ADDIS ABABA UNIVERSITY
SCHOOL OF GRADUATE STUDIES

Assessment of Physico-chemical and Microbiological Quality of Drinking Water at Sources and Household in Selected Communities of Akaki-kaliti sub city, Addis Ababa City Administration

A Thesis submitted to the School of Graduate Studies of Addis Ababa University in partial fulfillment of the requirements for the Degree of Master of Science in Environmental Science

By: MENGESTAYHU BIRHANU

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Mengestayhou Birhanu
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ACRONYMS AND ABBREVIATIONS
AAU Addis Ababa University
AAWSA Addis Ababa Water and Sewerage Authority
ANOVA Analysis of Variance
APHA American Public Health Association
AWD Acute Watery Diarrhea
AWWA American Water Works Association
BH Bore Hole
cfu colony-forming units
CRD Capital Regional District
CT Contact Time
CTR City Reservoir
d.f. Degree of freedom
DPD N,N-diethyl-p-phenylenediamine
E. coli Escherichia coli
EP Emergence Product
ETEC Enterotoxigenic Escherichia Coli
FC Feacal coliform
FCR Free chlorine residual
Fig. Figure
FOM Facility of medicine
FPTSDW Federal-Provincial-Territorial Subcommittee on Drinking Water
<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Full Form</th>
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<tbody>
<tr>
<td>FSC</td>
<td>Fanta spring chlorinated</td>
</tr>
<tr>
<td>FSNC</td>
<td>Fanta spring non chlorinated</td>
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<tr>
<td>FS</td>
<td><em>Faecal streptococci</em></td>
</tr>
<tr>
<td>MF</td>
<td>Membrane Filtration</td>
</tr>
<tr>
<td>NJF</td>
<td>Nordic Association of Agricultural Scientists</td>
</tr>
<tr>
<td>ISO</td>
<td>International Standard Organization</td>
</tr>
<tr>
<td>LSD</td>
<td>Least Square of Differences</td>
</tr>
<tr>
<td>OECD</td>
<td>Organization for Economic co-operation and Development</td>
</tr>
<tr>
<td>SI</td>
<td>Sanitary Inspection</td>
</tr>
<tr>
<td>TC</td>
<td>Total coliform</td>
</tr>
<tr>
<td>TDR</td>
<td>Tulu Dimitu Reservoir</td>
</tr>
<tr>
<td>Temp.</td>
<td>Temperature</td>
</tr>
<tr>
<td>THM</td>
<td>Trihalomethane</td>
</tr>
<tr>
<td>TID</td>
<td>Technical Information Document</td>
</tr>
<tr>
<td>TTC</td>
<td><em>Thermotolerant coliforme</em></td>
</tr>
<tr>
<td>Turb.</td>
<td>Turbidity</td>
</tr>
<tr>
<td>UMES</td>
<td>University of Minnesota Extension Service</td>
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<tr>
<td>UN-WATER/WWAP</td>
<td>United Nations Water/World Water Assessment Program</td>
</tr>
<tr>
<td>USEPA</td>
<td>United State Environmental Protection Agency</td>
</tr>
<tr>
<td>WHO</td>
<td>World Health Organization</td>
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<tr>
<td>WSTB</td>
<td>Water Science and Technology Board</td>
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Abstract

Since water is essential to sustain life, and when supplied as drinking water to consumers, a satisfactory quality must be maintained so that, provision of water, sanitation and good hygiene services are vital for the protection and development of human resources. Though ground water is much better than surface water in terms of biological quality, lack of source protection and inefficient treatment, waste management and sewerage system problem, poorly designed pit latrines and poor hygienic practice at the households affect the quality of the water. Therefore, assessment of physico-chemical and microbiological quality of drinking water from sources to household in selected communities of Akaki-kaliti sub city, Addis Ababa City Administration were conducted.

This study was conducted from September 2006 to January 2007. A survey of 82 triplicate water sample and sanitary surveys were conducted in 7 raw water sources, 5 chlorinated and non-chlorinated water points, 35 pipe water and 35 randomly selected households’ storage water containers. The water samples were examined for TTC and FS using membrane filtration method.

All raw water samples were positive for TTC and FS. High bacteriological load were found in BH8 (52.5 cfu/100ml) for FS and FSN (29 cfu/100ml) for TTC. TTC and FS concentrations detected were 12.3 and 11.6 cfu/100ml, respectively for bore hole EP4. For un-treated water sources the (KGW, EP5) TTC counts were higher (>15 cfu per 100). Similarly, the FS count for KGW (>15 cfu per 100 ml) was higher than EP5 (2 CFU/100ml). The health risk matrix assessment indicated that both the EP5 and KGW for TTC were within high risk score while FS risk to health classification EP5 and KGW lie on medium and high risk score, respectively.

Temperature at all three disinfection points were above permissible limit of 15 °C. Turbidity at CTR and FSC met the acceptable level of WHO and National standard limit of potability < 5 FAU. TDR was above the recommended limit. The pH values at all the three points were within the recommended limit (6.5 - 8.5). The free chlorine residual were 0.67, 0.6, 0.68 mg/l at CTR, TDR and FSC respectively which are less than the average value of the recommended limit of WHO (>0.8mg/l). Even if disinfected water sources (CTR, TDR, FSC) were better than non disinfected water sources (EP5, KGW), all sample sources were contaminated with TTC and FS having cfu >1 per 100ml and this were found out to be above WHO and National standards (cfu/100ml=0).

Only 1(2.9%) of pipe water samples was <15 °C whereas others were found to be above the limit of 15 °C. The temperature of pipe water was in the rage of 14.5 -22.5 °C which was warmer as compared to the standard temperature (15°C). This favors the regrowth of some indicator organisms like TTC in distribution systems. Out of the examined sampling sites 48.6% of them were within the range of acceptable chlorine residual limit (0.2-0.5 mg/l) and 17.1% were above the recommended level (0.5 mg/l). In all pipe water samples, pH values were within the recommended limit (6.5-8). In the pipeline, only 17.1% and 31.4% of sampling sites were found acceptable based on WHO and National standard for TTC and FS counts, respectively. The overall risk-to-health classification at pipe water (N=35) were 19(54.29%) as intermediate and 16(45.7%) as low classification range for FS whereas for TTC, 19 (54.29%), 8(22.88%) and 8(22.88%) were as intermediate, high and low risk to health matrix score, respectively.

For water samples at the household, only 14.3% were within the recommended free chlorine residual level. 8.6% and 17.1% of sample sites (N=35) were above the recommended limit of temperature (<15°C), and turbidity (<5FAU), respectively and only 1 (2.9%) was acceptable for both TTC and FS cfu levels. The health matrix classifications for bacteriological indicators (TTC and FS) were found to be 65.7% and 20% with in the high risk and medium risk score, respectively.
Distributing water without treatment and uncontrolled physico-chemical parameters such as temperature, turbidity, pH and inefficient chemical chlorine dosing, which led to low chlorine residual at distribution and household water containers were the major factors that contributed the occurrence of high bacterial numbers. Moreover, the water pipe lines and sewerage lines arrangement were also another factor that contributes for bacterial growth in the distribution system, there by compromising the quality of water at the point of use. Bacteriological load was greater at the household samples due to poor hygienic practice. Therefore, the management of water sources, appropriate treatment of the raw water sources, control of physico–chemical parameters at disinfection points, and promoting good hygienic practices are important to make the water quality acceptable in the study area. Moreover, installation and utilization of highly efficient technology is recommendable for production of high potable water.

**Key words:** disinfection points, pipe water, house holds drinking water, physico-chemical parameters, Thermotolerant coliforms, Faecal streptococci, source protection and sanitary survey
1. Introduction

Water quality is a critical factor affecting human health and welfare. Studies showed that approximately 3.1% of deaths (1.7 million) and 3.7% of disability-adjusted-life-years (DALYs) (54.2 million) worldwide are attributable to unsafe water, poor sanitation and hygiene (WHO, 2005). Ethiopia is one of the countries with worst health status in the world water quality problems. The problem is the backward socio-economic development resulting in one of the lowest standard of living, poor environmental conditions and low level of social services (UN-WATER/WWAP/, 2004).

The role of sanitation and safe water in maintaining health has been recognized for centuries. The provision of water, sanitation and good hygiene services is vital for the protection and development of human resources (Fewtrell et al., 2004).

The quality of drinking-water may be controlled through a combination of protection of water sources, control of treatment processes and management of the distribution and handling of the water (FPTSDW, 2001). The amount of treatment provided by the water utility is dependent on the nature and degree of contamination of source water. The majority of bacterial pathogens are removed or inactivated by standard water treatment practices. Standard drinking water treatment includes coagulation/ flocculation, sedimentation, filtration, and disinfection (Downie, 2005). Drinking water utilities may have to consider changing disinfectant to improve water quality and meet more stringent disinfection regulations (Volk et al., 2002).

Moreover, virtually anywhere a surface comes into contact with the water in a distribution system, one can find biofilms. Biofilms are formed in distribution system pipelines when microbial cells attach to pipe surfaces and multiply to form a film or slime layer on the pipe. Probably within seconds of entering the water distribution system, large particles, including microorganisms, absorb to the clean pipe surface (Clark, 2004). Factors that affect bacterial growth on biofilms include water temperature, type of disinfectant and residual concentration, assimilable organic carbon level, biodegradable organic carbon level, degree of pipe corrosion, and treatment/distribution system characteristics (Hunter et al., 2001).
Some pathogens may contaminate the water at the source, but contamination may also occur during transportation, distribution, or handling of the water in households or other working places (WHO, 2004b). If the raw water is used before it receives treatment, it presents a sanitary risk and may be unsafe. All treatment plants and their raw water sources should be located at a safe distance from potential sources of contamination. The transmission lines present a potential opportunity for liquids and materials to both enter and leave the system (USEPA, 1999).

Livestock and poultry operations have properties that can generate large amounts of manure and waste. Sometimes this can serve as a valuable resource; however, when improperly managed, nutrients, bacteria, and other pollutants can contaminate drinking water supply (Ross, 2003).

Pathogens are generally small and easily transported in water. Sources of pathogens to a water distribution system include: (1) source water contamination followed by improper or insufficient treatment, (2) regrowth of organisms due to insufficient disinfectant residual in the distribution system, (3) contamination due to transient pressure drops leading to infiltration of groundwater into water pipes, (4) contamination due to incorrect cross-connections with sewer lines, and (5) intentional addition of pathogenic organisms at the treatment plant or in the distribution system. Additional factors that can affect the impact of introduction of pathogens into the distribution system include (1) water temperature, pH, turbidity and oxygen concentration, (2) water demand in the system, and (3) distribution system configuration (Ailamaki et al., 2003).

Contamination by sewage or human excrement presents the greatest danger to public health associated with drinking water, and bacteriological testing continues to provide the most sensitive means for the detection of such pollution (Hrudey et al., 2003).

In the city, septic tanks, open dumps, in proper constriction latrines and surface impoundments are the most common sources for sewage contamination, so that regular examination of water quality for the presence of pathogenic organisms, chemicals and other physical contents must be conducted to provide information on the level of the safety of water (OECD/ WHO, 2003). Although modern microbiological techniques have made possible the detection of pathogenic bacteria, viruses and protozoa in sewage and sewage effluents, it is not practical to attempt to isolate them as a routine procedure from samples of drinking water (Hrudey et al., 2003).
Indicators of faecal pollution include the coliform group as a whole and particularly *Escherichia coli*, *Streptococci faecalis* and some Thermotolerant organisms such as *Clostridium perfringens* are essential parameters. Appropriate treatment and sanitary survey are also very important to protect and control the water borne diseases (OECD /WHO, 2003). A comparative approach to evaluate two currently accepted bacterial indicators of drinking water quality (Thermotolerant coliforms, *Streptococci faecalis*) and related physico-chemical parameters (Howard *et al.*, 2003; OECD/WHO, 2003; WHO,2004b and Dagnew *et al.*, 2006).

**1.1. Background and statement of the problem**

About 1.1 billion people in developing countries remain without access for improved sources of water, and about 2.4 billion have no access to any form of improved sanitation services. As a consequence, 2.2 million people in developing countries, most of them children, die every year from diseases associated with lack of safe drinking-water, inadequate sanitation and poor hygiene. Diarrhal illness remains a major killer in childrens and it is estimated that 80% of all illness in developing countries is related to water and sanitation (WHO, 2002).

Most of the population of Ethiopia in rural and urban areas does not have access to safe and reliable sanitation facilities. Majority of households do not have sufficient understanding of hygienic practices regarding food, water and personal hygiene. As a result, above 75 % of the health problems in Ethiopia are due to communicable diseases attributed to unsafe and inadequate water supply, and unhygienic waste management, particularly human excreta (UN-WATER/WWAP/, 2004).

Consequently pollution of surface and groundwater is one of the most serious problems affecting the health of the population of Addis Ababa (Meheret, 1999). According to Tamiru *et al.* (2003) it was reported that groundwater pollution in the city of Addis Ababa is similar to the reality existing in most developing countries. The level of water pollution tends to rise with increasing human population and low level of economic development in the city. In developing countries sources of pollution from domestic, agricultural, industrial activities are unregulated. Like wise in Addis Ababa, where there is no as such environmental protection practice there are a number of
pollutant sources that continuously deteriorate the quality of surface and ground water since the foundation of the city.

Some of the most serious problems are extremely hazardous sanitary conditions with raw sewerage coming out of residential houses and factories are commonly encountered problems in the Addis Ababa City. Collected excreta and garbage are often transported in unhygienic conditions and dumped on the periphery of the city or in the nearest refuse site without any treatment (Meheret, 1999). Or due to improper collection (overflowing containers), transportation (trucks are too old and few in numbers) and disposal of solid wastes, most parts of the city is polluted by solid wastes. Lack of roads in some pocket areas of the city, has worsened the situation (WHO/EHA, 2006). Refuse disposal is very usual in Addis Ababa city because not more than 50% of the garbage in the city is collected and disposed, Garbage is sprinkled all over the city and washed in the drainage line and the river courses during the rainy season. River lines are often used as waste management possibility (Muschalla, 2001).

When it comes to sanitary services, the proportion of units that are connected to a modern sewerage system is negligible in Addis Ababa. Only about 10% of the built up area of Addis Ababa has some access to conventional system (Solomon et al., 2004). Flush toilets are mostly in internal good condition but it comes often to seepage overflows of connected storage tanks, into public places, streets and ditches in Addis Ababa (Muschalla, 2001).

In Addis Ababa, around 60% of the population use pit latrines. The problem with the majority of pit latrines is they are often badly constructed improperly maintained and frequently overflow (WHO/EHA, 2006). Not surprisingly, therefore, the liquid waste that is generated by most households in the city either enters the dry pits and septic tanks that are commonly found close to most shelters or simply finds its way to the city’s open ditches and streams which have literally become sewers (Solomon et al., 2004). This has been ascertained by various studies in the city’s slum areas. Moreover the amount water distributed by Addis Ababa Water and Sewerage Authority (AAWSA); however, is less than the amount lost due to leakage problem. The 1996 survey estimated that 8% use flush toilet, 82% use pit latrines, 9.4% use fields/forests; 0.49% use household items/containers and 0.51% use other methods of disposing excreta. Moreover the
urban poor people in Addis Ababa live in a crowded, dilapidated, substandard make shifts with very poor or non-existing sanitation facilities and undesirable environment (AAWT, 2000).

The fact that an overwhelming majority of the dwelling units Addis Ababa were of poor quality can be seen from the fact that where about 73% of them were administered by kebeles. About 26% of the households had no sanitary facilities whatsoever and for the overwhelming majority the ratio of standpipes to households was in the order of 1:600 (Solomon et al., 2004).

Waste excretes from human body; animals and wastewater are the main potential sources of bacteria, viruses and parasites. In Addis Ababa, it is common to hear frequent occurrence of typhus and typhoid fever due to contamination of municipal water by seepage from "sweat lines" or infected persons wastes (Tamiru et al., 2003). According to the WHO/EHA (2006), there are two major problems in Addis Ababa with regard to poor quality water supply. Firstly, the actual demand out-weighs the supply and secondly the pipe system in Addis Ababa is very old. In some part of the city water is not available at all times. A total of 158 of Acute Watery Diarrhea (AWD) cases were reported in the city from August 04 to November 06/2006. A total of five deaths were registered during the reporting period.

Akaki Kalit has large percentage of urban area and ground water is the only sources of domestic water supplied by AAWSA. Groundwater wells pose their own set of health risks: they are rarely treated (except for chlorination) because they have been presumed to be largely immune to the types of pollution that get into surface water. Groundwater can be and often has been contaminated by people’s aboveground activities (Olson, 2003). In addition, Akaki-Kaliti areas are with in an industrial zone, surrounded by areas of mainly agricultural activities and highly polluted of Akaki River flowing across the sub city (Tamiru et al., 2003).

Even if the rate of pollution attenuation depends on the type of pollutants and on the local hydrogeological situations. Mechanism of pollution attenuation includes filtration, absorption, chemical processes, microbiological decomposition and dilution. Likewise considered the soil/over burden and unsaturated zone as the first and the second line of defense of pollution for ground water sources, however in urban areas, the unregulated disposal of industrial effluents and other wastes may contribute greatly to the poor quality of the water (Tamiru et al., 2000, 2001; WHO/OECD, 2003). While bacterial contamination zone Akaki well field and other wells lies
closest to the wellhead and therefore possesses the highest risk of pollution. Akaki well field of water wells are vulnerable to bacterial pollution that can easily move up to of 50m depth within 2 ½ hours which could be very effective during the heavy rain (high recharge) period (Tamiru et al., 2005). It is known that leaching of the waste by percolating water even from modern sanitary landfill. Inaccessibility of sewerage line forces people to discharge into water bodies to connect pit latrines with stream and unsecured splashing on the surface (Tamiru et al., 2000).

The existing conventional biological treatment plant located in Southern Addis Ababa covers about 40 hectares of land. The plant site falls within an industrial area and slopes down to the Little Akaki River (Tamiru et al., 2000). Akaki River was the highest contaminated river by parasitological and bacteriological characterizations (Yesehak et al., 1998). Even though the groundwater level around the Akaki River is located at about 30m below the river bed there could be hydraulic link between the river and the rock fractures. The river has direct impact on the nearby wells that tap water from alluvial layer (Tamiru et al., 2005).

Acute problems of public health have their origin in the pollution of waters in Addis Ababa. Indeed, the extreme run-down state of the main water distribution system may have made it possible for waste waters to seep through the drinking water system. Cases of typhoid fever and other infectious diseases are important and in some areas cases of cholera have been observed (Bezunesh, 2003). Even in 2006 there was rapid cut AWD in Addis Ababa, which was caused by lack proper sanitation and hygiene in the city these leads to contamination of drinking water and food. Forty eight percent (76/158) of AWD cases were reported from one sub city (Kolfe – Keraniyo). Akaki – Kality second next to Kolfe (WHO/EHA, 2006). The quality of the urban environment in Addis Ababa poses health threats including typhoid, diarrhea, cholera, intestinal worms. These diseases come from contamination of water and food; poor garbage collection, overcrowded housing and insufficient water for hygiene (AAWT, 2000).

1.1.1 Contamination of drinking water and its sources

In drinking water systems, microbial life is dependent on partly understood factors, such as differences in water treatment practices, disinfection, temperature, pipe materials, nutrients, hydraulic conditions (Phiri et al., 2005). The Unite State Environment protection Austerity (USEPA) is likely to rely on estimates of source water pathogen occurrence, and removal and
inactivation by treatment and transport through the distribution systems to predict concentrations in tap water (USEPA, 1997).

Assessment of the drinking water supply is a comprehensive multi-barrier drinking water program that include, source of water protection, sanitary surveys of the source area and distribution system to identify and prioritize risks to health, watershed or well-head protection plans, Expansion capacity for forecasted population growth, for treated water, continuous optimal treatment, routine maintenance of the distribution system and treatment plant and distribution system classification, operator training and certification (FPTSDW, 2001).

To understand the importance of protecting water sources, one must begin with a basic understanding of where one’s drinking water comes from. The main sources of drinking water are surface and ground water. a) Ground water is water that fills the open space or pore space, within the surface. b) Surface water is an open body of water, such as a river, stream, lake or estuary (Ring, 2003). Any type of surface water must be assumed to be polluted or at risk of pollution (USEPA, 1999).

Effective drinking water system management includes addressing the quality and protection of water sources (Hurst et al., 2002). Even if ground water seems to be pure compared to surface water, there is a need to prevent the running of drainage from streets, rooftops, driveways, feed lots, compost piles, etc. from running over or around or into the well casing. Storm water runoff from these sources carries substantial concentrations of pollutants (UMES, 1998). Several type of land application of waste or storm water may have contact with ground water that lead to ground water contamination (OECD/WHO, 2003). Many particles with domestic wastewater, livestock manure, septic tanks, cesspools, latrines and other on-site systems may also lead to contamination of ground water. Water percolating from these facilities contains viruses, bacteria and parasites and may contaminate ground water supplies (Ring, 2003). An extensive environmental investigation in France showed a groundwater source to the community had probably been contaminated by agricultural run-off and a failure in the chlorination system (Gallay et al., 2006).

The direction of surface water flow can affect the risk of contamination to drinking water supply (Ross, 2003). Groundwater supplies are derived primarily from wells, but not all well water is
truly “groundwater.” Water from shallow wells is usually under the influence of being contaminated from surface water via runoff and/or infiltration (NJF, 2006).

The most recent compilation of waterborne disease outbreak data for the years 1999 and 2000 in USA, indicated that 26 of 37 infectious disease outbreaks were attributed 70.5 % to groundwater by well water sources. Because of the presence of pit latrines close to the water sources, lack or little environmental protection, and poor catchments management, there were increased contamination the sources of water (Zamxaka et al., 2004).

In order to protect and control the contamination of pathogenic organisms at the source of water, one of the most important works, is to protect the delineated areas from sources of pollutants (Ring, 2003). Depending upon the nature of the catchments, it may be possible to protect against such events by removing grazing animals, diverting sewage overflows and discharge points (OECD/WHO, 2003). The USEPA determine that sanitary hazards can be located within a specified distance (e.g., 150 feet) of a well (USEPA, 1999). For example, Minnesota Department of Health has limited human activities beyond 50 ft of water tight casing, and twice farther from contaminating sources to minimize sources of contamination (Fig1) (UMES, 1998).

![Fig. 1 "Isolation" Distance between Wells and Contamination Sources (Source: UMES, 1998)](image)

Despite all these protection measures, the vulnerability of untreated groundwater supplies to microbial contamination via the rapid transport of pathogenic microorganisms, particularly
viruses should be recognized. There is a growing body of evidence that sewer leakage is significantly degrading ground water resources (Aidan, 2005).

The term water treatment is used here to mean manipulating the water to remove water-borne pathogens (e.g. those that cause diarrhoeal diseases) (AWWA, 2000). Control measures may include pretreatment, coagulation/flocculation /sedimentation, filtration and disinfection. Pretreatment includes processes such as roughing filters, micro strainers, off-stream storage and bank-side filtration (WHO, 2004a and 2004b). Almost three-fourths of all reported outbreaks in USA were attributed to consumption of contaminated well water. Approximately 40% of outbreaks were traced to inadequately treated water and another 30% to distribution system contamination (Mark et al., 2004).

Treatment systems should be designed based on the site-specific raw water quality. Seasonal variations should also be taken into account. The selected treatment systems should address all potential hazards and the level of risk associated with those hazards (FPTSDW, 2001). For effective disinfection, it is important that the turbidity should be as low as possible and preferably less than 0.1 nephelometric turbidity unit (NTU). In addition, when chlorination is practiced, the pH should preferably be less than 8.0 and the contact time greater than 30 minutes, resulting in a free chlorine residual of 0.2 - 0.5 mg/ liter. The higher residual chelorine is desirable for water from unprotected sources (WHO, 1984b).

The high faecal coliform levels in demonstrating the inefficiency of chlorination (Muyima et al., 1996). Faster chlorine decay also may lead to the total disappearance of the disinfectant, thus increasing the probability of microbiological contamination (Vieira et al., 2004).

Retention of water in reservoirs can reduce the number of faecal microorganisms through settling and inactivation, including solar, ultraviolet [UV] disinfection but also provides opportunities for contamination to be introduced (WHO, 2004a).

Properly treated water may become contaminated by microorganisms (bacteria, protozoa etc) again after it leaves the treatment plant and enters the distribution system (Downie, 2005). Factors that affect bacterial growth on biofilms include water temperature, type of disinfectant
and residual concentration, assimilable organic carbon level, biodegradable organic carbon level, degree of pipe corrosion, and treatment/distribution system characteristics (Vlek et al., 2006).

Physical and hydraulic integrity can lead to the influx of contaminants across pipe walls, through breaks, and via cross connections (WSTB, 2006). Increasing the amount of water available would help maintain pressure in the pipes and decrease cross-contamination (Semenza et al., 1998).

Monitoring program for water quality and other parameters, such as pressure in the distribution system can be control measures include using a more stable secondary disinfecting chemical than is used in primary treatment (e.g. chloramines instead of free chlorine), reducing the time that water spends in the system (e.g. avoiding stagnation in storage tanks and looping dead-end sections), replacing pipes, flushing and relining, and maintaining positive pressure in the distribution system (WHO, 2004a).

Using uncovered water containers are likely to increase water contamination between source and point-of-use as hands are dipped into vessels to scoop a cupful of water (Chidavaenzi et al. 1998). Many of the deaths are associated with diarrhoeal disease and infections stemming from poor hygiene (Dirk, 2001). The vast majority of diarrhoeal disease in the world (88%) is attributable to unsafe water, sanitation and poor hygiene actions (Nath et al., 2006).

In many parts of the developing world, drinking water is collected from unsafe surface sources outside the home and is then held in household storage vessels. In one study, earthenware vessels showed significantly higher levels of contamination (Vanderslice et al., 1993).

1.1.2. Health hazards associated with contaminated water

The Health hazards can be divided into four categories based upon the source of the involved pathogen and the route by which human recipients come in contact with that pathogen. Those categories could be defined as follows: a) Water-borne diseases, infections spread through water supplies: e.g. Cholera, Typhoid, Infectious hepatitis, Poliomyeliti b) Water-washed diseases, diseases due to lack of water for personal hygiene: e.g. skin and eye infections (Scabies, Trachoma) c) Water-based disease, infections transmitted through an aquatic intermediate animal
e.g. Schistosomiasis. d) Water related insect vectors, infections spread by insects that depend on water: e.g. Malaria, Yellow fever, Trypanosomiasis (Hurst et al., 2002).

The World Health Organization estimates that 80% of all illness in the world was attributable to insufficient water supplies or sanitation. Over 250 million new cases of waterborne diarrhea are reported worldwide each year, resultant in more than 10 million deaths. Today there are many recognized waterborne pathogens. All are present in large numbers in human or animal waste; sporadically both are commonly resistant to environmental decomposition. Many of these pathogens are proficient in causing infections even when ingested in extremely small numbers (Skraberl et al., 2005).

Several types of microorganisms are pathogenic. Typhoid, cholera and gastroenteritis are bacterial diseases, which are commonly waterborne. Similarly, viral diseases such as hepatitis, parasitic worms such as Schistasoma (bilharzia) and some tape worms, together with protozoan diseases such as amoebic dysentery, are waterborne. In the production of potable water, all water-borne organisms but especially water-borne pathogens are of concern. The majority of these pathogens affects the gastro-intestinal tract and can be bacteria, viruses, protozoa and sometimes fungi. Viruses, bacteria and protozoa are the three principal groups of microorganisms that can be transmitted via drinking water. They are all transmitted by the fecal-oral route, and so largely arise either directly or indirectly by contamination of water resources by sewage or possibly animal wastes (LeChevallier et al., 1996).

Ingress of pathogens into the distribution system can rapidly lead to an infection of thousands of people (Boe-Hansen, 2002). Most health-related water-quality problems are the result of microbial contamination (Smith et al., 2006). Bacteria that cause illness in most individuals are called primary pathogens while those that cause illness mainly in sensitive sub-populations (immuno-compromised, elderly, children) are called opportunistic pathogens.

Pathogens are microorganisms that can cause disease in other organisms or in humans, animals and plants. They may be bacteria, viruses, or parasites and are found in sewage, in runoff from animal farms or rural areas populated with domestic and/or wild animals, and in water used for swimming and/or drinking water. Fish and shellfish contaminated by pathogens, or the contaminated water itself, can cause serious illnesses (Ring, 2003). The majority of waterborne
outbreaks are classified as. Acute gastrointestinal illness (AGI) and etiologic agents include *Salmonella*, *Shigella*, *Campylobacter*, *Giardia*, *Cryptosporidium* and viral agents.

In addition, there are a number of newly recognized etiologic agents for which there is some evidence of an association with waterborne disease, such as enteric waterborne emerging pathogens which include caliciviruses, E.coli 0157:H7, *Helicobacter sp.*, *Mycobacterium avium* complex (MAC) and protozoa *Cryptosporidium sp.*, *Cyclospora sp.* and *Taxoplasma sp* (OECD/WHO, 2003). Waterborne disease outbreak usually involves, source contamination and the breakdown of the treatment barriers, contamination of the distribution system and the use of untreated water (WHO, 2004b).

Access to clean water is not just an issue for developing countries. Despite wealthy economies and access to proven drinking water-treatment technologies significant outbreaks of waterborne intestinal disease have occurred in North America and Western Europe over the last 10–15 years. Faulty distribution systems are a significant cause of waterborne outbreaks. For example, a review of waterborne outbreaks in the United States from 1991 shows that 38.7% of outbreaks were caused by problems within the distribution system (FPTSDW, 200; Smith *et al*., 2006). Epidemiological and microbiological characteristics of 89 reported outbreaks of waterborne infectious intestinal disease affecting 4321 people in England and Wales over the period 1992–2003 (Smith *et al*., 2006). A large waterborne-infection outbreak of infection that occurred during August 2000 in a local community in France was investigated initially via a rapid survey of visits to local physicians (Gallay *et al*., 2006).

The major prevalent water quality problems in Ethiopia are those related to physical, chemical, as well as microbiological parameters, the possible causes of which are natural, anthropogenic or both. Some of the major water quality problems in Ethiopia are given below in Table 1.

<table>
<thead>
<tr>
<th>No.</th>
<th>Water quality concerns</th>
<th>Parameters of concern</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Physical qualities</td>
<td>Colour, Odour, Turbidity, Taste</td>
</tr>
<tr>
<td>2</td>
<td>Chemical quality</td>
<td>Iron, Hardness, pH, nitate, Fluoride, Sulfate, Nitrite, Manganese, CO2, TDS</td>
</tr>
<tr>
<td>3</td>
<td>Microbiological quality</td>
<td>Total Coliforms, E.coli, Giardia, Amoeba</td>
</tr>
</tbody>
</table>

Source: (UN-WATER/WWAP/, 2004)
1.1.3. Microbial indicators and their significance

**Bacteriological indicators**

At the second stage, a survey can be conducted with the well-established microbial indices that are common ones like the TC and FC of faecal pollution. The recent more accepted ones are (*E.coli*, enterococci, spores of *Clostridium perfringens*) (OECD/WHO, 2003; Hurst *et al.*, 2002).

Indicator organisms are selected to demonstrate the presence of human waste and hence the potential presence of pathogens. Indicator organisms are usually of intestinal origin from endothermic animals. Therefore, the presence of these organisms in the water indicates contamination of fecal matter, which could also contain pathogens such as *Salmonella* and *Shigella*. USEPA regulations require three main groups of indicator organisms to be used to monitor water quality; they are total coliform (TC), fecal coliform (FC), and Enterococcus (USEPA, 1999). Certain criteria should exist before an indicator organism can be considerer liable in predicting a health risk: 1) The organism must be exclusively of fecal origin and consistently present in fresh fecal waste. 2) It must occur in greater numbers than the associated pathogen. 3) It must be more resistant to environmental stresses and persist for a greater length of time than the pathogen. 4) It must not proliferate to any great extent in the environment or they should not grow in natural waters. 5) Simple, reliable, and inexpensive methods should exist for the detection, enumeration and identification of the indicator organism (Pawsey, 2001).

Gastrointestinal pathogens known to have caused outbreaks of enteric disease are largely from the systematically defined family, *Enterobacteriaceae*, and include *Salmonella*, *Shigella*, *Yersinia enterocolitica*, *Klebsiella pneumoniae*, *Enterobacter* and *Enterotoxigenic Escherichia Coli* (*ETEC*). *Vibrio cholerae* and *Campylobacter jejuni* are two other enteric pathogens often found in contaminated water. These organisms are spread by water contaminated with fecal material from humans and other warm-blooded animals (Hach, 2000).

Many waterborne pathogens are difficult to detect and/or quantify and the specific methodology to detect them in environmental water samples has still to be developed. While *Faecal streptococci* are suggested as the recommended indicator for salt water, either Faecal streptococci or *Escherichia coli* can be used for monitoring freshwaters. Additional variables can be investigated if they are considered relevant, such as the spores of *Clostridium perfringens* in
tropical waters where the traditional indicators may increase in number in soil and water (Hardina et al., 1991). Recent literatures were reviewed to determine the most recent trends in assessing water quality using microbial indicators Thermotolerant coliforms and fecal streptococci. Fecal streptococci were selected based upon their inherent pathogenicity or their capabilities to indicate the presence of pathogens (OECD/WHO, 2003; Hurst et al., 2002).

Sanitary Significance of Thermotolerant coliforms (TTC) in the Environment

The coliform group is defined as all the aerobic and facultative anaerobic, Gram-negative, non-spore-forming, rod-shaped bacteria that ferment lactose with gas formation within 48 hours at 35-37°C (WHO, 2004a). Fecal coliforms are coliform bacteria that live in the intestines of warm-blooded animals.

The Thermotolerant coliforms are a group of coliform bacteria that grow at 44°C and include E. coli type 1 organisms as well as other species that may have an environmental source (Aliev et al., 2006). The presence of coliform bacteria in potable water indicates unsuitable sanitation practices. Such occurrences may be a result of poor water treatment, plant design problems, improper operating procedures, inadequate hygienic practices in plant operation, or after growths in the distribution system (Geldreich, 1996).

Microbial contamination is considered to be the most serious risk factor in drinking water quality because of the possible consequences of waterborne disease (AWWA, 2000). Therefore, it is important to determine the microbiological safety of these waters. The ideal manner for doing this would be to analyze the waters for the presence of specific pathogens of concern rather use by indicators (OECD/WHO, 2003). Frequent occurrences of high coliform counts signify the need for an alternative water source, or sanitary protection of the current source. A “boil water” order is needed when emergency water supplies fail to meet a criterion of zero (0) fecal and total coli forms (Hach, 2000).

Sanitary Significance of Feacal streptococci in the Environment

Fecal streptococci – Gram positive, sphere-shaped bacteria that give a positive reaction with Lance field’s Group D antisera. Fecal streptococci are associated with the feces of warm-blooded
animals. The presence of enterococci in water is an indication of fecal pollution and the possible presence of enteric pathogens (WHO, 2003). The faecal streptococci include genus Enterococcus and two species of *Streptococcus*, *Streptococcus bovis* and *Streptococcus equinus*. These organisms share certain biochemical properties and are predominantly found in animal faeces. Faecal streptococci are considered to have certain advantages over coliforms as pollution indicator. They rarely multiply in water; they are more resistant to environmental stress and chlorination than coliforms and intestinal enterococci group can be used as an index of faecal pollution. They are large numbers in sewage or wastes from humans and animals more persistent in water and sediments than coliforms more resistant to drying and more resistant to chlorination (WEDC/WHO, 2003; WHO, 2004b).

*Fecal streptococcus* are excreted by all warm-blooded animals, they are widespread in the environment wherever animal life is present. Streptococci have an interesting history and as a single genus of bacteria have probably caused disease that is more widespread and morbidity in man over the centuries than almost any other bacteria (WSI, 2004).

The fact that the enterococci do not multiply outside the body of intestinal tract shows a closer relationship with the pathogenic enteric bacteria (*Salmonella typhosa*), which also do not multiply outside the body, and therefore suggests that enterococci are better indicators of recent pollution (Litsky *et al.*, 2005). They are more persistent in water than *E. coli*, and so may be a better mirror of the presence of certain pathogens which also die off slowly (e.g. viruses) (ADWG, 2001).

Enterococci have received widespread acceptance as useful indicators of microbiological water quality because (i) they show a high and close relationship with health hazards, mainly gastrointestinal symptoms, associated with bathing in aquatic environments; (ii) they are not as ubiquitous as coliforms; (iii) they are always present in feces of warm-blooded animals; and (iv) their die-off is less rapid than that of coliform in water and persistence patterns are similar to those of potential waterborne pathogenic bacteria (WHO, 2000). These microorganisms are more closely related to the presence of human feces than are the fecal streptococci (Figueras, 1996).

The enterococci might well be better indicators of pollution in wells, swimming pools, and sewage treatment plants that are high in nutrient and low in oxygen. Enterococci have gained the
most acceptances, particularly when used in conjunction with E. coli (Stevens et al., 2003). Faecal streptococci are a suitably specific indicator making these bacteria a better indicator for the presence of certain pathogens that die off slowly. Their main value in assessing water quality is therefore as an additional indicator of treatment efficiency. Furthermore, streptococci are highly resistant to drying and may be valuable for purposes of routine control after new mains have been laid or distribution systems repaired, or for detecting pollution by surface run-off to groundwater or surface waters (WHO, 1996).

**Bacteriological Related Parameters**

Micro-organisms face a great diversity of habitats with very different physicochemical and nutritional conditions during the treatment, storage and distribution of drinking water. For instance proper chlorine dosage depends upon a number of factors including: chlorine demand, residual, contact period, temperature, pH (Herrmann et al., 2003; WHO, 2004c). Turbidity, pH and chlorine residuals (where supplies are chlorinated) are widely accepted as other critical water quality parameters describing microbiological quality of drinking water. These parameters recommended as they either directly influence microbiological quality (in the case of chlorine) or may influence disinfection efficiencies and microbiological survival (in case of pH and turbidity) (WEDC/WHO, 2003).

So long as the contact time is sufficient to ensure minimum contact time (CT) values, proper disinfection can also be determined by measuring the free chlorine residual, turbidity, and pH. However, microbiological monitoring should be performed to ensure disinfection efficiency (Hach, 2000). Therefore, non-microbial water quality data are important with bacteriological analyses (e.g. turbidity, temperature, pH, conductivity) and hydrological data (measurement of flow and precipitation) (OECD/WHO, 2003; Hurst et al., 2002).

**Free Chlorine Residue**

Chlorine is added to drinking water supplies for the purpose of destroying or deactivating disease-producing micro-organisms. This is termed water disinfection. Chlorine (Cl₂) is usually added to water in liquid form or as sodium or calcium hypochlorite chemicals. Maintaining an adequate level of residual chlorine is of great importance in terms of distribution water quality management (Housseini, 2003).
Assume that the contamination causing this outbreak was accompanied by a chlorine demand sufficient to consume entirely, the low chlorine dose thereby allowing inadequately disinfected water into the distribution system (Hrudey, 2003). Therefore, in addition to disinfectants, and different factors regulating bacterial growth, various chemical substances, such as organic and inorganic forms of nitrogen, hydrogen sulfide, iron, and manganese, react with chlorine in water, consuming the chemical and rendering it ineffective as a bactericide. This creates what is called a chlorine demand in water. The effective concentration of chlorine required to disinfect water is the chlorine demand plus the necessary germicidal concentration (Volk et al., 2002). If the time frame allows it, chlorine self-decomposition may take place, though at a much lower rate than the other reactions (Vieira, 2004).

Turbidity
Turbidity in drinking water is caused by particulate matter that may be present from source water as a consequence of inadequate filtration or from resuspension of sediment in distribution system (WHO, 2004a and 2004b).

The most important drinking water guidelines deal with microbiological quality that ensure a there minimal risk of exposure to disease-causing organisms in drinking water. Turbidity is also considered as surrogate microbiological parameter because it is closely linked to the microbiological safety of drinking water (FPTSDW, 2001). Turbidity can indicate that water may be contaminated with pathogens presenting human health concerns (Olson, 2004).

One study in the Eastern Cape Province, South Africa indicated that turbidity is typically high during a storm as a consequence of rapid erosion of surface soils into rivers (Zamxaka et al., 2004). Likewise, the rusted metal-piping system is probably contributing to the deterioration of the water quality by increasing turbidity at distribution. The high regrowth of heterotrophs and total coliforms occurring after chlorination indicates the inefficiency of the filtration and chlorination steps (Muyima et al., 1996).

Temperature
In analysis of the Physico-chemical quality of pipe water samples, temperature is considered as a critical parameter. It has an impact on many reactions, including the rate of disinfectant decay and by-product formation (Volk et al., 2002). As the water temperature increases the disinfectant
demand and by product formation, nitrification, microbial activity, algal growth, taste and odour episodes, lead and copper solubility increases. Moreover, sand calcium carbonate (CaCO₃) precipitation also increases (Collicott et al., 2003).

An aesthetic objective is set for maximum water temperature to aid in selection of the best water source or the best placement for a water intake. It is desirable that the temperature of drinking water should not exceed 15°C because the palatability of water is enhanced by its coolness. In addition to cool water tasting better than warm water, temperatures above 15 degrees Celsius can speed up the growth of nuisance organisms such as algae which can intensify taste, odour, and colour problems. Temperature also affects water treatment (TID, 2000).

If nutrients are available, the microbial activity (as measured by heteroplate count increases significantly at water temperatures above 15°C, in the absence of a disinfectant residual (WSTB, 2005). Therefore, water supplies generally tend to keep the temperature as low as possible in order to minimize the bacterial after growth. Keeping the temperature low reduces the risk for pathogenic proliferation and survival since the optimal temperature for most pathogens is close to the human body temperature (Boe-Hansen, 2002).

Fig. 2 Raw Water Entering Japan Gulch Plant Total Coliforms and Water Temperature in 2004 (source: CRD, 2005)
As Fig. 2 indicated above at the Japan Gulch Plant, the coldest daily water temperature recorded was 3.0°C in January while the warmest was 20.9°C in August 2004. The Guideline limit of 15°C was exceeded from July 9, 2004 to October 18, since the water services department cannot control the temperature of the water the number of coli forms increase at high temperatures in winter seasons (CRD, 2005).

**pH**

The latest guidelines from drinking water quality of WHO (2004b) does not recommend any health-based guideline for pH. However, pH is also one of the most important operational parameters for water treatment such as disinfection or coagulation-flocculation and pH adjustment is a common practice in water treatment (Cerdic et al., 2005). Because, dissociation is poor at pH levels below 6, from pH 6 to 8.5 a nearly complete dissociation of HClO occurs. Thus for disinfection with chlorine control of pH is critical. As a consequence, an increasing pH of the potable water requires rising amounts of chlorine for the same disinfection efficacy (Herrmann et al., 2003).

The microbial activity of chlorine is greatly reduced at high pH, probably because at an alkaline pH, the predominant species of chlorine is OCl−. Equilibrium concentrations of HOCl and OCl− depend on the pH of the water. If the pH of the water is high, chlorine is less effective in killing pathogens (USEPA, 1999). According to Kent and collaborators (1998) pH values ranging from 3 to 10.5 could favor both indicator and pathogenic micro-organism growth. The overall pH pattern showed that the pH values were relatively high in winter compared to summer.
2. OBJECTIVES

2.1. General Objective

To determine the physico-chemical and bacteriological quality of drinking water at their ground water sources to household level in Akaki Kaliti sub-city.

2.2. Specific Objectives

1. To evaluate the bacteriological quality of drinking water being supplied to the consumer and the potability of the water at the point of consumption using TTC and FS.
2. To analyze the bacteriological related physico-chemical quality (Temperature, pH, Turbidity, and free chlorine residual).
3. To assesses management practice of the water sources.
4. To generate baseline data on water quality status in the study area.

2.3. Significance of the study

This study is expected to give baseline information Akaki Kaliti catchments which one of the major ground water sources of Addis Ababa water quality, supplied by AAWSA and drinking water quality to the point of consumption. It will provide a framework to assess the on-going vulnerability of the supply to contamination and the major operational or infrastructure problems that may make future contamination likely. Moreover, it provides a hint on the relationships of non-bacteriological parameters like temperature, pH, free chlorine residual and turbidity one other and with bacteriological parameters on the treatment plants processes. In addition the study outcome will give information about the differences between treated and non-treated water on Addis Ababa water supply.

Limitations

The information on physico-chemical and bacteriological quality of water may not reflect the actual situation that may be examined in the various seasons of the year, as the information of water quality parameters was examined in October -January in the study. Since AAWSA is mixing chlorinated water with unchlorinated water sources at few distribution systems analyzing separate water sources were not possible in the study.
3. Materials and methods

3.1. Experimental design

Cross sectional study was done to examine the bacteriological and related physico-chemical quality of drinking water at sources, disinfected and non disinfected points, and pipe water and household containers and also supported using a standard sanitary survey work sheet. The study was conducted in Akai-Kaliti sub city, Addis Ababa, from September 2006 to January 2007.

3.2. Description of the Study Area

Akaki Kaliti sub-city is one of the outskirt sub-cities of Addis Ababa and is located between 976127m-990572m North latitude, and 471084m-486542m East longitude. Addis Ababa has a total area of 530.14 km² (204.75sq mi) and 18.2 km² is rural area. From total area Addis Ababa, 23.70% (12,797.36 ha) and 11.56- km² (1156 ha) areas are defined by Akaki Kaliti sub-city and rural area coverage, respectively.

The monthly mean maximum and minimum temperature records of Addis Ababa, observatory for the years between 1951 and 1998 can be used to calculate monthly and annual average. Therefore as it was the highest mean monthly maximum temperature occurs in the months of March (24.56 °C) and the lowest is in the month of August (20.07 °C). While the mean monthly minimum temperature ranges for the lowest from 7.47 °C in December to the highest 11.66 °C in the month of March. Thus, the average temperature of Addis Ababa (47 years data 1951-1998) is 16.02 °C. The rainy period of Addis Ababa/ Akaki Kaliti / is divided into two distinct seasons i.e. Kiremt and Belg. The period of heavy rain (Kiremt) commences from June to September and account for 80% of the annual rainfall. While the small rain (Belg) occur between March and May. The monthly mean records of rainfall for thirty-five years from the year between 1964 and 1998 shows that the, minimum, maximum and mean annual rainfall in station Akaki Mission (at an elevation of 2120m a.s.l.) were 4.31,303.79 and 1154.2mm, respectively (Tamiru et al., 2003).

The study area is the only sub-city in the Addis Ababa largely relies on ground water as its main source for drinking purpose. Highly productive aquifers are located in this sub city. The total production from Akaki catchments is about 32 % of the total recharge. Out of which 28 % is used for AAWSA production. In this area, majority of the aquifers are found to be volcanic
aquifer. Unless proper groundwater management strategy is implemented, in such condition of groundwater resource may become at risk of low recharge capacity (Maruo et al., 2004). However, the recharge amount at the present is increased from 32,000m³/h to 43,000m³/h.

3.2.1. Akaki- Kaliti groundwater system and water disinfection points

The disinfectant water reservoirs
The disinfectant water reservoirs in this sub-city include City Reservoir, Tulu Dimtu Reservoir and Fant spring Reservoir.

City Reservoir (CTR)
This treatment plant of the Akaki groundwater system is located 20 kilometers to the east of Addis Ababa. Its water supply is derived from 15 old and 13 new wells. Six of the old and 3 of the new wells were not functional during the period of sample collection. The treatment systems in CTR comprise an automatic controlled by sincere whoever, conventional chlorine-based chemical disinfection step before distribution for public use (Fig.3). The CTR supplied disinfected water to Akaki Kaliti sub city and other sub city completely or partially because the disinfected water flow and stored in other continuous reservoirs named as GW1, GW2, GW3, and GW4 as indicated in Fig.3.

Fig. 3 Main drinking water system of Akaki-kaliti sub city flow diagram named as City
Tulu Dimtu Reservoir (TDR)

TDR found close to city reservoir. The TDR water system has supplied to communities by gravity-fed water system. It has 1865 m$^3$/h service reservoir to supply to the near by community (Fig. 4). The reservoir was built in 1985 by AAWSA and disinfection used manually by addition dissolved calcium hypochlorite or high-test hypochlorite (powdered chlorine) as shown Fig.5 and 6. The raw water sources named EP4, EP6, EP7 and EP8 are inlet to TDR.

![Fig. 4 Tulu Dimtu Reservoir (TDR)](image)

Fanta Spring

The treatment plant of the Fanta spring drinking water system is located 25 kilometers to the east of Addis Ababa. Its water supply is derived from a natural spring as shown in Fig.7. (It has a production rate of about 1,068 m$^3$ per day and provides service to about half of the population of
Akaki. Its treatment system is manual that is, addition of chlorine like TDR. The disinfected water is settled in a collection box made of cement (Fig. 7 and 8).

![Fig. 7 Fanta natural spring water source](image1)

![Fig. 8 Fanta spring disinfection site](image2)

![Fig. 9 Fanta spring disinfected water](image3)

### 3.2.2 Non-disinfected water sources

From 5 non-disinfected wells that supply water to Addis Ababa, two water sources are from Kaliti Gabriel Well (KGW) and Emergence product-5 (EP5) (Fig. 10 and 11) wells which are found in the sub city of Akaki-Kaliti sub city. These wells have estimated water production capacity of about 367,920.00 M³/year and 236,520.00 M³/year respectively (Annex VIII). These wells directly supply water to the sub city.

![Fig. 10 Kaliti Gerbil Well (KGW)](image4)

![Fig. 11 Emergence product well (EP5)](image5)
3.2.3. Sampling points and frequency

As shown in Fig. 12, 82 sample points that were selected from five locations: (i) six raw water from Akaki well field boreholes (BH24, BH23, BH22, BH8, BH5, EP4) water sources were selected randomly and one unchlorinated spring, which feed the disinfection points of CTR and TDR (ii) two unchlorinated water sources named as EP5 and KGW that are directly distribut to the community (iii) three disinfection points (CTR, TDR and FSC ), sampling were taken just started from the distribution system or leave from disinfection points (iv) 35 pipe waters and 35 house hold water containers.

Fig. 12 Location map of Akaki Kaliti sub city and its sampling sites from sources to house hold water representatives
A total of 82 sampling points were conducted over 3 months (October, November and January) see annex IV. Samples were collected from the sampling stations two times /week intervals at 8:00-10:30 Am. Triplicate samples were taken for all points.

3.2.4. Sample size determination and sample collection procedures

Akaki-Kaliti sub city with a population of 188,808. AAWSA registered 10,053 housing units having a customer of drinking water distributed to Akaki-Kaliti sub city. From total customers, 35 household containers and 35 pipe water analyses were selected randomly from customer bill numbers. The sampling distribution, dependence on their weight proportion of bill numbers in each Keble customers’ of AAWSA (Table 2).

<table>
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<tr>
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<th>No of customers</th>
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<td>26</td>
<td>07</td>
<td>104</td>
<td>1</td>
</tr>
<tr>
<td>27</td>
<td>03</td>
<td>334</td>
<td>2</td>
</tr>
<tr>
<td>27</td>
<td>08</td>
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<td>2</td>
</tr>
<tr>
<td>27</td>
<td>09</td>
<td>351</td>
<td>2</td>
</tr>
<tr>
<td>27</td>
<td>10</td>
<td>723</td>
<td>3</td>
</tr>
<tr>
<td>27</td>
<td>11</td>
<td>1182</td>
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<td>19</td>
<td>55</td>
<td>901</td>
<td>3</td>
</tr>
<tr>
<td>19</td>
<td>57</td>
<td>466</td>
<td>2</td>
</tr>
<tr>
<td>Total</td>
<td>-</td>
<td>10,053</td>
<td>35</td>
</tr>
</tbody>
</table>

The method of sample collection at each source was according to the WHO Guidelines (WHO, 1994, 1995) for Drinking water quality assessment (annex I) and Laboratory manual (Monica, 2000). Water samples were collected in sterile glass bottles and transported to the laboratory in a cold box containing ice freezer packs. From each source, 250 ml (for bacteriological analysis and for chlorinated water samples for microbiological analysis were treated with sodium thiosulphate
to stop the chlorination process at the moment of taking the sample (i.e. 100 mg sodium thiosulphate/ l of distilled water were then sterilized in an autoclave for 15 minutes at 135 °C). Whereas for physiochemical analyses 500 ml polypaprine plastic of water sample were collected, labeled and transported to laboratory in icebox. Each sample was analyzed within not more than 3 hours of collection at Applied Microbiology Laboratory, AAU.

3.3. Sample Analyses
Samples were analyzed using standardized bacteriological methods for water quality parameters to determine the degree of contamination. All Samples were analyzed for the presence of indicator bacteria Termotolerant coliformes (TTC) and Faecal streptococci (FS). Water samples were filtered through sterile cellulose acetate, gridded membranes filterer placed on sterile, 47-mm, magnetic filter holders or filter apparatus and 100ml water samples were passed through the filters. Filters were then placed on the appropriate media of M-Lauryl Sulphate Broth (MSB) ISO 9308-1 (ISO, 1997) and KF streptococcus agar with 1% sterile solution of TTC added to cooled basal medium for as indicter of red colure ISO 7899-2 (ISO, 1999)(WHO, 2000). In all cases, analysis was performed by the membrane Filtra tion method (MF). To keep the validity of the analysis, control was included in distilled water for some time in TTC test and ethyl violet azide broth (EVA) without Faecal streptococci the confirmatory analysis of each sample. Detail procedure for membrane filtration analysis is found annexed in annex II (WHO, 1984b). Physico-chemical parameters related to bacteriology were measured at on site and at Applied Microbiology Laboratory, AAU.

3.3.1. Analytical procedures
Chemical and physical analysis
The turbidity and the pH of the each sample were determined using a HACH 2010 spectrometer (DR/2010 HACH, Loveland, USA) and a pH meter (Session, German) respectively, within one hour following the collection. The temperature of each sample was determined on the site of collection with a digital Thermometer (Multi Thermometer ST-9269, EUROLAB). Free chlorine residual, for each chlorinated sample was determined on site of collection with (a Lovibond 1000 Comparator system, France) using a DPD n°1 chlorine tablet.
Microbiological analysis of water samples

Enumeration of Thermotolerant coliforms

The isolation and enumeration of Thermotolerant coliforms were carried out using membrane filtration (MF) techniques (annex II); MF techniques in which bottles were aseptically opened and a 100ml of sample was filtered through the membrane filter (Millipore 45 μm nitro-cellulose filter). Membrane Lauryl Sulfate-Based medium (mLSB Oxoid, UNIPATH Ltd., Basingstoke, England) was prepared with 20-25 ml de-ionised water. The prepared mLSB measured in autoclaved measuring flask 2 ml of the solution was applied to filter pad which was placed on 50 mm Petri dish. The filter was placed on to the membrane pad containing mLSB incubated at an ambient temperature of 28°C for 4 h to permit bacterial resuscitation, before being transferred to 44°C for 14 h incubation. Post-incubation, all yellow colonies were counted, using a colony counting lens. Typical colonies were counted with binocular wide-field microscope at a low power (20 x magnifications) but were not verified by additional tests. Epi fluorescent microscope (Olympia B×51, Japan) was used to examine the morphological and structural features of Thermotolerant coliforms (ISO, 1997; WHO, 2000).

Enumeration of faecal streptococci

After cooling the autoclaved KF (Kennel Faecal) streptococcus agar and 1% sterile TTC (2, 3, 5-Triphenyl- Tetrazolium Chloride) solution added to it, ISO 7899-2 (ISO,1999; WHO, 2000). Then 100ml for each sample was filtered through a Millipore 45 μm nitro-cellulose filter and then transferred into KF agar medium and preincubated for 4 hrs at 30°C. Counting was done after incubating the perincubated samples at 37°C for 24 hrs. The method was especially selective for S. facalis and S. facium (WHO, 2000). Post-incubation all red, maroon and pink bacterial colonies that were smooth and convex were identified using a microscope and recorded as presumptive for Enterococci presence (APHA, 1998 and WHO, 1984b).

Biochemical and epifluorescence microscopes identification of the feacal streptococci

For biochemical analysis, only red colonies were subcultured inoculated by sterilized inculcating needle into 10ml of ethyl violet azide broth (EVA) and incubated at 35 ±0.5 °C for 48±2 hours. Tubes with blue–purple sediment and turbidity were considered positive for fecal streptococci (WHO, 1984b). Catalase test was done by a drop 3% H₂O₂ for bubble formation. The presence of
feacal streptococci in sample was further confirmed by looking morphological and anatomical structure of using epi fluorescence microscope (Olympia B×51, Japan).

3.3.2. Sanitary survey inspection
This approach was used to gather information regarding historical aspects of Akaki kaliti sources and distribution water quality and to provide new information that will help to delineate the reasons for source protection and the sources of microbial contaminated runoff, and seepage. Field studies also included site reconnaissance at each of the sampling locations. This reconnaissance included a survey of the area to determine the potential for site runoff to sewerage, the river or canals, uses (e.g. fishing, laundry of clothing) occurring in the area, and potential sources (e.g. livestock operations) that could contribute to water quality problems in the wells and spring. The survey work sheet is from WHO guideline in the annex III. In addition, information regarding the condition of household containers was obtained form elderly persons in each house hold sample using checklist set prepared by WHO (Howard et al., 2003). The microbial quality and sanitary inspection rating or score, grading of inspection risk to health matrix score by standard set by WHO (2004b).

3.4. Statistical Data Analysis
Data were recorded, organized and summarized in sample descriptive statistics methods using SPSS-PC statistical package (SPSS 14 for windows version). Results were analyzed using this statistical software analyses, and these results were presented in a descriptive stastics such as frequencies, correlations measures, ANOVAs, T-tests such as tables and graphs. Moreover, to compare variation in water systems, Least Square of Differences (LSD) was applied to all physicochemical parameters and the bacterial counts. The data were interpreted by their frequencies and magnitudes such as concentration of the organisms in a liter of water sample. Chi-Square test ($\chi^2$) results were used and a p-value of less than 0.05 considered statistically significant.

3.5. Ethical consideration
Data collection was conducted after obtaining informed consent from the concerned offices such as AAWSA. Regard to data collected at the household, study objectives were clearly explained to the house holds parents and/ or elder sister. Each household was assured that the information provided would be confidential and used only for the purpose of research.
4. Results and Discussion

4.1. Results on water sample analyzed and inspection of sanitary survey

In this study, a total of 82 water samples from raw water sources (6 Akaki well field boreholes and one unchlorinated at spring), non disinfected water sources (n=2), disinfected reservoirs (n=3), pipe water (N=35) and household containers (n=35) were considered for physico-chemical and bacteriological drinking water quality determination in Akaki-Kaliti sub-cities, Addis Ababa City Administration Conical. The result of physicochemical and microbiological water quality parameters were then compared to the standards set by the WHO (1984b, 1996 and 2004b) and National standard (ES 261:2001) (Annex VII).

Results in water sample analyzed

Raw water boreholes and spring

All samples were positive for TTC and FS. FS and TTC concentration detected in water samples obtained from BH8 and FSNC were 52.5 and 29 cfu/100ml, respectively. TTC and FS concentrations detected were 12.3 and 11.6 cfu/100ml, respectively for bore hole EP4 (Fig. 13).

![Fig.13 Mean values of TTC and FS concentration in raw water samples](image)

Non disinfected water sources

The pH and turbidity of none treated water sources of EP5 and KGW were within the acceptable limit of WHO (6.5-8); ES which is 6.5-8.5 and >5 FAU, respectively. The temperature of EP5 was above acceptable limit while KGW met in recommended limit of <15°C. TTC and FS concentrations detected in the water samples obtained from EP5 and KGW were 24.67, 17.67 and 2, 17.67 cfu/100ml, respectively (Table 3).
Table 3 The mean value of Physico-chemical and bacteriological analyses of the non treated water sources

<table>
<thead>
<tr>
<th>Water sources</th>
<th>Temperature (°C)</th>
<th>Turbidity (FAU=NTU)</th>
<th>pH</th>
<th>TTC (cfu/100ml)</th>
<th>FS (cfu/100ml)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Emergence product-5(EP5)</td>
<td>17.9</td>
<td>1.33</td>
<td>7.62</td>
<td>24.67</td>
<td>2</td>
</tr>
<tr>
<td>Kaliti Gabriel well(KGW)</td>
<td>14.27</td>
<td>4.33</td>
<td>7.85</td>
<td>17.67</td>
<td>23.67</td>
</tr>
</tbody>
</table>

Table 4 presents the physico-chemical and bacteriological water quality analyses of the three reservoirs, namely CTR, TDR and FSC. The temperature of three disinfection points were found to be 24.2 °C, 22 °C and 24.3 °C for CTR, TDR and FSC, respectively which are above the permissible limit of 15°C recommended by WHO (1996). Turbidity CTR and FSC of the samples analyzed met the acceptable level of WHO and National standard limit of potability which is < 5 NTU, while the value of TDR was greater than the recommended limit. The pH of CTR, FSC, and TDR lied with in the recommended range of ES which is 6.5-8.5. The averaged free chlorine residual (FCR) leaving the three disinfection points (CTR, TDR and FSC) were 0.67, 0.6, 0.68 mg/l, respectively (Table 4). The values of FCR were less than the recommended limit (0.6-1mg/l) (WHO, 2004b) and the disinfection practice of many counters (≥1mg/l). The mean values of TTC for CTR, TDR and FSC were 2.67, 6.33, and 1.67cfu/100ml, respectively. The mean concentration of FS in the three disinfection points were 5.33, 10, 0.33 cfu/100ml, respectively. Therefore the values were greater than WHO and ES acceptable limit which is of nil for both TTC and FS cfu/100ml (Table 4).

Table 4 The mean value of Phisico-chemical and bacteriological analyses of the three disinfection points

<table>
<thead>
<tr>
<th>disinfection sites</th>
<th>Temp (°C)</th>
<th>Turb. (FAU)</th>
<th>pH</th>
<th>FCR (mg/l)</th>
<th>TTC (CFU/100ml)</th>
<th>FS (CFU/100ml)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CTR</td>
<td>24.2</td>
<td>4</td>
<td>7.6</td>
<td>0.7</td>
<td>2.8</td>
<td>5.3</td>
</tr>
<tr>
<td>TDR</td>
<td>22</td>
<td>23</td>
<td>7.9</td>
<td>0.6</td>
<td>6.3</td>
<td>10</td>
</tr>
<tr>
<td>FSC</td>
<td>24.3</td>
<td>3.3</td>
<td>7.3</td>
<td>0.7</td>
<td>1.8</td>
<td>0.3</td>
</tr>
</tbody>
</table>

Keys: Temp, temperature; Turb, turbidity; TTC, Termotolerant coliforms; FS, Faecal streptococci CTR, City reservoir; TDR, Tulu dimtu reservoir; FSC Fanta spring chlorinated; CFU, coliform unit; FAU formazin attenuation unit
As summarized in Table 5, there is no significant difference in the true average values all of parameters between raw water feed for treatment and outlet water from disinfection points. (F calculated (5.32) < F(ratio) tabulated and p > 0.05).

Table 5 Analysis of variance table for physico-chemical and bacteriological analyses among points for raw water sources (n=7) and disinfected sites (n=3)

<table>
<thead>
<tr>
<th>Factors</th>
<th>Between Groups (df=1 for all below)</th>
<th>Within Groups(df=8 for all below)</th>
<th>Total (df=9)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Sum of sq</td>
<td>Mean sq</td>
<td>F-ratio</td>
</tr>
<tr>
<td>Temp</td>
<td>1.022</td>
<td>1.022</td>
<td>0.640</td>
</tr>
<tr>
<td>Turb</td>
<td>135.737</td>
<td>135.737</td>
<td>4.131</td>
</tr>
<tr>
<td>pH</td>
<td>0.009</td>
<td>0.009</td>
<td>0.234</td>
</tr>
<tr>
<td>TTC</td>
<td>56.923</td>
<td>56.923</td>
<td>0.800</td>
</tr>
<tr>
<td>FS</td>
<td>82.553</td>
<td>82.553</td>
<td>0.301</td>
</tr>
</tbody>
</table>

Keys: Temp, temperature; Turb, turbidity; TTC, thermotolerant coliforms; FS, Faecal streptococci; Sum of sq, sum of squares; Mean sq, Mean squares; F-ratio, the ratio of between and within samples; df, degree of freedom; Sig, significance

The bacteriological and physico chemical parameters strongly negatively correlated for each other and one another for instance, temperature and turbidity, temperature and TTC values were -0.706 and -0.75, respectively. On the other hand, the positively correlated values for turbidity and TTC, turbidity and FS the values were 0.877 and 0.742 respectively. Correlation also observed between FCR and TTC was value 0.671 and between FCR and FS with the value of 0.852 (Table 6). These were an indication of possibility indirect monitoring in disinfection practice.

Table 6 Paired samples correlations of physico-chemical and bacteriological indicators in disinfection points (n=3)

<table>
<thead>
<tr>
<th>All 15 pairs</th>
<th>FS</th>
<th>TTC</th>
<th>pH</th>
<th>FRC</th>
<th>Temp</th>
<th>Turb</th>
</tr>
</thead>
<tbody>
<tr>
<td>FS</td>
<td>-</td>
<td>-</td>
<td>0.628</td>
<td>0.070</td>
<td>0.464</td>
<td>0.208</td>
</tr>
<tr>
<td>TTC</td>
<td>0.628</td>
<td>0.70</td>
<td>-</td>
<td>-</td>
<td>0.485</td>
<td>0.186</td>
</tr>
<tr>
<td>FRC</td>
<td>-0.852</td>
<td>0.004</td>
<td>-0.671</td>
<td>0.48</td>
<td>-0.536</td>
<td>0.137</td>
</tr>
<tr>
<td>pH</td>
<td>-0.536</td>
<td>0.137</td>
<td>0.485</td>
<td>0.186</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Turb</td>
<td>0.742</td>
<td>0.22</td>
<td>0.877</td>
<td>0.002</td>
<td>0.235</td>
<td>0.542</td>
</tr>
</tbody>
</table>

Keys: Temp, temperature; Turb, turbidity; TTC, thermotolerant coliforms; FS, Faecal streptococci, Corr, correlations Sig, significance
As shown in Table 7, out of 35 pipe water samples investigated 24 (68.6%) were in the range of 15.01-20 °C and 10 (24.6%) were >20 °C which were beyond recommended limit of WHO is <15°C. Only1 (2.9%) samples were found to be met the acceptable limits. Turbidity analyses water samples showed that out of 35 samples, 20(57.1%) in the range of 2-5 FAU, 14(40%) in the range of 0.1-1.99 FAU in the recommended level of WHO and ES < 5 FAU and only 1(2.9%) was beyond acceptable level. All pipe water samples had pH levels within WHO permissible level in the range of 6.5-8 (WHO, 2004b). And the amount of FCR in the pipe water recommended value WHO and ES (0.2-0.5 mg/l). In the study area 17(48.6%) of water samples met the acceptable level, 6(17.1%) of it were from beyond the acceptable 0.5mg/l and 6(17.1%) within the range 0.1-1.99mg/l, 1(2.9%) was nil and 5(14.3%) distributed without disinfection initially from the sources (Table 7).

Table 7 Classification of drinking water according to magnitude of contamination of physico-chemical and bacteriological quality pipe water parameters (n=35)

<table>
<thead>
<tr>
<th>Levels On</th>
<th>Temp(°C)</th>
<th>Turb(FAU)</th>
<th>pH</th>
<th>FCR(mg/l)</th>
<th>TTC(CFU/100ml)</th>
<th>FS(CFU/100ml)</th>
</tr>
</thead>
<tbody>
<tr>
<td>contamination</td>
<td>N=35</td>
<td>%</td>
<td>N=35</td>
<td>%</td>
<td>N=35</td>
<td>%</td>
</tr>
<tr>
<td>&gt;20</td>
<td>10</td>
<td>28.6</td>
<td></td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>15.01-20</td>
<td>24</td>
<td>68.4</td>
<td></td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>&lt;15</td>
<td>1</td>
<td>2.9</td>
<td></td>
<td>-</td>
<td>-</td>
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</tr>
<tr>
<td>total</td>
<td>35</td>
<td>100</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&gt;5</td>
<td>-</td>
<td>-</td>
<td>1</td>
<td>2.9</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>2-5</td>
<td>20</td>
<td>57.1</td>
<td></td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>0.1-1.99</td>
<td>14</td>
<td>40.0</td>
<td></td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>total</td>
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<td>-</td>
<td>-</td>
<td>-</td>
<td>35</td>
<td>100</td>
</tr>
<tr>
<td>&gt;0.5</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>6</td>
</tr>
<tr>
<td>0.2-0.5</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>17</td>
</tr>
<tr>
<td>0.1-1.99</td>
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<tr>
<td>0</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1</td>
</tr>
<tr>
<td>Ntw (0)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>7</td>
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<tr>
<td>total</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>19</td>
</tr>
</tbody>
</table>

Keys: Ntw, non treated water; Temp, temperature; Turb, turbidity; FCR, free chlorine residual; TTC, Termotolerant coliforms; FS, Faecal streptococci coliform unit; FAU, formazin attenuation unit
Among the total samples (35), 19(54.3%) of them range from 1.01-9.99, 7(20%) were in the range of 10-100cfu/100ml. whereas, only 6 (17.1%) samples were found 0 of TTC cfu per 100ml which is in the acceptable limit of WHO and ES nil cfu/100ml. Regarding to FS, 13 (37.1%) were in the range of 1.01-9.99 cfu/100ml, 11(31.4%) were in the range of (0.01-1cfu/100ml) and 11(31.4%) were no any FS cfu per 100ml which was met the acceptable limit of WHO and ES (Table 7).

The physicochemical and bacteriological qualities of the household water samples are summarized in Table 8. With regard to temperature, from 35 samples, 5 (14.3%) were >20 °C high, 27(77.1%) were in the range of 15.01-20 °C medium, and 3(8.3%) <15°C recommended limit by WHO (1996). The average temperature of household water containers were in the range of 14.5-22.5°C (annex IV). Regarding to turbidity, 6(17.1%) showed >5FAU, which was above acceptable limit of potability, 9(27.5%) showed a turbidity values ranging from 0.1-1.99 FAU and 20(57.1%) levels within WHO and ES limit of <5 FAU. From 35 storage water samples, 28(80%) was found to met WHO and ES recommended range of pH 6.5-8. Whereas 7(20%) above the recommended limit of WHO, while it met ES which is 6.5-8.5. From the total of 35 examined storage containers for the concentration of FCR, 13(37.1%) range from 0.01-0.19 mg/l and 12(34.3%) attained score nil of the samples and only 5(14.3%) sample met the range of 0.2-0.5 mg/l which is recommended limit of WHO and ES. The same amounts (5(14.3%)) of the representative samples have no any chlorine at the point of distribution water supply (Table 8).

Table 8 presents classification of risk levels of bacterial indicator organisms in water samples from the household water containers. The mean values of TTC for the household water samples (n=35), 21(60%), 9(25.7%) and 4(11.4%) of the samples, count in the range of 10-100cfu/100ml, 1.01-9.99 and 0.01-1.01, respectively. Whereas, FS 18(51.3%), 11(31.4%) and 5(14.3%) cfu/100ml count of the samples, ranged 10-00 cfu/100ml, 1.01-9.99 and 0.01-1.01, respectively. Therefore, the average count of TTC and FS were beyond the recommended value of WHO and ES which is 0 cfu/100ml of sample. Only one (2.9%) sample to both TTC and FS met the recommended limit, nil cfu/100ml (Table 8).
### Table 8 Classification of drinking water according to magnitude of contamination of physico-chemical and bacteriological quality on household water containers (N=35)

<table>
<thead>
<tr>
<th>Levels on contamination</th>
<th>Temp(°C)</th>
<th>Turb(FAU)</th>
<th>pH</th>
<th>FCR(mg/l)</th>
<th>TTC(cfu/100ml)</th>
<th>FS(cfu/100ml)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N=35 %</td>
<td>N=35 %</td>
<td>N=35 %</td>
<td>N=35 %</td>
<td>N=35 %</td>
<td>N=35 %</td>
</tr>
<tr>
<td>Total</td>
<td>35 100</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&gt;20</td>
<td>5 14.3</td>
<td>- -</td>
<td>- -</td>
<td>- -</td>
<td>- -</td>
<td>- -</td>
</tr>
<tr>
<td>15.01-20</td>
<td>27 77.1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt;15</td>
<td>3 8.6</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>35 100</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&gt;5</td>
<td>- -</td>
<td>6 17.1</td>
<td>- -</td>
<td>- -</td>
<td>- -</td>
<td>- -</td>
</tr>
<tr>
<td>2-5</td>
<td>- -</td>
<td>20 57.1</td>
<td>- -</td>
<td>- -</td>
<td>- -</td>
<td>- -</td>
</tr>
<tr>
<td>0.1-1.99</td>
<td>- -</td>
<td>9 25.7</td>
<td>- -</td>
<td>- -</td>
<td>- -</td>
<td>- -</td>
</tr>
<tr>
<td>Total</td>
<td>- -</td>
<td>35 100</td>
<td>- -</td>
<td>- -</td>
<td>- -</td>
<td>- -</td>
</tr>
<tr>
<td>&gt;8</td>
<td>- -</td>
<td>- -</td>
<td>7 20</td>
<td>- -</td>
<td>- -</td>
<td>- -</td>
</tr>
<tr>
<td>6.5-8</td>
<td>- -</td>
<td>- -</td>
<td>28 80</td>
<td>- -</td>
<td>- -</td>
<td>- -</td>
</tr>
<tr>
<td>Total</td>
<td>- -</td>
<td>- -</td>
<td>35 100</td>
<td>- -</td>
<td>- -</td>
<td>- -</td>
</tr>
<tr>
<td>&gt;0.5</td>
<td>- -</td>
<td>- -</td>
<td>- -</td>
<td>0 0</td>
<td>- -</td>
<td>- -</td>
</tr>
<tr>
<td>0.2-0.5</td>
<td>- -</td>
<td>- -</td>
<td>- -</td>
<td>5 14.3</td>
<td>- -</td>
<td>- -</td>
</tr>
<tr>
<td>0.1-1.99</td>
<td>- -</td>
<td>- -</td>
<td>- -</td>
<td>13 37.1</td>
<td>- -</td>
<td>- -</td>
</tr>
<tr>
<td>0</td>
<td>- -</td>
<td>- -</td>
<td>- -</td>
<td>12 34.3</td>
<td>- -</td>
<td>- -</td>
</tr>
<tr>
<td>Ntw (0)</td>
<td>- -</td>
<td>- -</td>
<td>- -</td>
<td>5 14.3</td>
<td>- -</td>
<td>- -</td>
</tr>
<tr>
<td>Total</td>
<td>- -</td>
<td>- -</td>
<td>- -</td>
<td>35 100</td>
<td>- -</td>
<td>- -</td>
</tr>
<tr>
<td>10-100</td>
<td>- -</td>
<td>- -</td>
<td>- -</td>
<td>- -</td>
<td>21 60</td>
<td>18 51.4</td>
</tr>
<tr>
<td>1.01-9.99</td>
<td>- -</td>
<td>- -</td>
<td>- -</td>
<td>- -</td>
<td>9 25.7</td>
<td>11 31.4</td>
</tr>
<tr>
<td>0.01-1.01</td>
<td>- -</td>
<td>- -</td>
<td>- -</td>
<td>- -</td>
<td>4 11.4</td>
<td>5 14.3</td>
</tr>
<tr>
<td>0</td>
<td>- -</td>
<td>- -</td>
<td>- -</td>
<td>- -</td>
<td>1 2.9</td>
<td>1 2.9</td>
</tr>
<tr>
<td>Total</td>
<td>35 100</td>
<td>35 100</td>
<td>35 100</td>
<td>- -</td>
<td>- -</td>
<td>- -</td>
</tr>
</tbody>
</table>

**Keys:** Ntw, non treated water ;Temp, temperature; Turb, turbidity; FCR, Free chlorine residual ;TTC, thermotolerant coliforms; FS, Faecal streptococci coliform unit; FAU, formazin attenuation unit. As WHO,2004b microbial pollution levels recorded in classification of classified 0, 0.01-1, 1.01-9.99, 10-100,>100 cfu/100ml scored as very low, low, medium, high and very high respectively.

Fig. 14 and 15 show the relationship between FCR the number of cfu of TTC and FS drinking water from the pipe and household water containers. FCR and bacteriological indicators showed inverse relationships i.e when the concentration of FCR increases the density of cfu/100ml of TTC and FS, decreases both in pipe and household water containers.
In the ANOVA Table 9, it is possible to see the mean difference for all parameters between and within groups, unlike the significance of raw water sources and points of disinfection the result indicated that there were very strong significant differences among the points of disinfection (CTR, TDR, and FSC), pipe water and household water containers for all the parameters except pH (F calculated (3.2) < F (ratio) tabulated, p < 0.05).
Table 9 Analysis of variance table for physico-chemical and bacteriological analyses among point of disinfection, pipe and household water containers

<table>
<thead>
<tr>
<th>Factors</th>
<th>Between Groups (df=2 for all below)</th>
<th>Within Groups(df=62 for all below)</th>
<th>Total ( df=64)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Sum of sq</td>
<td>Mean sq</td>
<td>F</td>
</tr>
<tr>
<td>Temp</td>
<td>107.537</td>
<td>53.769</td>
<td>15.420</td>
</tr>
<tr>
<td>Turb</td>
<td>173.593</td>
<td>86.797</td>
<td>13.436</td>
</tr>
<tr>
<td>FCR</td>
<td>1.361</td>
<td>0.680</td>
<td>24.649</td>
</tr>
<tr>
<td>pH</td>
<td>9.310</td>
<td>4.655</td>
<td>1.123</td>
</tr>
<tr>
<td>TTC</td>
<td>3545.872</td>
<td>1772.936</td>
<td>7.118</td>
</tr>
<tr>
<td>FS</td>
<td>3916.367</td>
<td>1958.184</td>
<td>11.539</td>
</tr>
</tbody>
</table>

**Keys:** Temp, temperature; Turb, turbidity; FCR, Free chlorine residual; TTC, Thermotolerant coliforms; FS, Faecal streptococci; Sum of sq, sum of squares; Mean sq, Mean squares; F-ratio, the ratio of between and within samples df, degree of freedom; Sig, significance difference

The comparisons mean differences of Physicochemical and Bacteriological quality from disinfection to storage water containers

In Table 9a, Pair comparisons using LSD mean values indicated that significant difference in mean temperature occurred between water quality disinfection points and pipe, household water containers and disinfection points, Pipe and household water containers. There were also significant mean turbidity difference between disinfection points and pipe, household water containers and disinfection points the values were 7.96 and 7.13, respectively, but there was no significant mean difference of turbidity between pipe and household. Even if FCR, statically different (P<0.05) among distribution systems while there were slight mean differences of FCR significant analyses between disinfection points with pipe and household water containers and pipe water and household water containers, the values were 0.33, 0.56 and 0.23, respectively. The pH values of mean differences were not much significant differences among disinfection point to consumption (Table 10a). The mean difference of significant analysis of TTC and FS indicator organisms suggested that there were large significant differences of TTC between the value at disinfection point to household water containers, pipe and household water containers. The mean value differences were -14.60 and 16.48, respectively. There were also significant differences along disinfection points to pipe water the value were -10.87. Almost the same mean differences of FS and TTC in sample sites of water systems, because mean value FS differences were disinfection points and household water containers, pipe and household water containers were very significance values -15.74 and -13.09, respectively. The FS mean difference between
disinfection points and pipe water were slight significant difference the value was 2.65 (Table 10b).

**Table 10** Mean differences of physico-chemical and bacteriological factors at the disinfected points (n=3), pipe water (n=35) and household water containers (n=35)

A) Physicochemical

<table>
<thead>
<tr>
<th>Factors</th>
<th>(I) From treatments to consumption</th>
<th>(J) From treatments to consumption</th>
<th>Mean Difference</th>
<th>Std. Error</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temp.</td>
<td>pipe</td>
<td>house hold water</td>
<td>1.17634(*)</td>
<td>0.47430</td>
<td>0.016</td>
</tr>
<tr>
<td></td>
<td>disinfection points</td>
<td>pipe</td>
<td>4.89677(*)</td>
<td>1.12907</td>
<td>0.000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>house hold water</td>
<td>6.07312(*)</td>
<td>1.12907</td>
<td>0.000</td>
</tr>
<tr>
<td>Turb.</td>
<td>pipe</td>
<td>house hold water</td>
<td>-0.82796</td>
<td>0.64558</td>
<td>0.204</td>
</tr>
<tr>
<td></td>
<td>disinfection points</td>
<td>pipe water</td>
<td>7.96057(*)</td>
<td>1.53680</td>
<td>0.000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>house hold water</td>
<td>7.13262(*)</td>
<td>1.53680</td>
<td>0.000</td>
</tr>
<tr>
<td>FCR</td>
<td>pipe</td>
<td>house hold water</td>
<td>0.22634(*)</td>
<td>0.04220</td>
<td>0.000</td>
</tr>
<tr>
<td></td>
<td>disinfection points</td>
<td>pipe water</td>
<td>0.33176(*)</td>
<td>0.10045</td>
<td>0.000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>house hold water</td>
<td>0.55810(*)</td>
<td>0.10045</td>
<td>0.000</td>
</tr>
<tr>
<td>pH</td>
<td>pipe</td>
<td>house hold water</td>
<td>-0.76312</td>
<td>0.51719</td>
<td>0.145</td>
</tr>
<tr>
<td></td>
<td>disinfection points</td>
<td>Pipe water</td>
<td>0.06688</td>
<td>1.23116</td>
<td>0.957</td>
</tr>
<tr>
<td></td>
<td></td>
<td>House hold water</td>
<td>-0.69624</td>
<td>1.23116</td>
<td>0.574</td>
</tr>
</tbody>
</table>

*The mean difference is significant at the .05 level. Keys: Temp, Temperature; FCR, Free chlorine residual; Turb., Turbidity; pH, pH

b) Bacteriological

<table>
<thead>
<tr>
<th>Factors</th>
<th>(I) From disinfection points to consumption</th>
<th>(J) From disinfection points to consumption</th>
<th>Mean Difference</th>
<th>Std. Error</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>TTC</td>
<td>pipe</td>
<td>House hold water</td>
<td>-14.60(*)</td>
<td>4.01</td>
<td>0.001</td>
</tr>
<tr>
<td></td>
<td>disinfection points</td>
<td>pipe water</td>
<td>-10.87(*)</td>
<td>9.54</td>
<td>0.045</td>
</tr>
<tr>
<td></td>
<td></td>
<td>house hold water</td>
<td>-16.48</td>
<td>9.54</td>
<td>0.089</td>
</tr>
<tr>
<td>FS</td>
<td>pipe</td>
<td>house hold water</td>
<td>-15.74(*)</td>
<td>3.31</td>
<td>0.000</td>
</tr>
<tr>
<td></td>
<td>disinfection points</td>
<td>pipe water</td>
<td>2.65</td>
<td>7.88</td>
<td>0.738</td>
</tr>
<tr>
<td></td>
<td></td>
<td>house hold water</td>
<td>-13.09</td>
<td>7.88</td>
<td>0.102</td>
</tr>
</tbody>
</table>

*The mean difference is significant at the .05 level; Keys: TTC, Termotolerant coliforms; FS, Feacal streptococci

As indicated annex IV and V the confirmative test for FS were positive all samples using catalase test and EVA broth test. In catalase test bubble formation was observed, the sample was recorded as negative for feacal streptococci. Moreover as examined in Epi fluorescent microscope, TTCs was rod and FSs were sphere-shaped bacteria with duplicate or chain arrangement of bacteria (annex V).
Results of sanitary survey

Level of risk enables the comparison of water-related diseases with one another and a consistent approach for dealing with each hazard (WHO, 2004b). A cross-sectional sanitary assessment was carried out in each of the selected boreholes, spring, and household level to identify the risks for contamination with pathogenic organisms of faecal origin. The assessment followed a standardized procedure described by WHO. The procedure involved completing a ten- twelve points standardized data form with a series of questions with a yes, no options, and short answers for designated risks. Also sanitary survey was supported with visual pictures such as physical appearance of drinking water containers (annex VI).

Drinking water sources protection

Akaki-Kaliti areas and Akaki well fields are within an industrial zone surrounded by residents of mainly agricultural activities and different tributaries or streams of Akaki River such as Dangora River crossing in southwestern direction. The water sources are very close to crop production, cattle breeding and conventional pit latrine (Fig16).

Fig. 16 The Akaki well field boreholes and the possible contaminatees of water sources ( a Community settlement, b1 and b2 are boreholes, c domestic animals and d” Dangora river”)

Moreover, the tributaries or streams of the Akaki River and Aba Samuel Lake are nearby to boreholes and spring to cause pollution through infiltration (Fig.17, and 18).
Fig. 17 Akaki wells close to the location of the water flow over to Aba Samual Lake and latrine used by the community (a1 and a2 are boreholes, b Community settlement and c Aba Samual lake)

Fig. 18 Location of boreholes and a spring relative to rivers, lake and the main road

According to the sanitary survey, the risk frequency of the boreholes of Akaki well field for source of pollution within 50m, latrine or sewer within 50m of the borehole, and drainage around borehole with faulty pond were 100%, 36.36% and 27.27 %, respectively (Table 11).
Table 11 Result of sanitary inspection at Akaki well field boreholes, AA, 2006/07.

<table>
<thead>
<tr>
<th>Sanitary risk inspection (n=22)</th>
<th>Risk frequency with %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Is there a latrine or sewer within 50m of the borehole?</td>
<td>36.36%</td>
</tr>
<tr>
<td>Is the nearest latrines unsewered?</td>
<td>31.82%</td>
</tr>
<tr>
<td>Are there any other sources of pollution within 50m of borehole?</td>
<td>100%</td>
</tr>
<tr>
<td>Is there an uncapped open well within 100m of the borehole?</td>
<td>0%</td>
</tr>
<tr>
<td>Is there drainage around the borehole faulty allowing pond?</td>
<td>27.27%</td>
</tr>
<tr>
<td>Is the fence around the borehole missing or faulty?</td>
<td>0%</td>
</tr>
<tr>
<td>Is the floor of the pump house permeable to water?</td>
<td>0%</td>
</tr>
<tr>
<td>Does split water collect in the pump house close to the wellhead</td>
<td>4.50%</td>
</tr>
<tr>
<td>Is the well seal unsanitary (i.e. is not sealed against surface water)?</td>
<td>0%</td>
</tr>
</tbody>
</table>

The risk- to- health matrix classification for Akaki well field representative wells (BH24, BH23, BH22, BH8, BH5, EP4) indicated that 4 bore holes (BH24, BH23, BH22, BH5) were at medium risk whereas 2 bore holes sources (BH8 and EP4) were at high health risk (Table 12).

Table 12 Risk-to–health matrix of wells of Akaki well field representative raw water sources AA, 2006/07

<table>
<thead>
<tr>
<th>Akaki well field representative bore holes representative (n=6)</th>
<th>TTC cfu/100ml</th>
<th>FS cfu/100ml</th>
</tr>
</thead>
<tbody>
<tr>
<td>Si score</td>
<td>0</td>
<td>&lt;1</td>
</tr>
<tr>
<td>(0-2)</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>(3-5)</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>(6-8)</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>(9-10)</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Legend

| VERY LOW | LOW | MEDIUM | HIGH | VERY HIGH |

Sanitary survey on Fanta spring

Based on the sanitary risk inspection, the spring had high risk score classification. In combined analysis of sanitary inspection and water quality data as presented in Table 13, FSNC raw water sources classified on the level of high risk to health matrix both in TTC and FS cfu/100ml. The survey indicated that the spring source is located in Fanta River and the neighboring with out diversion ditch and dismantled fence (Fig.19). Open defecation was also prevalent around the spring.
Table 13 Risk –to-health matrix of FSNC (Fanta Spring non Chlorinated)

<table>
<thead>
<tr>
<th>SI score</th>
<th>TTC cfu /100ml</th>
<th>FS cfu /100ml Fanta spring non chelrinated</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-2</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>3-5</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>6-8</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>9-10</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Legend

- **Low**
- **Medium**
- **High**
- **Very high**

a) Fanta River a parts of Fanta spring  
b) Fanta Spring from the possible contaminates

**Fig. 19 (a, b)** Point of Fanta spring and exposure of its contamination

**EP5 and Kaliti Gabriel well sanitary survey**

It was observed that solid waste and waste water from high altitude directed easily to low altitude position of KGW and these well source water has been distributed to community without treatment (Fig 20). Moreover, there is a polluted river close to part of the catchments of KGW (Fig 21).

A) Solid waste  
b) liquid waste

**Fig 20(a, b)** Solid and liquid waste settled in sewerage places and moves to KGW
The risk-to-health ranking classification of water sources depicted that both EP5 and KGW were high risk score for TTC whereas in FS risk to health classification for KGW and EP5 lie on high and medium risk score, respectively (Table 14).

Table 14 Risk-to–health matrix of wells of unchlorinated water sources AA, 2006/07

<table>
<thead>
<tr>
<th>SI score</th>
<th>0</th>
<th>0.01-1</th>
<th>1.01-9.99</th>
<th>10-100</th>
<th>&gt;100</th>
<th>0</th>
<th>0.01-1</th>
<th>1.01-9.99</th>
<th>10-100</th>
<th>&gt;100</th>
</tr>
</thead>
<tbody>
<tr>
<td>(0-2)</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>(3-5)</td>
<td></td>
<td></td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>(6-8)</td>
<td></td>
<td></td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>(9-10)</td>
<td></td>
<td></td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
</tbody>
</table>

Legend

<table>
<thead>
<tr>
<th></th>
<th>VERY LOW</th>
<th>LOW</th>
<th>MEDIUM</th>
<th>HIGH</th>
<th>VERY HIGH</th>
</tr>
</thead>
</table>

Sanitary survey of the distribution system (pipe)

According to the sanitary survey conducted, there were pipe water interconnection with the sewerage lines which may cause contamination of disinfected water distribution systems (Fig. 22 a and Fig. b). Pipeline leakage was observed and attracted people to utilize for laundry and personal hygiene practice that might be possible cause contamination.
Fig. 22 (a, b) Pipe water passes through waste sewerage line

The overall risk-to-health classification at pipe water (N=35) were 19(54.29%) an intermediate and 16(45.7%) in low classification range for FS whereas for TTC, 19 (54.29%), 8(22.88%) and 8(22.88%) were in intermediate, high and low risk to health matrix score, respectively (Table 15 and 16).

Table 15 Risk-to-health matrix of pipe water in AA, 2006/07

<table>
<thead>
<tr>
<th>SI score</th>
<th>0</th>
<th>0.01-1</th>
<th>1.01-10</th>
<th>10-100</th>
<th>&gt;100</th>
<th>0</th>
<th>0.01-1</th>
<th>1.01-9.99</th>
<th>10-100</th>
<th>&gt;100</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2-4</td>
<td>10</td>
<td>6</td>
<td>7</td>
<td>0</td>
<td>0</td>
<td>6</td>
<td>2</td>
<td>9</td>
<td>6</td>
<td>0</td>
</tr>
<tr>
<td>5-7</td>
<td>1</td>
<td>5</td>
<td>6</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>9</td>
<td>2</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>8-10</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>10-12</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Legend

<table>
<thead>
<tr>
<th>Very low</th>
<th>Low</th>
<th>intermediate</th>
<th>High</th>
<th>Very high</th>
</tr>
</thead>
</table>
Table 16 Overall risks –to –health classification of pipe water in AA, 2006/07
(Pipe water 35 sites are inspected)

<table>
<thead>
<tr>
<th>Risk score</th>
<th>FS</th>
<th>TTC</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N. of pipe water proportion</td>
<td>N. of pipe water proportion</td>
</tr>
<tr>
<td>Very low</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>Low</td>
<td>45.7%</td>
<td>22.88%</td>
</tr>
<tr>
<td>Medium</td>
<td>54.29%</td>
<td>54.29%</td>
</tr>
<tr>
<td>High</td>
<td>0%</td>
<td>22.88%</td>
</tr>
<tr>
<td>Very high</td>
<td>0%</td>
<td>0%</td>
</tr>
</tbody>
</table>

Sanitary inspection of house hold water container

As annex VI indicated, 97.1% household water containers were plastic containers. As the table 16 indicates the causes for contamination were poor hygienic practice. 48.6% of storage containers were not narrow mouth containers (Table 17). The physical appearances and sanitary condition of the containers were indicated in the annex VI.

Table 17 Result of sanitary inspection of house hold water containers in AA, 2006/07

<table>
<thead>
<tr>
<th>Sanitary risk inspection of house hold water container (n=35)</th>
<th>Risk frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Is drinking water in separate containers?</td>
<td>45.7%</td>
</tr>
<tr>
<td>Is drinking water container kept above floor level and away from contamination?</td>
<td>48.6%</td>
</tr>
<tr>
<td>Do water containers have a narrow mouth/opening?</td>
<td>51.4%</td>
</tr>
<tr>
<td>Do containers have a lid/cover?</td>
<td>20%</td>
</tr>
<tr>
<td>Is this is in place at time of visit?</td>
<td>42.9%</td>
</tr>
<tr>
<td>Is the utensil used to draw from the containers clean?</td>
<td>40%</td>
</tr>
<tr>
<td>Is the utensil used to draw water the container kept away from surfaces and stored in a hygienic manner?</td>
<td>57.10%</td>
</tr>
<tr>
<td>Is the inside of the drinking water container clean?</td>
<td>54%</td>
</tr>
<tr>
<td>Is the outside of the drinking containers clean?</td>
<td>63.90%</td>
</tr>
</tbody>
</table>
The storage container washing frequency among the households has been assessed and it was found that only 17 (48.6%) households wash every day (Table 18). As indicated in Table 17, 23 (65.7%) of the households were cleaning their container by simple washing with pipe water (Table 19).

**Table 18** The frequency of cleaning storage water containers in the study area in AA, 2006/07

<table>
<thead>
<tr>
<th>Types of answers by the peoples</th>
<th>Frequency</th>
<th>Percent</th>
<th>Cumulative Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Valid every day</td>
<td>17</td>
<td>48.6</td>
<td>48.6</td>
</tr>
<tr>
<td>every week</td>
<td>9</td>
<td>25.7</td>
<td>74.3</td>
</tr>
<tr>
<td>every month</td>
<td>1</td>
<td>2.9</td>
<td>77.1</td>
</tr>
<tr>
<td>rarely</td>
<td>8</td>
<td>22.9</td>
<td>100.0</td>
</tr>
<tr>
<td>Total</td>
<td>35</td>
<td>100.0</td>
<td></td>
</tr>
</tbody>
</table>

**Table 19** Households water containers cleaning practice in the study area in AA, 2006/07

<table>
<thead>
<tr>
<th>Types of answers by the peoples</th>
<th>Frequency</th>
<th>Percent</th>
<th>Cumulative Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Valid Simply washing with pipe water</td>
<td>23</td>
<td>65.7</td>
<td>65.7</td>
</tr>
<tr>
<td>Washed with soap</td>
<td>6</td>
<td>17.1</td>
<td>82.9</td>
</tr>
<tr>
<td>Washes with different cleaning chemicals and materials</td>
<td>6</td>
<td>17.1</td>
<td>100.0</td>
</tr>
<tr>
<td>Total</td>
<td>35</td>
<td>100.0</td>
<td></td>
</tr>
</tbody>
</table>

Using TTC as a bacteriological indicator to determine the overall risk to health status, 23 (65.7%) were in the high risk score, 7 (20%) were medium, 4 (11.43%) were very high risk score. Using FS, 24 (68.5%), 7 (20%) and 4 (11.43%) were in the high risk, medium risk, and very high risk score, respectively (Table 20 and 21).
Table 20 Risk—to-health matrix of household water containers in AA, 2006/07

<table>
<thead>
<tr>
<th>household water container (n=35)</th>
<th>TTC cfu /100ml</th>
<th>FS cfu /100ml</th>
</tr>
</thead>
<tbody>
<tr>
<td>SI score</td>
<td>0</td>
<td>0.01-1</td>
</tr>
<tr>
<td>0-2</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>3-6</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>7-9</td>
<td>0</td>
<td>1</td>
</tr>
</tbody>
</table>

Legend

Low | Medium | High | Very high

Table 21 Overall risk to-health classifications of household water containers in AA, 2006/07

<table>
<thead>
<tr>
<th>Hose hold water container(n=35)</th>
<th>TTC</th>
<th>FS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Risk score</td>
<td>No. of storage water containers</td>
<td>proportion</td>
</tr>
<tr>
<td>Low</td>
<td>1</td>
<td>2.86%</td>
</tr>
<tr>
<td>Medium</td>
<td>7</td>
<td>20%</td>
</tr>
<tr>
<td>High</td>
<td>23</td>
<td>65.7%</td>
</tr>
<tr>
<td>Very high</td>
<td>4</td>
<td>11.43%</td>
</tr>
</tbody>
</table>

4.2. Discussion

Raw water sources before disinfection

All samples were positive for TTC and FS. FS and TTC concentration detected in water samples obtained from BH8 and FSNC were 52.5 and 29 cfu/100ml, respectively. TTC and FS concentrations detected were 12.3 and 11.6 cfu/100ml, respectively for bore hole EP4 (Fig. 13). Similar study conducted by Tamiru *et al.* (2003; 2005), that the underlying fractured rocks and the widespread uncontrolled waste disposals were contaminated the groundwater in Addis Ababa. For instance total coliform and *E.coli* in Akaki well field boreholes and springs were isolated at a level >16 coliform and *E.coli*/100ml in BH22, BH6 and Fanta spring which had high risk for pollution whereas other boreholes also had ≥1 coliform and *E.coli*/100ml.

According to the sanitary survey, the risk frequency of the boreholes(n=22) of Akaki well field for source of pollution within 50m, latrine or sewer within 50m of the borehole, and drainage around borehole with faulty pond were 100%, 36.36% and 27.27 %, respectively (Table 10). The
risk-to-health matrix classification for Akaki well field representative wells (BH24, BH23, BH22, BH8, BH5, EP4) indicated that 4 bore holes (BH24, BH23, BH22, BH5) were at medium risk whereas 2 bore holes sources (BH8 and EP4) were at high health risk (Table 11). In combined analysis of sanitary inspection and water quality data (Table 12) FSNC raw water sources can be classified on the level of high risk both in TTC and FS cfu/100ml. The risk category in the sources of their location showed that Akaki Kaliti areas and Akaki well fields are within an industrial zone surrounded by residents of mainly agricultural activities and different tributaries or streams of Akaki River such as Dangora River crossing along southwestern direction (Fig.16). Since the water sources are very close to with in grazing site and conventional pit latrine so that vulnerable to contamination (Fig 18). Moreover, the tributaries or streams of the Akaki River and Aba Samuel Lake are nearby to boreholes and spring to cause pollution through infiltration (Fig. 19, and 20).

The possible contamination route, to water sources were human settlement, sewer leakage and livestock grazing and these have to be adjusted in accordance with river flowing sites with in the limits of least 50 ft gap (UMES, 1998; Ring, 2003; OECD/WHO, 2003; Mengesha et al., 2004; Wright et al., 2004; Aidan, 2005 and NJF, 2006). Since some boreholes in Akaki well field were very close to farmer houses having poorly constructed latrines, and open field defecation, rivers and cattle farming, pollution travel time is supposed to decrease and reduce the quality of ground water by infiltration. This finding is supported by Tamiru et al. (2005) who calculated that conductivity values obtained at the time required for bacteria to reach the ground level in the cesspools are located between 25m (BH7) and 200m (BH22) in scoraceous basaltic aquifer range between 2 1/2 hours and 4 hours. Moreover, they concluded that Akaki River may not have direct impact on the water quality. However, there could be hydraulic link between the river and the ground water. The river has direct impact on the nearby wells that tap water from alluvial layer. Therefore, as Tamiru et al. (2005) concluded Akaki well field is located under serious threat of pollution, strict control and appropriate management of the well field are important so that bacterial contamination could minimize the risk. A study conducted in UK showed that sewer leakage was found to significantly degrade groundwater resources. Monitoring of the UK urban aquifers of Nottingham 23% and Doncaster 40% of FS were detected (Cronin et al., 2005) which was similar to this study. As Cronin et al. (2005)in the UK recorded the presence of sulphite-reducing clostridia and Enterovirus on some urban ground water system.
Unchlorinated water sources of KGW and EP5 wells

The average values of pH for EP5 and KGW were 7.62 and 7.85, respectively. Whereas the values of turbidity for EP5 and KGW were 1.33 FAU and 4.33 FAU, respectively. Hence, the pH and the turbidity values of EP5 and KGW were within the recommended limit of WHO and ES which had an optimum pH value in the range 6.5-8 (WHO, 2004b), the pH value in the range of 6.5-8.5 (ES, 2001) and the turbidity value < 5 NTU (WHO, 2004b; ES, 2001). The value of temperature for EP5 was 17.9 °C and KGW was 14.27 °C. Therefore the value of temperature for EP5 was not within the recommended limit of WHO which is <15 °C (WHO, 1996) (Table 3).

With regard to TTC and FS concentrations, the average value of TTC in EP5 was 24.67 cfu/100ml and KGW was also 17.67 cfu/100ml. Similarly, the value of FS in EP5 was 2 cfu/100ml and KGW was 23.67 cfu/100ml (Table 3). Therefore the values were beyond WHO (2004) and ES (2001) which is 0 cfu/100ml of a sample. According to Mengesha et al. (2004), a study conducted in North Gonder, in protected springs (n=14) demonstrated that 71.43%, of the samples were contaminated with all kind of indicator bacteria. For instance, out of 14 samples 10 (71.4%), 7 (50%) and 5 (37.72%) were detected for TTC, FC and E.coli respectively. Likewise, fifty percent of protected wells 7 (50%), 4 (28.6%) and 4 (28.6%) were contaminated with TTC, FS and E.coli respectively. Dagnew et al. (2006), in rapid assessment in Ethiopia showed that, 32% of the sample sites of boreholes were within unacceptable limit of the standards set by WHO and ES for TTC. From the total spring water sources, 57% and 23% had unacceptable limit of the standards set by WHO and ES for TTC and FS, respectively. A study conducted in South Africa and Zimbabwe by Gundry et al. (2006), reported that 12% of source samples were contaminated with E.coli more than 10 cfu/100 ml of sample at the point-of-supply which were unsafe to drink. Another study done in Pakistan villages by Jensen et al. (2003) showed a higher level of E. coli was detected in unchlorinated stand pipe water than chlorinated ones. In contrast, a study conducted in Chikwawa by Jabu et al. (2005) showed that the samples were contaminated with neither coliforms nor E. coli because of appropriate protection of water sources.

The risk-to-health ranking classification of water sources depicted that both EP5 and KGW were high risk score for TTC whereas in FS risk to health classification for KGW and EP5 lie on high and medium risk score, respectively (Table 12). Similar study conducted by Haruna et al. (
Kampala city, shows that seventy percent of the springs had a high risk score (51-80%), while 30% had a medium risk score (31-50%). No spring attained a risk score of either nil (0%) or very high (81 to 100%). Sanitary inspection and observational result showed these might be because of the absence of diversions ditches, sewage disposal and traditional latrine which were evident by the vulnerability to contaminates for ground water quality of KGW and EP5 by infiltration (Fig 21, 22 and 23). Moreover, there is a polluted river close to part of the catchments of KGW (Fig 22). Since these well water sources have been distributed to community without treatment (Fig 10 and 11). The finding showed that the water sources need appropriate protection and treatment processes. Similar study in Addis Ababa by Tamiru et al. (2003 and 2005), reported that the surface and ground water sources were vulnerable to domestic, industrial and sewerage wastes. Moreover, as Hunter et al. (2004) indicated the possible sources contamination of ground water in the US could be the presence of pit latrines close to the water sources. In general, lack or little environmental protection, and poor catchments management might increase the density of indicator bacteria. Therefore in the United States showed that 127 drinking water outbreaks were reported due to unprotected ground water sources.

The phisco-chemical and bacteriological quality of Disinfection points

The temperatures for the TDR, CTR, and FSC result were 22.8°C, 23.3°C, and 23°C, respectively. These results, were beyond the recommended limit of WHO which is <15°C (Table 4). These values did not only meet the palatability of drinking water, but also make the chance of biofilms in the distributed water and increases the time of chlorine decay. As also the LSD mean comparisons values result also indicated that there was a significance difference (p<0.05) in mean temperature occurred between water quality disinfection points and pipe, disinfection point and household, pipe and household water container (Table 9a). On one hand these values indicated that at the disinfection points (TDR, CTR and FSC) water temperate were the highest compared with that of the pipe and household water containers. On the other hand the pipe water had slightly greeter values than household water therefore, the temperature of household water containers only 3 (8.3%) <15°C this may be due to uncontrolled water temperatures after disinfection. Similar study in Italy by Sisti et al. (1998) showed that the effect of chlorine compound was markedly influenced by water temperature. At a summer water temperature (20 oC), the efficiency of chlorine tested was found to be two to three times lower compared to that
found at a winter temperature (5 °C). These results were similar with Rogers et al. (1994) and Vieira et al. (2004).

The appearance of water with a turbidity of less than 5 NTU is usually acceptable to consumers. However, two samples sites FSC and CTR had turbidity levels within the recommended value of WHO and ES, whereas the turbidity level of TDR was beyond the standards set by WHO and ES which is >5 FAU. This might be most likely to occur from mishandling of the water sources, or disinfection points. According to Momba et al. (2006), 55% of the water treatment plants of South Africa were within the acceptable limits, while the other 45% showed high turbidity values. According to Momba et al. (2006) and Downie (2005), turbidity was the most common indicator of water quality. High turbidity indicates the presence of organic suspended material, which promotes the growth of micro-organisms. It is used as a crude indicator of contamination with organisms such as Cryptosporidia.

Turbidity was chosen as a parameter for its correlation with potential microbial problems. Particulate matter can protect microorganisms from the effect of disinfection and can stimulate bacterial growth (WHO, 2004a and 2004b). High turbidity can interfere with disinfection and provide a medium for microbial growth. Hence, for effective disinfection the turbidity should be below 0.1 NTU. Water plants must remove as much particulate material (e.g., clays, microbes, etc) as possible in order to increase the effectiveness of disinfection (USEPA, 1997). In this study, none of the disinfectant points fulfilled the recommended limit set by (WHO, 2004a; 2004b) which is, < 0.1 FAU for disinfection. Hence, pre-treatment might be required to decrease the turbidity in order to increase the chlorination efficiency.

Moreover, a correlation paired T-test for turbidity and indicator organisms (TTC and FS) had strong positive correlation value of 0.877 and 0.742, respectively at disinfection points (Table 6). Those water sources found to implicate contamination of pathogens with high turbidity. Several studies have shown a correlation between turbidity levels and microbial contamination of raw and treated water (Clark et al., 1992; LeChevallier et al. 1991 and 1993; Mackenzie et al., 1994; Schwartz et al., and 2006 Trevett et al., 2006). Therefore, controlling Turbidity at disinfection point increases the disinfection efficiency.
According to WHO the recommended value for pH is 6.5 to 8.0. Therefore all the three disinfection points met the recommended pH value set by WHO and ES (6.5 to 8.5). However, pH value beyond the limit causes a progressive decrease in the efficiency of chlorine disinfection and alum coagulation. Many water treatment processes operate most efficiently at a fairly neutral pH (TID, 2000). Consequently it is suggested that pH adjustments to water within distribution systems could reduce or control biofilms growth (Meckes, 2000). Chlorination is considered to be effective for virus inactivation if the water has a turbidity of ≤1.0 NTU, a free chlorine residual of >1mg/l for at least 30 minutes, and a pH of <8.0 (USEPA, 1999).

As shown on Table 4 indicated, the average free chlorine residual leaving the three disinfection points (CTR, TDR and FSC) were 0.67, 0.6, 0.68 mg/l, respectively which had low value as compared to the disinfection practice of other countries. For instance, Uzbekistan Pitnyak in reservoir of Urgench free residuals at the point starting to distributions is > 1.2 mg/l (Semenza et al., 1998), Massachusetts water resources authority of two treatment plants, Metro Boston supply 1.4 mg/l and Norumbega, 1.6mg/l free chlorine residual (MWRA, 2002). However, WHO (2000 and 2004b) recommended >1mg/l or 0.6-1mg/l for disinfection practice. Therefore maintaining chlorine residual at disinfection sites are very important.

The three disinfection sites have practice of free chlorine and/or powder chlorine as disinfecting chemical only, this may not be effective disinfection of microbes, in highly vulnerable contaminated raw water sources. So that, in addition adjusting the concentration of FCR to disinfection practices, it should be appropriate to select the type of disinfectants. For instance, the study shows that chlorine dioxide is highly effective for disinfection possibly because it can easily permeate a bacterial cell wall (Volk et al., 2002). According to Hurst et al. (2002) ClO₂ may be more effective than chlorine (OECD/WHO, 2003), Chloramine is considered to be more effective than chlorine for controlling Legionella in biofilms, presumably because chloramine is more stable and thus less reactive than chlorine, allowing it to penetrate the biofilm more deeply (Hunter et al., 2001). One study indicated that combining chlorination and chloramination processes can induce more inhibition of biofilm formation in drinking water system models than only chlorine or chloramine disinfection (Momba et al., 2002). In order to combat waterborne microbial diseases and prevent the formation of undesirable products; public water systems
should disinfect drinking water with alternative disinfectants, such as ozone, UV, activated carbon, osmosis and membrane (OECD/WHO, 2003; Downie, 2005).

The mean values for TTC for the CTR, TDR and FSC were 2.67, 6.33, and 1.67, cfu/100ml respectively. The mean concentration of FS in the three disinfection points were 5.33, 10, 0.33 cfu/100ml, respectively (Table 4). Therefore, the average counts of TTC and FS were beyond the recommended values of WHO and ES which is 0 cfu/100ml of a sample. One study showed that TDR and FSC disinfection points contain the opportunistic pathogen Cryptosporidium oocysts which were not assayed in this study (Nigus, 2005). Similarly in a study, on three disinfection reservoirs in the South Africa; N1, N2 and N3 showed that, N1 contained = 4 to 5 colonies/100 ml, N2 = 0 to 7 colonies/100 ml and N3 = 7 to 10 colonies/100 ml for both total and faecal coliforms which exceeded the recommended limits of both WHO and South African Standards (Muyima et al., 1998). Different investigators also detected indicator organisms in disinfected sources (Muyima et al., 1998; Jensen et al., 2003; Hrudey et al., 2003; Wright et al., 2004; Gundry 2006; Momba et al., 2006; Trevett et al., 2006 and Von Hertzen et al., 2007).

On the other hand, the ANOVA results showed that, there was no significant difference in the true average counts of TTC and FS between samples of after and before disinfection (p>0.05, Table 5). These might be because of the use of poor disinfection practices. On the contrary, the water from three disinfection points has a strong correlation among each parameter (Table 6). Moreover, analyses of variance revealed high significant differences of all parameters from disinfection to point of consumption (Table 8). For example, inefficiency of treatment plant may increase the formation of biofilms in distributions systems up to the end point of consumption. Also the disinfection points of outlet water parameters were highly correlated with each other, r>0.7 (Table 6), except the pH values (P <0.05). All these indicated that, there has an association of phisco-chemical parameters to disinfection of microbes. This necessitates the treatment plants to adjust pH, turbidity, temperature and other bacteriological related parameters that make disinfection efficiency better than simple and conventional addition of chlorine. Similar study by LeChevallier, et al. (1993) showed that a chlorine dose of 5 mg/l with one hour of contact time resulted in a 99.5% reduction in coliforms in waters with a turbidity of 5 NTU. However, in similar conditions but with turbidities of 8 to 13 NTU, the reduction was only 20%. Another study made by Volk et al. (2002) indicated that, in addition to disinfectants, other parameters also
control the development of biofilms and subsequent bacterial water quality in distribution systems. The study concluded that, it is difficult to predict the effects of a treatment change at a specific site, since it depends on the weight of the different factors regulating bacterial growth. Other studies also reported the importance of indirect monitoring of disinfection practice by controlling physico-chemical parameters (Rogers et al., 1994; Muyima et al., 1998; Momba et al., 2002; Volk et al., 2002; Jensen et al., 2003; WHO, 2004a; WHO, 2004c; Momba et al., 2006; Velk et al., 2006 and Traversay et al., 2006).

**Physico-chemical and bacteriological quality of pipe water**

As Arrhenius’s law expresses, for most chemical reactions the kinetic coefficient of chlorine decay increases with temperature. Based on Vieira et al. (2004) modeling chlorine decay in water supply influence initial chlorine concentration, bulk decay constants depends on temperature. From series test results at temperatures: T1=14.6°C, T2= 20.0°C, T3=24.5°C; chlorine rate decay was faster in the order of T3 >T2 >T1. According to WHO (1996) report re-growth of Thermotolerant coliforms in the distribution system is unlikely unless sufficient bacterial nutrients are present or the water temperature is above 15 °C, and there is no free chlorine residual.

Out of the 35 samples investigated in this study, temperature levels 15.01-20 °C was recorded in 24 (68.6 %) samples ,>20 °C in 10 (24.6%) samples and <15 °C in 1(2.9%) sample (Table 7). In the present study 34 out of 35 samples (97.1%) showed an average temperature above 15 °C in the pipe water system. Under practical conditions the temperature of drinking water during distribution is found to be about 15°C during the night and early morning and 23°C in the afternoons in summer time (Volk et al., 2002). Samples that were collected in early morning of pipe water had average temperatures of 14.5 - 22.5 °C, which is warm (annex VI). Such conditions can favor the re-growth of some indicator organisms like: TTC in distribution systems. Similar study in Italy by Sisti et al. (1998) showed that the survival curves Aeromones spp. A more rapid decline at low temperature (5 °C), whereas (20 °C) a temperature resembling that of water in distribution systems. The fact that at 20 °C, free chlorine is inactivated /combined more rapidly with compounds with a reduced microbial activity.
The study in pair comparisons test using LSD mean values indicated significant difference in TTC cfu/100ml of samples observed between water quality disinfection points and pipe water value -10.87 (at P<0.05) (Table 10b). These might be because of lack of controlling temperature at disinfection points, which leads to the re-growth of TTC. Previous studies have shown that temperatures greater than 15°C (LeChevallier et al. 1996; Kaye and Nagy, 1999, Momba et al., 2002) have been associated with biofilm formation in drinking water distribution systems. A study conducted in Ontario, Canada indicated that, bacterial concentrations are related to water temperature. Other findings showed that Heterotrophic plate counts and TC cfu/100ml levels in the plant effluent and distribution system were increased by approximately 60% when temperature (i.e. >15°C) increased dramatically in August (significant difference, p<0.01) (Volk et al., 2002). Another study in Canadian cities, Japan Gulch water treatment Plant also indicated that the warm temperature in the distribution systems favor the growth of coliforms as seen in Fig. 2 (CRD, 2005). The high regrowth of heterotrophs and total coliforms occurring after chlorination indicates the inefficiency of the filtration and chlorination steps because the study indicated that the higher the temperature, the faster the regrowth of coliforms (Muyima et al., 1998). Such results may be associated with uncontrolled physico-chemical parameters and/or changing the pipe materials to those which have a reduced biofilm-forming potential or changing the disinfection regime (LeChevallier et al., 1990; Momba et al., 2002 and CRD, 2005.).

When water temperature increases, disinfectant demand and microbial activity will also increase so that palatability of water quality decreases (Collicott et al., 2003; WHO, 2004b and 2004c). Therefore, in order to reduce the level of biofilm formation and to make pipe water potable, controlling water temperature is very crucial. Some studies in Danish distribution networks often encountered high temperatures as a result of high retention times at disinfection points (Boe-Hansen, 2002). According to WHO (2004b), to reduce higher temperature water cooling devices (cooling towers and evaporative condenser) associated with air conditioning system is important.

Since pH usually has no direct impact on consumers, no health –based guideline value has been proposed. But, usually pH is suggested to be in the range of 6.5-8 (WHO, 2004b) and ES is 6.5-8.5. In this study all pipe water samples had pH levels within WHO and ES permissible level. Turbidity analysis result from 35 water samples showed that only 1(2.9%) sample was above
acceptable level, while 20(57.1%) and 14(40%) of the samples lie in the range of 2-5 FAU 0.1-1.99 FAU, respectively were in the acceptable level of WHO and ES.

The amount of FCR in the pipe water is recommended 0.2-0.5 mg/l by WHO and ES. In the study area 17(48.6%) met the acceptable level, 6(17.1%) were from beyond the acceptable 0.5 mg/l and 6(17.1%) had in the range of 0.1-1.99 mg/l, 1(2.9%) was nil and 5 (14.3%) distributed without disinfection initially from the sources. As this research result showed that, more than 34% of the households, who had accesses to pipe water, lacks detectable levels and/or very small amount of chlorine residues in their drinking water (Table 7). These met the WHO and ES recommended limit of palatable of drinking water <0.5mg/l. While as, in Fig. 14 showed that FCR and bacteriological parameters showed inverse relationships i.e. when the concentration of FCR increases the density of cfu/100ml of TTC and FS decreases, in pipe water. So increasing the chlorine concentration has an important implication to reduce and/or eliminate pathogens in the water. In areas, where there is little risk of a cholera outbreak, a chlorine residual of 0.2 to 0.5 mg/l at all points in the supply is recommended (Muyima et al., 1998). A case study in Eastern Cape Province of South Africa by Momba et al., (2006), showed an increase of 1 mg/l in free chlorine resulted in a decrease of about 0.36 and 0.18 in the mean total coliform and faecal coliform counts, respectively. This means that a chlorine residual of about 1 mg/l when water leaves the treatment plant is needed for health reasons; it is recommended that such high level at points of consumption. Similarly a study another study in Uzbekistan revealed that, more than 30% of the households with piped water lacked detectable levels of chlorine residues in their drinking water (Semenza et al., 1998). In contrast to other studies in Pakistan by Jensen et al. (2003) and in developing countries, Jensen et al. (2004) even if it was limited size and cannot provide conclusive evidence. However, the study showed no association between the incidence of childhood diarrhoea and the number of Escherichia coli in the drinking water sources.

Among the total samples (n=35), 19(54.3%) of them range from 1.01-9.99, 7(20%) were in the range of 10-100 cfu/100ml. whereas, only 6 (17.1%) samples were found 0 of TTC cfu per 100 ml which is in the acceptable limit of WHO and ES nil cfu/100ml. Regarding to FS, 13 (37.1%) were in the range of 1.01-9.99 cfu/100ml, 11(31.4%) were in the range of (0.01-1cfu/100ml) and 11(31.4%) were no any FS cfu per 100ml which was met the acceptable limit of WHO and ES.
Similar studies conducted by Mengesha et al. (2004), in North-Gonder indicated that, none of the water line samples had zero coliform count per 100 ml, 21% had 18 and above coliforms per 100 ml. From the total samples, 21% also had 1-3 coliforms per 100 ml and E.Coli was found in 35.71% of the total samples. Similarly as reported by Nigus (2005), in Addis Ababa water supply (AAWSA) the mean differences of Cryptosporidium oocysts and Giardia cysts in pipe waters were greater than to treated water point of Legdade Reservoir.

Even if, the number of sample is very low and very high risk were scored as overall risk-to-health classification of pipe water in both indictors, most of the samples lie on a medium risk score i.e 19(54.29%) out of 35 samples from both indicators (Table 14 and 15). Since drinking-water distribution systems encompass many pipes and cover many kilometers including storage reservoirs and interconnections between the site of production and the tap up to the home of the consumers it may accumulate pathogenic organisms by formation of biofilms (Skraber et al., 2005).

As Table 9b indicated, the pipe water TTC was significantly greater than the disinfection points. This may be due to the sanitary survey conducted. These study indicted that in some areas the pipe water passes through sewerage lines, leakage problem without maintenances and in efficiency or distribution of untreated water supply, so that these may cause contamination of disinfected water distribution systems (Fig 24 and 25). This finding is also supported by different studies and reports. For instance, the present drainage facility in Addis Ababa comes only 33.8% from the total area of Addis Ababa (Solomon et al., 2004). Moreover, most of the examined underground pipes in Addis Ababa are in a very bad condition (Muschalla, 2001). As reported by Solomon et al. (2004), Addis Ababa city’s water supply services loose an estimated 30 to 40 % of the treated water that is pumped into the water main line due to leakage. UN-WATER/WWAP/ (2004) report emphasized that loss of water because of system failures, inefficiencies, poor maintenance and other reasons, is one problem that affects the supply of water to users in Ethiopia, particularly in Addis Ababa. Tamiru et al. (2003) also showed that drainages in the city are connected to the nearby watercourses. The streams also directly receive untreated sewage from toilets, petrol stations, garages, industries, etc. Semenza et al. (1998) conducted a test in Uzbekistan the on problem of water distribution support the hypothesis that

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diarrhea in the pipe water could be attributed to cross-contamination between the municipal water supply and sewer, due to leaky pipes and lack of water pressure.

**Physico-chemical and bacteriological quality of household water containers**

Cool water is generally more palatable than warm water. High water temperature enhances the growth of microorganisms and may increase taste, odour, colour and corrosion problems (WHO, 2004b). It is desirable that the temperature of drinking water should not exceed 15°C because the palatability of water is enhanced by its coolness (WHO, 2003). Temperature has also a marked influence on the chemical and biochemical reactions that occur in water bodies. High temperature for instance, increases the toxicity of many substances such as heavy metals and pesticides. All chemicals are most efficient at moderate temperature (15-20 °C) and at a pH of 6-9 (Horman, 2005). It also increases the sensitivity of living organisms to toxic substances and as WHO (1996, 2003 and 2004a). From 35 household water samples as indicated in Table 9, 5 (14.3%) were >20 °C and 27(77.1%) were in the range of 15.01-20 °C. Only 3(8.3%) from the whole samples had met the recommended limit of <15°C. Generally, the average temperatures of household water containers were from 12-22°C (*Annex IV*).

Among the 35 household water samples, as far as turbidity is concerned, the largest percentage 20(57.1%) was in the level of 2-5 FAU. However, the most acceptable limit i.e 0-1.99 FAU. From the total sample, 9 (27.5%) was in the range of 0.1-1.99 FAU and none of the water samples was 0 FAU. However, 6(17.1%) was >5 FAU which is above the WHO and ES level. The pair comparisons test result using LSD mean values (Table 10a) indicated a significant difference between the means of water quality disinfection points and household water containers. Therefore, those household water containers that had high turbidity have an implication on pathogen contamination. These might be because of lack of enough concentration of disinfectants in point of consumption that lead to regrowth of bacteria, and/or because of poor sanitation and hygiene problems at household level. Reports in Philadelphia by Schwartz *et al.* (2006) indicated that the daily counts of hospital admissions are high as the turbidity levels of water increases in the distribution system that expose elderly residents to a risk of waterborne gastrointestinal illness.
From 35 storage water samples, 28(80%) met WHO and ES recommended range of pH. However, 7(20%), met ES which is 6.5-8.5 which is above the recommended limit of WHO which is 6.5-8 (Table 8). Minimum target concentration residual for chlorine at point of delivery are 0.2 mg/l in normal circumstances and 0.5 mg/l in high-risk circumstances (WHO, 2004b). The amount of FCR levels from the total of 35 water samples 13(37.1%) ranged from 0.01-0.19 mg/l and 12(34.3%) of the samples attained score of nil, only 5(14.3%) of the samples met the recommended (0.2-0.5 mg/l) level. Similarly, 5(14.3%)) of the representative samples had no any chlorine at the point of distribution of the water supply (Table 8). From these result it was observed that no sample was found to be above the acceptable limit to any health risk. However, there is a problem of inefficiency in disinfection of pathogens. The concentration of FCR < 0.2mg/l and/or its absent was very high which represent >17(48.6%) of the total samples. These may be due to the concentration of FCR quality of disinfection point reflected by pipe and storage water. Fig.15 indicated, that FCR and bacteriological analyses showed inverse relationship i.e. when the concentration of FCR increases the density of cfu/100ml of TTC and FS decreases in household water containers. The study result clearly showed an increase in the amount of free chlorine residual and a decrease in the number of indicator bacteria. Similar case study in rural areas of South Africa, indicated negative correlations between chlorine and total and faecal coliform counts with values of -0.3595 and -0.2271, respectively (Momba et al., 2006). These might be due to the less concentration of FCR or non continuous disinfection process. This could be also reflected to pipe and household water containers. Therefore, if appropriate concentration could be maintained at disinfection points, there would be a chance of maintaining required amounts at pipe water and household water containers.

The pair comparisons using LSD mean value analysis (Table 10a) indicated very slight mean differences of FCR, which were almost insignificant, between pipe water and household water containers. One one hand, there was a very strong negative correlation between FCR and both indicator bacteria (TTC and FS) (values were -0.671 and -0.852 respectively) (Table 6). On the other hand, the concentrations of FCR in disinfection points were smaller than other study areas as seen at disinfection points. Therefore, maintain FCR to ≥1 mg/l at disinfection points, can solve the discontinuity in the distribution and reduce chemical reaction with organic compounds which in turn, may have a chance of decreasing nil FCR concentrations at household water containers. Similar studies conducted by Semenza et al. (1998) in Nukus, indicated that water
sample in 45 (38%) of the houses lack any detectable levels of free or bound chlorine because of inappropriate disinfection process at treatment plants.

Table 8 presents classification of risk levels of bacterial indicator organisms in water samples from the household water containers. The mean values of TTC for the household water samples (n=35) for the 21(60%) 9(25.7%) and 4(11.4%) of the samples were in the range of 10-100 cfu/100ml, 1.01-9.99 and 0.01-1.01, respectively. Whereas, FS 18(51.3%), 11(31.4%) and 5(14.3%) cfu/100ml count of the samples, ranged 10-100 cfu/100ml, 1.01-9.99 and 0.01-1.01, respectively. Therefore, the average count of TTC and FS were beyond the recommended value of WHO and ES which is 0 cfu/100ml of both TTC and FS. Only one (2.9%) of the samples met the recommended limit, 0 cfu/100ml (Table 8). The result showed that very high number of TTC and FS were encountered in household water containers compared to distribution systems. Similarly an intervention study in Colombo, Sri Lanka by Dissanayake et al. (2004) showed that water stored inside the household had often a worse bacteriological quality than water from the source. Similarly the report conducted in Ethiopia by Dagnew et al. (2006) on drinking water quality indicated that the TTC in household containers were very small. Therefore, compliance is significantly higher for household piped water (85.4%) than from household water containers (43.6%). This study also showed that more than half of the samples showed post-source contamination. Similar study conducted in South Africa and Zimbabwe indicated that, more than 40% of the survey households using improved sources had water samples that were ‘unsafe’ at point-of-use i.e. contained more than 10 cfu / 100 ml of E. coli (Gundry et al., 2006).

A study shows that most nosocomial pathogens can persist on inanimate surfaces for weeks or even months (Kramer et al., 2006). Vanderslice and Briscoe (1993) and Mintez (1995) also showed that earthenware vessels had significantly higher levels of contamination than other types of containers. However, during this study period, earthenware vessels were not common rather most storage water containers were plastic (97.1%) (Annex VI). The causes for contamination were poor hygienic practice and also might be 48.6 % of storage containers were not narrow mouth containers (Table16 and 17). This study also showed that the physical appearances of some water containers were unclean and kept outside in unsanitary condition (annex VI). The storage container washing frequency among the households has also been assessed. It was found out that only 17 (48.6%) households wash every day (Table18). As far as the washing practice is
concerned, only 23(65.7%) of the households clean their container by simple washing with pipe water (Table 17 and 19). Therefore, the presence of high bacterial count in drinking water indicates that the water has been faecally contaminated. This indicates a potential risk of excreta related diseases associated with poor sanitation and hygiene problems of houses. Also sanitary inspection supports that using TTC as a bacteriological indicator to determine the overall risk to health status, 23(65.7%) were in the high risk score, 7(20%) were medium, 4(11.43%) were very high risk score. Using FS, 24(68.5%), 7(20%) and 4(11.43%) were in the high risk, medium risk, and very high risk score respectively (Table 20 and 21). Therefore, inappropriate cleaning of storage water containers, poor sanitation and hygiene in house hold were the main factors for contamination of stored water in home. Similar drinking water quality assessment study in Oromiya and Addis Ababa, Ethiopia showed that, out of the 41 samples tested for faecal streptococci, only 56.1% met the requirements of WHO and ES which is 0 cfu/100ml sample. In addition to, the study shows more than half of household containers in the country can be classified as high risk –to-health classification level (Dagnew et al., 2006).

This intervention study in three months time showed that water stored inside households has often worse bacteriological quality than water found in the distortion system. Multiple comparisons of one way ANOVA mean differences result (Table 10b) indicated a significant difference in water quality between TTC and FS from disinfection point to the point of consumption. For example, the disinfection points of pipe and house hold water containers had value of TTC -10.87 and -16.48 and FS values of 2.65 and -13.09, respectively. Moreover, the mean difference between pipe water and house hold water with TTC and FS were -14.60 and -15.74, respectively (Fig.10b). The results presented here provide some indication as to when this post-collection contamination was occurring. The increased TTC and FS counts in stored water may be due to either to bacterial regrowth or to recontamination of water through dipping with hands and stored water container. The presence of biofilms on the inner surfaces may also offer a suitable medium for contaminating good quality water. Similar studies in developing countries by Wright et al. (2004) shoed that systematic meta-analysis of 57 developing countries; the bacteriological quality of drinking water significantly declines after collection in many settings. There were no instances where microbiological water quality improved significantly after collection.
5. Conclusions and Recommendations

5.1. Conclusion

In this study water analyses showed that both unchlorinated and chlorinated water supplies, at sources, pipe, and household water containers were in general are not safe for both physic-chemical and bacteriological quality except the pH. Therefore, the following conclusion may be drawn from the study.

All water systems were grossly polluted. The effect, therefore, is attributed to constructional defects, poor sanitation, low level of hygiene education, poor supervision and maintenance, irregular disinfection and/or without disinfection and uncontrolled of related parameters to efficient disinfection processes.

Communities that are along rivers settled on well fields, animals grazing in the well field had a direct impact on the near by wells and Fanta spring. Therefore, water management at different points very essential followed by appropriate treatment of the raw water sources. Strict control and appropriate management of the well fields are also important so that bacterial contamination could be minimized.

Grazing animals, surface water, sewage and pit latrines present near by wells and spring may increase density of CFU of indicator bacteria (TTC and FS). This is indicated by limited water sources protection on water sources such as EP5, KGW and FSNC. Therefore, the water sources need appropriate source control and treatment management. Since the sanitation-inspection showed that the water sources are within high health-risk-score.

Even if disinfected water points (CTR, TDR, FSC) are better than non disinfected water sources (EP5, KGW), the three disinfection water points TTC and FS were found at levels of more than 1 cfu per 100ml which is above WHO and National standards (cfu/100ml=0). This necessitates the method of chlorination should be standardized and controlled with other bacteriological related parameters. This also helps to maintain the concentration FCR at appropriate levels (avoid below/overloading) distribution and at the point of consumptions.
Water temperatures may increase in the distributed water due to the warming of the soil and/or as a result of higher temperatures in the source water that favor the growth biofilms and decreases the palatability of the water.

This study also showed that there is a need to regulate the line water distribution systems from vulnerability of pollution from sewage lines and immediate maintenance of the distribution. These may help to control contamination due to incorrect cross-connections with sewer lines.

Since the number of cfu/100ml, mean significant differences of TTC and FS and sanitary inspection matrix on health score were so high in the household that integrated water supply, sanitation and hygiene education program are very important.

5.2. Recommendation
Based on the research finding, the following recommendations are forwarded:

Distribution of pathogen-free water for human consumption is, in this respect, the chief objective of water for AAWSA so that, in addition to increase the quantity of water supply to the community. There is a need of selecting appropriate treatments depending on the water quality stage and using multi barrier approach such as protection and delineation of water sources from sources of contamination, to educate the sanitation and hygiene awareness promotion of the community.

Water storage treatments sites should be chlorinated regularly the one which is not add disinfectants and distributed without treatment has on risk on health of the communities so that, if AAWSA not possible treatment processes, they could use regular ground water disinfection process for KGW and EP5 ground water sources.

Even if the concentration of free chlorine residual the average values were 0.67 mg/l, 0.6 mg/l, 0.68 mg/l in CTR, TDR and FSC respectively, there is a need of more research on water sources on the concentration of the chlorine demand plus the necessary germicidal concentration. Because the ground water sources may be associated with oxidizable inorganic and organic species, which reduce the efficiency of chlorine. Moreover, further study is needed to determine the seasonal variations in the contamination level of the water sources and distribution systems.
Since, the chlorine demand in water is high in both the pipe water and household level increasing chlorine simply may lead to undesirable by-products like THMs so that, selecting appropriate treatments and controlling of treatments system may reduce the level of contamination to point of consumption. Results of the present study confirm that simple addition of free chlorine or sodium hypochlorite as a water treatment process cannot guarantee safeguard against bacterial infection. Therefore, if possible need of high efficient technology for production of potable water.

Moreover, irrespective of bio-medical evidence, there is a need of mobilizing policy makers, mass Medias and NGOs with respect to water source protection areas and awareness promotion of the community. Improving or evaluating with respect to programs intended to improve environmentally related behaviors is very important. That may reduce health risks from poor sanitation and hygiene water supply and at household level.
6. References


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