BACTERIAL CONTAMINATION OF SCHOOL'S DRINKING WATER IN ADDIS ABABA, ETHIOPIA

Dawit Debebe[1], Zerihun Getaneh[1], and Fiseha Behulu[1] *

[1] School of Civil and Environmental Engineering; Addis Ababa Institute of Technology (AAiT), Addis Ababa University, Ethiopia

*corresponding author: fiseha.behulu@aait.edu.et

ABSTRACT

Access to safe drinking water and hygienic living conditions is a global concern and these issues are especially serious in developing countries. The objective of this study is to evaluate the quality of water consumed by kindergarten schools' children in Addis Ababa city, who are highly susceptible to issues associated with microbial contamination in water. Total coliforms, *E. coli,* pH and residual chlorine in the water distribution system were measured at three water sources and 38 schools. The microbial analysis result shows 7 out of 38 schools were contaminated with total coliform bacteria. However, E. coli was not detected in any of the samples, meaning that all samples were free from fecal contamination. In addition, the free chlorine level of the samples was also tested. The results indicated that 16 out of 38 (42.1%) of the water samples had a free chlorine value below the WHO recommended 0.2mg/L. It is therefore, possible to conclude that the efficiency of a water supply infrastructure determines the concentration levels of microbial contamination and residual chlorine that reaches the end users. The study addresses critical issues and methods to mitigate the problems caused by microbial contamination in water supply distribution infrastructure.

Key words: Addis Ababa, *E.coli*, Residual Chlorine, Total Coliforms

INTRODUCTION

A healthy and safe school environment encompasses the physical surroundings, the psychosocial, learning, and health-promoting environment of the school. Additionally, hygienic practices, such as accessing to sanitation and providing clean water are all important contributors to children's health [1].

Access to clean water and sanitation is declared as a human right by United Nations in 2010. It is a prerequisite for the realization of many human rights, including those relating to people's survival, education and better standard of living. Safe drinking water and hygienic living conditions is a global concern and these issues are especially serious in developing countries, like Ethiopia that have suffered from a lack of safe drinking water and inadequate sanitation services [2].In several educational institutions, waterborne diseases have become common problems causing health complications on children and adults. This may be related to contamination of water tanks or infiltration of the microorganisms in water pipes. According to a data from the educational statistics annual abstract (2017) taken from Addis Ababa Education Bureau, there are 164,072 students, 51.16% male and 48.84% female, attending in 1172 Kindergarten schools in the city.

All of the children are directly affected by the contamination of water they get from their school's tap water. Their families are also indirectly affected by costs of medical treatment they spend on their children, which is unaffordable to most of the poor family members living in the city. Therefore, the monitoring and further analysis of the quality of water originating from faucets for school children's consumption becomes important for diagnosing the problem and to develop prevention and mitigation strategies.

Microbial contamination is by far the most important public health challenge of drinking water supply systems. All microbial organisms of viral, bacterial, parasitic and protozoan origins can be found in the distribution network of the water supply [3]. These harmful organisms can originate from a variety of sources such as industrial waste, decayed plant matter, agricultural runoff and human wastes. Some of these microbial organisms are more pathogenic than others. The hazardous pathogens in drinking water are usually associated with human or animal excreta in many circumstances, but there are also other pathogens capable of causing infection through the drinking water. The most transmissible diseases related to drinking water are those caused by pathogenic viruses, bacteria and parasites[4]. Examples of pathogenic organisms implicated for water borne disease outbreaks include *E. coli* O157:H7, *Salmonella, Norovirus, Cryptosporidium* and *Giardia*. These pathogens are also different in characteristics, behavior and resistance. Simultaneously they affect different persons in various ways, reliant on factors as age, sex, state of health and living conditions [4]. This study is focused on indicator organisms (total coliforms and *E. coli*) in characterizing the microbial quality of the water from the distribution network.

Addis Ababa has grown very rapidly since it was founded in 1886. This growth has put enormous pressure on water supply services and the sewerage system. The water supply infrastructure in the city is more than 40 years old and is known for its low output capacity and high-water losses due to degraded pipelines [3]. The water supply infrastructure in the city is more than 40 years old and is known for its low output capacity and high-water losses due to degraded pipelines[3]. Similarly, Abay[5] has also stated that the growth of Addis Ababa City has been unregulated and unstructured and the city has not had formal urban planning until recently. This has put many constraints on the water supply system. A major concern is the significant losses of water caused by leakage from the old supply infrastructure.

The national drinking water standards are identical to the World Health Organization's[4] guideline for the provision of safe drinking water. However, the treated water is generally delivered to households and schools in old metallic (galvanized iron and cast iron) pipelines. Some piping has been replaced by HDPE and PVC materials. Pipes are either buried underground or exposed to the environment. In many of the slum dwellings, the pipelines are very old and degraded. Approximately 30-40% of the drinking water supplied to the city does not reach consumers. The water is lost at different levels of the distribution system due to leaking pipes and aging infrastructures [3, 5].

The combination of the degraded infrastructure and a cross-connected distribution system may provide a favorable environment for drinking water contamination to occur. Considering the poor environmental conditions in many districts of the city, there are many chances for drinking water contamination in cracked and leaky water supply pipes. Currently, there is no comprehensive water quality monitoring or data for drinking water quality at the household and school levels. It is therefore unclear how much contamination is occurring to the drinking water quality once it is distributed from the treatment plants, and whether the water is safe to drink once it reaches school.

MATERIALS AND METHODS

Study area and sampling locations

The study was conducted in Addis Ababa, capital city of Ethiopia, which has a population of more than 4 million in an area of 540 km^2[6]. The city gets its treated water from three sub-systems:

A. Akakisubsystem is located in the southern part of the city. It has a groundwater source and its treatment system is mainly limited to disinfection (chlorination).
B. Legedadi subsystem has both surface and groundwater sources which are situated in the western part of the city.
    - Its surface water source part of this subsystem has a conventional water treatment system. This system includes pre-chlorination, coagulation, sedimentation, filtration and post chlorination components [7].
    - The groundwater source from Legedadi subsystem has a treatment system of disinfection (chlorination). These two systems then blended at some central reservoirs for further distribution to the end users.

C. Gefersa subsystem is located in the northwestern end of the city. It has surface water source with conventional water treatment system. This system is the same as Legedadi (surface water source) and it includes pre chlorination, coagulation, sedimentation, filtration and post chlorination [7].

According to Addis Ababa Education Bureau there are 164,072 kindergarten children in the city. For every 4000 children one representative water sample was collected. Therefore, a total of 41 samples are needed. But since the city has a problem regarding shortage of water, thirty-eight samples were collected. Fifteen kindergarten schools from *Akaki*sub-system, fifteen from *Legedadi*, and eight schools from *Gefersa* sub-systems were selected according to the sub system's coverage areas. Random sampling technique was used to select the schools in the sub-systems. But the schools were chosen in a way that they would be representative of their sub-system as shown in figure 1. The distance from the schools to the treatment plants can also be seen in figure 1. The samples were collected from 11 May 2018 to 17 May 2018 on a dry season. The sampling was carried out based on the standardized sampling techniques as outlined in USEPA guidelines for water testing [8].

One water sample was taken from each school giving a total of 38 samples. However, from the sources, two water samples were taken from each treatment plant, before and after the water is treated, which means six samples have been taken from the three treatment plants. The total number of samples taken is sum up to 44. The samples from the schools were taken from a tap which was directly connected to the municipal water supply. Flushed water samples were taken and each sample had a volume of 500-1000ml, collected using pre-labeled 500 -1000 ml sterile plastic bottles. The bottles were initially cleaned using standard detergents and distilled water. The water samples were transported to the Addis Ababa University Faculty of Science, Department of Microbiology laboratory. The samples were then tested for pH (measured onsite), residual chlorine, E-coli and total coliforms within 24 hours of sampling. Results on the blood lead level from the same sample points were given in previous work by Debebe*et. al*. [9].

Measuring chlorine

The residual chlorine in the water was tested using portable Palintest 7100 photometer (i.e. made in England for water quality and wastewater tests). The instrument has dual light source photometer offering direct reading of pre-programmed test calibrations, absorbance and transmittance. It works in wave length ranges of 450nm, 500nm, 550nm, 570nm, 600nm, and 650nm at measurement accuracy of±1%. During the test, a reagent called diethyl-p-phenylene diamine (DPD1) was used. DPD1 reacts with chlorine in water and changes its color to pink. The change in color is read by the photometer to get the residual chlorine content of the sample water.

Measuring pH and Temperature

pH and temperature were measured simultaneously using a hand pH meter. Each sample was poured in a beaker and the hand pH meter was inserted. Each sample was measured 3 times and an average result was taken.

Microbial Analysis for Total Coliform and E. coli

Total coliform counts were carried out by membrane filtration technique[10]. A sterilized pad dispenser was used to introduce the growth absorbent pads into the base of Petri dishes, and the growth pads were saturated with the Lauryl Sulphate Broth. 100ml water sample was filtered using a membrane filter (0.45µm) in a vacuum filtration apparatus, and all the filters were transferred to the absorbent pad which was saturated with the broth.

The Petri dishes were incubated at 37°C for 4hr for resuscitation to recover physiologically stressed coliforms before incubation. Then after, plates for total coliform counts were incubated at 37°C for 24hrs, and then colonies were counted and recorded.

*E. coli*was tested using Eosine Methylene Blue (EMB) agar. This selective media grows only gram-negative bacteria. Since E. coli are groups of gram-negative bacteria, it was possible to test using this media. If *E. coli* bacteria are present in the sample, it shows a metallic green color on the media after it’s kept in an incubator for 24 hours at 37^{o}C [11].

The samples were carefully processed in FASTER TWO 30hub. This hub creates avertical laminar flow which guarantees excellent decontaminated working area and particle-free conditions. Also, to prevent any environmental contamination, the media and petri dishes were autoclaved. The researcher’s hands were also sanitized with 70% denatured ethanol at all times during the work on the hub to prevent contamination. The processed samples were finally put in an oven for 24 hours at 37^{o}c.

As a quality control mechanism, all sampling bottles were appropriately labeled, and the samples were collected using standardized drinking water sampling techniques. The collected water samples kept in icebox during transportation put at 4 degree Celsius before analysis in the laboratory.

Before analysis, sterilization of required laboratorial equipment and culture medium was carried out. Moreover, to ensure the validity of the analysis, blank samples were analyzed following the same procedure. Water quality analysis guideline, protocol, and quality control were used.

RESULTS AND DISCUSSIONS

In Addis Ababa rapid urbanization and population growth are taking place. This rapid growth has led to an increasing demand for water which is growing at a faster rate than the supply. Even though Addis Ababa Water Supply and Sewerage Authority (AAWSA) is working to increase the supply capacity, it is currently not able to supply enough drinking water to the growing population. This has resulted in water shortages in many areas of the city. As a result, drinking water is now being supplied in an intermittent manner. Unscheduled water supply disruptions are common in many parts of the city. It is common for tap water to be supplied only once per week in some parts of the city. This is worst for residents located at higher altitudes and those living in the higher floors of condominium apartments. Such challenges are further resulted in insufficient pressure in the system to supply the water to elevated areas unless a booster pump is used. The combination of scheduled water supply and an old, leaky distribution systems result in low pressures in the distribution network. This can result in the intrusion of external contaminants into the leaky and cross-connected infrastructure during supply interruption and reinstatement events.

pH and Temperature

The results showed that the average temperature records of water samples taken from the schools was 25.4^{o}C ranging from 22.4^{o}C to 28.1^{o}C. Similarly, earlier studies in Gondar zone [12], Bahir Dar [13]and Nekemt[14]reported a mean temperature of 21.3^{o}C, 23.8^{o}C and 20.8^{o}C, respectively. In tropics, the climate is characterized by high temperature and convective rainfall, and these factors might have contributed to the high temperature records of water samples from different cities of Ethiopia that did not meet the WHO standard of < 15^{o}C [14].

Akaki catchment having a ground water source has the largest mean and median PH values of 7.96 and 8 respectively. The next is the *Gefersa* catchment with mean and median PH values of 7.75 and 7.71 respectively. Finally, *Legedadi* catchment has the lowest mean and median PH values of 7.6 and 7.57. PH results for the samples taken from the treatment plants is given in table 1 and PH values of the schools is given in figure 1.

Table 1 PH levels of samples taken from the treatment plants

Sources	**pH**	
	Before Treatment	**After Treatment**
Akaki treatment	8.33	8.2
Legedadi treatment	7.9	7.7
Gefersa treatment	7.3	7.72

For comparison, the average PH levels of various cities' water sources are given in the table below. The variation could be due to geological conditions of the water sources.

Table 2 The average PH levels of various cities' water sources

City	**PH level**	**Reference**
Ziway	8.3	[15]
Adama	7.8	[16]
Nekemte	6.8	[14]

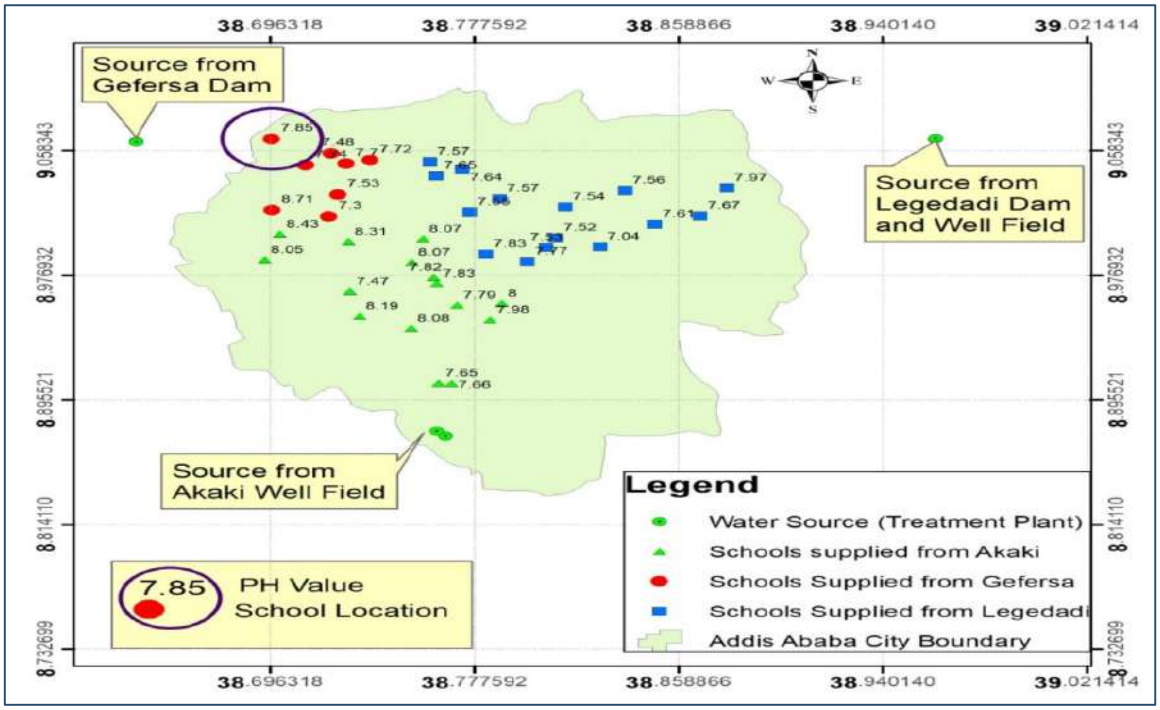

Figure 1 Distribution of PH in Addis Ababa

All samples remained within the recommended standard limits of 6.5-8.5as noted by WHO [17] and ESA [18]. The average pH levels from all 38 schools were 7.77 and the PH levels measured from the schools' tap water were generally lower than the source for all sub-systems. Both median and mean values of the samples from the schools were also smaller than the source water (AAT, LAT and GAT). The slight reduction in the PH values measured in the water samples may be attributed to the corrosion of aged and cross-connected metallic pipeline materials used in the water supply distribution system. This decrease in PH is consistent with the study by Mekonnen [3] who reported that the PH in drinking water decreases as a result of corrosion taking place in distribution systems.

Free Chlorine

The minimum recommended WHO value for free chlorine residue in treated drinking water is 0.2 mg/L. In this study, 16 out of 38 (42.1%) of the school water samples had a free chlorine value below 0.2mg/L. Highlighted samples in figure 2 show samples having free chlorine level below 0.2mg/l. Similar studies showed that 15.2%, 37.5%, and 95.7% of tap water samples from tap water distribution systems in Nekemte [14], Ziway [15] and Bahr Dar towns [13] contained lower free chlorine than the recommended limits.

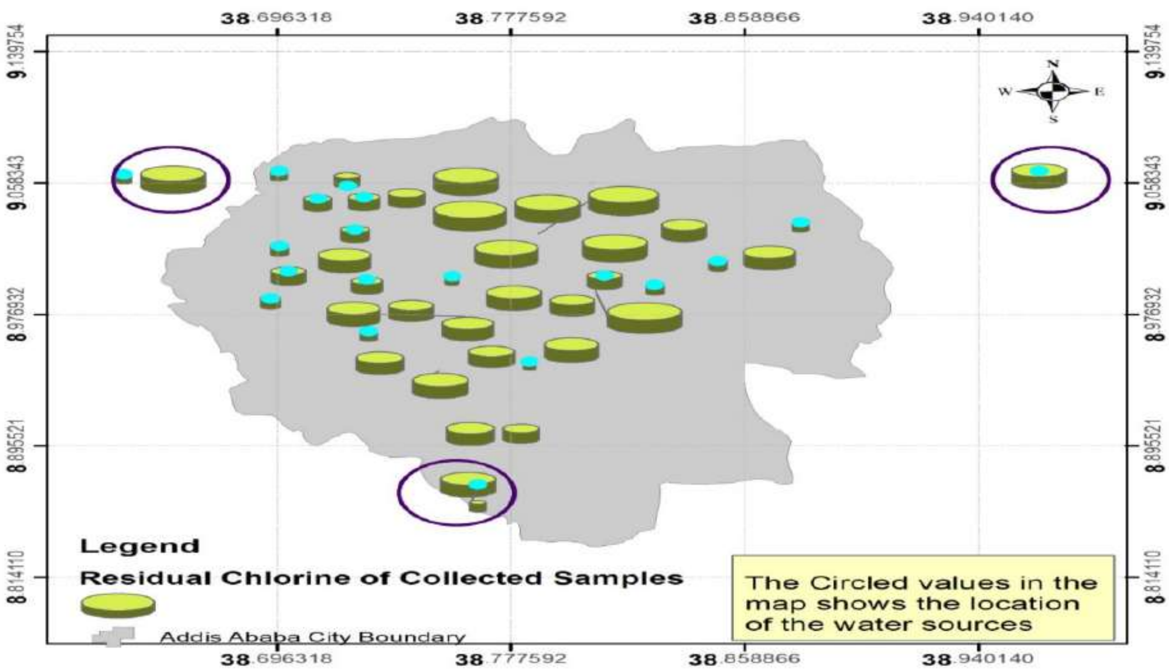

Figure 2 Free chlorine distribution (highlighted samples have residual chlorine below 0.2mg/L)

In the *Akaki* catchment, 40% (6 out of 15) of the samples have residual chlorine values below the recommended 0.2mg/L. For *Legedadi*, 26.67% (4 out of 15) and for *Gefersa* 75% (6 out of 8) of the samples have values below 0.2mg/L. The free chlorine levels of the samples from the treatment plants are also listed in table 3.

Table 3 Free chlorine levels of samples taken from the treatment plants

Sources	Free Chlorine (mg/l)	
	Before Treatment	After Treatment
Akaki treatment	0.04	0.45
Legedadi treatment	0	0.45
Gefersa treatment	0	0.04

Similar studies showed that the free chlorine level of water samples from disinfection point in Nekemte town was 0.23mg/l[14]. The treatment outlet of Ziway town had free chlorine of 0.79mg/l[15]. But unlike these two studies, 0.03mg/l free chlorine was recorded from the main distribution tank of Bahir Dar town[13]which is similar to the free chlorine level of Gefersa treatment plant as seen on table 2.

For the treatment plant assessment, chlorine residue was tested based on the data collected on the 18th of May 2018. The test results revealed that treated water leaving Gefersa treatment plant had no residual chlorine. Since this was not logical, that water leaving a treatment plant must have residual chlorine, another sample was collected on the 19th of May 2018 in order to clarify such issues. But the sample from had a value of 0.04mg/l which was less than the WHO recommended 0.2mg/l. This clearly shows the poor management and quality control works in the treatment plants.

For the assessment of distribution systems' performance in terms of residual chlorine, it is expected that the concentration degrades when treated water enters into the distribution system. A possible reason for this rapid drop in concentration could be due to the breakdown of residual chlorine by microbes attached to biofilms, corrosion in pipes and water aging in distribution system. Another possible reason could be the intermittent supply of water that can lead to negative pipe-pressure and intrusion of contaminants. These contaminants could further reduce the residual chlorine in the distribution system. The distance of the schools to the treatment plants and increasing time spent in water storage reservoirs and pipes could also deplete the residual chlorine before it reaches the schools taps. These assumptions are similar to study findings by Mekonnen[3] who reported that rapid deterioration of residual chlorine occurred in the water distribution network of *Legedadi* sub-system. This was a result of, the distance from the treatment plant, the intermittent supply leading to contaminant intrusion, and growth of bacteria in pipes due to the depletion free residual chlorine. In addition, a study by Kumpel and Nelson [19] compared the microbial water quality in an intermittent and continuous piped water supply. It was reported that a significantly higher proportion of samples collected from a continuous supply met the minimum standard for residual chlorine concentrations when compared to samples from intermittent water supplies.

Microbial Analysis

Bacteriological analysis of the samples revealed that there was total coliform bacteria contamination in the three catchments. Accordingly, 3 out of 15 samples from *Akaki* ,2 out of 15 from *Legedadi* and 2 out of 8 samples from *Gefersa* catchment were contaminated. Table 3 shows the bacterial count for the 3 catchments. Treated water samples taken from the treatment plants were also free from contamination.

Table 4 Total coliform count of samples contaminated

Catchment	Sample Local Name	CFU/100 ml
Akaki	Auxilium catholic school	2
Akaki	Great Ethiopian transformers school	120
Akaki	TibebGebeya school	1
Legedadi	Goro primary school	65
Legedadi	Vision academy	20
Gefersa	BiruhTesfa kindergarten	1
Gefersa	Amigonian school	1

The highest total coliform count was recorded from tap water at Great Ethiopian transformers school in Akaki catchment with 120 CFU/100ml. This is similar with a study byDuressaet. al [14] in Nekemte town that reported a highest total coliform count of 95 CFU/100ml.

All of the samples did not show any sign of *E. coli* contamination. This means the water is safefrom fecal contamination. However, on the contraryto the presented findings, a study by Mekonnen[3] showed *E.coli* contamination in *Legedadi* sub-system. This is presumably due to the fact that samples in that study were taken from July to September on the rainy seasons. Therefore, contaminants can easily enter the distribution system in these wet seasons. On a similar study in Nekemte town, 37% of samples showed fecal contamination [14].

Total coliform contamination was found in all catchments and all contaminations are directly related with the free chlorine. The seven contaminated samples had residual chlorine below 0.12mg/l which contradicts the WHO recommended value of 0.2mg/l. Similarly, studies by Kumpel and Nelson [19] in Hubli-Dharwad, India and Mekonnen[3] in Addis Ababa, Ethiopia have also reported frequent and elevated bacterial contamination in tap water samples with residual chlorine concentrations below the recommended guideline values. Zero bacteria counts are reported in water samples retaining good residual chlorine concentrations in both studies which resembles the present study.

The microbial water quality results measured in this study strongly agree with a study conducted by Kumpel& Nelson [19]. It was reported that bacterial contamination is more frequent in intermittent water supply networks when compared to those continuously supplied. The study reported by Mekonnen[3] also suggests that bacterial contamination in an intermittent water supply could be caused to the intrusion of contaminants from the environment when the water supply to pipelines is turned off. This causes negative pipe-pressure events and causes problems when combined with cross-connection pipelines. These issues are common in Addis Ababa and are the main problems within the study areas.

CONCLUSIONS

Based on the results from this study, we can conclude that the main cause of water quality degradation in the distribution system is likely due to the efficiency of water distribution infrastructures. This is associated with the disruption in water supply, intermittent supply, lack of continuous flow in distribution network and age of pipes which are susceptible to leakages. This results in the intrusion of external contaminants in the pipelines of the distribution system. This may ultimately result in non-compliance with the WHO drinking water standards. To combat such challenges improving water distribution system efficiency, regular monitoring of water quality level at the source as well as within distribution network and automated system management strategies are relevant recommendations. From school children health point of view localized water supply treatment at school inlet systems are also possible options.

REFERENCES

[1] Bakır B, Babayigit MA, Tekbaş ÖF, Oğur R, Kılıç A, Ulus S. Assessment of Drinking Water Quality in Public Primary Schools in a Metropolitan Area in Ankara, Turkey International Journal of Health Sciences and Research. 2015;5(4):257-66.

[2] Amenu D, Menkir, S., Gobena, T., . Bacteriological quality of drinking water sources in rural communities of Dire Dawa Administrative council. Int J Res Dev Pharm L Sci, . 2013:775-80.

[3] Mekonnen D.K. The Effect of Distribution Systems on Household Drinking Water Quality in Addis Ababa, Ethiopia, and Christchurch, New Zealand. [MSc. Thesis,] 2015.

[4] WHO. Guidelines for drinking-water quality, fourth edition incorporating the first addendum: World Health Organization;; 2017.

[5] Abay GK. The impact of low-cost sanitation on groundwater contamination in the city of Addis Ababa. [MSc. Thesis] 2010.

[6] CSA. Population and housing census of Ethiopia 2007.

[7] AAWSA. Annual report of planning, implementation and evaluation of Addis Ababa Water and Sewerage Authority. *Official Report* 2014.

[8] USEPA. Human Health Evaluation Manual, Supplemental Guidance: Standard Default Exposure Factors 1991.

[9] Debebe D, Behulu F, Getaneh Z. Predicting children's blood lead levels from exposure to school drinking water in Addis Ababa, Ethiopia. Journal of Water and Health. 2020.

[10] Bartram, Jamie, Ballance, Richard. World Health Organization & United Nations Environment Programme. Water quality monitoring: a practical guide to the design and implementation of freshwater quality studies and monitoring programs / edited by Jamie Bartram and Richard Ballance. London : E & FN Spon. https://apps.who.int/iris/handle/10665/41851 1996.

[11] MacFaddin J.F. Biochemical Tests for the Identification of Medical Bacteria. Baltimore (Md.) PA, USA: Williams & Wilkins Publishers, ISBN-0683053183, 3rd edition; 2000.

[12] Damite D, Endris M., Tefera Y. Assessment of microbial and physic-chemical quality of drinking water in North Gondar Zone, Northwest Ethiopia. Journal of Environmental and Occupational Science. 2014;3 (4):170.

[13] Kassahun G. Physicochemical and bacteriological drinking water quality assessment of Bahirdar town water supply from source to yard connection, North western Ethiopia. [MSc. Thesis]: Addis Ababa University,Ethiopia; 2008.

[14] Duressa G., Assefa F., Jida M. Assessment of Bacteriological and Physicochemical Quality of Drinking Water from Source to Household Tap Connection in Nekemte, Oromia, Ethiopia. Journal of Environmental and Public Health. 2019.

[15] Bedane K. Assessment of physicochemical and bacteriological quality of drinking water in Central Rift Valley System, Ziway town, Oromia regional state. [MSc. Thesis]. Addis Ababa: Addis Ababa University, Ethiopia; 2008.

[16] Eliku T., Sulaiman H. Assessment of physco-chemical and bacteriological quality of drinking water at sources and household in Adama Town, Oromia, Ethiopia. African Journal of Environmental Science and Technology. 2009;9(5):413–9.

[17] WHO. Guidelines for Drinking-Water Quality, Surveillance and Control of Community Supplies 1997; volume 3,2nd edition.

[18] ESA. Drinking Water Specifications, Compulsory Ethiopian Standards, CE58, (Ethiopian Standards Agency), Addis Ababa, Ethiopia, 1st edition. Official report. 2013.

[19] Kumpel E, Nelson KL. Comparing microbial water quality in an intermittent and continuous piped water supply. . Water research. 2013;47(14):5176-88.