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Microbial contamination of pipe-network and associated health risk in Kumasi, Ghana

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Abstract

Having access to piped water on premises is commonly related to clean and safe drinking water, in both developed and developing countries. Even though relatively few studies have been done on the subject, they show poor drinking water quality have been associated with piped water on premises. In some cases, the water quality from piped water at the point of use is unsafe for consumption than other water sources such as private boreholes and wells used by the people. The main reason for the poor quality of piped water on premises is the contamination of water in the distribution network of the water supply system. Several waterborne disease outbreaks have been associated with the contamination of the water distribution network.

The purpose of this study was to compare the water quality and assess the microbial health risk for piped water in slum and non-slum areas. The study was conducted in Kumasi, Ghana. Ten sampling points were selected from each area and a total 166 water samples were collected over a period of five weeks 79 from the slum area and 87 from the non- slum area. The study assessed the levels of *Escherichia coli*, *Escherichia coli O157:H7 and Salmonella* in the water samples.

This study showed that 25.9% (43/116) of the samples contained *Escherichia coli*, 19% (15/79) in the slum area and 32% (28/87) in the non- slum area. *Escherichia coli O157:H7* was only detected in one sample from the slum area and none from the non-slum area throughout the study period. Salmonella was not detected in any of the samples in both study areas. By applying the extrapolation method, the risk of being infected by the norovirus was set to 4.86 x 10^{-3} for the slum area and 7.02 x 10^{-3} for the non- slum area. The risk for being infected by *E. coli* O157:H7 was 1.24 x 10^{-8} for the slum area and 2.19 x $10^{-8}$for the non-slum area. At last the risk of being infected by salmonella in the slum area was respectively 3.18 x 10^{-7} and 5.51 x 10^{-7} in the non-slum.

Because of the poor water quality, recommendation for further investigations and studies is suggested, and investment in the old pipe network is necessary due to the poor water quality delivered to consumer trough the distribution system can cause health risk to the population in Kumasi.

Sammendrag

Tilgang til innlagt vann er ofte knyttet til rent og trygt drikkevann, like mye i u-land som i-land. Selv om relativt få studier er blitt gjort rundt dette emnet, viser studier dårlig drikkevannskvalitet til forbundet flere steder. I noen tilfeller er vannkvaliteten på det innlagte vannet ved forbruker mer forurenset enn andre vannkilder som private borehull og brønner som brukes. Hovedårsaken til den dårlige kvaliteten er forurensning av vann i distribusjonsnettverk før vannet når forbruker. Flere vannbårne sykdomsutbrudd har vært forbundet med forurensning av vannforsyningsnettet.

Hensikten med dette studiet var å sammenligne vannkvaliteten og vurdere den mikrobielle helserisiko for innlagt vann i et slumområde sammenlignet med et ikke- slumområde. Studiet ble gjennomført i Kumasi, Ghana. Ti prøvepunkter ble valgt fra hvert av disse to områdene, og totalt 166 vannprøver ble tatt, på over en periode på fem uker, 79 fra slumområdet og 87 ikke-slumområde. Studiet vurderte nivåene av *Escherichia coli*, *Escherichia coli* O157:H7 og Salmonella i vannprøvene.

Studiet viste at 25,9% (43/ 116) av prøvene inneholdt Escherichia coli, 19% (15/ 79) i slum-området mens innholdet var 32% (28/ 87) i ikke- slumområde. *Escherichia coli* O157: H7 ble bare påvist i en prøve fra slumområdet, mens ingen fra ikke- slumområde. Salmonella ble ikke påvist i noen av de 166 vannprøvene. Ved å bruke ekstrapolering metoden, ble risikoen for å bli smittet av norovirus satt til 4.86 x $10^{-3}$for slum område og 7.02 x 10^{-3} for ikke- slumområdet.. Risikoen for å bli smittet av *Escherichia coli* O157: H7 var 1.24 x 10^{-8} for slum område og 2.19 x 10^{-8} for ikke-slumområdet. Til slutt ble risikoen for å bli smittet av salmonella i slumområdet satt til 3.18 x 10^{-7}og til 5.51 x 10^{-7}i ikke-slumområde.

På grunn av dårlig den dårlige vannkvalitet ved forbruker, foreslås det at videre studier blir gjort rundt denne problemstillingen og at investeringene blir foretatt i de gamle rørsystemene. Dette sees på som en nødvendighet da dårlig vannkvalitet levert til forbruker i Kumasi gjennom fordelingssystemet kan forårsake alvorlige sykdommer og påvirke mange mennesker.

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Table of contents

List of abbreviations

CFU – Colony- Forming units

CI – Confidence interval

E. coli – Escherichia coli

GPS- Global positioning system

JMP -Joint Monitoring Program

KNUST- Kwame Nkrumah University of Science and Technology

MPN- Most Probable Number

NS.01-NS.10- Non-slum 01-non-slum 10

ORP- Oxidation reduction potential

PE- Polyethylene

PVC- Polyvinylchloride

QMRA- Quantitative Microbial Risk Assessment

S.01-S.10 – Slum 01-Slum 10

SSA -Salmonella and Shigella Agar

TCU - True Color Units

US(A)- United States (of America)

UV-light - Ultra Violet – light

WHO – World Health Organization

1 INTRODUCTION

Water is an effective medium for the transmission of pathogens of viral, bacterial, parasitic and protozoan origins; and has been implicated for disease outbreaks in developed and developing countries (Gasana et al. 2002). 2.5 million deaths, particularly among children under age of five were attributed to risk factors including the consumption of contaminated water (WHO 2012). In 2010, the UN recognized safe drinking water as a human right and advocated for an increase in investments towards the achievement of this right (UN 2010). This was also in line with the Millennium development goal of halving the population without access to safe and sustainable drinking water sources by 2015 (Hutton 2012). Recent estimates show that the Millennium development goal for water has been achieved; and that the proportion of the world´s population with access to piped-water connections had increased from 44% in 1990 to 55% in 2010 (Figure 1.1). Notwithstanding this tremendous improvement in access, there is an increasing recognition that improved water sources do not always lead to improvements in water quality and quantity for households (Lee & Schwab 2005). In areas where there is poor wastewater management combined with insanitary conditions, piped water quality tends to deteriorate due to contamination of water in the pipe-network (Moe et al. 1991).

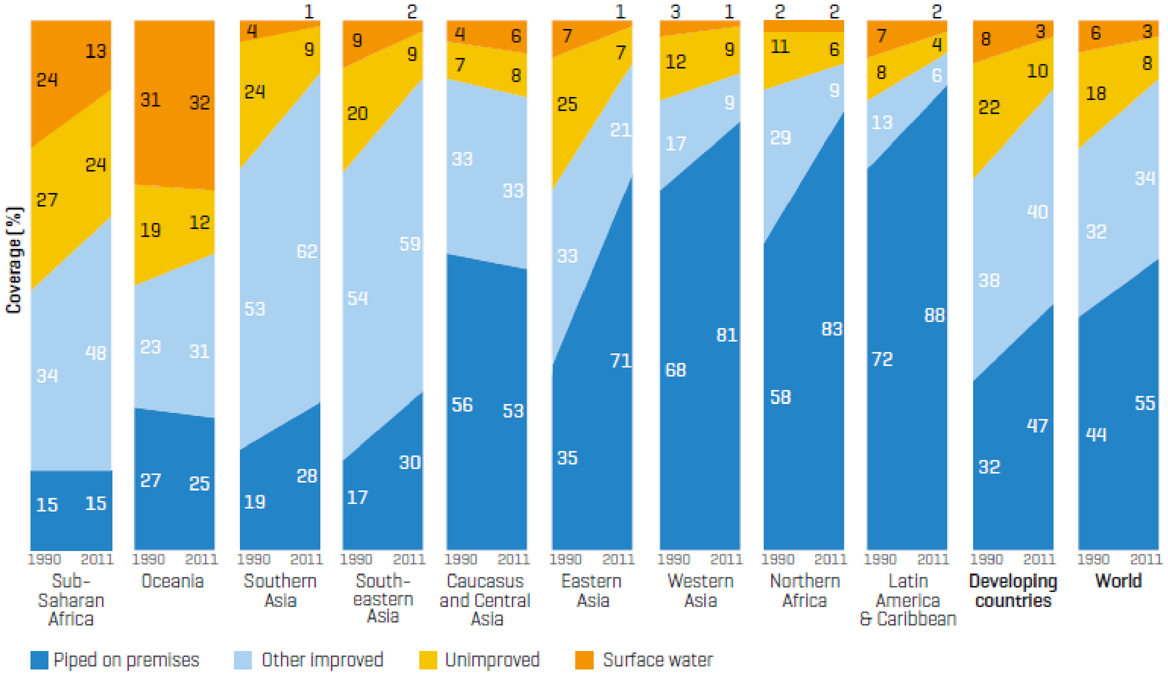


Figure 1.1 Sources of drinking water in different regions (WHO & UNICEF 2013)

Several studies, particularly from developed countries have implicated the contamination of pipe networks for the incidence of water-borne disease outbreaks (Semenza et al. 1998). For instance, in the United States, nearly 20% of the waterborne disease outbreaks are attributed to the contamination of the pipe network (Craun & Calderon 2001). Some of the main reasons for the contamination of pipe-networks is intermittent water supply, which is prevalent in developing countries, including Ghana (Awuah et al. 2009; WHO & UNICEF 2013). In Ghana, 33% of the urban population has access to water piped into their premises (WHO & UNICEF 2013). However, this access is characterized by extreme intermittent flow, with households going without water for days. A recent study in the capital city Accra, showed that only 25% of the population with access to water piped to their premises had water supply during the whole day every day of the week (Awuah et al. 2009) . This intermittent flow as mentioned earlier could lead to the contamination of treated water in the pipe-network. Also wastewater management (collection, transportation, treatment and disposal) is poor in most cities in Ghana and could significantly affect treated water in pipe networks. Studies have shown that there are about 70 wastewater treatment plants in the country while only 7% are functioning to full capacity (Murray & Drechsel 2011). In areas where there is no wastewater connection, particularly slum areas, on-site septic tanks are used for the collection and storage of human excreta while grey water is discharged into storm water drains without further treatment. In these slum areas, pipe connections are usually informal in some cases, and pipe-networks are often found lying in storm water drains. Therefore even if water is treated to acceptable quality levels and is considered improved, there is a high likelihood of the water being contaminated through the distribution network within the slum areas prior to consumption (Moe et al. 1991). A much lower contamination is expected in non-slum areas where wastewater management practices is relatively better.

So far, in Ghana, no comprehensive study has been undertaken to assess the degree to which water quality deteriorates in the pipe-networks of slum (non-informal, poorly planned settlements and with poor wastewater management) and non-slum (high-class residential settlements with good wastewater management) areas. The microbial risk level associated with the consumption of pipe-water from the two areas is also not known. This assessment is critical if improvements for the general planning of water distribution and further investments in the pipe-network are to be made.

1.1 Research aim and objectives

The overall aim of this study was to investigate the quality and assess the microbial health risk of water from the pipe network in a slum area compared to a non-slum area in Kumasi, Ghana.
In line with the overall aim, the specific objectives of the study were to:

1) Assess the microbial, physical and chemical qualities of water from the pipe-network in the slum and non-slum areas;

2) Identify the potential source of microbial contamination in the pipe-network in the slum and non-slum areas;
3) Asses the microbial health risk associated with the consumption of piped-water from the slum and non-slum areas.

2 LITERATURE REVIEW

2.1 Water distribution systems

A water distribution system is planned and built to deliver water to people at sufficient pressure, quantity and quality (Ministry of urban development 2005). Throughout the epochs of history, several civilizations have developed pipe-networks to transport water from water sources to settlements. The Classic Mayas (200-650 AD) used water pressure systems that could control the water supply to and within urban areas (French & Duffy 2010). The Romans and the Greeks built aqueducts for the transportation of water from fountains to built up areas (Geldreich 1996). In these early civilizations, the main aim for the design of the water distribution system was to ensure the supply of water in sufficient quantities to the population (Geldreich 1996). Water quality was not a major concern. For instance, the Romans covered some of the aqueduct for the purpose of protecting the water against the heat of the sun and enemies that could destroy or contaminate the distribution system (Geldreich 1996).

In the last century, there have been significant developments in the planning and design of water distribution systems, to ensure that treated water is transported through the water distribution network in sufficient quantity and quality to consuming populations. Despite these advances, water distribution networks are still vulnerable to contamination and have been implicated in waterborne disease outbreaks (WHO 2011b). Several factors account for the vulnerability of the water distribution network to contamination.

2.1.1 Factors contributing to the contamination of water distribution systems

Contamination of water distribution systems has been attributed to a wide range of factors. Some of these factors are presented as follows:

2.1.2 Infiltration of contaminants into the pipe-network

Infiltration of contaminants into water distribution systems is a major problem in many countries. This happens when contaminated water outside the distribution system enters the distribution system to cause contamination. For this to occur, three conditions have to be met: contaminated water around the distribution system, a low-pressure zone in the system and a path for the contamination to enter the pipes (IWA-publishing 2003). Contaminated water around the pipes can be a leakage from sanitary facilities, storm- or combined sewers etc. and can then enter

the distribution system when the pressure in the pipes are low. A low- pressure zone in the pipes can occur at different times. For example, if there is a fire and fire workers using significant amounts of water. Low- pressure zone can also take place if there is damage on the piped system in terms of breach of pipes, or when in general there is low pressure in the systems.
Backpressure is also an issue that leads to the contamination of the water in the distribution system. Backpressure occurs when the pressure of the system outside of the water distribution system is higher than the distribution system itself. Because of the higher pressure the water flow will go in reverse and the surroundings of the pipe system will be sucked into the distribution system and lead to contamination (EPA 2001). Contaminants may also enter the water distribution network through holes created by corrosion, cracks or leaking joints in the wall of the distribution system.

2.1.3 Unprotected Water Reservoirs in the distribution system

Open water storage reservoirs in the distribution system can make the water vulnerable to contamination from the outside. For instance, bird excreta containing Salmonella can contaminate water in the reservoir if it is not properly secured (Angulo et al. 1997). In addition, reservoirs facilitate the growth of toxin- forming bacteria (IWA-publishing 2003).

2.1.4 Intermittent and continuous piped water supply

In drinking water supply, continuous supply is critical. In urban Africa, Latin America and the Caribbean one-third, and in Asia, half of the water distribution systems, work intermittently (WHO & UNICEF 2000). Intermittently water supply can lead to damages to the distribution system due to changes in flow that can stress the pipes and additionally weakening of pipes and joints. Likewise the hygienic aspect is also crucial as contaminated water can enter the pipes through joints or cracks when the water supply is operating intermittently. A major reason for intermittent operations in the water supply system is power cuts that affects the pumps and hence flow (Thompson et al. 2001).

A recent study in India revealed that water supply systems with continuous supply of water gave much safer water to consumers than water from an intermittent pipe-network. The study showed the presence of *E. coli* in 0.7% of the samples from the continuous piped supply, compared with 31.7% in the water from the intermittent water supply system. In addition, chlorine residual above 0.2 mg/L was found in 68.3% of the samples from the continuous network and 39.9% from the intermittent network (Kumpel & Nelson 2013).

2.1.5 Water age and biofilm formation

Deterioration of water quality is closely related to the age of the bulk water within a water distribution system. The main factors related to the worsening of water quality in the distribution system due to water age are (AWWA & Economic and Engineering Service Inc 2002):

1. The contact between the water in the distribution system and the pipes; and
2. The reaction in the drinking water which is in the distribution system

In the distribution system, water quality is influenced by factors such as chemical, physical and aesthetical transformations (AWWA & Economic and Engineering Service Inc 2002). These factors are governed by other elements such as the flow rate in the pipes, pipe materials, organic matter in the distribution system and etc.(AWWA & Economic and Engineering Service Inc 2002). As the pipes gets old, problems like leakage and break caused by various factors like corrosion, biofilm, change in the physical and chemical parameters can occur (O’Connor 2002). Chlorine decay is another important factor that is influenced by the age of the pipe and its condition. Research on various types of pipes, such as cement-lined ductile iron, steel, unplasticized (PVC) and polyethylene (PE) shows that the decay of chlorine in the distribution system is correlated with the pipe age (Al-Jasser 2007). The research shows that steel pipes are most influenced by the age regarding chlorine decay, while cement-lined ductile iron is less affected. The PVC and PE is also negatively affected by the age, but the decay is quite low compared to the steel and the ductile iron pipes (Al-Jasser 2007).

Biofilm growth in pipes can cause various contamination in the distribution system and eventually for the consumer. Growth of biofilms in the pipes leads to corrosion in pipes, increased demand for chlorine, and the occurrence of poor taste and odor (Little & Ray 2002; Lu et al. 1999).

2.2 Pipe materials

Pipe materials and their age are crucial for drinking water distribution (Al-Jasser 2007), and there are several materials and standard used globally, which varies from country to country. However, there are some factors that has to be taken into consideration when planning a distribution network (World Plumbing Council & WHO 2006). These include:

1. The sustainability of the product/material regarding the transportation of water;
2. The effect of the product/material of the pipe on water quality and the associated public health; and

3. The environmental impact of the pipe-material.

Material used for drinking water is divided into two main categories: metallic and non-metallic materials. The most widespread type are galvanized steel, galvanized iron, copper, Chlorinated polyvinylchloride (CPVC), unplasticized polyvinylchloride (PVC) and polyethylene (PE) (World Plumbing Council & WHO 2006). Galvanized steel and iron is in use many places worldwide, however in the last years the demand is decreasing. Some of the reason for it not being as popular as previously is the heavy weight that makes it difficult to handle and the corrosion problems that can be caused by the galvanized steel or iron materials (World Plumbing Council & WHO 2006).

Copper pipes can be very flexible to use and handle. Although corrosion is a problem as well, copper pipes are not as corrosive as the two types previously mentioned. This type of material is especially good when it comes to supply of hot water (World Plumbing Council & WHO 2006).

PVC pipes are much lighter than steel or iron pipes and easy to handle. In many places across the world it is used for drainage water, such as storm water drainage. PE pipes is a non-metallic, light, and flexible material, which makes it easy to install. It is separated in three categories: High- density PE (HPE), Medium-density PE(MPE) and Low-density PE(DPE) (World Plumbing Council & WHO 2006).

2.3 Water quality assessment

The quality of water in the distribution network can be assessed based on several microbial, physical and chemical parameters of the water from the distribution network. Some of these parameters, which were also accounted for in this study are presented as follows:

2.4 Microbial water quality parameters

Microbial contamination is by far the most important public health challenge of drinking water supply systems. All microbial organisms of viral, bacterial, parasitic and protozoan origins can be found in the distribution network of the water supply due to some of the factors mentioned above. Some of these microbial organisms are more pathogenic than others. The hazardous pathogens in drinking water are usually associated with human or animal excreta, and in many circumstances, but there are also other pathogens capable of causing infection through the drinking water. The most transmissible diseases related to drinking water are those caused by pathogenic viruses, bacteria and parasites (WHO 2011b). Examples of pathogenic organisms implicated for water borne disease outbreaks include *E.coli O157:H7, Salmonella*, Norovirus, *Cryptosporidium* and *Giardia*. These pathogens are also different in characteristics, behavior and resistance. Simultaneously they affect different persons in various way, reliant on factors as age, sex, state of health and living conditions (WHO 2011b). The contamination can be found in different places in the distribution network. For instance, *Legionella* can grow in piped distribution systems (WHO 2011b). This study focused on pathogenic bacteria (*E. coli* O157:H7 and *Salmonella*) and indicator organisms (total coliforms and *E. coli*) in characterizing the microbial quality of the water from the distribution network.

2.4.1 Enterohaenrrhagic *E. coli* O157:H7

E. coli O157:H7 is one of the most important pathogenic bacteria of public health concern in drinking water supply systems (WHO 2011a). *E. coli* O157:H7 can cause severe diarrhea, and in some cases death in affected individuals (Petridis et al. 2002). The infectious dose of *E. coli* O157:H7 is low and the bacteria can be found in the faeces of cattle (Griffin & Mead 1998). Outbreaks of diseases caused by *E. coli* O157:H7 occurs rarely in developed countries, while in developing countries it takes place more often (WHO 2011b). Even though outbreaks rarely take place in developed countries, large outbreaks have occurred in countries such as Canada leading to 2000 illnesses (Petridis et al. 2002).

2.4.2 Salmonella

Salmonella is a bacteria, which is divided into two groups: *Salmonella enterica* and *Salmonella bongori* (WHO 2011b). Out of 2500 *salmonella* enteric serotypes confirmed, all of them are found to lead to disease in humans (WHO 2013). Worldwide, *salmonella* is recognized as the number one cause for enteric disease regarding food (WHO 2013). However, *Salmonella* has also been the reason for water borne disease outbreaks. In the United States, a waterborne disease outbreak implicating Salmonella tyfimurium, led to 650 illnesses, 15 hospitalizations and 7 deaths (Angulo et al. 1997). The main risk factor associated with this outbreak was birds entering the water storage tanks of the distribution system and contaminating the drinking water. Another study from Tajikistan showed that in a period of six month, 8901 cases of typhoid fever and 95 related deaths were reported. This outbreak was attributed to the lack of chlorination, equipment failure and back-siphonage in the distribution system (Mermin et al. 1999). When these problems were addressed in the water supply system, the number of people infected with typhoid fever decreased remarkably (Mermin et al. 1999).

2.4.3 Norovirus

Norovirus is a type of virus that often causes diarrheal sicknesses where both vomiting and diarrhea is normal when infecting people. The Norovirus is well researched and is recognized as number one nonbacterial cause of diarrheal outbreaks in the world (Dolin 2007). Studies shows that for 85 % of the know outbreak during a period of 3 years (1997-2000) the Norovirus was the blamable organism and other studies even shows 96% of the nonbacterial outbreaks was caused by the Norovirus (Fankhauser et al. 1998).

2.5 Indicator organisms

Indicator organisms are useful for various purposes since they are organism that helps us to find out if a pathogenic microorganism is in a sample or not. It can be used to discover if a microorganism is in a sample, in a filtration system, or as disinfection validation (WHO 2011b). When using indicator organisms we are not detecting the hazardous organism itself but an organism that will be present when the hazard organism is present. For example, *E. coli* is widely used as an indicator for fecal contamination (WHO 1997). *E. coli* is commonly used because it can be complex, expensive and time consuming to detect pathogenic organisms in a water sample (WHO 2011b). The indicator organisms accounted for in this study were total coliforms and *E. coli* indicator organisms.

2.5.1 Total –and fecal coliforms

The Coliform group are different types of bacteria with various characteristics and are often correlated with fecal contamination (IWA-publishing 2003) . Coliform bacteria are found in the environment as in the soil, vegetation, intestines or feces of warm-blooded animals and humans, and are mostly not harmful (Office of Drinking Water 2011). The coliform bacteria are divided into two groups, total coliforms and fecal coliforms, depending on their characteristics (British Colombia 2007). Total coliforms are not helpful as fecal organism indicator, but is good in evaluating the purity and reliability of a distribution system and additionally as indicator for the presence of biofilm in the distribution network (WHO 2011b).

The total coliforms multiply at 37 ºC and stand for the whole group of coliforms (IWA-publishing 2003). They are generally found in soil and vegetation and if detected the main source is most likely environmental , but if the total coliform is discovered in drinking water, one have to be sure that the sample is not contaminated by pathogens from of fecal contaminants (Office of Drinking Water 2011). When fecal coliforms has been detected in a water source or a water sample it means that there is a great possibility of recently contamination by fecal contaminants as feces from animals or humans, and that it can contain bacteria, viruses or protozoa which can be the cause of different disease as diarrhea (British Colombia 2007). For that reason, application of fecal coliform bacteria as indicator organism is a good way to indicate fecal contamination in water.

2.5.2 *Escherichia coli*

E. coli is a bacterium that exists in the gut of warm-blooded animals and humans. It is a thermotolerant bacteria, meaning that it can grow in higher temperature (44.2 ºC) (IWA-publishing 2003), but it grows best in moderate temperatures from 7-10 ºC up to 50 ºC, with an ideal growing temperature at 37 ºC (Adams & Moss 2008).
Mostly the *E. coli* bacterium itself is not pathogenic, however, a limited number of special sorts like *E. coli O157:H7* can cause acute diarrhea (Berg 2004). When there is *E. coli* in drinking water, then there is a high likelihood of fecal contamination in the water.

The application of *E. coli* as indicator for monitoring drinking water has existed for many years, and is a well-recognized indicator organism as it is an important indicator for fecal pollution and treatment efficiency. *E. coli* is a good indicator since, as mentioned, it exists in large number in intestines of warm-blooded animals and human beings, and are normally not harmful (Berg 2004), and are respectable in monitoring drinking water because of the high amounts in polluted waters (WHO 2011b). *E. coli* cannot multiply in natural waters and it is persistent in water in the same way as other pathogenic organisms. It is also found in greater numbers than the fecal pathogen and responds to treatment in the same way as fecal pathogen. Finally, it is easy to detect *E. coli* in samples and it is economically beneficial compared to other methods (WHO 2011b). When using fecal indicators as *E. coli*, the WHO guidelines says that water intended for drinking purposes should not contain any *E. coli* in a 100 ml water sample (WHO 2011b). It is important to note that relying only on *E. coli* as indicator alone can in many cases, as they may not reflect the behavior of pathogenic organisms such as viruses and protozoa (IWA-publishing 2003). For example *E. coli*, is very sensitive to chlorine (IWA-publishing 2003) while viruses and protozoa are more resistant to it.

2.6 Physical – chemical water quality parameters

Besides the microbial parameters, there are other physical and chemical parameters of water that can give an indication of potential contamination of the pipe network or serve as indicators for water quality. These include pH, Oxidation Reduction Potential (ORP), Temperature, Color and residual chlorine.

2.6.1 pH

The pipe can be corroded when the pH of the water in the pipe-network is low. This can cause problems such as leaching of metals such as copper, zinc etc. (Health & Section 2009). Corrosion causes the surface of pipes to become thinner while red stains shows in the iron or the steel; and blue-green stains in copper and brass plumbing systems. Water flow in pipes can get reduced because of oxidation of copper or different types of metals. The valves and other water instruments can be damaged by this process (McFarland et al. 2012). However, this type of corrosion is not only caused my acidic water since acidic soil or environment can also cause the same damage (McFarland et al. 2012).

2.6.2 Temperature

Temperature is one of the most important factors affecting microbial growth in drinking water and affects many other different factors (LeChevallier et al. 1996). Organisms living in the water need a certain temperature range for their survival (LCRA 2012). In the pipe-network, temperature can affect corrosion rate and water distribution hydraulics, odor, taste and color (LeChevallier et al. 1996). This can lead to changes in the odor, taste and color of the water in the distribution network (WHO 2011b). A study have shown that the biofilm activity decreases with lower temperatures, suggesting a decrease of around 50% from 17 ºC to 25 ºC (Hallam et al. 2001).

2.6.3 Oxidation- reduction potential

Oxidation-reduction potential (ORP) measures in mV, the oxidation effectiveness in water, meaning that it indicates the antimicrobial potential of the water (WHO 2011b) . The ORP has an advantage when it comes to water system monitoring since it is easy to use and gives good indications of the disinfection potential in the water. Research an ORP value of 650-750 mV gives *E. coli* O157:H7 a survival time of less than 10 seconds and salmonella less than 20 seconds. In this way it is easy to monitor the survival of hazard pathogens (Suslow 2004). The ORP and the pH are correlated, and it is shown that an increase in pH lowers the ORP value, while a decrease increases the ORP value (Cheryl et al. 2004). Therefore ORP is also used to check the HOCl and the OCl^- amounts in water since an increase in ORP indicates a greater amount of HOCl and vice-versa (Suslow 2004).

2.6.4 Color

Color as indicator in drinking water is important, primarily at the consumer since they judge the water by its appearance, taste and odor. Mostly color above 15 true color units (TCU) can be detected by the eyes in a glass of water, and therefore, color under 15 TCU will be pleasing to the consumers and the water will be colorless (WHO 2011b). It is shown that people may even turn to unsafe drinking water sources when their own water sources is exceeding 15 TCU, even though the water is safe (WHO 1997). Color in natural waters is often caused by natural organic matter, mostly humus that is related to humus element of the soil. Color of the water is also affected by iron and other metals in the water, this can be corrosion in pipes of the distribution system or natural reasons from the water sources and its surroundings (WHO 2011b).

2.6.5 Chlorine

Chemical disinfection is an important and critical treatment barrier in drinking water distribution There are three different disinfection that are used related to pathogenic microorganism: ozone, UV and chlorine. Since this study targets the water quality at the point of use, and the treatment plant in Kumasi only uses chlorine for disinfection. The application of chlorine as disinfection is frequently used (WHO 2011b) and is effective when it comes to inactivate bacteria and viruses (IWA-publishing 2003). For chlorination we are able to use liquefied chlorine gas, sodium hypochlorite solution or calcium hypochlorite granules for disinfection. However, by using any of this three mediums in the drinking water, we will get hypoclorous acid (HOCl) and the hypochlorite ion (OCl^{-}) (WHO 2011b). The HOCl is much more effective for disinfection then the OCl^{-}ion, therefore striving for more HOCl is important. Figure 2.1 show the relation between HOCl and OCl^{-} at different pH. As the figure shows, at
pH > 8.5 the chlorine is in the form of OCl^{-}, and on the other side in form of HOCl at a pH < 6.5. Since HOCl is many times more effective than OCl^{-}effort should be put to add the chlorine at a low pH and in that way save chemicals and money (Ødegaard 2012).

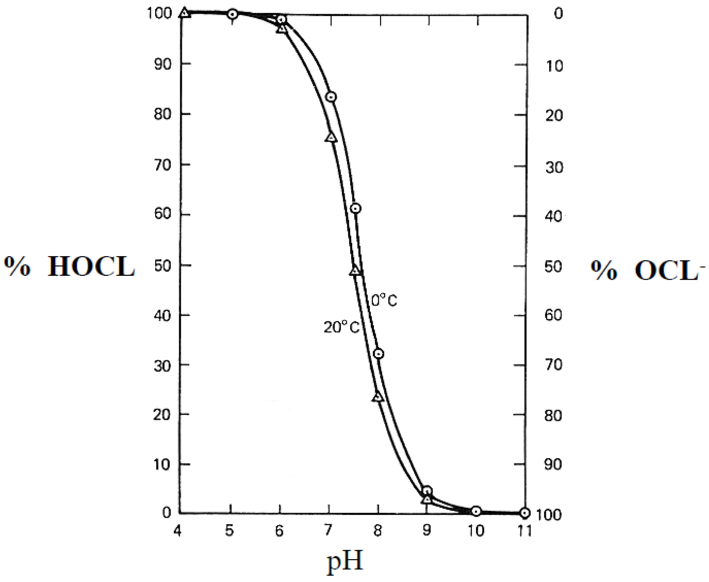


Figure 2.1 Relation between HOCl and OCl^- in different pH values
Source: (White 1972)

Even though chlorine is frequently used and known, it has to be applied in the right way. For example, when high dosage of chlorine is used in the treatment process and there is organic matter in the water, the high dosage of disinfection can result in high concentration of by-products that may be toxic. (IWA-publishing 2003) Even though chlorination partially is used at the treatment plant, developing countries are more and more using chlorination at household level in form of tablets and sachets, sometimes together with coagulants that removes turbidity.(IWA-publishing 2003) In Nukus, Uzbekistan research was done by studying three different groups, one group with connection to piped water from the municipality treatment plant, one group without piped water which were trained to use chlorine in their drinking water, and the last group also without piped water but without any disinfection in their water (Semenza et al. 1998). At the end of 9.5 weeks the study clearly shows that the group trained to use chlorine in their water compared to people without chlorine in the water and the group with connection to piped water had much lower much diarrhea rate, representatively the two latter groups had 85 % and 62% higher diarrhea rate (Semenza et al. 1998).

3 METHODOLOGY

3.1 Study location and water sampling

The study was conducted in a slum (Ayigya) and a non-slum (residential areas of the Kwame Nkrumah University of Science and Technology (KNUST)) neighborhoods in the Kumasi Metropolitan Area, Ghana. Water samples were collected from the pipe-network of the two neighborhoods from 14 March to 17 April 2014. Samples were taken from 9 a.m-2pm on each sampling day. A total of 166 samples were collected comprising 79 and 87 water samples from the slum and non-slum areas respectively. All samples were collected using pre-labeled 500-1500 mL sterile bottles. Samples were put on ice and transported to the laboratory for microbial analysis and analyzed within 24 hours. Physical and chemical parameters of the water samples (Temperature, pH, and ORP) were determined in-situ using a temperature/pH and ORP measuring instrument.

Figure 3.1 Map showing Kumasi located in Ghana (ildado 20014)

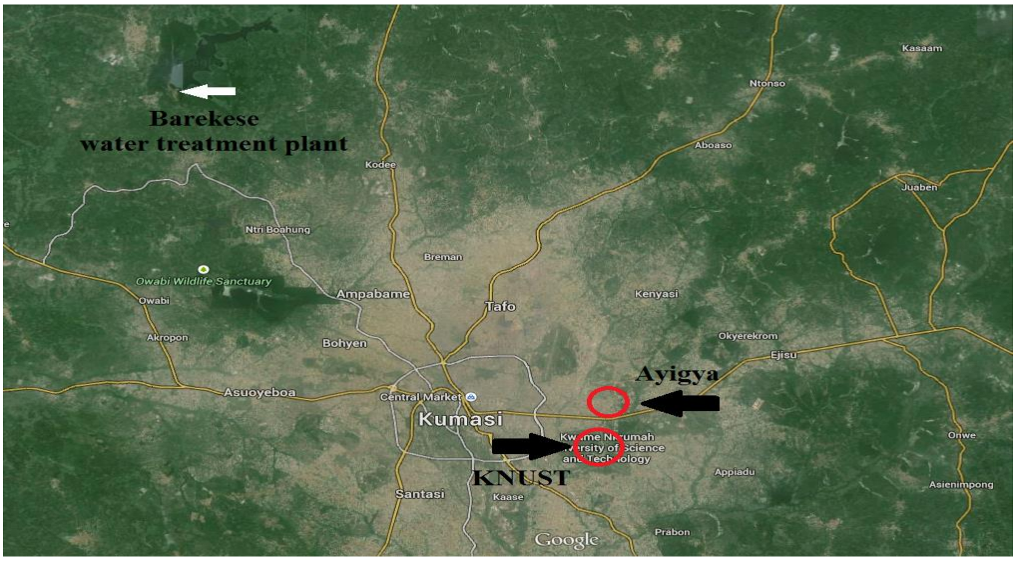


Figure 3.2 Overview over the Barekese water treatment plant which supplies drinking water to Ayigya and KNUST (Google maps 2014)

Figure 3.3 Overview over the sampling points in Ayigya (Google maps 2014)

Figure 3.4 Overview over the sampling points in KNUST (Google maps 2014)

3.2 Microbial analysis

3.3 Total Coliforms and *E. coli* analysis

Total coliforms and *E. coli* and in the water samples was enumerated using Quanti-Tray/2000 (IDEXX, Westbrook, USA) without further serotyping. Briefly, 100mL of the water sample was made ready for examination. A snap pack of Colisure reagent was first poured into the 100 mL sample. After allowing the reagent to dissolve, the solution was transferred into a Quanti-Tray containing 49 large and 48 small wells. The tray was sealed in a Quanti-Tray sealer, which automatically distributes the reagent mixture into the separate wells. The sealed trays were incubated at 37^0C for 24 hours. After the incubation wells with the purple color are wells that contains colonies of total coliforms, while the wells with pink color do not contain total coliforms (Figure 3.5). E. coli in the sample metabolize Colisure's nutrient-indicator MUG (4-methylumbellifery β-Dglucuronide) to fluoresce the sample. The number of red/magenta wells that fluoresce after incubation represents positive results for *E. coli*. To count the number of wells that fluoresce, a 6-watt, 365 nm UV light was held within 5inches of the tray (Figure 3.6). The number of wells that presented the purple color and fluoresce was referred to the MPN table to obtain the MPN of total coliforms and *E. coli* per 100mL of the sample.

Figure 3.5 Quanti-tray showing from the left total Coliforms in all of the well, while the second in some few and the last one is not yet been incubated

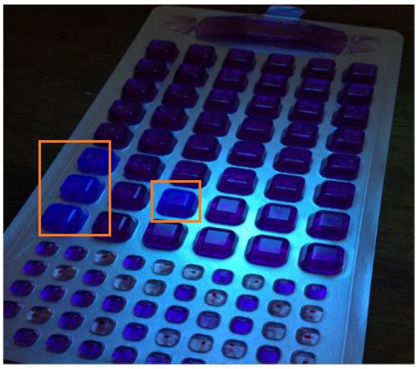


Figure 3.6 *E. coli* detected in four of the big wells

3.4 Salmonella detection

For detection of salmonella, 9 mL of peptone water and 1 mL of the sampling water was incubated in 37°C for 24 hours. Then Salmonella and Shigella Agar (SSA) was prepared in petri-dishes were small portions of the incubated sample was taken on the agar by using the method of striking. The striking was preformed by using a thin iron tread that was heated up by fire for disinfection. As soon as the iron tread was disinfected it was dipped into the bottle of peptone water and sampling water and spread around on the petri-dish with the agar (Figure 3.7). Then the sample was incubated for 24 hours in 37°C. After the incubation, the samples was ready for reading were black colonies with cream outer margin on the SSA indicates presence of *Salmonella* and no bacteria growth or no black colonies with cream outer margin meant negative result and no *Salmonella*.

Figure 3.7 The SSA and the peptone water with 1 mL water from the sampling sites, and the doing of the striking shown at the right side

3.5 *E. coli O157:H7* detection

The method used for examining for *E. coli O157:H7* was to take samples from the Quanti- tray wells that where confirmed with *E. coli* and by using Sorbitol MacConkey Agar which is pink colored on petri-dishes and then the striking was done. Then the respective samples was incubated for 24 hours in 37°C. Forward the samples as shown in Figure 3.8, that had a cream-colored colonies instead of the original pink agar, was taken for a confirmation test using the latex agglutination kit from Oxoid.

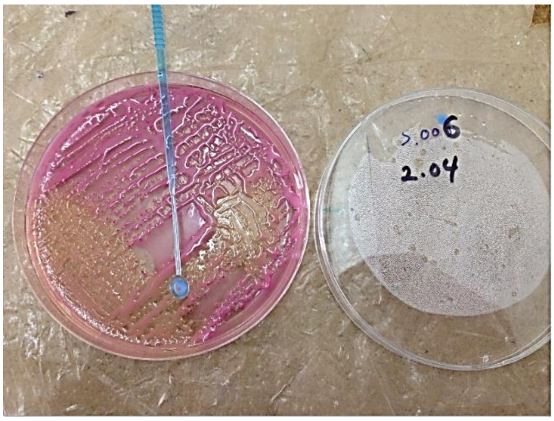


Figure 3.8 The pink color is the Sorbitol MacConkey Agar while the creamed-colored part has to be checked for E. coli O157:H7 in sample S.06 from the slum area

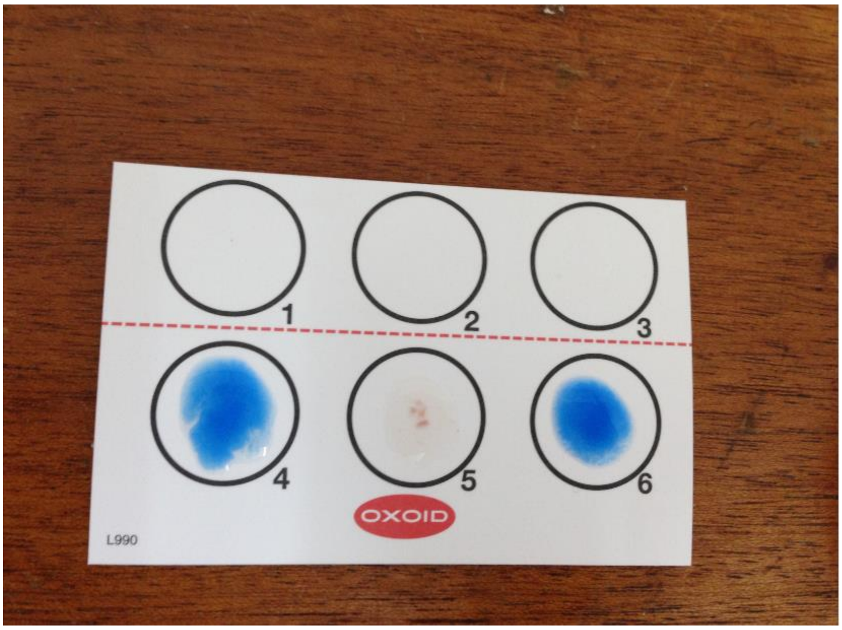


Figure 3.9 Confirmation test of E. coli O157:H7 using the Oxoid kit.

3.6 Statistical Analysis and Risk Assessment

3.6.1 Descriptive Analysis

Descriptive analysis was conducted to assess the statistical distribution of the different microbial, physical and chemical parameters for the slum and non-slum areas. ANOVA analysis was conducted to assess whether there was significant difference between the different physical, chemical and microbial parameters within and between the slum and non-slum areas. For this the non-parametric Kruskal-Wallis test was used to assess the existence of any statistical significance between the slum and non-slum areas for the different parameters. All the descriptive analysis and ANOVA analysis was conducted with SPSS Version 20.

3.7 Risk assessment

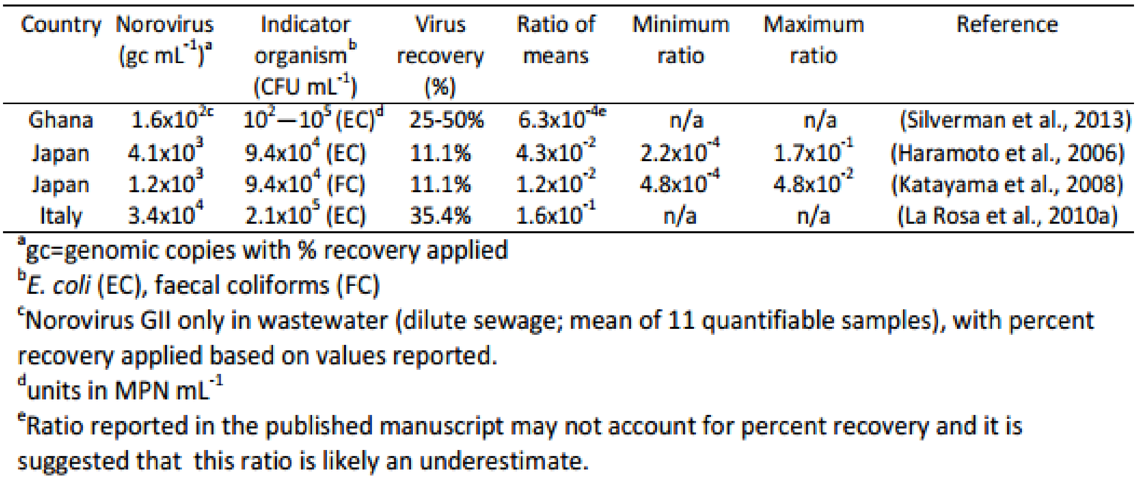
3.7.1 Quantitative Microbial Risk Assessment

Quantitative Microbial Risk Assessment (QMRA) was used to assess the health risk associated with the consumption of drinking from the pipe networks of the slum and non-slum areas. The assessment was based on the methodology of (Haas et al. 1999) with the following interlinked steps:

3.7.2 Hazard Assessment

E. coli O157:H7, *Salmonella* and norovirus in the drinking water were the main hazards considered in this study. All these pathogens have been implicated for water-borne disease outbreaks. *E. coli O157: H7* and Salmonella were quantified directly from the water samples as presented earlier, while norovirus was not quantified in the water samples. The concentration of norovirus in the water sample was estimated based on *E. coli* to Norovirus ratio. *The E. coli* to Norovirus ratio was based on the study of Barker et al. (2014) where a Uniform Probability Distribution was fitted to the *E. coli* to Norovirus ratios based on the data in Table 3.1**Feil! Fant ikke referansekilden.**. For purposes of comparison *E. coli* to *Salmonella*/*E. coli* O157:H7 ratios were also used to estimate the likely concentration of Salmonella and *E. coli* O157:H7 if only indicator *E. coli* were to be used for the analysis. For the estimation of *Salmonella* and *E. coli* O157:H7 from the *E. coli* data, it was assumed that 10^{-6} – 10^{-5} Salmonella/*E. coli* O157:H7 was equivalent to 1 *E. coli*.

Table 3.1Table used for making norovirus to *E. coli* ratios



Country	Norovirus (gc mL^{-1})[a]	Indicator organism[b] (CFU mL^{-1})	Virus recovery (%)	Ratio of means	Minimum ratio	Maximum ratio	Reference
Ghana	$1.6x10^{2c}$	10^2—10^5 (EC)[d]	25-50%	$6.3x10^{-4e}$	n/a	n/a	(Silverman et al., 2013)
Japan	$4.1x10^3$	$9.4x10^4$ (EC)	11.1%	$4.3x10^{-2}$	$2.2x10^{-4}$	$1.7x10^{-1}$	(Haramoto et al., 2006)
Japan	$1.2x10^3$	$9.4x10^4$ (FC)	11.1%	$1.2x10^{-2}$	$4.8x10^{-4}$	$4.8x10^{-2}$	(Katayama et al., 2008)
Italy	$3.4x10^4$	$2.1x10^5$ (EC)	35.4%	$1.6x10^{-1}$	n/a	n/a	(La Rosa et al., 2010a)

[a] gc=genomic copies with % recovery applied

[b] *E. coli* (EC), faecal coliforms (FC)

[c] Norovirus GII only in wastewater (dilute sewage; mean of 11 quantifiable samples), with percent recovery applied based on values reported.

[d] units in MPN mL^{-1}

[e] Ratio reported in the published manuscript may not account for percent recovery and it is suggested that this ratio is likely an underestimate.

Adapted from (Barker et al. 2014)

3.7.3 Exposure Assessment

In the exposure assessment the dose of *Salmonella*, *E. coli* O157:H7 and norovirus was determined. This was based on the equation:

$$d = Am \text{ x } Pa$$

Where A_m is the amount of water consumed per day and Pa is the pathogen in the water consumed. A uniform probability distribution (1.2-2.9) was used to describe the amount of water consumed based on the study of Machdar et al. (2013).

3.7.4 Dose- response assessment

In the dose- response assessment, the infection risk associated with the ingestion of any of the three pathogens was assessed using their dose-response models. Studies have shown that the dose –response model for Salmonella, *E. coli O157:H7* and norovirus is best described by the β-Poisson dose response model, which is given as:

$$P_i = 1 - \left[1 + \left(\frac{d}{N_{50}}\right)(2^{\frac{1}{\alpha}} - 1)\right]^{\alpha} \text{ (Haas et al. 1999)}$$

where P_i is the probability of being infected by exposure to a dose of the organism d; N_{50} is the number of pathogens required to cause infection in 50% of the population and α is the parameter describing the beta-Poisson model. The N_{50} and α varies for different organisms. For the *E. coli O157:H7* the N_{50} = 5.96 x 10^5 and α = 0.49 (Haas et al. 2000). For the *Salmonella* N_{50} = 2.36 x 10^4 and α = 0.3126 (Haas et al. 1999). For norovirus the N_{50} = 16963 and α = 0.1109 (Haas et al. 1999).(Haas et al. 1999)

3.7.5 Risk Characterization

In the risk characterization the probability of infection associated with a single exposure event through the consumption of drinking water from the pipe-network in the slum and non-slum areas was assessed. The assessment accounted for the infection risk based on the extrapolated data for norovirus, *E. coli* O157:H7 and Salmonella. The actual *E. coli* O157:H7 and the Salmonella data were also used in the risk assessment. To account for uncertainty and variability in the input parameters, a Monte-Carlo simulation was run with 10,000 iterations. The risk assessment was conducted using @Risk 6.2 added on to Microsoft Excel.

3.8 Limitation of the study

The study did not account for water quality parameters such as turbidity, residual chlorine, conductivity and color. In addition, the water pressure at the distribution network could not be accounted for even though it would helped to explain some of the findings made in the study.

4 RESULTS

4.1 Physical- chemical parameters

4.1.1 pH

Figure 4.1 Mean pH slum and non-slumshows the pH level at the 10 nodes (sampling points) of the distribution network in the slum and the non- slum areas respectively. In the slum area, the mean pH was 6.85 (6.40-7.30) compared with a mean pH of 6.64 (5.58-7.20) in the non-slum area. The pH variation across the 10 nodes in the slum area was not statistically significant (p = 0.877) while in the non-slum area this variation was statistically significant (p = 0.000). The difference in the mean levels of pH between the slum and non-slum areas was also statistically significant (p = 0.000).

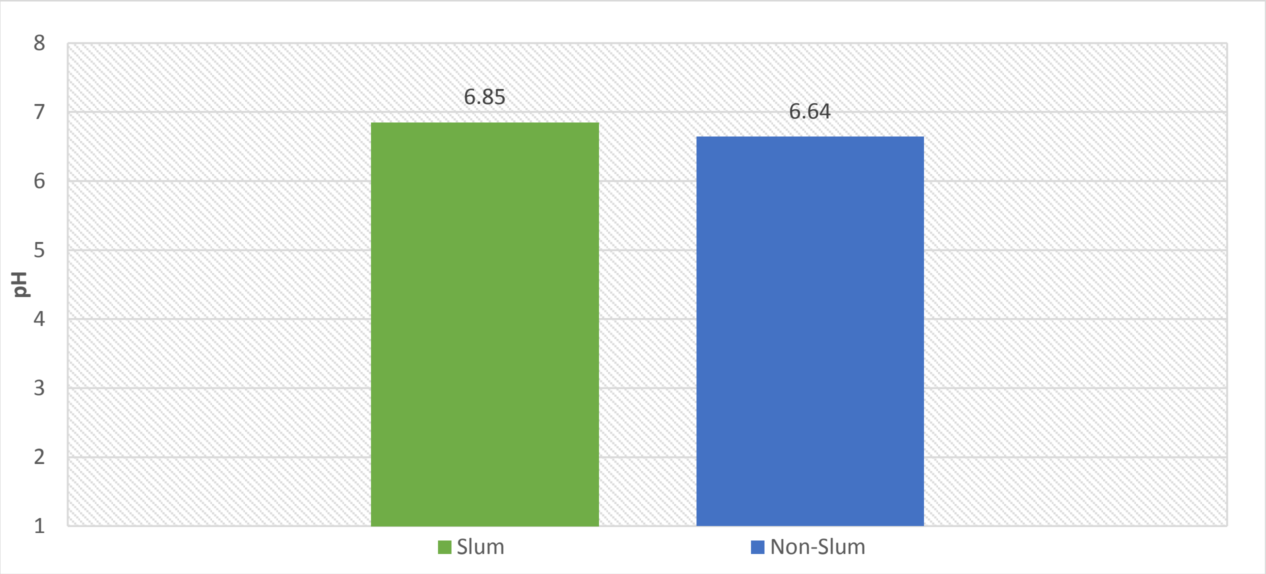


Figure 4.1 Mean pH slum and non-slum

4.1.2 Temperature

Figure 4.2 shows the temperature levels at the 10 nodes of the distribution network in the slum and the non- slum area respectively. The mean temperature in the slum area was 29.72°C (27.00°C -34.80°C) compared with a mean temperature of 30.05°C (27.80°C -34.60°C) in the non-slum area. The temperature variations across the 10 nodes in the slum area was not statistically significant (p = 0.192) while the variation in slum area was statistically significant (p = 0.011). The difference in the mean levels of temperature between the slum and non-slum areas was not statistically significant (p = 0.081).

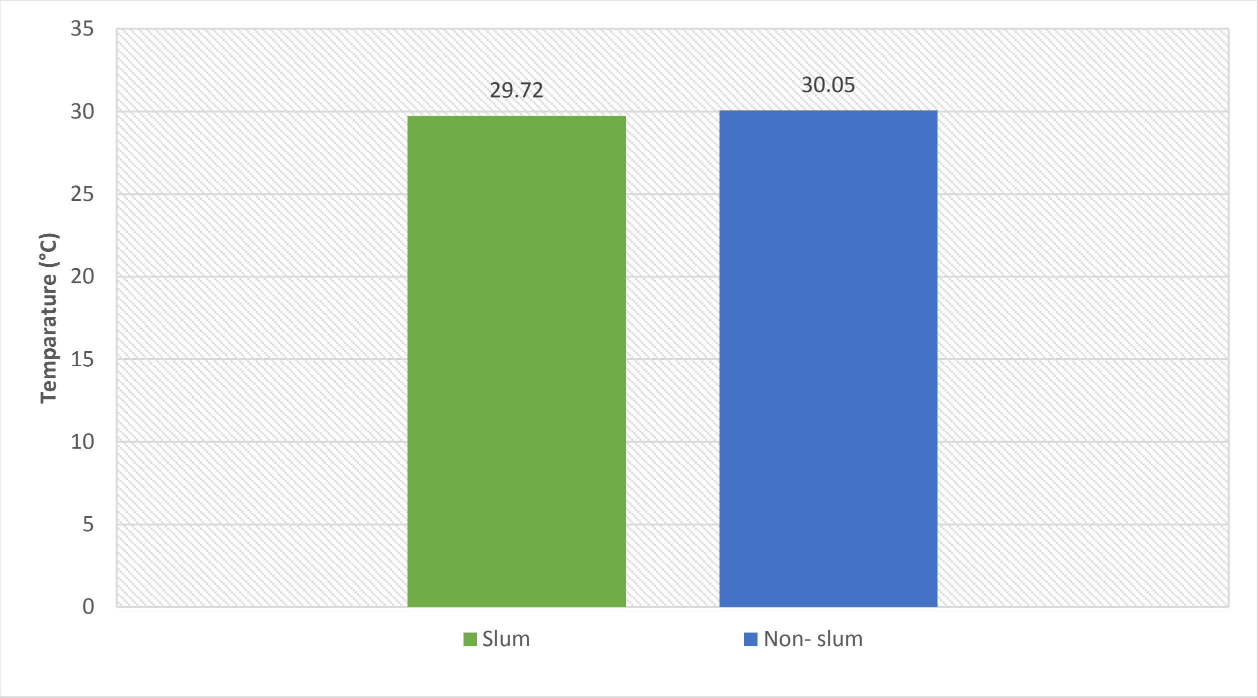


Figure 4.2 Mean temperature slum and non-slum area

4.1.3 ORP

Figure 4.3 shows the ORP distribution between the two sampling sites. The mean ORP given in mV was 15.26 mV (-10.90 mV – 41.80 mV) in the slum area and 27.15 mV (-10.0 mV - 86.0 mV) in the non-slum area. Variation in ORP across the 10 nodes was not statistically significant in the slum area (p = 0.850) but was statistically significant in the non-slum area (p = 0.000).

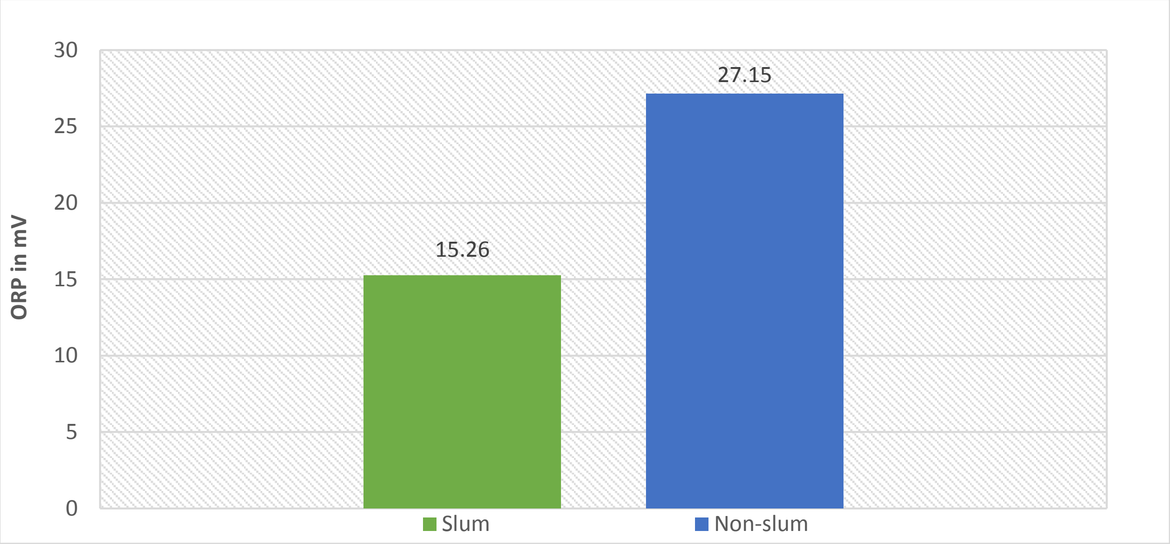


Figure 4.3 mean ORP in the slum and non-slum area

4.2 Microbial parameters

4.2.1 Total coliforms

Figure 4.4 shows the distribution of total coliforms between the two respectively areas. Based on the Kruskal Wallis test, the total coliforms was statistically different across the sampling points along the piping network in slum area (p = 0.017), while in the non-slum area the total coliform was not statistically different across the sampling points (p = 0.644). This difference in the mean levels of total coliforms between the slum and non-slum areas was not statistically significant (p = 0.487). The total amount of total coliforms found in the slum area and the non-slum area was in the range between 0.0 and < 2419.6 MPN/100mL. However, the mean of the total coliforms in the slum area was 442.42 MPN/100mL, while the mean of the total coliforms in the non-slum area was 435.90 MPN/100mL.

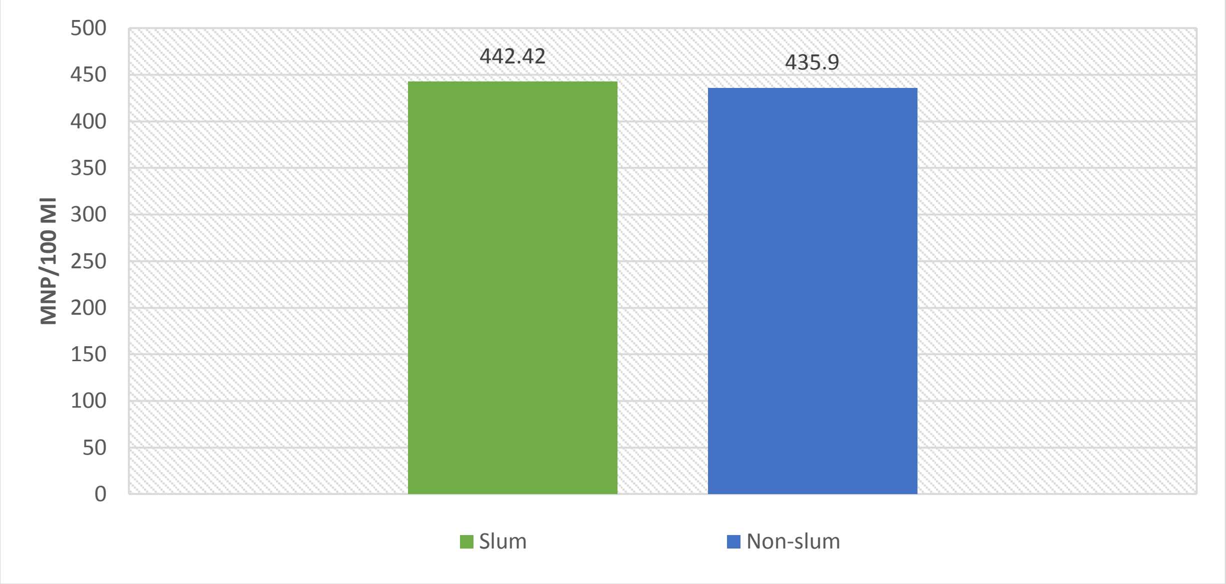


Figure 4.4 Mean of total coliforms in the slum and the non-slum area

4.2.2 *E. coli*

Figure 4.5 shows the *E. coli* distribution between the two sampling areas. Based on Kruskal Wallis test, the *E. coli* was statistically not different across the sampling points along the piping network in the slum area (p = 0.844), while in the non-slum area the *E. coli* was statistically different across the sampling points (p = 0.048). The difference in the mean levels of *E. coli* between the slum and non-slum areas was statistically significant (p = 0.000). The total amount of *E. coli* found in the slum and non-slum area was in the range of 0.0 1046.2 MPN/100mL.

However, the mean of *E. coli* in the slum area was 8.55 MPN/100mL and 14.12 MPN/100mL for the non-slum area.

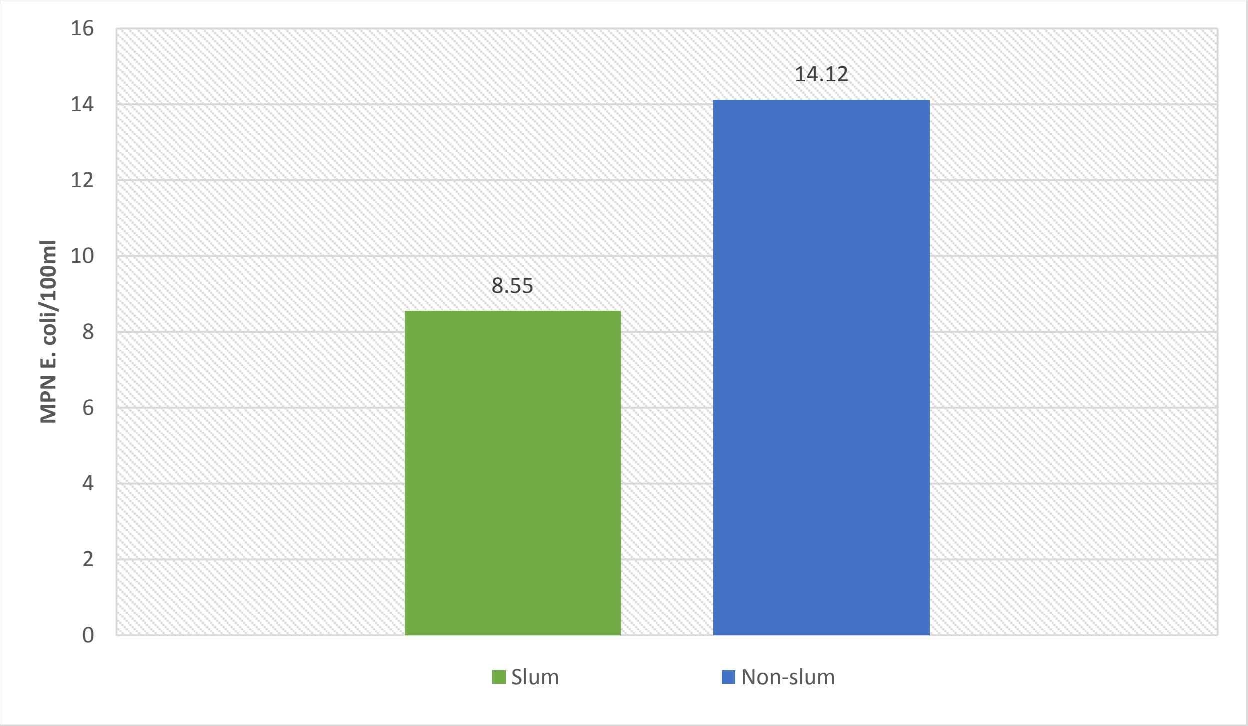


Figure 4.5 Mean distribution of E. coli in the slum and the non-slum area

4.2.3 E. coli O157:H7 and Salmonella

In the two study areas, there was only one sample from the slum area positive for *E. coli O157:H7* (1/166 samples). For *Salmonella* all of the samples (166/166 samples) were negative.

4.3 Infection risk based on *E. coli* Extrapolation

4.3.1 Norovirus infection risk based on the *E. coli* extrapolation

Detail results of the norovirus infection risk are presented in Appendix B. The risk assessment showed that the norovirus infection risk for the slum area was 4.86 x 10^{-3} (95% CI : 2.23 x 10^{-4} – 1.24 x 10^{-2}), while the norovirus infection risk in the non-slum area was 7.02 x 10^{-3} (95% CI : 4.06 x 10^{-4} – 1.63 x 10^{-2}). Among the nodes in the pipe network in the slum area, node 5 had the highest level of norovirus infection risk (3.58 x 10^{-2} 95% CI: 1.75 x 10^{-3} – 8.87 x 10^{-2}) . In the non-slum area node 3 had the highest level of norovirus infection risk (5.99 x 10^{-2} 95% CI: 3.68 x 10^{-3} – 1.34 x 10^{-1})

4.3.2 *E. coli O157:H7* infection risk based on the *E. coli* extrapolation

Detail results of the *E. coli O157:H7* infection risk are presented in Appendix B. The risk assessment showed that the *E. coli O157:H7* infection risk for the slum area was 1.24 x 10^{-8} (95% CI: 8.28 x 10^{-10} – 3.39 x 10^{-8}), while the *E. coli O157:H7* infection risk in the non-slum area was 2.19 x 10^{-8} (95% CI: 1.50 x 10^{-9} – 5.95 x 10^{-8}).

Among the nodes in the pipe network in the slum area, node 5 had the highest level of *E. coli O157:H7* infection (9.73 x 10^{-8} (95% CI: 6.49 x 10^{-9} – 2.64 x 10^{-7}) . In the non-slum area node 3 had the highest level of *E. coli O157:H7* (1.99 x 10^{-7} 95% CI: 1.36 x 10^{-8} – 5.39 x 10^{-7})

4.3.3 *Salmonella* infection risk based on the *E. coli* extrapolation

Detail results of the *Salmonella* infection risk are presented in Appendix B. The risk assessment showed that the *Salmonella* infection risk for the slum area was 3.18 x 10^{-7} (95% CI: 2.15 x 10^{-8} – 8.74 x 10^{-7}), while the *Salmonella* infection risk in the non-slum area was 5.51 x 10^{-7} (95% CI: 3.83 x 10^{-8} – 1.52 x 10^{-6}).

Among the nodes in the pipe network in the slum area, node 5 had the highest level of *Salmonella* infection, 2.50 x 10^{-6} (95% CI: 1.69 x 10^{-7} – 6.89 x 10^{-6}). In the non-slum area node 3 had the highest level of *Salmonella*, 4.99 x 10^{-6} (95% CI: 3.48 x 10^{-7} – 1.38 x 10^{-5})

4.4 Infection risk based on actual *E. coli O157:H7* data

Detail results of the actual risk infection risk are presented in Appendix B. The risk assessment showed that the *E. coli O157:H7* infection risk for the positive *E. coli O157:H7* at node 4 in the slum area was 6.89 x 10^{-6} (95% CI: 4.33 x 10^{-6} – 9.45 x 10^{-6}).

5 Discussion

The finding in this particular study revealed that the water quality in Ayigya (slum area) compared to KNUST (non-slum area) was safer to consume. In total approximately 19% (15/79) of the samples contained *E. coli* in the slum area, while for the non- slum area, *E. coli* was found in approximately 32% (28/87) of the samples. On average 5.46 MPN/100mL less *E. coli (*mean: was found in the slum area (mean: 8.66 MPN/100mL) compared to the non-slum area (mean: 14.12 MPN/100 mL). However, the total coliform was slightly higher in the slum areas (mean: 442.42 MPN/100mL) compared to the non-slum area (435.9 MPN/100 mL). These mean levels of *E. coli* and total coliforms do not meet the drinking water quality guideline (0 MPN/100mL) of either the Ghana Water Company Limited or WHO (WHO 2011b). Two samples slum area (S.05 and S.09) was regarded as “High risk” and one sample from the non-slum area (NS.03) as “very high risk” by the “Classification and colour- code scheme for thermotolerant (faecal) coliforms and *E. coli* in water supplies” used by WHO (WHO 1997). The findings on Total coliform and *E. coli* in both areas also confirm contamination of the pipe- water distribution network. One of the possible explanations can be the intermittent water supply in these areas. As studies have shown, intermittent water supply is common in African countries due to loss of electricity power. Intermittent supply network affects the water quality (Kumpel & Nelson 2013; Thompson et al. 2001; WHO & UNICEF 2000).

Pipe age, pipe material and the condition of the distribution network is a crucial factor when it comes to contamination in both Ayigya and KNUST. This because, cracks, leakage, types of metals and the age of the distribution system will have a big impact on the water quality when the pressure in the area is low, and because these problems are common all over the world (Al-Ghamdi & Gutub 2002; EPA 2001; IWA-publishing 2003). Studies from Bogotá, Colombia shows that there are 187 pipe breaks for 100 km each year and in Minsk, Belarus the number of breaks are 70 per 100 km each year (The World Bank 1996). For that reason, there is a great possibility that also in the city of Kumasi, pipe breaks can be one of the causing factors for contamination in the water distribution network.

Even though the pipes in the non -slum area was not visible, the high amount of total coliform and *E. coli* indicates that there must be cracks/ holes in the pipes along the distribution system that makes a pathway for microbial contaminants to enter the pipe network and be transported to the consumer in KNUST. However, for the slum area, the piping was often not under the ground and water pipes was often seen lying in the open and even in gutters where grey water also flowed, in some cases the water pipes were difficult to detect because of they were submerged by grey water (See Appendix E). Studies from Cebu, Philippines shows that leaky water pipes laying in the gutter, caused contamination in water distribution systems (Moe et al. 1991).

The risk of being infected by the norovirus using *E. coli* as indicator organism was 4.86 x 10^{-3} per single exposure event for the slum area and 7.02 x 10^{-3} per single exposure event for the non- slum area. This is high compared to the WHO tolerable annual infection risk of 10^{-4} per person per year. However, looking at the extrapolation of both *Salmonella* and *E. coli O157:H7,* we can see that the amount from the result is high, compared to the reality and the actual samplings taken from the slum and the non-slum. As shown, only one sample in total (1/166) was detected with *E. coli O157:H7,* and none of the samples contained *Salmonella*. Therefore, the use of such ratios may not give an accurate reflection of the actual risks.

In total 166 samples were collected of which only one sample in the slum area (S.04, 01.04) was positive for *E. coli O157:H7*. This finding has significant public health implication given the low infectious dose of *E. coli* O157:H7 and its associated disease burdens. A potential source for the occurrence of *E. coli* O157:H7 in the distribution network is animal faeces around the pipes or in the grey water that intersect with the water distribution pipes (See Appendix E).

6 CONCLUSION

This study shows that access to piped-network to premises do not ensure clean and safe drinking water to consumer in any of the study areas. Since most of the samples from the study exceeded the WHO and Ghana Water Company Limited guideline for drinking water quality, action has to be taken regarding the water distribution network. Old pipes, intermitted water supply and water pipes lying uncovered and in gutters, are the potential reasons for the contamination of treated water in the pipe-network. It is critical that investment are made in replacing old pipes and in improving the sanitary conditions around the pipe-network to reduce contamination.

Other recommendations is for Ghana Water Company Limited, who are responsible for the water distribution in urban Ghana, to do measurement regarding chlorine residual and add more chlorine to the distribution system if the residual is not sufficient. This because chlorination is an effective way of inactivate microbes such as *E. coli* and *Salmonella*.

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APPENDIX A – SAMPLING DATA FROM THE SLUM AND THE NON-SLUM AREA

Sampling points	Date of fetched water	Reading of the sample	Water fetched by	pH	*Temperature*	*ORP*	Total coliforms (CFU/100 ml)	*E. coli* (CFU/100 ml)	*Salmonella*	*O157:H7*
S.01	14.03	-	No Water	-	-	-	-	-	-	-
S.01	18.03	-	No Water	-	-	-	-	-	-	-
S.01	20.03	-	No Water	-	-	-	-	-	-	-
S.01	23.03	26.03	House owner	-	-	-	248.9	0	No	No
S.01	25.03	-	No water	-	-	-	-	-	-	-
S.01	27.03	28.03	House owner	-	-	-	2	0	No	No
S.01	1.04	4.04	House owner	-	-	-	1986.3	0	No	No
S.01	3.04	4.04	House owner	-	-	-	>2419.6	2	No	No
S.01	8.04	-	Not at home	-	-	-	-	-	-	-
S.01	9.04	10.04	Me	7.1	30	-0.1	1299.7	0	No	No
S.01	14.04	-	No water	-	-	-	-	-	-	-
S.01	15.04	-	No water	-	-	-	-	-	-	-
S.01	16.04	17.04	House owner	-	-	-	1046.2	0	No	No
S.02	14.03	-	No water	-	-	-	-	-	-	-
S.02	18.03	-	No water	-	-	-	-	-	-	-

S.02	20.03	-	No water	-	-	-	-	-	-	-
S.02	23.03	26.03	House owner	-	-	-	0	0	No	No
S.02	25.03	-	No water	-	-	-	-	-	-	-
S.02	27.03	28.03	House owner	-	-	-	0	0	No	No
S.02	1.04	2.04	Me	6.9	27.1	14.3	>2419.6	0	No	No
S.02	3.04	-	No water	-	-	-	-	-	-	-
S.02	4.04	9.04	Hose owner	-	-	-	6.3	0	No	No
S.02	8.04	-	No water	-	-	-	-	-	-	-
S.02	9.04	10.04	Me	7.1	33.3	5.1	>2419.6	0	No	No
S.02	14.04	-	No water	-	-	-	-	-	-	-
S.02	15.04	16.04	House owner	-	-	-	14.8	0	No	No
S.02	16.04	17.04	Me	6.7	29.6	24.8	165.8	0	No	No
S.03	14.03	-	No water	-	-	-	-	-	-	-
S.03	18.03	-	No water	-	-	-	-	-	-	-
S.03	20.03	-	No water	-	-	-	-	-	-	-
S.03	25.03	26.03	House owner	-	-	-	1119.9	0	No	No
S.03	27.03	28.03	Me	6.9	29.1	7	>2419.6	0	No	No
S.03	1.04	2.04	Me	6.8	30.5	16	>2419.6	0	No	No
S.03	3.04	-	No water	-	-	-	-	-	-	-
S.03	8.04	-	Forgot to fetch	-	-	-	-	-	-	-
S.03	9.04	10.04	Me	7.1	34.8	4.8	1119.9	0	No	No

S.03	14.04	15.04	No water	-	-	-	-	-	-	-
S.03	15.04	16.04	No water	-	-	-	-	-	-	-
S.03	16.04	17.04	Me	6.8	32.2	16	99	1	No	No
S.03	17.04	18.04	Me	7	30.3	10.1	980.4	0	No	No
S.04	14.03	-	No water	-	-	-	-	-	-	-
S.04	18.03	-	No water	-	-	-	-	-	-	-
S.04	20.03	-	No water	-	-	-	-	-	-	-
S.04	21.03	23.03	House owner	6.9	-	6.7	307.6	0	No	No
S.04	25.03	26.03	Me	7	28.2	0.5	>2419.6	0	No	No
S.04	27.03	28.03	Me	6.7	28.6	20.6	>2419.6	0	No	No
S.04	1.04	4.04	House owner	-	-	-	>2419.6	2	No	Yes
S.04	3.04	-	Not at home	-	-	-	-	-	-	-
S.04	8.04	-	Not at home	-	-	-	-	-	-	-
S.04	9.04	10.04	Me	7.3	33.1	-5.9	1299.7	0	No	No
S.04	14.04	15.04	Me	6.9	29.4	20.8	1299.7	0	No	No
S.04	15.04	16.04	Me	6.8	28.9	19.5	1732.9	1	No	No
S.04	16.04	17.04	Me	6.7	29.4	18.8	0	0	No	No
S.05	14.03	-	No water	-	-	-	-	-	-	-
S.05	18.03	-	No water	-	-	-	-	-	-	-
S.05	20.03	-	No water	-	-	-	-	-	-	-
S.05	21.03	23.03	House owner	6.8	-	13	>2419.6	0	No	No
S.05	25.03	26.03	Me	7	27.9	4.4	>2419.6	0	No	No
S.05	27.03	28.03	Me	6.8	27.7	18.2	>2419.6	0	No	No

S.05	1.04	2.04	Me	6.5	27.8	33.5	>2419.6	0	No	No
S.05	3.04	4.04	Me	6.7	30.5	22.4	>2419.6	0	No	No
S.05	8.04	9.04	Me	6.9	30	12.5	7.5	0	No	No
S.05	9.04	10.04	Me	7.1	34.1	0.6	1299.7	0	No	No
S.05	14.04	15.04	No water	-	-	-	-	-	-	-
S.05	15.04	16.04	Me	6.7	29.2	28.8	1	1	No	No
S.05	16.04	17.04	Me	6.7	29.1	25.6	2419.6	517.2	No	No
S.06	14.03	-	No water	-	-	-	-	-	-	-
S.06	18.03	-	No water	-	-	-	-	-	-	-
S.06	20.03	-	No water	-	-	-	-	-	-	-
S.06	21.03	23.03	House owner	7.2	-	-10.9	13.2	0	No	
S.06	25.03	26.03	Me	6.6	28.2	23	133.4	0		
S.06	27.03	-	Wedding	-	-	-	-	-	-	-
S.06	1.04	2.04	Me	6.6	27.6	38	>2419.6	16.9	No	No
S.06	3.04	4.04	Me	6.6	29.3	28.2	>2419.6	0	No	No
S.06	8.04	9.04	No water	-	-	-	-	-	-	-
S.06	9.04	10.04	No water	-	-	-	-	-	-	-
S.06	14.04	-	No water	-	-	-	-	-	-	-
S.06	15.04	17.04	House owner	-	-	-	3	1	No	No
S.06	16.04	17.04	Me	6.7	28.9	26	112.6	0	No	No
S.06	17.04	18.04	Me	7	27.9	5.7	59.4	0	No	No
S.07	14.03	-	No water	-	-	-	-	-	-	-
S.07	18.03	-	No water	-	-	-	-	-	-	-
S.07	20.03	-	No water	-	-	-	-	-	-	-

S.07	21.03	23.03	House owner	6.9	-	12	39.9	0	No	No
S.07	25.03	26.03	Me	6.9	29.2	14.1	275.5	0	No	No
S.07	27.03	28.03	Me	6.8	28.3	13.9	0	0	No	No
S.07	1.04	2.04	Me	6.5	29.7	34.2	920.8	8.6	No	No
S.07	3.04	4.04	No water	-	-	-	-	-	-	-
S.07	4.04	9.04	House owner	-	-	-	3.1	0	No	No
S.07	8.04	9.04	Me	6.9	31.1	11.2	6.3	0	No	No
S.07	9.04	10.04	Me	7	31.6	7.3	185	0	No	No
S.07	14.04	-	No water	-	-	-	-	-	-	-
S.07	15.04	-	No water	-	-	-	-	-	-	-
S.07	16.04	17.04	Me	6.7	30.3	25.8	105.4	0	No	No
S.08	14.03	-	No water	-	-	-	-	-	-	-
S.08	18.03	-	No water	-	-	-	-	-	-	-
S.08	20.03	21.03	Me	6.9	30.6	16.3	0	0	No	No
S.08	25.03	26.03	Me	6.9	29.2	11.5	0	0	No	No
S.08	27.03	28.03	Me	6.8	27.7	18.2	16	0	No	No
S.08	1.04	2.04	Me	6.4	28.8	41.8	11	0	No	No
S.08	3.04	4.04	Me	6.7	29.9	25.7	0	0	No	No
S.08	8.04	9.04	Me	7.2	30.6	-2.4	20.1	0	No	No
S.08	9.04	10.04	Me	7.3	33.1	-6.3	313	0	No	No
S.08	14.04	15.04	Me	7	29.7	9.8	686.7	0	No	No
S.08	15.04	16.04	Me	6.6	29.2	35.5	17.5	0	No	No
S.08	16.04	17.04	Me	6.7	30.3	25	98.8	1	No	No
S.09	14.03	-	No Water	-	-	-	-	-	-	-
S.09	18.03	-	No Water	-	-	-	-	-	-	-

S.09	20.03	-	No Water	-	-	-	-	-	-	-
S.09	21.03	23.03	House owner	6.9	-	8.8	1732.9	0	No	No
S.09	25.03	26.03	Me	6.9	29.9	11.2	>2419.6	0	No	No
S.09	27.03	28.03	Me	6.9	28.5	7.5	>2419.6	4.1	No	No
S.09	1.04	2.04	Me	6.5	29.7	34.2	920.8	8.6	No	No
S.09	3.04	4.04	Me	6.7	29	26.6	145	0	No	No
S.09	8.04	9.04	Me	7.1	29.8	4.9	18.9	0	No	No
S.09	9.04	10.04	Me	7.3	31.7	-6.5	224.7	0	No	No
S.09	14.04	-	No water	-	-	-	-	-	-	-
S.09	15.04	16.04	Me	6.7	29.7	26.7	38.4	0	No	No
S.09	16.04	17.04	Me	6.7	29.7	24.9	49.5	109.2	No	No
S.10	14.03	-	No water	-	-	-	-	-	-	-
S.10	18.03	-	No water	-	-	-	-	-	-	-
S.10	20.03	-	No water	-	-	-	-	-	-	-
S.10	21.03	23.03	House owner	6.8	-	5.7	>2419.6	0	No	No
S.10	25.03	26.03	Me	6.9	29.5	13.7	8.6	0	No	No
S.10	27.03	28.03	Me	6.9	28.1	10.3	44.1	1	No	No
S.10	1.04	2.04	Me	6.5	27	33	2419.6	0	No	No
S.10	3.04	4.04	Me	6.6	29.6	32	1011.12	0	No	No
S.10	8.04	9.04	Me	7.1	29.8	4.9	105.4	1	No	No
S.10	9.04	10.04	Me	7.3	31.4	-9.3	727	0	No	No
S.10	14.04	15.04	Me	7	28.2	10.4	50.4	0	No	No
S.10	15.04	-	No water	-	-	-	-	-	-	-
S.10	16.04	17.04	Me	6.7	29.5	26.8	13.4	0	No	No

Sampling point	Date of sampling	Reading of the sample	Water at point of use on the sampling day	No water at the point of use on the sampling day	pH	*Temperature*	ORP	Total coliforms (CFU/100 ml)	*E. coli* (CFU/100 ml)	*Salmonella*	*E. coli O157: H7*
NS.01	24.03	25.03	X		6.7	30.5	29.4	96	8.6	No	No
NS.01	26.03	27.03	X		6.9	30.4	11.2	410.6	5.2	No	No
NS.01	31.03	01.04	X		6.7	29	22.1	920.8	0	No	No
NS.01	02.04	03.03	X		6.8	29.5	20.2	1046.2	14.8	No	No
NS.01	08.04	09.04	X		7	30.2	1.5	21.8	0	No	No
NS.01	09.04	10.04	X		6.8	32.3	21.1	159.7	2	No	No
NS.01	14.04	15.04	X		6.8	32.2	24.4	261.3	2	No	No
NS.01	15.04	16.04	X		6.8	30	20.2	152.3	6.3	No	No
NS.01	16.04	17.04	X		6.9	31.4	20.1	145.5	4.1	No	No
NS.02	26.03	27.03	X		6.9	30.5	2.1	>2419.6	0	No	No
NS.02	31.03	01.04	X		6.7	29.2	29.8	686.7	0	No	No
NS.02	02.04	03.04	X		6.8	29.6	15	>2419.6	0	No	No
NS.02	03.04	04.04	X		6.6	30.8	26.3	980.4	0	No	No
NS.02	08.04	09.04	X		6.8	30.9	20.7	25.9	0	No	No
NS.02	09.04	10.04	X		6.9	34.2	8	1119.9	40.8	No	No
NS.02	14.04	15.04	X		6.7	30.4	26.8	816.4	0	No	No
NS.02	15.04	16.05	X		6.7	30.4	29.3	186.3	0	No	No
NS.02	16.05	17.05	X		6.7	31.7	24.3	1203.3	1	No	No
NS.03	24.03	25.03	X		7	28.5	16	11	0	No	No
NS.03	26.03	27.03	X		6	29.1	59.1	517.2	0	No	No
NS.03	31.03	01.04	X		6.2	28.5	48.6	>2419.6	0	No	No

NS.03	02.04	03.03	X		6.6	30.2	27.6	>2419.6	1	No	No
NS.03	08.04	09.04	X		6.1	30.4	51.6	63.7	2	No	No
NS.03	09.04	10.04	X		6.3	31	44.8	1413.6	1046.2	No	No
NS.03	14.04	15.04	X		6.5	29.8	36.8	18.9	0	No	No
NS.03	15.04	16.04	X		6.1	29.4	57.5	1986.3	0	No	No
NS.03	16.04	17.04	X		6.7	32.6	16	155.3	0	No	No
NS.04	24.03	25.03	X		6.8	30.9	1	22.6	1	No	No
NS.04	26.03	27.03	X		6.6	34.6	35.4	>2419.6	0	No	No
NS.04	31.03	01.04	X		6.7	31.9	14.4	>2419.6	0	No	No
NS.04	02.04	03.03	X		6.9	29.1	11.8	2419.6	0	No	No
NS.04	08.04	09.04	X		6.7	29.3	19	44.1	0	No	No
NS.04	09.04	10.04	X		6.8	29.7	20.7	1986.3	1	No	No
NS.04	14.04	15.04	X		6.6	33.2	31.9	261.3	0	No	No
NS.04	15.04	16.04	X		6.8	27.8	18.9	57.6	0	No	No
NS.04	16.04	17.04	X		6.7	30.1	30.3	20.3	0	No	No
NS.05	24.03	25.03	X		6.9	29.5	8.6	5.2	0	No	No
NS.05	26.03	27.03	X		6.6	30.4	30.9	82	0	No	No
NS.05	31.03	01.04	X		6.6	29.6	30.9	>2429.6	0	No	No
NS.05	02.04	03.03	X		6.8	28.5	21.9	>2419.6	0	No	No
NS.05	08.04	09.04	X		6.8	28.9	12.8	6.2	0	No	No
NS.05	09.04	10.04	X		6.8	29.2	16	110.6	0	No	No
NS.05	14.04	15.04	X		6.5	30.8	33.6	22.8	0	No	No
NS.05	15.04	16.04	X		6.6	28.3	25.2	1	0	No	No
NS.05	16.04	17.04	X		6.7	30	23.6	172.2	0	No	No
NS.06	24.03	25.03	X		7.2	29.1	-10	13.5	4.1	No	No
NS.06	26.03	27.03	X		7	30.7	3	>2419.6	0	No	No
NS.06	31.03	01.04		X	-	-	-	-	-	-	-

NS.06	02.04	03.03	X		6.9	30.1	11.1	>2419.6	0	No	No
NS.06	08.04	09.04	X		7	30.6	7.4	74.4	1	No	No
NS.06	9.04	10.04	X		6.7	31.7	32.0	>2419.6	0	No	No
NS.06	14.04	15.04	X		6.9	30.3	19.3	1770.1	0	No	No
NS.06	15.04	16.04	X		7	29.7	10.7	6.3	0	No	No
NS.06	16.04	17.04	X		7	30.6	8.6	218.7	0	No	No
NS.07	24.03	25.03	X		6.4	28.9	32.0	54.6	0	No	No
NS.07	26.03	27.03	X		6.6	29.8	27.6	>2419.6	3.1	No	No
NS.07	31.03	01.04	X		6.6	29.2	25.3	>2419.6	0	No	No
NS.07	02.04	03.03	X		6.5	29.2	35.9	>2419.6	0	No	No
NS.07	08.04	09.04	X		6.7	30.6	23.4	50.4	5.2	No	No
NS.07	09.04	10.04	X		6.7	34.2	23.9	1203.3	0	No	No
NS.07	14.04	15.04	X		6.5	31.4	33.4	275.5	0	No	No
NS.07	15.04	16.04	X		6.5	30.4	35.4	156.6	1	No	No
NS.07	16.04	17.04	X		6.6	30.3	30.7	325.5	1	No	No
NS.08	24.03	25.03	X		6.9	28.2	13.8	142.1	0	No	No
NS.08	26.03	27.03	X		7	29.3	9.2	>2419.6	0	No	No
NS.08	31.03	01.04	X		7	29.5	6.3	>2419.6	7.4	No	No
NS.08	02.04	03.03	X		6.7	28.7	23.4	>2419.6	3.1	No	No
NS.08	08.04	09.04	X		7	30.3	11.3	41	7.4	No	No
NS.08	09.04	10.04	X		7.1	31.4	6.3	1413.6	0	No	No
NS.08	14.04	15.04	X		6.9	30.7	14.6	137.6	0	No	No
NS.08	15.04	16.04	X		6.9	28.4	16.4	31.3	0	No	No
NS.08	16.04	17.04	X		6.8	29.5	22.6	76.7	13.5	No	No
NS.09	24.03	25.03	X		7	28.3	7.0	49.6	2	No	No
NS.09	26.03	27.03	X		6.5	29.1	33.5	>2419.6	0	No	No

NS.09	31.03	01.04	X		6.4	29	35.9	>2419.6	0	No	No
NS.09	02.04	03.03	X		6.5	28.7	30.8	1553.1	0	No	No
NS.09	08.04	09.04	X		6.5	29.5	35.6	18.9	0	No	No
NS.09	09.04	10.04		X	-	-	-	-	-	-	-
NS.09	14.04	15.04	X		6.7	29.4	30.3	52.9	13.2	No	No
NS.09	15.04	16.04	X		6.7	28.8	24.7	133.1	24.6	No	No
NS.09	16.04	17.04	X		6.7	29.7	24.9	99.1	0	No	No
NS.10	24.03	25.03	X		5.8	28.8	86.0	0	0	No	No
NS.10	26.03	27.03	X		5.9	29.9	67.4	613.1	4.1	No	No
NS.10	31.03	01.04	X		5.9	28.9	68.2	1732.9	0	No	No
NS.10	02.04	03.03	X		5.8	28.8	76.1	166.4	0	No	No
NS.10	08.04	09.04	X		5.8	29.7	75.8	2	0	No	No
NS.10	09.04	10.04	X		5.9	30.7	63.6	1553.1	2	No	No
NS.10	14.04	15.04	X		6	29.1	54.8	50.4	0	No	No
NS.10	15.04	16.04	X		5.8	28.6	76.4	14.6	0	No	No
NS.10	16.04	17.04		X	-	-	-	-	-	-	-

APPENDIX B – INFECTION RISKS

Norovirus Infection Risk Slum Area

Name	1	2	3	4	5	6	7	8	9	10
Mean	0.000192231	0	9.62653E-05	0.000192804	0.03588444	0.001636863	0.000827124	9.67259E-05	0.009626533	9.72146E-05
5% Perc	7.05697E-06	0	3.42678E-06	7.3439E-06	0.001755665	5.80078E-05	2.95392E-05	3.16043E-06	0.000367464	3.36163E-06
95% Perc	0.000568045	0	0.000283414	0.000561844	0.08878779	0.004714211	0.002399493	0.000279677	0.02652087	0.000282059
Mean of the whole area	0.00486502									
Mean 5% perc	0.000223503									
Mean 95% perc	0.01243974									

Norovirus Infection Risk Non-Slum Area

Name	1	2	3	4	5	6	7	8	9	10
Mean	0.001412465	0.003790944	0.05996748	9.8739E-05	0	0.000398539	0.000510574	0.001317266	0.002334931	0.000397844
5% Perc	5.0283E-05	0.000136357	0.003682665	3.58384E-06	0	1.53172E-05	2.04467E-05	5.23178E-05	9.3292E-05	1.26831E-05
95% Perc	0.004072081	0.01089586	0.1341572	0.000288067	0	0.00115491	0.001452022	0.003791362	0.006720382	0.001156045
Mean of the whole area	0.007022878									
Mean 5% perc	0.000406695									
Mean 95% perc	0.016368793									

E.coli O157:H7 Infection Risk Slum Area

Name	1	2	3	4	5	6	7	8	9	10
Mean	3.80912E-10	0	1.90108E-10	3.80168E-10	9.73409E-08	3.18466E-09	1.63844E-09	1.90505E-10	2.1157E-08	1.91013E-10
5% Perc	2.5526E-11	0	1.31379E-11	2.76832E-11	6.49078E-09	1.96626E-10	1.11693E-10	1.41656E-11	1.3885E-09	1.2085E-11
95% Perc	1.03717E-09	0	5.1616E-10	1.03441E-09	2.64442E-07	8.86499E-09	4.50925E-09	5.17262E-10	5.77412E-08	5.15529E-10
Mean of the whole area	1.24654E-08									
Mean 5% perc	8.2802E-10									
Mean 95% perc	3.39178E-08									

E.coli O157:H7 Infection Risk Non-Slum Area

Name	1	2	3	4	5	6	7	8	9	10
Mean	2.7921E-09	7.73732E-09	1.99314E-07	1.84798E-10	0	7.74286E-10	1.00305E-09	2.5822E-09	4.67521E-09	7.75095E-10
5% Perc	1.90505E-10	5.28447E-10	1.36848E-08	1.1994E-11	0	5.2921E-11	7.00711E-11	1.70427E-10	3.16822E-10	5.42528E-11
95% Perc	7.48519E-09	2.11812E-08	5.39868E-07	5.10715E-10	0	2.12869E-09	2.79039E-09	7.06485E-09	1.24708E-08	2.14904E-09
Mean of the whole area	2.19838E-08									
Mean 5% perc	1.50802E-09									
Mean 95% perc	5.95649E-08									

Salmonella Infection Risk Slum Area

Name	1	2	3	4	5	6	7	8	9	10
Mean	9.57415E-09	0	4.75691E-09	9.49867E-09	2.50097E-06	8.14255E-08	4.11996E-08	4.74285E-09	5.2644E-07	4.81292E-09
5% Perc	5.91289E-10	0	3.1055E-10	6.68751E-10	1.68684E-07	5.45287E-09	2.601E-09	3.08098E-10	3.59839E-08	3.12913E-10
95% Perc	2.62205E-08	0	1.2893E-08	2.61763E-08	6.8868E-06	2.2003E-07	1.11748E-07	1.31046E-08	1.42774E-06	1.32428E-08
Mean of the whole area	3.18342E-07									
Mean 5% perc	2.14914E-08									
Mean 95% perc	8.73795E-07									

Salmonella Infection Risk Non-Slum Area

Name	1	2	3	4	5	6	7	8	9	10
Mean	7.11368E-08	1.96618E-07	4.99277E-06	4.80663E-09	0	1.9782E-08	2.50863E-08	6.48985E-08	1.16481E-07	1.955E-08
5% Perc	4.53234E-09	1.38507E-08	3.48068E-07	3.26145E-10	0	1.30679E-09	1.70901E-09	4.65189E-09	7.80649E-09	1.20463E-09
95% Perc	1.96438E-07	5.30269E-07	1.37874E-05	1.3185E-08	0	5.47024E-08	6.86143E-08	1.75148E-07	3.18201E-07	5.38201E-08
Mean of the whole area	5.51112E-07									
Mean 5% perc	3.83456E-08									
Mean 95% perc	1.51978E-06									

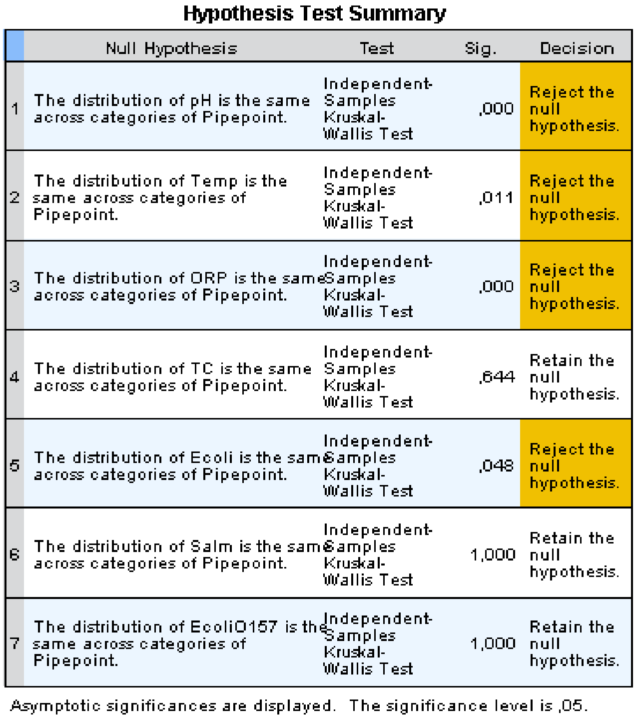
Actual E. coli O157:H7 risk Slum Area

Name	1	2	3	4	5	6	7	8	9	10
Mean	0	0	0	6.89095E-05	0	0	0	0	0	0
5% Perc	0	0	0	4.32552E-05	0	0	0	0	0	0
95% Perc	0	0	0	9.44895E-05	0	0	0	0	0	0
Mean of the whole area	6.89095E-06									
Mean 5% perc	4.32552E-06									
Mean 95% perc	9.44895E-06									

Actual E. coli O157:H7 risk Non-Slum area

Name	1	2	3	4	5	6	7	8	9	10
Mean	0	0	0	0	0	0	0	0	0	0
5% Perc	0	0	0	0	0	0	0	0	0	0
95% Perc	0	0	0	0	0	0	0	0	0	0
Mean of the whole area	0									
Mean 5% perc	0									
Mean 95% perc	0									

APPENDIX C - DISTRIBUTION OF VARIABLES ACROSS LOCATIONS IN THE SAMPLING AREA

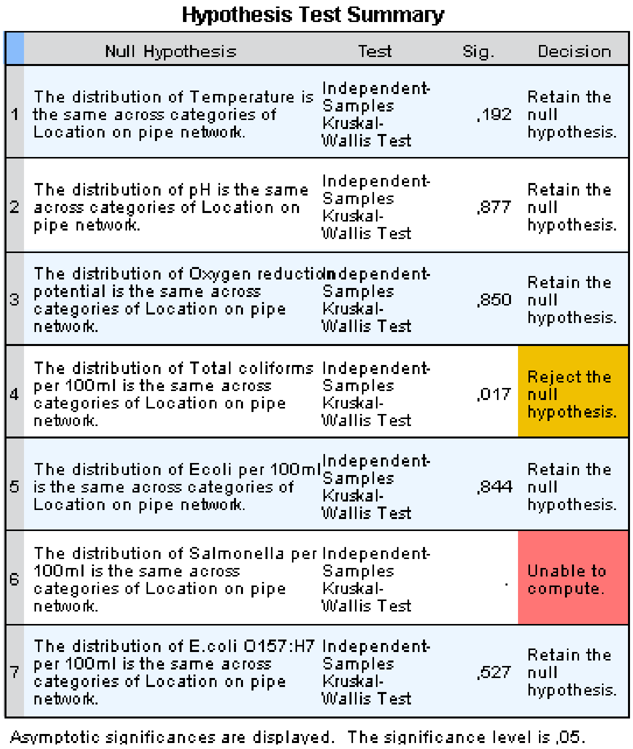


Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The distribution of pH is the same across categories of Pipepoint.	Independent-Samples Kruskal-Wallis Test	,000	Reject the null hypothesis.
2	The distribution of Temp is the same across categories of Pipepoint.	Independent-Samples Kruskal-Wallis Test	,011	Reject the null hypothesis.
3	The distribution of ORP is the same across categories of Pipepoint.	Independent-Samples Kruskal-Wallis Test	,000	Reject the null hypothesis.
4	The distribution of TC is the same across categories of Pipepoint.	Independent-Samples Kruskal-Wallis Test	,644	Retain the null hypothesis.
5	The distribution of Ecoli is the same across categories of Pipepoint.	Independent-Samples Kruskal-Wallis Test	,048	Reject the null hypothesis.
6	The distribution of Salm is the same across categories of Pipepoint.	Independent-Samples Kruskal-Wallis Test	1,000	Retain the null hypothesis.
7	The distribution of EcoliO157 is the same across categories of Pipepoint.	Independent-Samples Kruskal-Wallis Test	1,000	Retain the null hypothesis.

Asymptotic significances are displayed. The significance level is ,05.

95% CI in the Slum area

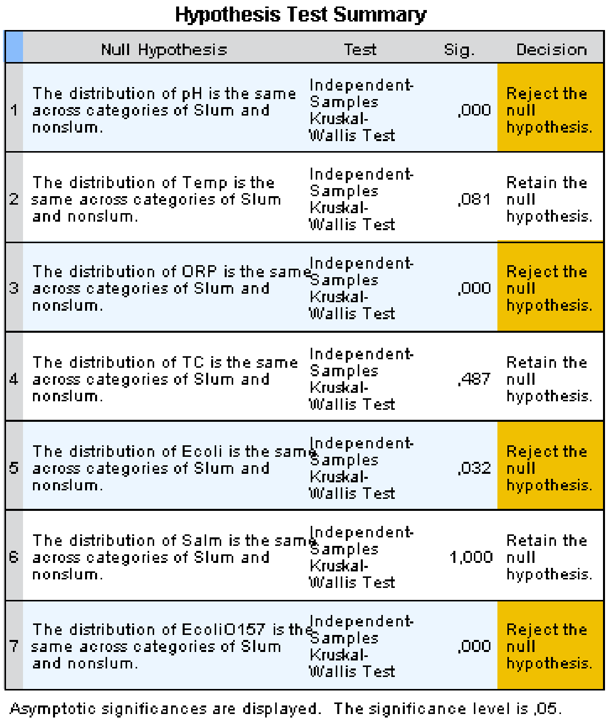


Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The distribution of Temperature is the same across categories of Location on pipe network.	Independent-Samples Kruskal-Wallis Test	,192	Retain the null hypothesis.
2	The distribution of pH is the same across categories of Location on pipe network.	Independent-Samples Kruskal-Wallis Test	,877	Retain the null hypothesis.
3	The distribution of Oxygen reduction potential is the same across categories of Location on pipe network.	Independent-Samples Kruskal-Wallis Test	,850	Retain the null hypothesis.
4	The distribution of Total coliforms per 100ml is the same across categories of Location on pipe network.	Independent-Samples Kruskal-Wallis Test	,017	Reject the null hypothesis.
5	The distribution of Ecoli per 100ml is the same across categories of Location on pipe network.	Independent-Samples Kruskal-Wallis Test	,844	Retain the null hypothesis.
6	The distribution of Salmonella per 100ml is the same across categories of Location on pipe network.	Independent-Samples Kruskal-Wallis Test	.	Unable to compute.
7	The distribution of E.coli O157:H7 per 100ml is the same across categories of Location on pipe network.	Independent-Samples Kruskal-Wallis Test	,527	Retain the null hypothesis.

Asymptotic significances are displayed. The significance level is ,05.

95% CI in the non-slum area



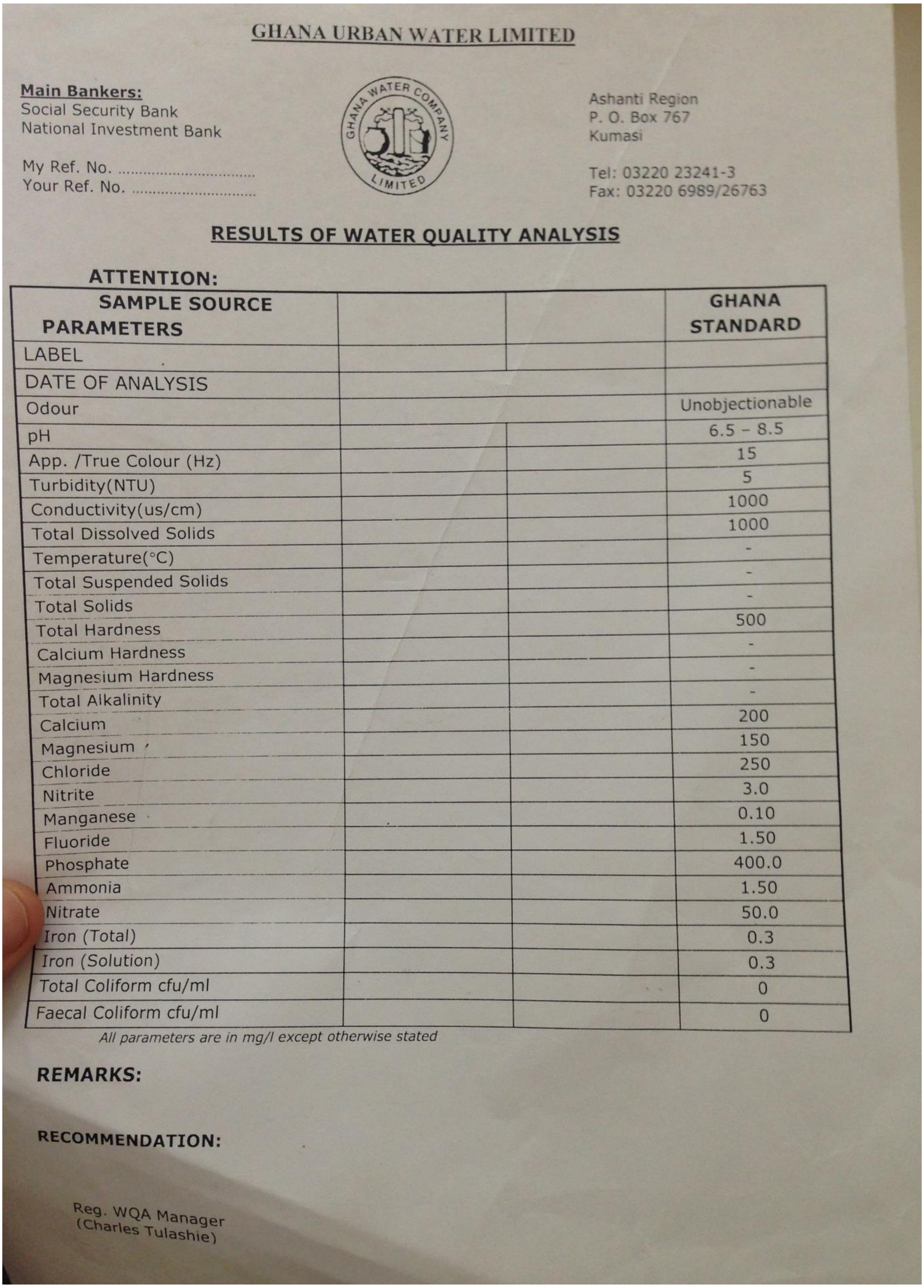
Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The distribution of pH is the same across categories of Slum and nonslum.	Independent-Samples Kruskal-Wallis Test	,000	Reject the null hypothesis.
2	The distribution of Temp is the same across categories of Slum and nonslum.	Independent-Samples Kruskal-Wallis Test	,081	Retain the null hypothesis.
3	The distribution of ORP is the same across categories of Slum and nonslum.	Independent-Samples Kruskal-Wallis Test	,000	Reject the null hypothesis.
4	The distribution of TC is the same across categories of Slum and nonslum.	Independent-Samples Kruskal-Wallis Test	,487	Retain the null hypothesis.
5	The distribution of Ecoli is the same across categories of Slum and nonslum.	Independent-Samples Kruskal-Wallis Test	,032	Reject the null hypothesis.
6	The distribution of Salm is the same across categories of Slum and nonslum.	Independent-Samples Kruskal-Wallis Test	1,000	Retain the null hypothesis.
7	The distribution of EcoliO157 is the same across categories of Slum and nonslum.	Independent-Samples Kruskal-Wallis Test	,000	Reject the null hypothesis.

Asymptotic significances are displayed. The significance level is ,05.

Comparison between the slum and the non-slum

APPENDIX D – GHANA WATER COMPANY LIMITED STANDARDS



GHANA URBAN WATER LIMITED

Main Bankers:
Social Security Bank
National Investment Bank

My Ref. No. ……………………………
Your Ref. No. …………………………

Ashanti Region
P. O. Box 767
Kumasi

Tel: 03220 23241-3
Fax: 03220 6989/26763

RESULTS OF WATER QUALITY ANALYSIS

ATTENTION:

SAMPLE SOURCE **PARAMETERS**			**GHANA STANDARD**
LABEL			
DATE OF ANALYSIS			
Odour			Unobjectionable
pH			6.5 – 8.5
App. /True Colour (Hz)			15
Turbidity(NTU)			5
Conductivity(us/cm)			1000
Total Dissolved Solids			1000
Temperature(°C)			-
Total Suspended Solids			-
Total Solids			-
Total Hardness			500
Calcium Hardness			-
Magnesium Hardness			-
Total Alkalinity			-
Calcium			200
Magnesium			150
Chloride			250
Nitrite			3.0
Manganese			0.10
Fluoride			1.50
Phosphate			400.0
Ammonia			1.50
Nitrate			50.0
Iron (Total)			0.3
Iron (Solution)			0.3
Total Coliform cfu/ml			0
Faecal Coliform cfu/ml			0

All parameters are in mg/l except otherwise stated

REMARKS:

RECOMMENDATION:

Reg. WQA Manager
(Charles Tulashie)

APPENDIX E– PICTURES FROM THE SLUM AREA

Typical water tap in the slum area

Drinking water pipe going trough the gutter

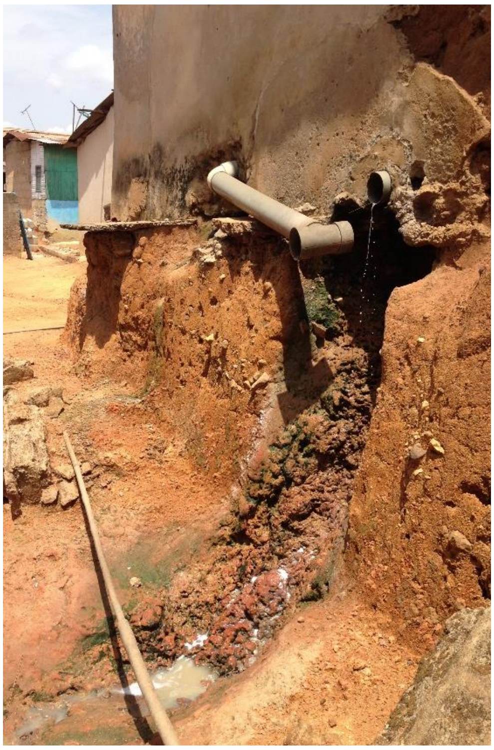
Drinking water pipe at the entrance in the door entrance

Drinking water pipe lying in the gutter together with grey water

Drinking water pipes in the open with garbage around

Drinking water pipes in the open

Many pipes laying close to each other. The drinking water pipes also goes trough the septic tank



Drinking water pipe exposed to grey water

Typical view in the slum area

Stones are used hold the pipes stable and to take the pressure from the water

Leakage from a water pipe

The leaking pipe is crosses above the grey water in the gutter

Leaking pipe

Hole in the water pipe exposed

Hole in the water pipe

This picture is taken few days after the pictures above. Soil has been put on the top of the pipe ,but the hole is not fixed and water i leaking out in to the area

Eexposed pipe going through the gutter

Animal feces on the drinking water pipe

The water pipe is exposed and goes under the toilet and shower

APPENDIX F – PICTURES FROM THE NON-SLUM AREA

Outside the building of sampling point NS.03

Sampling point NS.09

Sampling point NS.10

Sampling point NS.01

Water tap in one of the sampling points

Water tap at the right hand side in one of the sampling points

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