, they can last for many months. The cysts of Giardia and Entamoeba, and oocysts of Cryptosporidium in the infective stages are robust in waters and wastewaters. And they are resistant to standard disinfectants, such as chlorine. Therefore, ultraviolet disinfection is commonly applied in developed countries, because those parasites are found to be susceptible to ultraviolet (Bitton 1999). WSPs can efficiently remove these parasites because of the occurrence of sedimentation and exposure to ultraviolet under sunlight in wastewater stabilization ponds (WSPs) (Davies-Colley *et. al*., 2000). Worm parasites (helminths) can cause severe symptoms and sometimes death (Bitton1999). At least 50% of the world's population may be infected with one or more helminth species (Davies-Colley *et. al*., 2000). Like protozoan parasites, worm parasites can also be efficiently removed in WSPs for the same reasons mentioned above.

Total coliform bacteria

Total coliform bacteria are defined as aerobic or facultative anaerobic, Gram negative, non-spore forming, rod shaped bacteria, which ferments lactose and produce gas at 35°C (Standard Methods, 1995). Total coliforms include bacteria of known faecal origin such as E. coli as well as bacteria that may not be of faecal origin such as Klebsiella spp, Citrobacter spp, Serratia spp and Enterobacter spp which are found in nutrient rich water, soil decaying vegetation and drinking water with relatively high levels of nutrients (Pinfold, 1990; Ramteke *et. al.,* 1992; WHO, 1996). The recommended test for the enumeration of total coliforms is membrane filtration using mEndo agar and incubation at 35°C to 37°C for 24 hrs. to produce colonies with golden green metallic shine (Standard Methods, 1995). In water quality studies, total coliform bacteria are used as a systems indicator, which provides information on the efficiency of water treatment (Standard Methods, 1995). The presence of total coliform in water samples are therefore, an indication that opportunistic pathogenic bacteria such as Klebsiella and Enterobacter which can multiply in water environments and pathogenic pathogens such as Salmonella spp, Shigella spp, V. cholera, Campylobacter jejuni, Campylobacter coli, Yersinia enterocolitica and pathogenic E. coli may be present (DWAF, 1996; Grabow, 1996). These pathogens and opportunistic microorganisms could cause diseases such as gastroenteritis, dysentery, cholera, typhoid fever and salmonellosis to consumers (DWAF, 1996;

Grabow, 1996). In particular, individuals who suffer from HIV/AIDS related complications are more at risk of being infected by these microorganisms (DWAF, 1996).

Faecal coliform bacteria

Faecal coliform bacteria are Gram negative bacteria, also known as thermotolerant coliforms or presumptive E. coli (Standard Methods, 1995). The faecal coliform group includes other organisms, such as Klebsiella spp, Enterobacter spp and Citrobacter spp, which are not exclusively of faecal origin (Standard Methods, 1995). Escherichia coli are specifically of faecal origin from birds, humans and other warm blooded animals (WHO, 1996a; Maier *et. al.,* 2000). Faecal coliform bacteria are therefore considered to be a more specific indicator of the presence of faeces (Maier *et. al.,* 2000). The recommended test for the enumeration of faecal coliforms is membrane filtration using mFC agar and incubation at 44.5°C for 24 h to produce blue coloured colonies (Standard Methods, 1995). Faecal coliforms are generally used to indicate unacceptable microbial water quality and could be used as an indicator in the place of E. coli (SABS, 2001). The presence of faecal coliforms in a water sample indicates the possible presence of other pathogenic bacteria such as Salmonella spp, Shigella spp, pathogenic E. coli, V. cholera, Klebsiella spp and Campylobacter spp associated with waterborne diseases (DWAF, 1996). Unfortunately, faecal coliform bacteria exhibit species to species variations in their respective stability and resistance to disinfection processes; do not distinguish between faeces of human and animals' origin; have low survival rates and have been detected in water sources thought to be free of faecal pollution (Goyal *et. al*., 1979; Fujioka *et. al*., 1988).

Faecal enterococci bacteria

Faecal enterococci bacteria are found in the genus Enterococcus and include species like Enterococcus faecalis, Enterococcus faecium, Enterococcus durans and Enterococcus hirae (Standard Methods, 1995; WHO, 1996). The genus Enterococcus are differentiated from the genus Streptococcus by their ability to grow in 6.5% sodium chloride, pH 9.6, temperatures of 45ºC and their tolerance for adverse growth conditions (Maier *et. al.,* 2000). Faecal enterococci are spherical, Gram positive bacteria, which are highly specific for human and animal faecal pollution (Standard Methods, 1995). Most of the species in the Enterococcus genus are of faecal origin and is regarded as specific indicators of human faecal pollution, although some species are found in the faeces of animals and plant material (WHO, 1996). The recommended test is membrane filtration using mEnterococcus agar and incubation at 35°C to 37°C for 48 h to produce pink colonies (Standard Methods, 1995). Faecal enterococci rarely multiply in polluted water environments and are more resistant to disinfection and treatment processes than the Gram negative faecal coliform bacteria (Standard Methods, 1995). The presence of faecal enterococci in water samples are therefore, an indication of the health risk to waterborne diseases such as meningitis, endocarditis and infections of the eyes, ears and skin (DWAF, 1996; Grabow, 1996).

Clostridium perfringens bacteria

Clostridium perfringens is a Gram positive, sulphite reducing anaerobic, rod shaped, spore forming bacteria normally present in faeces of humans and warm blooded animals (Standard Methods, 1995). However, C. perfringens are also found in soil and water environments (WHO, 1996). The spores can survive much longer than coliform bacteria and are highly resistant to water disinfection and treatment processes (Standard Methods, 1995). Clostridium perfringens are therefore used as an indicator of faecal pollution to indicate the potential presence of enteric viruses, which may include Enteroviruses, Adenoviruses and Hepatitis viruses as well as the cysts and oocysts of protozoan parasites such as Giardia, Entamoeba and Cryptosporidium in treated drinking water (Payment and Franco, 1993). The enumeration test includes membrane filtration using specific medium (e.g. mCP or Perfringens selective OPSP medium with supplements) and incubation 35°C to 37°C for 48hrs at in micro-aerophillic conditions to produce black colonies (Standard Methods, 1995).

Bacteriophages

Bacteriophages are viruses, which specifically infect bacteria (Grabow, 2001). Bacteriophages have been suggested as useful indicators to predict the potential occurrence of enteric viruses in water (Grabow *et. al.,* 1984*;* Leclerc *et. al*., 2000). The survival of bacteriophages is affected by the densities of the host and the bacteriophages in the water sample (Grabow, 2001). In addition, the association of the bacteriophage with solids and the presence of organic matter in the water sample could influence the attachment of the bacteriophages to the host bacterium (Grabow, 2001). Several studies have shown that ultra violet light, temperature, pH of the water, and ion concentrations in the water could.

RESEARCH METHODOLOGY

Description of study location

Kenema is the third largest city in Sierra Leone (after Freetown and Bo), and the largest city in the country's Eastern Province. Kenema is the provincial headquarter town of Kenema District and a major economic center of the Eastern Province. Its 2015 population was 200,354 (Statistics Sierra Leone, 2015). Kenema District has an area of 6,053 km^2 (2,337 sq. mi) and comprises sixteen chiefdoms. By road, it is approximately 300 kilometers (185 mi) southeast of Freetown and about 60 kilometers (40 mi) south of Bo. The District of Kenema borders Bo District to the west; the Republic of Liberia to the southeast; Tonkolili District and Kono District to the north; Kailahun District to the east and Pujehun District to the southwest. One of Sierra Leone's six municipalities, Kenema is governed by a directly elected city council, headed by a mayor to whom executive authority is vested, and who is responsible for the city's general management. The mayor and council members are elected every four years. Kenema's growth was originally promoted by the logging and carpentry industries, which were linked to the city by the now-closed railway. Since then, its economy has benefited from the diamond mines first discovered in the area in 1931. Kenema has a mix economy made up of diamond and gold mining as well as agricultural product of coffee, cacao and rice farming. The chiefdom where the samples were collected is in the Nongowa chiefdom in a sections called Nyandayama, Lambayama, Simbeck, Konduboteihun and Lekpeteiyeh.

The Global Positioning System (GPS) Location of Kenema

The Global Positioning System (GPS) location of Kenema District is latitude: 7^0 52` 36.73” North and longitude: -11$^0$ 11` 24.90” West.

The Climatic/Weather Pattern of Kenema

The climate of Kenema is tropical. The rainfall is significant most months of the year, and the short dry season has little effect. According to Koppen and Geiger, this climate is classified as Am. In Kenema, the average annual temperature is 25.7^{0}C. About 2743mm of precipitation falls annual. The driest month is January, with 15mm of the rain. Most of the precipitation here falls in august, average 499mm. March is the warmest month of the year. The temperature in March averages 27.0^{0}C. August is the coldest month, with temperatures averaging 24.1^{0}C. There is a difference of 484mm of precipitation between the driest and wettest months. Throughout the year, temperatures vary by 2.9^{0}C.

Topography of Kenema

The topography within 2 miles of Kenema contains very significant variations in elevation with a maximum elevation change of 1,027 feet and an average elevation above sea level of 673 feet. Within 10 miles also contain very significant variations in elevation (1,798 feet). Within 50 miles contains very significant variations elevation (2,615 feet). The area within 2 miles of Kenema is covered by grassland (49%), tress (28%), and cropland (18%), within 10 miles by cropland (35%) and tress (29%), and within 50 miles by tress (44%) and cropland (28%).

The Vegetative cover of Kenema.

In Kenema most of the tropical rainforest has been reduced to secondary vegetative cover due to human disturbances. The vegetation is on perennial crop plantations (cacao, coffee and oil palm) as well as the vegetation on the cropped areas (upland rice farm site and swamp) considerably changed after harvest. On the upland rice farm site, rice was intercropped with sorghum, maize and okra etc. In the swamp paddy rice was cultivated during the rainy season and vegetables (okra, eggplant, pepper, tomato) during the dry season.

Water System of Kenema

Kenema get their water supply system through the following processes;

Borehole- this is done by machinery way of digging deep down above 50m onwards also with treatment storage tank and pipes network with taps within the community. Hand dug wells form standard-protected hand dug well with hand pump and unprotect hand dug well with rope and buck. Gravity water supply also form catchment of water from up in the hills down to the community with storage tank and pipe network within the community with taps. Big town water supply is by using machinery treatment plant, storage tank of treated water and pipes network with taps within the towns and cities with the use of machine to pump raw water to the treatment tank and after treatment to the distribution tank from here to the pipes network with taps within the community.

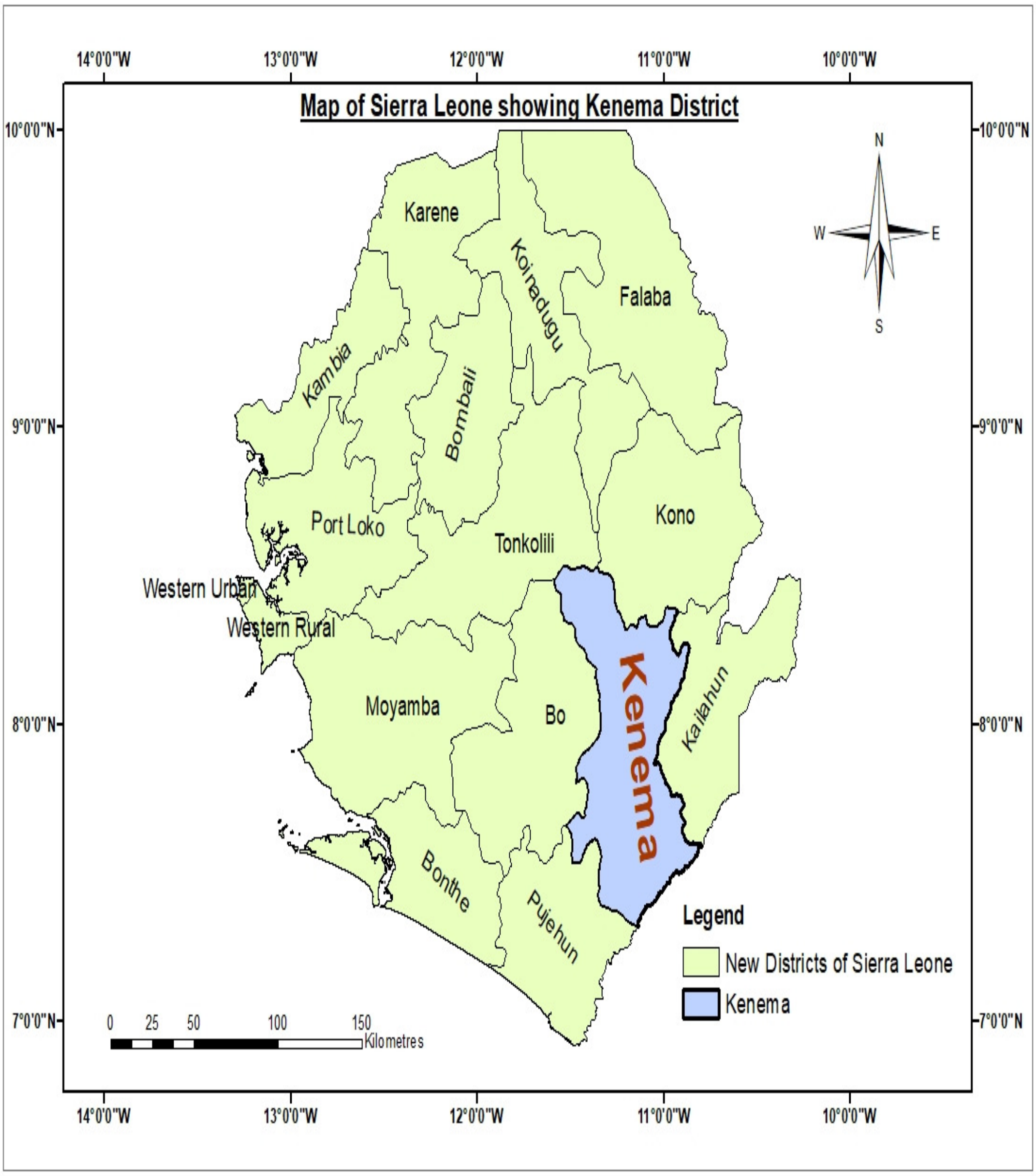

Figure 1: Map of Sierra Leone showing Kenema District

Sampling Area

The sampling areas, which were taken into consideration in this research work, were as follows:

1. Nyandayema
2. Lambayama
3. Konduboteihun
4. Simbeck
5. Kpetawoma
6. Lekpeteiyeh

Nyandayama

Nyandayama is a large section in Kenema City where in the inhabitant are mostly traders and majority of them get there drinking water supply from hand dug wells by WATER WASH while some are constructed by themselves in the section although some have access to tap water supply.

Lambayama

Lambayama is also a large section in Kenema City where in some of the inhabitant are involved in agricultural activity due to swamp found within the area. They get their drinking water supply from hand dug wells constructed by the land owners and few tap water supplies.

Konduboteihun

Konduboteihun is a larger section in Kenema City where in some of the inhabitant get there drinking water supply by hand dug wells constructed by them self in the community. They use the water for drinking, bathing and other domestic purposes as well.

Simbeck

Simbeck is a large section in Kenema City where in the people around this place are mostly involve in business activity. In this section some of the people get there drinking water mostly from wells and use for cooking, bathing, and other domestic use.

Lekpeteiyeh

Lekpeteiyeh is small section in Kenema City where in the people are involve in agricultural and mining activity. Some use hand dug well for their drinking purposes and other uses such as cooking bathing and domestic purposes.

Identification of Sampling Point

This survey was made along the water course for both Nyandayema, Lambayama, Konduboteihun, Simbeck, Kpetawoma and Lekpeteiyeh with a vision to establish safe drinking water supply to these six section and two samples was collected form each locations.

Sampling point at Nyandayema

Nyandayema is a large area in Kenema where in some people use hand dug well as main drinking water supply sources and for domestic uses. It is a densely populated area in Kenema City and the people are mostly involved in business activities.

Sampling point at Kpetawoma

Kpetawoma is also a large section in Kenema City, in this area flooding normally occur due to poor drainage system or pattern and it also a swampy area therefore most people in this area have their drinking water supply source from hand dug wells and for domestic purposes as well. Majority of the people are involving in petty trading business.

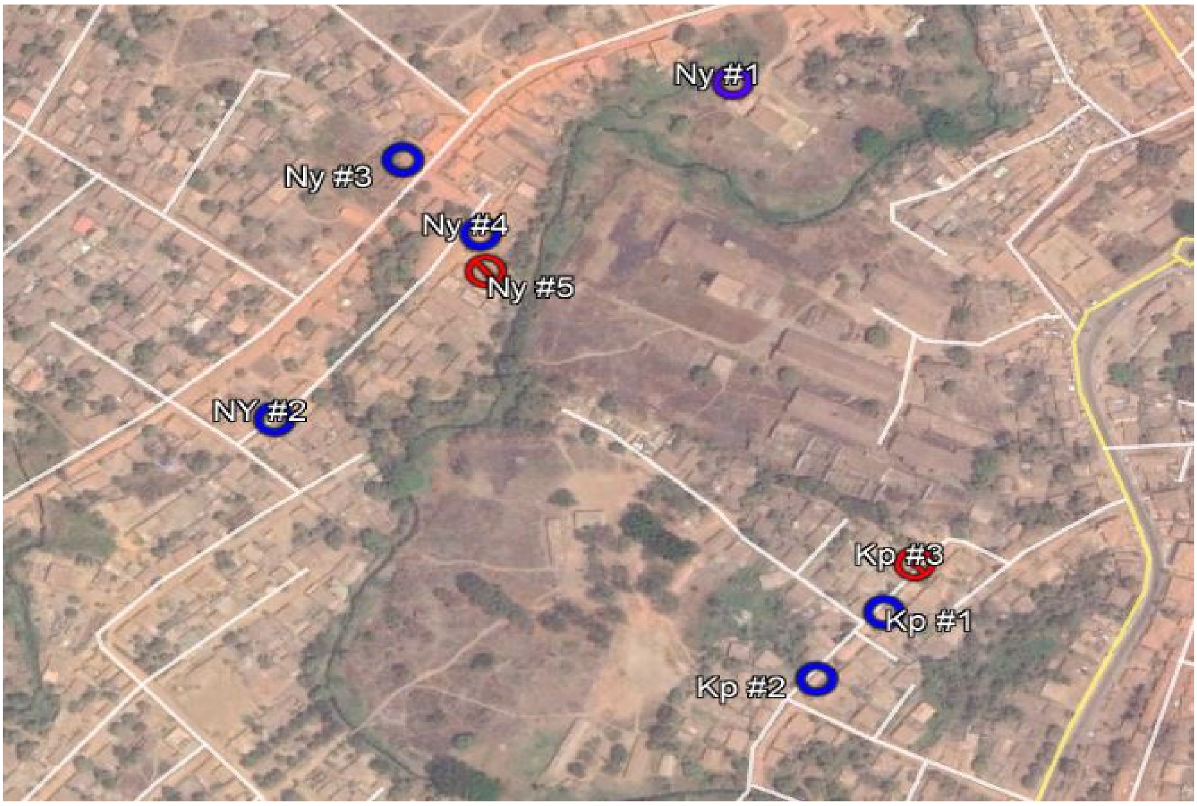

Figure 2-Map showing sampling points for Nyandayama and Kpetawoma

Sampling point at Lambayama

Lambayama is also a large section in Kenema City where in due to the expansion of this area some people uses hand dug well as their main drinking water supply sources and for domestic uses. It is also a dense populated area and people are involved in both business and agricultural activities too.

Figure 3: Map showing sampling points at Lambayama (La) section

Sampling point at Konduboteihun

Konduboteihun is also another larger area in Kenema City that comprises of hilly region due to its expansions some area mainly have hand dug wells as their main drinking water supply sources and for domestic purposes. They are involved in minor agricultural activity and business activity.

Figure 4: Map of Kenema showing sampling points at Konduboteihun section

Sampling point at Simbeck

Simbeck is a large area in Kenema City that comprises of a swampy area. Some people use hand dug well as their main drinking water supply source and for domestic uses. The people in this area are involved in business activity i.e. petty trading.

Figure 5: Map showing sampling points at Simbeck (Si) section

Lekpeteiyeh

Lekpeteiyeh small section in Kenema City, in this section some of the people use hand dug well for drinking purpose and domestic purposes such as cooking, laundry etc.

Figure 6: Map showing sampling points at Lekpeteiyeh (Le) section

Sample Collection and Preservation

Various containers pre-treatment procedures were undertaking before the sample collection process. The containers use during the research was polyethene rubber bottle prior to use. All the containers were washed and sterilize for two days. The clean polyethene rubber bottles were then sealed in clean polyethene bag until required for use. The water sample was collected in sterile 500ml polyethene bottle. The collected samples were used immediately after the collection processes and later been put in an incubator for 48hours.

Transport to Laboratory

The sterile 500-ml sample rubber bottles were carefully numbered and labelled according to the sections where the samples were been collected. Samples were transported to the Laboratory of Water Resource Management/Water Directorate in Kenema District in cooler at 4^0C. The transportation of the water samples of Nyandayema, Lambayama, Konduboteihun, Simbeck, Kpetawoma and Lekpeteiyeh at the laboratory was done by motor bike.

Analytical Parameters

The sample was analysed for Bacteriological parameters:

i. Faecal coliform
ii. *E*. coli
iii. Non faecal coliform

Instrumentation

Lovibond Water Testing Kit

This instrument was use to carry out the field analysis. It contained, pH meter and conductivity meter, tube, photometer, gloves, Global Positioning System (GPS) and Microsoft excel.

Experimental Procedure

The chemicals and equipment used for this analytical procedure were:

i. Growth media
ii. Polythene bottles
iii. Big and small compartment bag

This process involved adding the Growth media into 100ml of water samples into the small compartment bag and gently pressed it until it become white then later transfer it into the big compartment bag and preserve it between 40^0C to 45^0C in the incubator for 48hour to ensure that faecal coliform contaminants are been determined. After which if there is a green colouration it indicates that there is a high level bacteriological contaminants that is *E*.coli, Faecal coliform and non-faecal coliform in water sample tested and if its shows an orange colouration it indicates the purity of the water.

Figure 7- Showing Lovibond Water Testing Kit

RESULT AND DISSCUSSION

Relation between *E. coli* and other measures of contamination (coliform counts)

There is a strong correlation between all three measures of water quality (Figures 4.1 & 4.2). The *E. coli* counts were surprisingly low, as none were detected in half the wells sampled, in contrast non-faecal coliforms were found in nearly all wells. In this figure the faecal coliform counts ranges from 0-30 colonies and the non-faecal ranges from 0-35 colonies which exceeds World Health Organization (WHO) standard. In this case non-faecal coliform predict the faecal coliform with a high degree of reliability. The faecal coliforms are group of non-faecal that are considered to be present specifically in the gut and feces of warm-blooded animal (WHO 2001), thus non-f predicts f with a high degree of reliability $r^2 = 0.881$ (that is 88% of the variation in the f is explained by variation in the non-f). (Statistical test linear regression, $p<0.001$, N=24).

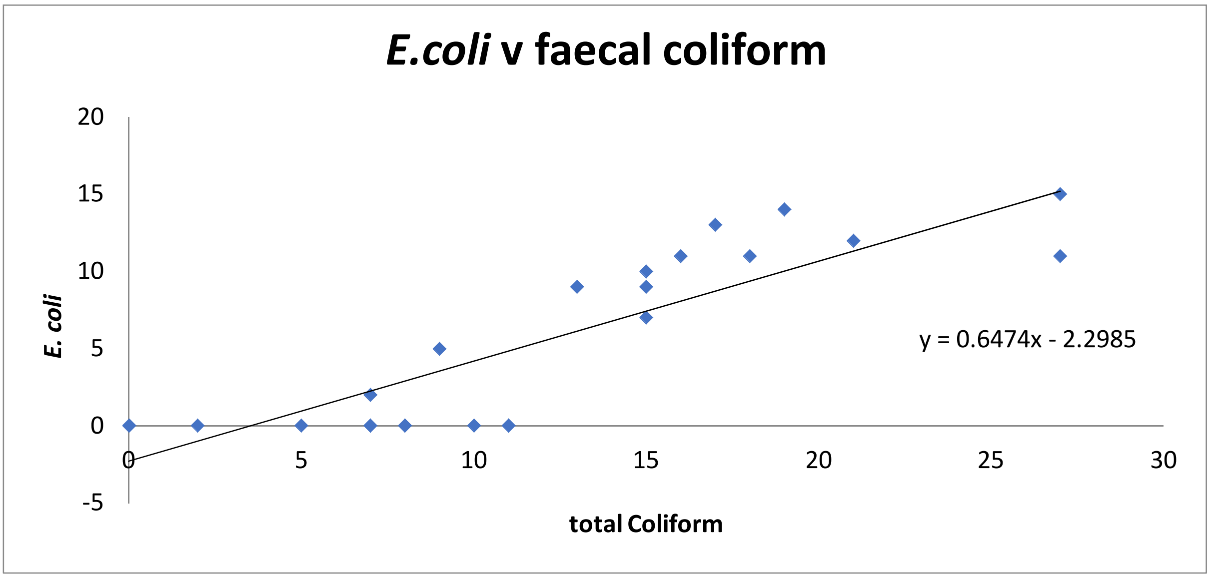

Figure 8 showing E. coli with respect to faecal coliform bacteria in hand dug wells.

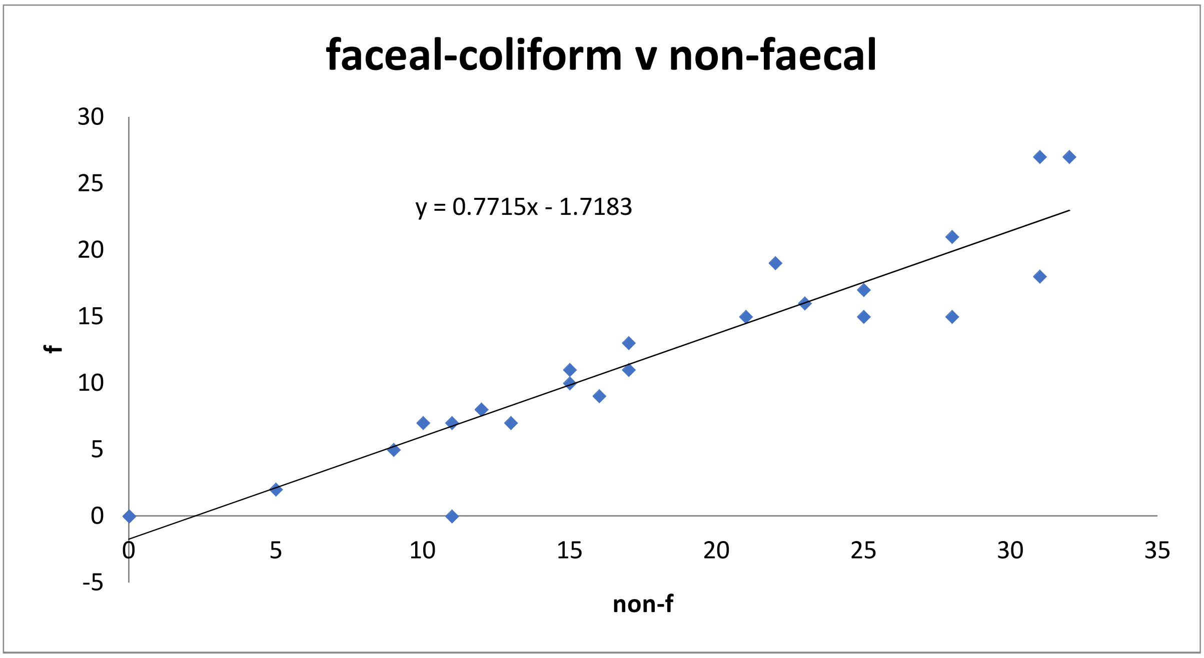

Figure 9 showing a plot of faecal coliform with respect to non- faecal coliform in hand dug drinking wells.

Relationship between contamination and age of the well

The non-faecal coliform bacteria count ranges from 0-35. The World Health Organization (WHO) standard is less than 10 per 100ml of water. The hypothesis is that a well gets older it is more likely to become contaminated. In the case of the wells in Kenema contamination did increase with the age of the well (Figure 4.3), however, this is NOT statistically significant (linear regression, adjusted r^2 =0.031, p=NS, N=23).

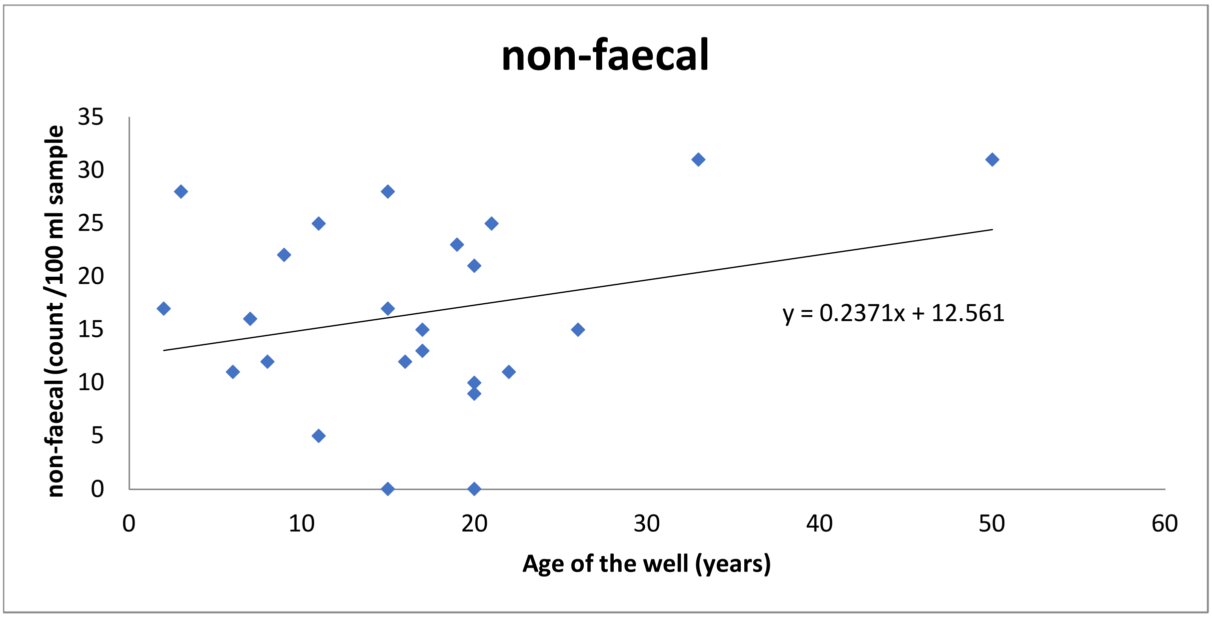

Figure 10 showing the relationship between non-faecal coliform in the water (count per 100 ml) with respect to the age (in years) of the well.

Relationship between contamination and distance from the nearest latrine

We would expect that contamination of a well is related to how close point source pollution sources are. We estimated the distance from the well to the nearest latrine. Figure 4.4 show that contamination does increase when latrines are close, however, this relationship is NOT statistically significant, (linear regression, r2=0.016, p>0.05, N=24).

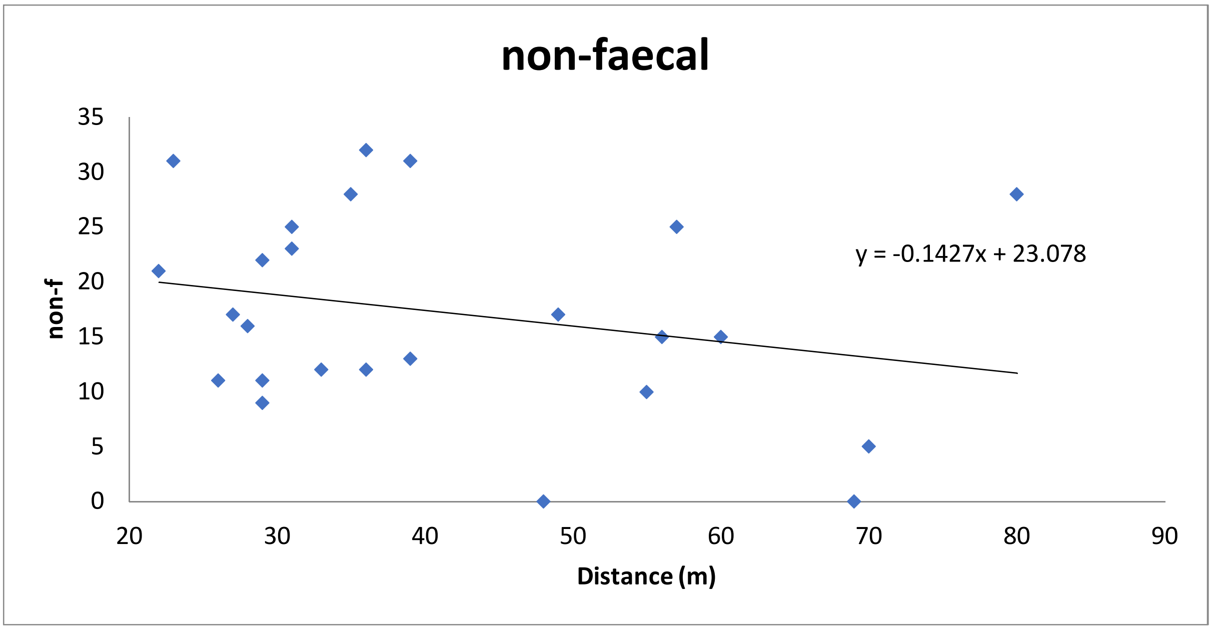

Figure 11 showing a plot of non-faecal coliform bacteria with respect to the distance to the nearest latrine.

Discussion

The high quantity of bacteria counts may result from the closeness to latrines in the study areas (section 4.3). The amount of E. coli present in the water samples ranges from 0-18 and the faecal coliform ranges from 0-30 while the maximum permissible standard limit for World Health Organization (WHO) for E. coli and faecal coliform is zero colony. Some of the water samples analysed have been contaminated except sample at NSW1 and NSW4 which fall within the maximum permissible standard limit of World Health Organization standard. High number of *E. coli* in drinking in drinking water can cause water borne diseases and sickness to the people living in the study area. Therefore, proper treatment must be put in place to avoid widespread water borne disease and sickness like Diarrhoea, Dysentery, Typhoid and Cholera etc. Furthermore, the result on the hand dug drinking wells revealed high level of pollution. The high number of *E. coli* bacterial from (ranges 0-18) shows the degree of pollution which is attributed to the sampled wells. It maybe suggested that some of the wells sample having high faecal coliform counts (range 0-30) might have resulted from closeness to latrines, and uncovered wells. Total coliforms are an indicator of water vulnerability to contamination by more harmful microorganisms and are not likely to cause illness. In this situation the results indicated that the hand dug wells had high susceptibility to contamination by other microorganisms. The World Health Organisation (WHO) drinking water guidelines for feacal coliforms are 0 per 100 ml; the hand dug well only 2 met the guidelines. The other hand dug sample points do not.

In the case of ground water, hand dug wells and unprotected water connection systems, it should be possible to achieve very low levels of contamination. However, the study result indicated that protected water sources are subjected for a high level of fecal contamination in almost all cases. Some of the protected water sources are said to be chlorinated though not regularly done. In regularly checked water sources the E. coli count should have been almost zero per 100ml (Cheesbrough, 1987). One of the possible reasons might be constructional defects on casing, concrete covers, fences and diversion ditches. Furthermore, lack of regular supervision, disinfection and proper maintenance might be the reasons for contaminating protected water sources (MOH, 1997). The high level of *E.* coli can also be explained by the fact that poor sanitation habit and hygiene education influences the use of protected water supplies. As a result, health impact reduction in diarrhoea was marginal. Thus sanitation has great impact on the hand dug wells. All water sources are grossly polluted. The effect, therefore, is attributed to constructional defects, poor sanitation, low level of hygiene education, poor supervision and maintenance and irregular disinfection.

Hypothesis

Hypothesis 1: The perception of water quality is not dependent on the educational level of the people. According to this hypothesis, all the people in the study area have a basic knowledge on some physical water parameters such as the taste, color and smell. However, there are differences between their knowledge on water and the actual laboratory results. Based on the result for bacteriological parameter, it shows that there is greater contamination of feacal coliform and non-feacal coliform including E-coli bacteria present in hand dug wells within the study area. Therefore, this hypothesis is true.

Hypothesis 2: Does the bacteriological contaminants in water leads to water borne disease.

According to this hypothesis, the presence of bacteriological contaminants such as E. coli, faecal coliform and non-faecal in water can lead to various water borne diseases and sickness like diarrhoea, dysentery, typhoid and cholera which can implicate the health of people drinking the well water. Therefore, this hypothesis is true.

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

Summary

This study was undertaken to investigate the impact of temperature on microbial quality of drinking water samples in Kenema City together with bacteriological characteristics in some drinking water within Kenema City, the eastern part of Sierra Leone. Pollution of water bodies is one of the areas of major concern to environmentalists. Water quality is an index of health and wellbeing of a society.

Industrialization, urbanization, and modern agriculture practices have direct impact on the water resources as well. These factors influence the water resources quantitatively and qualitatively. Twenty-five (25) water samples were randomly collected from different hand dug wells in five sections in Kenema City; namely: Konduboteihun, Lambayama, Lekpeteiyeh, Nyandayama, and Simbeck. They were analyzed for their bacteriological properties. The bacteriological analysis carried out on the water samples involves determination of *E*. coli, faecal coliform and non faecal coliform counts. The water samples revealed that faecal coliform and the non faecal coliform are in higher ranges than the *E*. coli counts. The result also indicates that only these samples NYS1, NYS2, NYS3, NYS4, LPS14, KS16, KS19, KS2O, KPS21, and KPS22 analysed where within the WHO recommended values for potable drinking water for the E. coli and for the faecal coliform only sample NYS5, NYS1, KS16 are within the WHO recommended value for potable drinking water. The recommendations aimed at improving water quality and educating the inhabitant in their localities with respect to the use of hand dug well water i.e. should be kept under good sanitary condition by encouraging individual's house owners to provide modern toilet facilities for their conveniences.

Conclusions

It was discovered from the research that none of the hand dug well were not contaminated due to the closeness or nearness of the latrine. Some of the targeted area met the World Health Organization (WHO) guidelines of drinking water quality. Some of the hand dug well where free from *E*. coli, feacal coliform and non faecal coliform contaminations. The contamination of these water sources with pathogenic organisms due to the absence of fencing of water sources that could prevent the entrance of animals, livestock grazing nearby water sources, collecting of water with unclean jug, cups, agricultural activities nearby water sources, in some specially for unprotected hand dug wells its difficulty to disinfect the water or treat the water sources before collecting the water. The total faecal bacterial count (ranges 0-30), *E*-coli (0-18) and the non-faecal coliform (0-35) exceeds the WHO standard. These contaminants might have originated from latrines and refuse dumpsites located close to the hand-dug wells. Therefore, the water in the study area must be treated before human consumption. It would be useful if the following important points are addressed: proper sanitary survey, design and implementation of water and/or sanitation projects; regular disinfections, constructional defects, concrete covers, fences and diversion ditches maintenances and supervisions of water sources; and regular bacteriological assessment of all water sources for drinking in a planned manner.

Recommendations

These are some of the recommendation drive from the findings:

1. The hand dug wells should be chlorinated within every three months for each wells and it should be done on regularly due to the presence of bacteriological parameters.
2. The existing hand dug wells should be well kept and developed, while the uncovered ones are to be provided with good covers.
3. The community in general should be kept under good sanitary condition by encouraging individual's house owners to provide modern toilet facilities for their conveniences. And also this general recommendation should be implemented to improve good drinking water standards.

- The State Government are to construct and develop good hand dug wells which penetrate into the aquiferous zones while the local Government councils are to monitor the sanitary conditions of the communities.
- The Ministry of Water Resources Management /Water Directorate should make available laboratory analysis free for all university student who are in need of help for their project writings and other necessary research work pertaining water.
- The government and NGOs should take an active role to ensure that the toilet location are constructed at a distance of 30 meters away from hand dug drinking water sources to prevent

possible water contamination of bacteria. Also good constructions, hygiene awareness through media and regular maintenance should be provided to the community people in the study area.

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